



NSW OCEAN AND RIVER ENTRANCE TIDAL LEVELS ANNUAL SUMMARY 2015–2016

Report MHL2475
October 2016



King tide and storm 5 June 2016



29 June 2016

prepared for
Office of Environment and Heritage



Office of
Environment
& Heritage

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Report MHL2475
October 2016

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Cover photograph: East Coast Low storm during a king tide, 5 June 2016,
Collaroy Beach Surf Life Saving Club.
Photo courtesy Rosie Jacobs

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Foreword

Manly Hydraulics Laboratory (MHL) 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). MHL is a business unit within 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 2015 to 30 June 2016, 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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<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 advice and analysis by Ben Blumberg and Indra Jayewardene
- 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 2015–2016
- [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.

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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](#).
- 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 at the end of each financial year. The system is shown in [Figure 1.5](#).

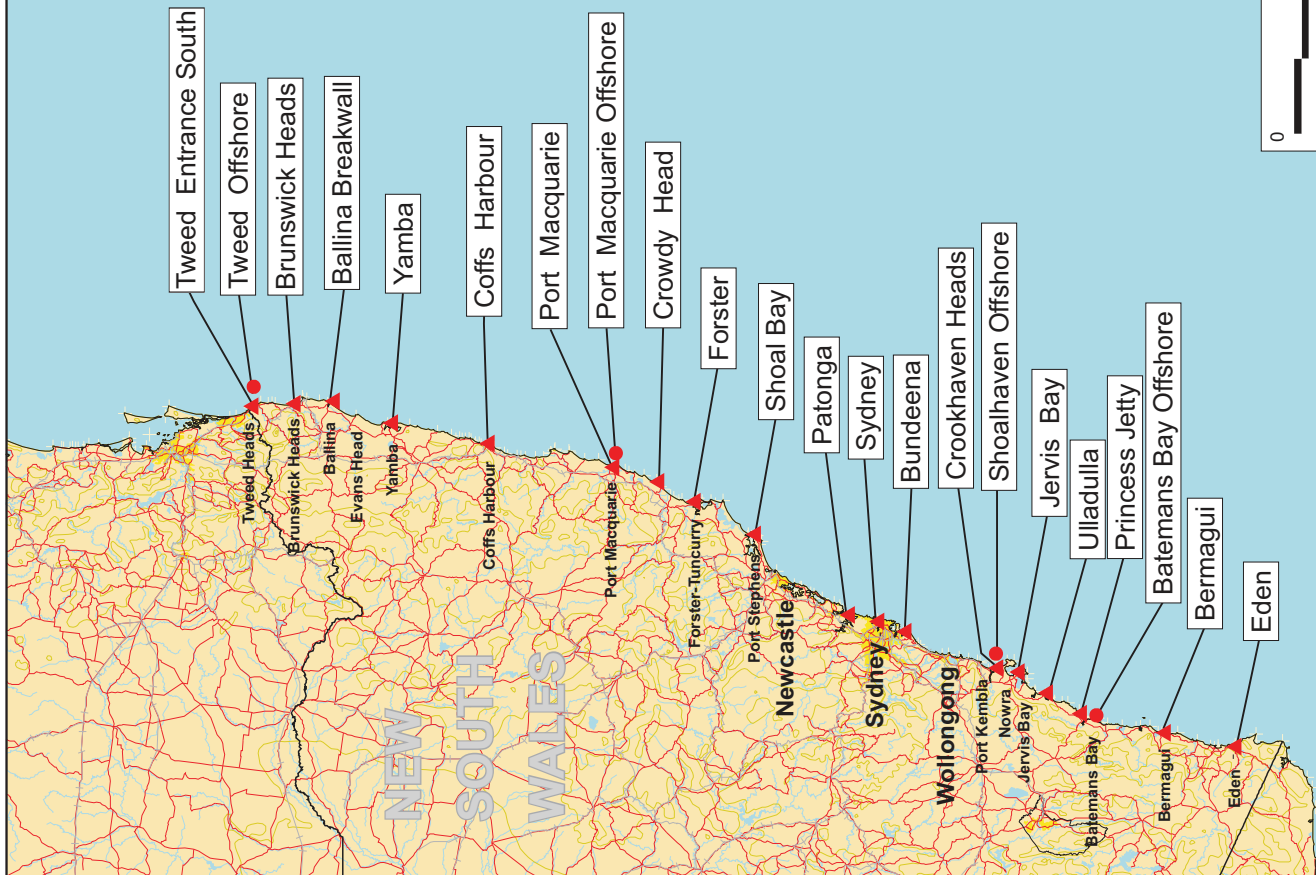
Tidal data with the exception of offshore tide gauges is transferred to MHL's data server and is then made available in near-real time for external users to view. A backup copy is also transferred to the NSW Data Collection Warehouse. The 15-minute tide data is available on-line in tables or as plots. One-minute and some one-second data is also available on request (see [Table 4.2](#) and Appendix D, [Figure D1](#)).

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

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

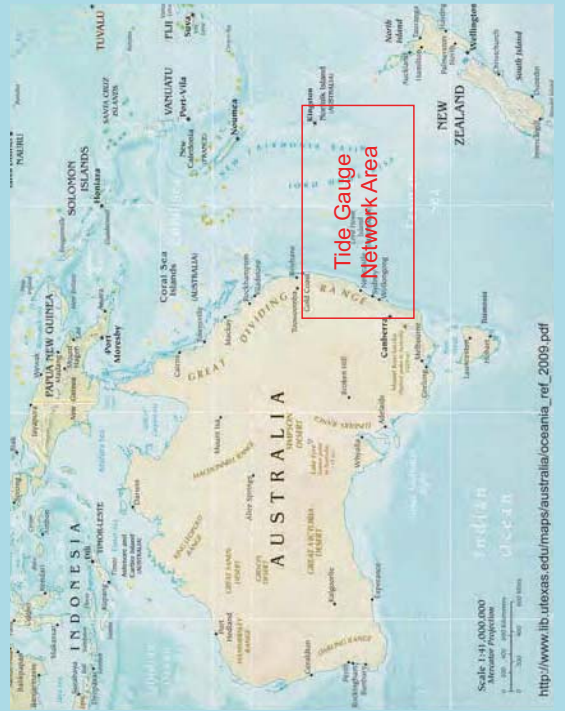
The station locations and data summaries for 2015–2016 are presented in [Appendix A](#).

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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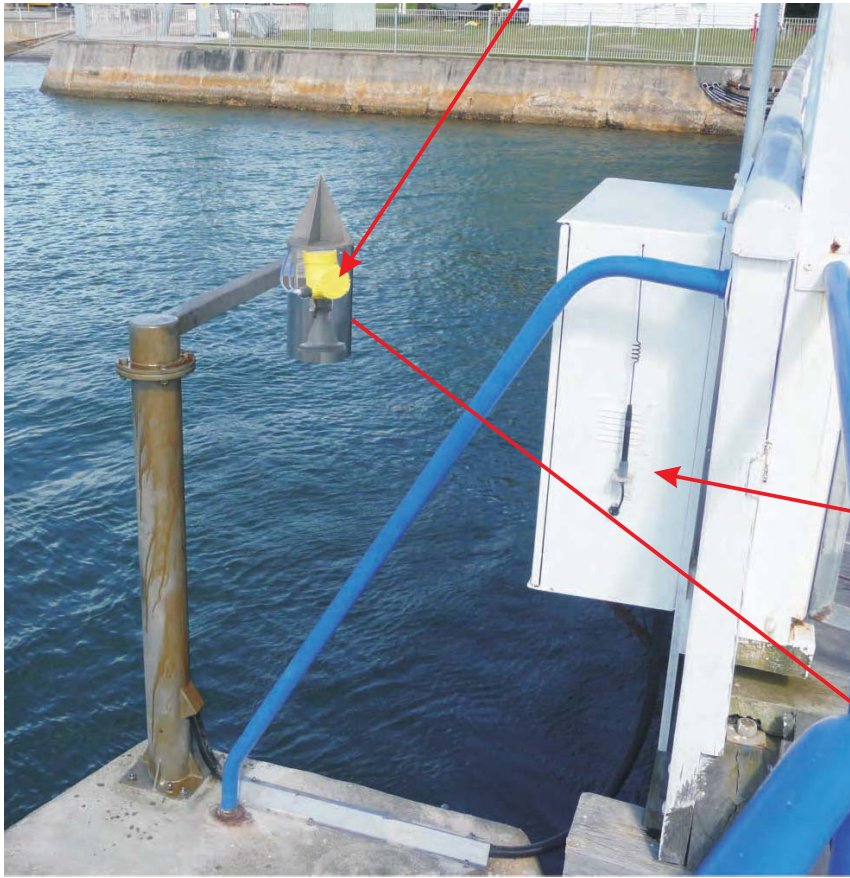
OCEAN TIDE GAUGE NETWORK

MHL
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Figure
1.1

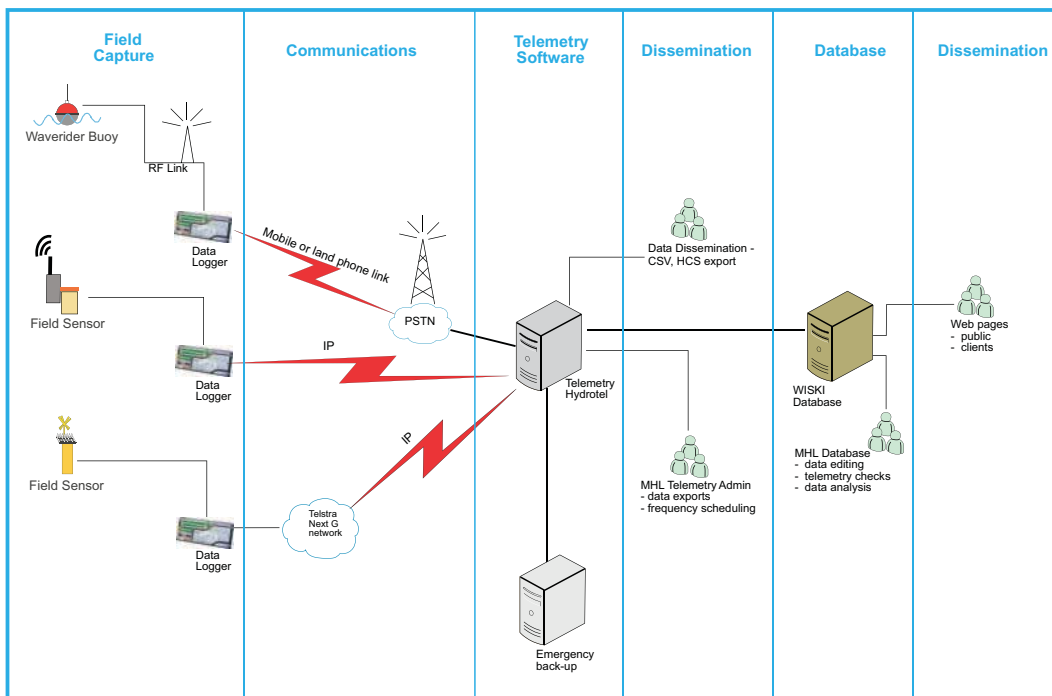
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Radar inside protective housing

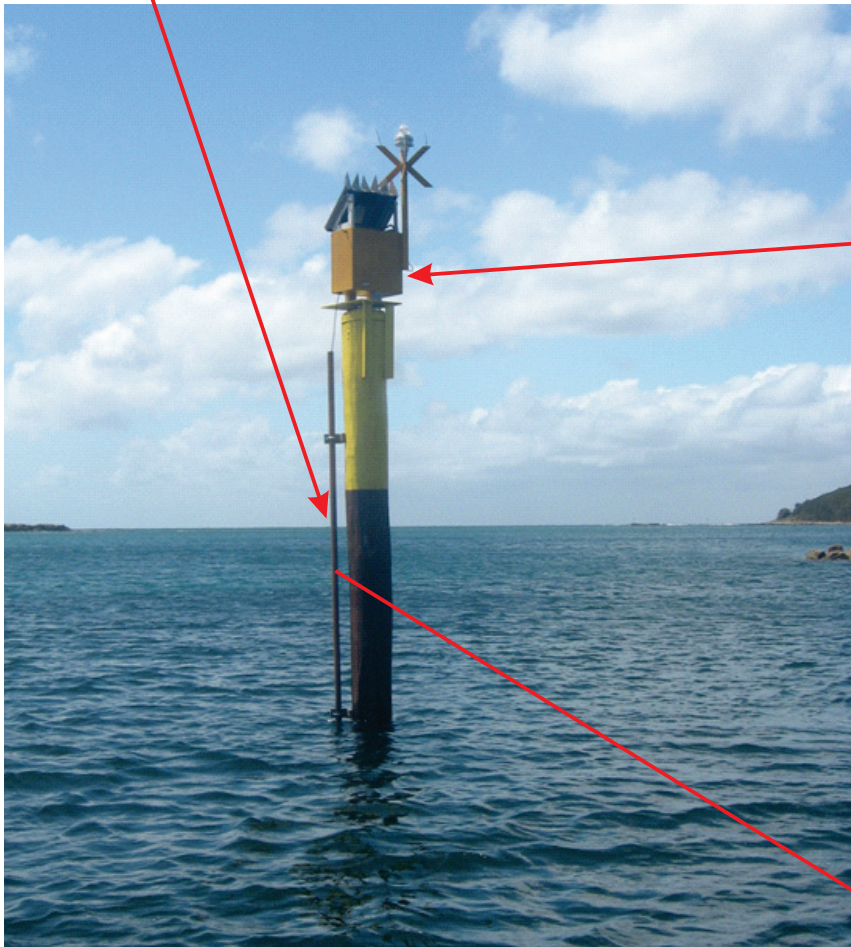


Enclosure containing modem, battery and data logger

DATA TRANSFER via telephone modem (landline or cellular)

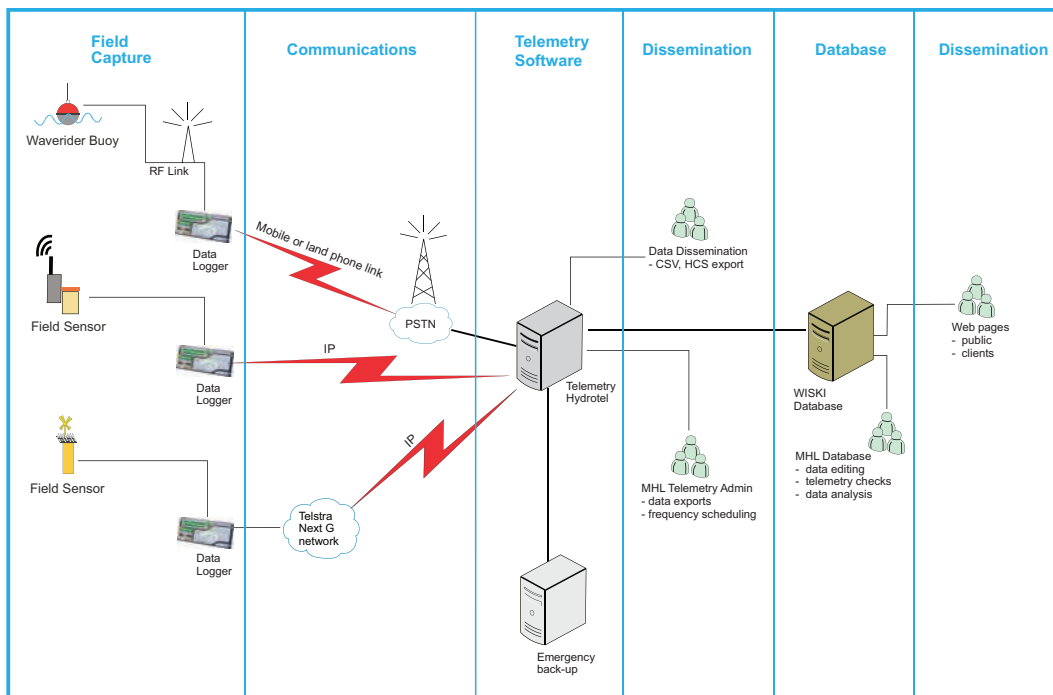


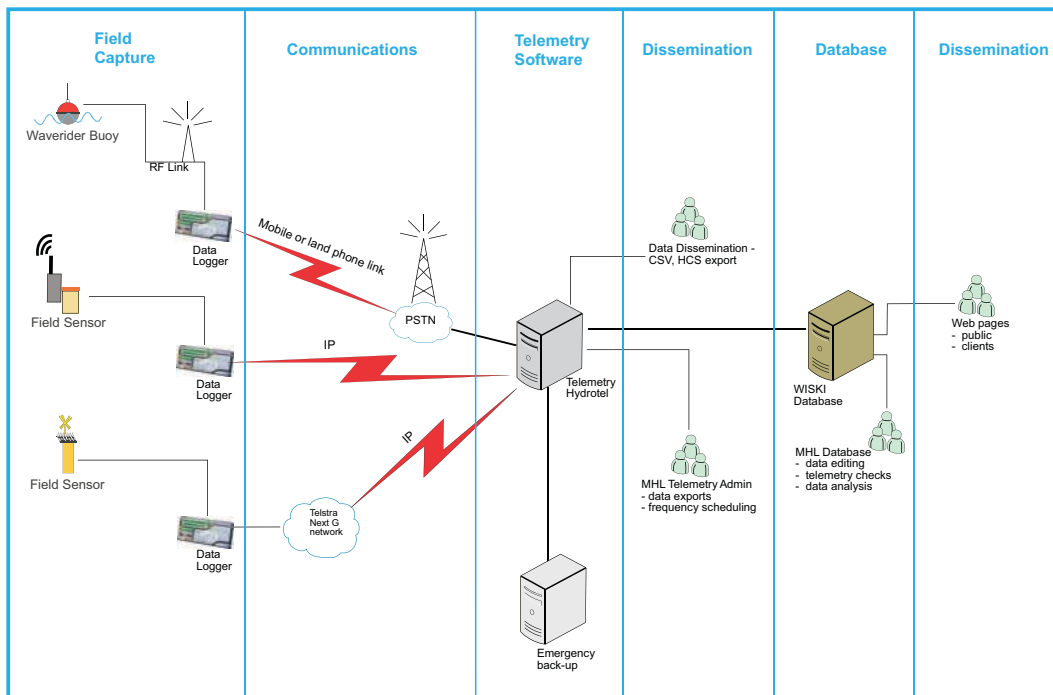
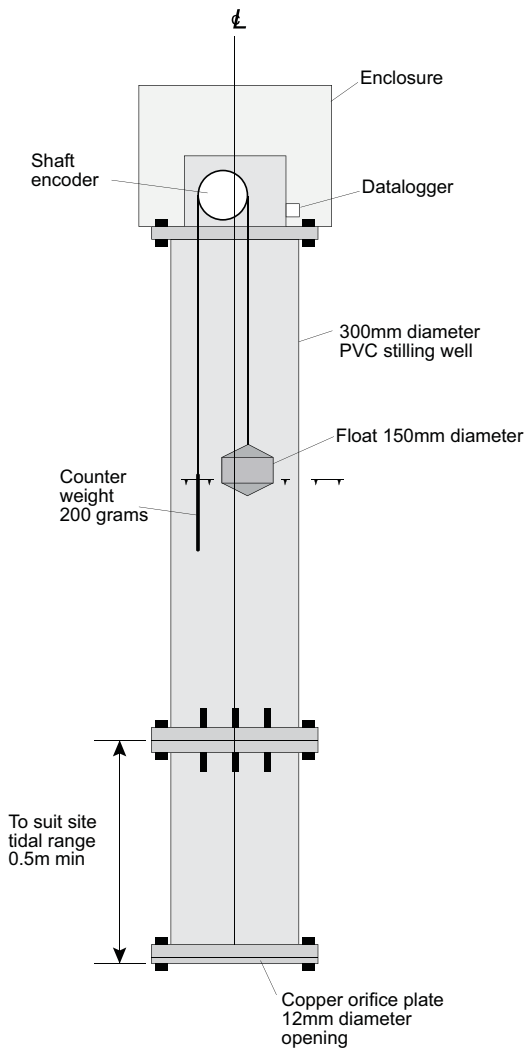
Pressure sensor submerged inside copper tube

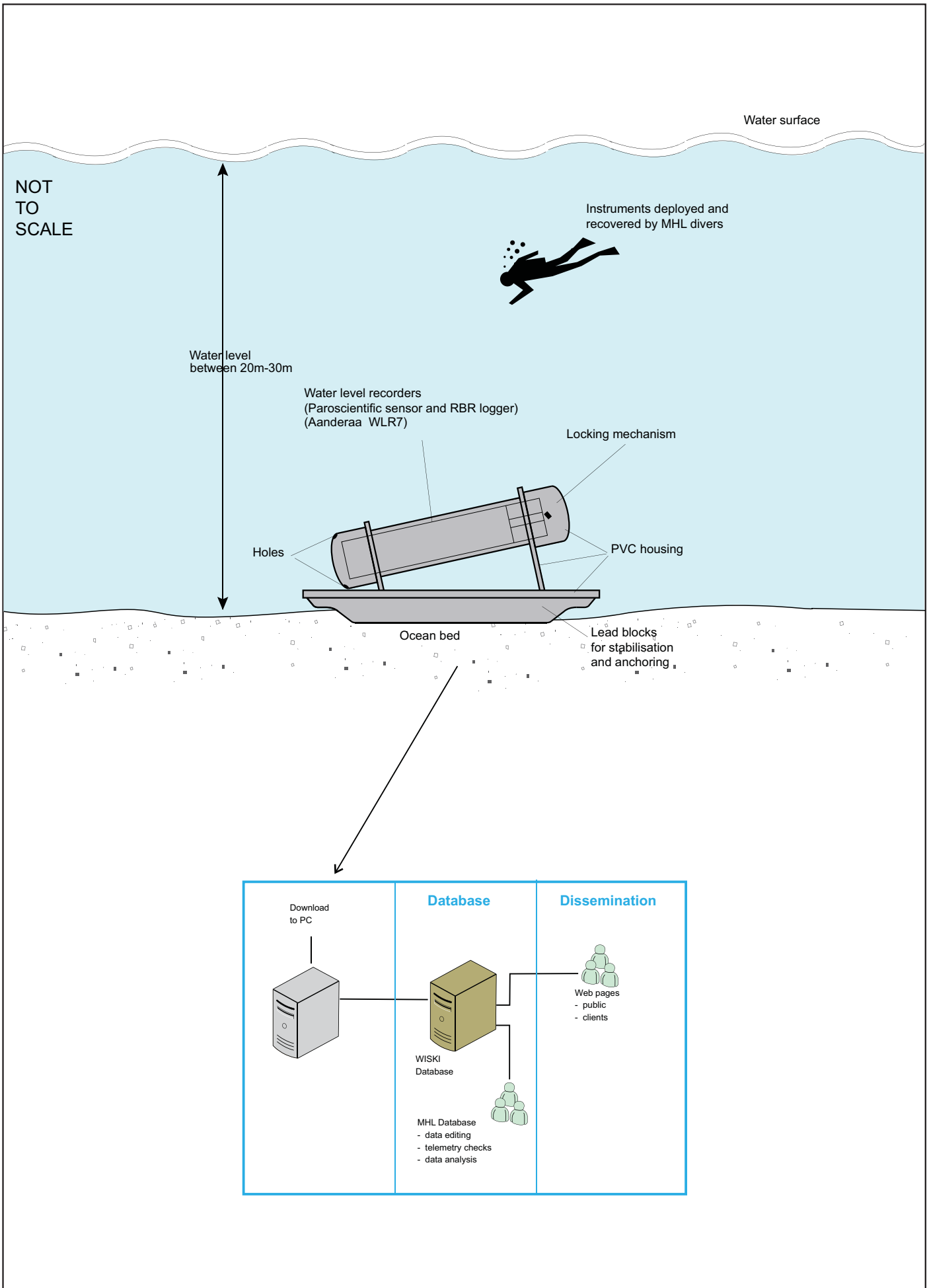


Enclosure containing modem, battery and data logger

DATA TRANSFER via telephone modem







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 2015 to 30 June 2016. 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 2015–2016. 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 four 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	Richmond River Valley Datum	0.860
Yamba	Iluka Port Datum	0.895
Coffs Harbour	Coffs Port Datum	0.882
Port Macquarie	Australian Height Datum	0.000
Port Macquarie Offshore	Mean Sea Level	N/A
Crowdy Head	Crowdy Head Datum	0.911
Forster	Forster Hydro Datum	1.061
Shoal Bay	Port Stephens Hydro Datum	0.944
Patonga	Australian Height Datum	0.000
Sydney	Zero Fort Denison	0.925
Fort Denison (Sydney Ports)	Zero Fort Denison	0.925
Bundeena	Zero Fort Denison	0.925
Crookhaven Heads	Australian Height Datum	0.000
Shoalhaven Offshore	Mean Sea Level	N/A
Jervis Bay	Chart Datum	1.070
Ulladulla	Australian Height Datum	0.000
Princess Jetty	Australian Height Datum	0.000
Batemans Bay Offshore	Mean Sea Level	N/A
Bermagui	Bermagui Local Hydro Datum	0.714
Eden	Twofold Bay Hydro Datum	0.924
Lord Howe Island	Lord Howe Island Hydro Datum	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, or comparative to, the closest offshore site. 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.

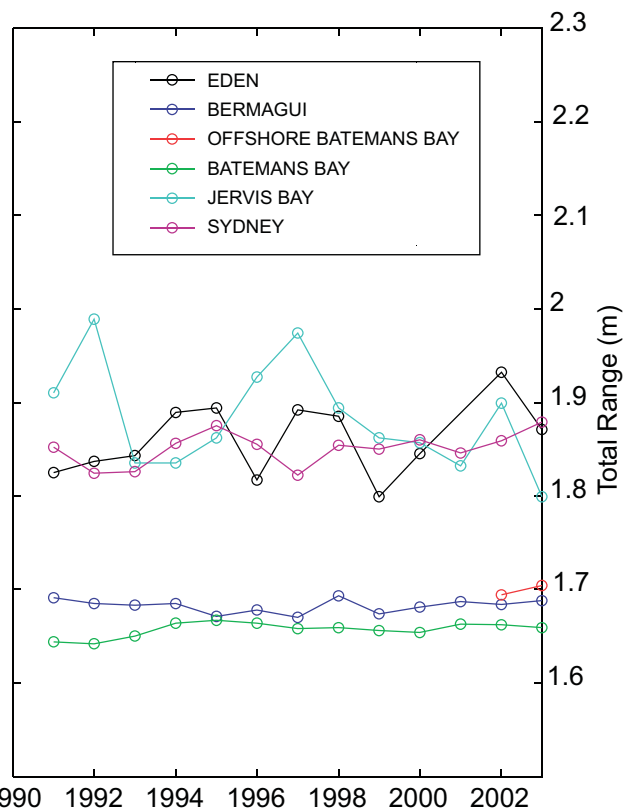
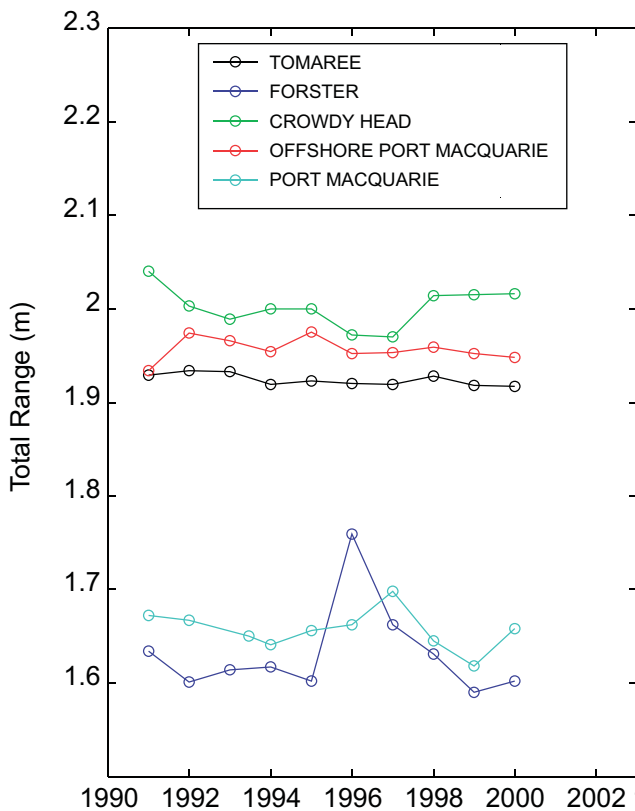
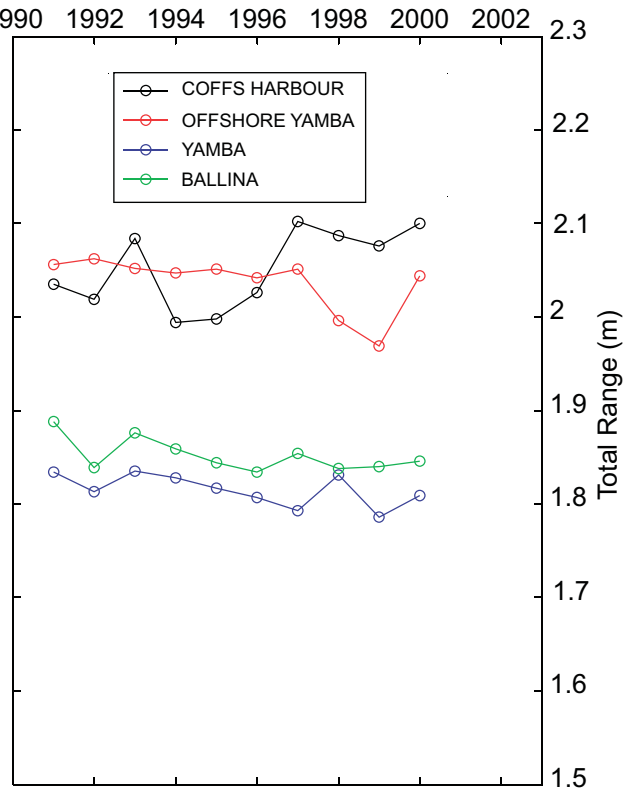
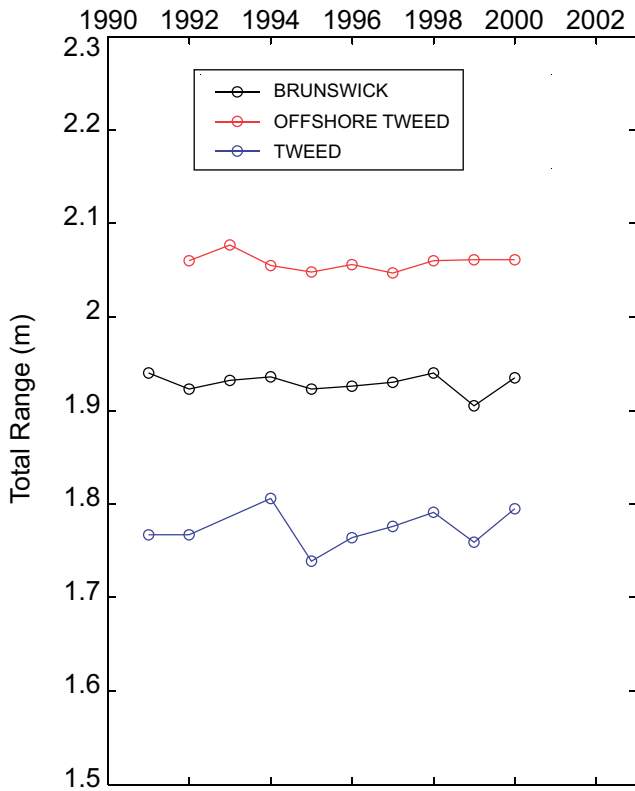
A long-term forecast was produced in 2015 for each ocean tide site for the full data range of historical data and predicted to 2020. The methodology determined the average of the yearly constituent values then converted them to a single average phase and amplitude value (including Z_0 or MSL). From these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

Table 2.2 Ocean and river entrance tide HAT and LAT values

Site	Period 1995–2014				Range (HAT-LAT)	Period 1995–2014	
	HAT	LAT	HAT (AHD)*	LAT (AHD)*		MSL	MSL (AHD)*
Tweed Heads	1.99	0.02	1.10	-0.87	1.97	0.93	0.04
Brunswick Heads	1.22	-0.85	1.17	-0.90	2.07	0.07	0.02
Ballina Breakwall	2.02	0.04	1.16	-0.82	1.98	0.89	0.03
Yamba	2.01	0.07	1.12	-0.83	1.94	0.95	0.05
Coffs Harbour	2.12	-0.11	1.24	-0.99	2.23	0.90	0.02
Port Macquarie	1.04	-0.74	1.04	-0.74	1.78	0.02	0.02
Crowdy Head	2.10	-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

Site	Period 1995–2014				Range (HAT-LAT)	Period 1995–2014	
	HAT	LAT	HAT (AHD)*	LAT (AHD)*		MSL	MSL (AHD)*
Sydney	2.07	0.03	1.15	-0.90	2.04	0.96	0.03
Port Hacking	2.11	0.09	1.19	-0.84	2.02	1.00	0.08
Crookhaven Heads	1.01	-0.08	1.01	-0.08	1.09	0.03	0.03
Jervis Bay	2.19	0.10	1.12	-0.97	2.09	1.09	0.02
Ulladulla	1.20	-0.90	1.20	-0.90	2.10	0.05	0.05
Princess Jetty	1.06	-0.79	1.06	-0.79	1.85	0.06	0.06
Bermagui	1.72	-0.18	1.01	-0.89	1.90	0.69	-0.02
Eden	1.92	-0.11	1.00	-1.03	2.03	0.84	-0.08
Lord Howe Island	2.35	-0.06	n/a	n/a	2.41	1.10	n/a
Norfolk Island	1.97	0.03	n/a	n/a	1.94	0.97	n/a

* AHD offsets given in [Table 2.1](#)



Notes: Each offshore gauge has been grouped with the closest nearshore gauges for comparison
 Total range defined by: tidal plane formula = $HHWSS - ISLW$
 or by: tidal constituent formula = $2(M_2 + S_2 + 1.2K_1 + 1.2O_1)$

Source: MHL 2005



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

MHL
 Report 2475

Figure
 2.1

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3. Significant events 2015–2016

Data recovery rates across the NSW Ocean Tide Network in 2015–2016 were very high; the data recovery on the 15-minute records was 98.5% and for 1-minute data was 97.1%. Losses of data occurred at Ballina due to damage to sensors in a storm in April 2016, Shoal Bay due to vandalism of the communication lines in March 2016, Bundeena damaged in a storm in June 2016 and Jervis Bay logger problem and damaged in a storm in June 2016. The data recovery for the four offshore tide sites was 64.2%. Data loss for this financial year occurred at Shoalhaven Offshore from 1 October 2015 onward due to a communication failure between the logger and sensor and Batemans Bay Offshore which suffered battery failure from 24 November 2015 onward.

The 2017 NSW Tide Charts are available for download, 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.

3.1 Tidal anomalies

The main drivers of anomalies are barometric pressure, wind setup and coastal 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 and the effects of tropical cyclones off the Queensland coast.

