NSW OCEAN AND RIVER ENTRANCE TIDAL LEVELS AND AIR PRESSURE ANNUAL SUMMARY

2021-2022

Report MHL2907
June 2023

Prepared for:

NSW Department of Planning and Environment
Biodiversity and Conservation Division

Cover photograph: Drone image taken of Narrabeen beach during March 2022 swell and tide event
Narrabeen, NSW, 4 March 2022
Photo courtesy of Eduardo Pombo Lavin

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Foreword

Manly Hydraulics Laboratory (MHL) is a business unit within the Water Group of the NSW Department of Planning and Environment. MHL operates and maintains ocean river entrance tidal and barometric recording stations along the NSW coast under a service level agreement with the Biodiversity and Conservation Division of the NSW Department of Planning and Environment.

The NSW ocean tide database developed by MHL supports a number of Biodiversity and Conservation Division programs associated with coastal, floodplain and estuary management. These include the operations of ports and marine facilities, water level forecasts, fisheries management, determining property boundaries and developing a detailed understanding of oceanic processes. The monitoring service outputs are publicly available.

This summary provides information on how to access the ocean tide and barometric database and the data analysis capabilities of MHL.

The monitoring program's protocols and station arrangements are guided by the *Australian Tides Manual Special Publication 9 Version 6* (2021) published by the Intergovernmental Committee on Surveying and Mapping (ICSM) and reviewed by contributing agencies to the Tides and Sea Levels Working Group (TSLWG).

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Executive summary

This annual summary presents ocean and river entrance tidal levels and coastal air pressure data captured by the automatic tide level and barometric sensor recording stations along the coastline of NSW over the period 1 July 2021 to 30 June 2022. It provides a catalogue of all ocean and river entrance tidal data collected in NSW by MHL for the Biodiversity and Conservation Division.

The 2021–2022 target data recovery rate of over 95% for the 15-minute ocean tide data (99.3%) and barometric data (100.0%) was achieved.

The offshore tide data recovery rate (36.0%) did not achieve the 95% target due to combined failure of the primary and secondary monitoring equipment at three of the four stations and unsuitable dive conditions for redeployment of gauges at the fourth station. The offshore monitoring equipment has served the ocean tides program well, with more than 10 years' and 30 years' service for the primary and secondary equipment, respectively. A complete new fleet of offshore gauges (two per site) has been procured and is predominantly established at the offshore sites, following next generation equipment trials in 2020. **Section 4** provides further details on the end-of-life technology issues and the adopted replacement program for ongoing offshore monitoring designed to achieve the target recovery rate.

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 2021–2022
- **Appendix A**, the annual data summaries for each ocean tide site (see **Figure 1.1** for site locations)
- **Appendix B**, the annual data summaries for each barometric site (see **Figure 2.1** for site locations)
- **Appendix C**, current tidal station data
- **Appendix D**, detailing the historical tidal data available
- **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 thirty-sixth year of data collected by automatic ocean tide level recorders for the State of NSW. MHL provides tide data through a network of recorders and an efficient service of associated analysis routines.

