



Public Works
Manly Hydraulics Laboratory

NSW OCEAN AND RIVER ENTRANCE TIDAL LEVELS ANNUAL SUMMARY 2013–2014

Report MHL2292
October 2014



prepared for
Office of Environment and Heritage



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NSW Ocean and River Entrance Tidal Levels Annual Summary 2013–2014

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October 2014

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Cover photograph: King Tide 3 January 2014 – showing depth of sea water propagating onto residential streets in Mona Vale (Photo courtesy R. Jacobs).

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Foreword

NSW Public Works Manly Hydraulics Laboratory (NSW Public Works MHL) operates and maintains a number of ocean and river entrance tidal recording stations along the NSW coast under contract with the Department of Premier and Cabinet, Office of Environment and Heritage (OEH). NSW Public Works is a division of the Office of Finance and Services.

The NSW ocean tide database has been developed by NSW Public Works 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 over the period 1 July 2013 to 30 June 2014, and catalogues all ocean and river entrance tidal data collected in NSW by NSW Public Works MHL.

This summary has been prepared as a guide to enable ready access to the ocean tide database and the data analysis capabilities of NSW Public Works 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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Electronic copies of the reports in this series can be downloaded at:
<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.

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 2013–2014
- [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 NSW Public Works MHL
- [Appendix E](#), a glossary of terms
- [Appendix F](#), a list of other publications which may be of interest.

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1. Tidal Network Measurement Program

This report presents the twenty-ninth year of data collected by automatic ocean tide level recorders for the State of NSW. NSW Public Works 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. 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. 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. 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 NSW Public Works MHL's data server after recovery from the ocean bed by divers. The system is shown in [Figure 1.5](#).

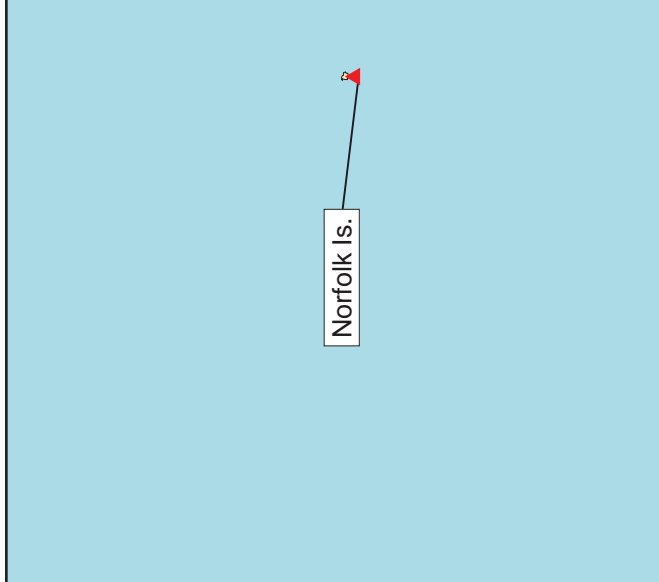
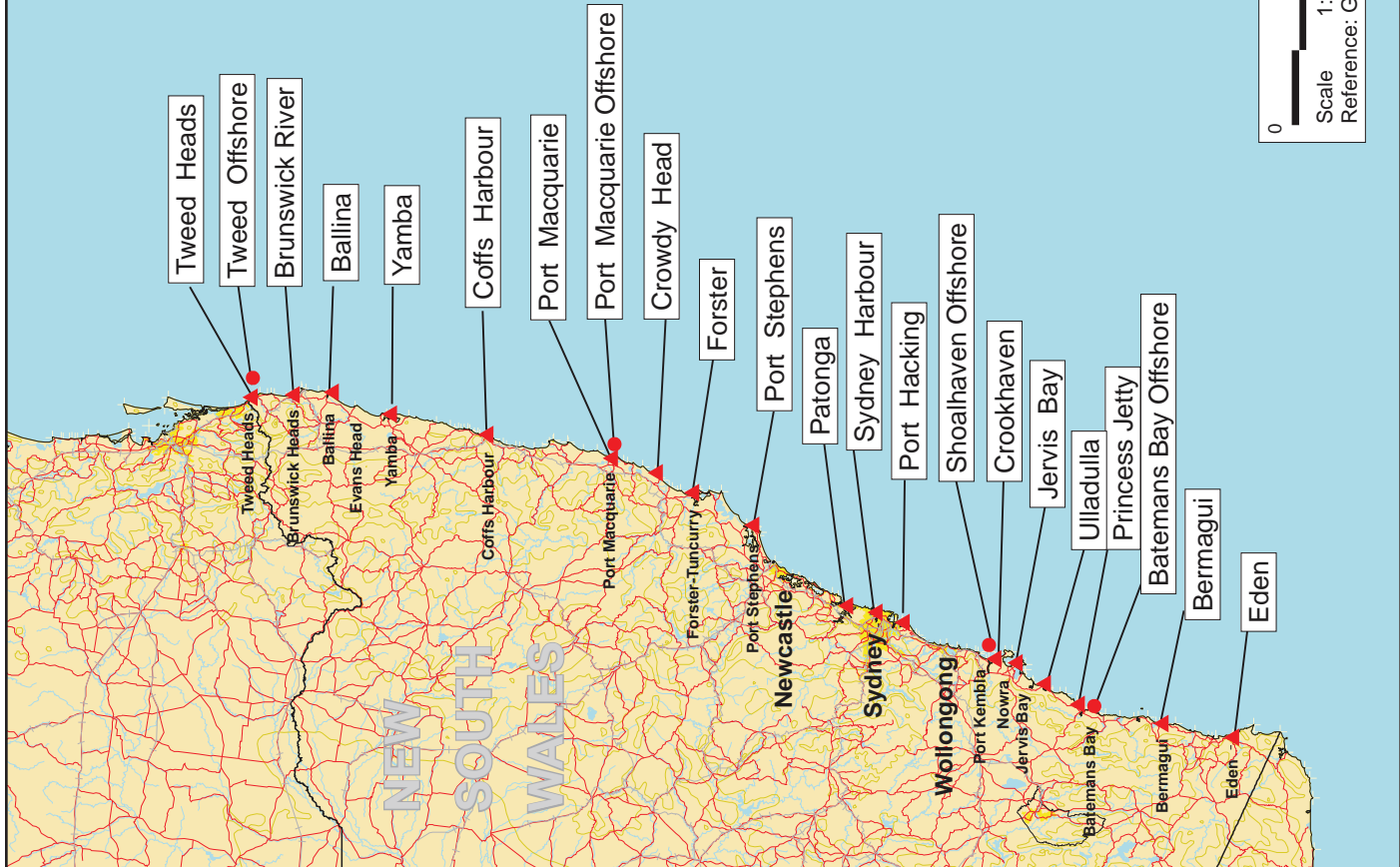
Tidal data is transferred to NSW Public Works MHL's data server and is then immediately available to external users to view. A backup copy is also transferred to the NSW Data Collection Warehouse. The 15-minute tide data is available on-line in tables or as plots. One-minute data is also available on request (see Appendix D, [Figure D1](#)).

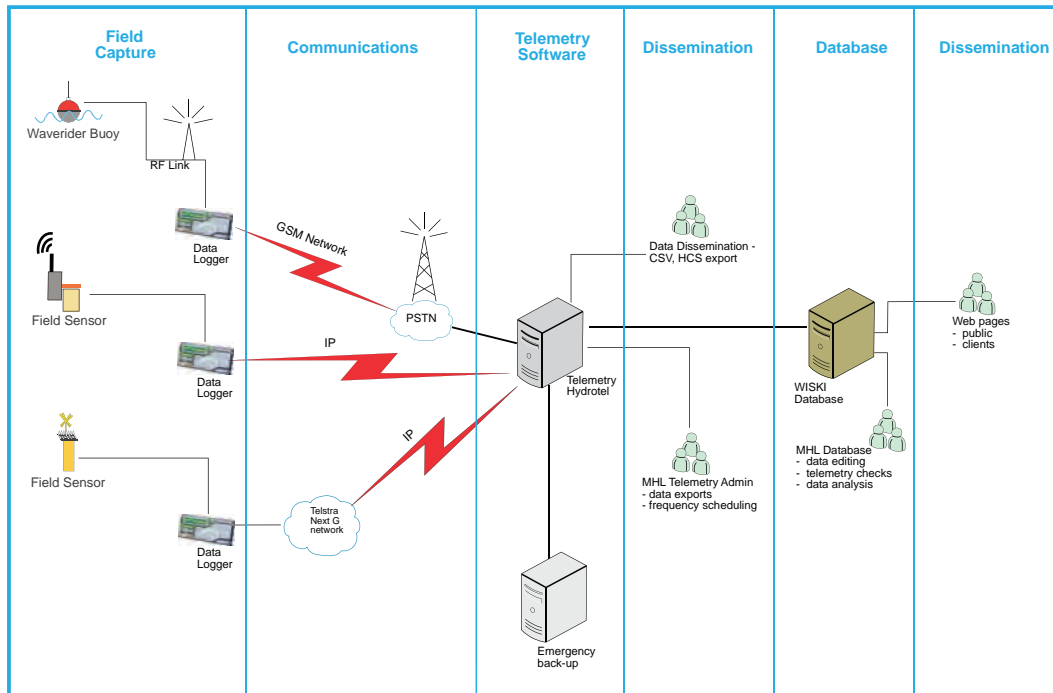
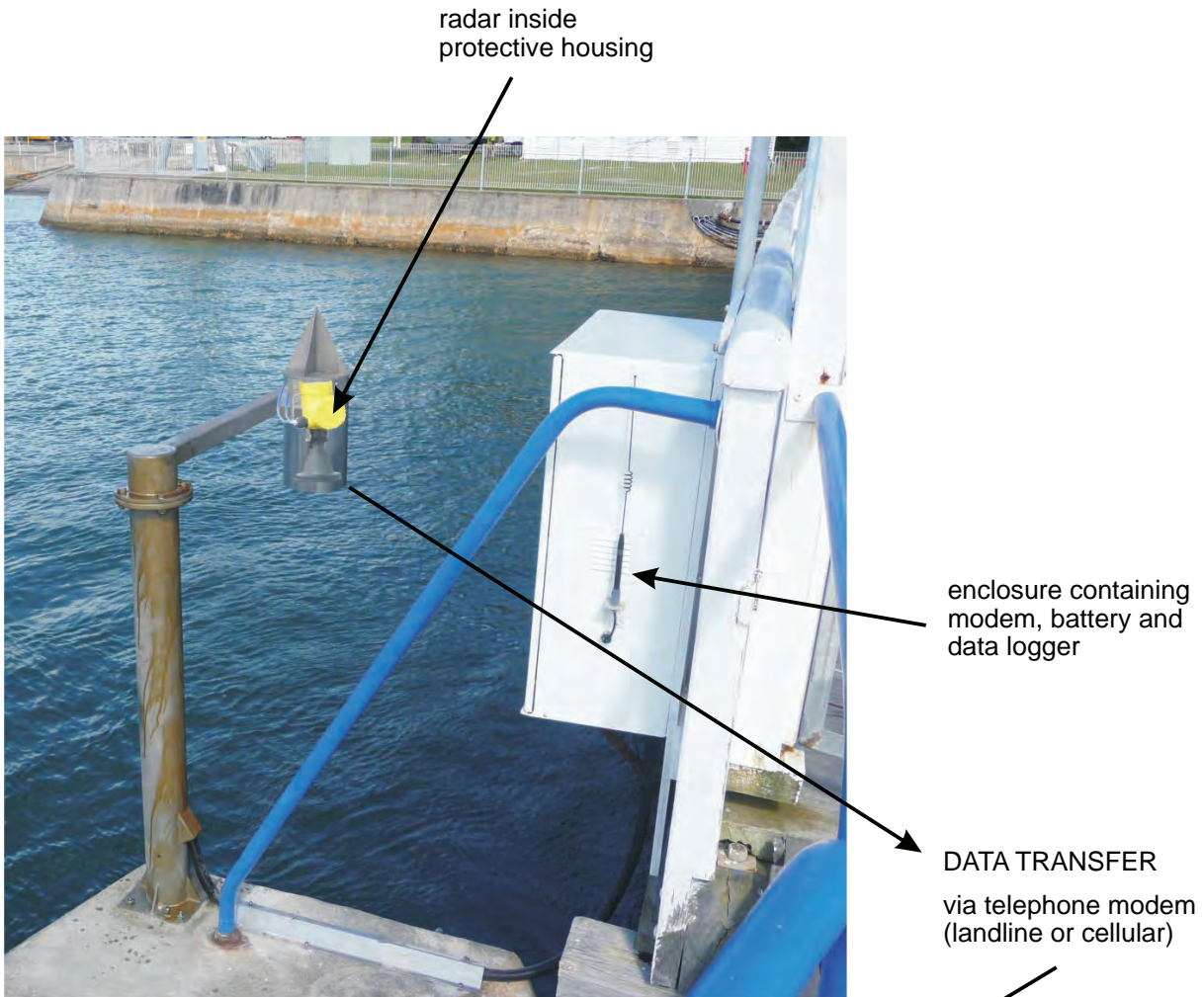
The data is stored in a database and subjected to a quality assurance process which involves several control steps to ensure data quality is maintained. Computer programs are used to further format and analyse data.

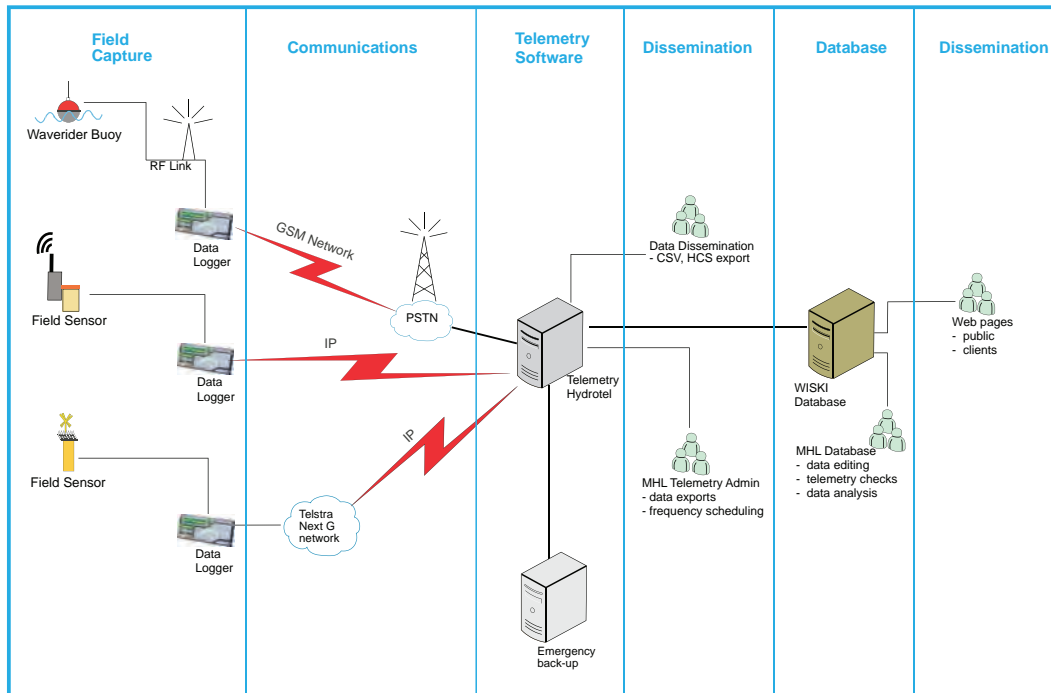
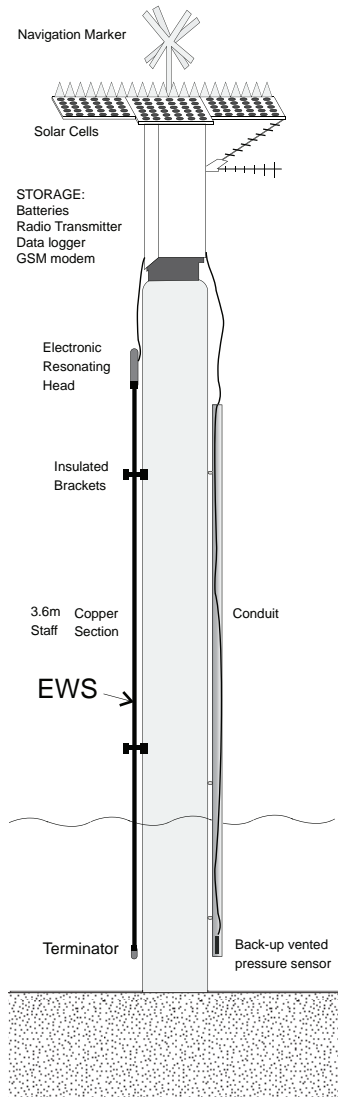
The database is backed up daily and data archived to magnetic tape as a security measure at regular intervals. A complete mirrored backup database is also kept at the NSW Data Collection Warehouse.

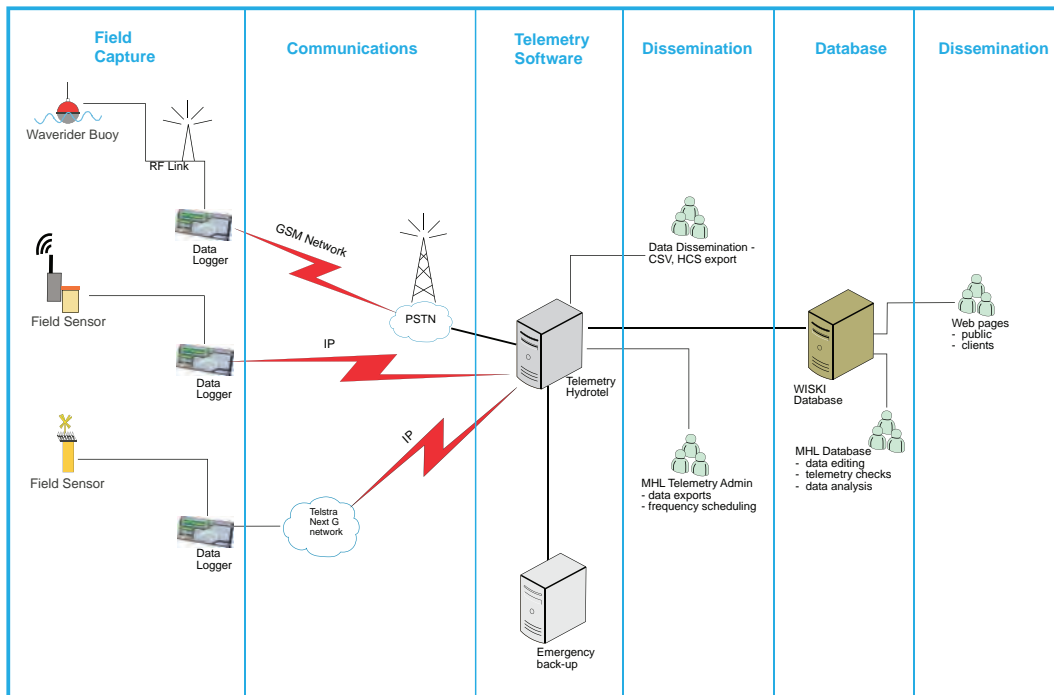
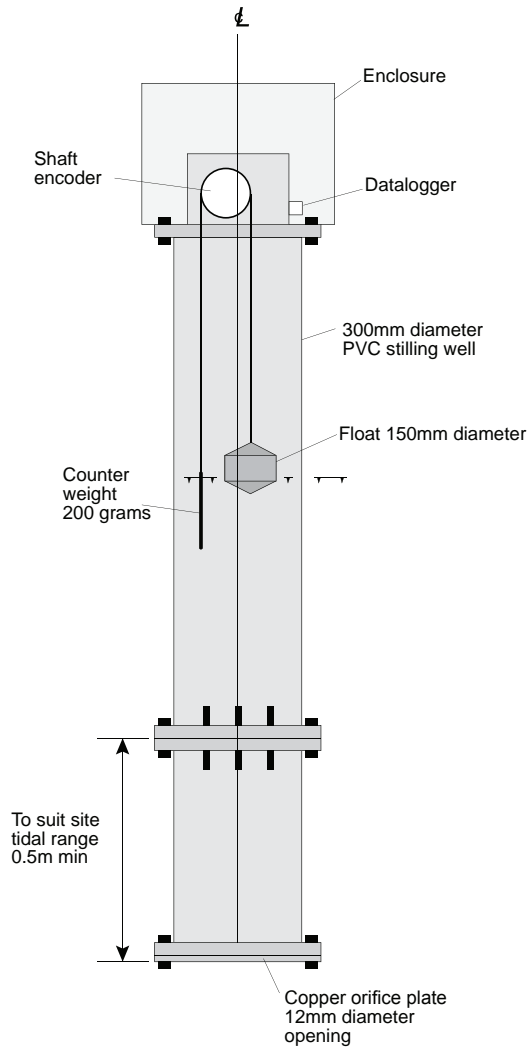
The station locations and data summaries for 2013–2014 are presented in [Appendix A](#).

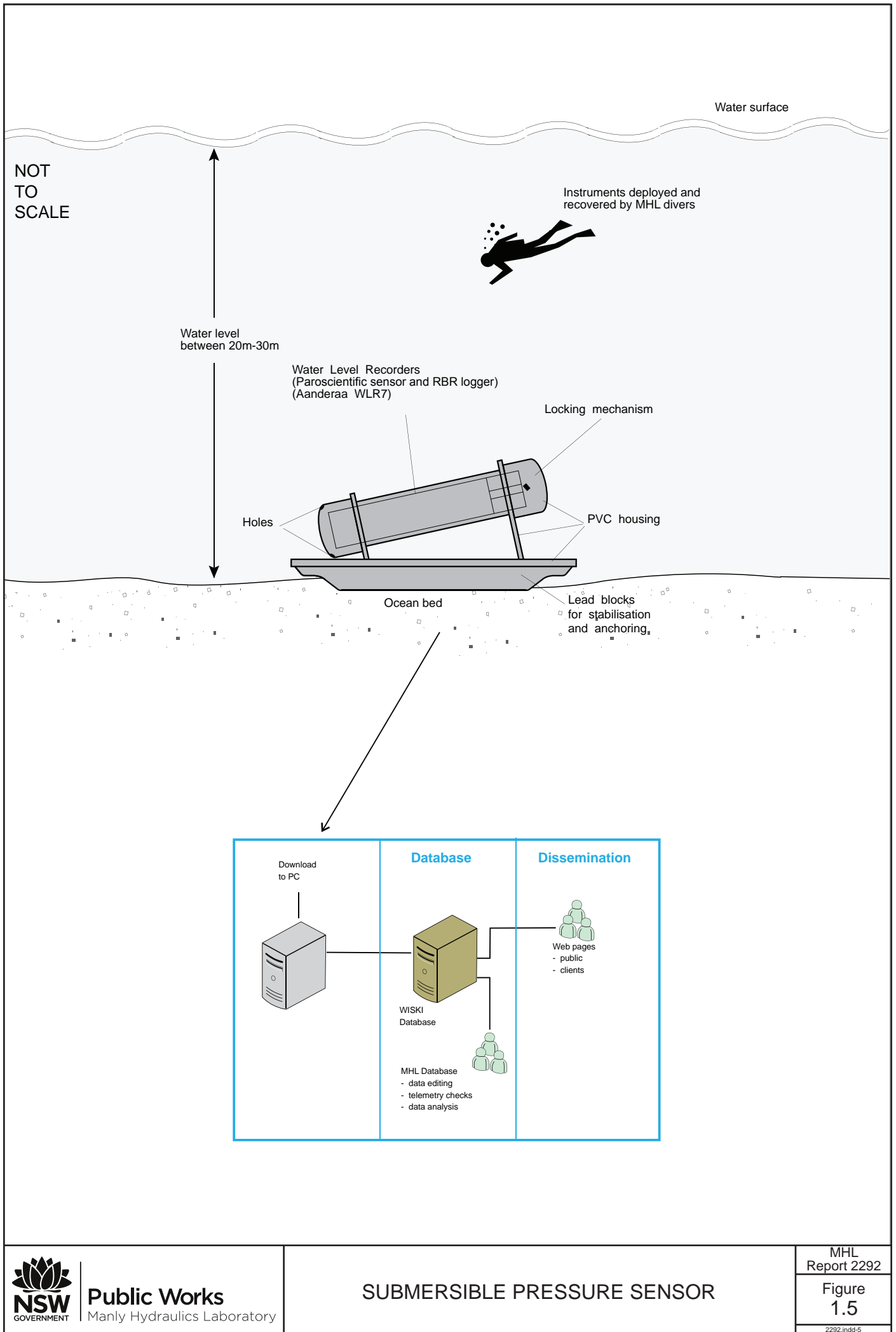
Details of current sites available in a digital format are catalogued in [Appendix B](#). [Appendix C](#) contains a list of historical data available in various formats and locations.











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 New South Wales over the period 1 July 2013 to 30 June 2014. 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 2013–2014. 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. The following options are available and samples are shown in [Appendix D](#):

- graphical plots ([Figure D1](#))
- time series data ([Figure D2](#))
- tidal analyses ([Figure D3](#))
- tidal level ranking ([Figure D4](#))
- tidal predictions ([Figure D5](#)).