Tidal anomalies in this report are calculated as the difference between the recorded data and the long-term epoch forecasts discussed in [Section 2.4](#). Generally, tidal anomalies are caused by a range of oceanographic and meteorological 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 are driven by East Coast Lows or large high pressure systems. In addition, a coastal trapped wave was recorded between 25 November and 2 December 2015. Some of these events are 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 three cyclones in North Queensland during the 2015–2016 reporting period:

- 28 June to 3 July 2015, Tropical Cyclone Raquel – Category 2 – formed over the Solomon Islands, triggered the earliest cyclone warning on record issued for the Queensland zone. The official Queensland cyclone season is from November to April.
- 9 to 15 February 2016, Tropical Cyclone Tatiana – reached Category 2 on 12 February but remained well offshore of the Queensland coast.
- 11 to 24 February 2016, Tropical Cyclone Winston – Category 5 – was classified by the Fiji Meteorological Service and tracked toward Vanuatu and Tonga before intensifying to category 5 on 19 February. The cyclone reached its peak intensity on 20 February, with ten-minute sustained winds of 230 km/h (145 mph) and a pressure of 915 hPa, shortly before making landfall on Viti Levu, Fiji. Tropical Cyclone Winston inflicted extensive damage on many islands, killed 44 people and damaged 40,000 homes.

All these cyclones were well offshore of the Queensland coast and none of the cyclones showed up clearly in the NSW ocean tide traces.

3.2 Tsunami events

Table 3.1 lists the tsunami events in the Pacific Region for the period of time corresponding to the 2015–2016 data in this report.

Table 3.1 Tsunami events July 2015 to June 2016

Date	Cause	Location	Observable on NSW tide recordings
	Earthquake magnitude (M _w)		
10/7/2015	6.7	Solomon Islands	No
18/7/2015	7.0	Solomon Islands	No
16/9/2015	8.3	Chile	No
11/11/2015	6.9	Chile	No
13/11/2015	6.7	Japan	No
2/3/2016	7.8	Indonesia, SW Sumatra	No
16/4/2016	7.8	Ecuador, off coast	No
28/4/2016	7.0	Vanuatu 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 2015 to June 2016. The Bureau of Meteorology collects specific tsunami data for issuing warnings, and the data can be requested from BoM for further use.

3.3 King tide events

King tides occurred on 3 July 2015, 10 February 2016 and 5 June 2016. The July king tide produced a water level in Sydney of 1.89 m Zero Fort Denison (ZFD) datum (0.97 m AHD), whilst the February king tide reached 1.87 m ZFD (0.94 m AHD). The highest tide of the year occurred when the king tide in June 2016 coincided with an East Coast Low storm and a water level of 2.21 m ZFD (1.29 m AHD) was recorded at the Sydney gauge.

3.4 East Coast Low events

A number of East Coast Lows (ECL) impacted on the NSW coast in the 2015–2016 reporting period. The ECLs causing the most significant ocean anomalies, highlighted in [Figure 3.2](#), occurred on 12–15 July and 23–28 September 2015, and 1–7 February, 25–28 May and 4–8 June 2016. Another ECL that occurred on 23–26 August 2015 caused widespread flooding but did not rank as a significant anomaly for the period. MHL (2015) presents this ECL flood event that impacted the NSW South Coast.

The ECL that occurred between 4 and 8 June 2016 caused significant impact along the whole of the NSW coast. The system developed in the far north coast of NSW on the afternoon of Saturday 4 June 2016. The system tracked south past Sydney on the afternoon of Sunday 5 June and continued towards the Victorian border on Monday and Tuesday, and on to Tasmania until Wednesday 8 June. Apart from causing significant rainfall and strong north-east winds along the adjoining NSW coast, the event was coincident with the winter aphelion spring tide (king tide), with positive tidal residuals and large ocean waves. The coincidence of elevated ocean levels and large waves arriving at the coast from the east and east-north-east (a somewhat atypical storm wave direction) resulted in substantial and widespread erosion and damage to the NSW coast.

At Eden, a maximum individual wave height of 17.7 m was recorded, being 2.8 m higher than the previously largest measured individual wave of 14.9 m recorded off Sydney on 21 April 2015. The maximum recorded water level at the Sydney Middle Head tidal gauge was 2.21 m ZFD (1.29 m above AHD) on Sunday 5 June 2016.

[Figures 3.10](#) to [3.14](#) show the water level data during the 4 to 8 June ECL along with some photographs during the event. [Figure 3.10](#) shows a comparison of water levels along the NSW coast from Tweed River entrance, Sydney and Eden and photos during the event. The maximum water level recorded on 4 June 2016 at Tweed Heads of 2.45 m Tweed River Hydro Datum (1.56 m AHD) includes flood water discharge from the Tweed River. At Eden the maximum water level recorded was 2.13 m Twofold Bay Hydro Datum (1.21 m AHD) on Monday 6 June.

[Figure 3.11](#) shows the Sydney measured, forecast and residual data and photos during the event. [Figure 3.12](#) shows two synoptic charts and photos during the event. [Figures 3.13](#) and [3.14](#) show photos around Sydney's northern beaches during and after the event.

3.5 Seiching and meteotsunami events

The ocean tide and river entrance data are becoming increasingly valuable and, with increases in data accuracy, quality and frequency, closer inspection of the data is revealing more detailed information about features that were previously not clearly defined. Seiching and meteotsunamis are cases in point, where the increased data quality and resolution are clarifying these events in the tidal trace, which may have previously been thought of as spikes in the data.

A seiche is a standing wave oscillating in a closed or open embayment. Seiches are caused by energy from wind, barometric changes, or waves acting on the water body forcing water from one end of the embayment to the other. Once movement is initiated the water then oscillates within the embayment dependent on the morphology of the embayment.

Jayewardene et al. (2016) provides detailed investigation of seiching occurring in NSW at Coffs Harbour.

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

The processes involved in creation and amplification of a meteotsunami are a rapid change in barometric pressure, movement of the pressure system at the same speed as the wave celerity (known as Proudman or Greenspan resonance) and the influence of the shape and depth of the shelf and local morphology close to the shoreline (Monserrat et al. 2006).

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

MHL used the Sydney tide gauge to examine the seiche and meteotsunami waves within the 1-minute dataset available from May 2011 to current. A 3-hour low pass filter was applied to the Sydney tidal residual time series. By subtracting the filtered time series from the residual time series a filtered trace is produced which allows visual indications of seiches and meteotsunamis. The single NSW meteotsunami example mentioned in Pattiaratchi et al. (2015) occurred on 26 November 2011 and is shown in the Sydney tidal record in [Figure 3.15](#). The filtered time series shows the meteotsunami, and a sharp drop in the barometric

pressure can also be observed just prior to the commencement of the meteotsunami. The meteotsunami residual has a maximum amplitude of 220 mm over 14 minutes (840 seconds), whilst the oscillations have a period in 20–30 minute range. [Figure 3.15](#) also shows the barometric pressure analysis charts for the period of this meteotsunami. A trough between two highs associated with a low pressure system can be seen moving across the coast at Sydney at this time, and whilst it appears to be moving west to east there may have been a period where the trough coincided with the movement of the wave to produce the required Proudman resonance.

Closer examination of the Sydney data, in the 2015–2016 year presented in this report, identified 16 possible meteotsunami events (24 July 2015, 2 August 2015, 12 August 2015, 24 August 2015, 3 September 2015, 7 October 2015, 6 November 2015, 20 November 2015, 2 December 2015, 16 December 2015, 14 January 2016, 22 January 2016, 30 January 2016, 1 May 2016 and 12 May 2016). However, on closer inspection and following discussion (C Pattiaratchi 2016 pers. comms. 2 September) it is thought that many of these events are likely to be seiche events rather than meteotsunamis. In many cases sharp barometric changes may be the initial driver of the anomaly and the presence or absence of Proudman resonance is the determining factor as to whether a meteotsunami or a seiche results. If the Proudman resonance occurs then the initial wave is amplified and modified by local morphology to cause a meteotsunami. If Proudman resonance does not occur it appears that initial water level change can energise parts of Sydney Harbour with seiche waves.

Whilst these seiches and meteotsunamis appear to be a relatively small anomaly in the ocean tide data sets they may be more significant when they occur with a storm event. Anecdotal evidence (A Gordon 2016, pers. comms. 14 September) indicates that seiche waves have occurred in the past, and contributed to damage, during storm events such as the May to June 1974 storms.

[Figure 3.16](#) shows a plot of one example of a meteotsunami/seiche event from this year's data on 24 August 2015. The figure also shows relevant synoptic charts as the event progresses. In an attempt to identify these events mathematically, data was processed in Matlab software with a Fast Fourier Transform (FFT) to identify frequency components of wave events throughout the year. [Figure 3.17](#) shows the results of the FFT for the 2015–2016 data. The dotted line indicates a signal magnitude of 5 standard deviations from zero. The FFT results shown in [Figure 3.17](#) indicate increased energy within the 20–35 minute wave period band for events above this 5 standard deviation line. A number of these peaks in the FFT coincide with waveforms observed in the tidal residual and noted above. Specifically, the example in [Figure 3.16](#) on 24 August 2015 is clearly evident as a peak in the FFT on 26 November 2011. Thus, the FFT analysis may be a method of assisting with the identification of these events.

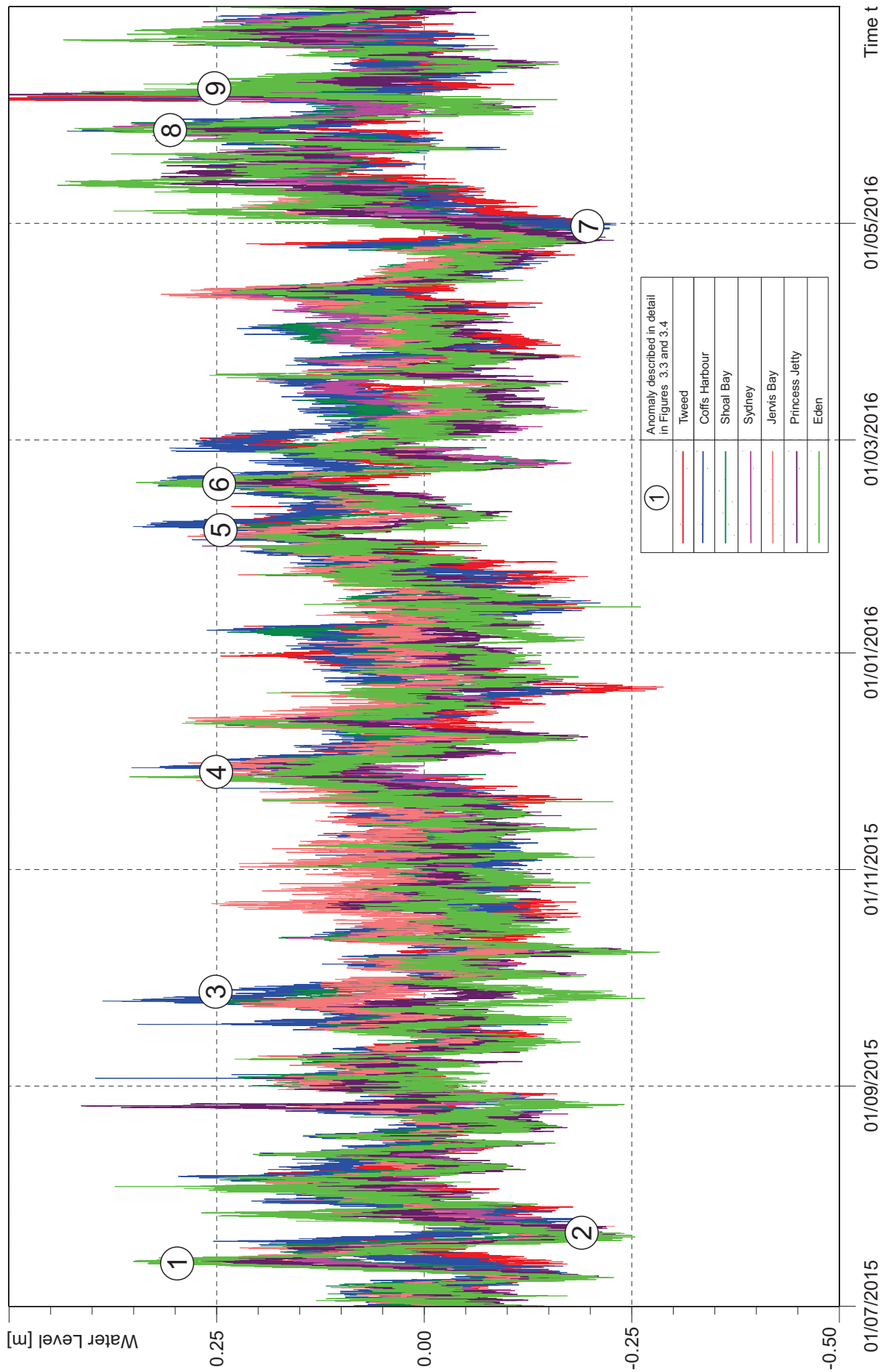
The difficulty of showing evidence of Proudman resonance is shown in the lower half of [Figure 3.17](#). The figure shows barometric pressure data from land-based Bureau of Meteorology sites (provided by Mr A Taylor, BoM), coinciding with the events shown in [Figure 3.16](#). The sharp change in barometric pressure is evident, but without offshore barometric data it is difficult to show that Proudman resonance occurred during this event.

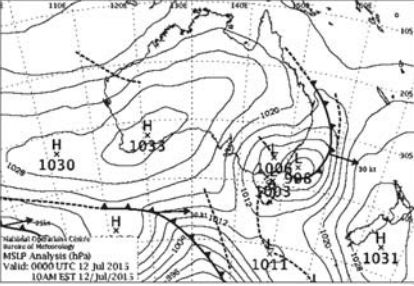
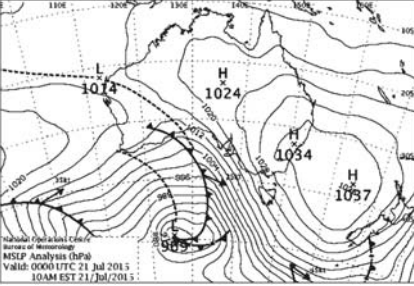
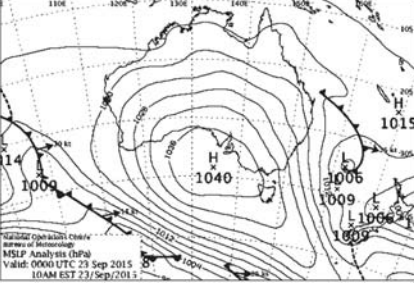
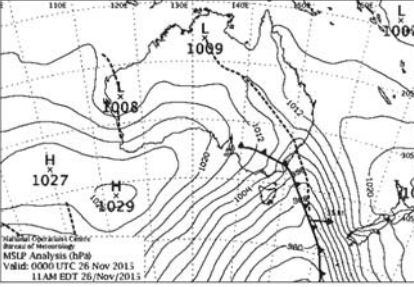
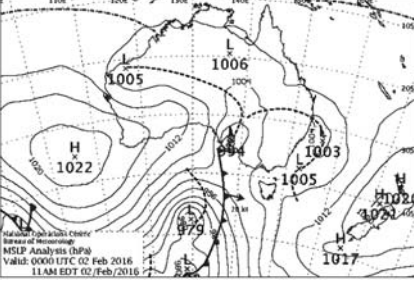
Further investigation into seiching and meteotsunamis using frequency analysis needs to be conducted if a capacity to recognise past events by using such a technique is to be developed. Such a capacity, together with a better understanding of the resonance and amplification mechanisms associated with these events, may also allow a prediction of future events.

Identifying the difference between the seiche and meteotsunamis also needs to be further clarified. Due to the difficulty of proving the occurrence of Proudman resonance in NSW it is not yet clear which waves can be defined as meteotsunamis. In [Figure 3.16](#) it is arguable that some of the residuals in the trace could be meteotsunamis, however, unless evidence of Proudman resonance exists they may be defined as seiche waves.

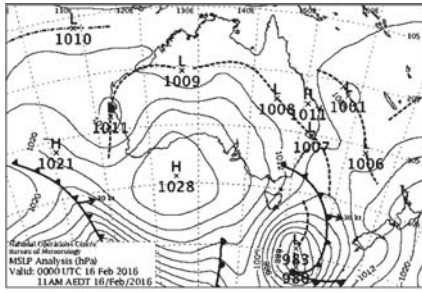
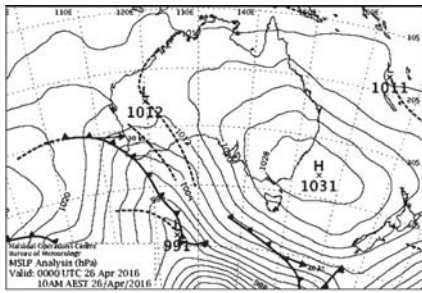
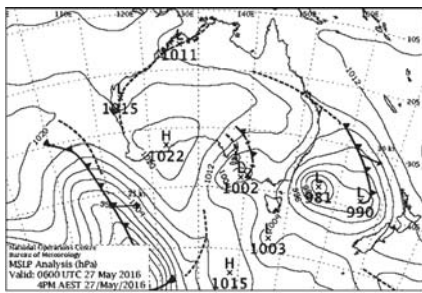
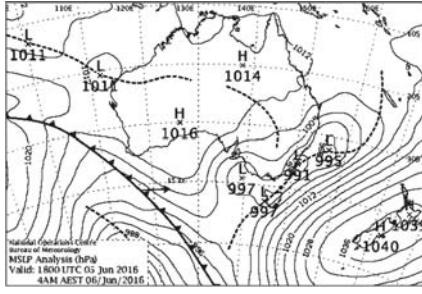
These seiches and meteotsunamis may also be more significant in NSW estuaries and coastal lakes with low tidal ranges and in formation of seiche waves in small NSW harbours. Following the observation of these events in the Sydney data a brief inspection of NSW estuary and coastal lagoon data was also conducted. These sites do not currently have 1-minute data logging and therefore detailed inspection of such events at these sites is not yet possible. However, an example event on the Clarence River on 9 March 2015 shown in [Figure 3.18](#) indicates such meteotsunamis could occur in river systems and this is supported by Pattiaratchi and Wijeratne (2015) who created meteotsunamis numerically in a long narrow canal. At both Lawrence and Ulmarra [Figure 3.18](#) shows a peak water level some 100 mm above the tidal high for the day. The magnitude of the displacement in these plots compared to tidal range at the time indicates these could be significant events in rivers and coastal lagoons.

NSW also has a number of small harbours in which seiche waves are known to occur. There are a number of known causes of seiche waves but it is highly likely that the meteotsunami phenomena is also a contributing cause of seiching in these harbours.



Event Number (see Figure 3.2)	Event Period	BoM Weather Map*	Peak	Sites where Anomaly > +/- 0.2m
1	12–15 July 2015	 <p>East Coast Low</p>	Site Bermagui Date 13/7/2015 Time 2100 Peak Value 0.38	Forster, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
2	19–25 July 2015	 <p>Large high pressure system</p>	Site Ulladulla Date 19/7/2015 Time 1745 Peak Value -0.30	Yamba, Port Macquarie, Crowdy Head, Patonga, Sydney, Bundeena, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
3	23–28 Sept 2015	 <p>East Coast Low</p>	Site Coffs Harbour Date 24/7/2015 Time 2300 Peak Value 0.39	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Jervis Bay, Ulladulla
4	25 Nov–2 Dec 2015	 <p>Coastal Trapped Wave</p>	Site Bermagui Date 27/11/2015 Time 1100 Peak Value 0.31	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Shoal Bay, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
5	1–7 Feb 2016	 <p>East Coast Low</p>	Site Coffs Harbour Date 5/2/2016 Time 1445 Peak Value 0.35	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven, Jervis Bay, Ulladulla, Bermagui, Eden



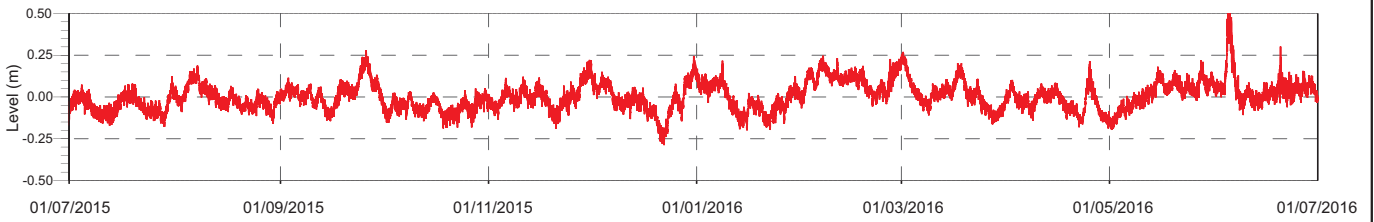
Event Number (see Figure 3.2)	Event Period	BoM Weather Map*	Peak	Sites where Anomaly > +/- 0.2m
6	14–21 Feb 2016	 <p>Series of complex low pressure systems</p>	Site: Eden Date: 18/2/2016 Time: 0000 Peak Value: 0.35	Brunswick, Ballinas, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
7	25–30 April 2016	 <p>Large slow moving high pressure system</p>	Site: Ulladulla Date: 26/4/2016 Time: 0830 Peak Value: -0.25	Tweed, Yamba, Port Macquarie, Coffs Harbour, Crowdy Head, Patonga, Bundeena, Ulladulla, Princess Jetty, Bermagui
8	25–28 May 2016	 <p>East Coast Low</p>	Site: Coffs Harbour Date: 26/5/2016 Time: 2300 Peak Value: 0.43	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven, Ulladulla, Princess Jetty, Bermagui, Eden See Note 1
9	4–8 June 2016	 <p>East Coast Low</p>	Site: Brunswick Date: 5/6/2016 Time: 0200 Peak Value (flood affected): 1.12 Peak Value (Sydney non-flood affected): 0.34	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven, Ulladulla, Princess Jetty, Bermagui, Eden See Note 1

Note 1: Jervis Bay site not functioning during this event

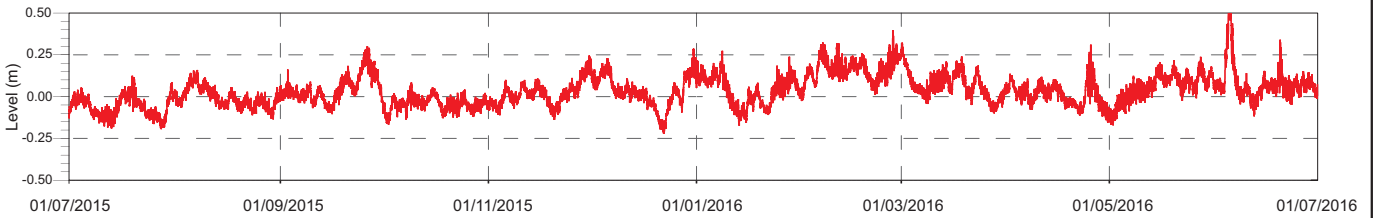
*Weather map images courtesy BoM © Commonwealth of Australia, Bureau of Meteorology



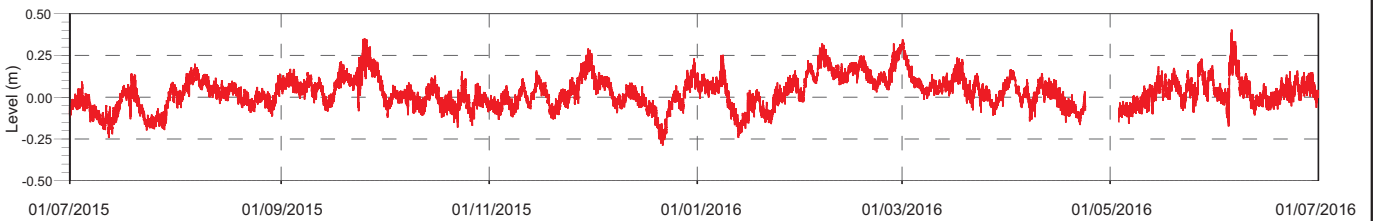
Tweed Entrance South



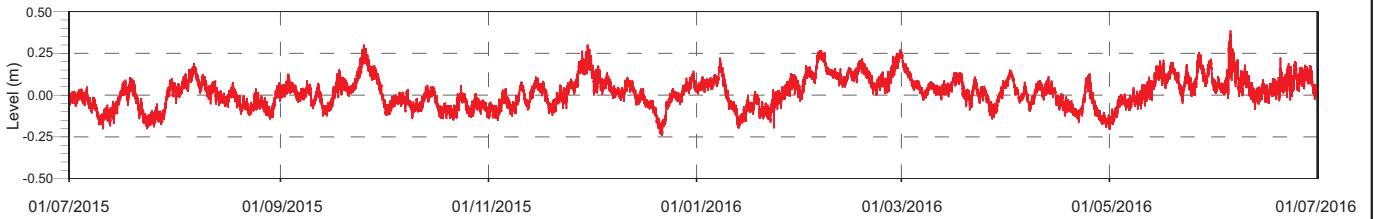
Brunswick Heads



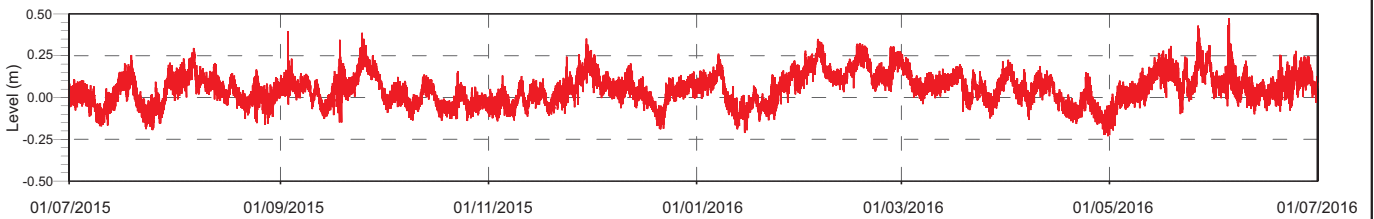
Ballina Breakwall



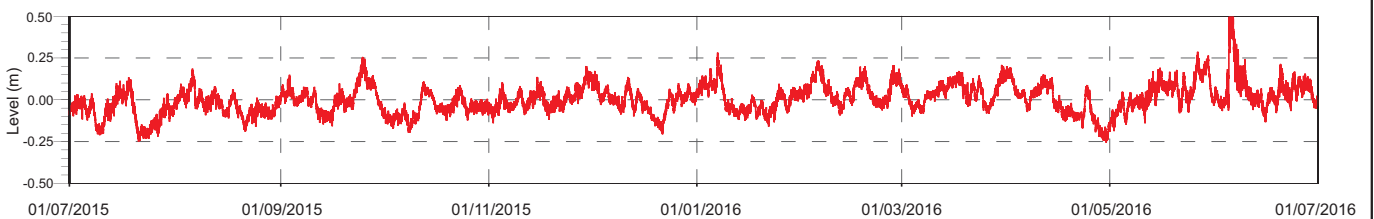
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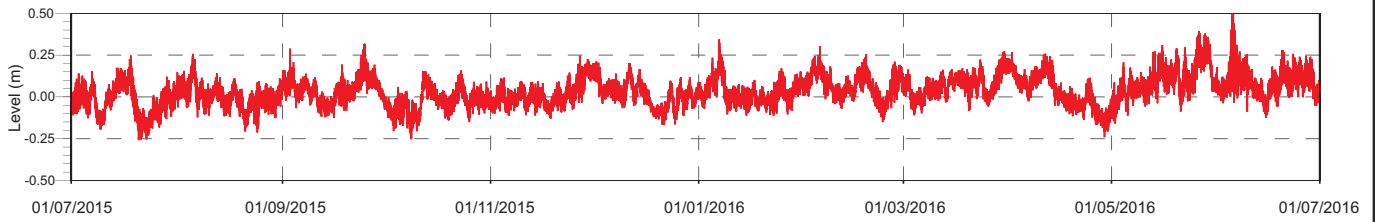
Coffs Harbour