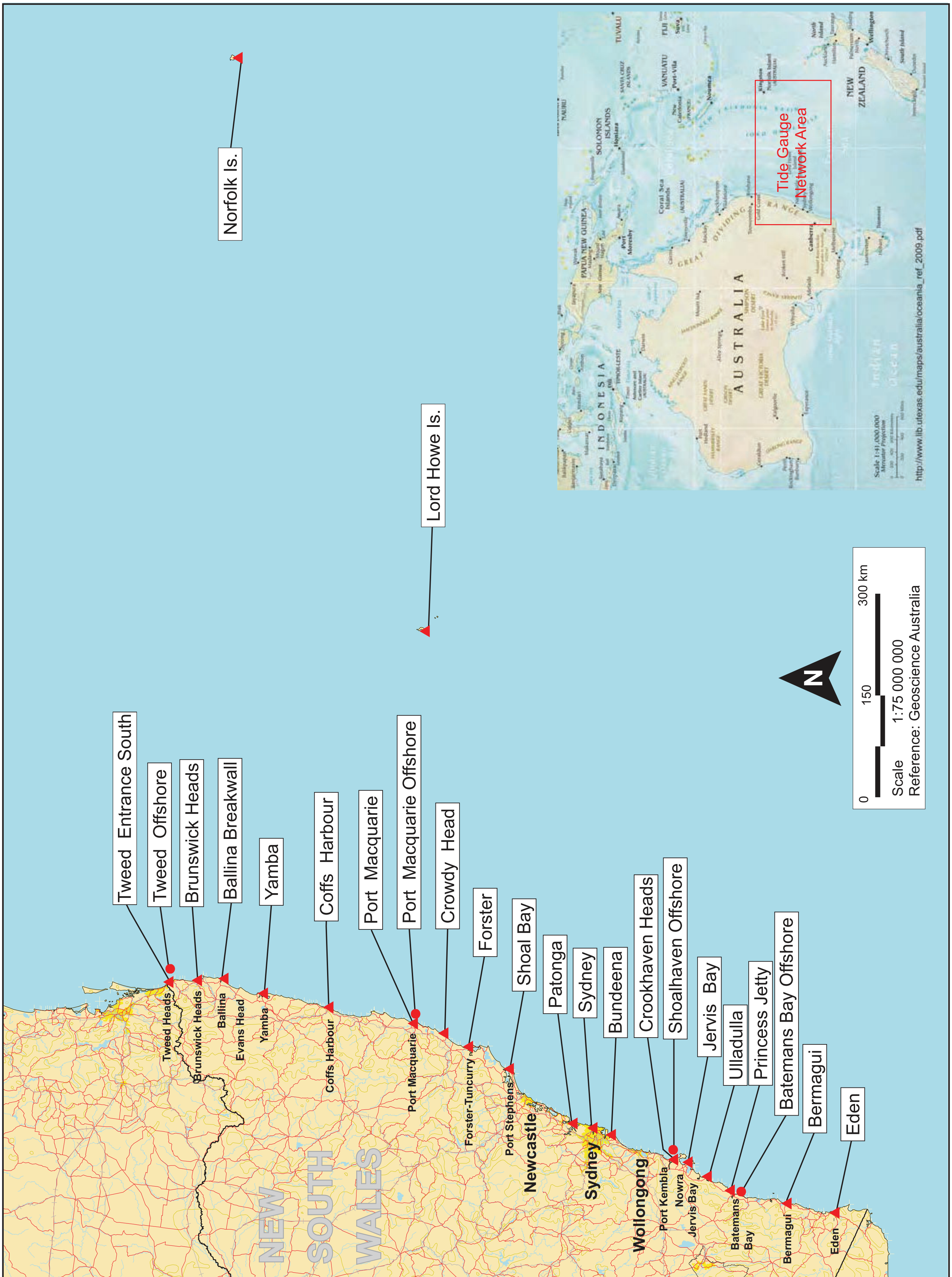
The present program is based on a network of automatic ocean tide level recording stations installed at eighteen coastal and four offshore sites, and one open ocean site located on Lord Howe Island. Additional data for Norfolk Island is provided by the Bureau of Meteorology's National Tidal Unit (NTU) (**Figure 1.1**). The ocean tide monitoring network features three distinctive system types for data capture: radar, vented pressure sensor and submersed water level pressure recorder. Electromagnetic tide poles and solid state floatwells were also previously used to collect water level data in the ocean tide program. For further details of the monitoring equipment types and the associated metadata for each individual monitoring station refer to MHL Report 2546 *Review of NSW OEH Automatic Water Level Recorder Network* (MHL 2020).

Tidal data[1] is transferred to the NSW Government Data Centre and to MHL's data server using an internet protocol (IP) network and landline telephone (Lord Howe Island). The last seven days of 15-minute tide data is available online in tables or as plots. One-minute and some 1-second data is also available on request (see MHL 2020). All data presented in this report are in Australian Eastern Standard Time (AEST). Allowance for daylight saving time needs to be made by the user of the data if required.