Data can be requested by contacting NSW Public Works MHL by email via data-request@mhl.nsw.gov.au

NSW Public Works 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 NSW Public Works 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 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 NSW Public Works 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 Local Adjustment to AHD

Station	Station Datum	Adjustment (Local to AHD ¹)
Tweed Heads	Tweed River Hydro Datum	0.893
Tweed Heads Offshore	Mean Sea Level	N/A
Brunswick Heads	Brunswick River Flood Mitigation Datum	0.046
Ballina	Low Water Ordinary Spring Tide	0.860
Yamba	Iluka Port Datum	0.895
Yamba Offshore	Mean Sea Level	N/A
Lord Howe Island	Lord Howe Island Hydro Datum	N/A
Norfolk Island	Lowest Astronomical Tide	N/A
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
Port Stephens	Port Stephens Hydro Datum	0.944
Patonga	Australian Height Datum	0.000
Sydney	Zero Fort Denison	0.925
Fort Denison	Zero Fort Denison	0.925
Port Hacking	Zero Fort Denison	0.925
Shoalhaven Offshore	Mean Sea Level	N/A
Crookhaven Heads	Australian Height Datum	0.000
Jervis Bay	Chart Datum	1.070
Ulladulla	Australian Height Datum	0.000
Batemans Bay Offshore	Mean Sea Level	N/A
Princess Jetty	Australian Height Datum	0.000
Bermagui	Bermagui Local Hydro Datum	0.714
Eden Boat Harbour	Twofold Bay Hydro Datum	0.924

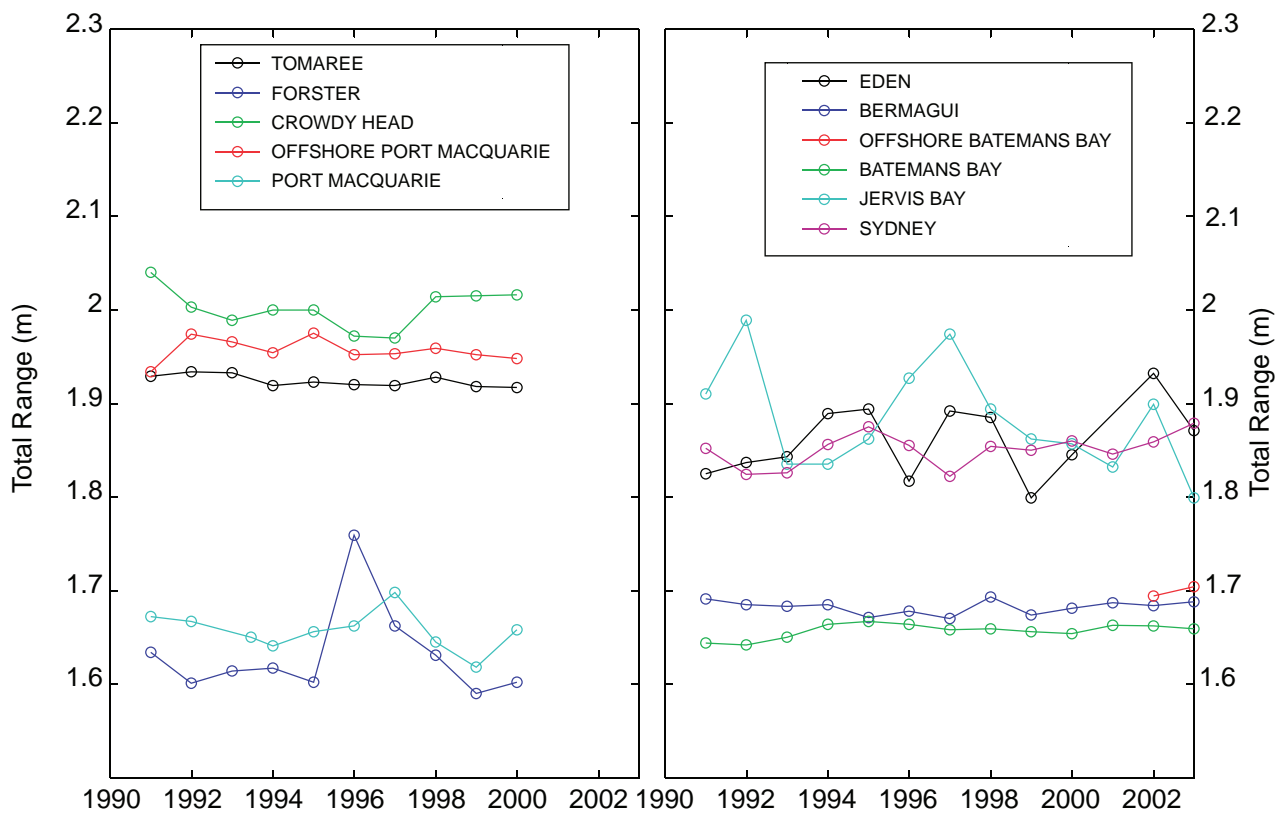
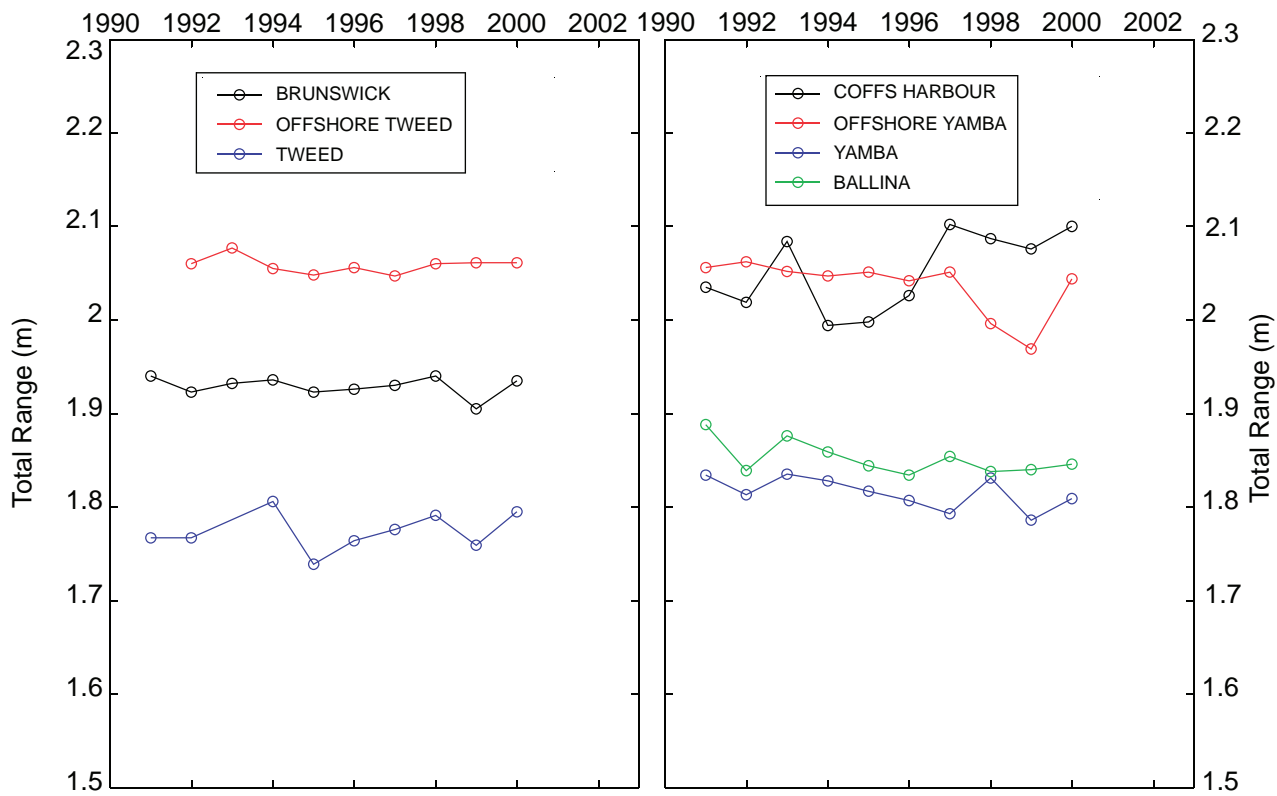
¹ subtract adjustment from data values to convert to AHD.

2.3 Tidal Planes

NSW Public Works 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, NSW Public Works 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 NSW Public Works 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 its intended purpose.



Note: Each offshore gauge has been grouped with the closest nearshore gauges for comparison

Source: MHL1269 2005



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TIDAL RANGE FOR GROUPED OFFSHORE AND NEARSHORE GAUGES 1990-2003

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Figure 2.1

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3. Significant Events 2013–2014

Data recovery rates across the NSW Ocean Tide Network in 2013–2014 were very high, with an overall average of 99.9% data collected.

In 2015, NSW Public Works MHL will make NSW Tide Prediction Charts available via download from the internet. The charts will be available free of charge for the first time via the NSW Public Works MHL website. The charts remain the most complete authoritative charts for coastal NSW ([Figure 3.1](#)) but the distribution will be modernised. As for previous tide prediction publications, NSW Public Works MHL has adopted the Sydney Harbour Middle Head tide gauge as the primary reference station, and the ocean tide predictions for NSW are based on an analysis of hourly 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.

3.1 Tidal Anomalies

Tidal anomalies in this report are calculated as the difference between the recorded data and the Foreman (1977) tidal prediction based on the previous year's (July to June) data. 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](#). [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 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.

Significant anomaly events impacting the NSW coastline are documented in [Figures 3.3](#) and [3.4](#), together with probable causative mechanisms. Most appear to be driven by east coast lows or large high pressure systems.

The Bureau of Meteorology (BoM) recorded two cyclones in North Queensland during the 2013–2014 reporting period:

- 25–31 January 2014, Cyclone Dylan Category 2. Tropical Cyclone Dylan formed in the Coral Sea and caused increased tides and strong to gale force winds along a large stretch of the Queensland east coast in the days leading up to Dylan's landfall near Bowen. Dylan also caused heavy rainfall along parts of the central Queensland coast and about adjacent inland areas as the system moved over the interior of the state. There is no clear evidence of this cyclone in the NSW ocean tide traces.
- 5–14 April 2014, Cyclone Ita Category 5. Tropical Cyclone Ita originated in the Coral Sea but on the afternoon of 10 April intensified extremely rapidly, reaching Category 4 and then Category 5 in the span of six hours. At the same time, it turned south-west towards the far north Queensland coast, where it made landfall at about 10 pm on the evening of Friday 11 April near Cape Flattery where a maximum wind gust of 160 km/h was recorded. Near landfall, the centre of Ita came within 5 km of the resort at Lizard Island. Unofficial readings showed the air pressure dropped to approximately 954 hPa and wind gusts reached approximately 155 km/h before the instrument failed. Considerable vegetation damage but only minor structural damage to buildings was recorded there. Upon landfall, Ita continued to track southward through the inland North Tropical Coast district. It weakened reasonably quickly and passed 20 km west of Cooktown. There is no clear evidence of this cyclone in the NSW ocean tide traces.

Table 3.1 lists the tsunami events in the Pacific Region for the period of time corresponding to the 2013–2014 data in this report.

Table 3.1 Tsunami Events July 2013 to June 2014

Date	Cause		Location	Observable on NSW Tide Recordings
	Earthquake Magnitude (M_w)	Other Causes		
21/7/2013	6.5		New Zealand – Cook Strait	No
16/8/2013	6.5		New Zealand – Wellington	No
25/10/2013	7.1		Japan – off east coast of Honshu Island	No
16/3/2014	6.7		Chile – northern Chile	No
1/4/2014	8.2		Chile – northern Chile	Slight
3/4/2014	7.6		Chile – northern Chile	Slight
12/4/2014	7.6		Solomon Islands	No
13/4/2014	7.4		Solomon Islands	No
19/4/2014	7.5		Papua New Guinea – Solomon Sea	No
23/6/2014	6.9		New Zealand – Kermadec Islands	No

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

The Bureau of Meteorology and Geoscience Australia host the Joint Australian Tsunami Warning Centre (JATWC). No tsunami warnings were issued by JATWC from July 2013 to June 2014. 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 Chile earthquake events. The events are close together and are not possible to separate in the water level traces. Traces from indicative sites are shown in [Figure 3.10](#).

3.2 Other Tide Events 2013–2014

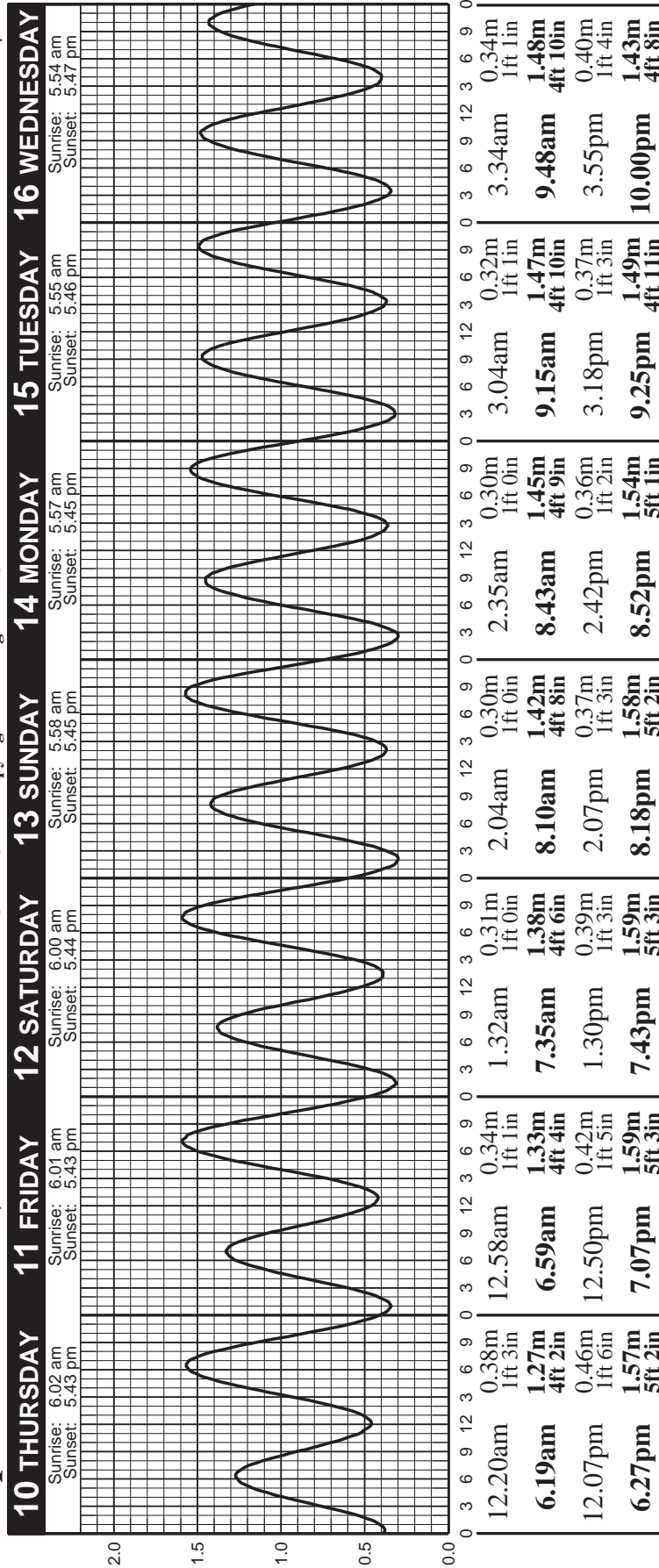
Other water level events that occurred during the 2013–2014 reporting period included:

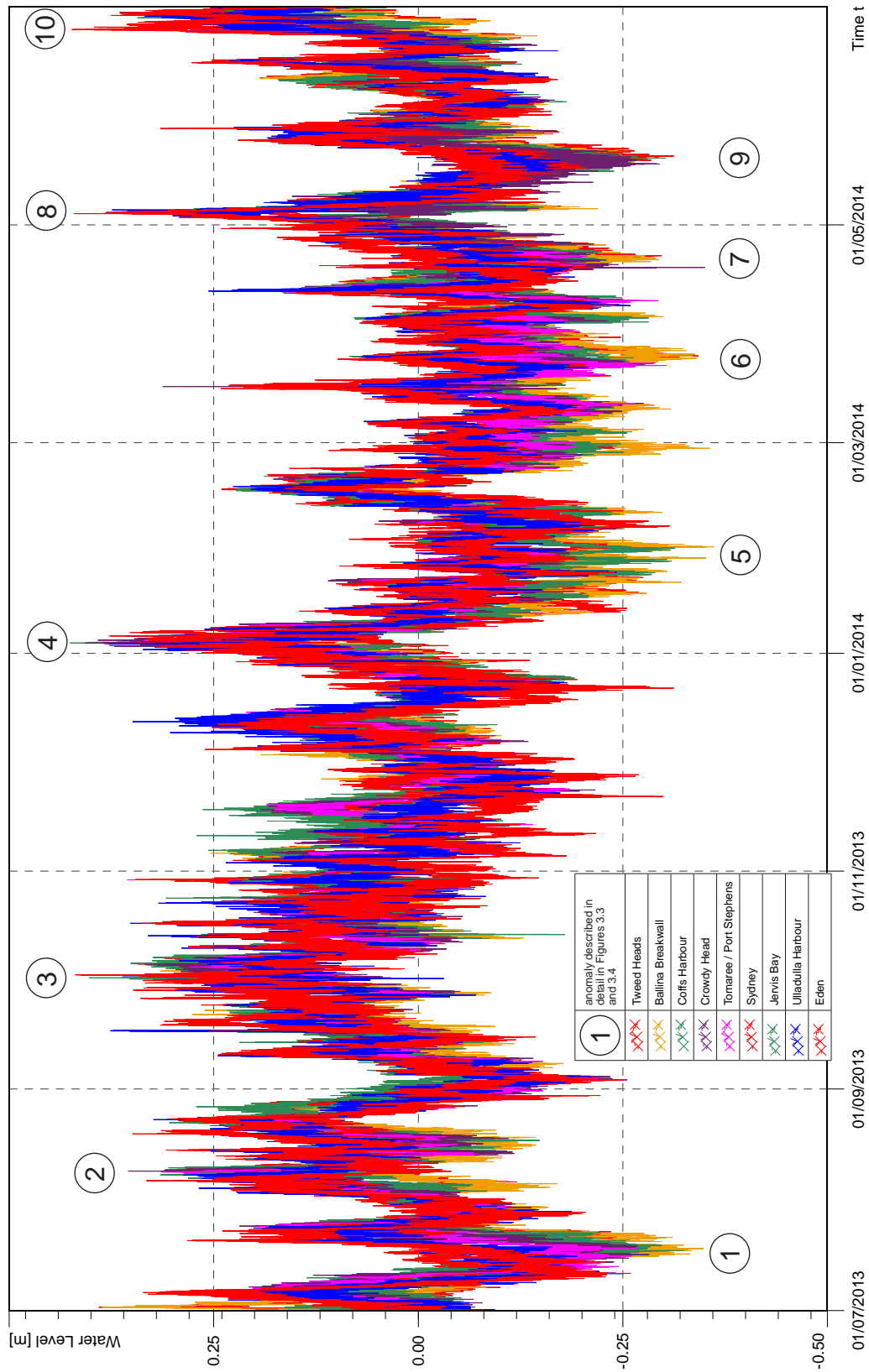
- 2, 3 January 2014 – King Tide event. The highest water level of the fiscal year of 2.19 m (1.26 m AHD) was recorded at the Sydney gauge. The next highest water level was 2.07 m on 23/7/2013. [Figures 3.11](#) and [3.12](#) show the Sydney water level data along with some photographs of the event.

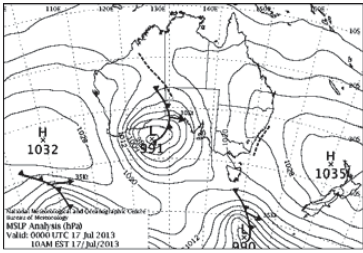
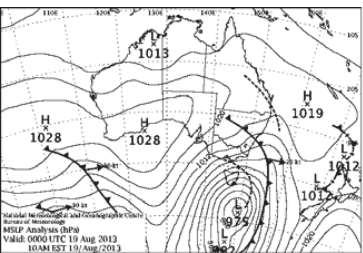
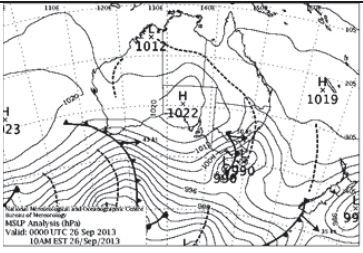
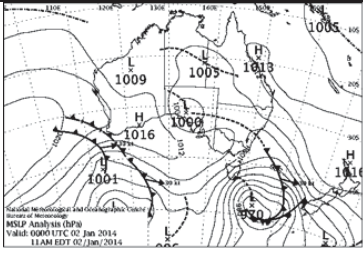
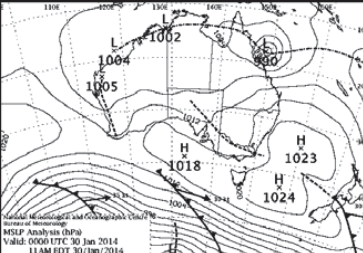
September 10–16, 2015

Australian Eastern Standard Time
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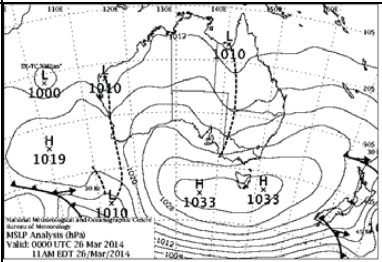
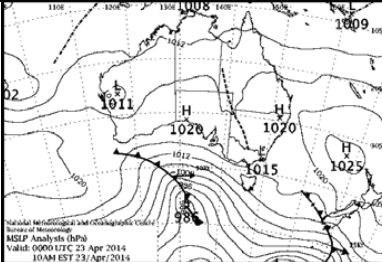
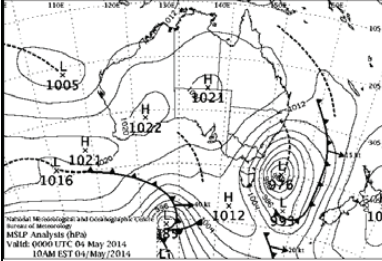
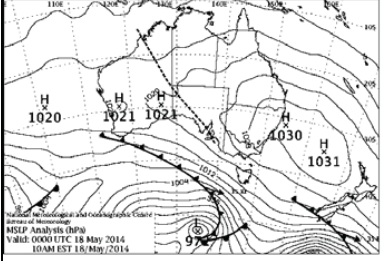
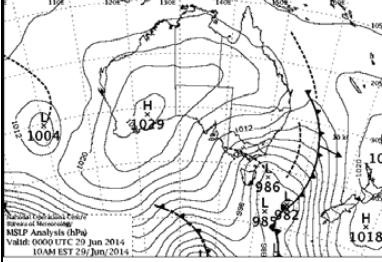
● New Moon Sep 13





Event Number (see Figure 3.2)	Event Period	BOM Weather Map*	Peak	Sites where Anomaly > +/- 0.2m
1	15 - 22 July 2013	 <p>High Pressure System affecting Northern NSW</p>	Site: Ballina Date: 18/7/13 Time: 0800 Peak Value: -0.35	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Port Stephens
2	18 - 27 Aug 2013	 <p>Series of Low pressure systems in Bass Strait</p>	Site: Eden Date: 18/8/13 Time: 1100 Peak Value: -0.35	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Port Stephens, Patonga, Port Hacking, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
3	26 Sept - 8 Oct 2013	 <p>Series of East Coast Low pressure systems</p>	Site: Eden Date: 3/10/13 Time: 0030 Peak Value: -0.42	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Port Stephens, Patonga, Sydney, Port Hacking, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
4	1 - 7 Jan 2014	 <p>Low pressure south of NSW</p>	Site: Coffs Harbour Date: 3/1/14 Time: 2100 Peak Value: 0.43	Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Port Stephens, Patonga, Sydney, Port Hacking, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
5	12 Jan - 11 Feb 2014	 <p>Prolonged high pressure system off NSW coast</p>	Site: Yamba Date: 30/1/14 Time: 1245 Peak Value: -0.41	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden

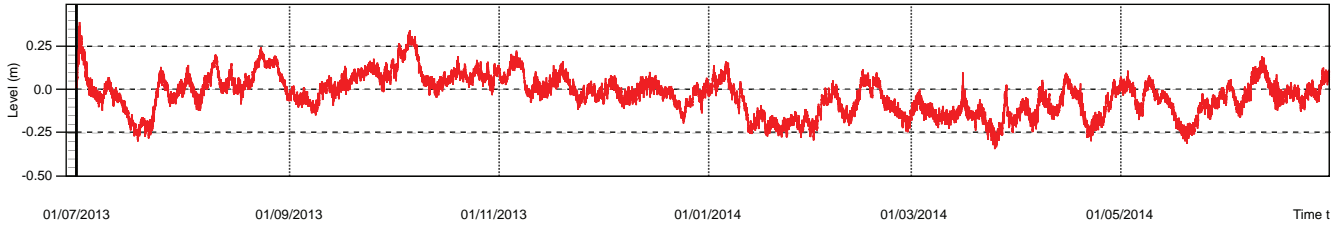


Event Number (see Figure 3.2)	Event Period	BOM Weather Map*	Peak	Sites where Anomaly > +/- 0.2m
6	21 – 27 March 2014	 High Pressure off NSW Coast	Site: Yamba Date: 24/3/14 Time: 1745 Peak Value: -0.40	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Port Stephens, Patonga, Sydney, Port Hacking, Crookhaven, Ulladulla,
7	18 – 26 April 2014	 High Pressure off NSW Coast	Site: Patonga Date: 19/4/14 Time: 0615 Peak Value: -0.38	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Port Stephens, Patonga
8	3 – 6 May 2014	 East Coast Low off NSW south coast	Site: Eden Date: 4/5/14 Time: 0215 Peak Value: 0.42	Sydney, Port Hacking, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
9	16 – 23 May 2014	 High pressure over NSW coast	Site: Port Macquarie Date: 18/5/14 Time: 0215 Peak Value: -0.32	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Port Stephens, Patonga, Sydney, Port Hacking
10	23 – 30 June 2014	 Low pressure system in Bass Strait	Site: Eden Date: 24/6/14 Time: 1700 Peak Value: 0.42	Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Port Stephens, Patonga, Sydney, Port Hacking, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden

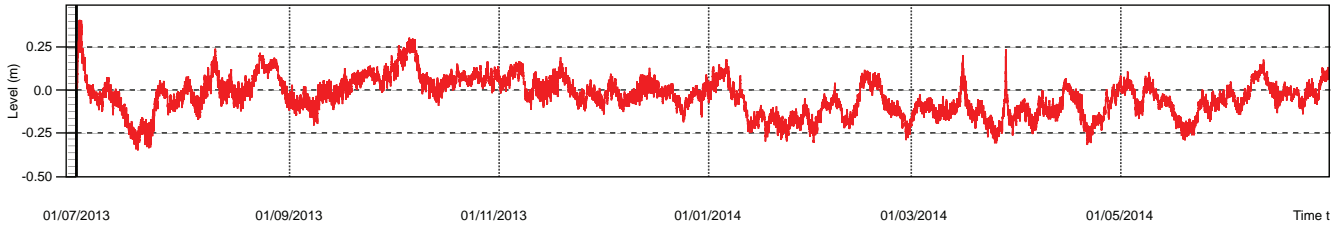
* - Weather Map images courtesy BOM © [Copyright](#) Commonwealth of Australia , Bureau of Meteorology