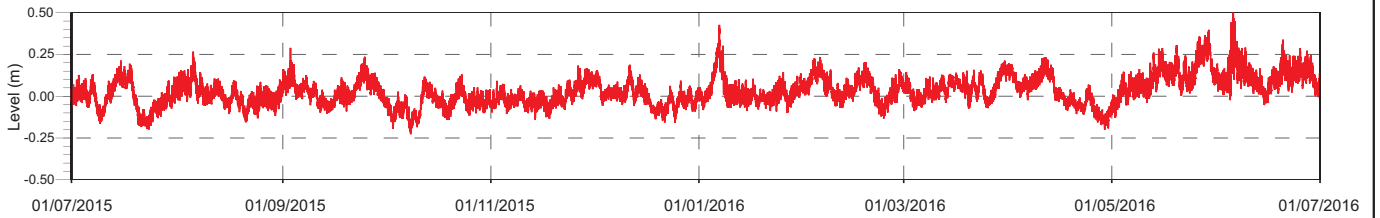
Port Macquarie



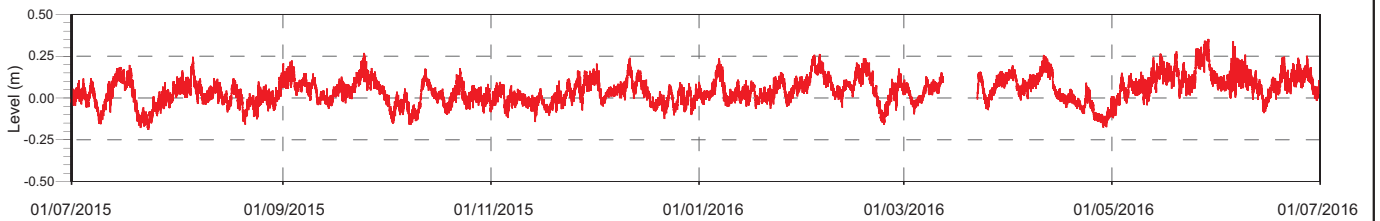
Crowdy Head



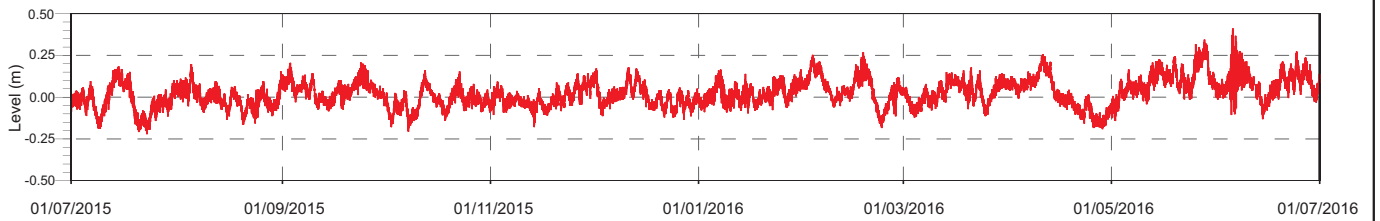
Forster



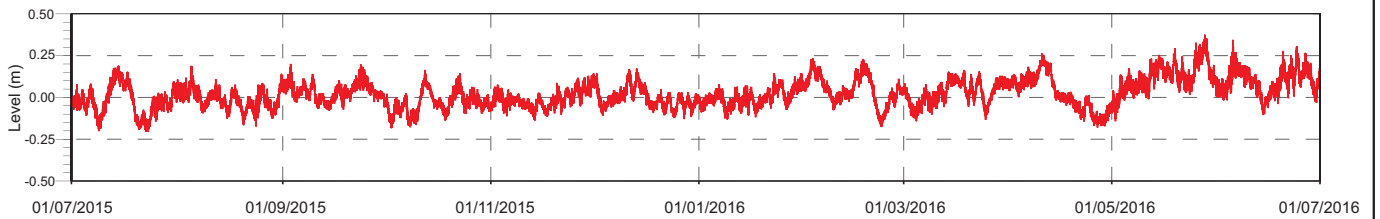
Shoal Bay



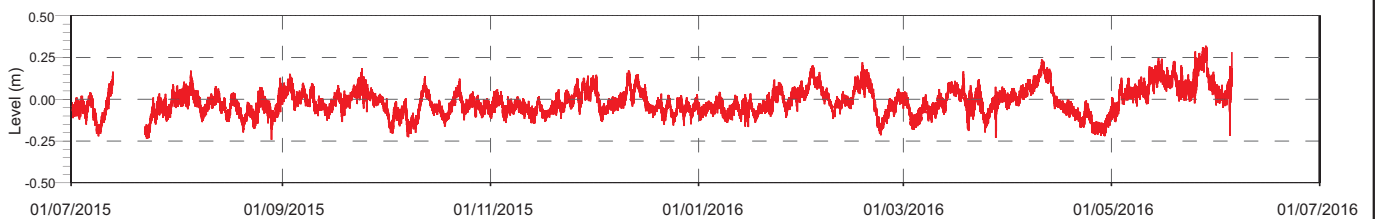
Patonga



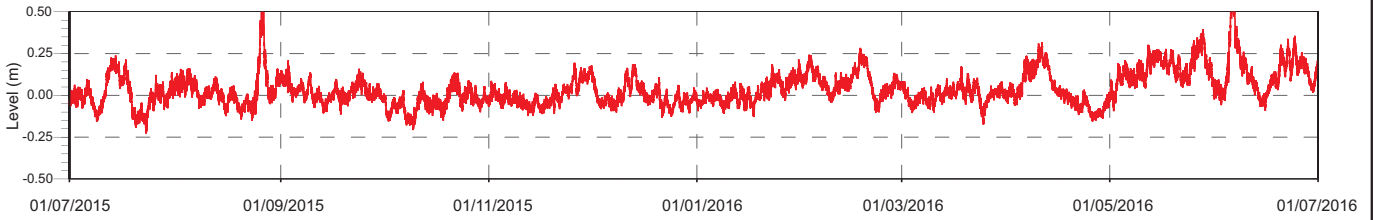
Sydney



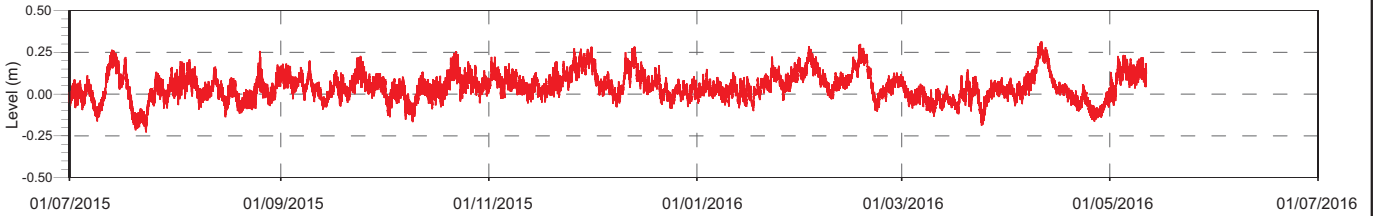
Bundeena



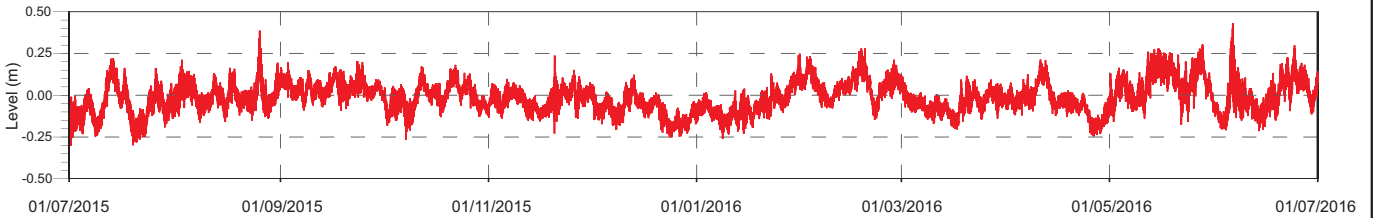
Crookhaven Heads



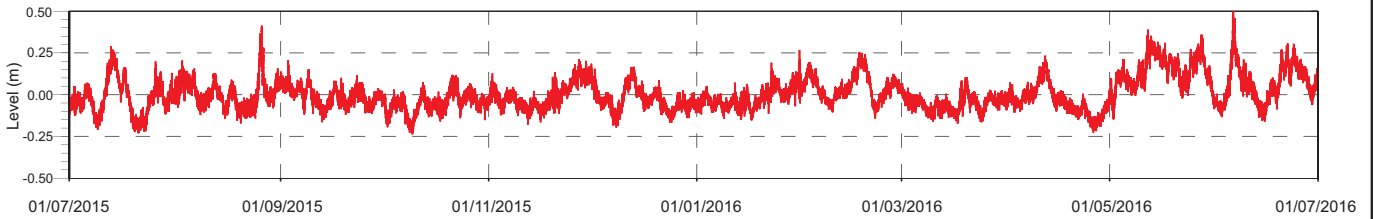
Jervis Bay



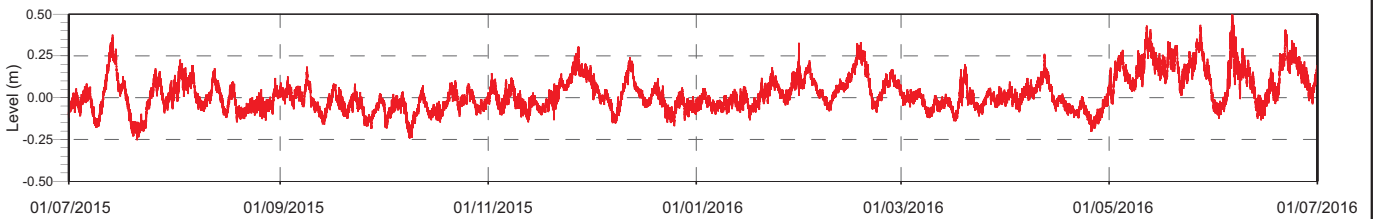
Ulladulla



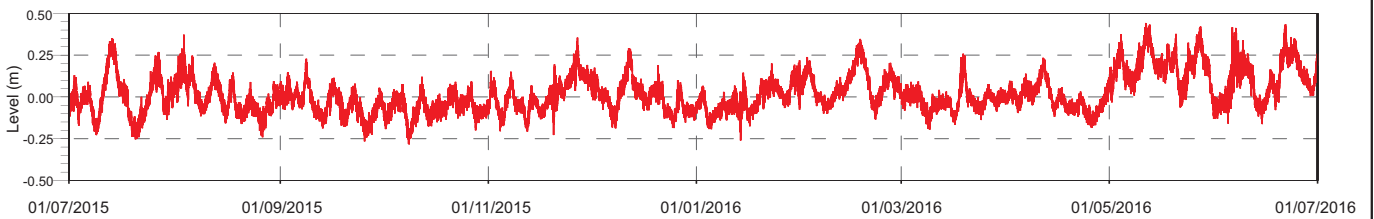
Princess Jetty



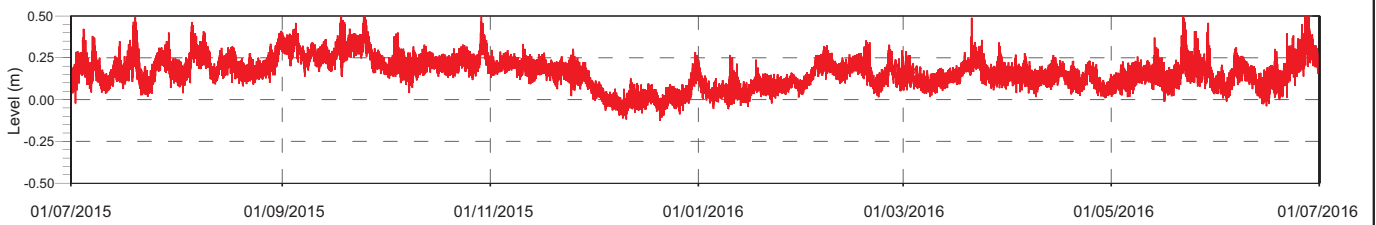
Bermagui



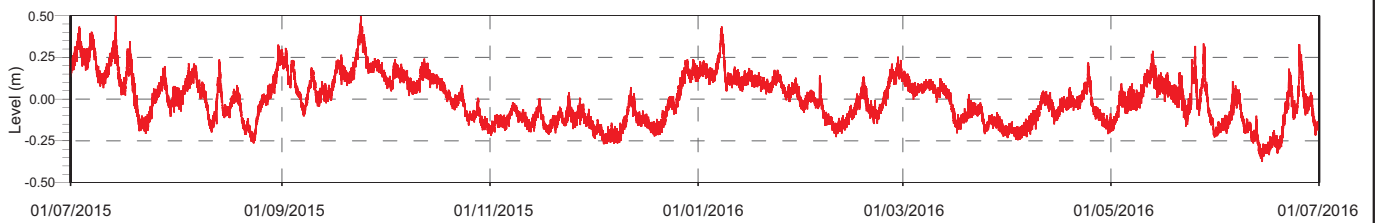
Eden



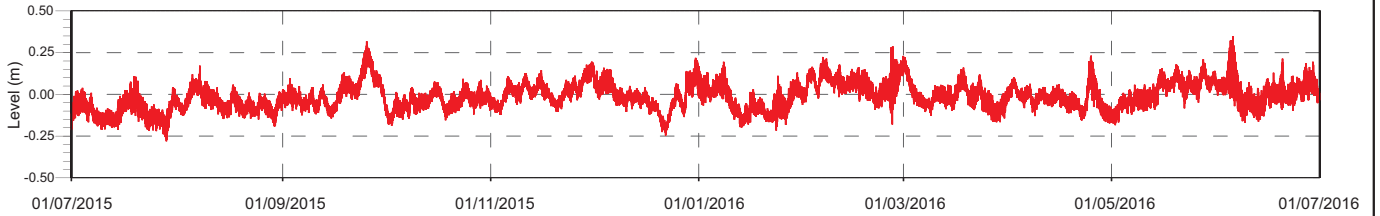
Norfolk Island



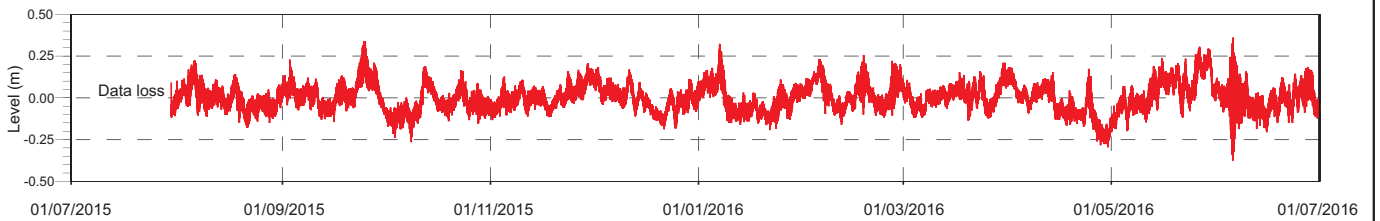
Lord Howe Island



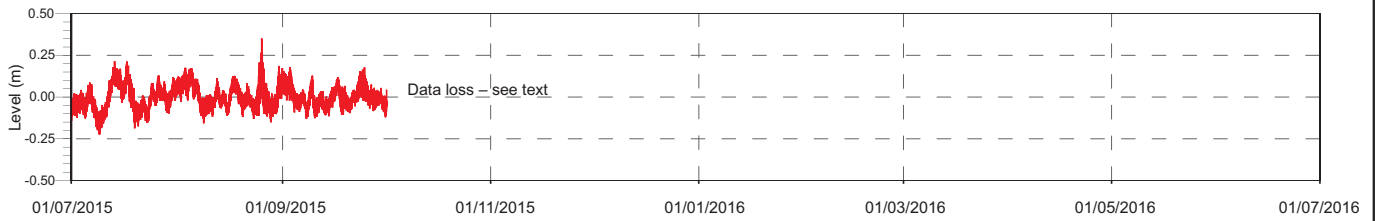
Tweed Heads Offshore



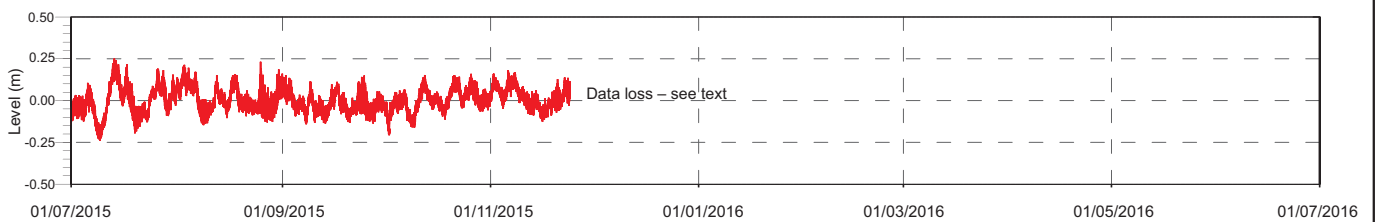
Port Macquarie Offshore

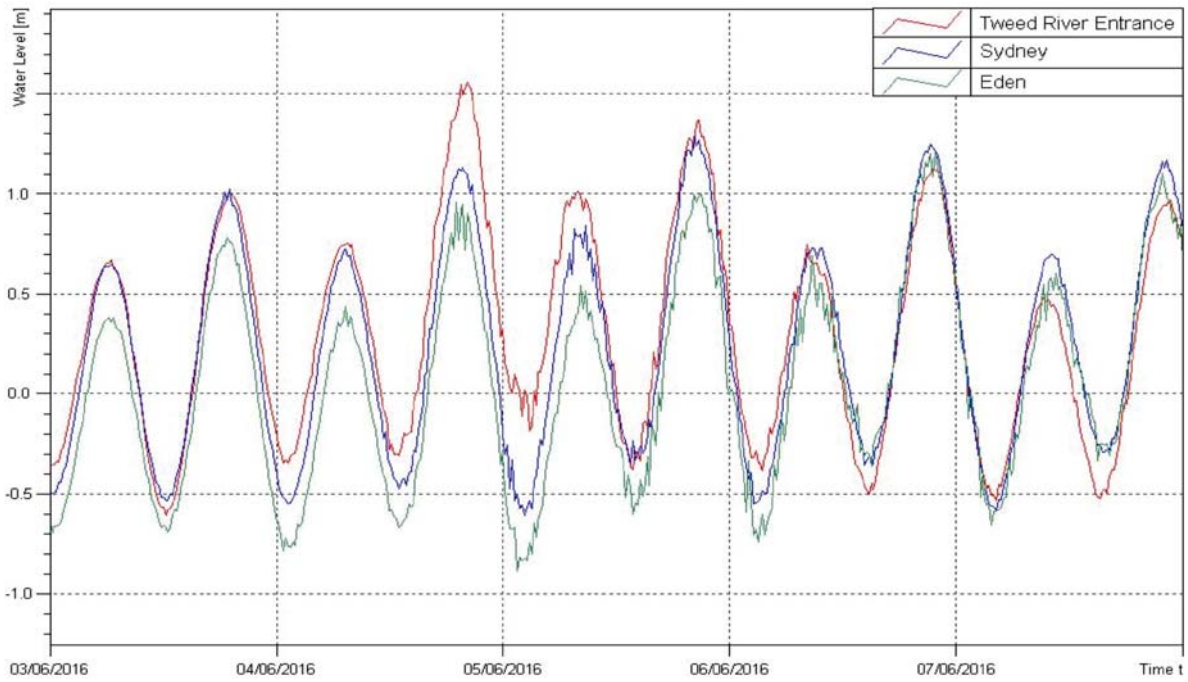


Shoalhaven Offshore



Batemans Bay Offshore

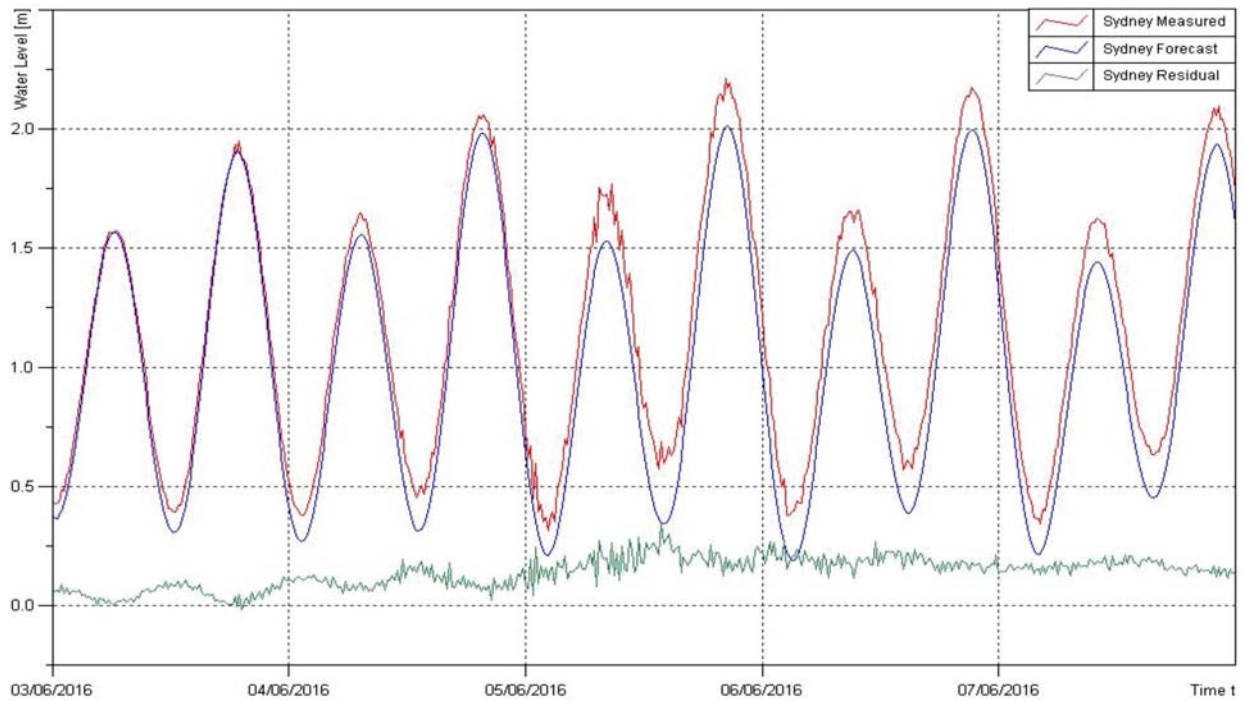




Stuart Street, Collaroy Beach
Photo: R Jacobs, 05/06/2016



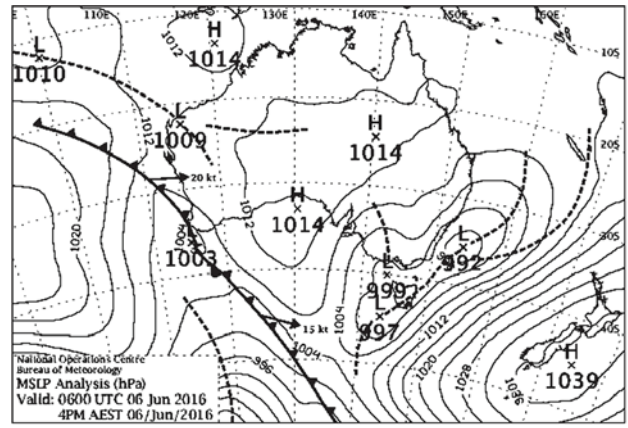
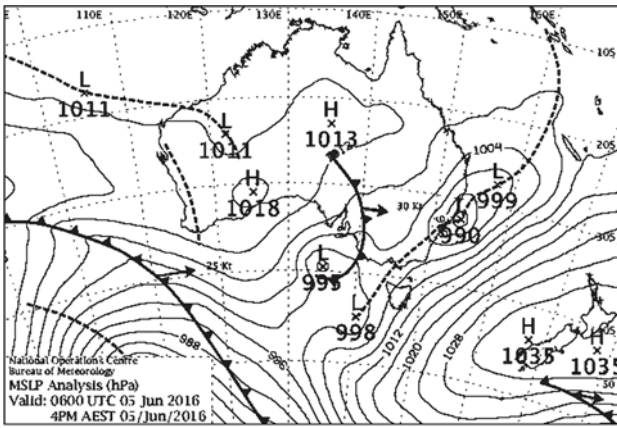
Marine Parade, Manly
Photo: S Young, 05/06/2016



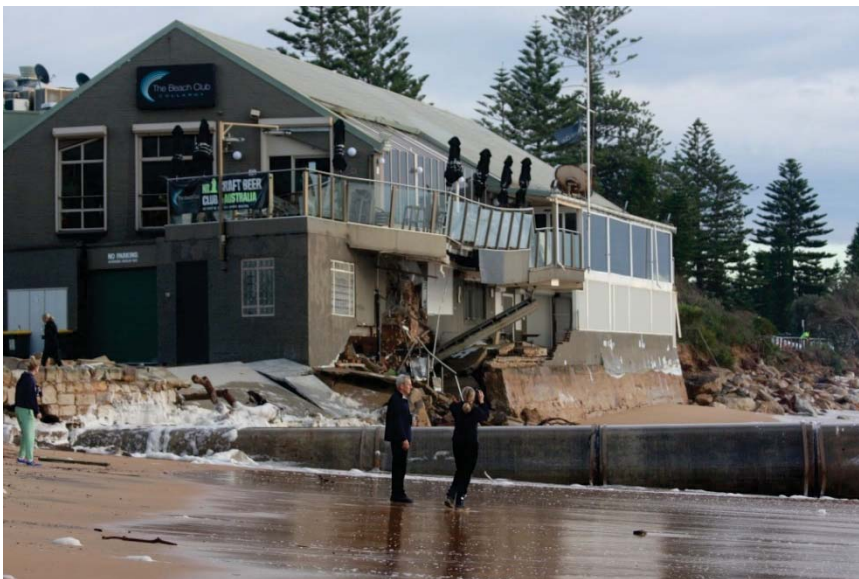
Collaroy Pool
Photo: R Jacobs, 05/06/2016



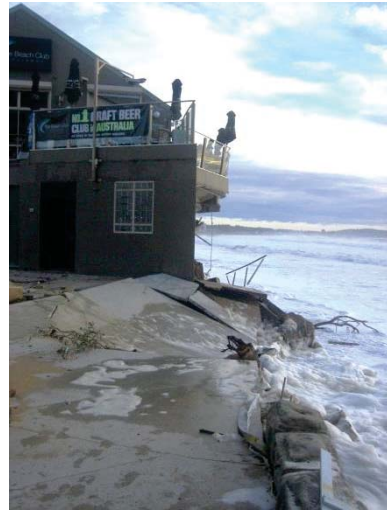
Dee Why Beach Promenade
Photo: S Yeates, 05/06/2016



Ramsay Street, Collaroy Beach
Photo: R Jacobs, 06/06/2016



The Beach Club, Collaroy
Photo: R Jacobs, 06/06/2016



Collaroy Beach Promenade 05/06/2016 (L) and Beach Club 06/06/2016 (R)
 (Photos: R Jacobs)



Collaroy Beach Promenade storm debris 05/06/2016 (L) and 29/06/2016 (R)
 (Photos: R Jacobs)



Collaroy Beach Surf Life Saving Club 05/06/2016 (L) and 29/06/16 (R)
 (Photos: R Jacobs)

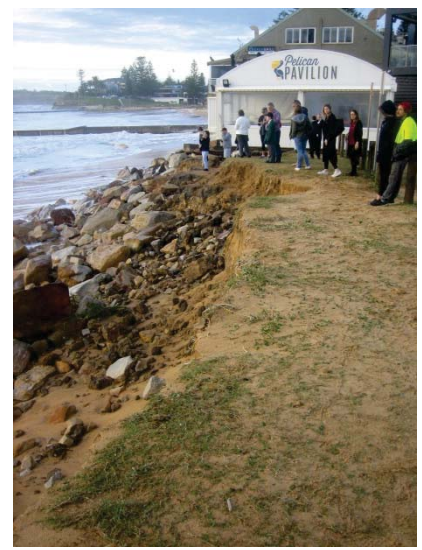




Marine Parade, Manly 05/06/2016 and 06/06/2016
(Photos: S Young and I Jayewardene)

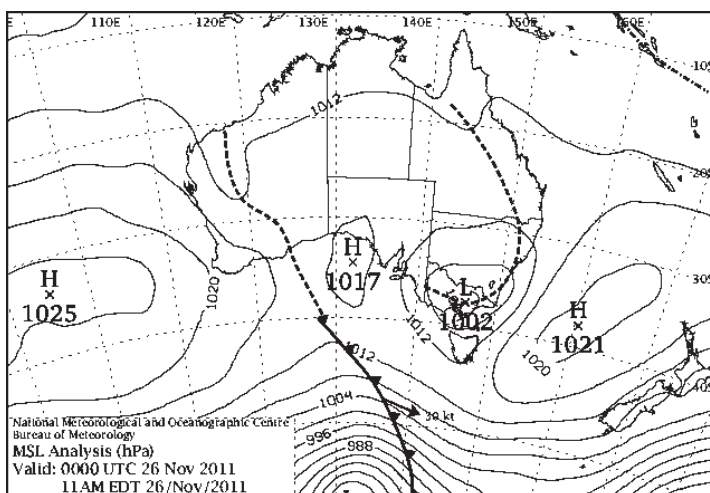
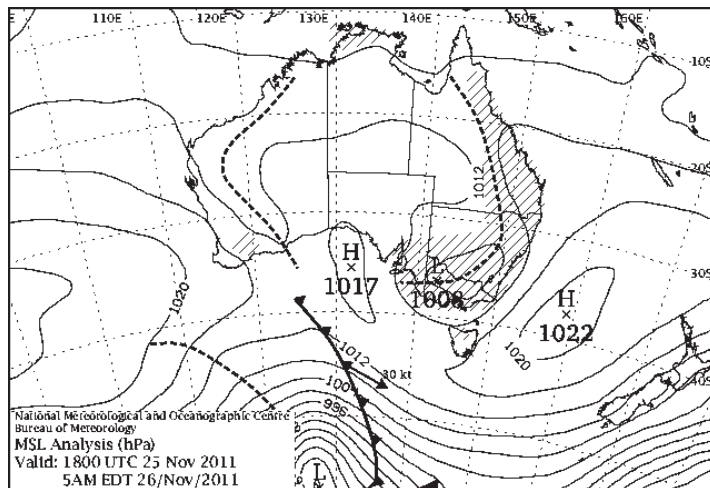
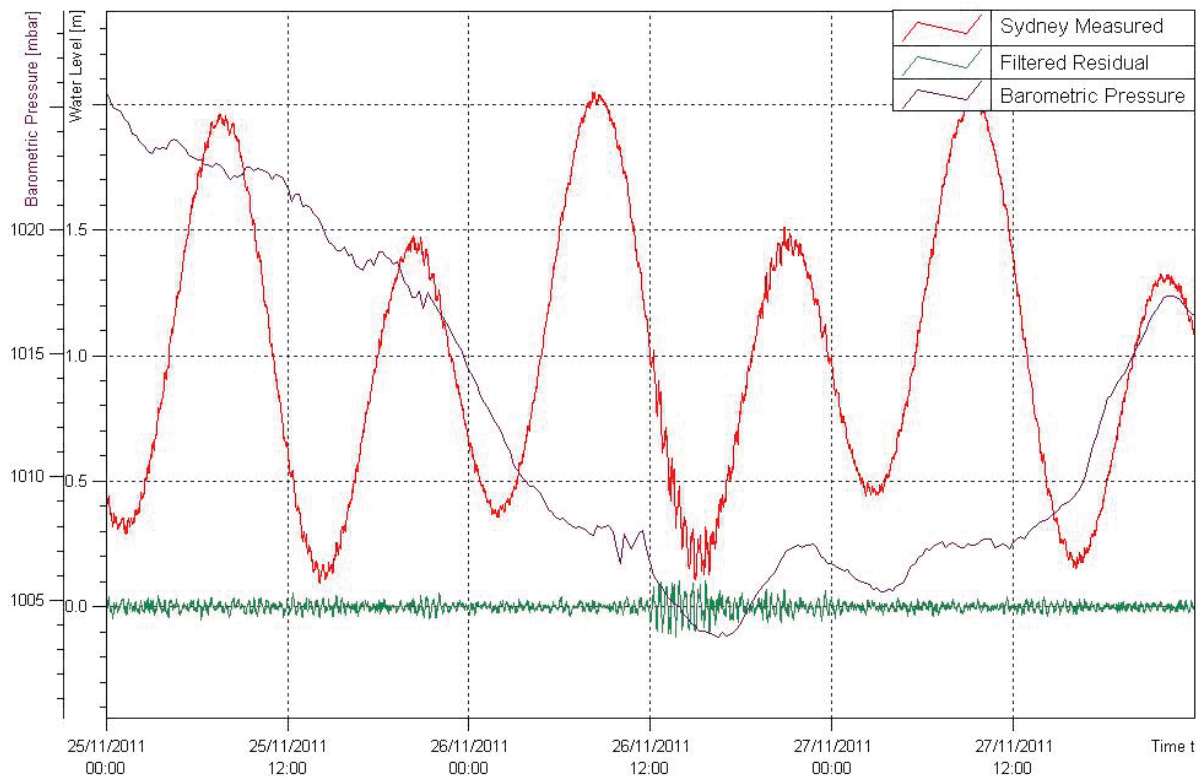


Narrabeen Lagoon 05/06/2016 (L) and 29/06/2016 (R)
(Photos: R Jacobs)



Collaroy Beach Pelican Pavilion 05/06/2016 (L), 05/06/2016 (C) and 06/06/2016 (R)
(Photos: E Couriel and R Jacobs)





Weather map images courtesy BoM. Copyright Commonwealth of Australia, Bureau of Meteorology



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SYDNEY METEOTSUNAMI
26 NOVEMBER 2011

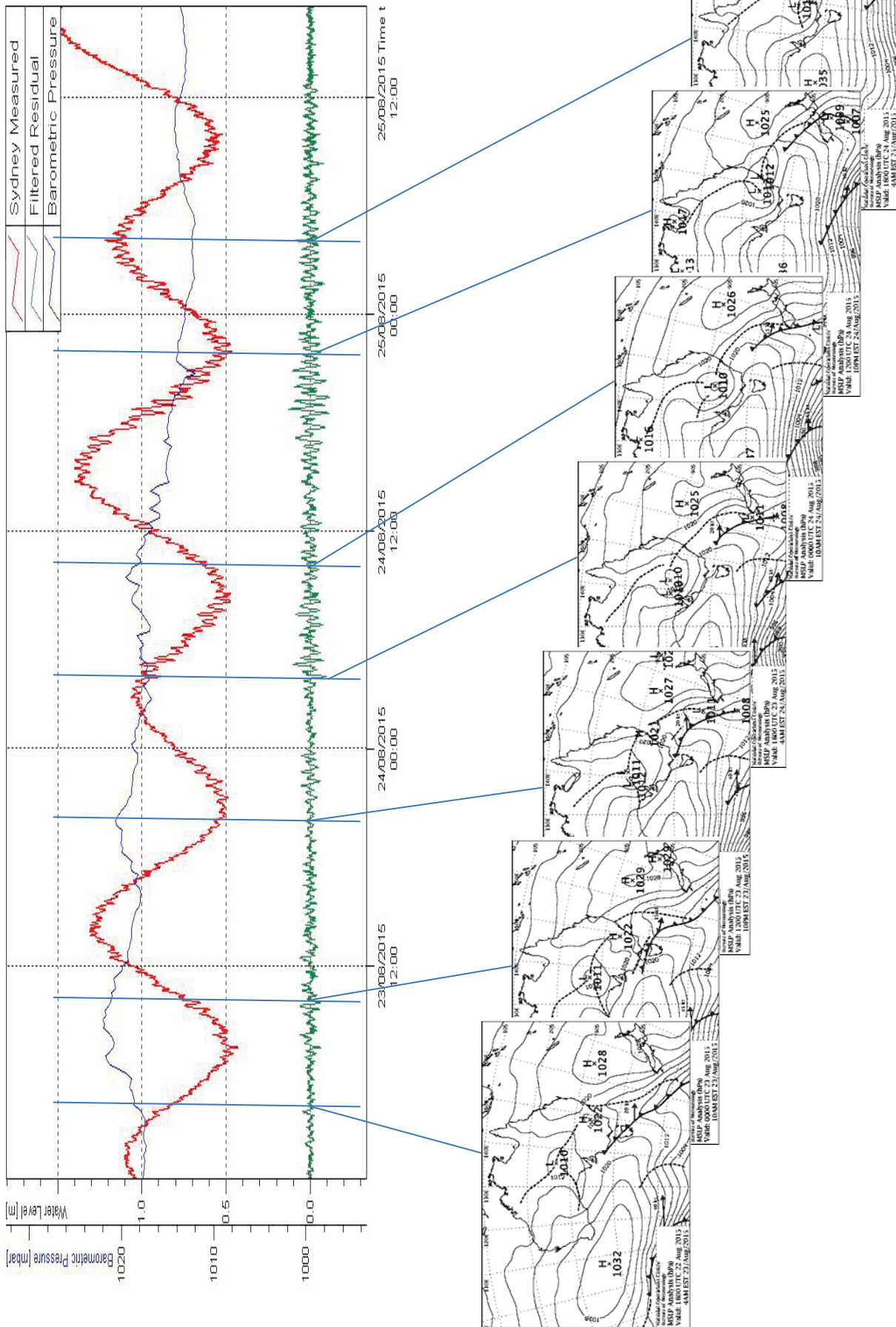
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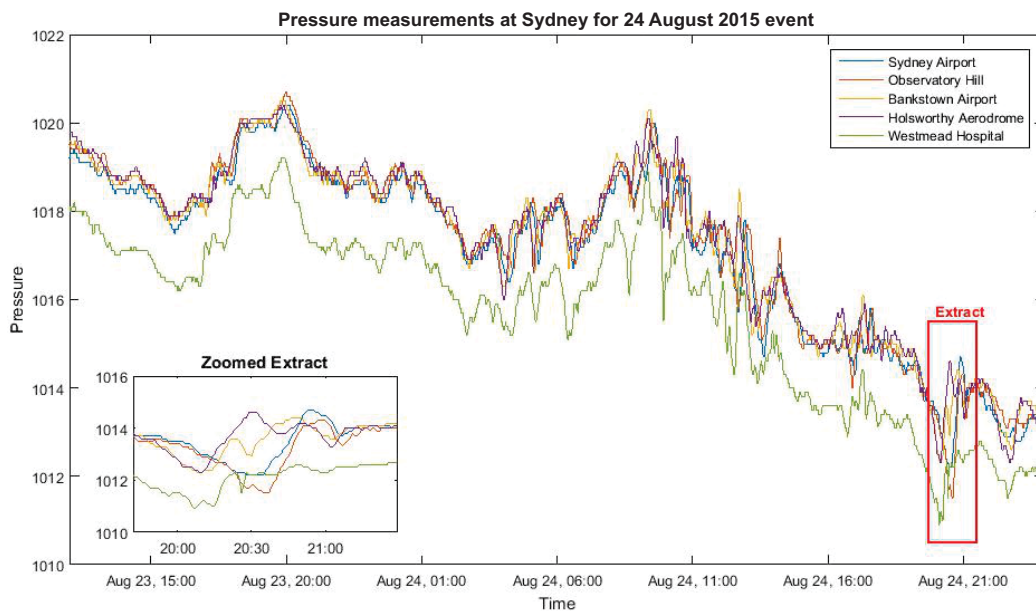
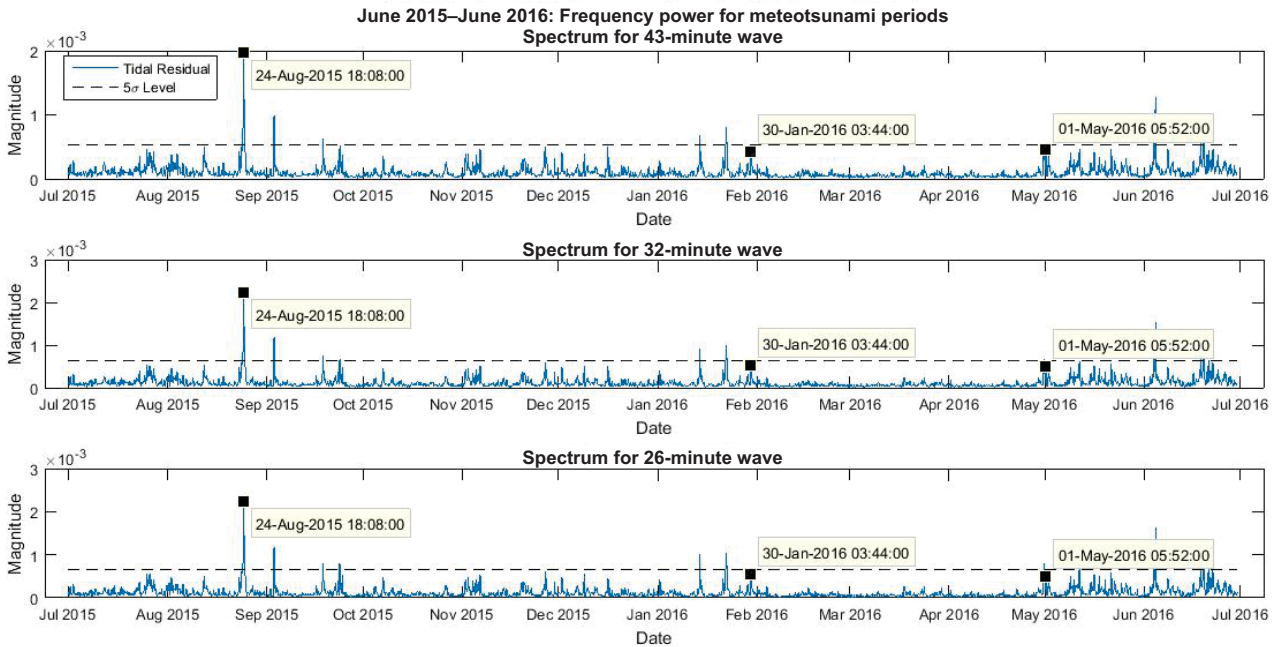
Figure
3.15