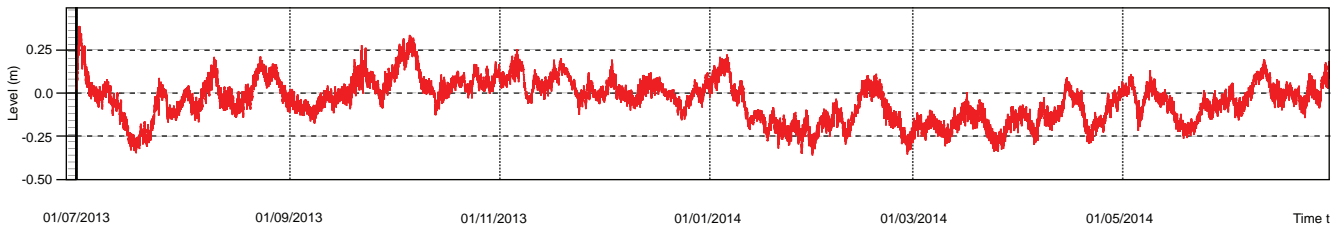
Tweed River at Tweed Heads



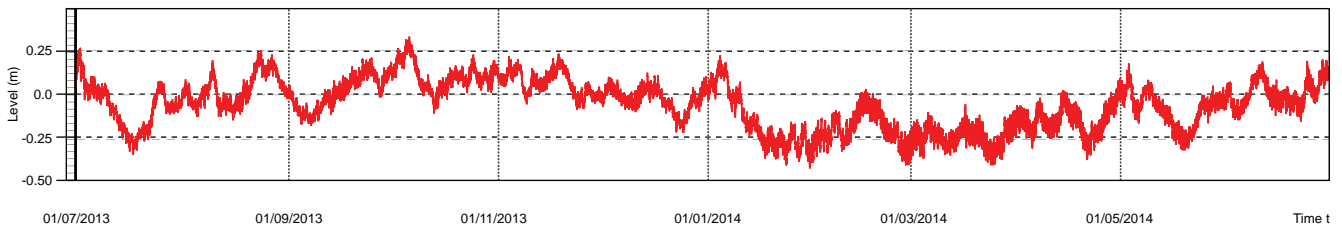
Brunswick River at Brunswick Heads



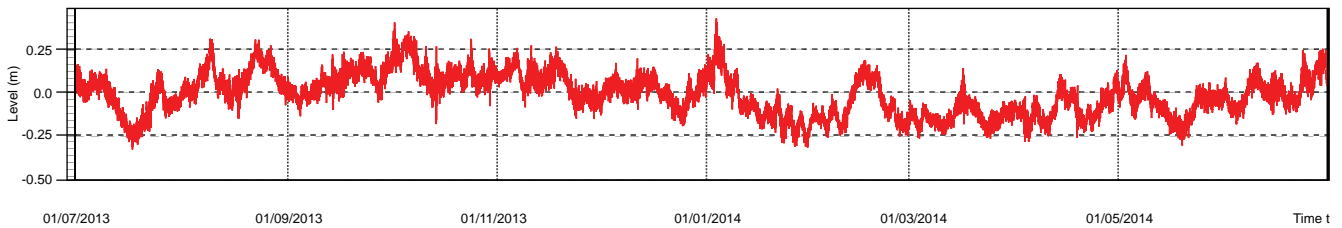
Richmond River at Ballina Breakwall



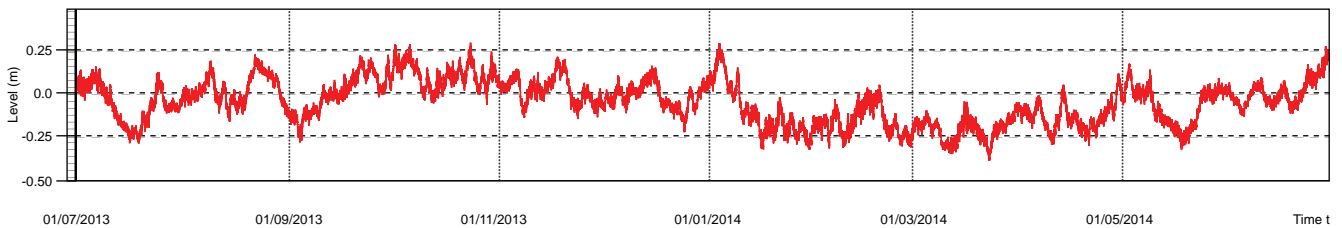
Clarence River at Yamba



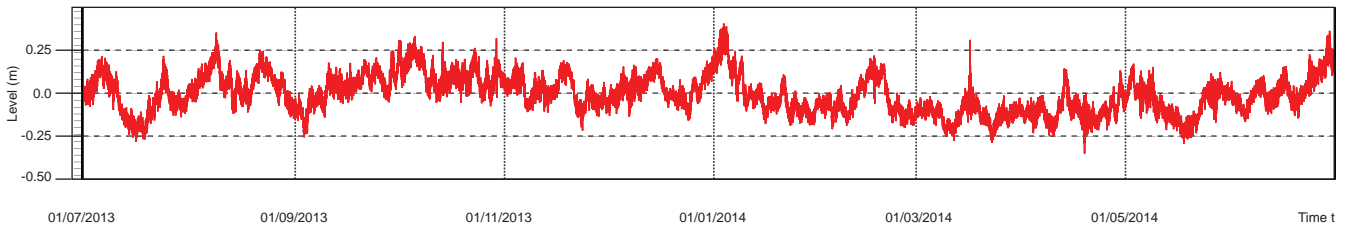
Tasman Sea at Coffs Harbour



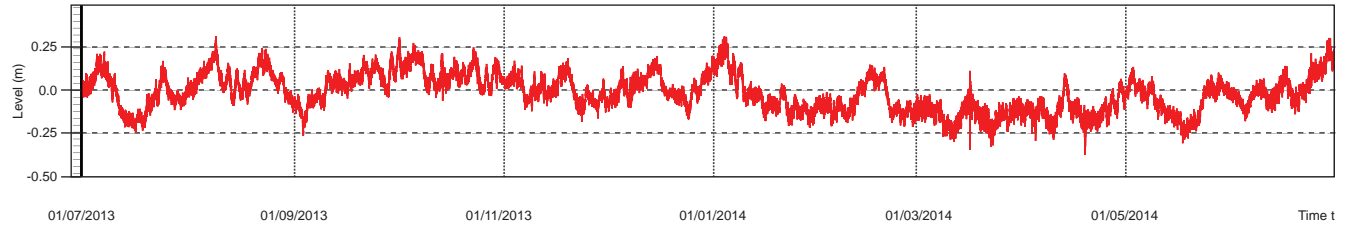
Hastings River at Port Macquarie



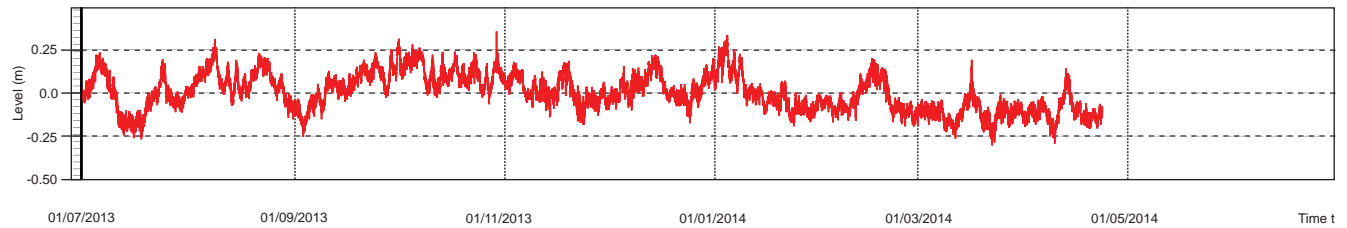
Tasman Sea at Crowdy Head Boat Harbour



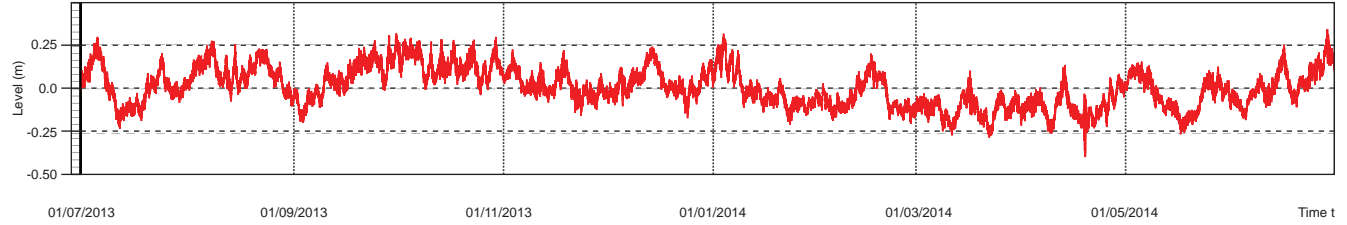
Wallis Lake Entrance at Forster



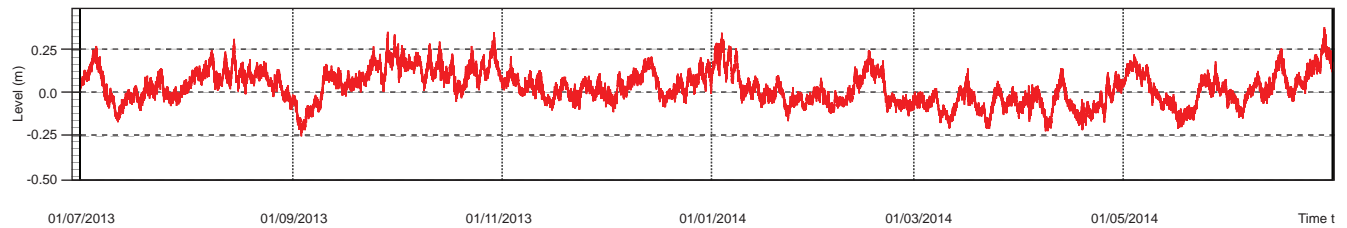
Port Stephens at Tomaree



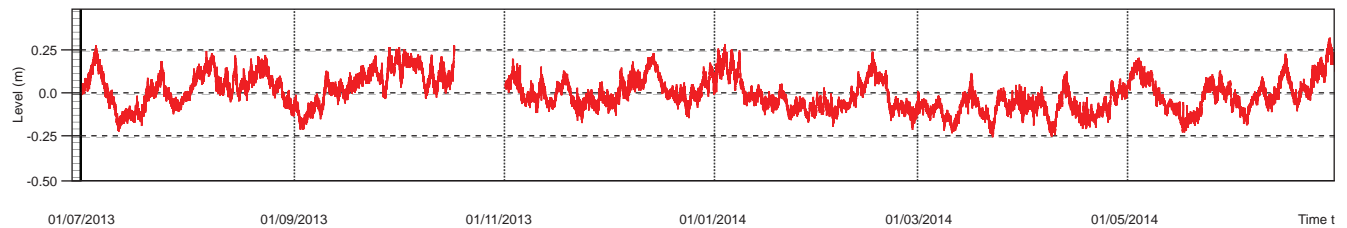
Hawkesbury River at Patonga



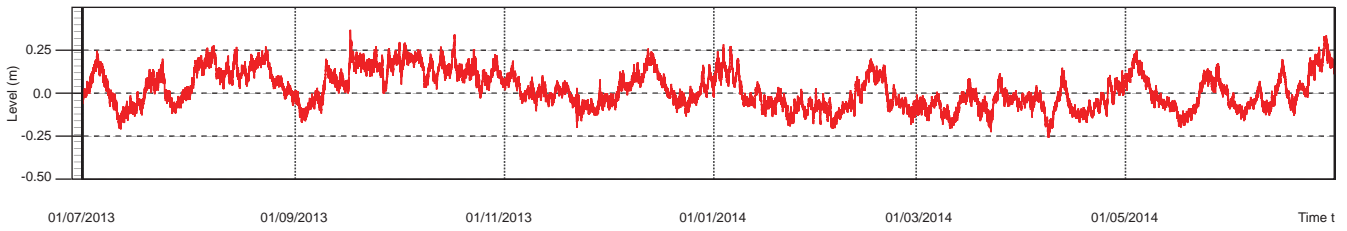
Port Jackson at Sydney



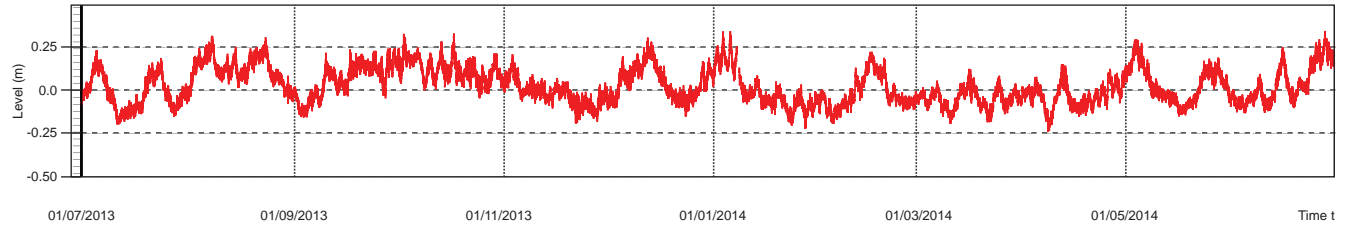
Port Hacking at Port Hacking



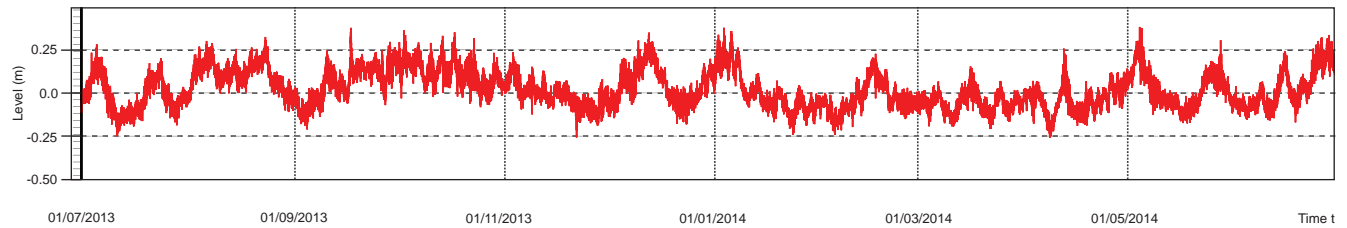
Crookhaven River at Crookhaven Heads



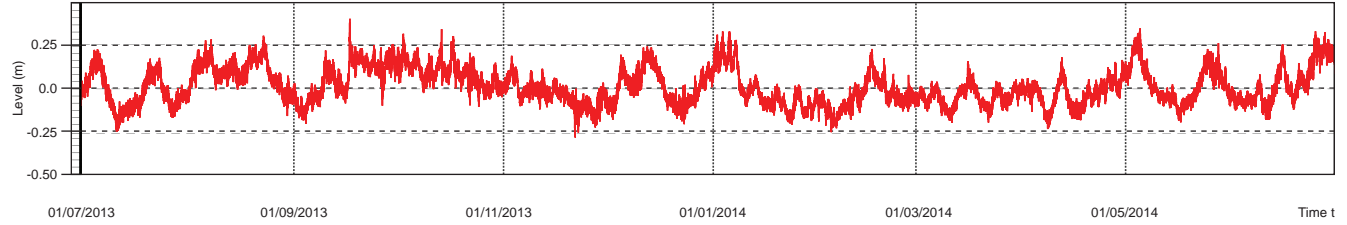
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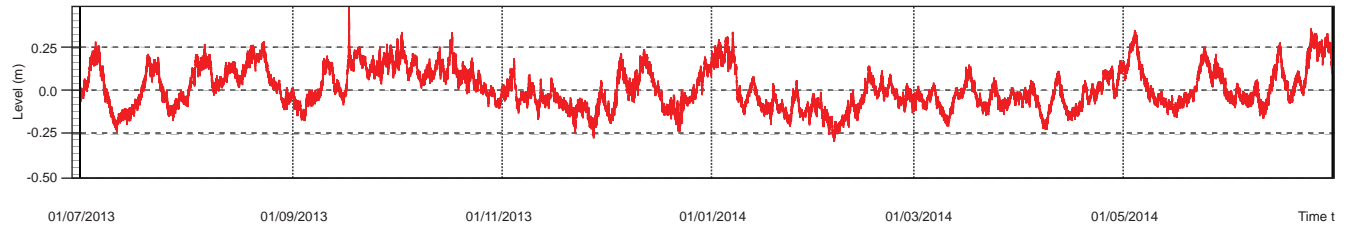
Tasman Sea at Ulladulla Boat Harbour



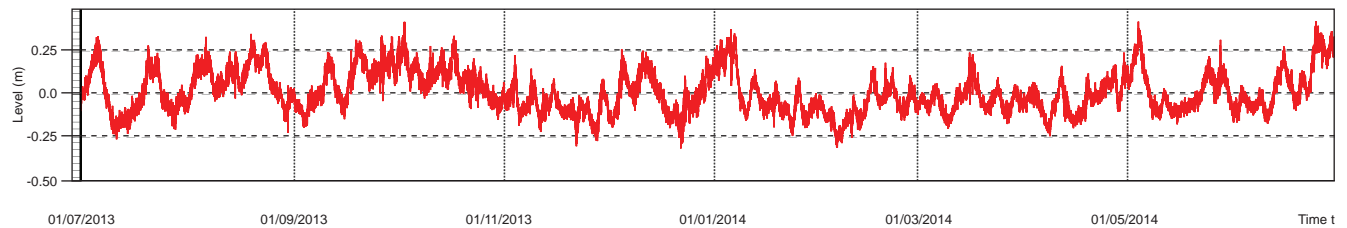
Princess Jetty at Batemans Bay



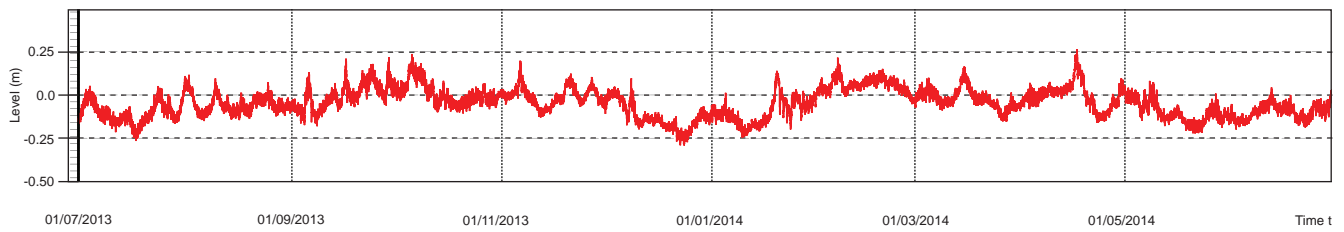
Bermagui Harbour at Bermagui



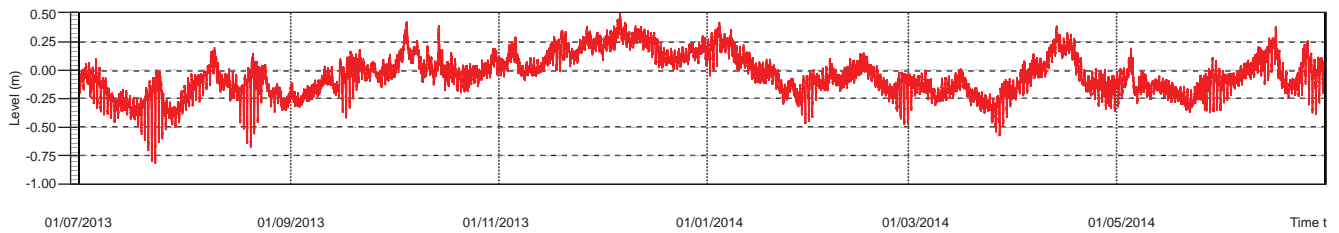
Tasman Sea at Eden Boat Harbour



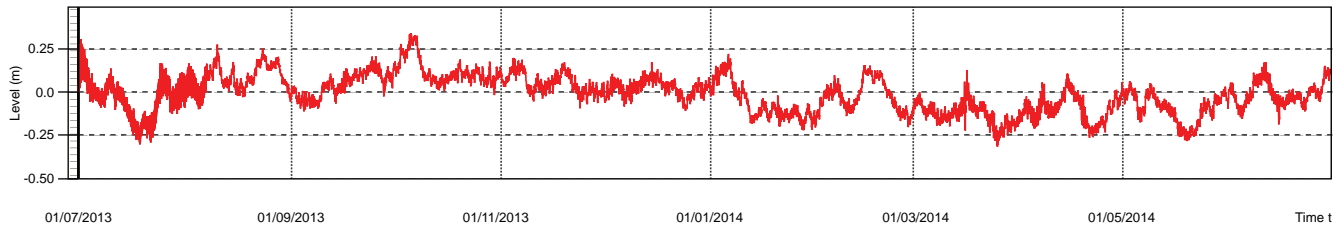
Tasman Sea at Norfolk Island



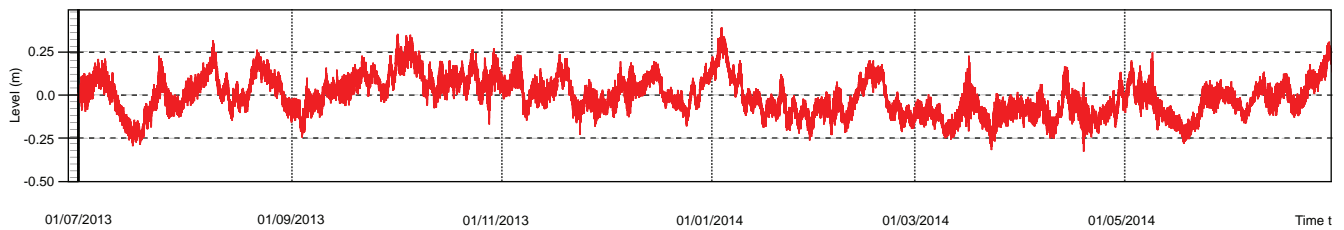
Tasman Sea at Lord Howe Island



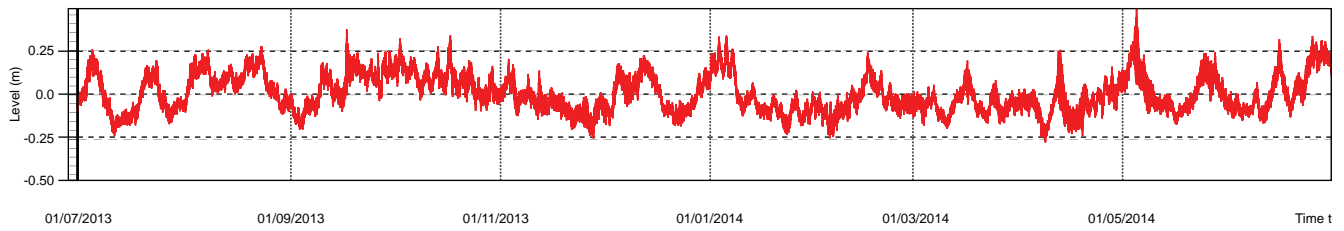
Tweed Heads Offshore



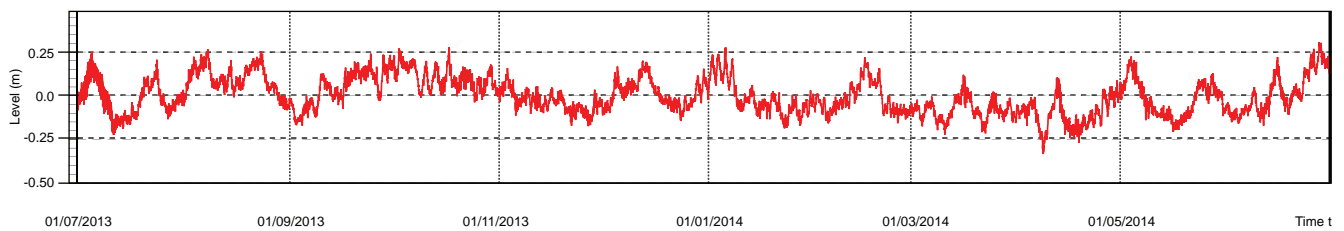
Port Macquarie Offshore

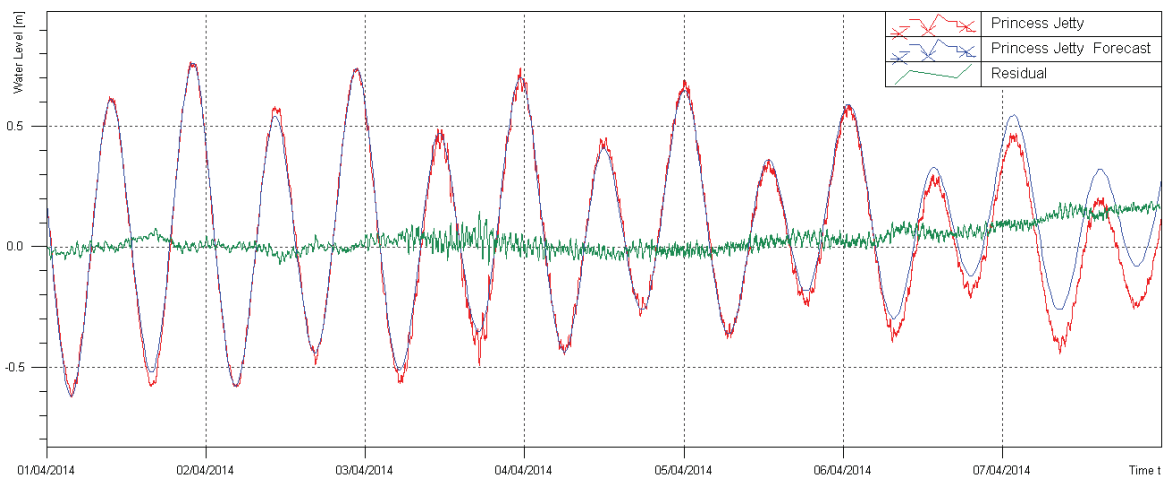
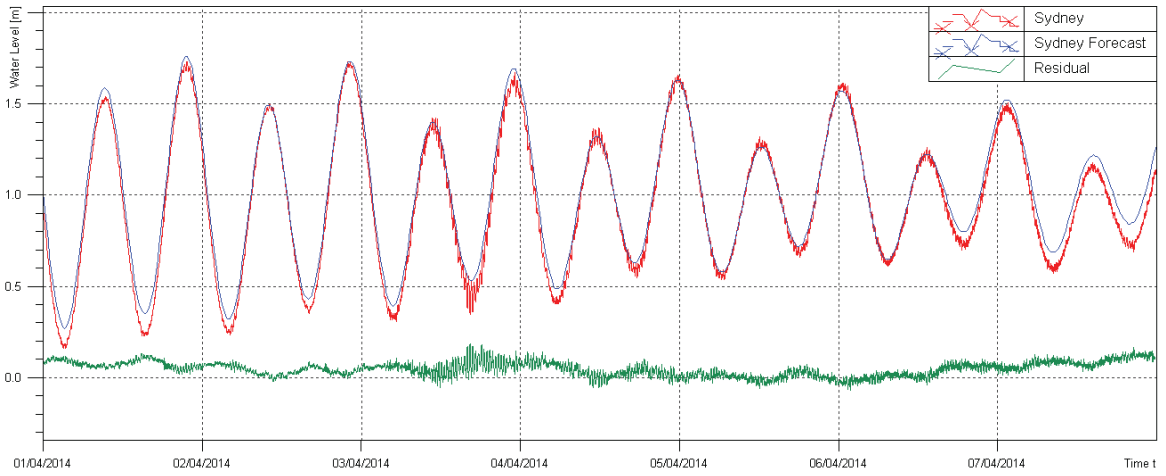
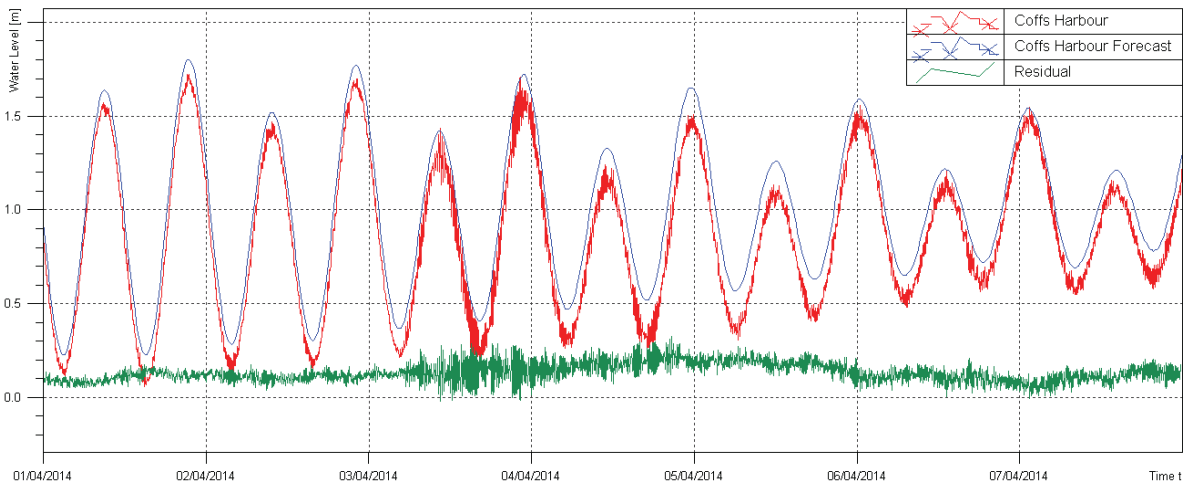


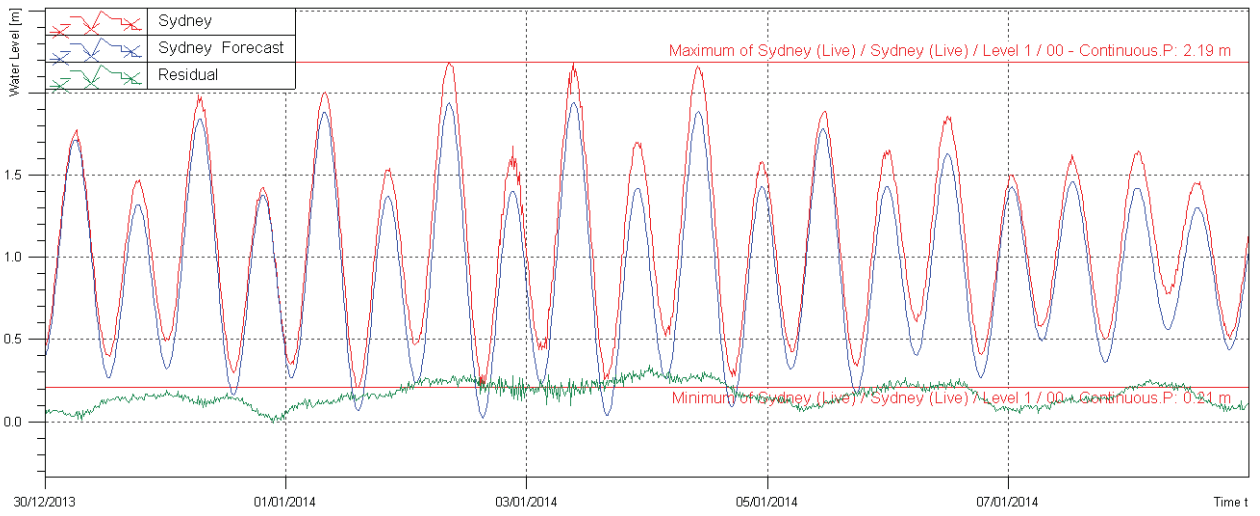
Batemans Bay Offshore



Shoalhaven Offshore







Collaroy Pool
Photo R. Jacobs



Narrabeen Pool
Photo R. Jacobs



The Spit, Middle Harbour
Photo M Galloway



Bayview
Photo R. Jacobs



Clontarf Pool
Photo M Galloway



4. Program Developments 2013–2014

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 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 Heads	Onshore River Entrance	OR
Tweed Heads	Offshore Open Ocean	O
Brunswick Heads	Onshore River Entrance	OR
Ballina Breakwall	Onshore River Entrance	OR
Yamba	Onshore River Entrance	OR
Norfolk Island	Onshore Open Ocean	OO
Lord Howe Island	Onshore Open Ocean	OO
Coffs Harbour	Onshore Bay or Port	OB
Port Macquarie	Onshore River Entrance	OR

Station	Classification	Classification Code
Port Macquarie	Offshore Open Ocean	O
Crowdy Head	Onshore Bay or Port	OB
Forster	Onshore River Entrance	OR
Port Stephens	Onshore Bay or Port	OB
Patonga	Onshore Bay or Port	OB
Sydney	Onshore Bay or Port	OB
Port Hacking	Onshore Bay or Port	OB
Shoalhaven	Offshore Open Ocean	O
Crookhaven	Onshore River Entrance	OR
Jervis Bay	Onshore Bay or Port	OB
Ulladulla	Onshore Bay or Port	OB
Princess Jetty	Onshore River Entrance	OR
Batemans Bay	Offshore Open Ocean	O
Bermagui	Onshore River Entrance	OR
Eden	Onshore Bay or Port	OB

4.2 Program Improvements/Changes

Further improvements and changes to the network have continued in 2013–2014. [Table 4.2](#) shows the status of the sites as of June 2014. The following summarises the major changes:

- Lord Howe, Tweed Entrance South, Port Macquarie, Shoal Bay, Princess Jetty and Patonga sites primary sensor upgraded to record at 1-second intervals to onsite data storage card (see example data in [Figure D1](#)).
- Tomaree site decommissioned due to wharf being condemned. Site upgraded and relocated to a new wharf location at Shoal Bay.
- New site established at Tweed Heads on the southern side of the river entrance (Tweed Entrance South) to replace the aging pile-based location on the northern side of the river.
- Primary sensors upgraded to radars at Yamba and new Tweed Entrance South site.
- Further development of the new NSW Public Works MHL database and public website.