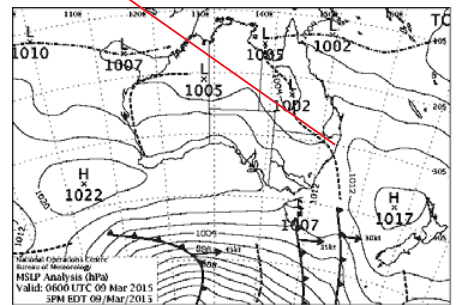
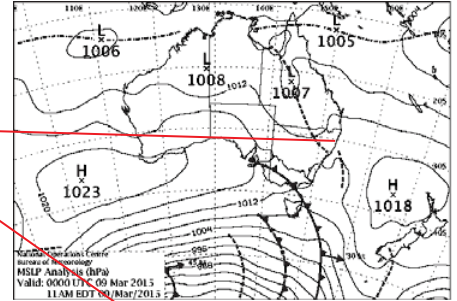
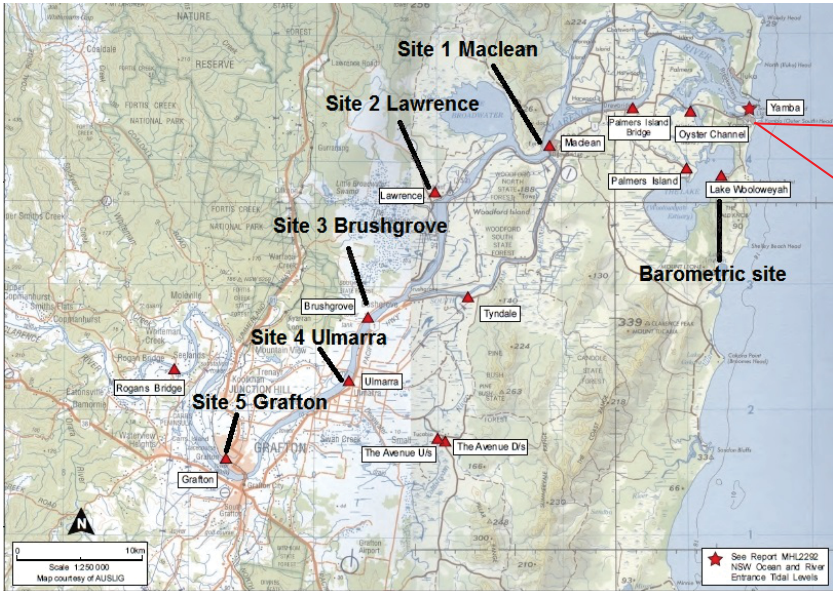
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SYDNEY WATER LEVEL AND SYNOPTIC CHARTS

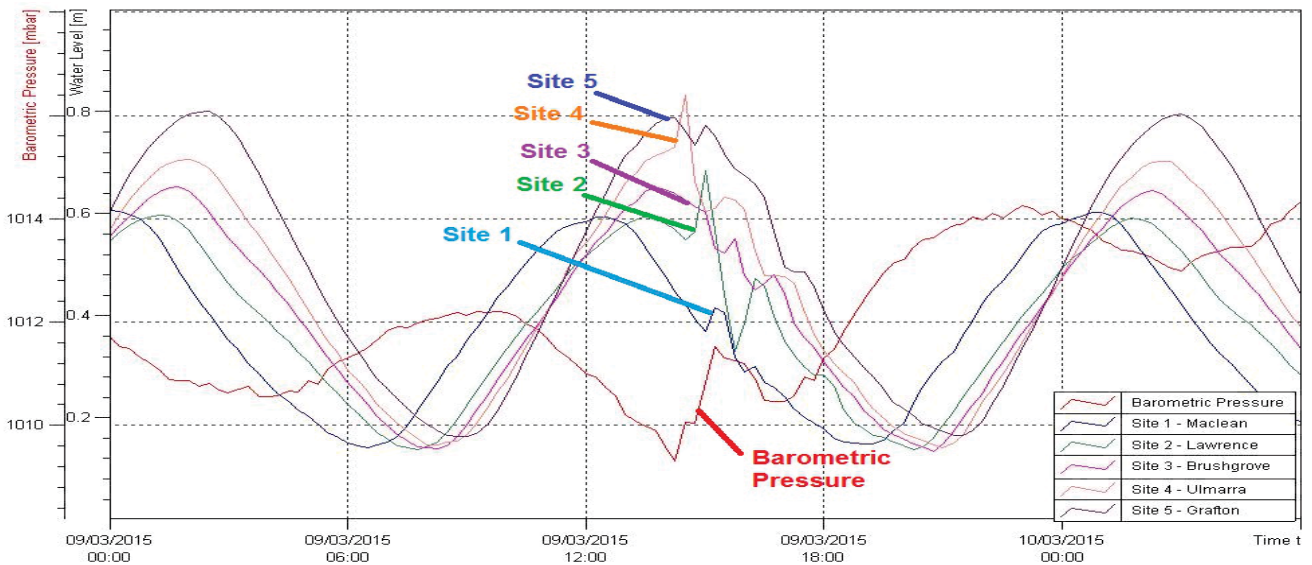
24 AUGUST 2015







Clarence River OEH monitoring sites and barometric pressure analysis 9/3/2015, 1100 and 1700 hours



Clarence River barometric pressure and meteotsunami trace 9/3/2015

Weather map images courtesy BoM. Copyright Commonwealth of Australia, Bureau of Meteorology



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CLARENCE RIVER METEOTSUNAMI
9 MARCH 2015

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Figure
3.18

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4. Program developments 2015–2016

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
Forster	Onshore River Entrance	OR

Station	Classification	Classification code
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 developments

Further improvements and changes to the network have continued in 2015–2016. The following summarises the major changes:

- This year the program suffered some station damage and resulting data loss due to storm events. Ballina sensors were damaged in the April 2016 storm and the June 2016 storm caused damage to stations at Bundeena, Patonga and Jervis Bay.
- Upgrading of the Sydney wharf by Royal Australian Navy at HMAS Penguin required data from the Sydney backup site to be used for the site from 15 April 2016.
- At Coffs Harbour and Eden sites the loggers were upgraded to record the primary sensor at 1-second intervals to onsite data storage cards.
- The Norfolk Island site was decommissioned on 15 September 2015 as part of the program plans from 2014–2015 due to its location being duplicated by the BoM tsunami gauge. Following decommissioning of the MHL gauge, data has been supplied by BoM for the rest of the reporting period. In future reports the data will also be provided by BoM for the Norfolk Island site.
- Eden site communications were upgraded to enable networked IP data transfers rather than telemetry. A website was created which provides the Eden Pilot with access to the latest 5 minutes of data.
- A calibration of the Eden gauge was conducted by Sydney Ports on 15 March 2016 (Port Authority NSW 2016). The calibration included levelling between the tide gauge and benchmarks (13 March 2016), installation of tide board and connection to benchmarks (14 March 2016), and tide gauge calibration readings at 15-minute intervals between 0545 and 1745 hrs on 15 March 2016. The average residual between the tide board readings and tide gauge logging values was 7 mm over this period. Four recommendations were made to improve the accuracy of the tide board readings for future calibrations.

Table 4.2 shows the status of the sites as of June 2015.

Table 4.2 MHL tidal logging and sensing system status 1/7/2015–30/6/2016

Station	Site classification ¹	Primary loggers ²	Secondary loggers ²	Primary sensors	Secondary sensors	Station	
						Sampling	Logging
Tweed Entrance South	OR	CR1000	-	Radar	Vented Pressure	120 samples averaged 1 minute either side of the quarter hour and 60 samples averaged 30 seconds either side of each minute and 9 sites logging at 1 second to onsite data storage card (Tweed Ent South, Coffs Harbour, Port Macquarie, Lord Howe, Shoal Bay, Patonga, Sydney, Princess Jetty and Eden)	15 minutes on the quarter hour and 1 minute on the minute
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		
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		
Bundeena	OB	CR800	-	Radar	Vented Pressure		
Crookhaven Heads	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	CR1000	-	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 Paroscientific Pressure Sensor and RBR Logger	Aanderaa Submersible Pressure (only at 2 of the 4 sites per deployment year)	Integrated over 40 seconds	RBR 5 minutes Aanderaa 60 minutes
Port Macquarie Offshore	O	RBR Virtuoso	WLR7				
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),

4.3 Program plans 2016–2017

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 2016–2017 program upgrades include:

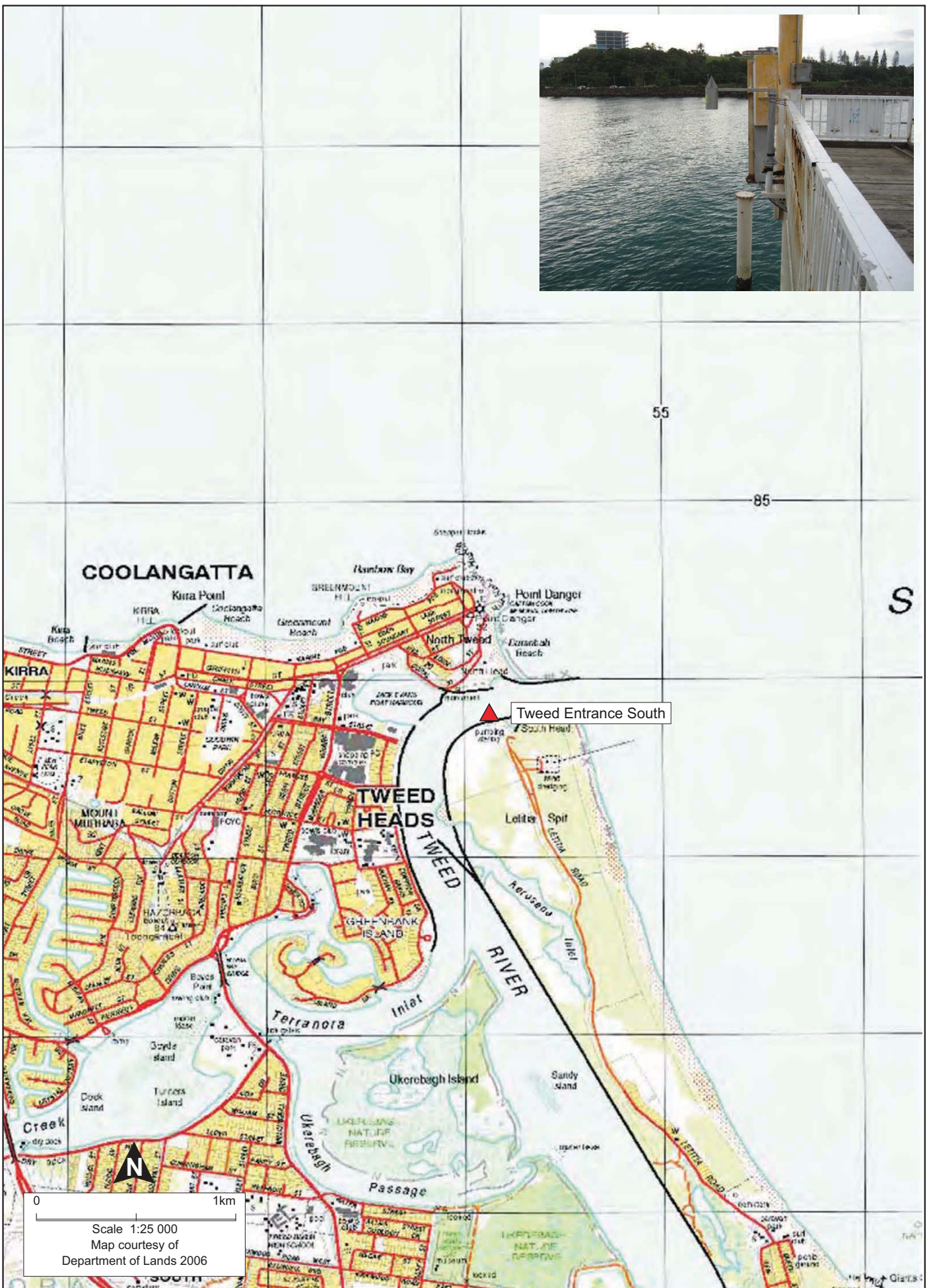
- high frequency logging (1 second) upgrade at Jervis Bay
- upgrade communications to enable networked IP data transfers rather than telemetry at selected sites
- investigation of radar installations at Bermagui, Ulladulla, Crookhaven and Forster.

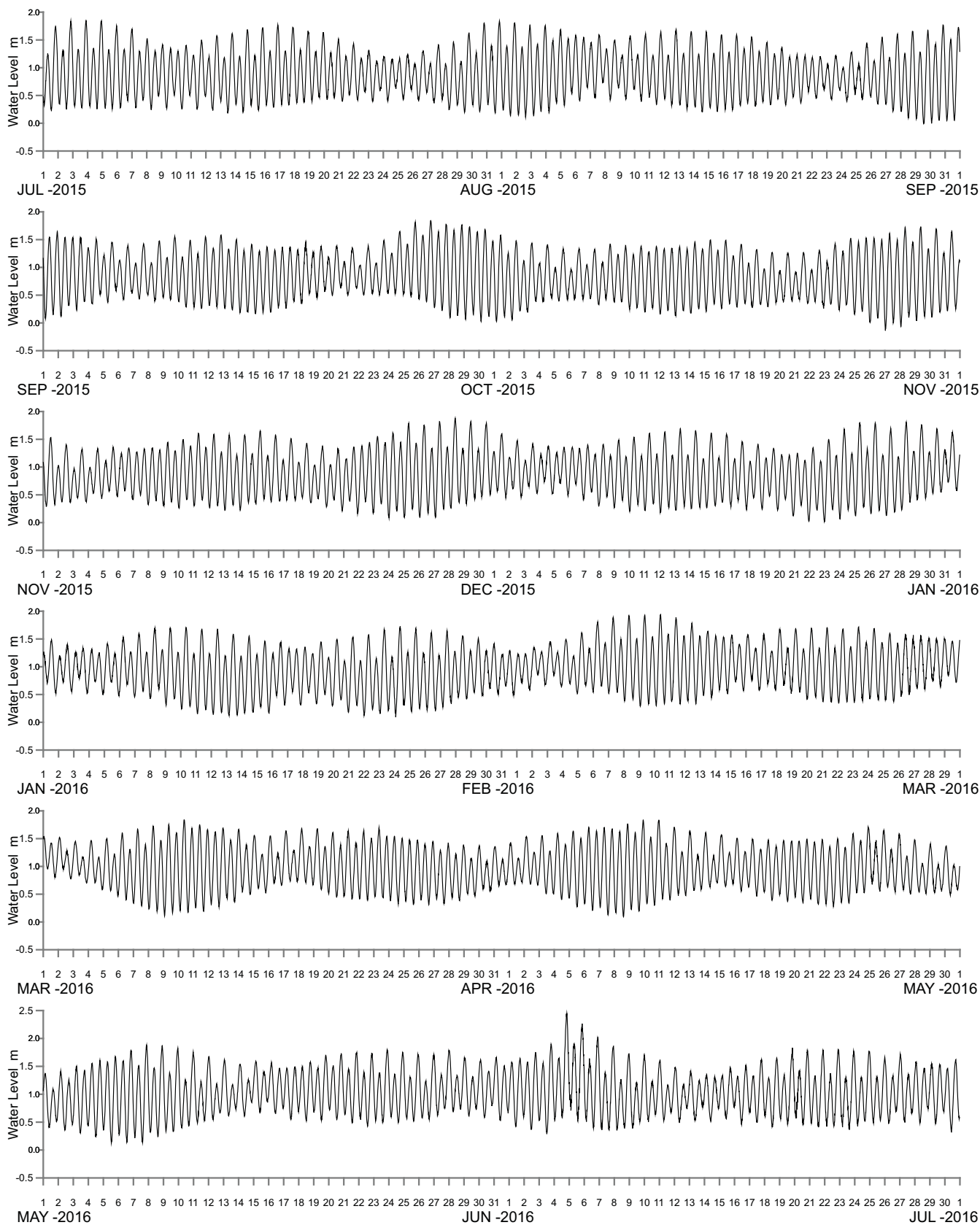
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Appendix A

Annual data site summaries





WATER LEVEL REFERENCED TO TWEED RIVER HYDRO DATUM

----- DATA LOSS



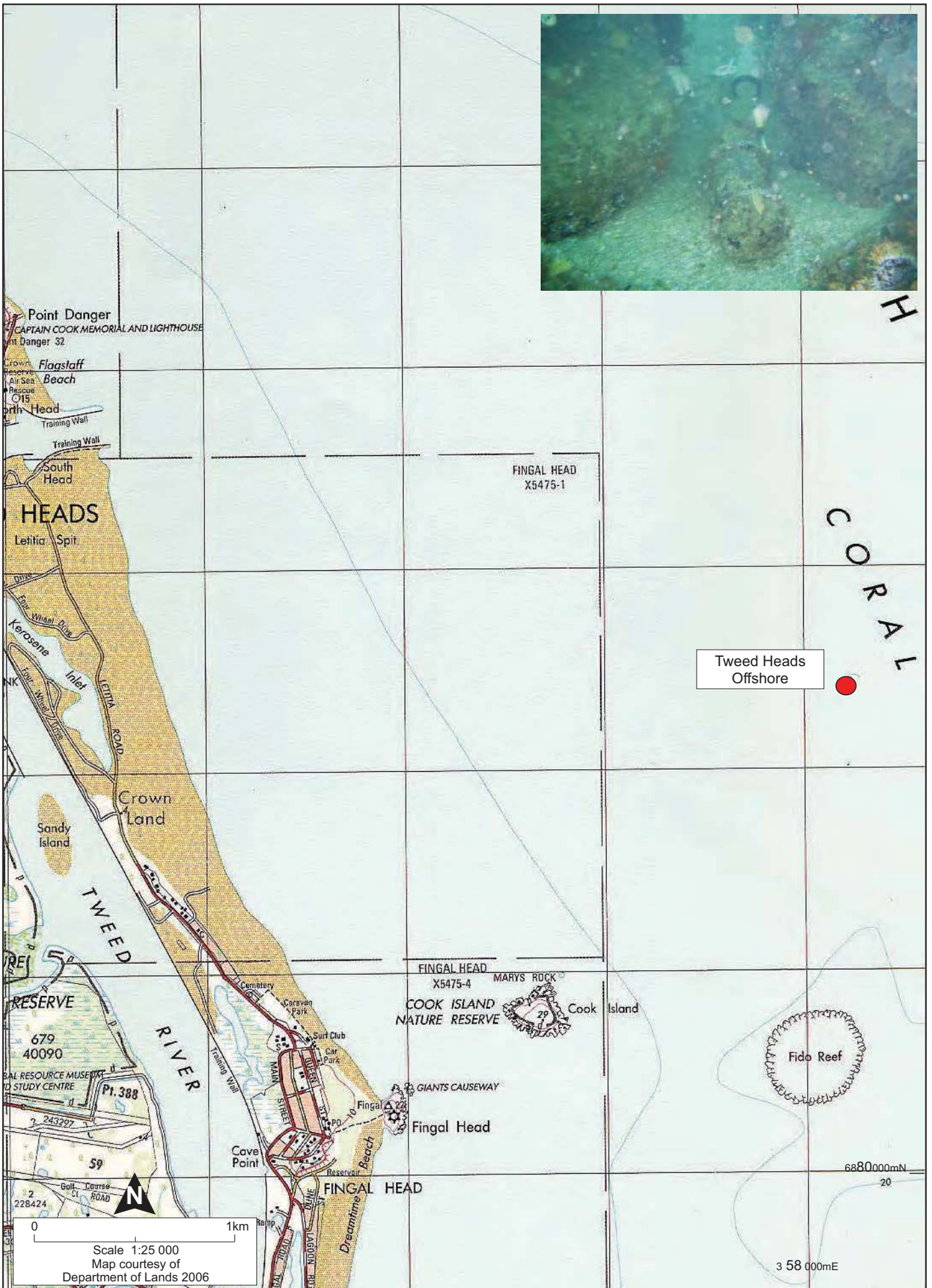
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**TWEED ENTRANCE SOUTH DATA SUMMARY
2015–2016**

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Figure
A2

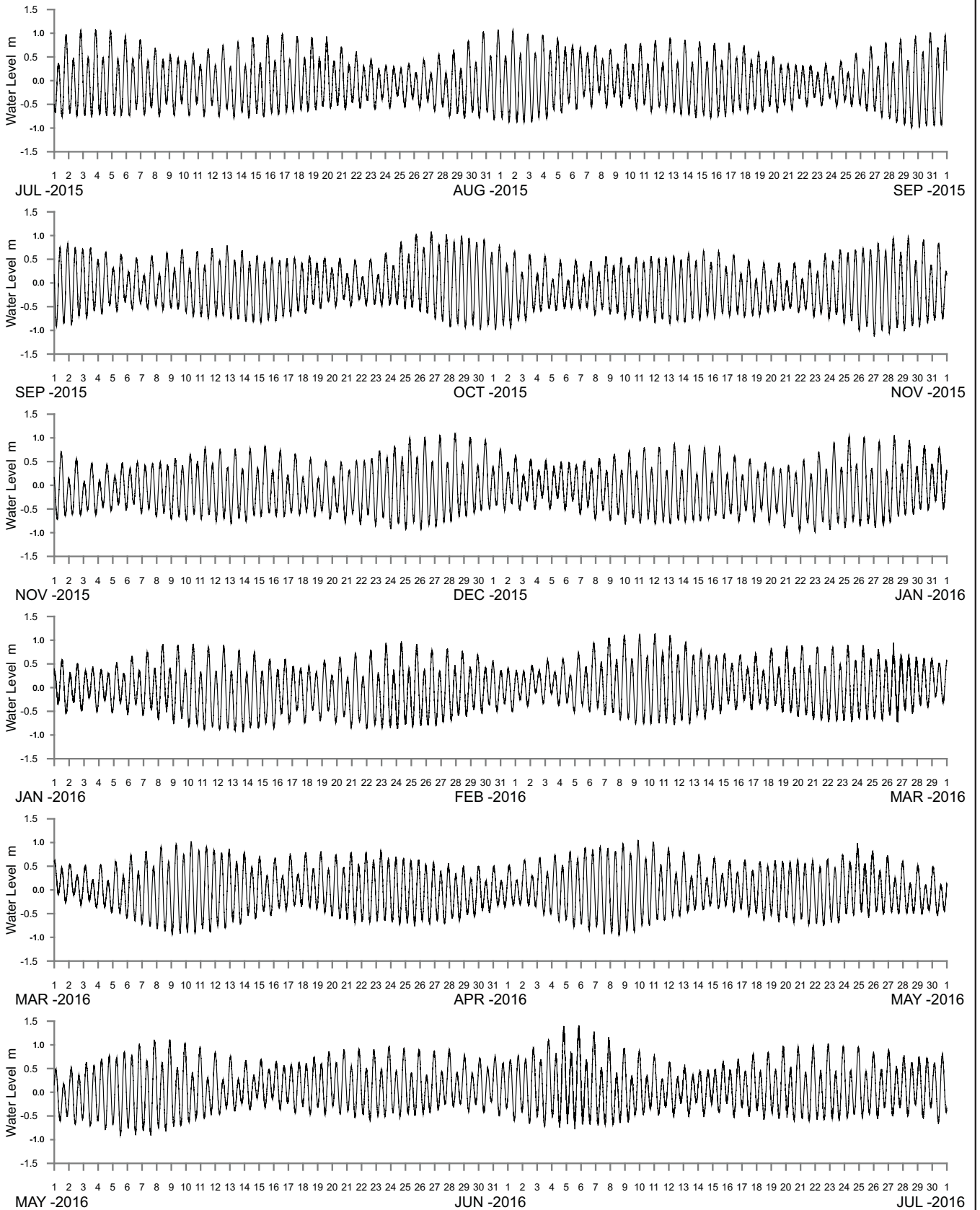
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**TWEED HEADS OFFSHORE
TIDE GAUGE LOCATION**

MHL
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**Figure
A3**
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WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



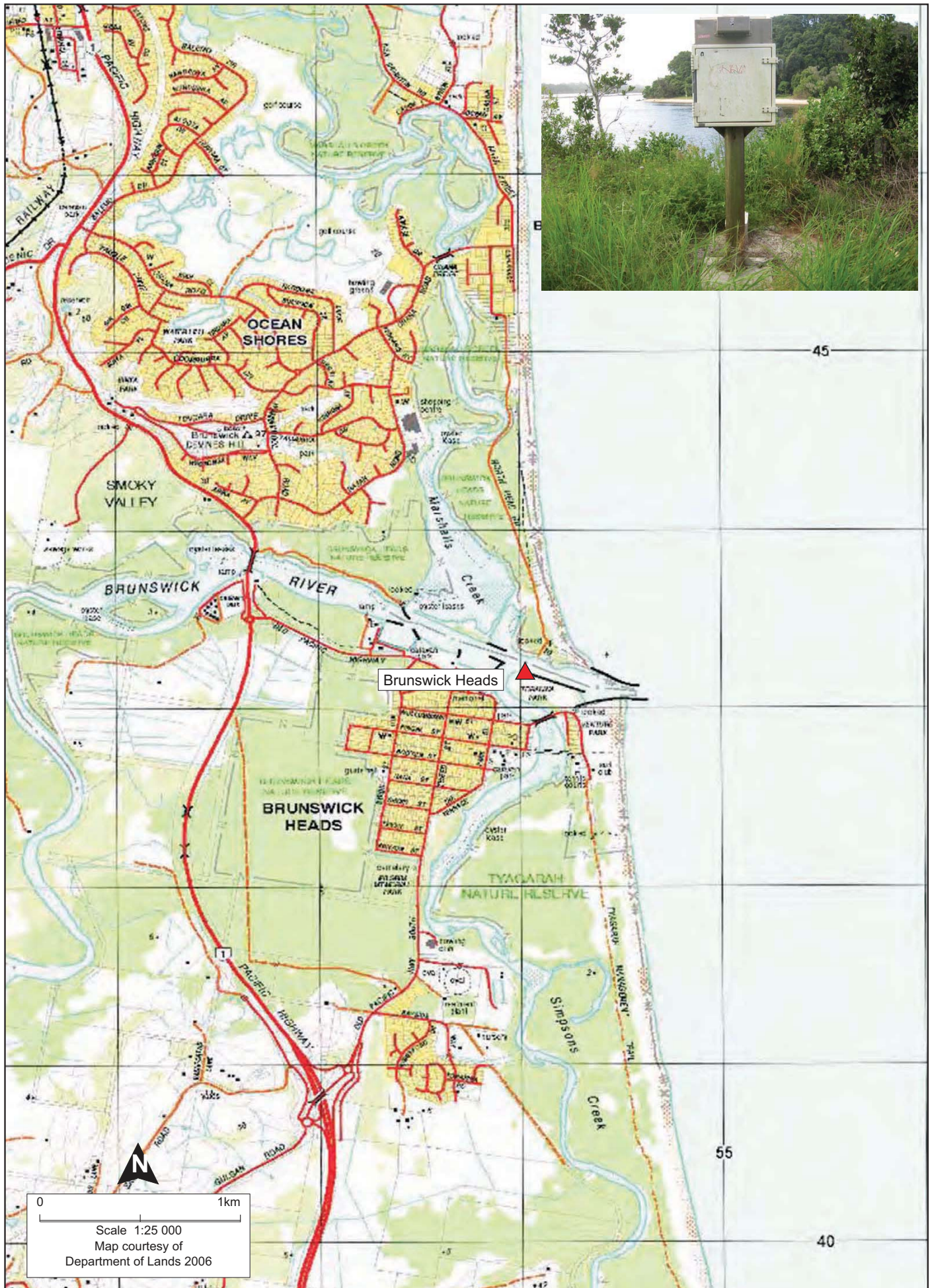
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TWEED HEADS OFFSHORE DATA SUMMARY
2015-2016

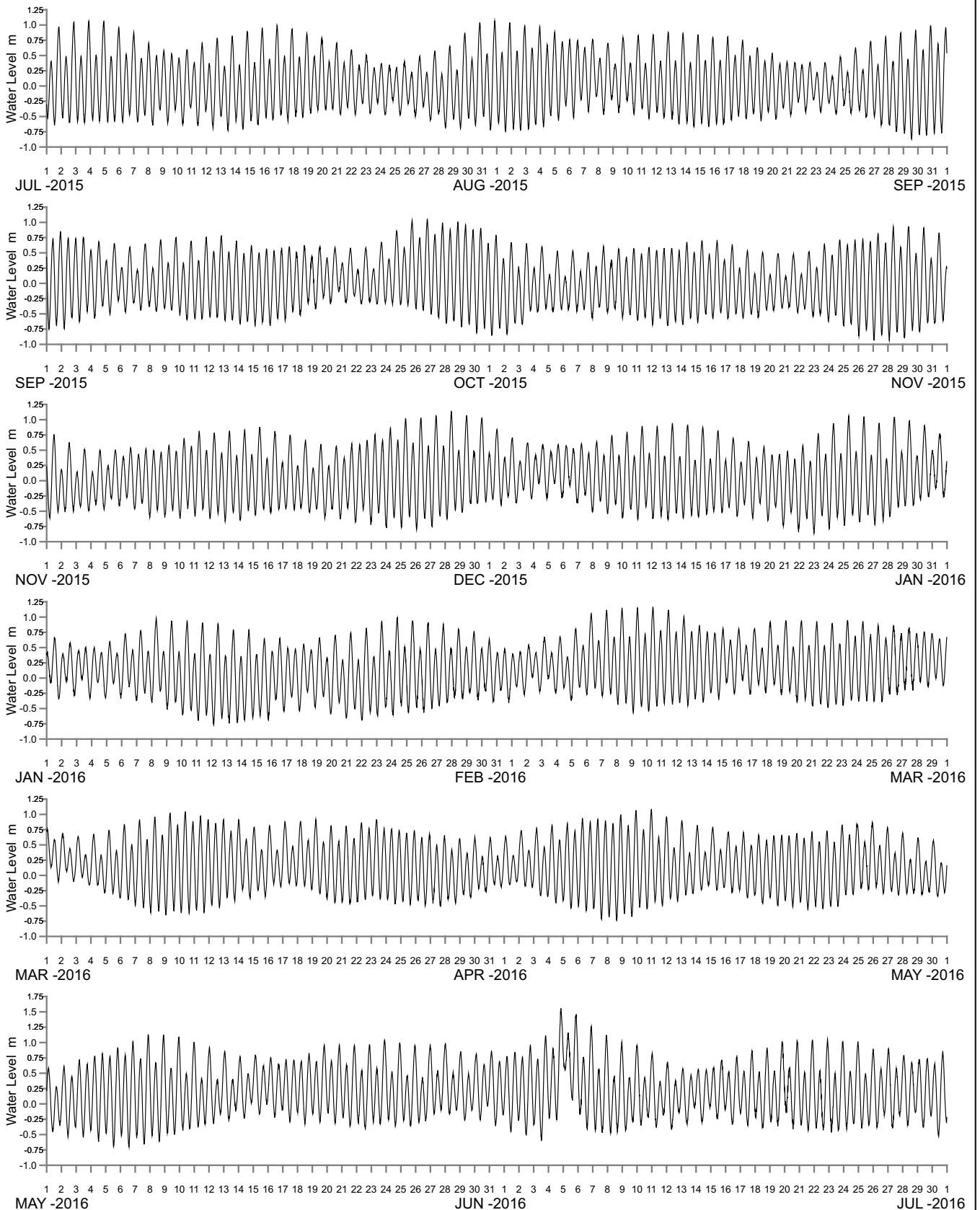
MHL
Report 2475

Figure
A4

DRAWING 2475-A3.cdr



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 Map courtesy of
 Department of Lands 2006



WATER LEVEL REFERENCED TO BRUNSWICK RIVER FLOOD MITIGATION DATUM

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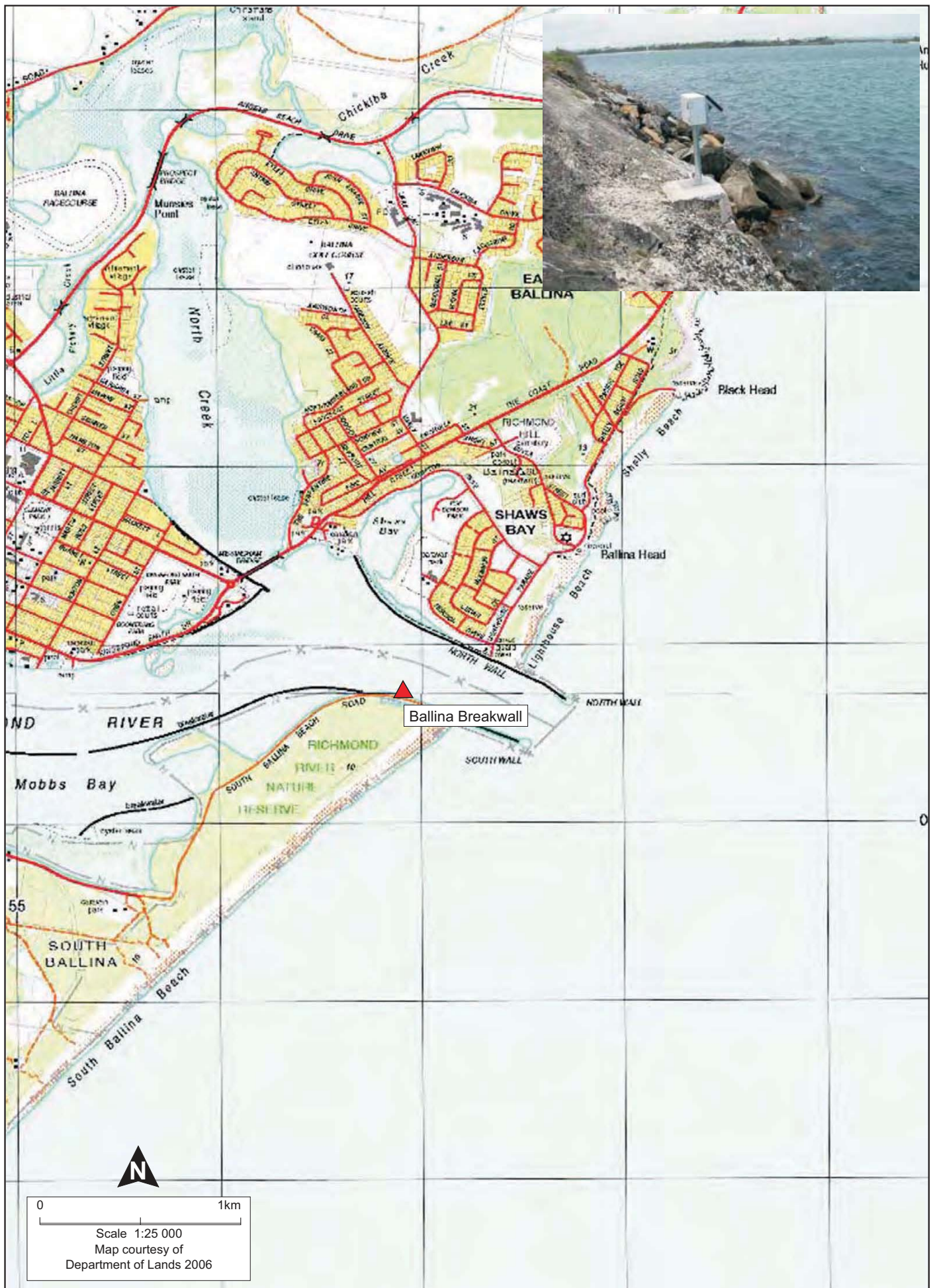
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BRUNSWICK HEADS DATA SUMMARY
2015–2016