Table 4.2 NSW Public Works MHL Tidal Logging and Sensing System Status June 2014

Station	Site Classification ¹	Primary Loggers	Secondary Loggers	Primary Sensors	Secondary Sensors	Station	
						Sampling	Logging
Tweed Heads	OR	CR800	-	Vented Pressure	Vented Pressure	120 samples averaged 1 minute either side of the quarter hour and 60 samples averaged 30 seconds either side of each minute	15 minutes on the quarter hour and 1 minute on the minute
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		
Coffs Harbour	OB	CR800	-	Radar	Vented Pressure		
Port Macquarie	OR	CR1000	-	Radar	Vented Pressure		
Crowdy Head	OB	CR800	-	Radar	Vented Pressure		
Forster	OR	CR800	-	Vented Pressure	Vented Pressure		
Port Stephens	OB	CR800	-	Radar	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	OB	CR800	MetOcean	Electromagnetic	Vented Pressure	Lord Howe, Tweed Ent South, Port Macquarie, Shoal Bay, Patonga and Princess Jetty sites logging at 1 second to onsite data storage card	
Crookhaven	OR	CR800	-	Vented Pressure	Vented Pressure		
Jervis Bay	OB	CR800	-	Radar	Vented Pressure		
Ulladulla	OB	CR800	-	Vented Pressure	Vented Pressure		
Princess Jetty	OR	CR1000	-	Radar	Vented Pressure		
Bermagui	OR	CR800	-	Vented Pressure	Vented Pressure		
Eden	OB	CR800n	-	Radar	Vented Pressure		
Norfolk Island	OO	CR800	-	Floatwell	Vented Pressure		
Lord Howe Island	OO	CR1000	-	Radar	Vented Pressure		
Tweed Heads Offshore	O	RBR	WLR7	Submersible Paroscientific Pressure Sensor and RBR Logger	Aanderaa Submersible Pressure		Integrated over 40 seconds
Port Macquarie Offshore	O	RBR	WLR7				
Shoalhaven Offshore	O	RBR	WLR7				
Batemans Bay Offshore	O	RBR	WLR7				

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

4.3 Program Plans 2014–2015

NSW Public Works 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 2014–2015 program upgrades include:

- relocate the Port Hacking site to Bundeena and upgrade to the radar sensor
- high frequency logging (1-second) upgrades at Sydney, Jervis Bay and Eden
- decommission the Norfolk gauge due to its location being adjacent to a new BoM gauge
- decommission Tweed Heads site including removal of the pile
- radar sensors to be installed at Bundeena and possibly Ulladulla
- further investigation into automated status reports from the field to the database.

5. References

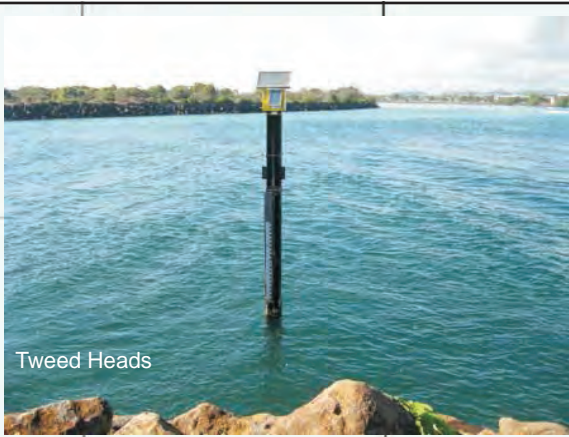
Foreman, M.G.G. 1977, *Manual for tidal heights analysis and prediction*, Pac. Mar. Sci. Rep. 77-10, Inst. of Ocean Sciences, Patricia Bay, Sidney, B.C., 58pp (2004 revision)

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

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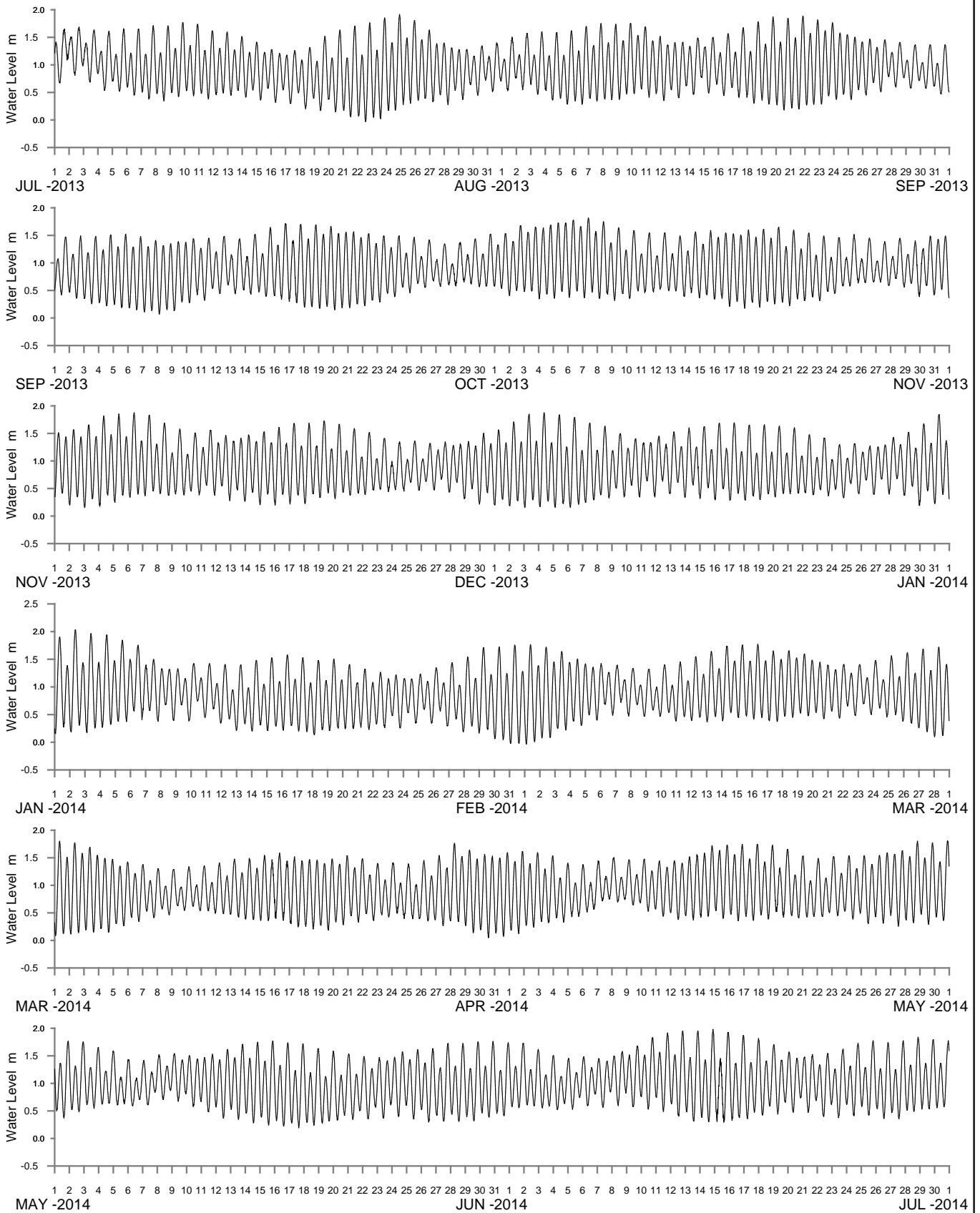
Appendix A
Annual Data Site Summaries



Public Works
Manly Hydraulics Laboratory

**TWEED HEADS
STATION LOCATION**

MHL
Report 2292
Figure
A1



WATER LEVEL REFERENCED TO TWEED RIVER HYDRO DATUM

----- DATA LOSS



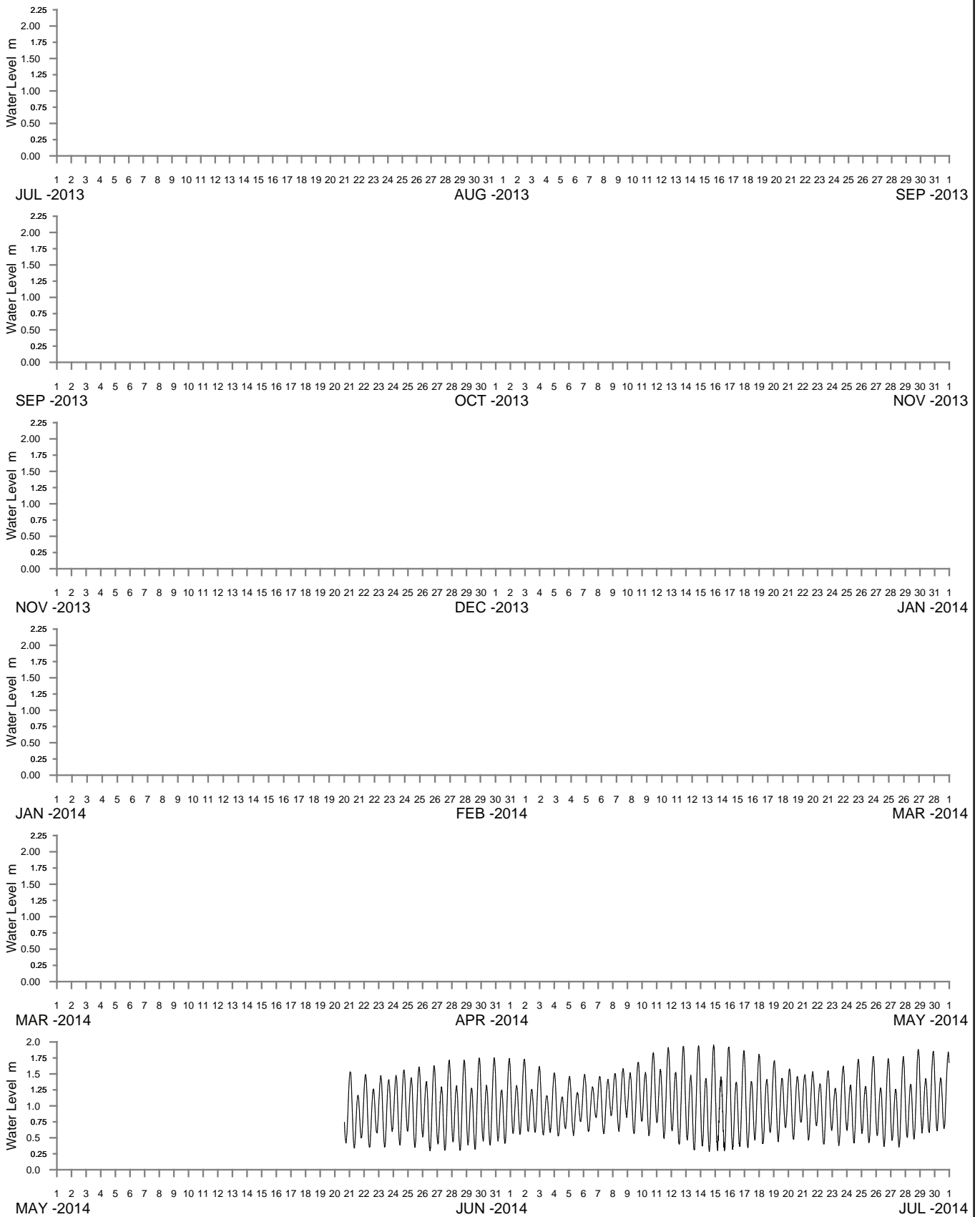
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TWEED RIVER AT TWEED HEADS

MHL
Report 2292

Figure
A2

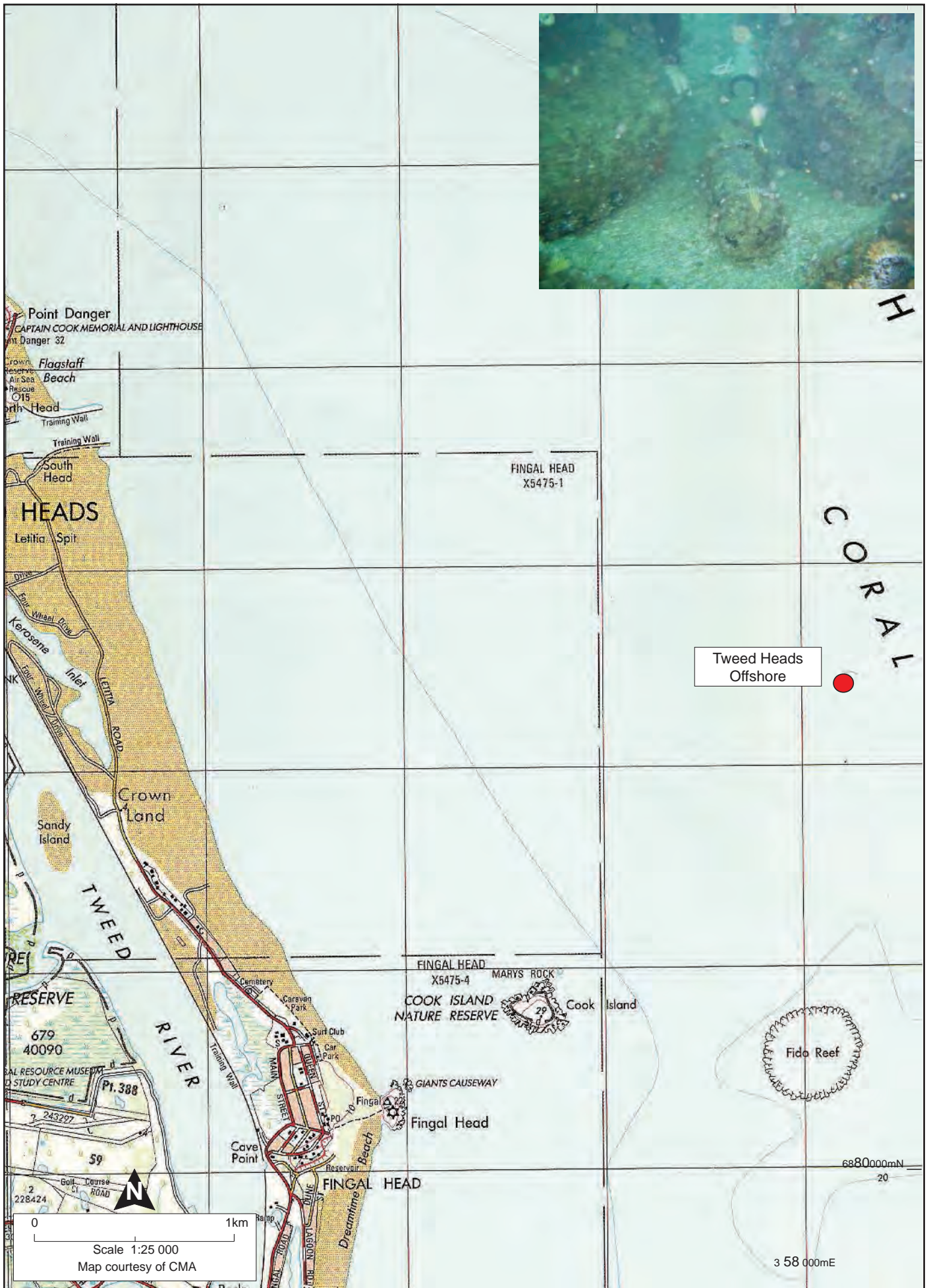
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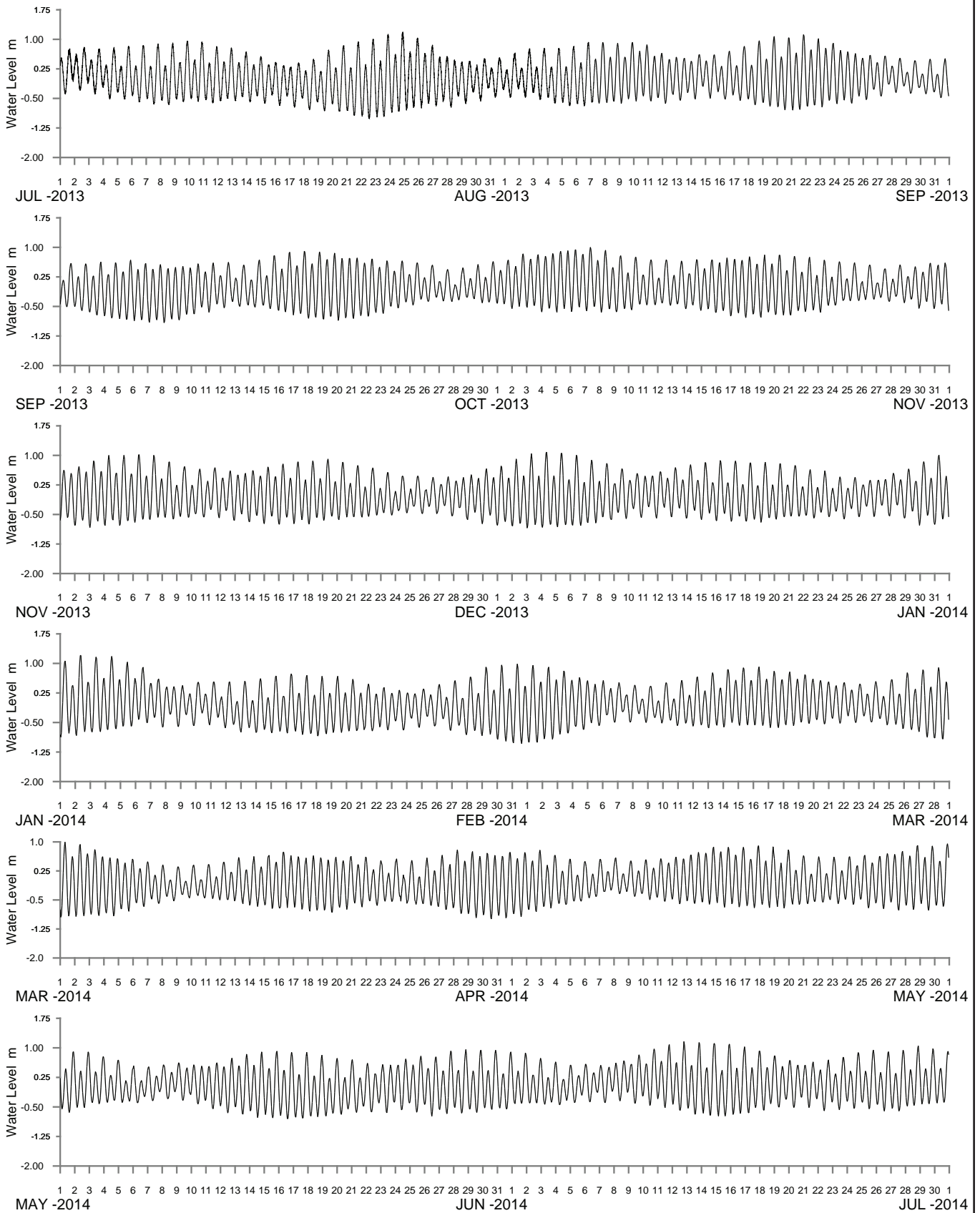
Public Works
Manly Hydraulics Laboratory

**TWEED HEADS OFFSHORE
TIDE GAUGE LOCATION**

MHL
Report 2292

Figure
A4

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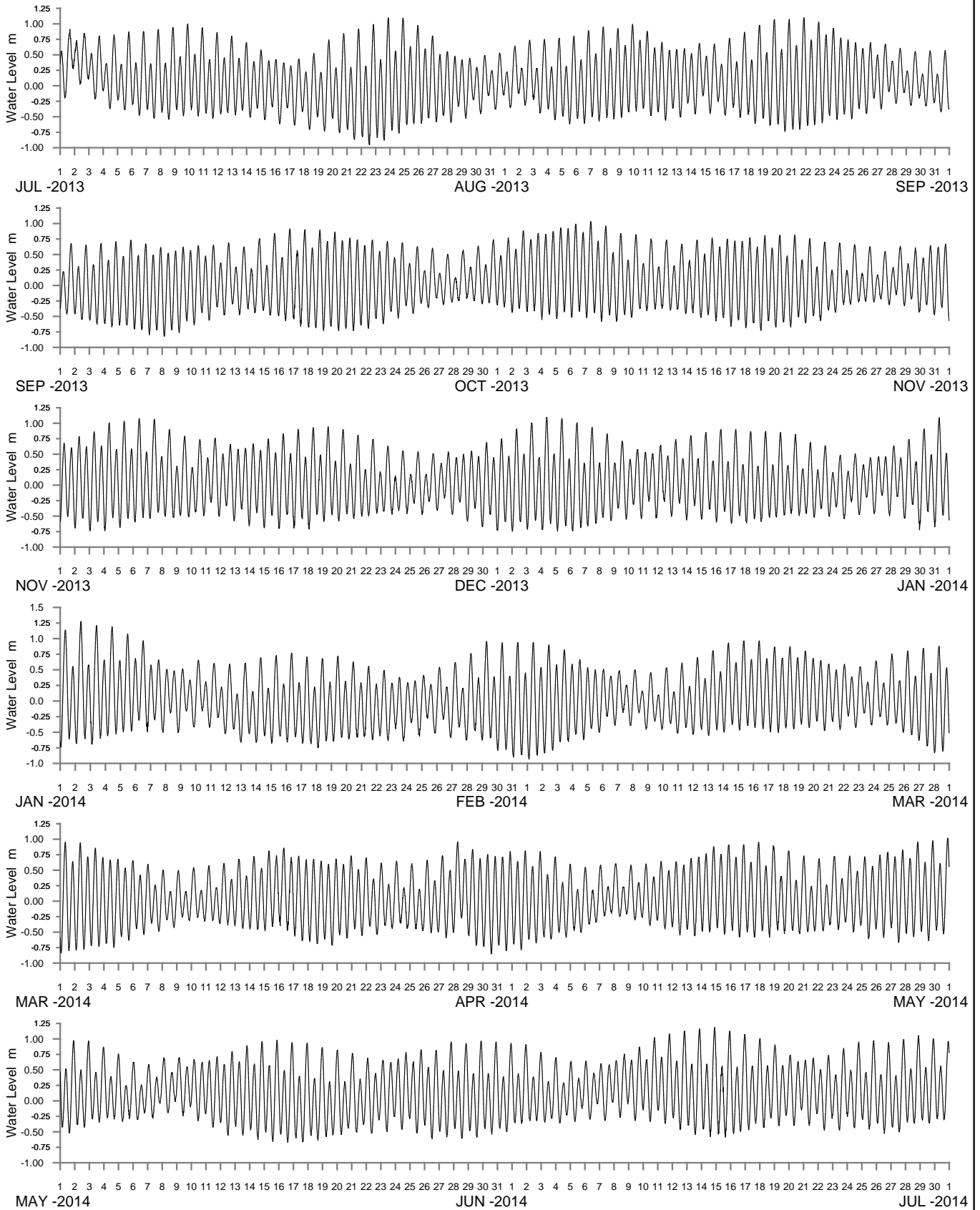


WATER LEVEL REFERENCED TO MEAN SEA LEVEL

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WATER LEVEL REFERENCED TO BRUNSWICK RIVER FLOOD MITIGATION DATUM

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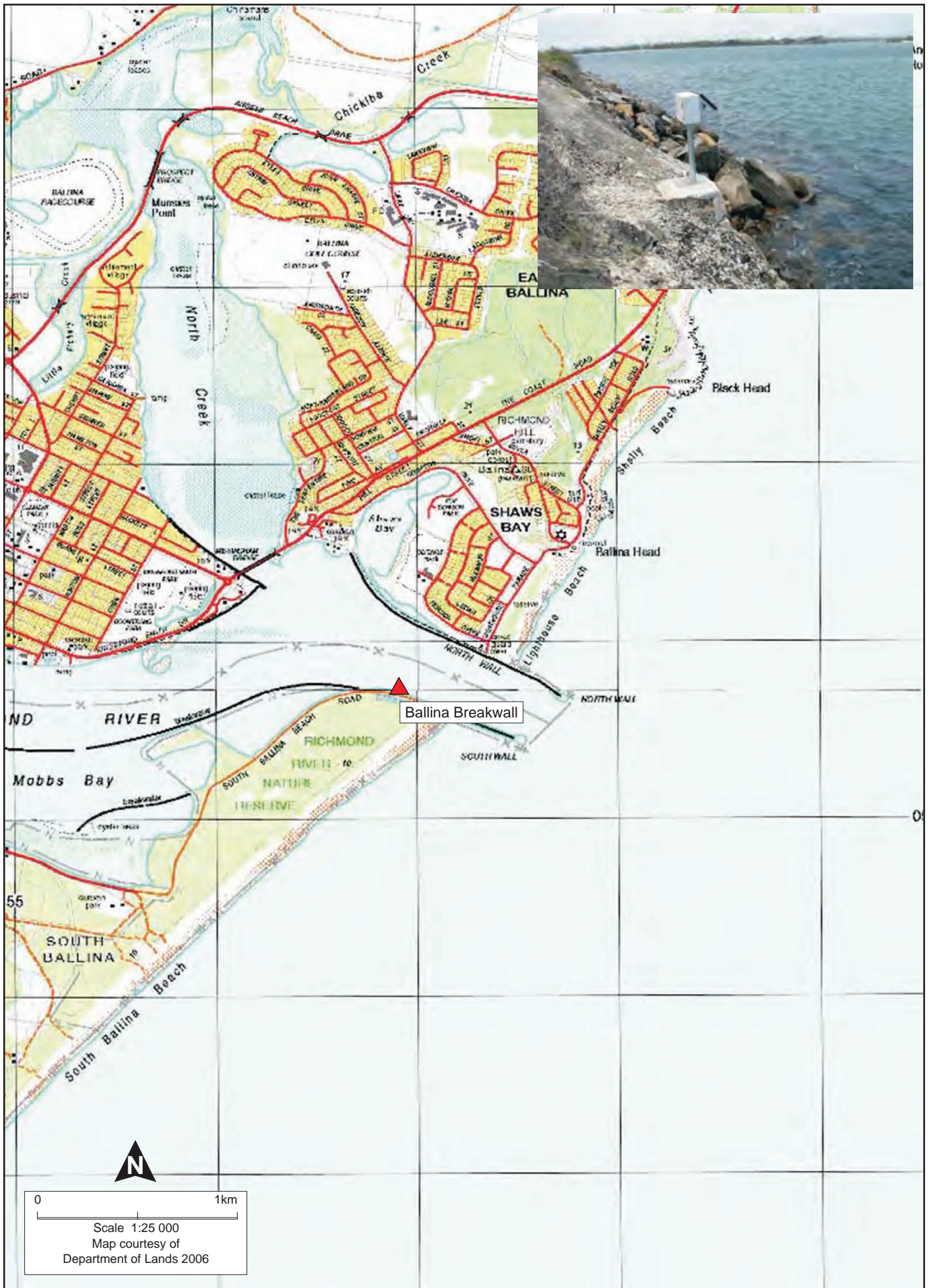
Public Works
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BRUNSWICK RIVER AT BRUNSWICK HEADS