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Figure
A6

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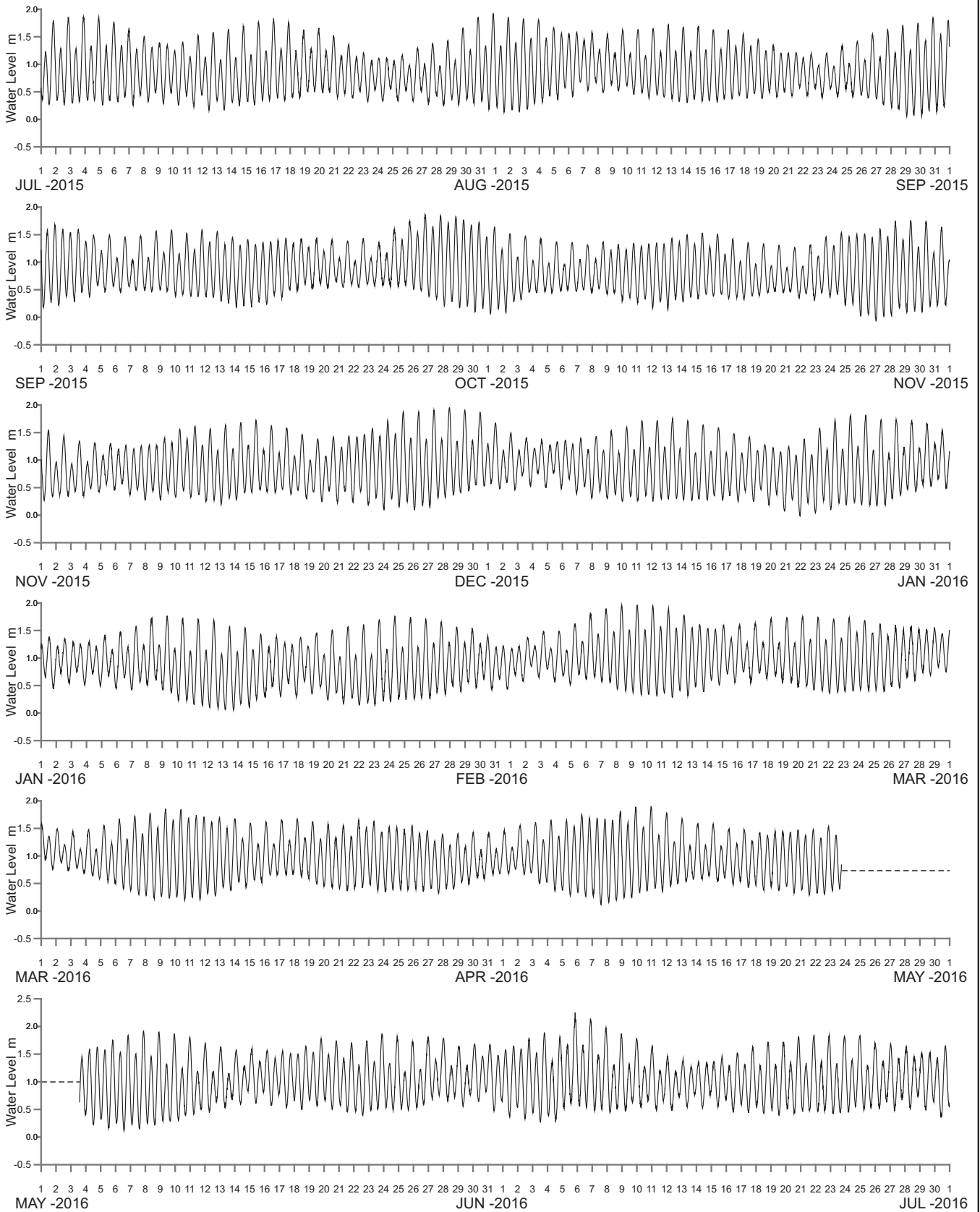
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BALLINA BREAKWALL STATION LOCATION

MHL
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Figure
A7

DRAWING 2475-A7.cdr



WATER LEVEL REFERENCED TO RICHMOND RIVER VALLEY DATUM

----- DATA LOSS



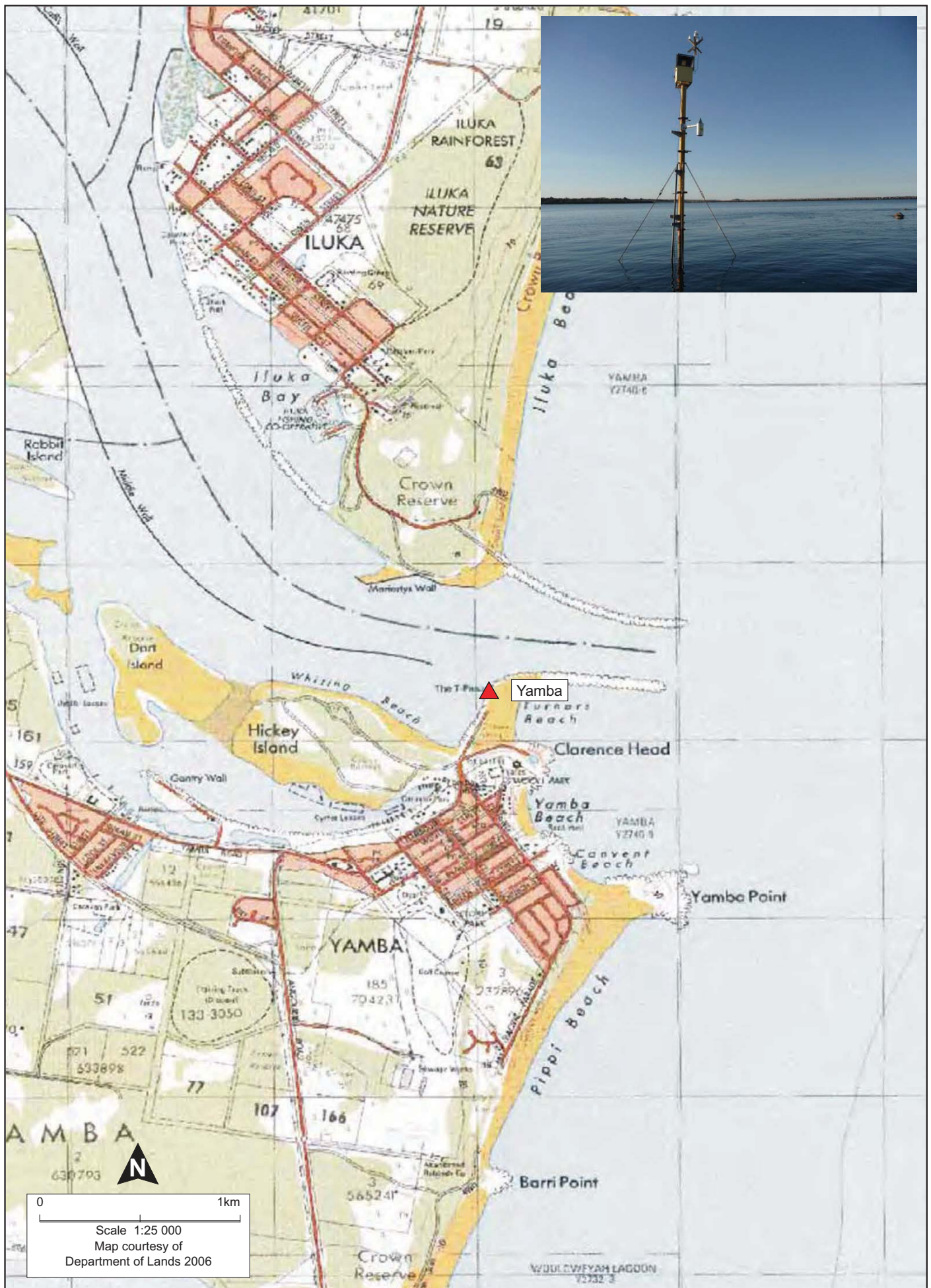
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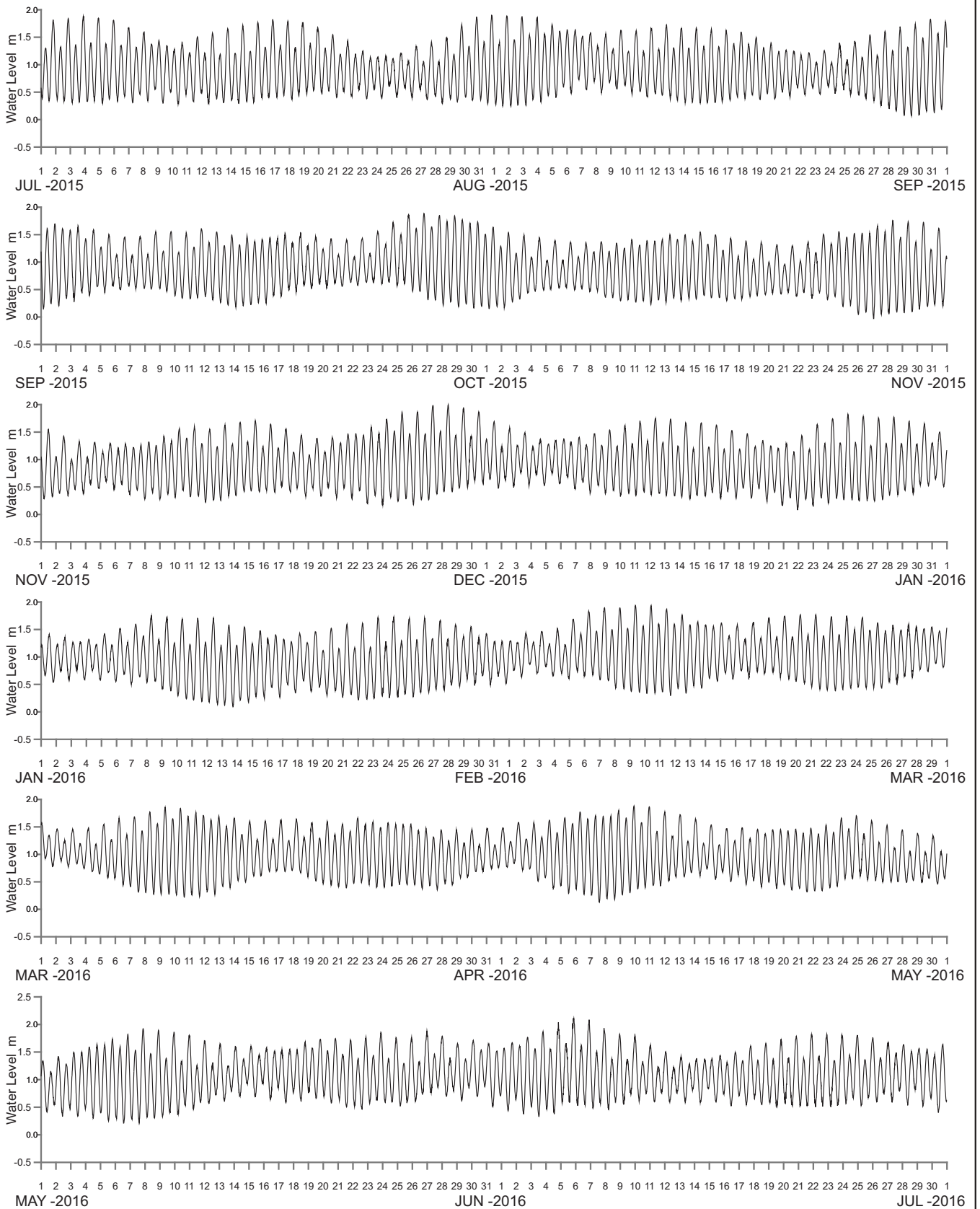
BALLINA BREAKWALL DATA SUMMARY
2014–2015

MHL
Report 2475

Figure
A8

DRAWING 2475-A7.cdr





WATER LEVEL REFERENCED TO ILUKA PORT DATUM

----- DATA LOSS



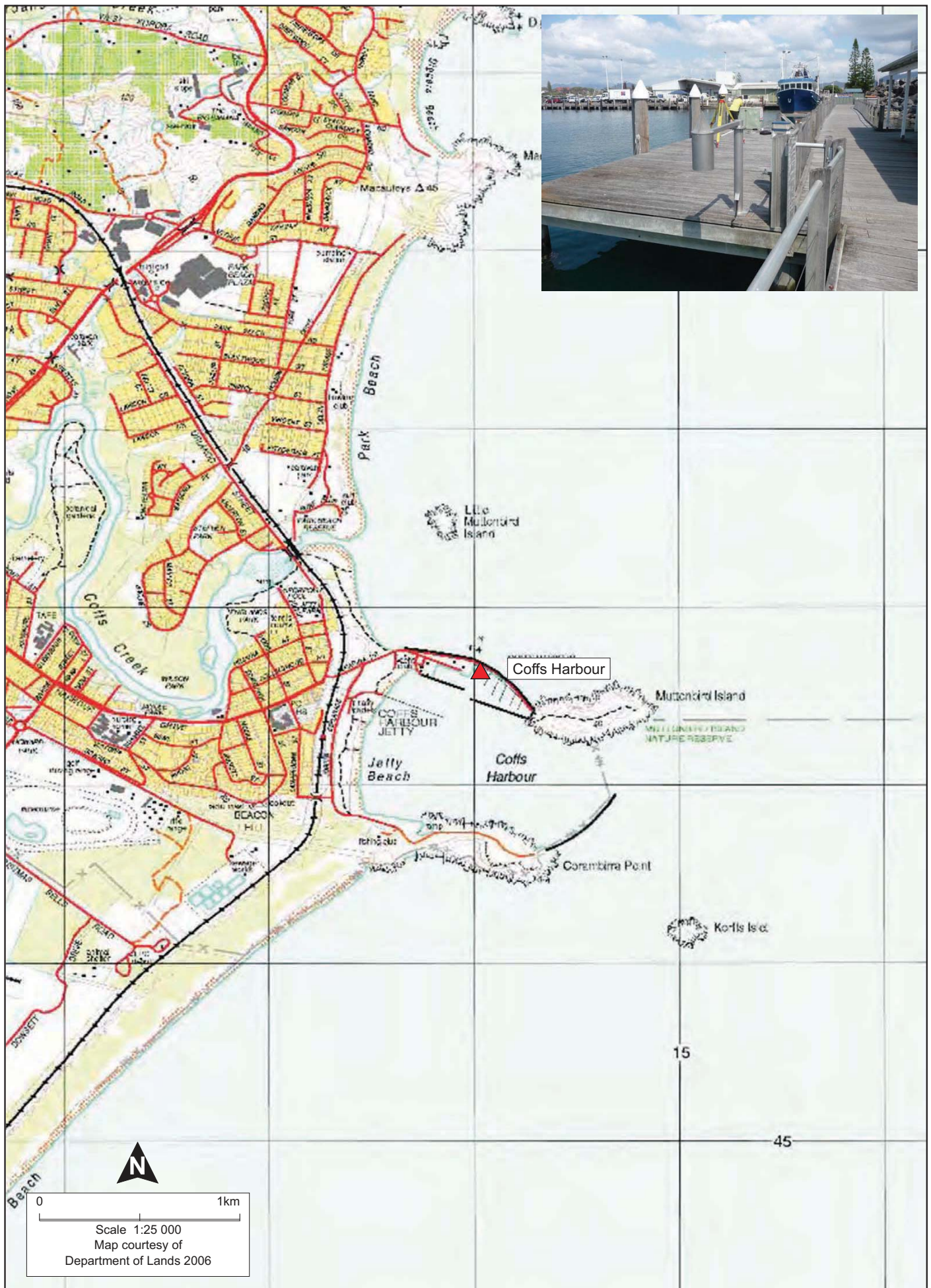
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YAMBA DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A10

DRAWING 2475-A9.cdr



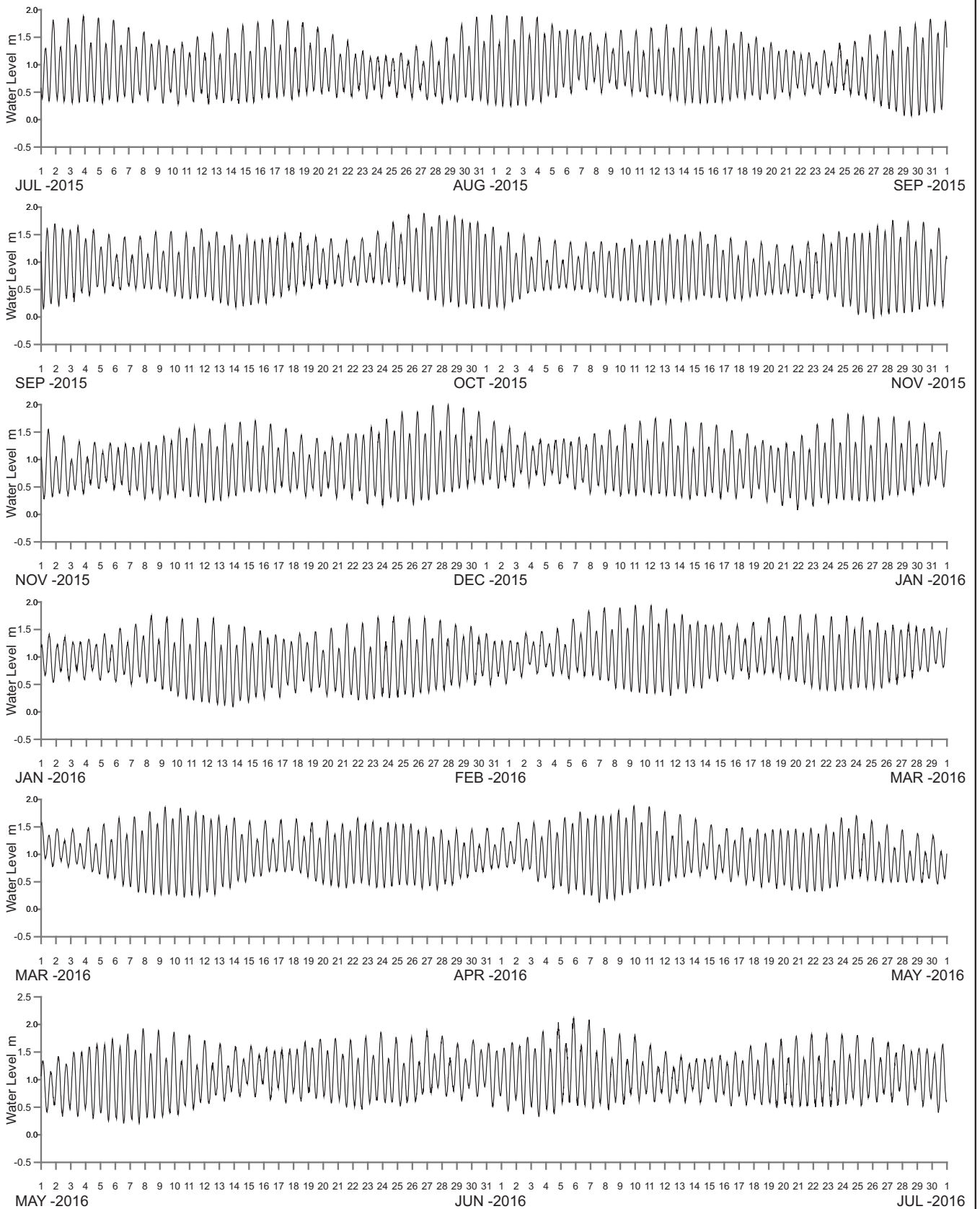
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COFFS HARBOUR STATION LOCATION

MHL
Report 2475

Figure
A11

DRAWING 2475-A11.cdr



WATER LEVEL REFERENCED TO COFFS PORT DATUM

----- DATA LOSS



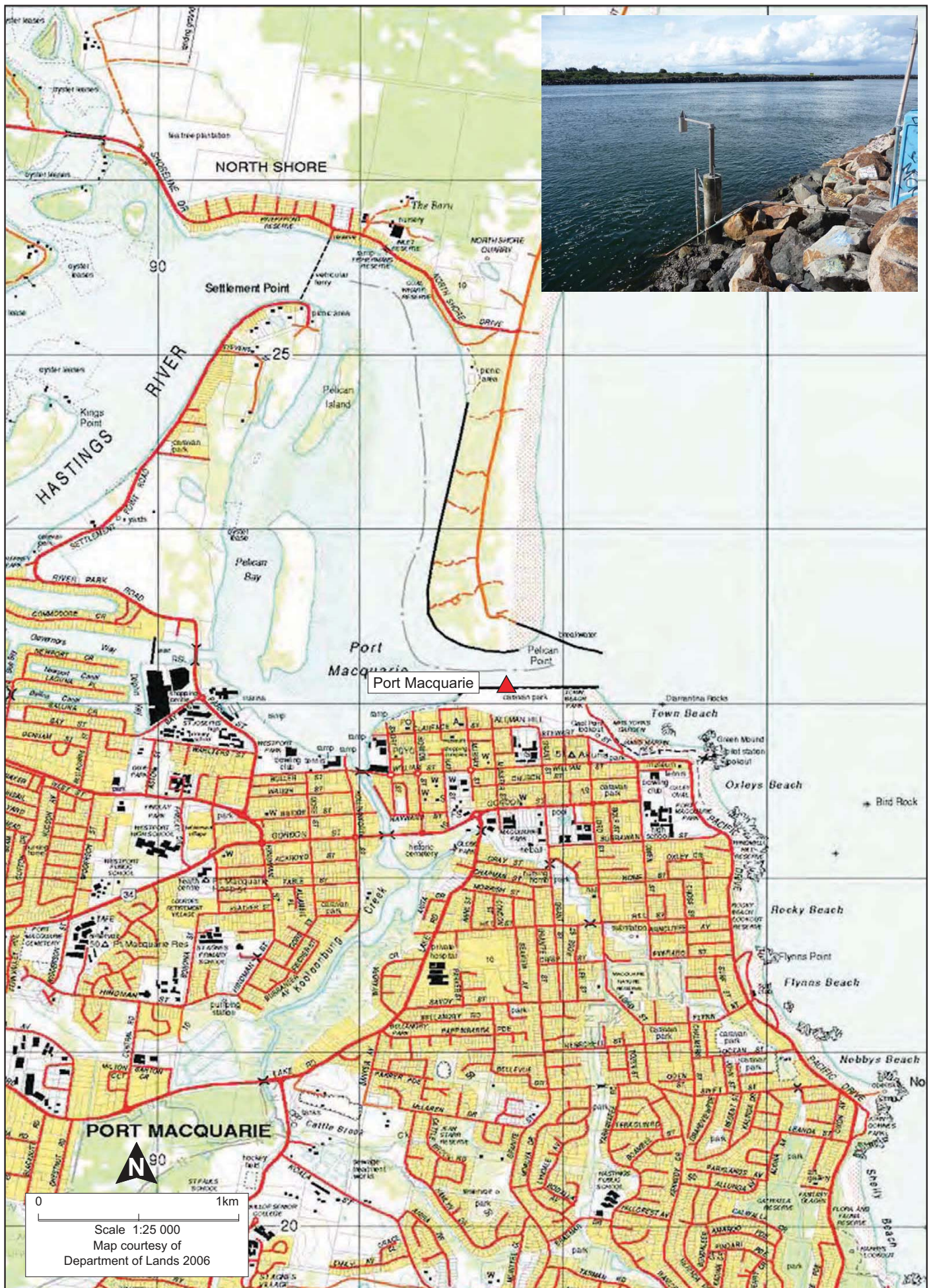
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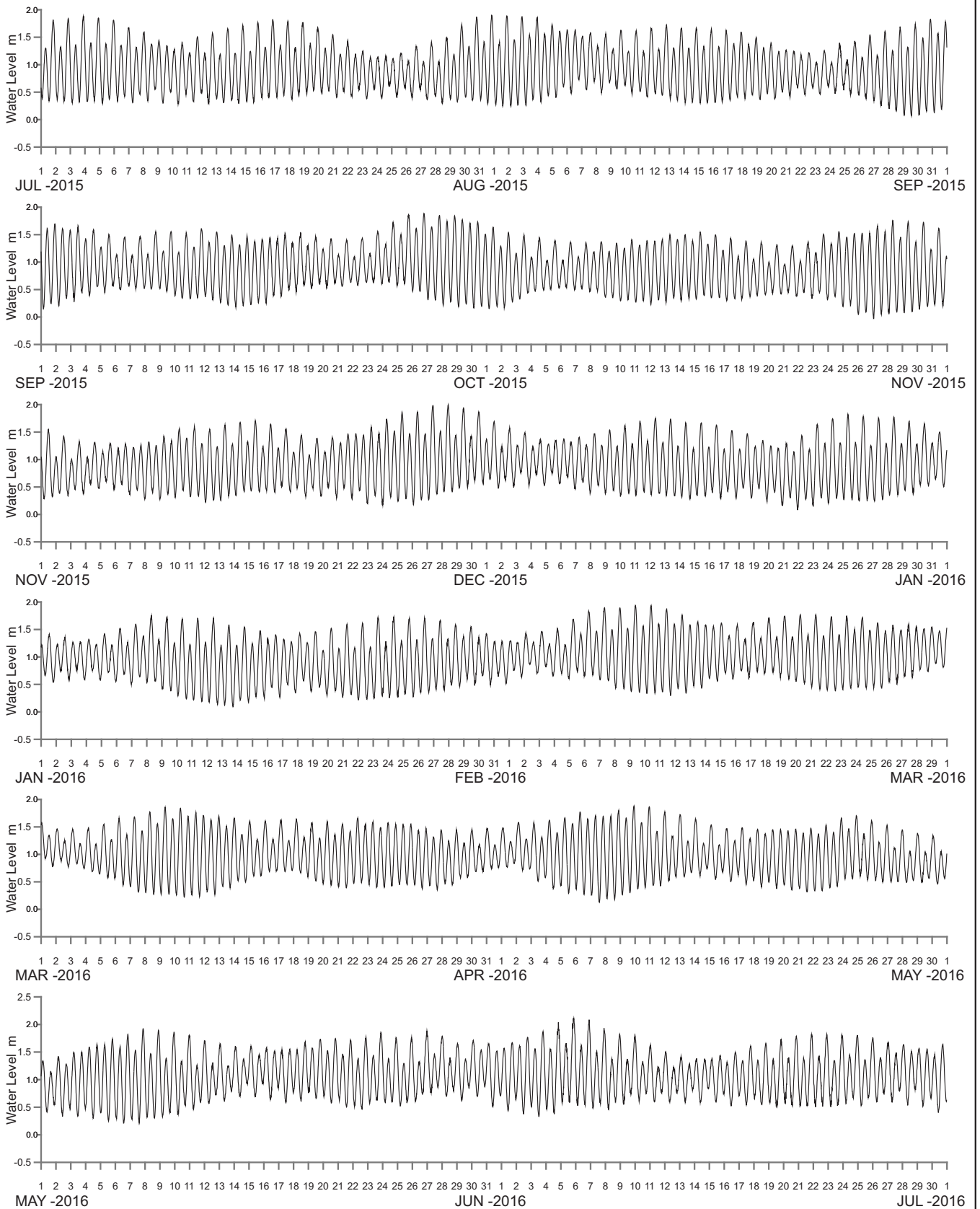
COFFS HARBOUR DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A12

DRAWING 2475-A11.cdr





WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



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PORT MACQUARIE DATA SUMMARY
2015–2016

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Figure
A14

DRAWING 2475-A13.cdr



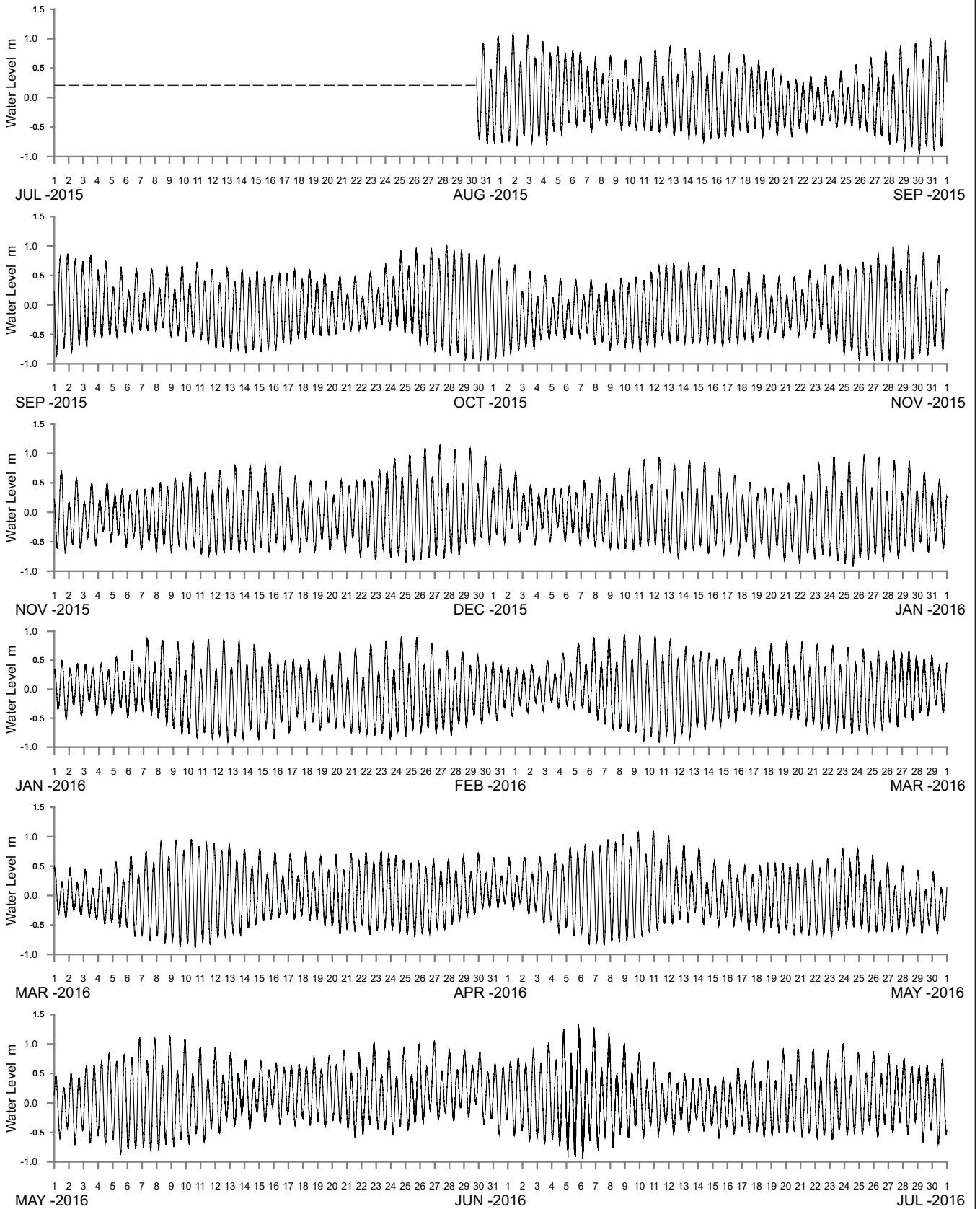
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**PORT MACQUARIE OFFSHORE
TIDE GAUGE LOCATION**

MHL
Report 2475

Figure
A15

DRAWING 2475-A15.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



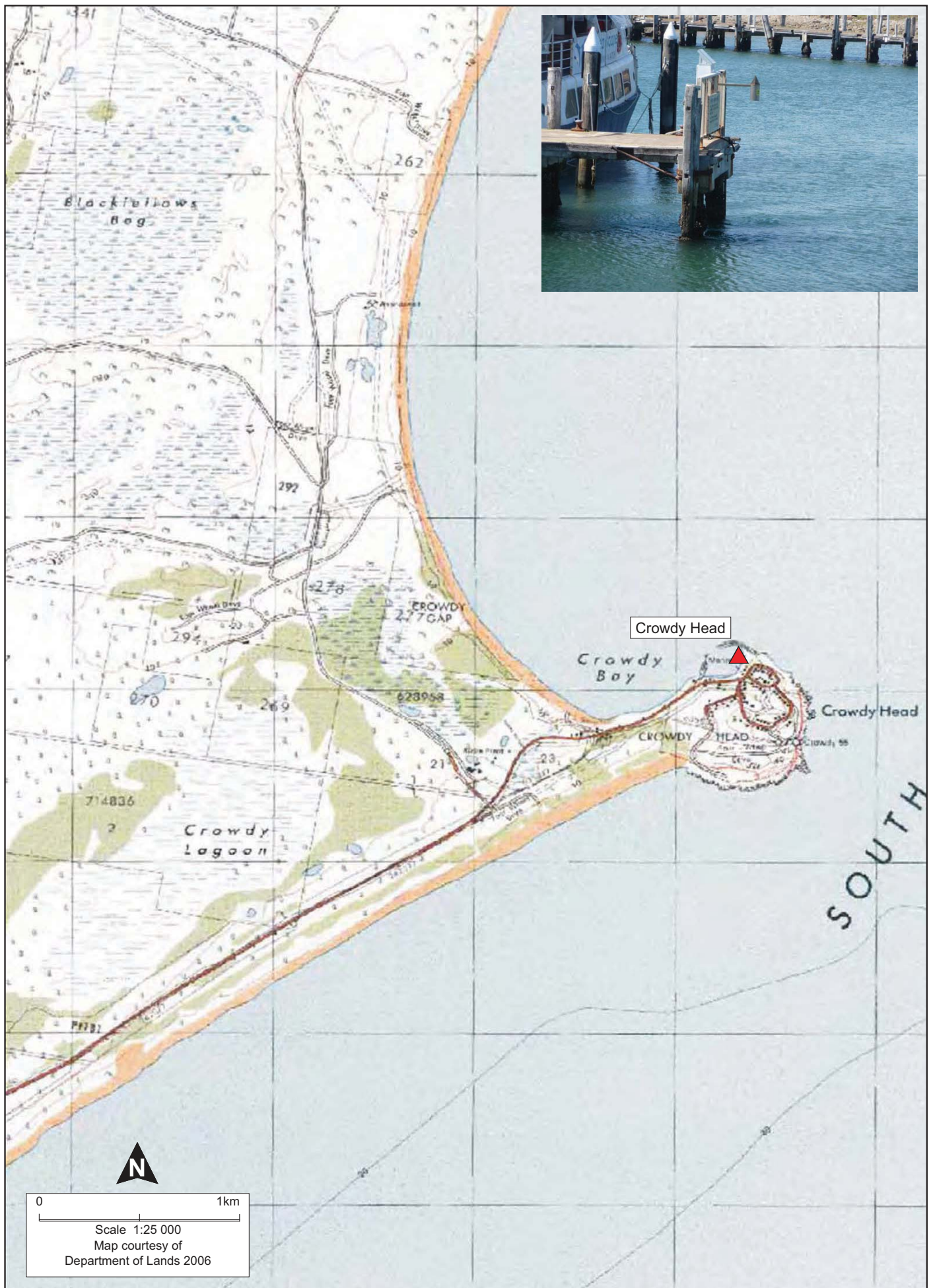
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PORT MACQUARIE OFFSHORE DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A16