MHL
Report 2292

Figure
A7

2292.indd-25



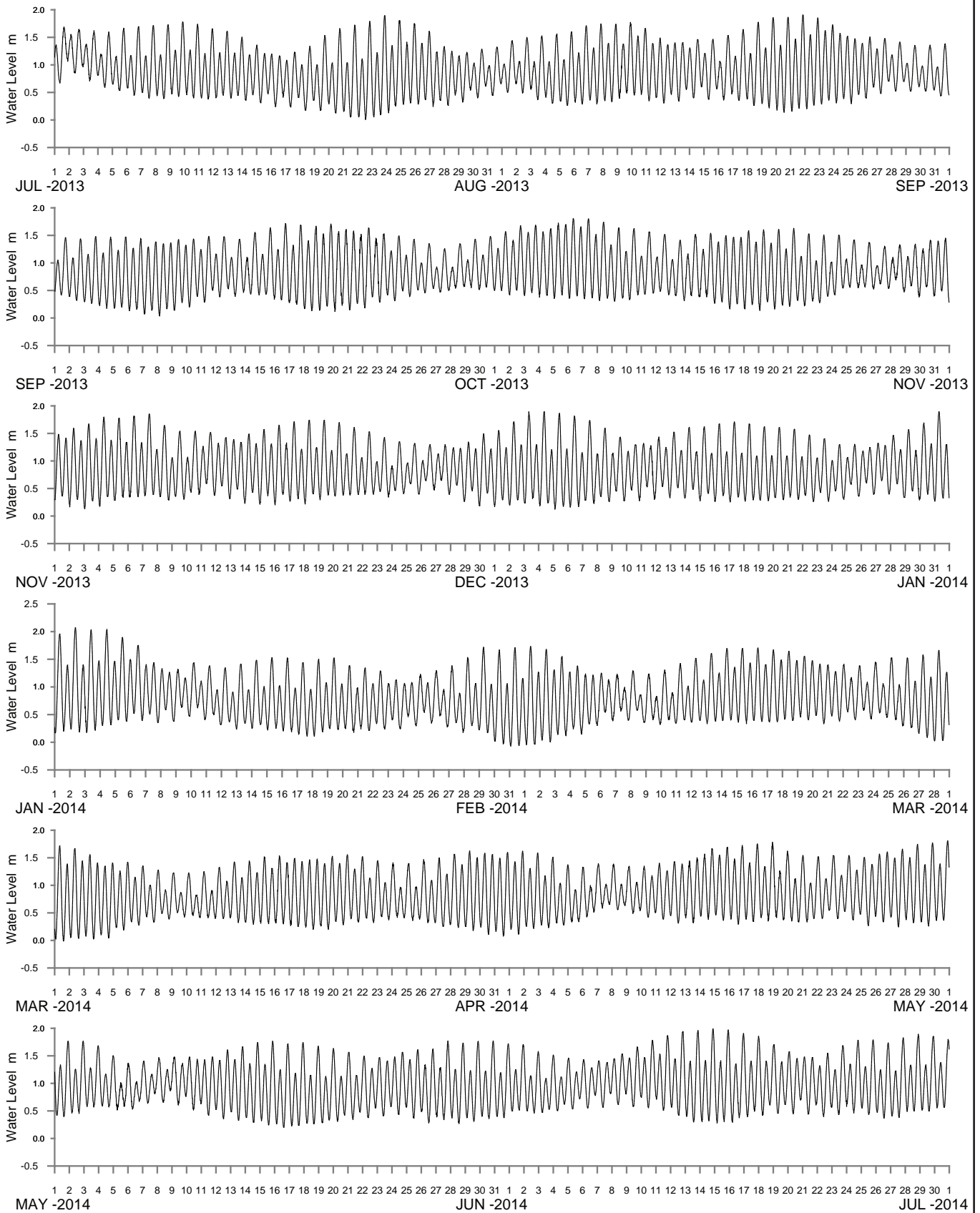
0 1km
 Scale 1:25 000
 Map courtesy of
 Department of Lands 2006



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**BALLINA BREAKWALL
 STATION LOCATION**

MHL
 Report 2292
 Figure
 A8

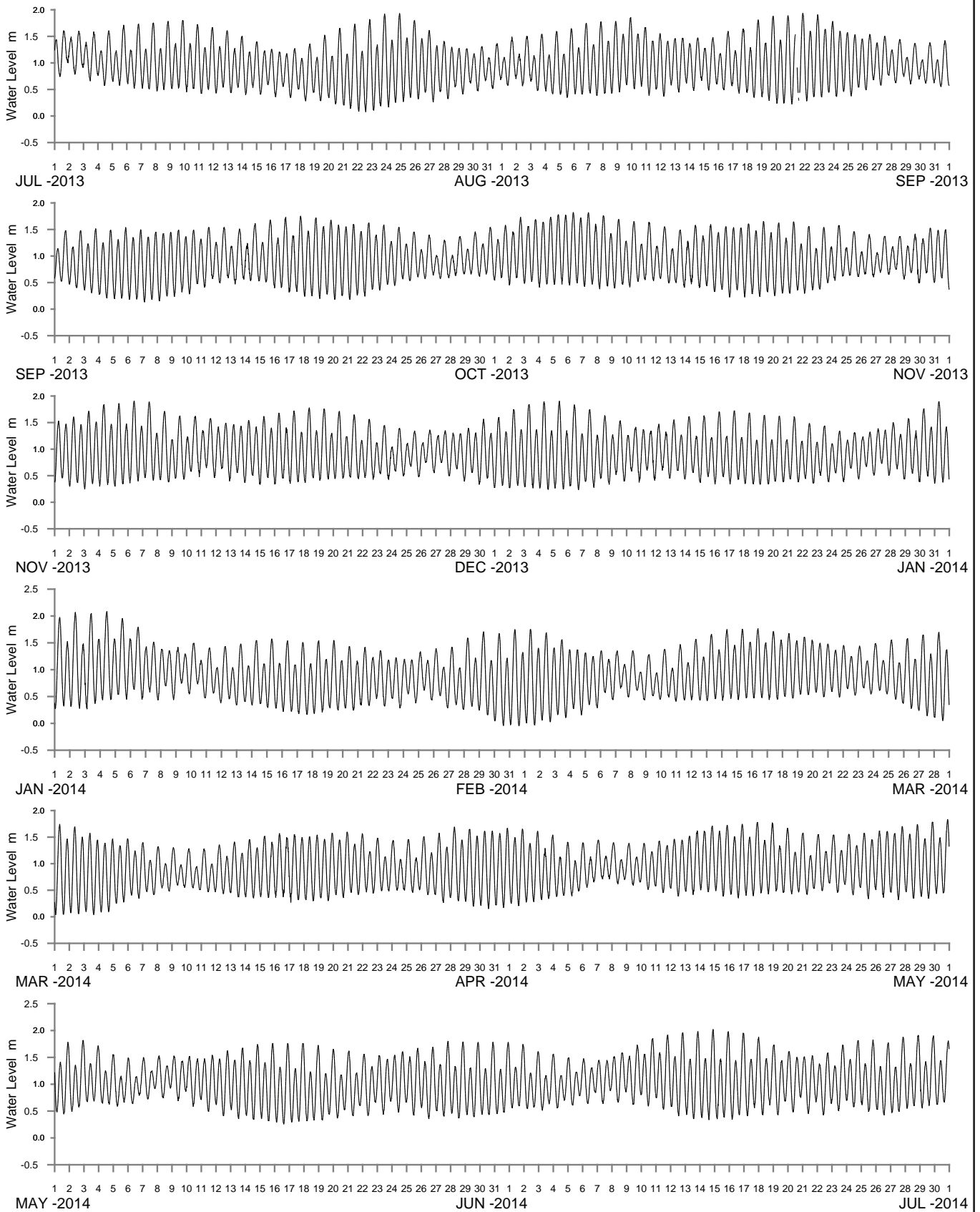


WATER LEVEL REFERENCED TO RICHMOND RIVER VALLEY DATUM

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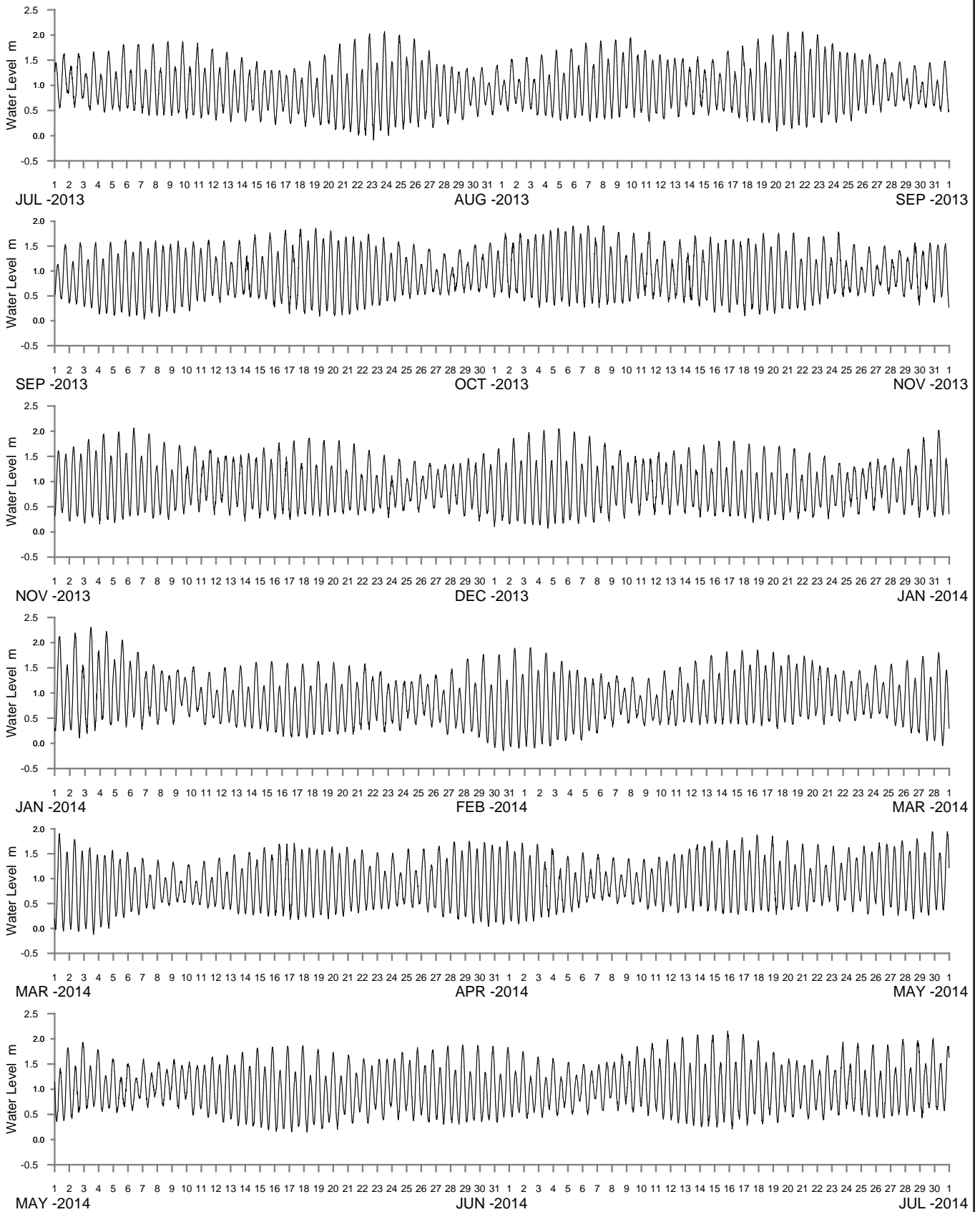


WATER LEVEL REFERENCED TO ILUKA PORT DATUM

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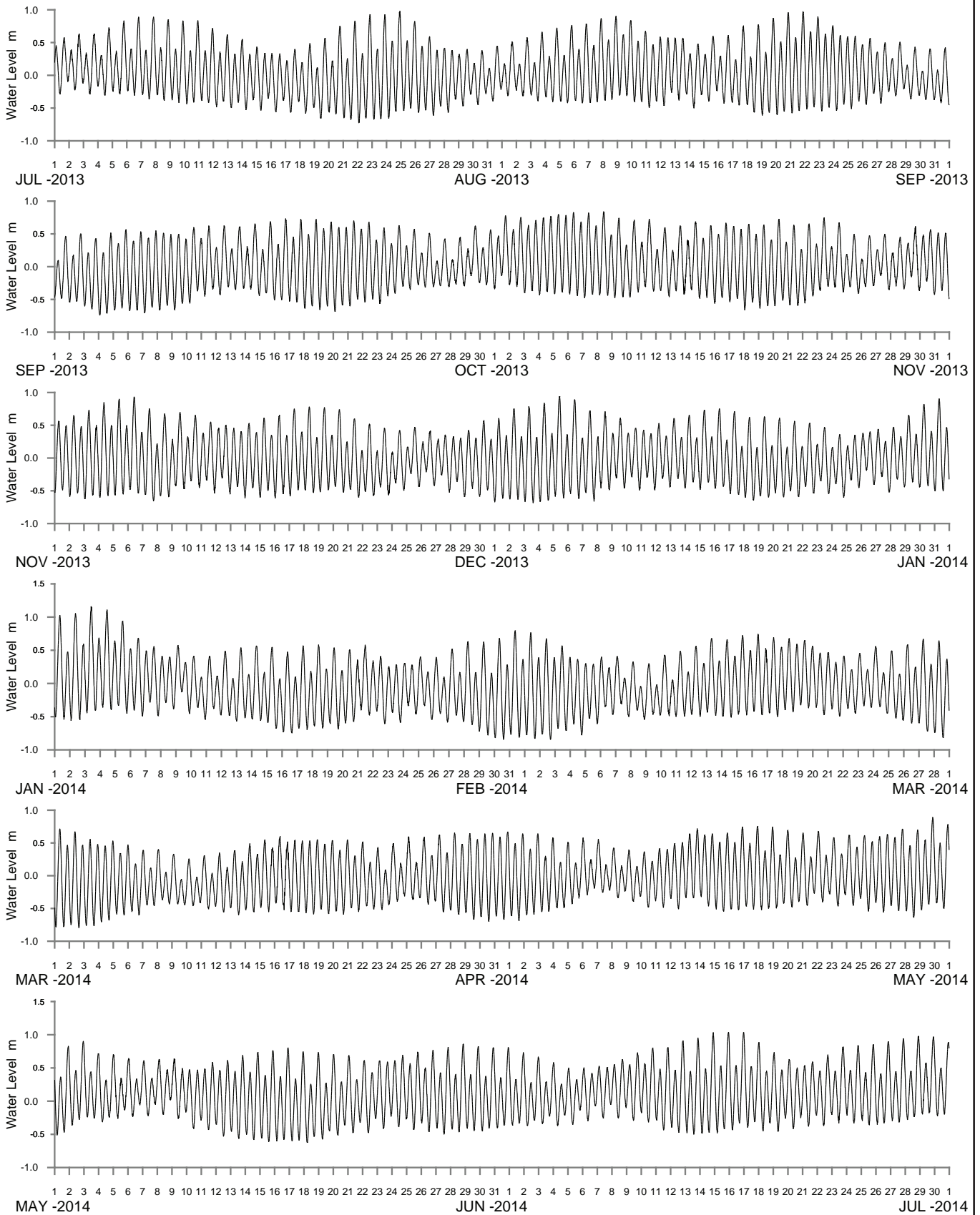


WATER LEVEL REFERENCED TO COFFS PORT DATUM

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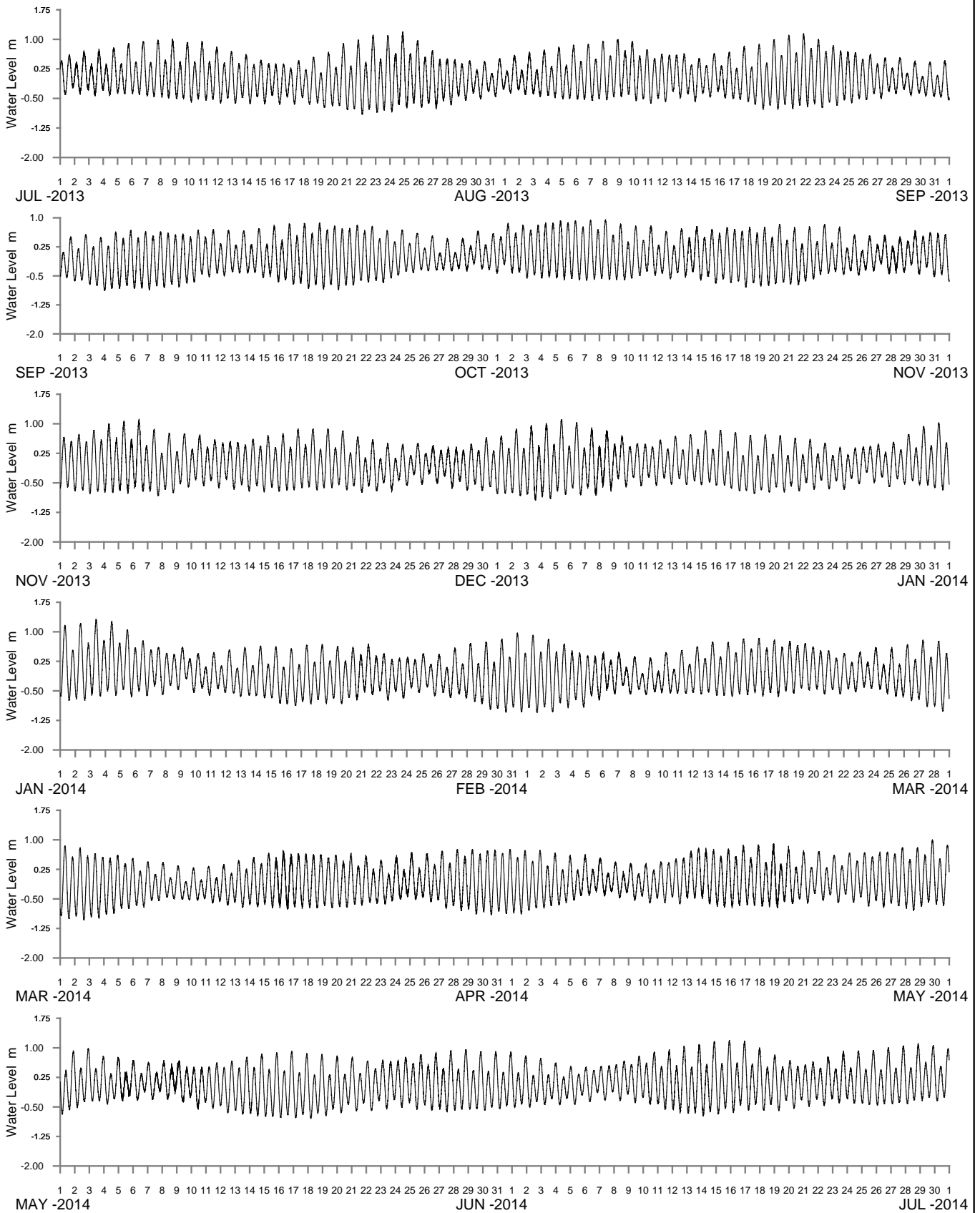


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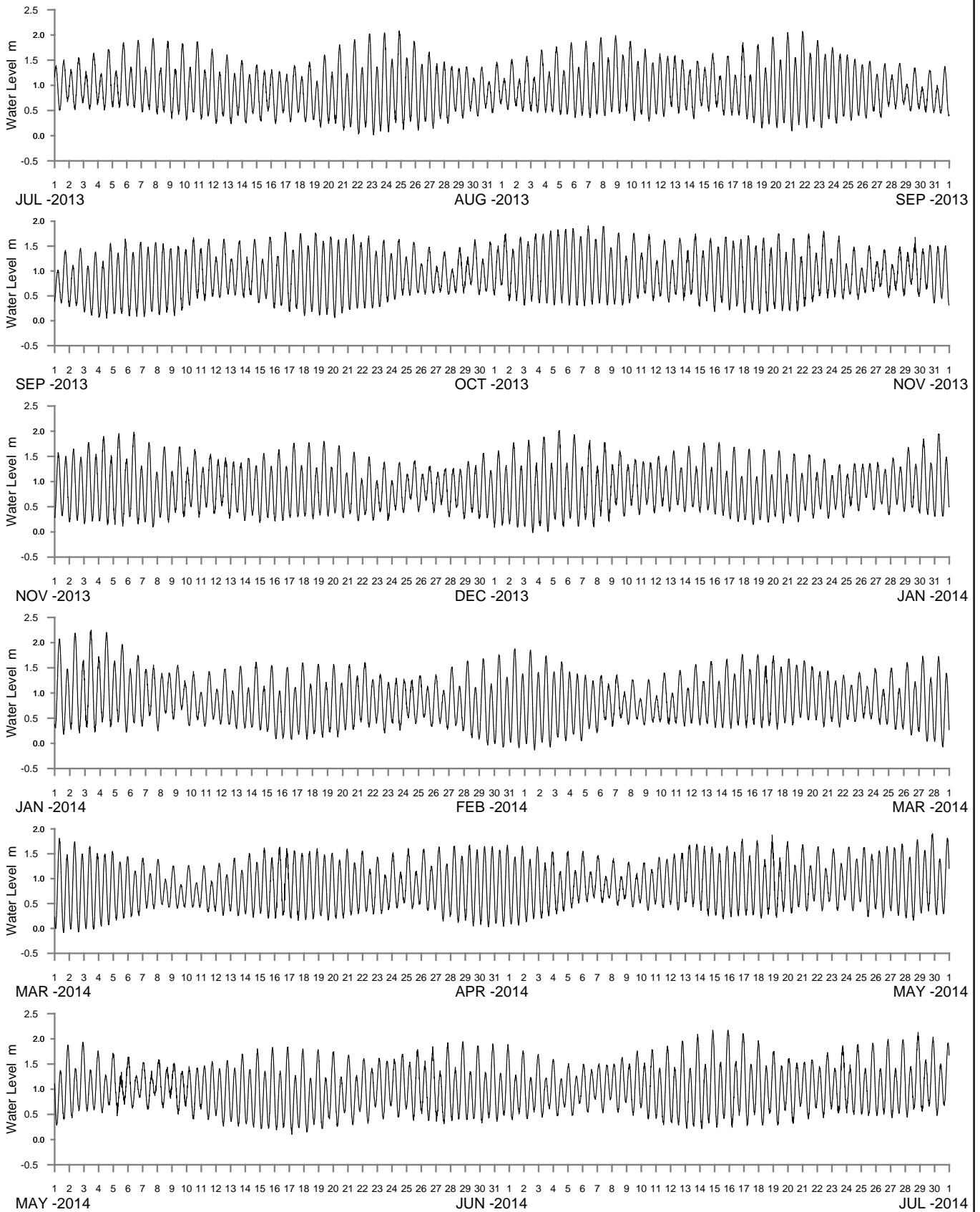


WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS







WATER LEVEL REFERENCED TO CROWDY HEAD DATUM

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

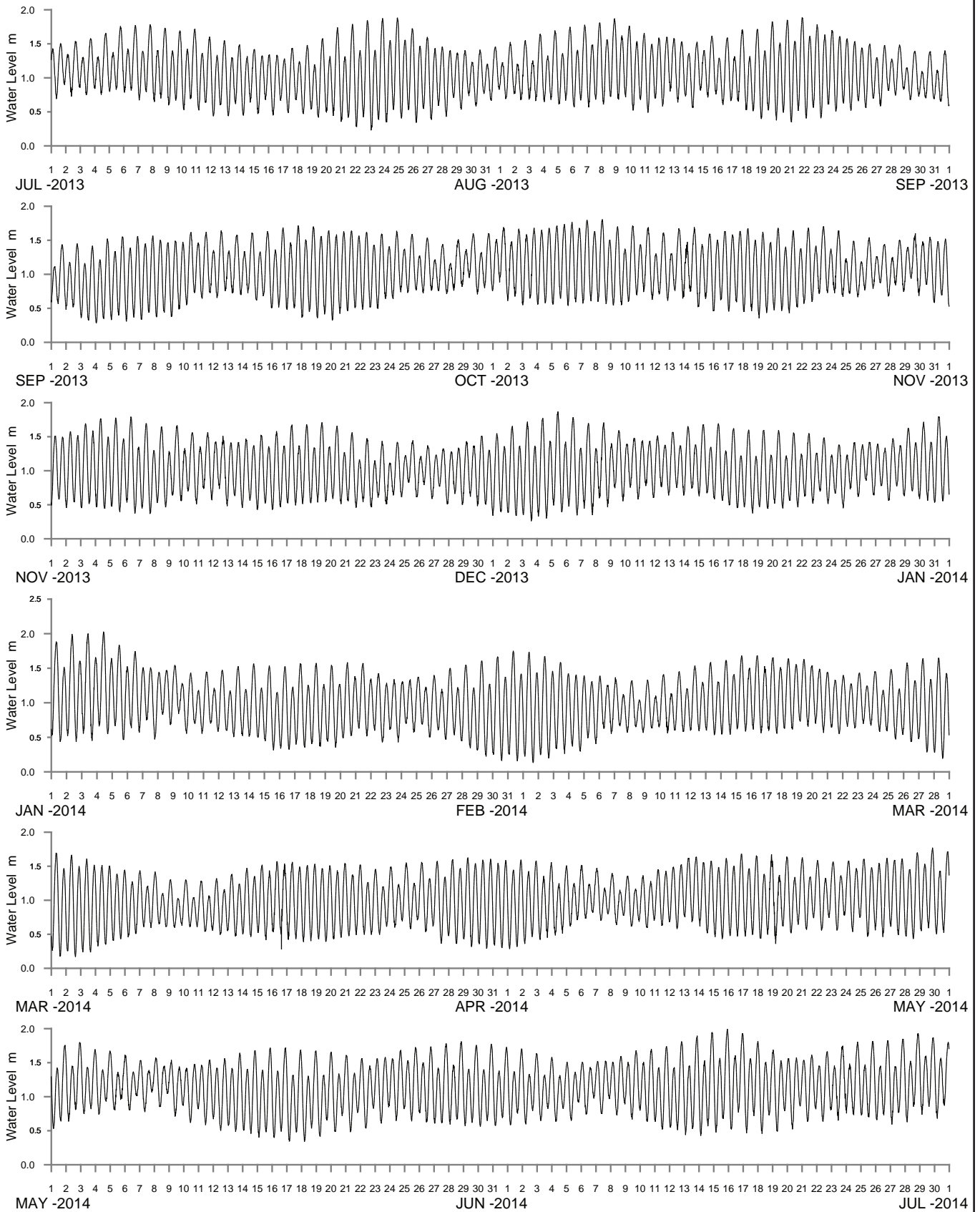
TASMAN SEA AT CROWDY HEAD BOAT HARBOUR

MHL
Report 2292

Figure
A19

2292.indd-37

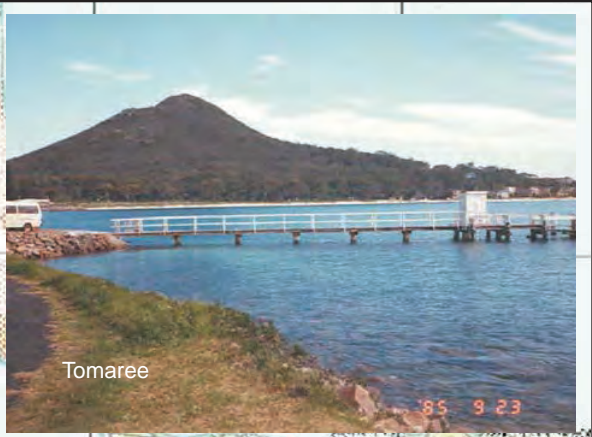




WATER LEVEL REFERENCED TO FORSTER HYDRO DATUM

----- DATA LOSS

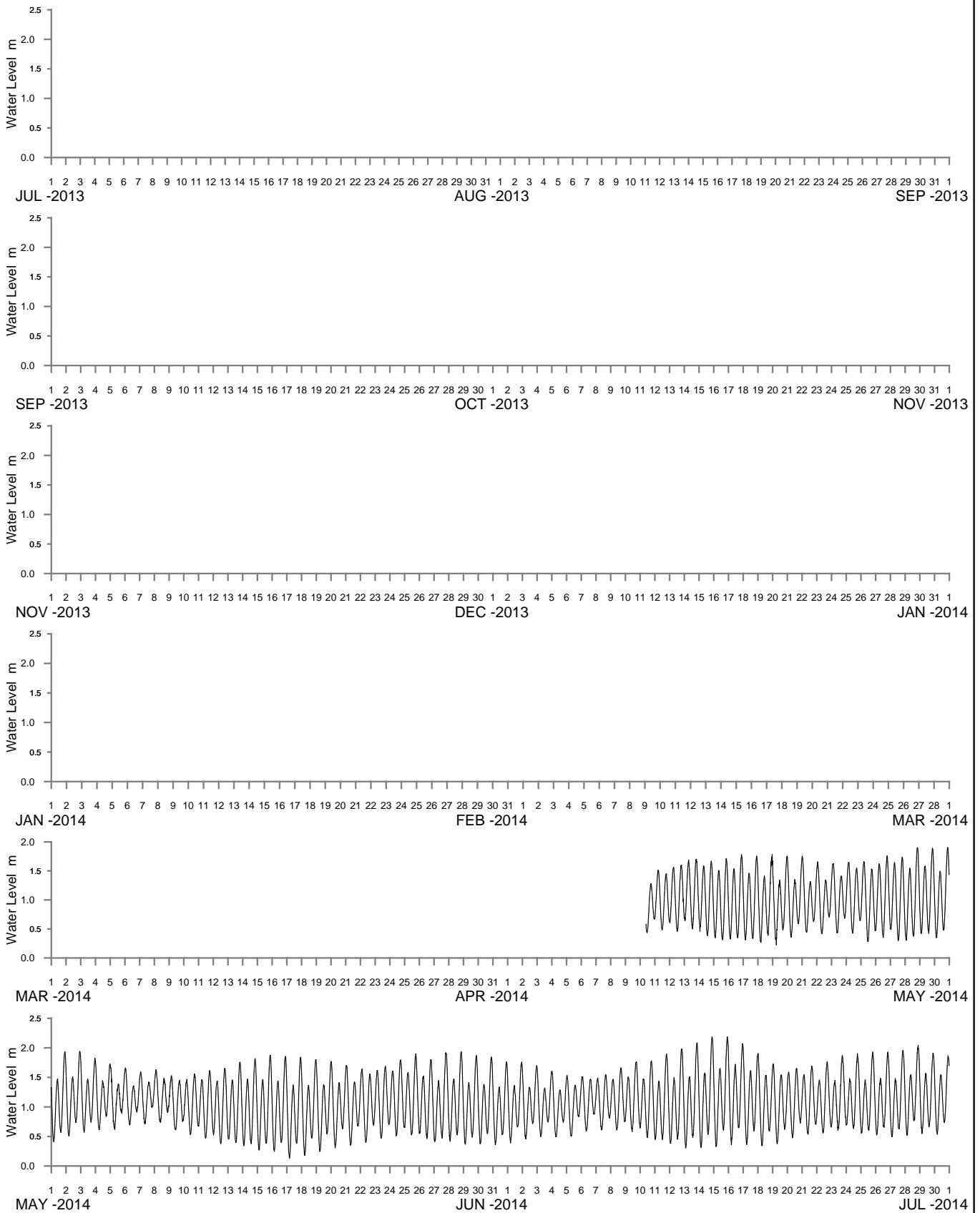




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**PORT STEPHENS
STATION LOCATION**