DRAWING 2475-A15.cdr



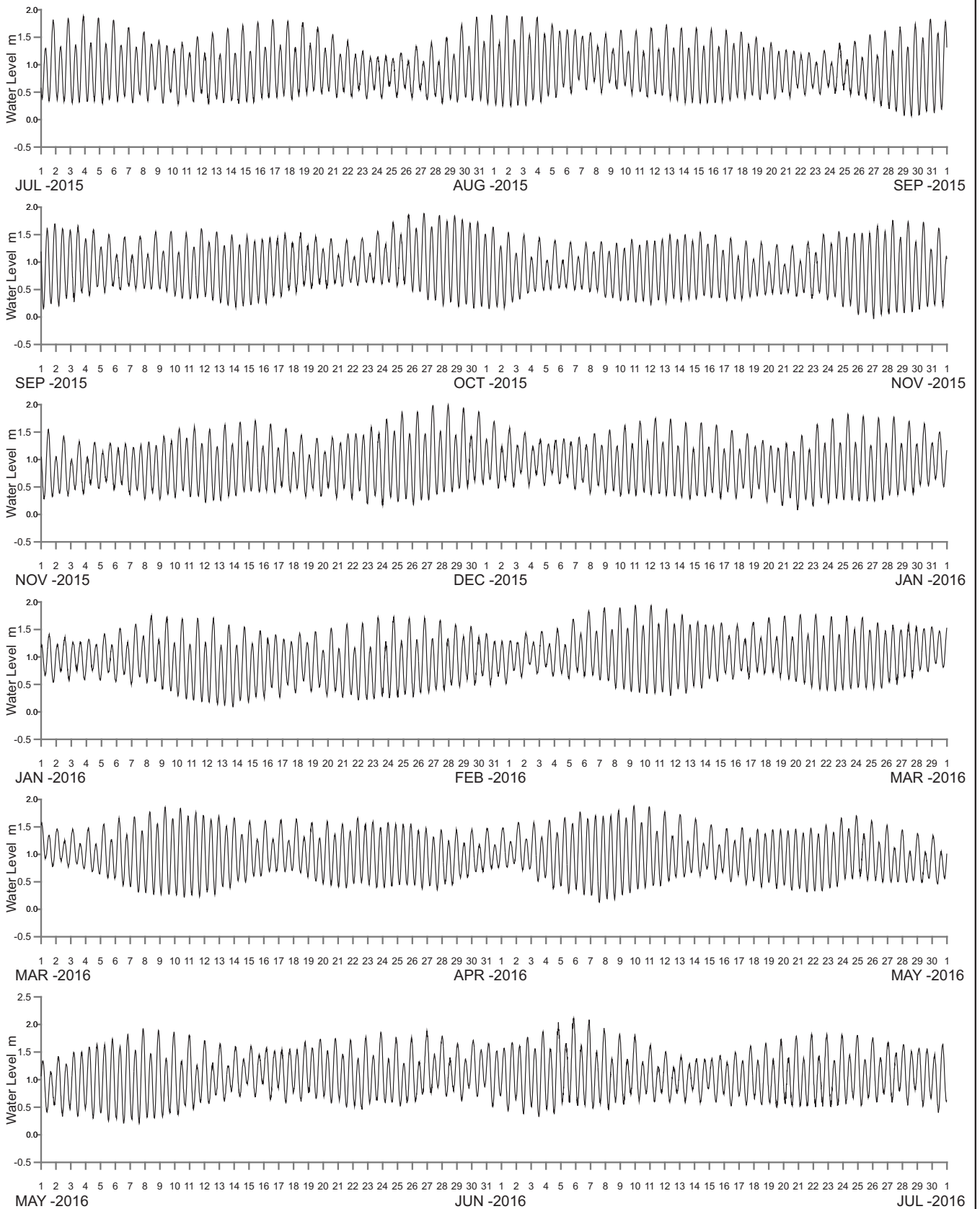
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**CROWDY HEAD
STATION LOCATION**

MHL
Report 2475

Figure
A17

DRAWING 2475-A17.cdr



WATER LEVEL REFERENCED TO CROWDY HEAD DATUM

----- DATA LOSS



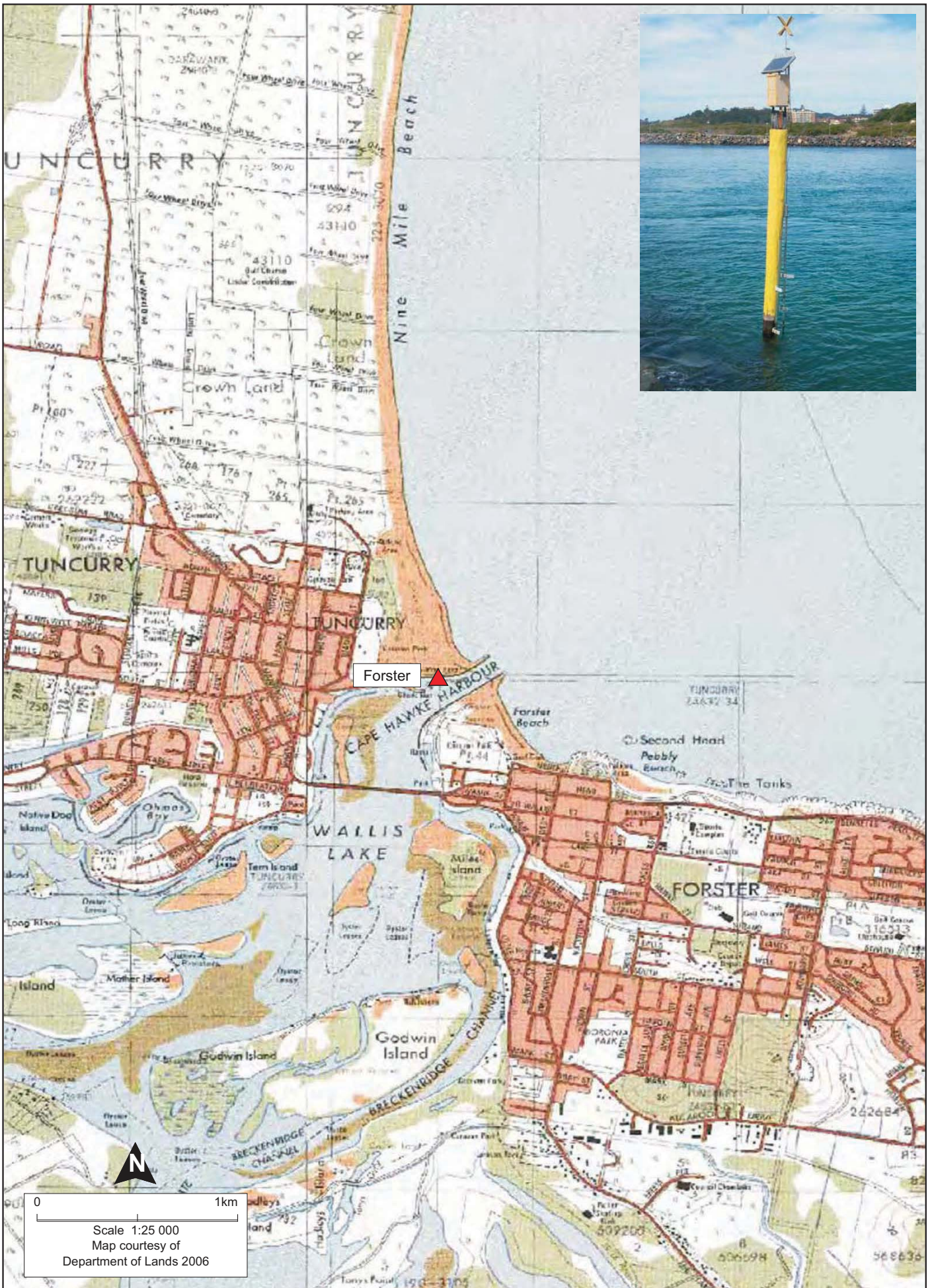
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CROWDY HEAD DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A18

DRAWING 2475-A17.cdr



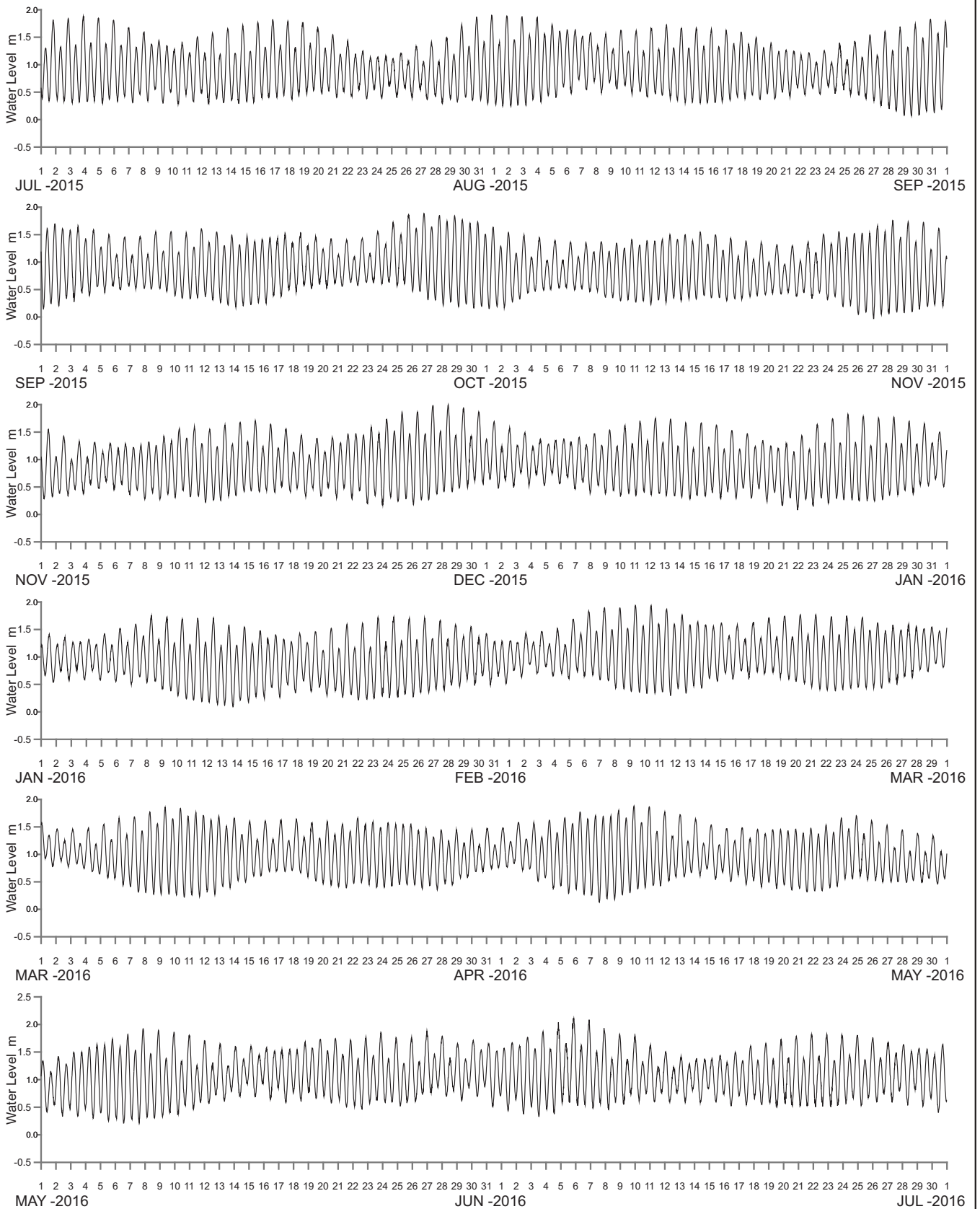
Public Works
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**FORSTER
STATION LOCATION**

MHL
Report 2475

Figure
A19

DRAWING 2475-A19.cdr



WATER LEVEL REFERENCED TO FORSTER HYDRO DATUM

----- DATA LOSS



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FORSTER DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A20

DRAWING 2475-A19.cdr



Shoal Bay



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



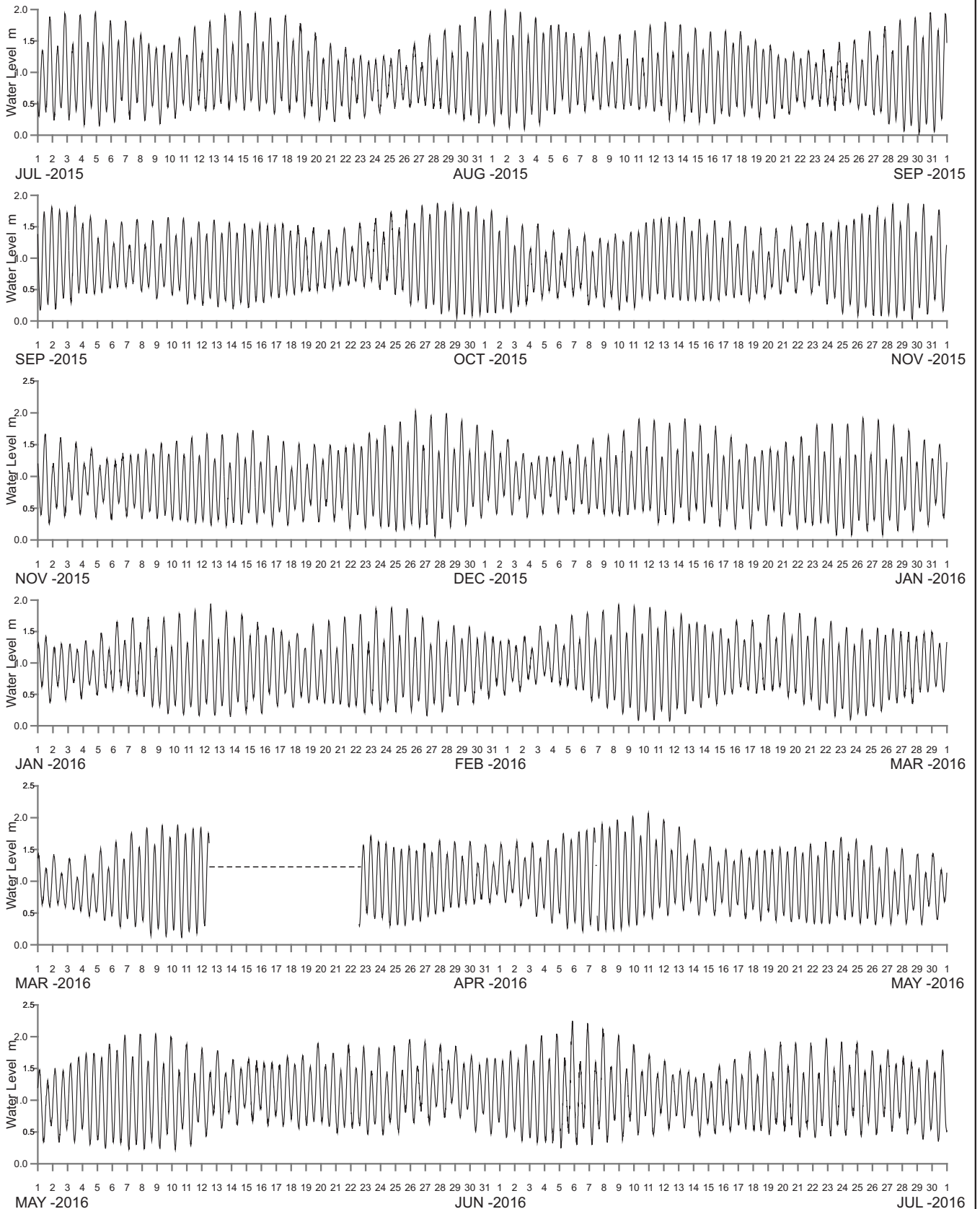
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**SHOAL BAY
 STATION LOCATION**

MHL
 Report 2475

Figure
 A21

DRAWING 2475-A21.dcr



WATER LEVEL REFERENCED TO PORT STEPHENS HYDRO DATUM

----- DATA LOSS



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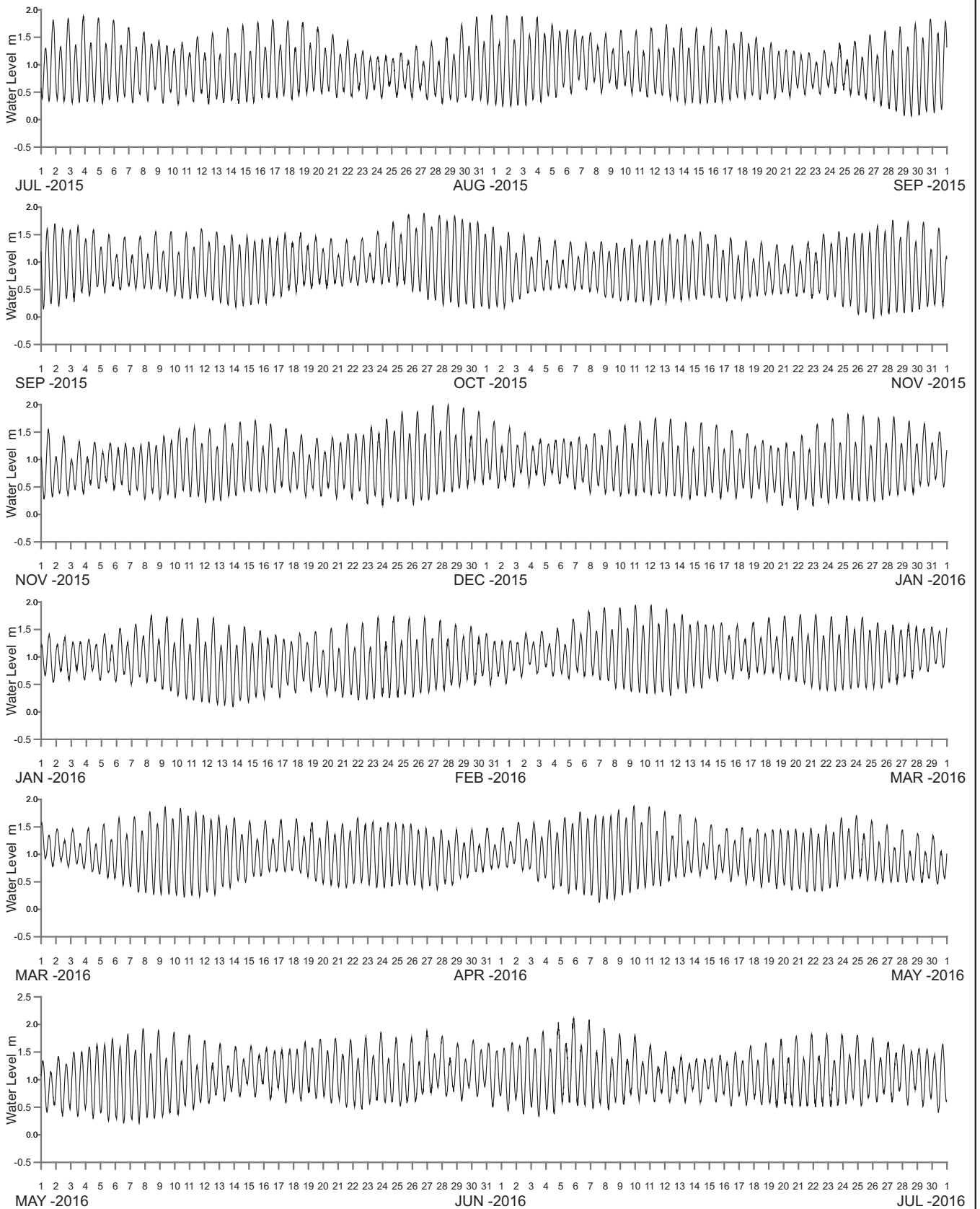
SHOAL BAY DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A22

DRAWING 2475-A21.cdr





WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS

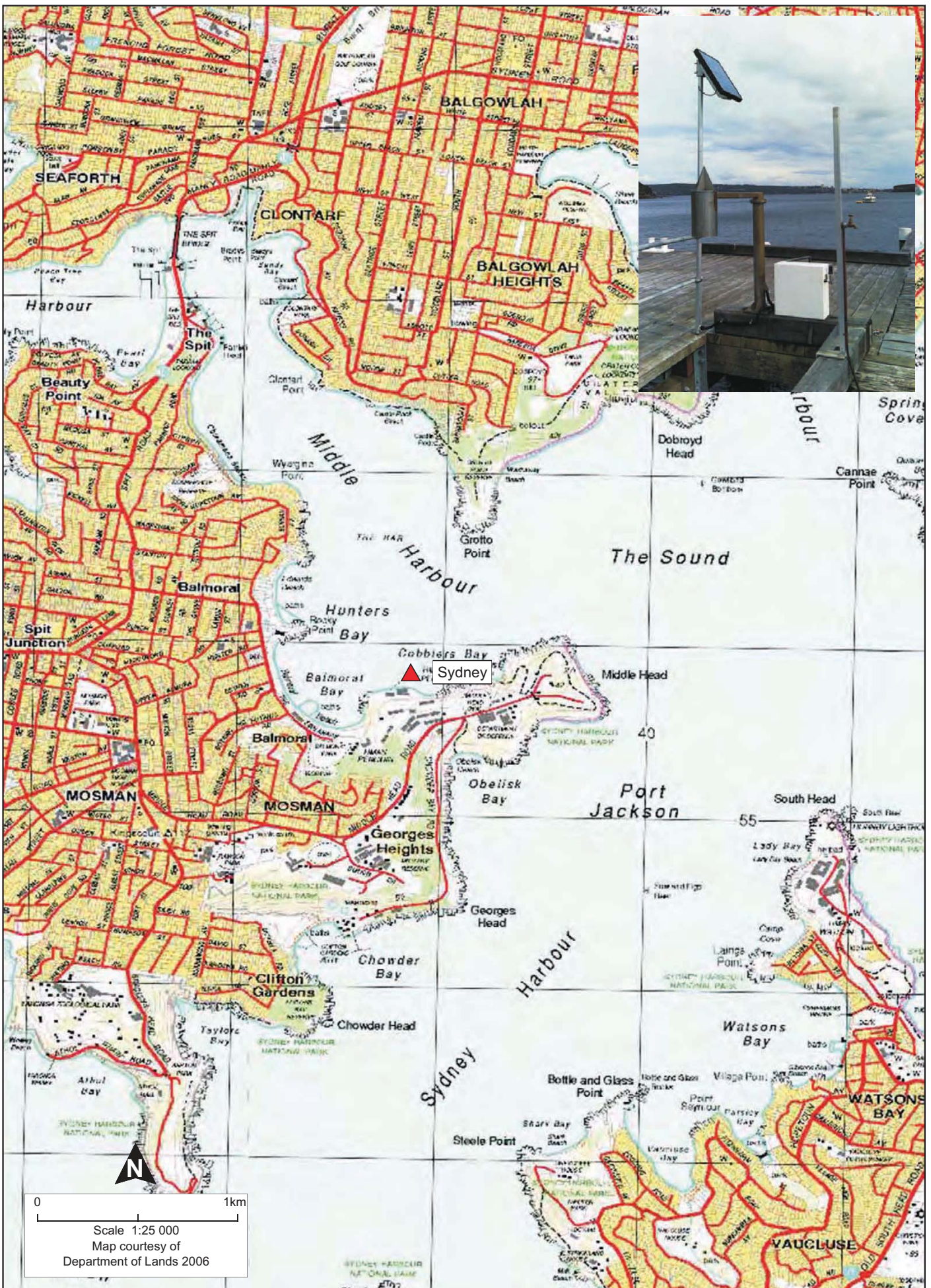


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PATONGA DATA SUMMARY
2015–2016

MHL
Report 2475
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A24

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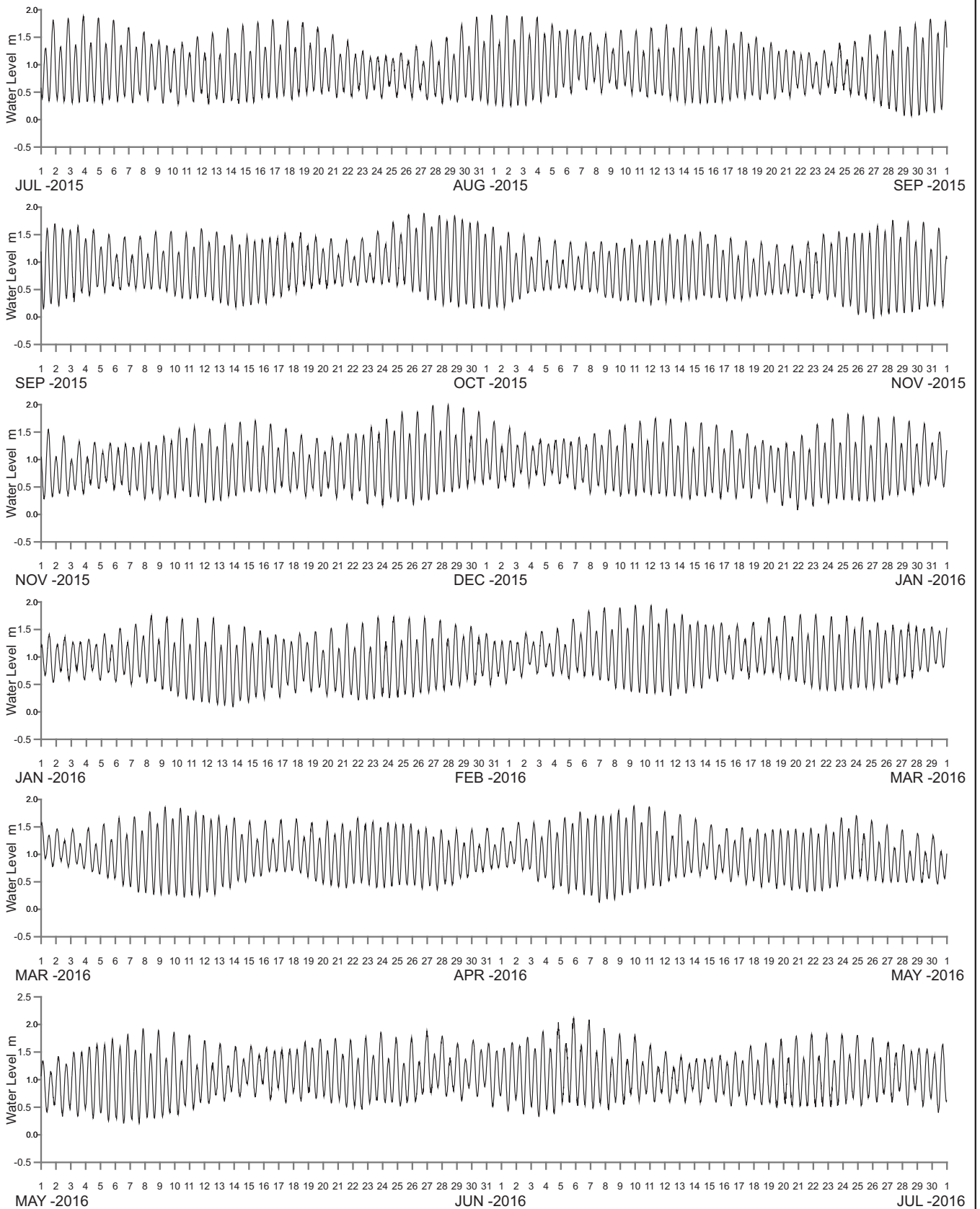
Public Works
Manly Hydraulics Laboratory

**SYDNEY
STATION LOCATION**

MHL
Report 2475

Figure
A25

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WATER LEVEL REFERENCED TO ZERO FORT DENISON

----- DATA LOSS



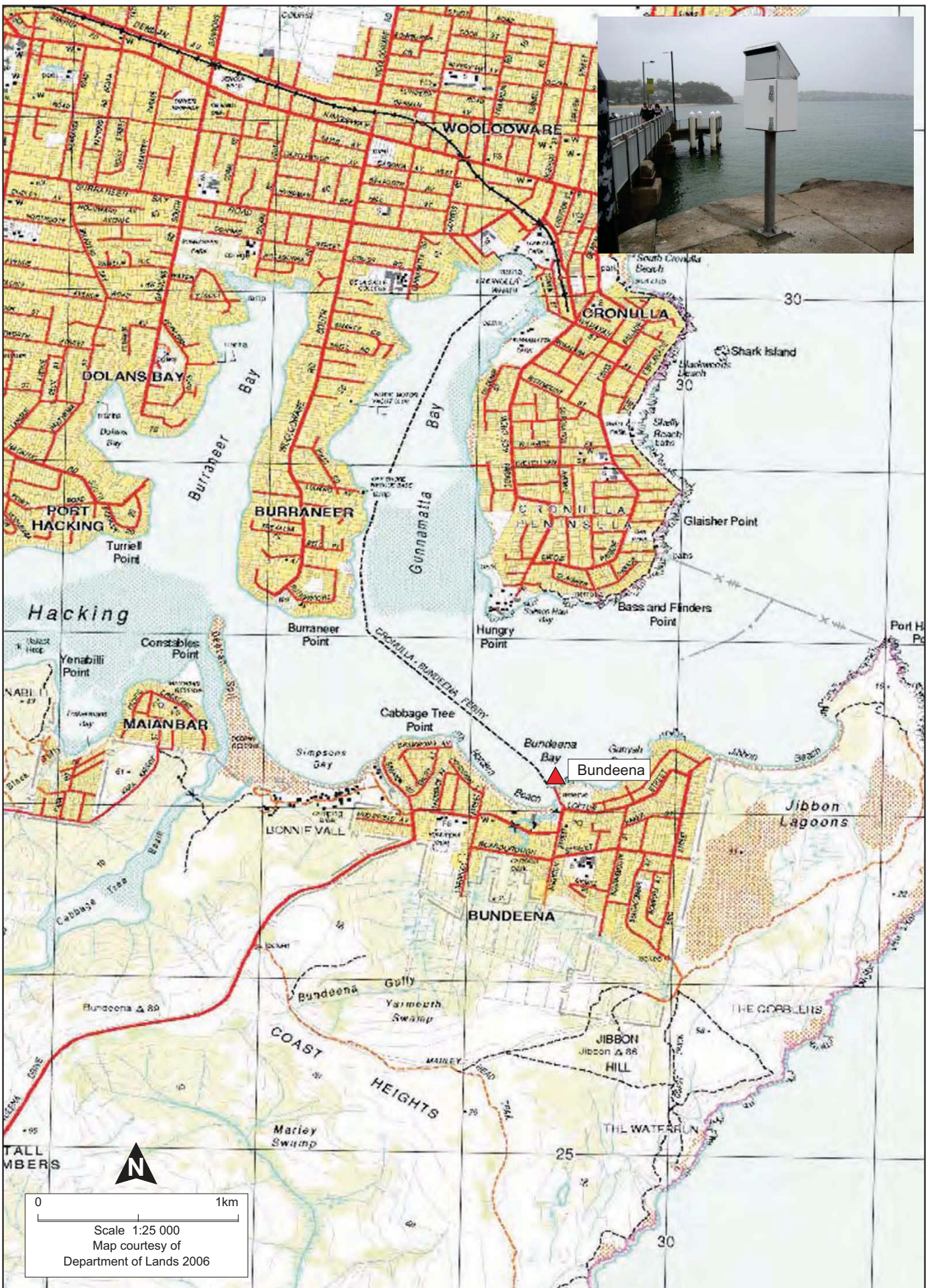
Public Works
Manly Hydraulics Laboratory

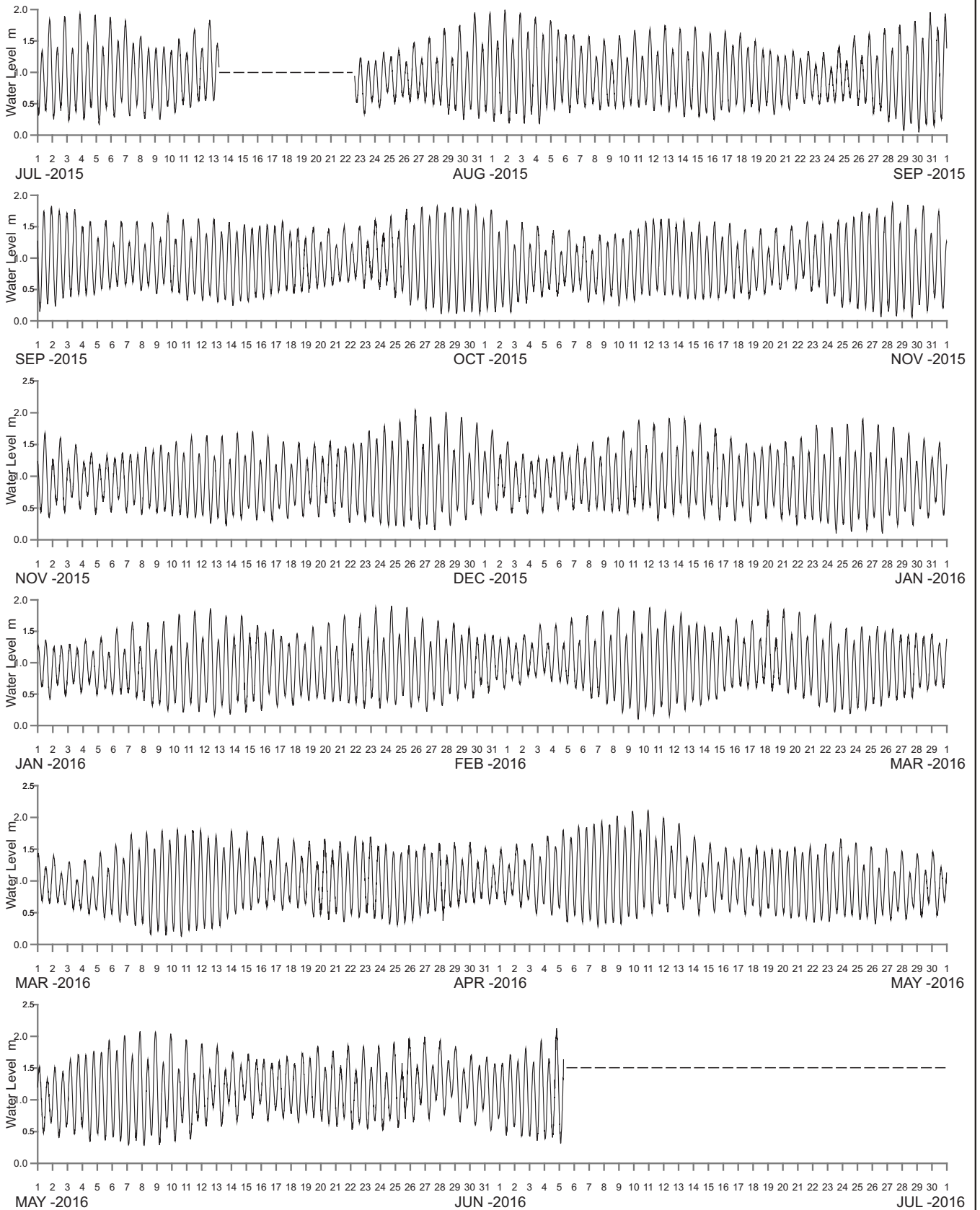
SYDNEY DATA SUMMARY
2015–2016

MHL
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Figure
A26

DRAWING 2475-A25.cdr





WATER LEVEL REFERENCED TO ZERO FORT DENISON

----- DATA LOSS



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BUNDEENA DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A28