MHL
Report 2292
Figure
A22



WATER LEVEL REFERENCED TO PORT STEPHENS HYDRO DATUM

----- DATA LOSS





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

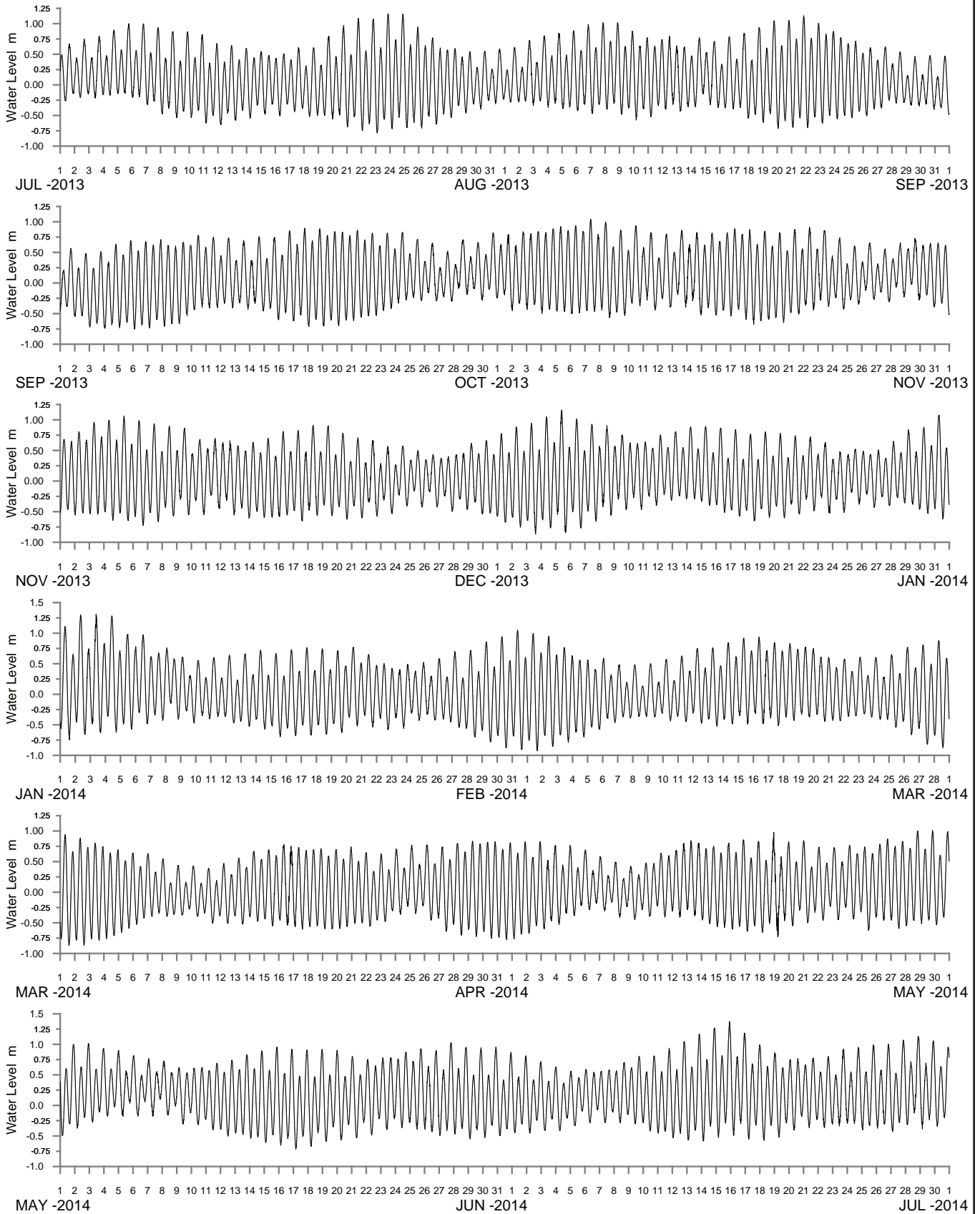


Public Works
 Manly Hydraulics Laboratory

**PATONGA
 STATION LOCATION**

MHL
 Report 2292

Figure
 A25



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



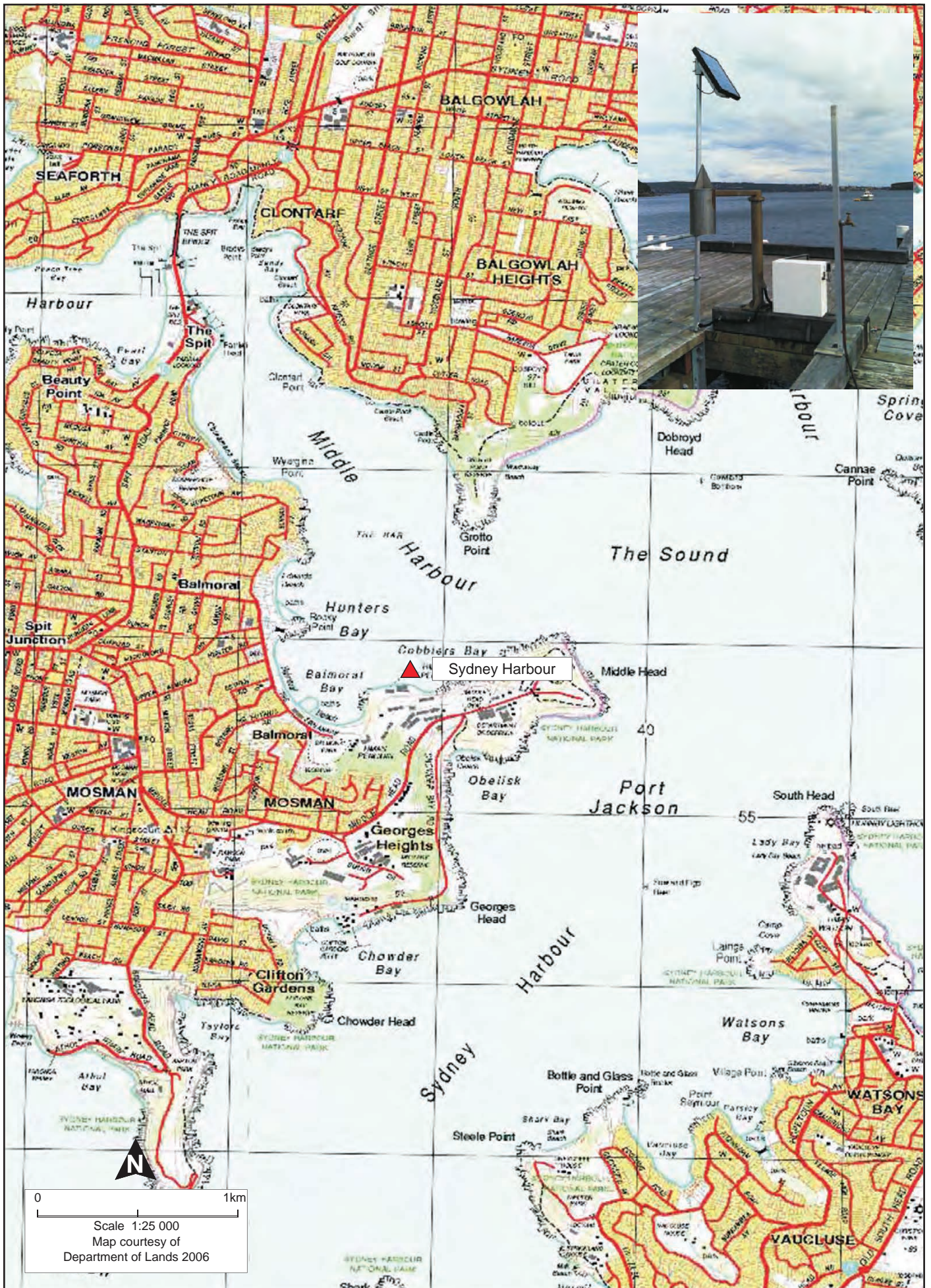
Public Works
Manly Hydraulics Laboratory

HAWKESBURY RIVER AT PATONGA

MHL
Report 2292

Figure
A26

2292.indd-44

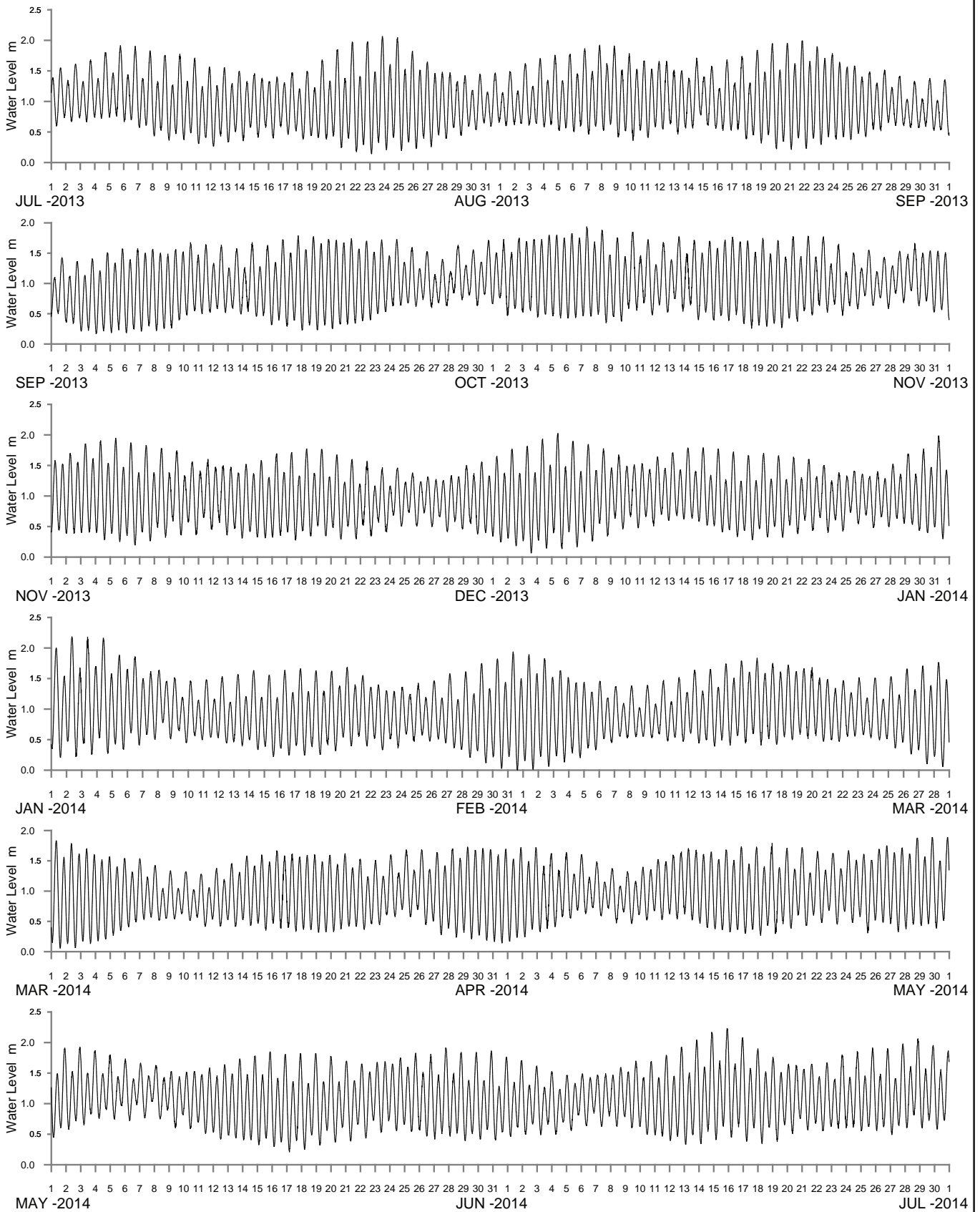


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**SYDNEY HARBOUR
STATION LOCATION**

MHL
Report 2292

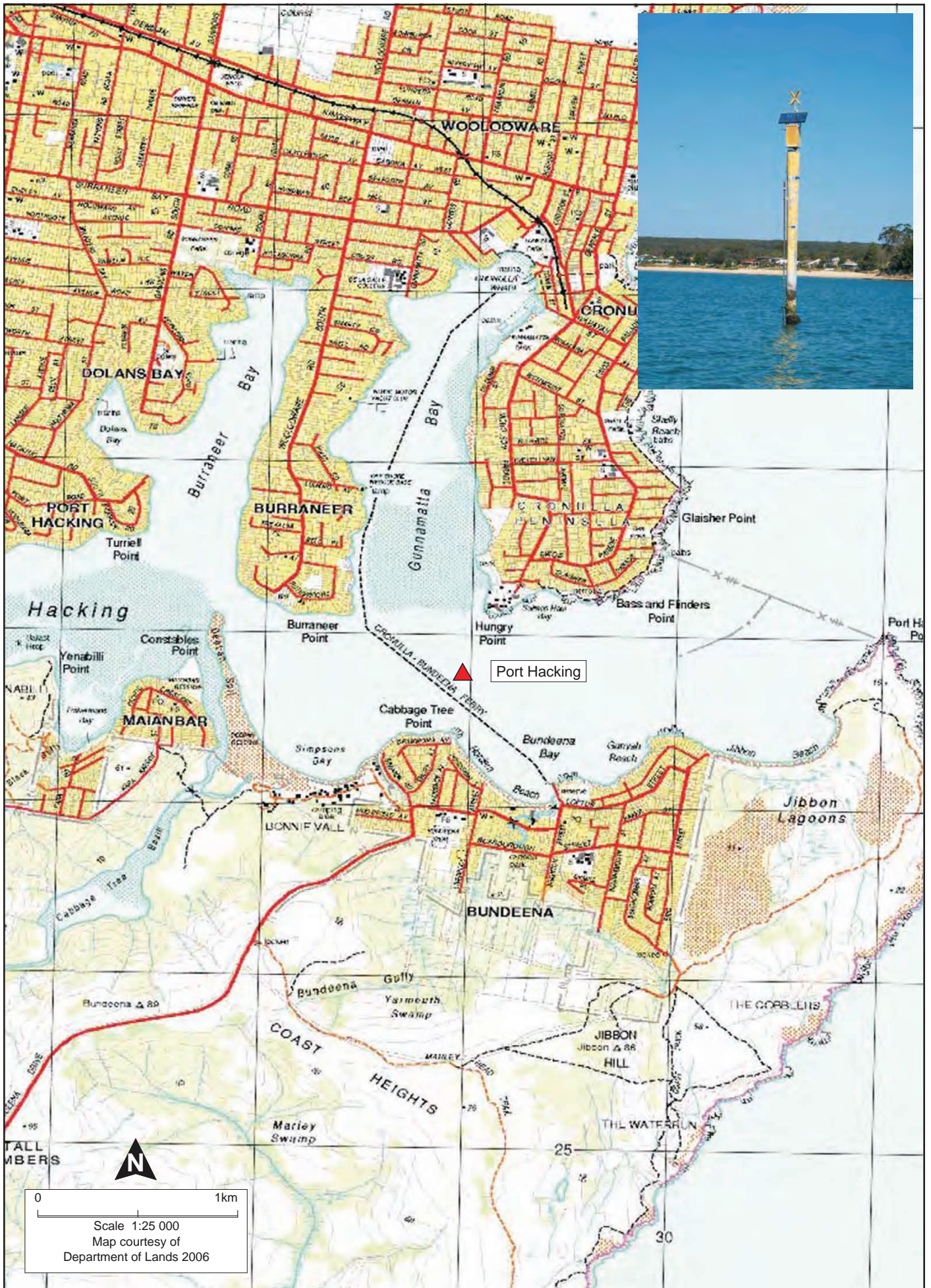
Figure
A27

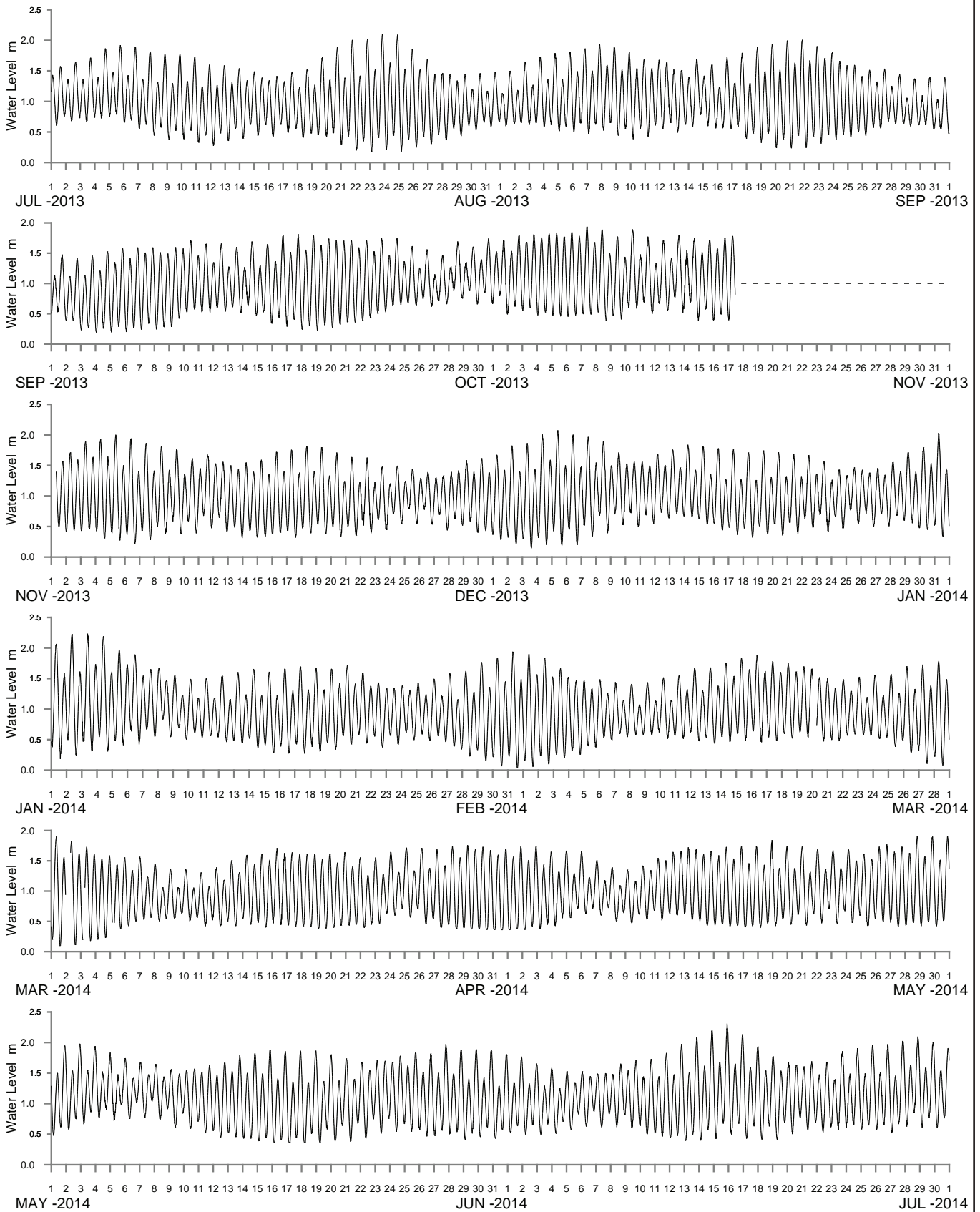


WATER LEVEL REFERENCED TO ZERO FORT DENISON

----- DATA LOSS







WATER LEVEL REFERENCED TO ZERO FORT DENISON

----- DATA LOSS





Shoalhaven Offshore



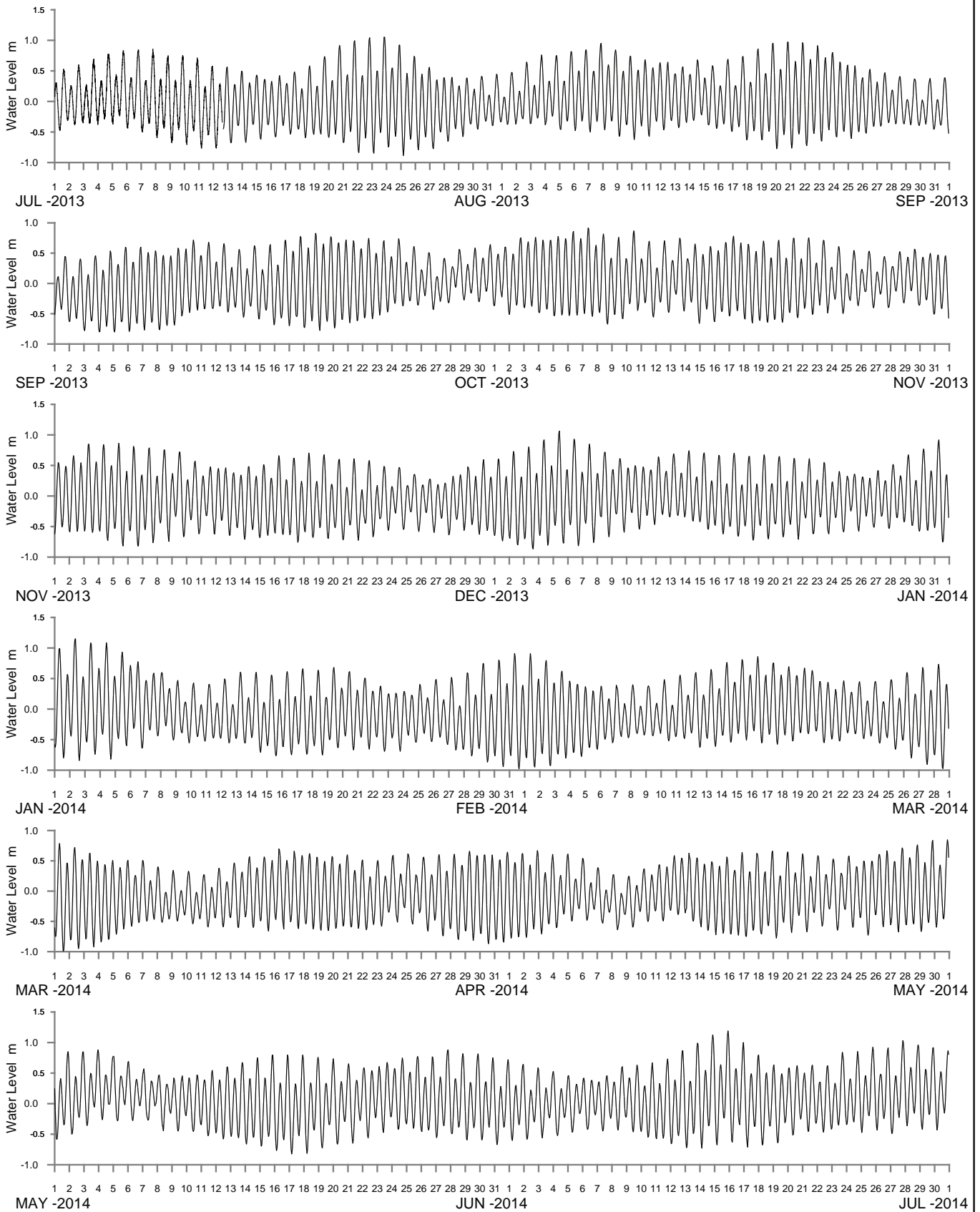
Public Works
Manly Hydraulics Laboratory