DRAWING 2475-A27.cdr



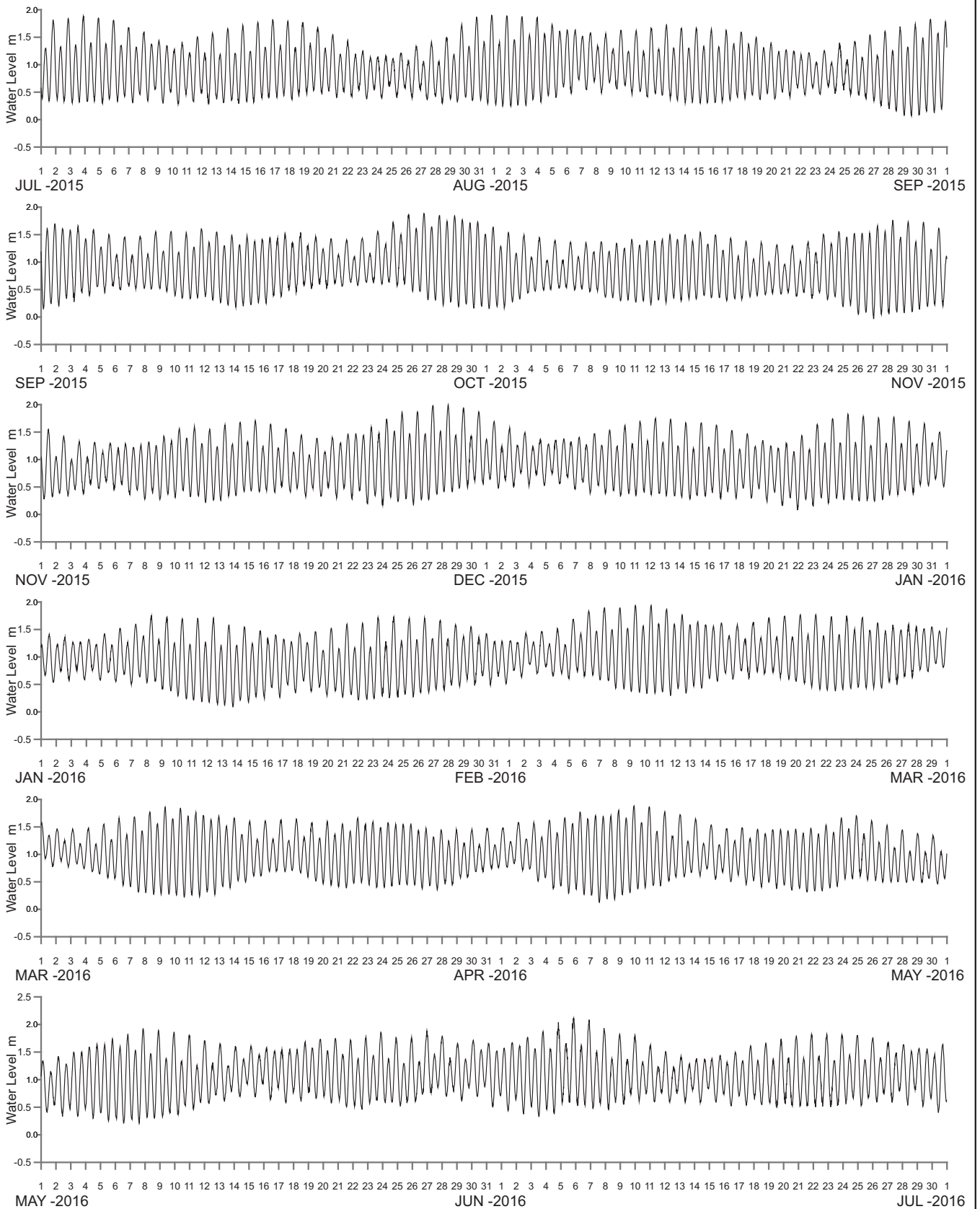
Public Works
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**CROOKHAVEN HEADS
STATION LOCATION**

MHL
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Figure
A29

DRAWING 2475-A29.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



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CROOKHAVEN HEADS DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A30

DRAWING 2475-A29.cdr



Shoalhaven Offshore



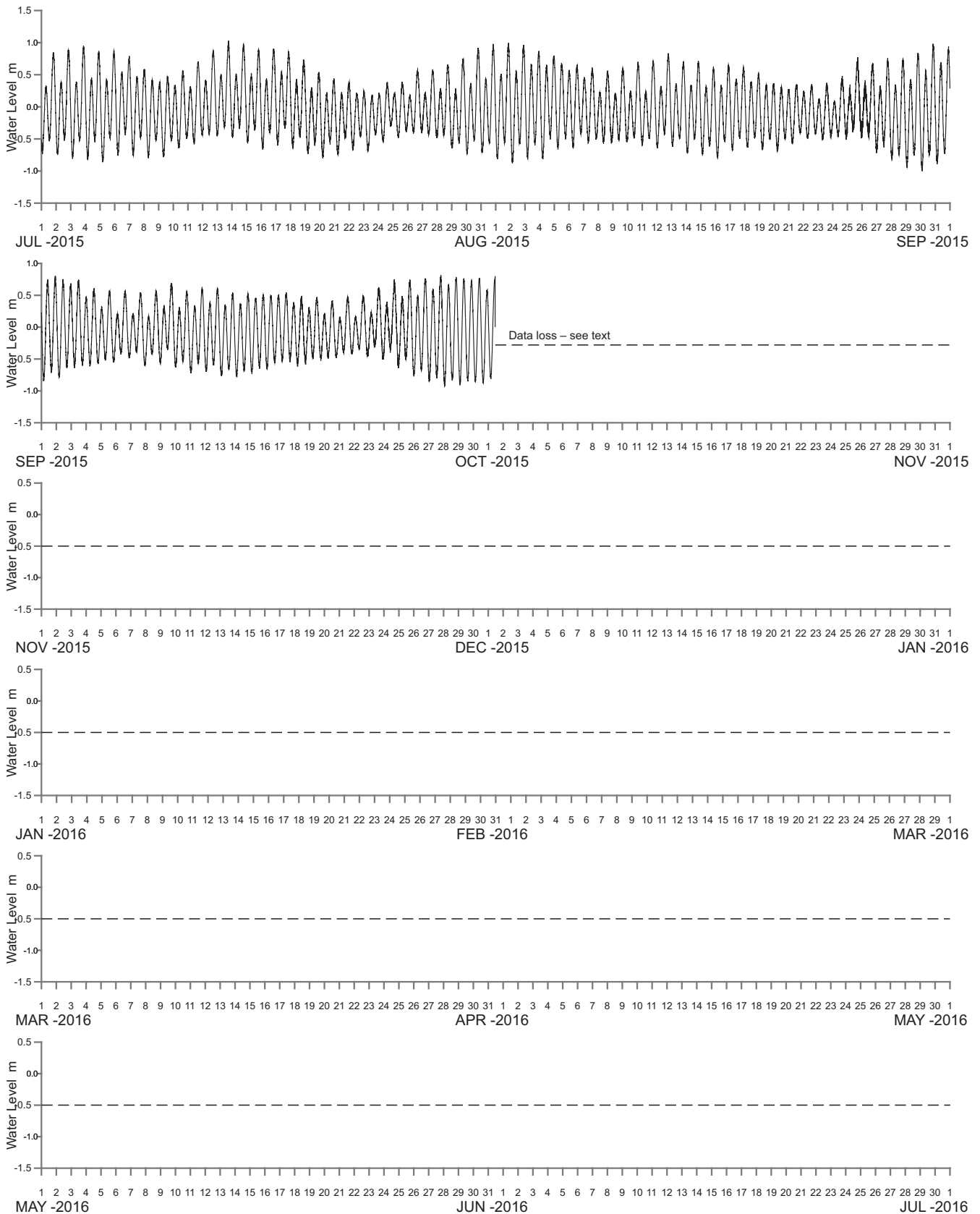
Public Works
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**SHOALHAVEN OFFSHORE
TIDE GAUGE LOCATION**

MHL
Report 2475

Figure
A31

DRAWING 2475-A31.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



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SHOALHAVEN OFFSHORE DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A32

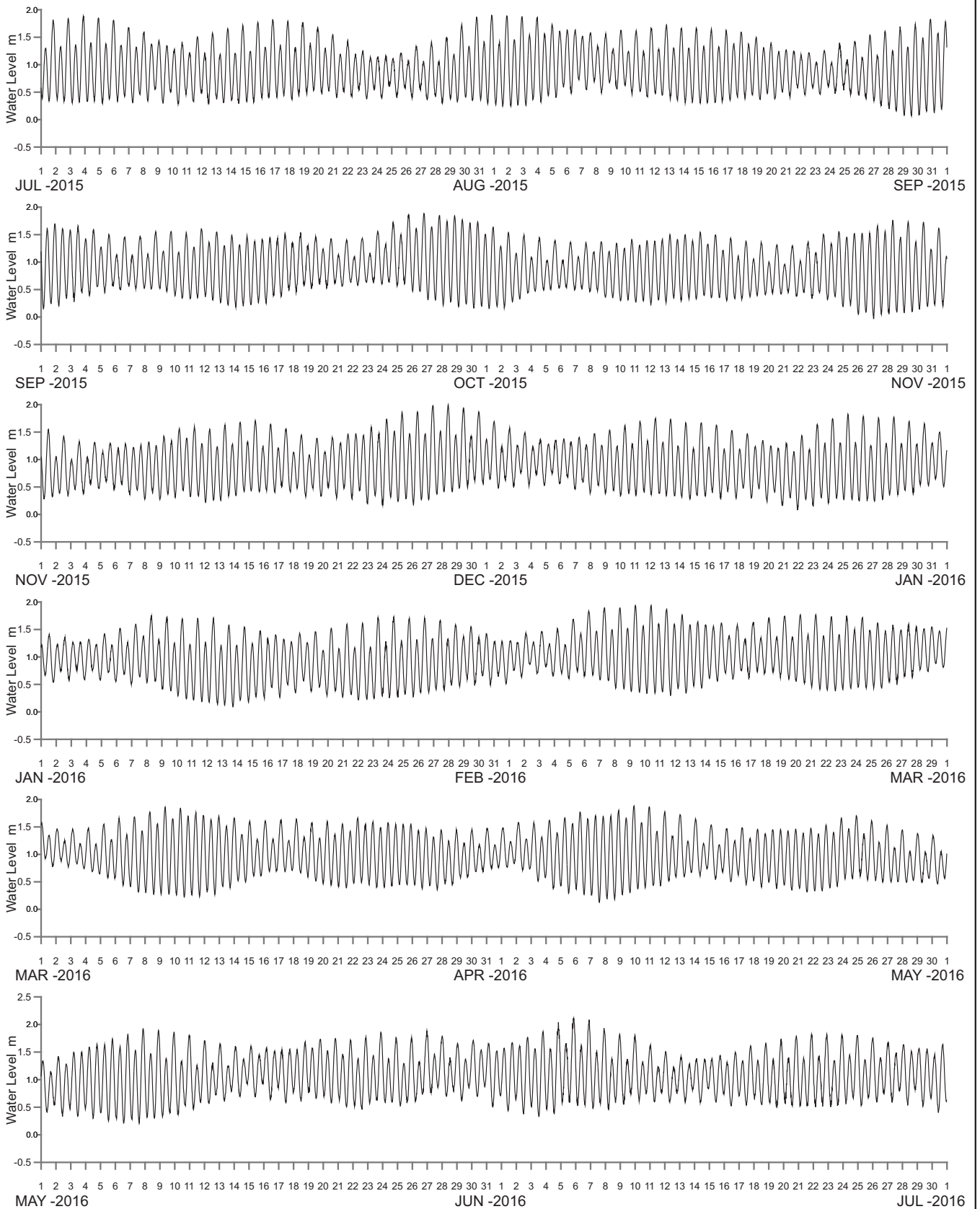
DRAWING 2475-A31.cdr



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**JERVIS BAY
STATION LOCATION**

MHL
Report 2475
Figure
A33
DRAWING 2475-A33.cdr



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

----- DATA LOSS



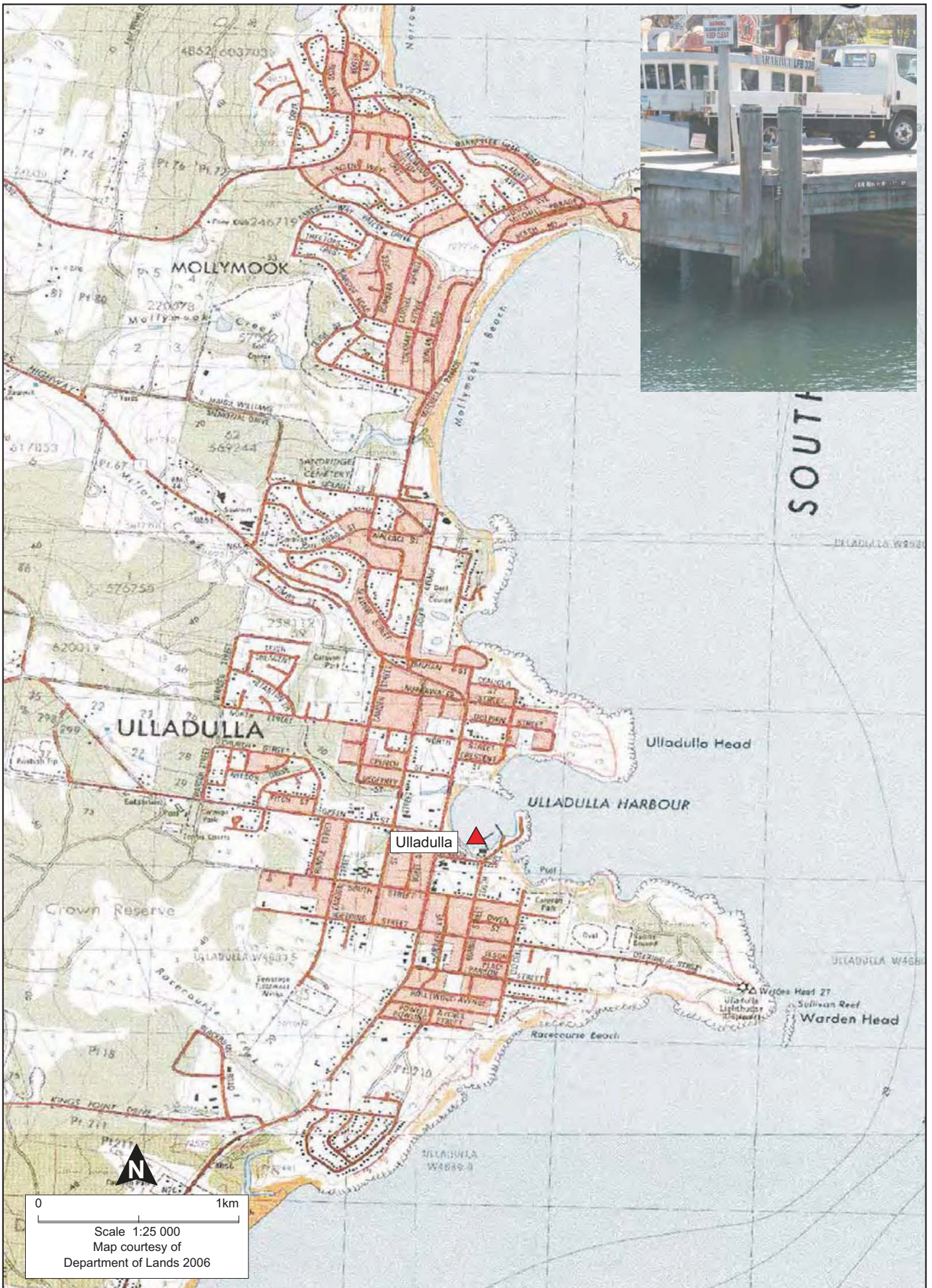
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JERVIS BAY DATA SUMMARY
2015–2016

MHL
Report 2475

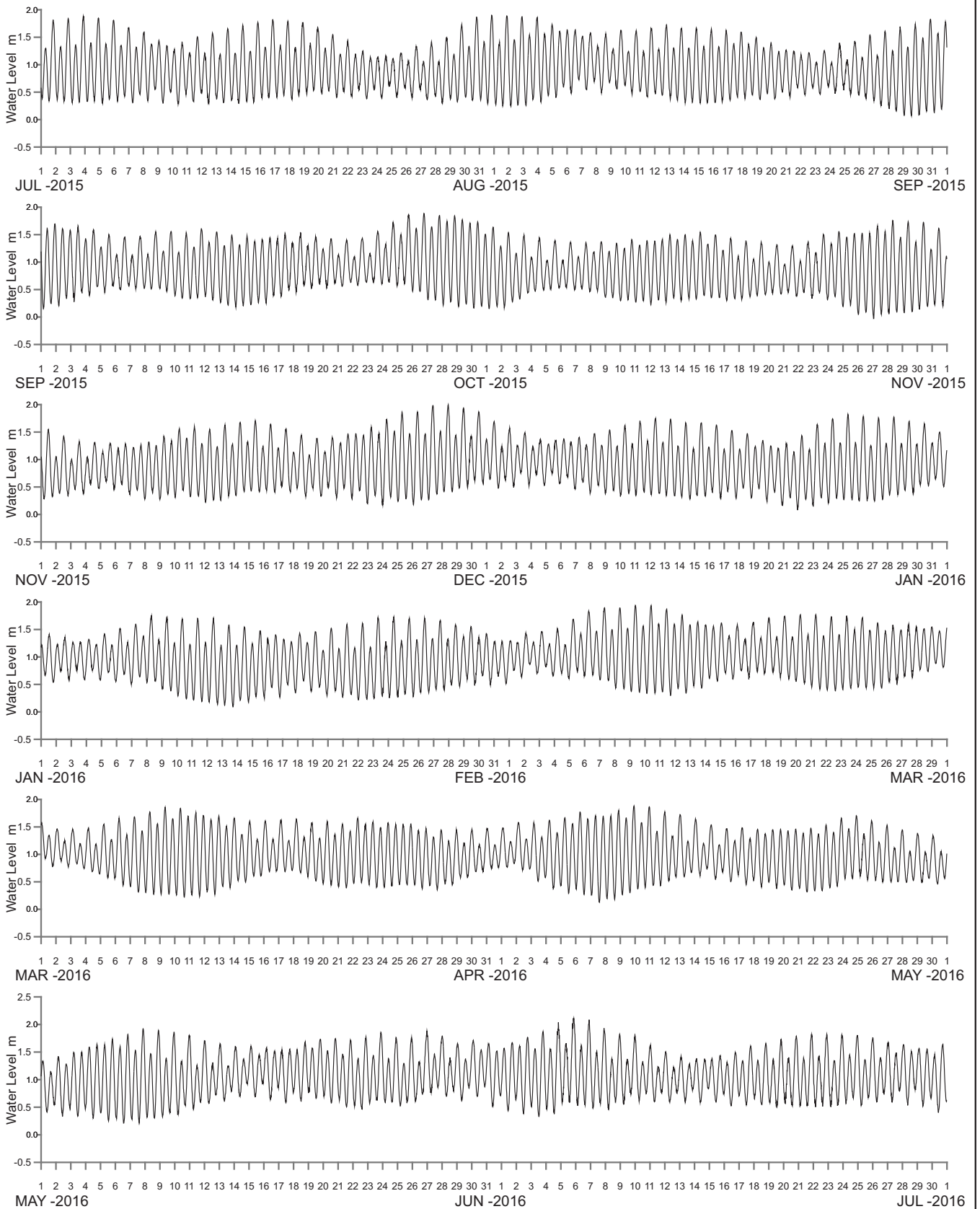
Figure
A34

DRAWING 2475-A33.cdr



SOUTH

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



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

----- DATA LOSS



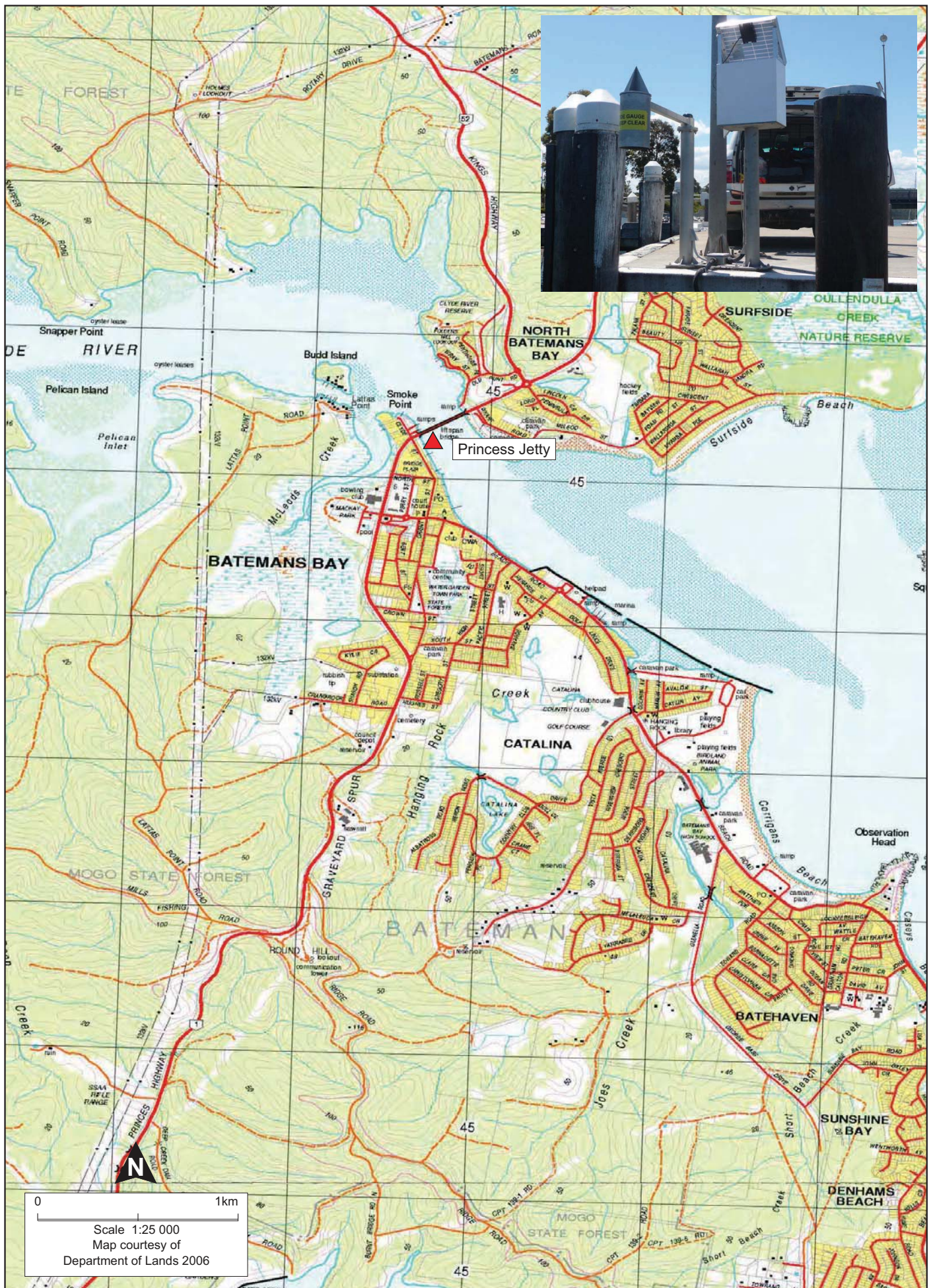
Public Works
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ULLADULLA DATA SUMMARY
2015–2016

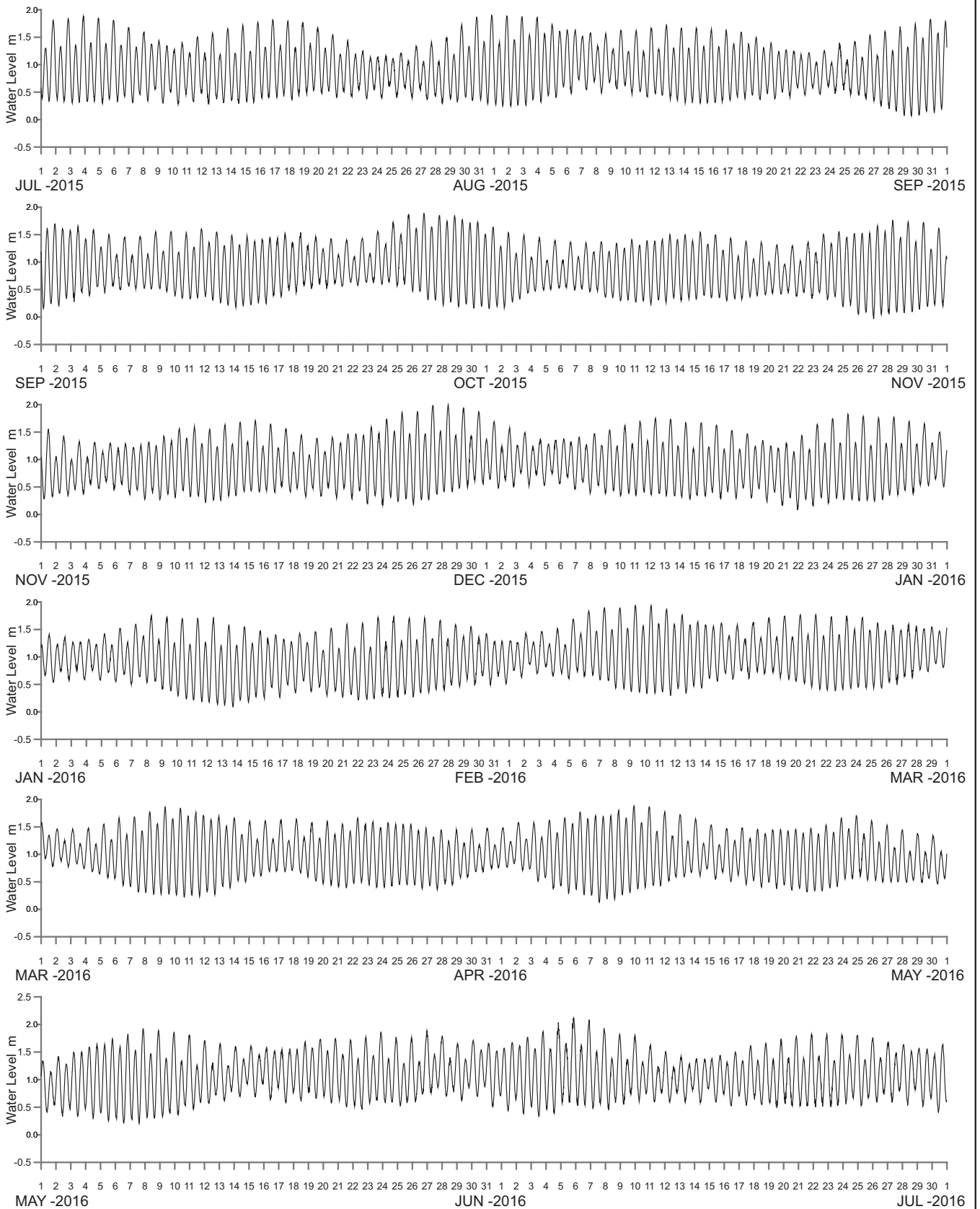
MHL
Report 2475

Figure
A36

DRAWING 2475-A35.cdr



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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PRINCESS JETTY DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A38

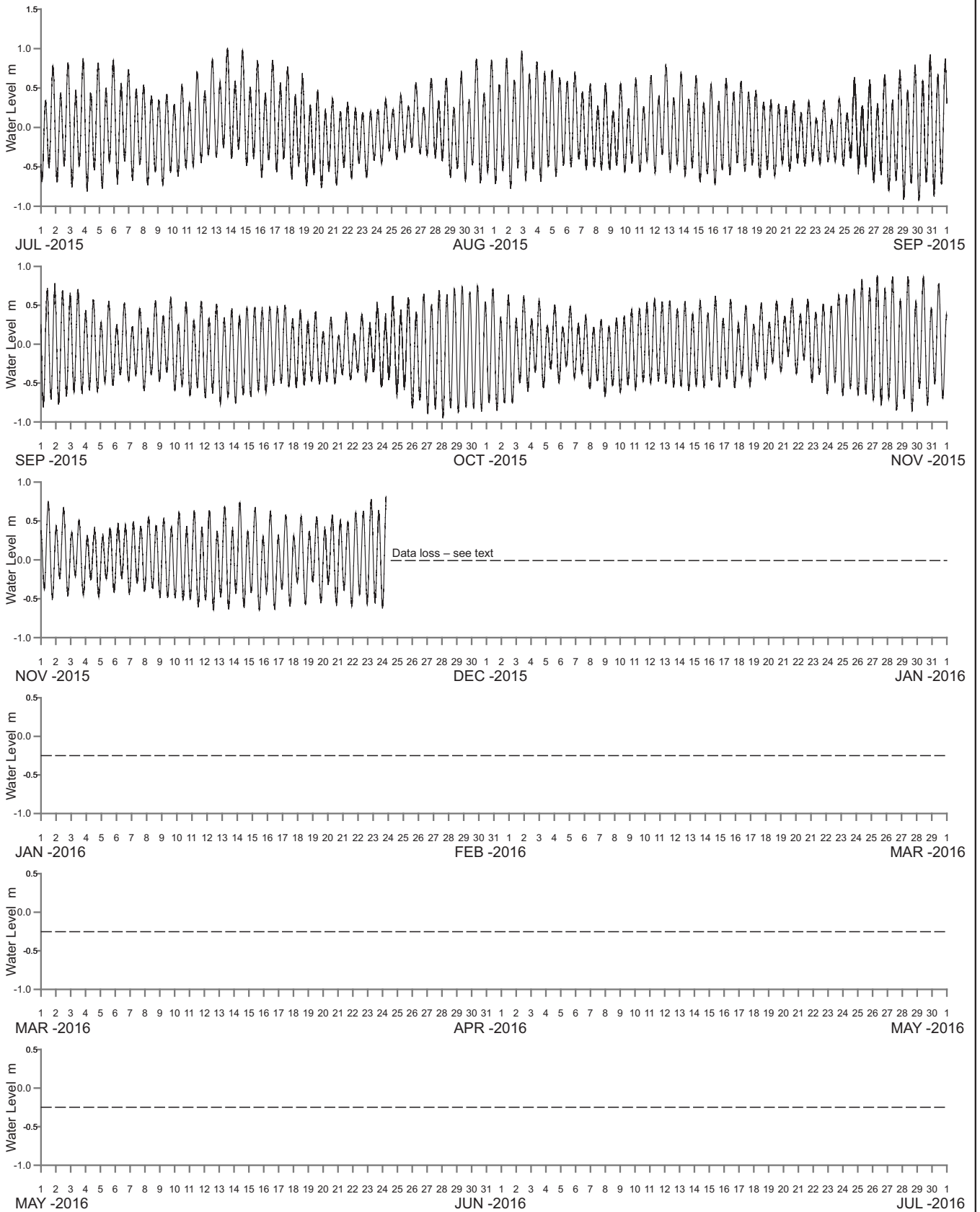
DRAWING 2475-A37.cdr



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**BATEMANS BAY OFFSHORE
TIDE GAUGE LOCATION**

MHL
Report 2475
**Figure
A39**
DRAWING 2475-A39.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

----- DATA LOSS



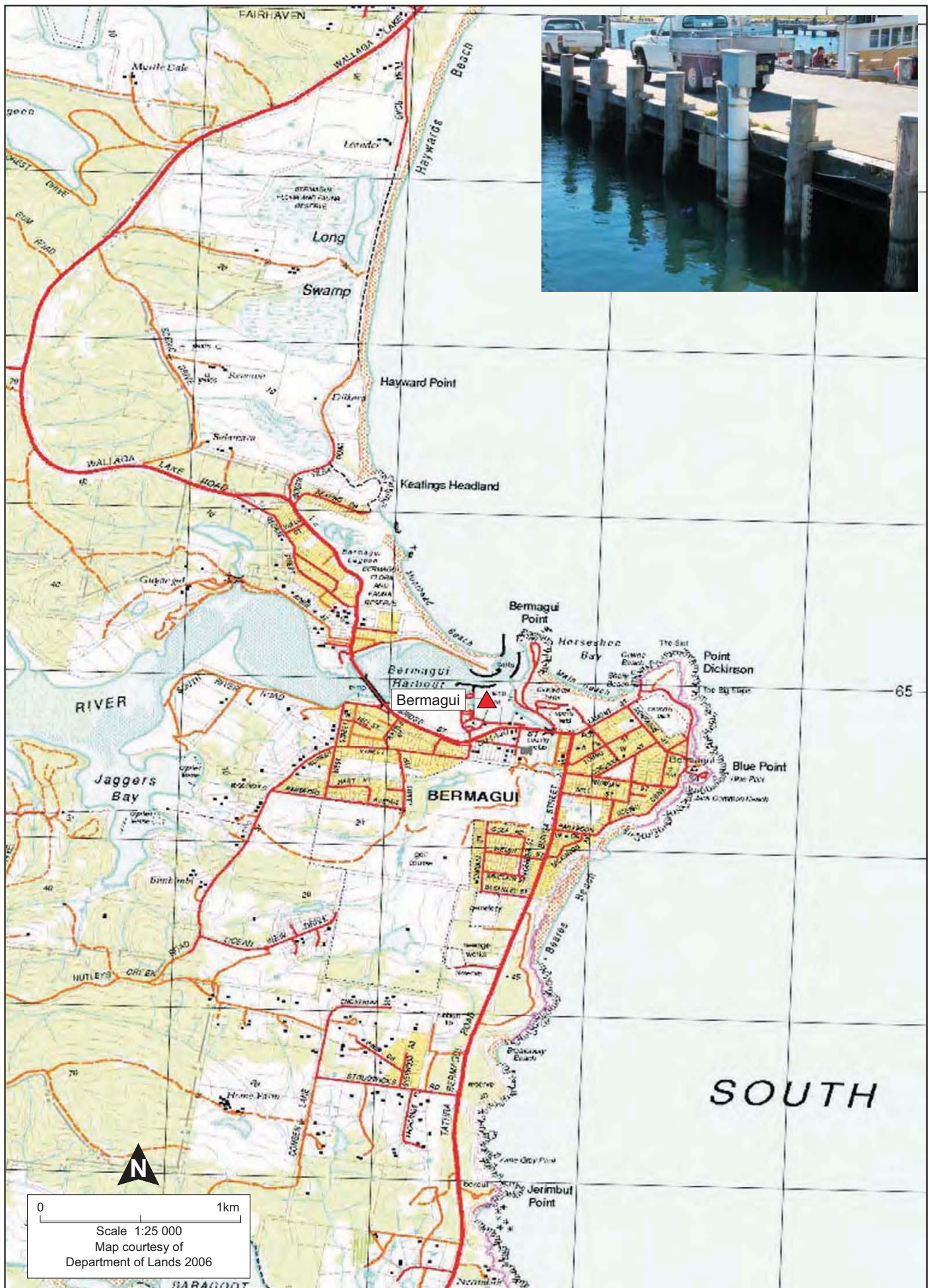
Public Works
Manly Hydraulics Laboratory