**SHOALHAVEN OFFSHORE
TIDE GAUGE LOCATION**

MHL
Report 2292

Figure
A31

2292.indd-49

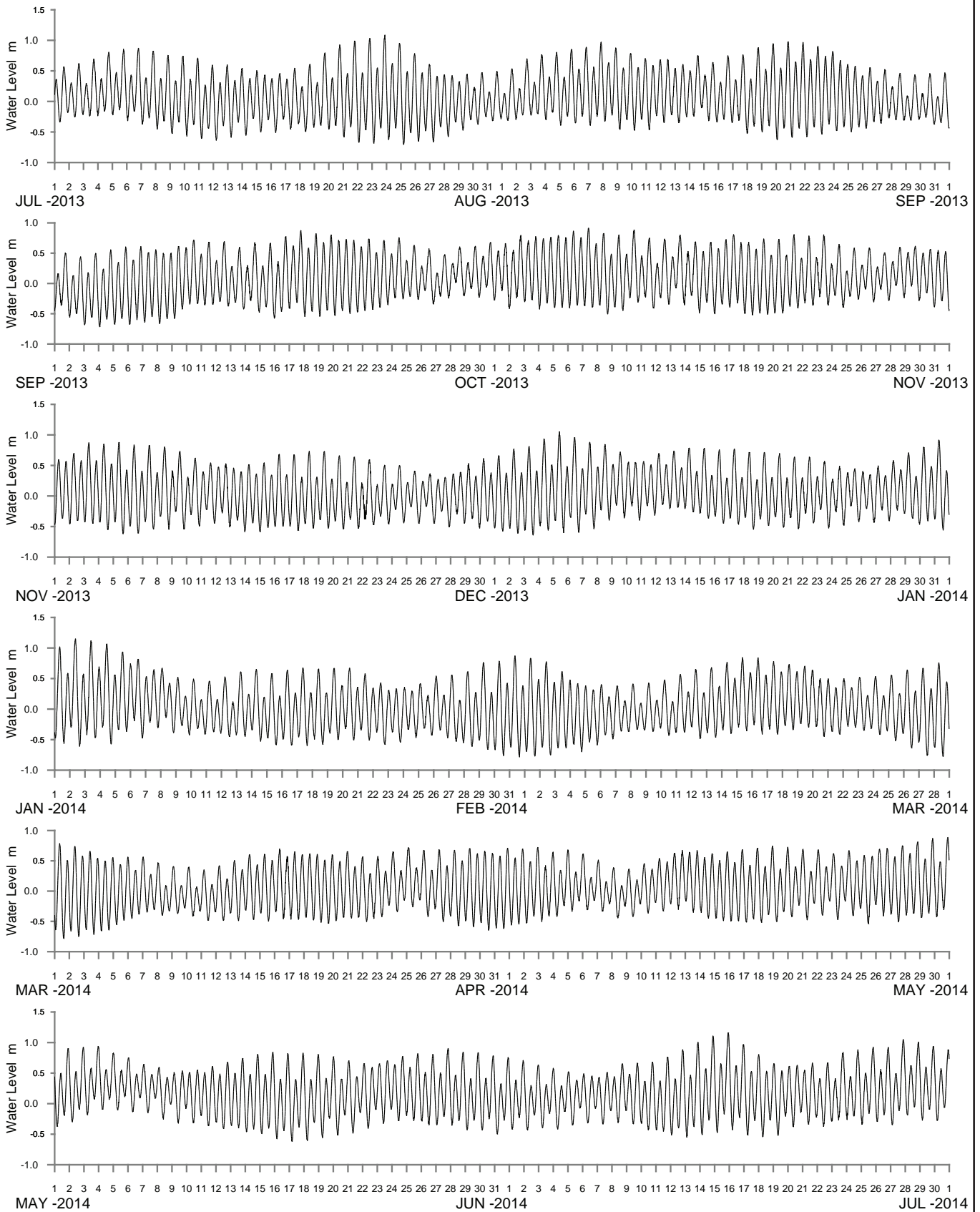


WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS







WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

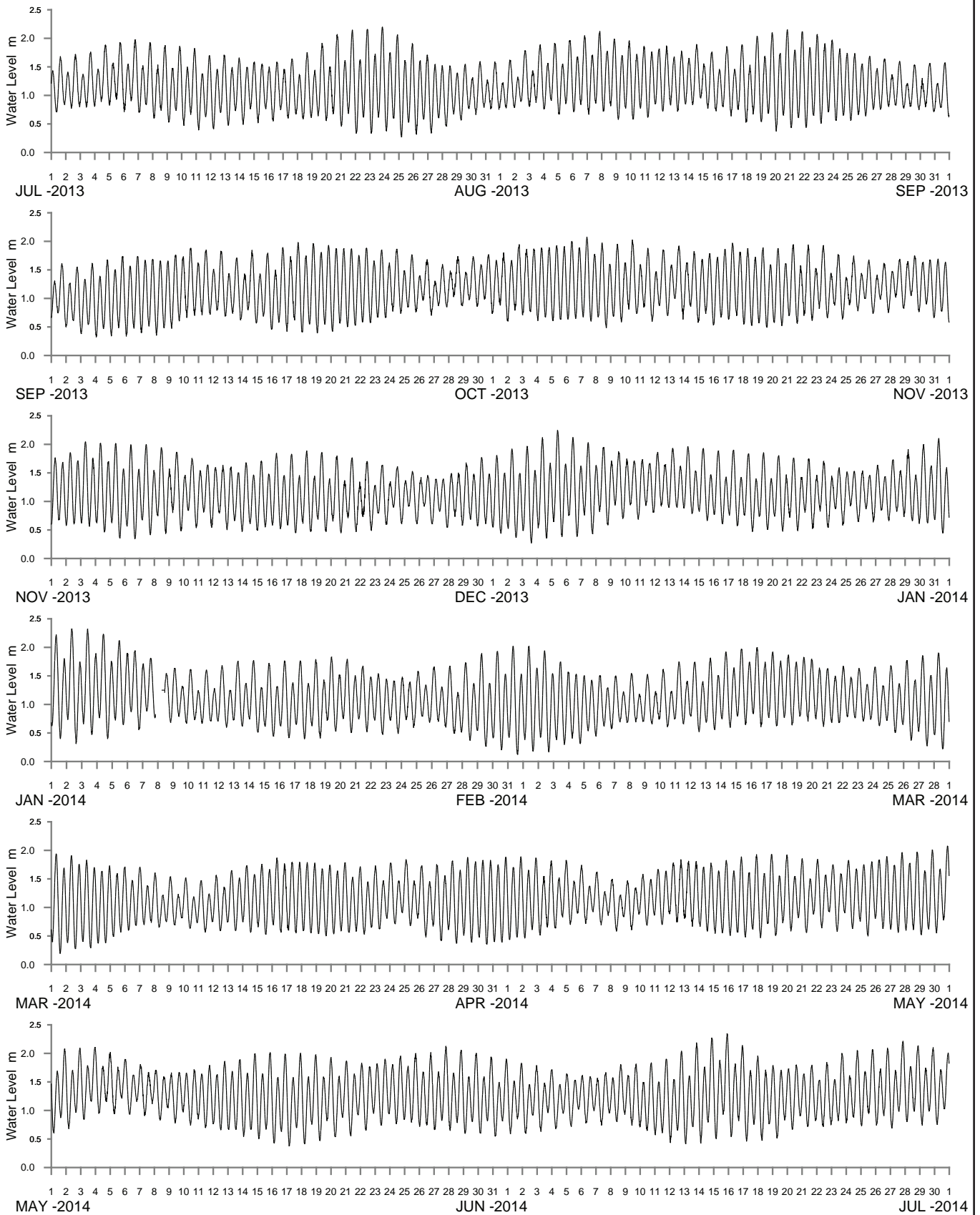
CROOKHAVEN RIVER AT CROOKHAVEN HEADS

MHL
Report 2292

Figure
A34

2292.indd-52





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

----- DATA LOSS



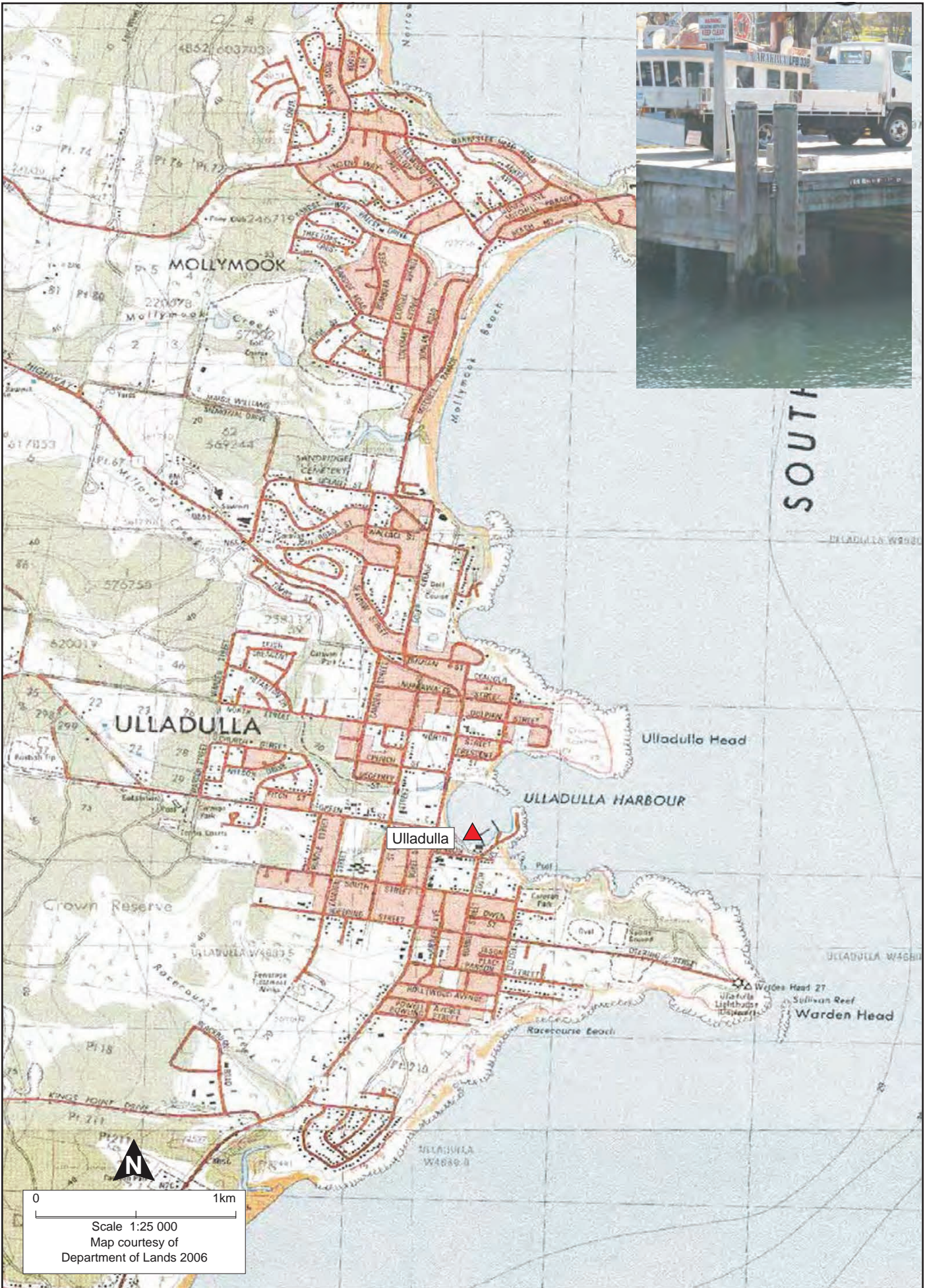
Public Works
Manly Hydraulics Laboratory

JERVIS BAY AT HMAS CRESWELL

MHL
Report 2292

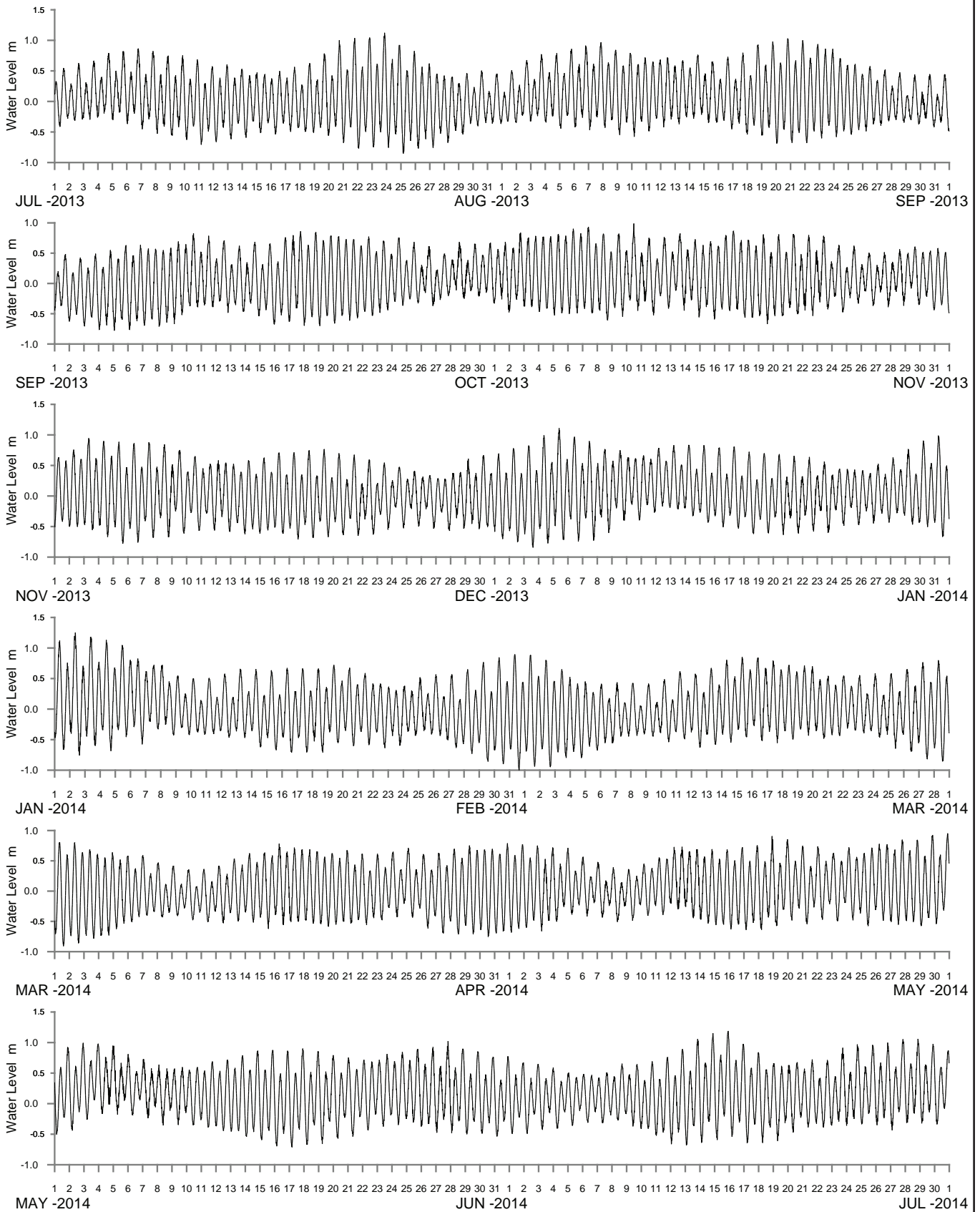
Figure
A36

2292.indd-54



SOUTH

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



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



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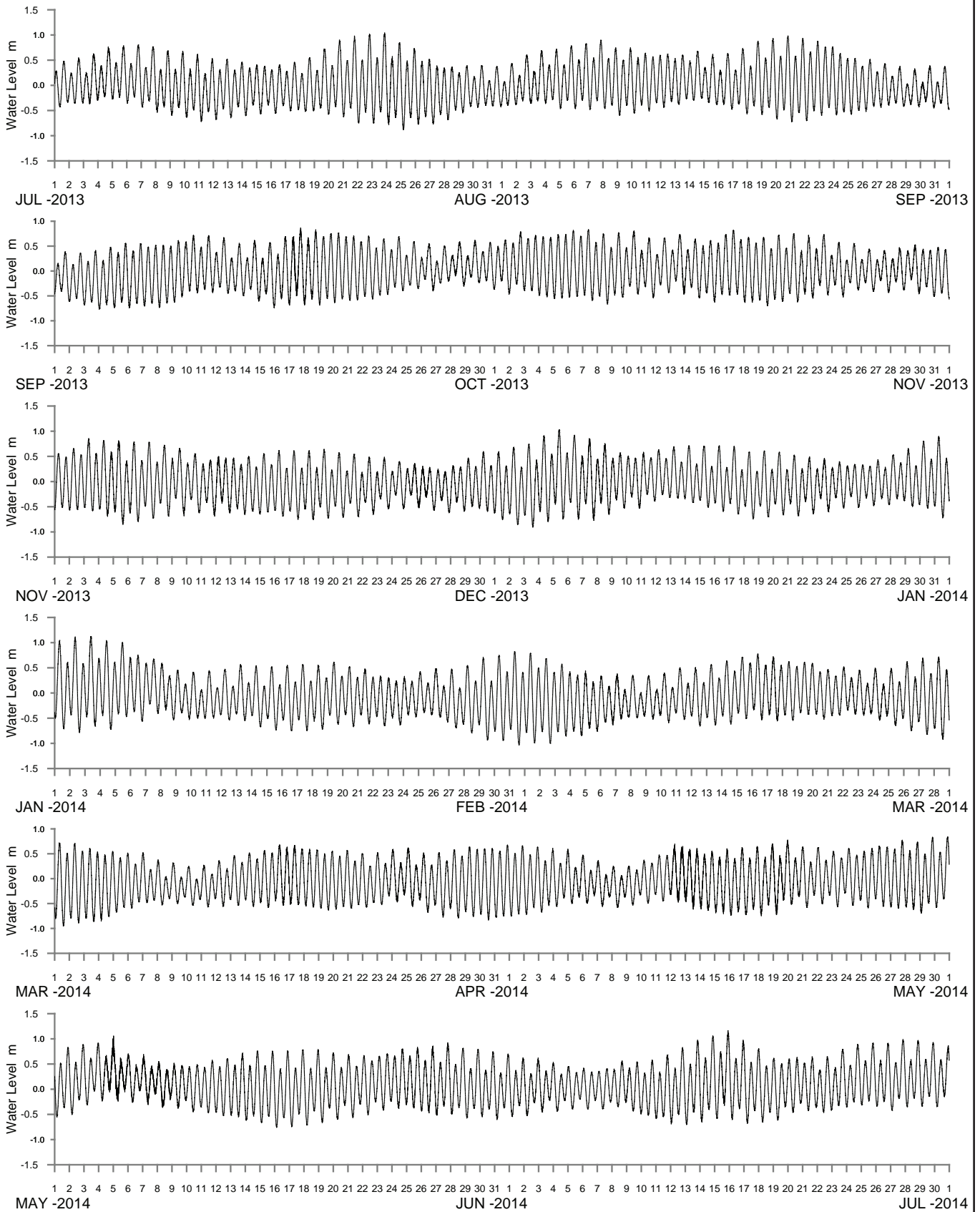
TASMAN SEA AT ULLADULLA BOAT HARBOUR

MHL
Report 2292

Figure
A38

2292.indd-56





WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS





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

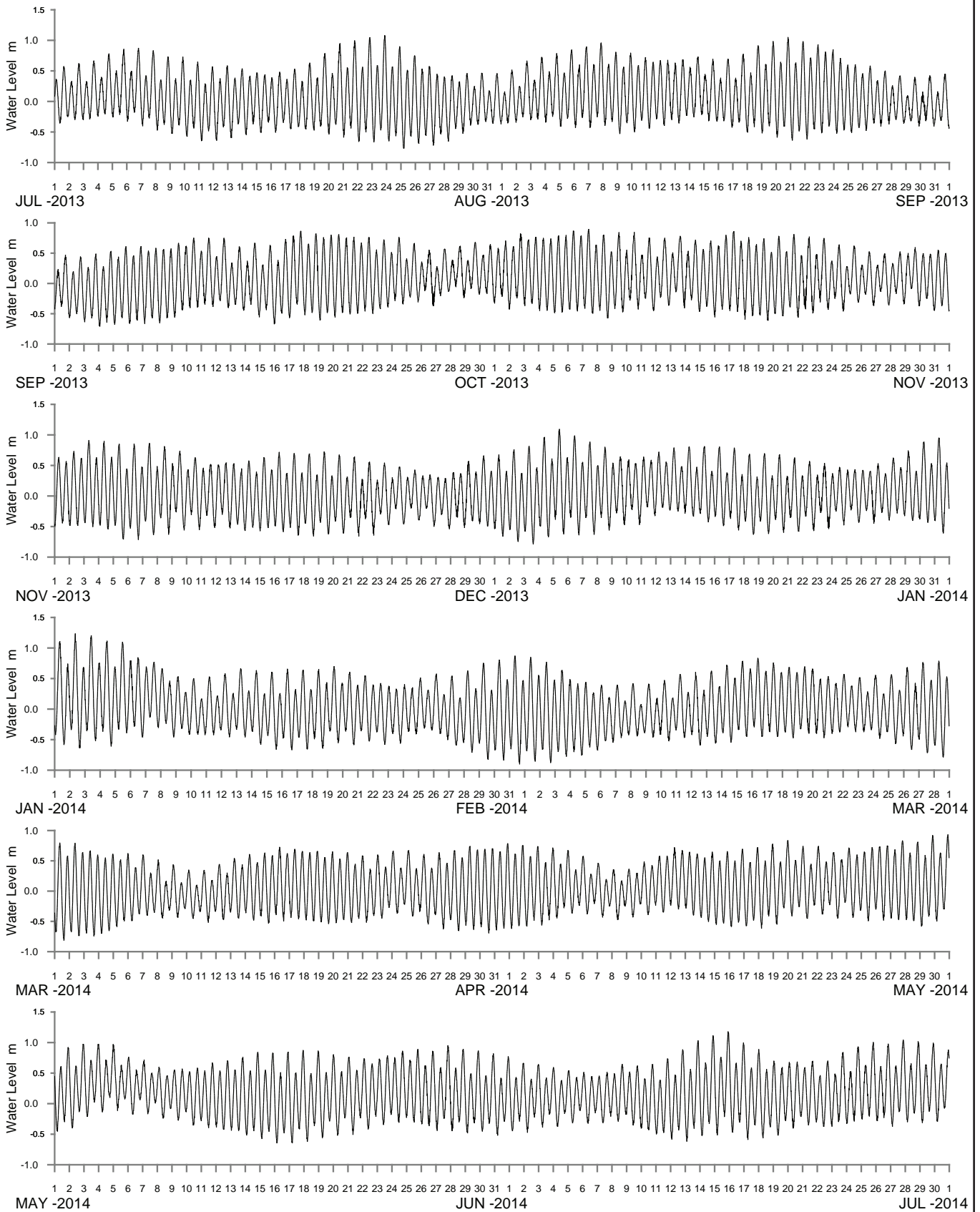


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**PRINCESS JETTY
 STATION LOCATION**