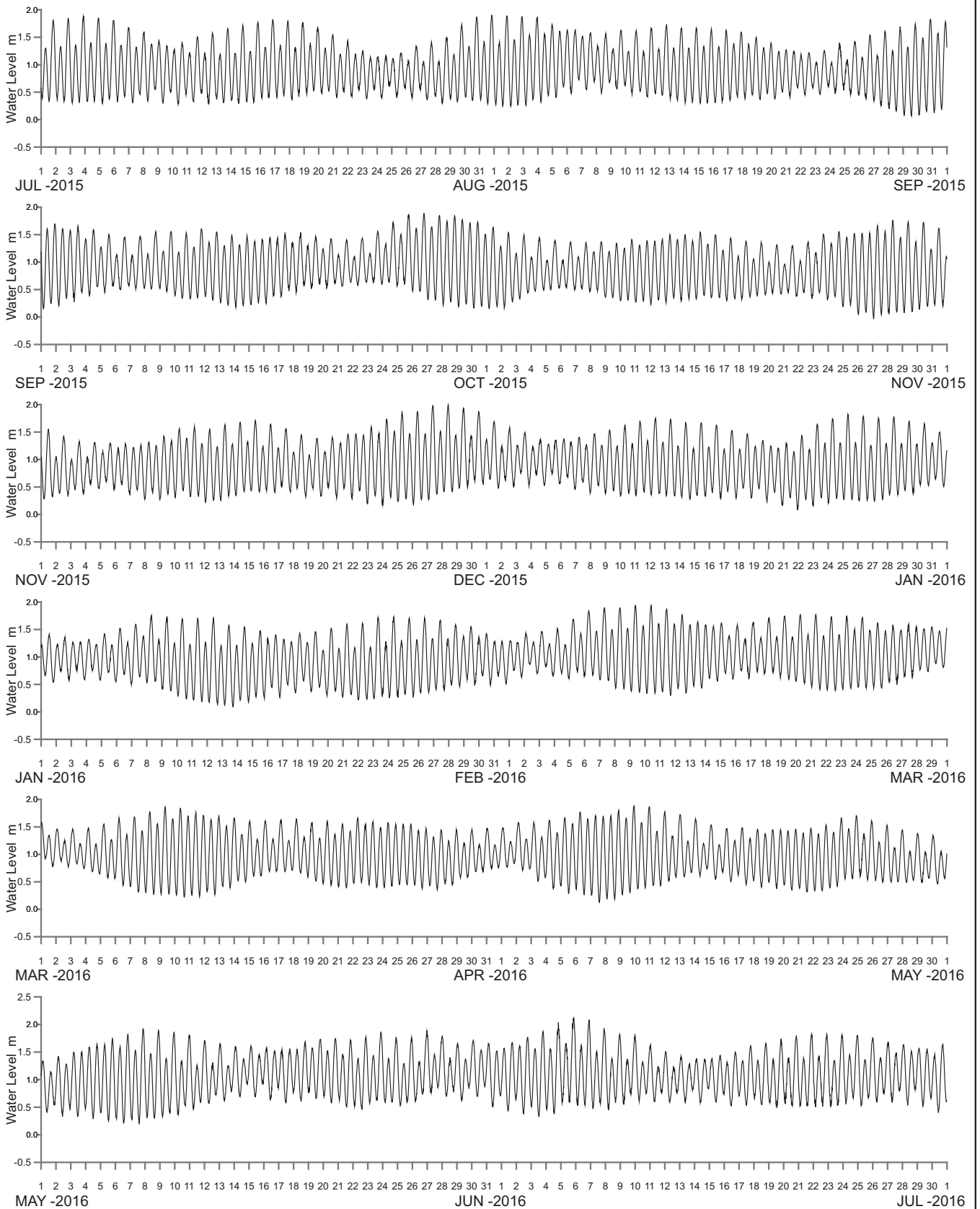
BATEMANS BAY OFFSHORE DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A40

DRAWING 2475-A39.cdr





WATER LEVEL REFERENCED TO BERMAGUI LOCAL HYDRO DATUM

----- DATA LOSS



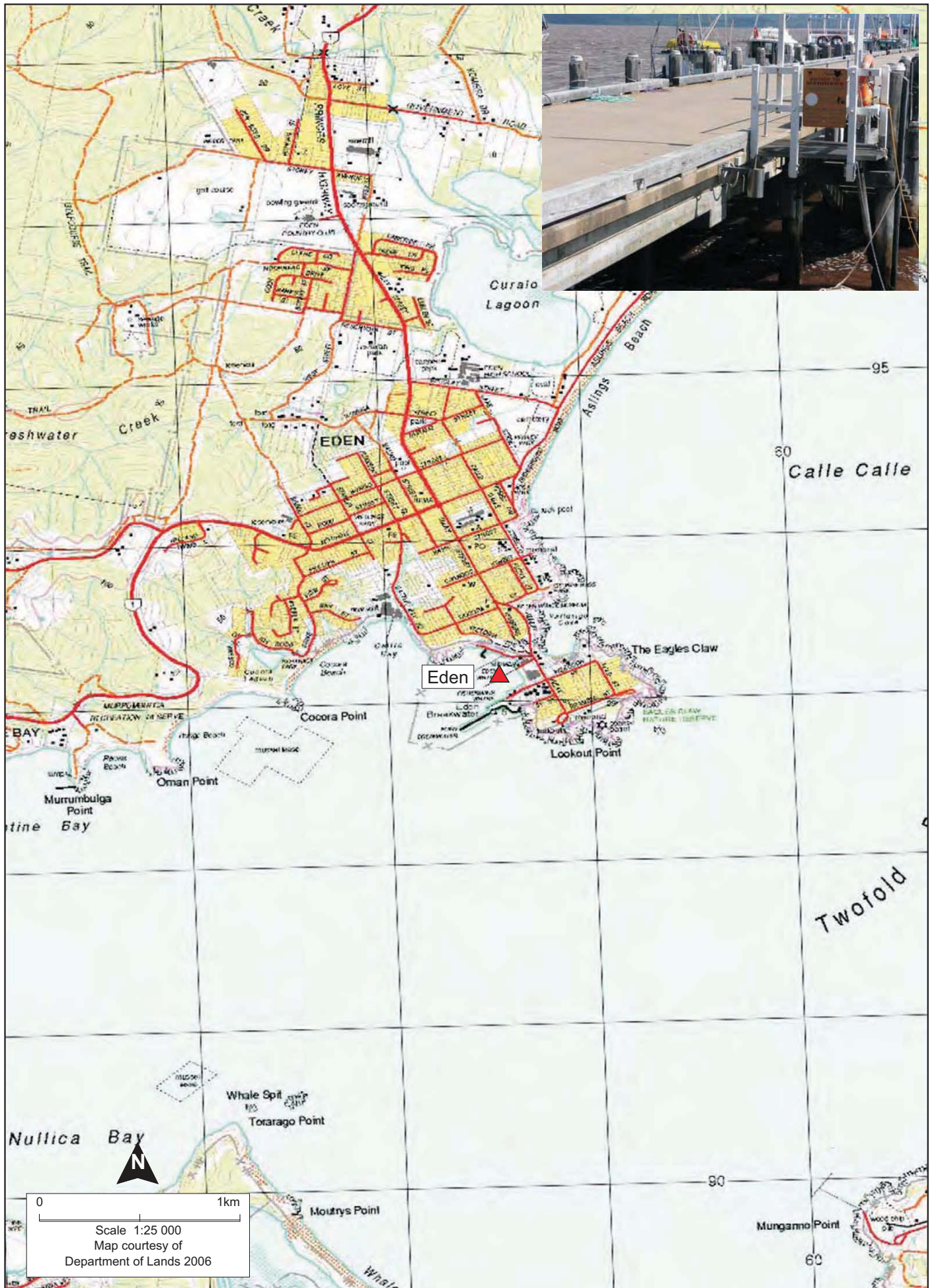
Public Works
Manly Hydraulics Laboratory

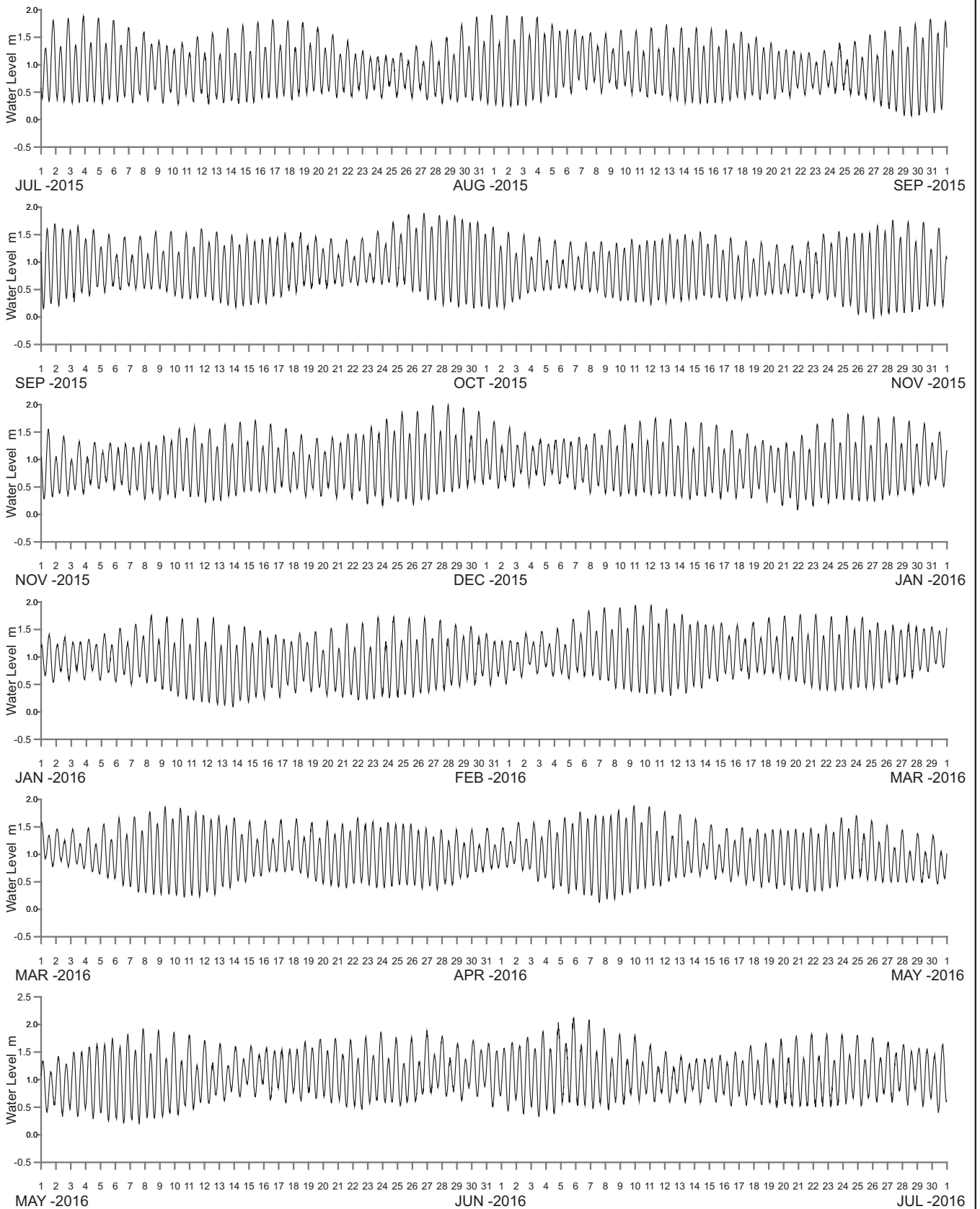
BERMAGUI DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A42

DRAWING 2475-A41.cdr





WATER LEVEL REFERENCED TO TWOFOLD BAY HYDRO DATUM

----- DATA LOSS



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EDEN BOAT HARBOUR DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A44

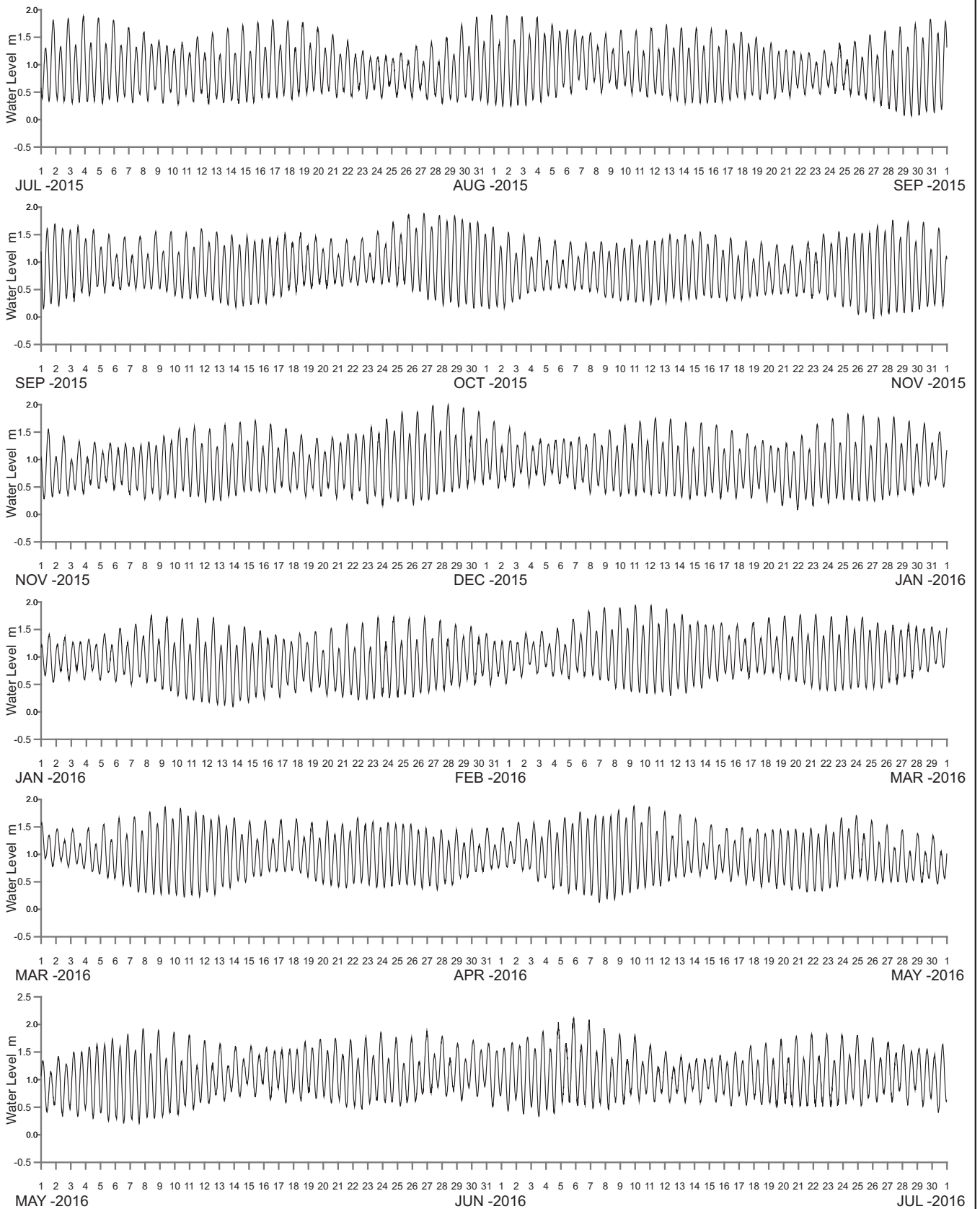
DRAWING 2475-A43.cdr



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**NORFOLK ISLAND
STATION LOCATION**

MHL
Report 2475
**Figure
A45**
DRAWING 2475-A45.cdr



WATER LEVEL REFERENCED TO LOWEST ASTRONOMICAL TIDE

----- DATA LOSS



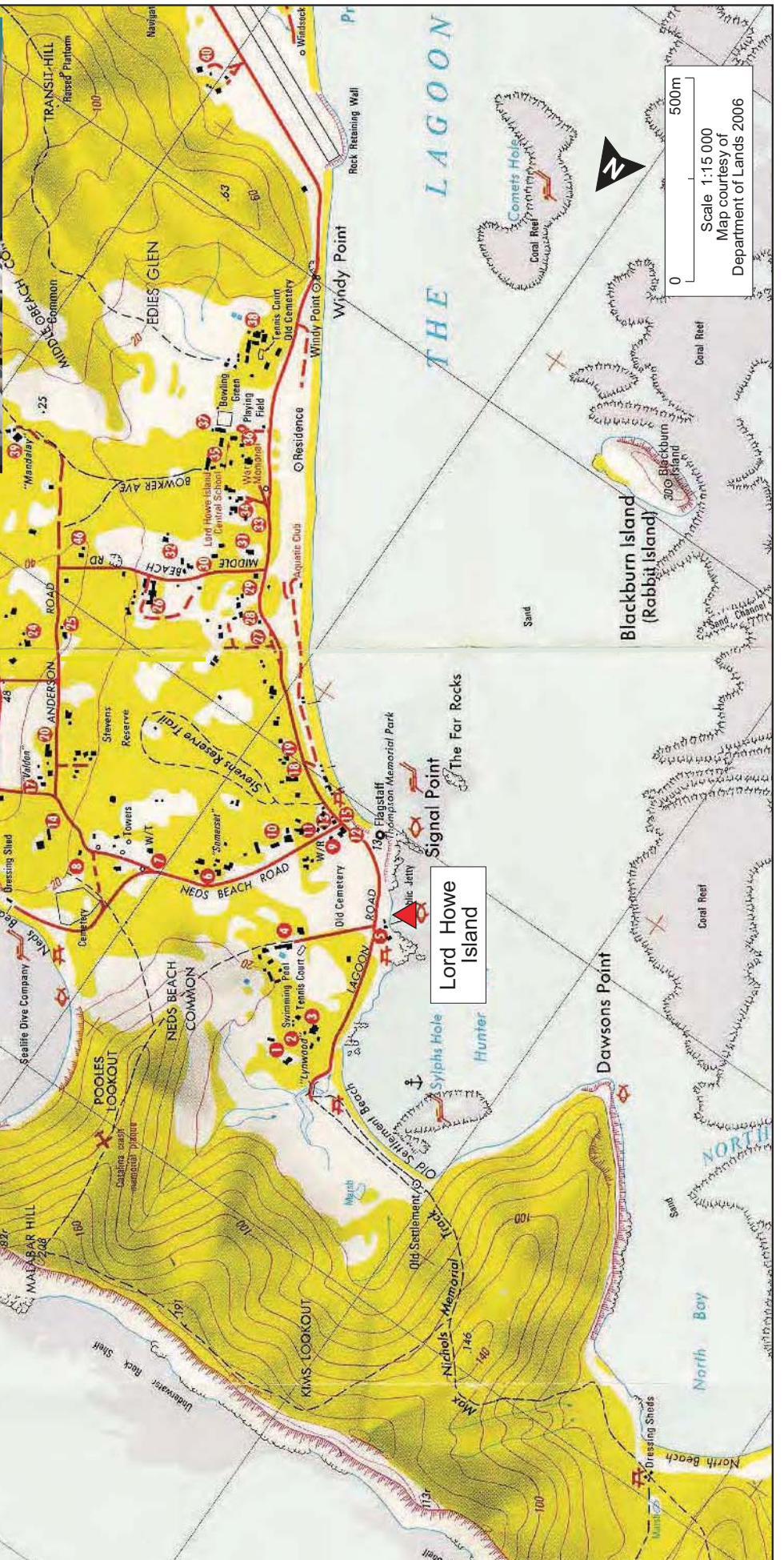
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Manly Hydraulics Laboratory

NORFOLK ISLAND DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A46

DRAWING 2475-A45.cdr



Lord Howe Island

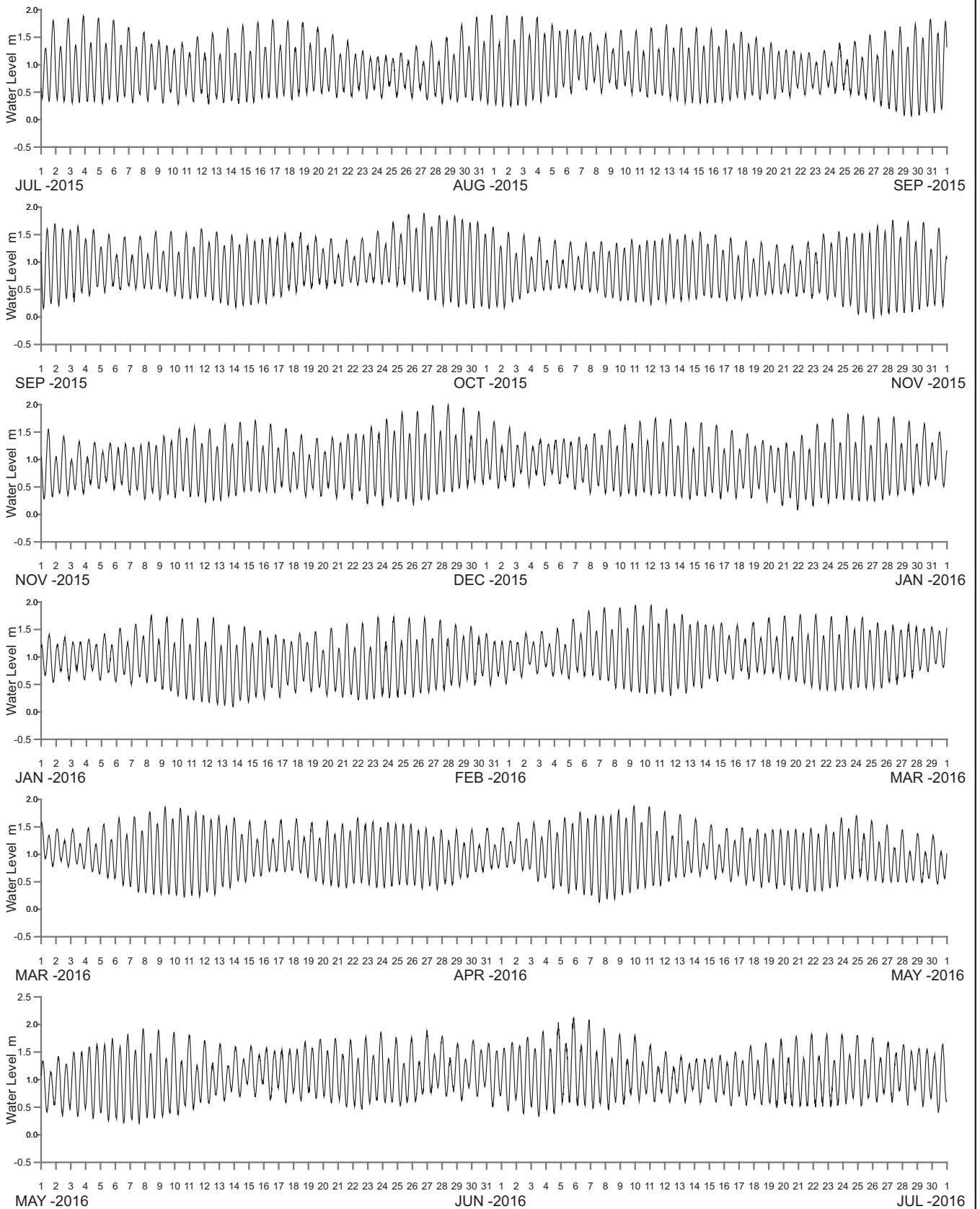


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**LORD HOWE ISLAND
STATION LOCATION**

MHL
Report 2475
**Figure
A47**

DRAWING 2475-A47.cdr



WATER LEVEL REFERENCED TO LORD HOWE ISLAND TIDAL DATUM

----- DATA LOSS



Public Works
Manly Hydraulics Laboratory

LORD HOWE ISLAND DATA SUMMARY
2015–2016

MHL
Report 2475

Figure
A48

DRAWING 2475-A47.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

¹ Site has changed location during data period

Appendix C
Historical tide data

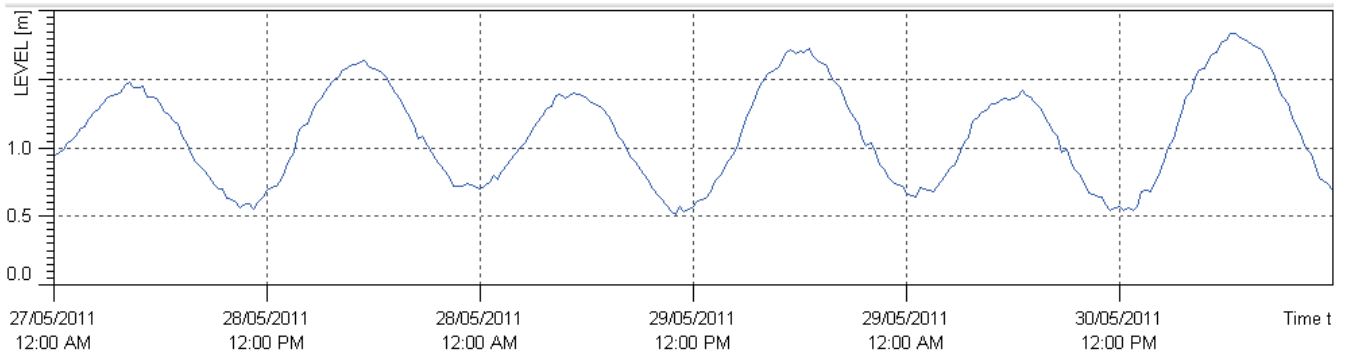
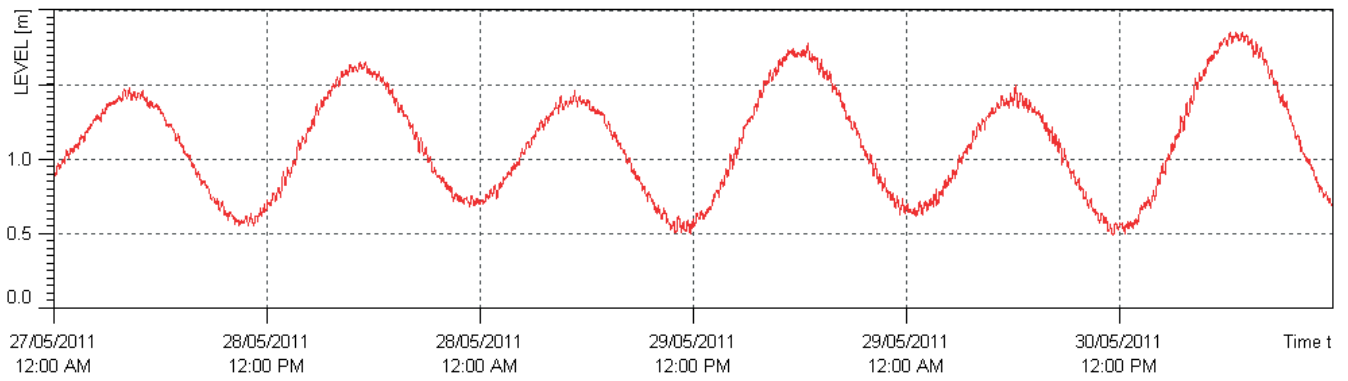
Table C1 Historical tide data

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 State Archives
Coffs Harbour	Main harbour	1966–68 and 1969–72	Microfiche MHL
Coffs Harbour	Main harbour	1972–1973	Microfiche MHL
Coffs Harbour	Main harbour	1951–52, 1961–64	HiLos State Archives
Coffs Harbour	Outer harbour 205470	1951–1996	On line
Coffs Harbour	Outer harbour	1953–56, 1957–60	Microfiche MHL
Coffs Harbour	Water Police Jetty Inner Harbour 205470	1990–1996	On line
Macleay River	Entrance 206477	1901–1913	HiLos on line
Crowdy Head	CSIRO 208470	1985–1986	On line
Tomaree	Hospital Jetty 209471	Oct 1985–Apr 2014	On line
Tomaree	Hospital Jetty	1967–1969	HiLos State Archives
Newcastle	Boat harbour 210461	1899–1921	HiLos on line
Newcastle	Breakwater	1946–1961	HiLos State Archives
Port Hacking	Hungry Point	Nov 1987–Feb2015	On line
Port Jackson	Fort Denison 60370	1914–2008	On line
Port Kembla	Harbour	1957–1965	Microfiche State Archives
Port Kembla	Harbour 214480	1987–1992	On line
Jervis Bay	HMAS Creswell 216471	1914–1919	HiLos on line
Jervis Bay	Huskisson 216472	1987–1993	On line
Batemans Bay Offshore	Snapper Island 216451	1986–1990	On line
Batemans Bay Offshore	Offshore 216452	1987–1988	On line (MHL556)
Moruya River	Moruya Heads 217403	1951–1952	HiLos State Archives
Moruya River	Entrance	1951–52, 1987–88	On line
Eden	Snug Cove 220470	1978–1990	On line
Eden	Snug Cove	1954–1956	Microfiche State Archives
Norfolk Island	Kingston Jetty	1994-2015	On line

Fort Denison data courtesy of Sydney Ports Corporation and BoM National Tidal 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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 1/05/2014,4:30:00,0.489,55 (Fair)
 1/05/2014,4:45:00,0.527,55 (Fair)
 1/05/2014,5:00:00,0.574,55 (Fair)
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 1/05/2014,5:45:00,0.731,55 (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)
 1/05/2014,8:00:00,1.304,55 (Fair)
 1/05/2014,8:15:00,1.366,55 (Fair)
 1/05/2014,8:30:00,1.374,55 (Fair)
 1/05/2014,8:45:00,1.42,55 (Fair)
 1/05/2014,9:00:00,1.443,55 (Fair)

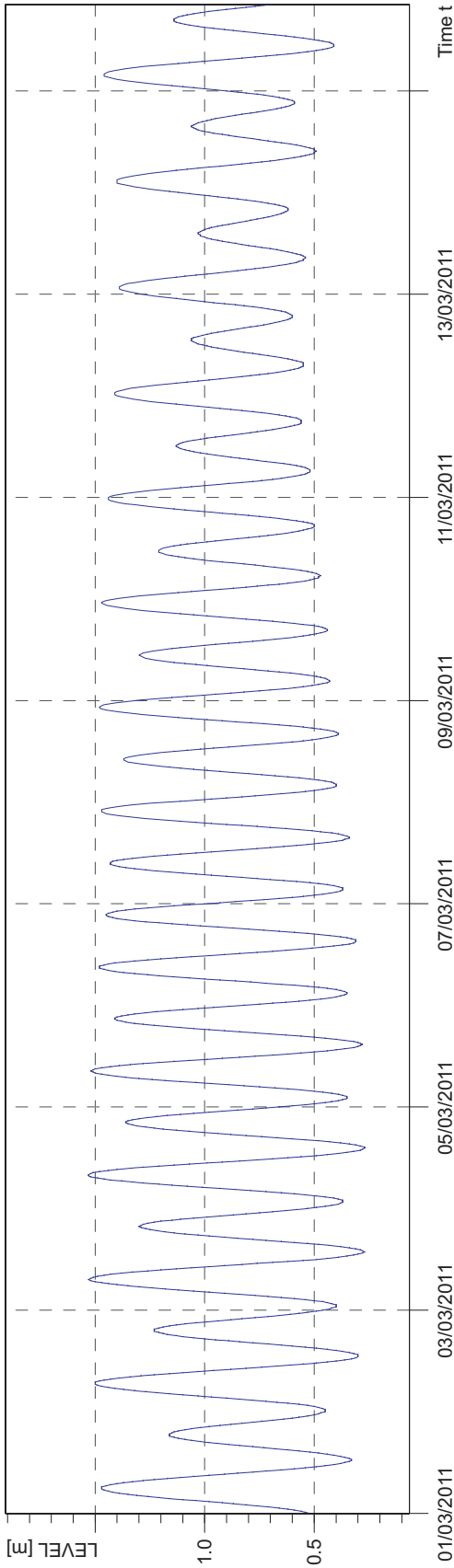


NSW PUBLIC WORKS, MANLY HYDRAULICS LABORATORY

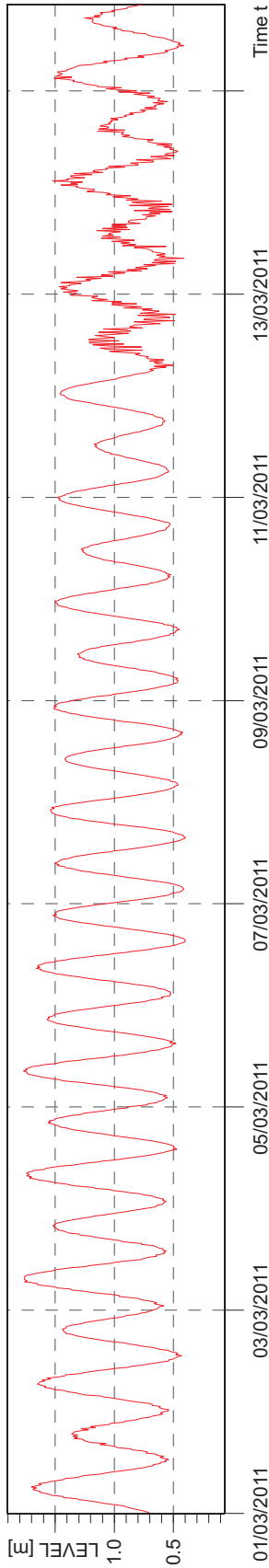
STATION NAME : Sydney (Live)
 RECORDER TYPE : MHL Station
 A.W.R.C. No. : 213470
 DATA START : 29.06.2013
 DATA FINISH : 30.06.2014
 DATA TOTAL : 1 years 2 days
 DATABASE TIME INTERVAL (second): 0
 THRESHOLD LEVEL (m) : 1.900
 DATUM : Zero Fort Denison
 DATE OF ISSUE : 09:00 22.10.2014
 ANALYSIS PERFORMED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

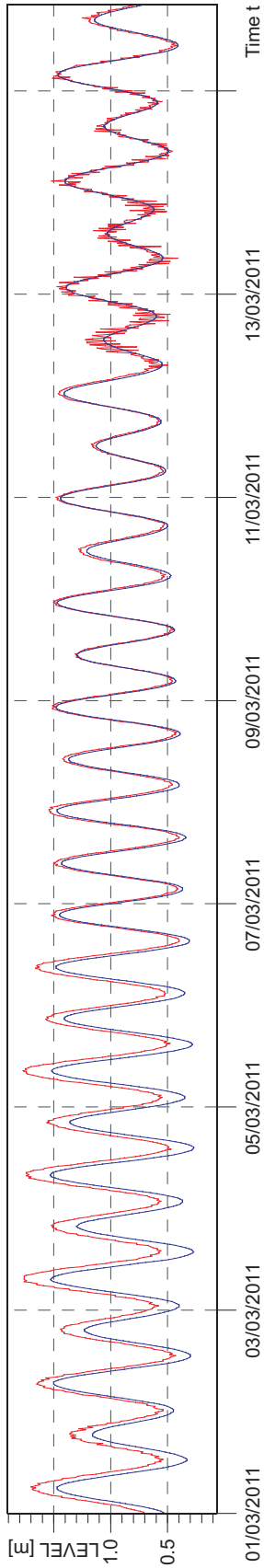




Predicted Data



Measured Data



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 $y = A \cos(at + a)$, 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 $(at + a)$ 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_i 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_i 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.
King tide	A non-scientific term used to describe especially high tide events occurring twice a year around early January and early July. They occur when the earth, sun and moon are in alignment and when the sun is closest and furthest from the earth (perihelion and aphelion respectively).
Lambda	Smaller lunar evectional constituent. This constituent, with V_2 , U_2 , and (S_2), modulates the amplitude and frequency of M_2 for the effects of variation in solar attraction of the moon. This attraction results in a slight pear-shaped lunar ellipse and a difference in lunar orbital speed between motion toward and away from the sun. Although (S_2) has the same speed as S_2 , its amplitude is extremely small. Speed = $2T - s + p = 29.455,625,3^\circ$ per solar hour.
Low water (LW)	The minimum height reached by a falling tide. The low water is due to the periodic tidal forces and the effects of meteorological, hydrologic, and/or oceanographic conditions. For tidal datum computational purposes, the minimum height is not considered a low water unless it contains a tidal low water.
Lower high water (LHW)	The lowest of the high waters of any specified tidal day due to the declination A_i 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_i 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).
Meteotsunami	An irregular water level oscillation with a meteorological rather than a seismic origin. Meteotsunamis are often generated by a rapid change in barometric pressure and amplified by the movement of the pressure system at the same speed as the wave celerity. Further amplification of the meteotsunami can occur from the influence of the shape and depth of the continental shelf and the local morphology at the shoreline.
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).

Z₀

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 2014-15

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 (9-98), 1013 (98-99), 1069 (99-00), 1129 (00-01), 1205 (01-02), 1277 (02-03), 1347 (03-04), 1423 (04-05), 1512 (05-06), 1764 (06-07), 1848 (07-08), 1933 (08-09), 2010 (09-10), 2089 (10-11), 2158 (11-12), 2219 (12-13), 2292 (13-14), 2384 (14-15).

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