MHL
 Report 2292

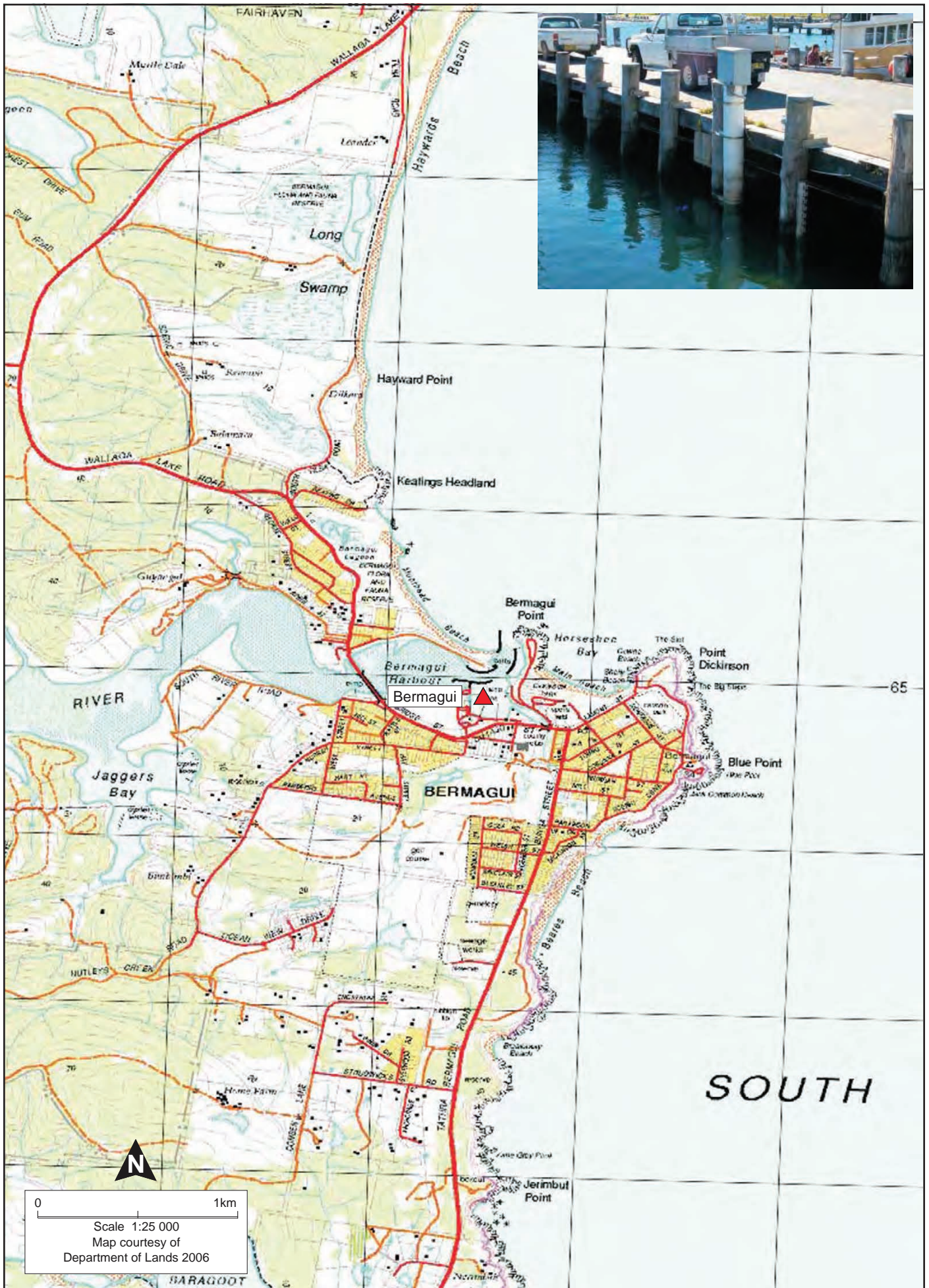
Figure
 A41

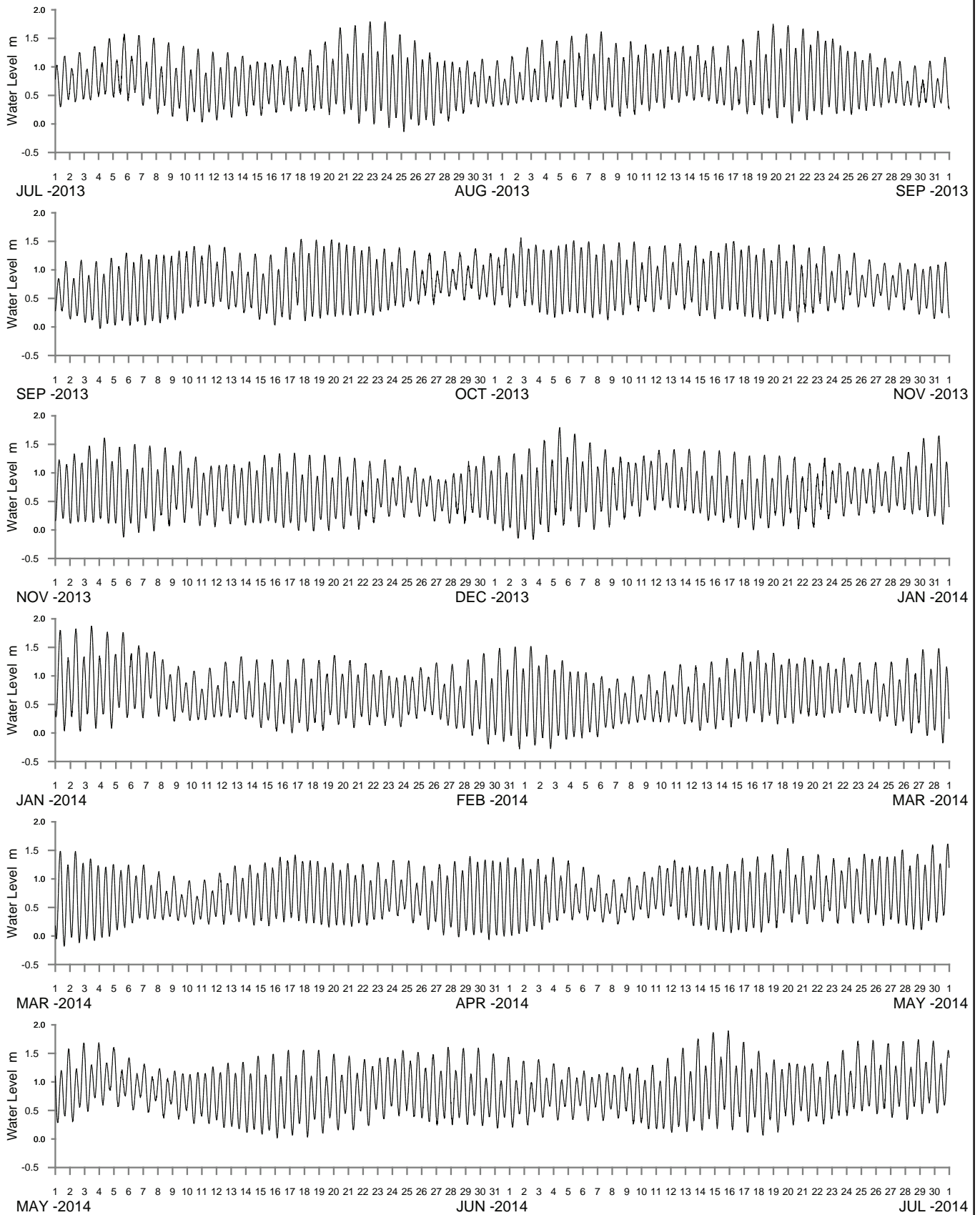


WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS





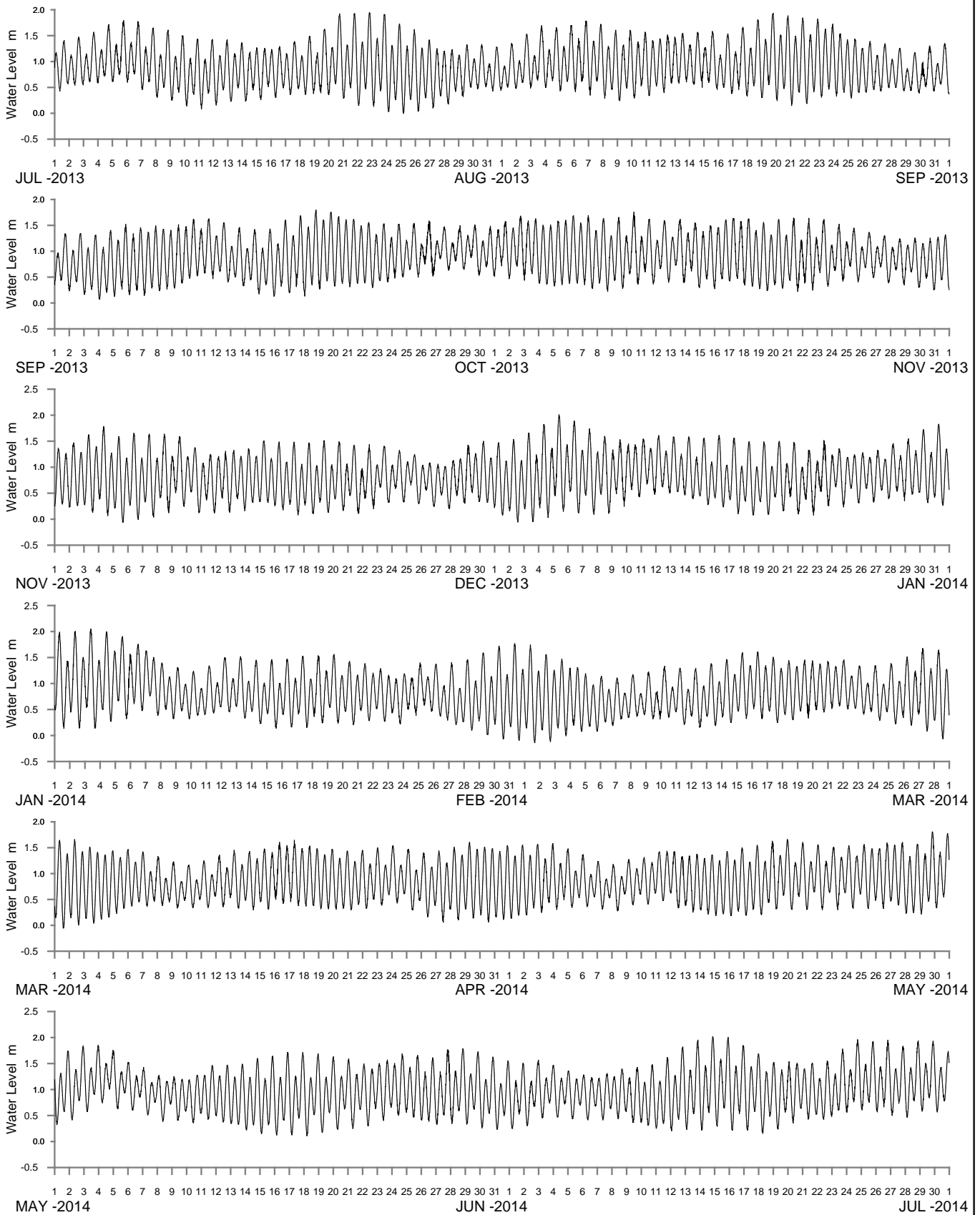


WATER LEVEL REFERENCED TO BERMAGUI LOCAL HYDRO DATUM

----- DATA LOSS





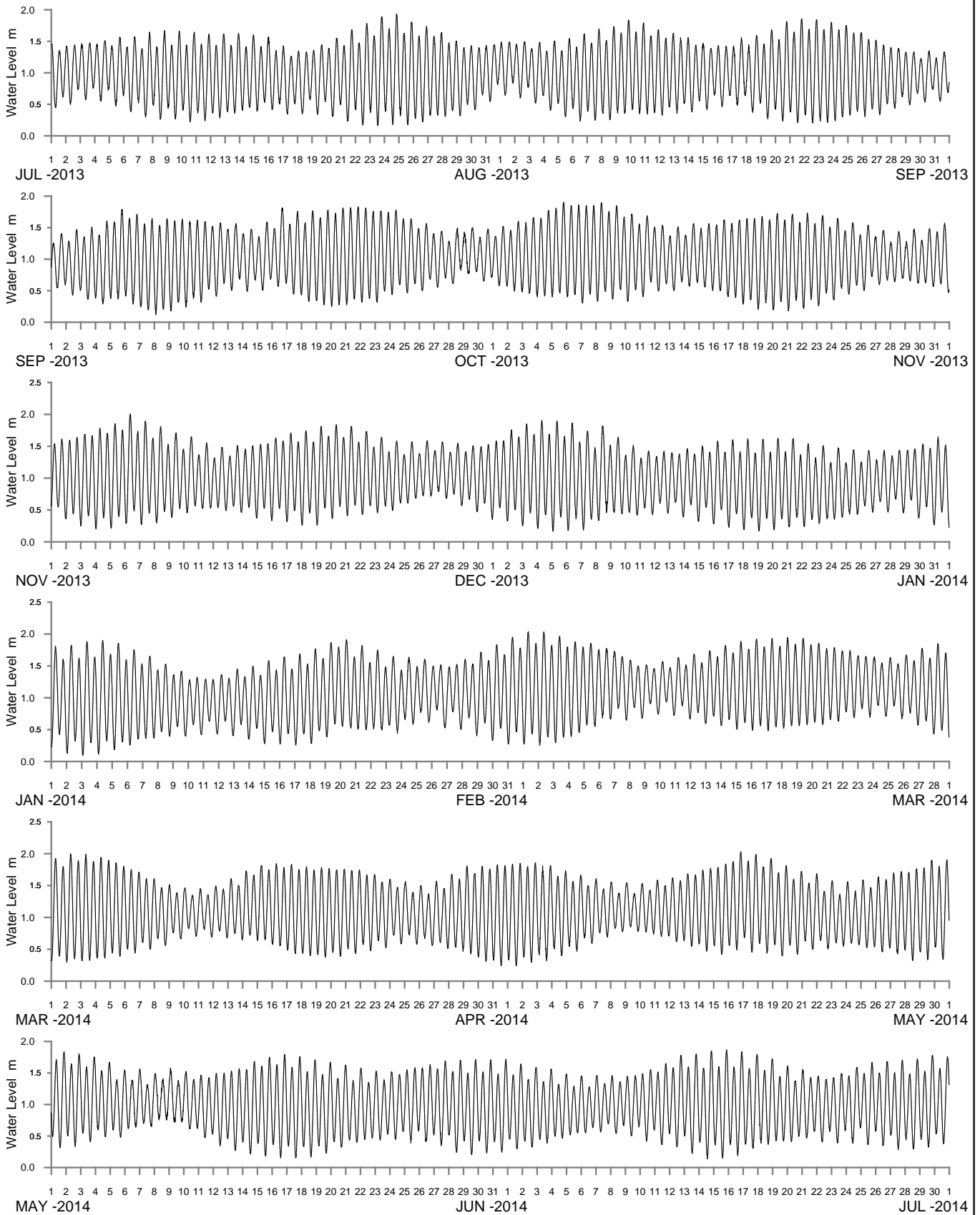


WATER LEVEL REFERENCED TO TWOFOLD BAY HYDRO DATUM

----- DATA LOSS



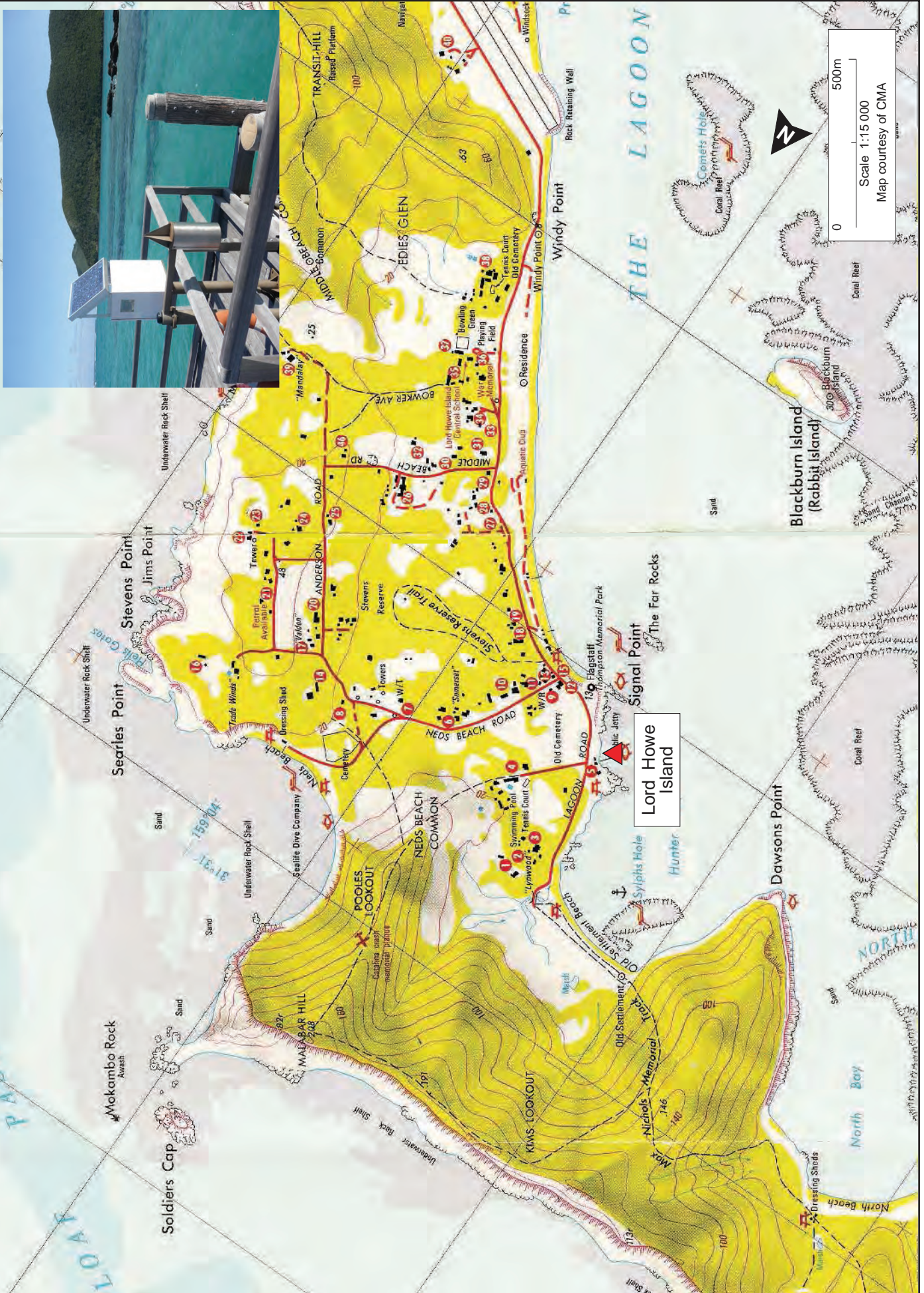




WATER LEVEL REFERENCED TO LOWEST ASTRONOMICAL TIDE

----- DATA LOSS



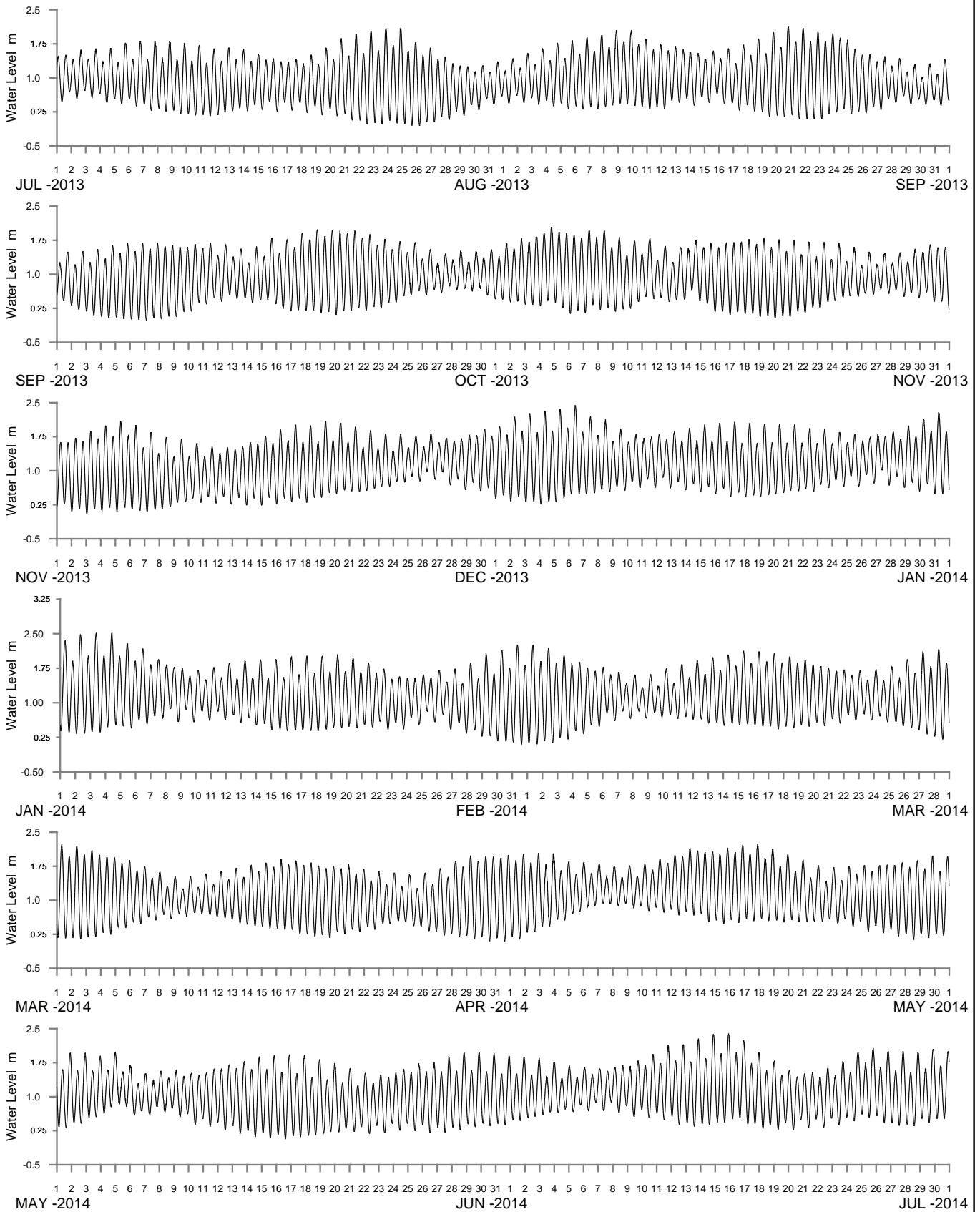


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**LORD HOWE ISLAND
STATION LOCATION**

MHL
Report 2292

Figure
A49



WATER LEVEL REFERENCED TO LORD HOWE ISLAND TIDAL DATUM

----- DATA LOSS



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TASMAN SEA AT LORD HOWE ISLAND

MHL
Report 2292

Figure
A50

2292.indd-68

Appendix B
Current Sites Digital Data

Table B1 Current Sites Digital Data

Coastal Region	Site Name	Location	Period of Data
North	Tweed Regional	North breakwater	Feb 1987–ongoing
North	Tweed Entrance South	South breakwater	May 2014–ongoing
North	Tweed Offshore ¹	Offshore	Dec 1982–ongoing
North	Brunswick Heads	Upstream of breakwater	Mar 1986–ongoing
North	Ballina	Breakwater	Dec 2008–ongoing
North	Yamba	Upstream of breakwater	Jul 1986–ongoing
North	Coffs Harbour ¹	Harbour	Aug 1996–ongoing
Mid North	Port Macquarie	Breakwater	Mar 1986–ongoing
Mid North	Port Macquarie Offshore ¹	Offshore	Dec 1984–ongoing
Mid North	Crowdy Head ¹	Harbour	Jul 1986–ongoing
Mid North	Forster	Upstream of breakwater	Jul 1986–ongoing
Central	Shoal Bay	Public wharf	Apr 2014–ongoing
Central	Patonga	Public wharf	Jun 1992–ongoing
Central	Sydney	Middle Head	Sep 1987–ongoing
Central	Port Hacking	Hungry Point	Nov 1987–ongoing
Central	Crookhaven	Upstream of breakwater	Mar 1992–ongoing
Central	Jervis Bay	HMAS Creswell	Sep 1989–ongoing
South	Shoalhaven Offshore	Offshore	Sep 2005–ongoing
South	Ulladulla	Harbour	Dec 2007–ongoing
South	Princess Jetty	Public wharf	Dec 1985–ongoing
South	Batemans Bay Offshore	Snapper Island	Sep 2000–ongoing
South	Bermagui	Inner Harbour	Mar 1987–ongoing
South	Eden	Working jetty	Sep 1986–ongoing
North Tasman Sea	Lord Howe Island	Main wharf	Aug 1994–ongoing
North Tasman Sea	Norfolk Island	Main jetty	Sep 1994–ongoing

¹ Site has changed location during data period

Appendix C
Historical Tide Data

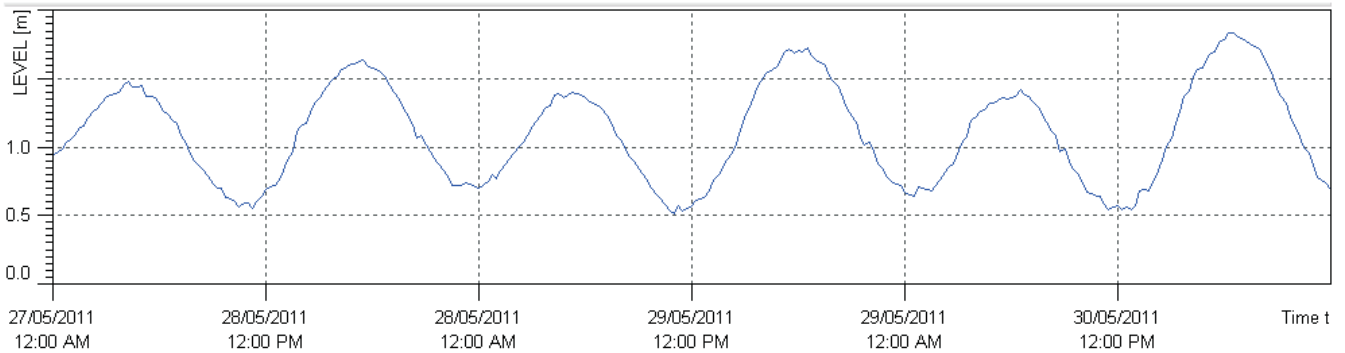
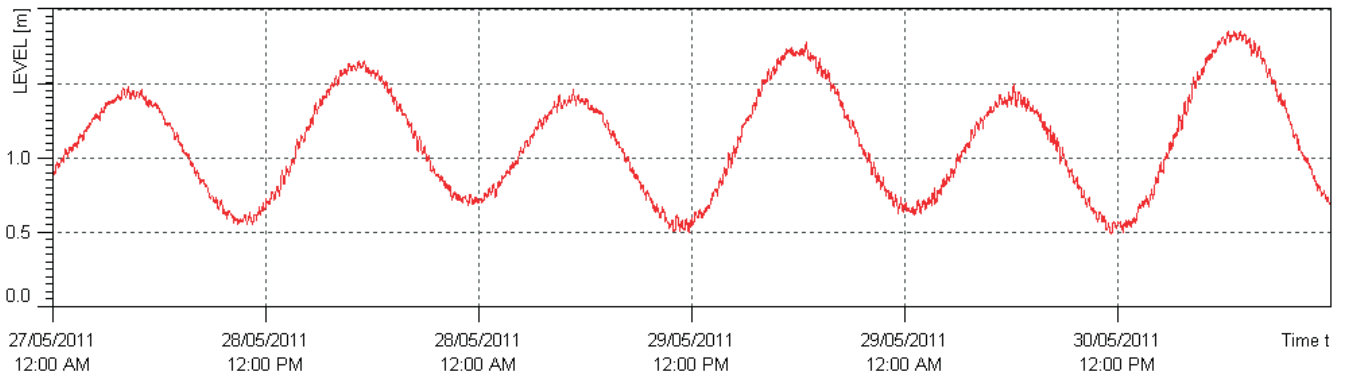
Table C1 Historical Tide Data

Site Name	Location	Period of Record	Location
Tweed Regional	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 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)
1/05/2014,3:00:00,0.486,55 (Fair)
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1/05/2014,3:30:00,0.445,55 (Fair)
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1/05/2014,5:45:00,0.731,55 (Fair)
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1/05/2014,6:15:00,0.868,55 (Fair)
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1/05/2014,7:00:00,1.067,55 (Fair)
1/05/2014,7:15:00,1.132,55 (Fair)
1/05/2014,7:30:00,1.195,55 (Fair)
1/05/2014,7:45:00,1.243,55 (Fair)
1/05/2014,8:00:00,1.304,55 (Fair)
1/05/2014,8:15:00,1.366,55 (Fair)
1/05/2014,8:30:00,1.374,55 (Fair)
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1/05/2014,9:00:00,1.443,55 (Fair)

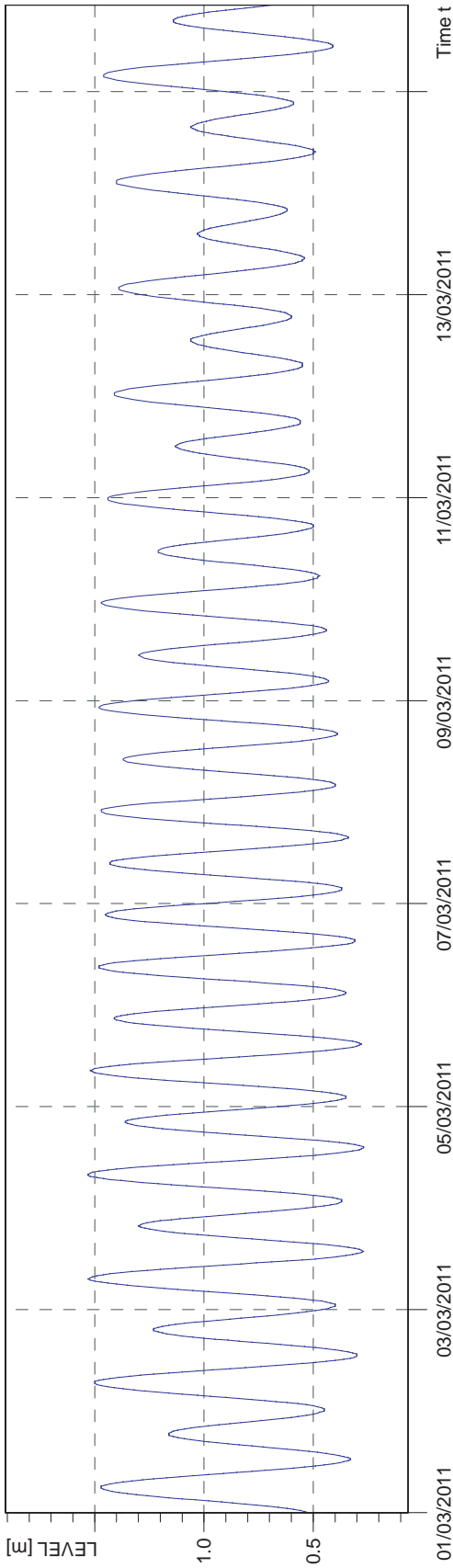


NSW PUBLIC WORKS, MANLY HYDRAULICS LABORATORY

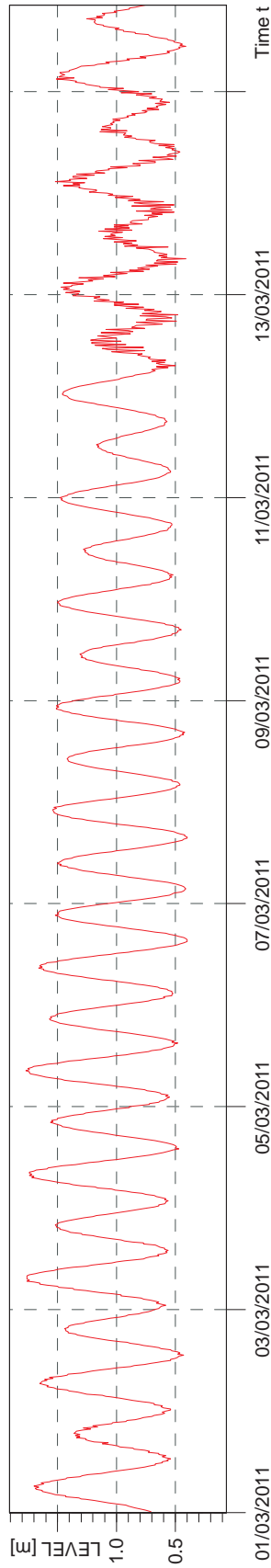
STATION NAME : Sydney (Live)
 RECORDER TYPE : MHL Station
 A.W.R.C. No. : 213470
 DATA START : 29.06.2013
 DATA FINISH : 30.06.2014
 DATA TOTAL : 1 years 2 days
 DATABASE TIME INTERVAL (second): 0
 THRESHOLD LEVEL (m) : 1.900
 DATUM : Zero Fort Denison
 DATE OF ISSUE : 09:00 22.10.2014
 ANALYSIS PERFORMED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

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

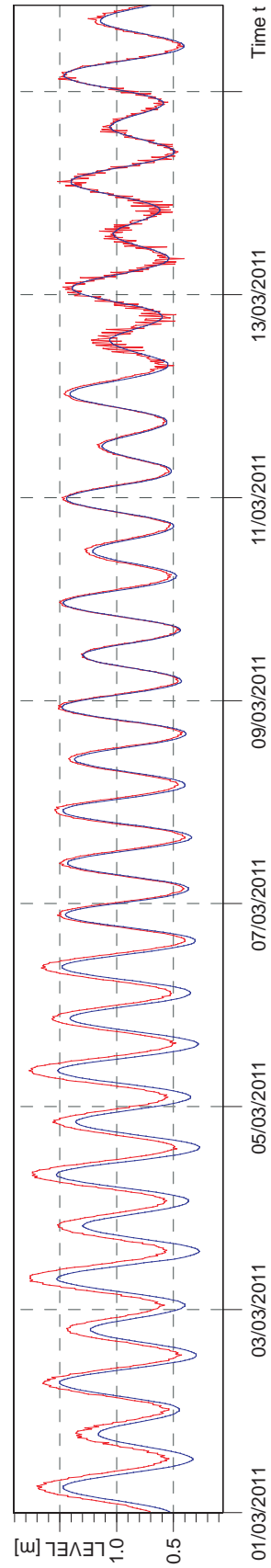




Predicted Data



Measured 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° per solar hour.
Seiche	A stationary wave usually caused by strong winds and/or changes in barometric pressure. It is found in lakes, semi-enclosed bodies of water, and in areas of the open ocean. The period of a seiche in an enclosed rectangular body of water is usually represented by the formula: Period (T) = 2L / square root (gd) in which L is the length, d the average depth of the body of water, and g the acceleration of gravity.
Semi-diurnal	Having a period or cycle of approximately one-half of a tidal day. The predominant type of tide throughout the world is semi-diurnal, with two high waters and two low waters each tidal day. The tidal current is said to be semi-diurnal when there are two flood and two ebb periods each day. A semi-diurnal constituent has two maxima and two minima each constituent day, and its symbol is the subscript 2.
Shallow water constituent	A short-period harmonic term introduced into the formula of tidal (or tidal current) constituents to take account of the change in the form of a tide wave resulting from shallow water conditions. Shallow water constituents include the overtides and compound tides.
Slack water (slack)	The state of a tidal current when its speed is near zero, especially the moment when a reversing current changes direction and its speed is zero. The term also is applied to the entire period of low speed near the time of turning of the current when it is too weak to be of any practical importance in navigation. The relation of the time of slack water to the tidal phases varies in different localities. For a perfect standing tidal wave, slack water occurs at the time of high and of low water, while for a perfect progressive tidal wave, slack occurs midway between high and low water.
Solar tide	<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).

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

University of Queensland, 2010, Tropical Cyclone 'Roger' Storm Surge Assessment, Research Report CE162, J. Stewart, D. Callaghan and P. Nielsen, July 2010



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