The data quality control process for onshore water level information can be found in Appendix D of MHL Report 2906 *NSW Estuary and River Water Levels Annual Summary* (MHL 2023b).

The station data summaries for 2021–2022 are presented in **Appendix A**.

[1] Excluding the offshore sites which are a sensor and logger combination only without telemetry capability.



NSW GOVERNMENT

OCEAN TIDE GAUGE NETWORK

Manly Hydraulics Laboratory

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Figure

1.1

DRAWING 2907-01-01.cdr

2 Air pressure program

Manly Hydraulics Laboratory has measured air pressure along the NSW coast since 1987. This data enables the correction of water level data recorded by total pressure transducers and to provide barometric information to assist the understanding of water levels associated with ocean storms.

Barometers developed by MHL, utilising an analogue pressure transducer, were installed at six Waverider buoy receiving stations until the network was decommissioned and superseded by a more comprehensive coastal air pressure monitoring system between August 1999 and February 2000 (**Figure 2.1**).

The barometer network now utilises digital barometers that sample air pressure every 5 to 15 minutes in the range 50 hPa to 1100 hPa at ± 0.2 hPa. At the barometer station air pressure data is corrected to mean sea level and stored by a data logger before it is downloaded to MHL's central server. Communications have been upgraded to the Virtual Private Network (VPN) with barometric data now uploading every 15 minutes with the water level data.

The station data summaries for 2021–2022 are presented in **Appendix B**.

NSW GOVERNMENT

NEW SOUTH WALES
COASTAL BAROMETER LOCATIONS

Manly Hydraulics Laboratory

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Figure

2.1

DRAWING 2907-02-01.cdr

3 Tidal data access, metadata and analysis

3.1 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 2021 to 30 June 2022. 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. Location maps of each station can be found in MHL 2020 with the plot of the data from that station provided in **Appendix A**. The plot confirms the availability of data for the fiscal year 2021–2022. For the availability of historical data which has been collected, refer to **Appendix C** and **Appendix D**.

Once a selection of data has been made the analysis and/or presentation can be obtained in a variety of formats: graphical plots, time series data, tidal analyses, tidal level ranking and tidal predictions.

MHL provides a full online data access service via the internet for its clients, and a limited service for the general public at http://www.mhl.nsw.gov.au.

Typically, the last seven days of telemetered data are available online in a non-quality-controlled form to aid quick access to raw data records. The online service for clients can provide access to all data catalogued in **Appendix C** and **Appendix D**.

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

3.2 Station location terminology

Tidal station locations can be referred to in several ways. As described in **Appendix C**, 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 considered. The specific latitude and longitude details of stations are distributed as part of the metadata on request. In this report, the station name, as shown in **Table C.1**, has been used throughout the report to avoid any naming convention confusion. The only exception is where references to other work are made, in which case the naming convention of the original author(s) is retained.

3.3 Datums

Most ocean tide water levels are recorded in the local port datum which generally equates to Indian Spring Low Water (ISLW). An indicative adjustment of each station from Australian Height Datum (AHD71) to local port datum is shown in **Table 3.1**. Low water datums were calculated circa 1990 for MHL by NSW Public Works Survey, using range ratio method and tidal harmonic analysis over varying time periods. AHD values should be used with caution, as AHD levels are revised from time to time and improvements to surveying techniques may provide additional refinement.

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

Table 3.1 Summary of adjustment from AHD to local port datum

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

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

3.4 Tidal planes and tidal forecasts

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

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

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

MHL has updated the 1990-2010 tidal planes analysis to the 2001–2020 tidal epoch in MHL Report 2786 *NSW Tidal Planes Analysis 2001-2020 Harmonic Analysis (*MHL2023a*)*.

The updates include standard tidal constituents and tidal planes, as well as the addition of Highest Astronomical Tide (HAT) and Lowest Astronomical Tide (LAT) at each site, including AHD referencing.

HAT, LAT, mean sea level (MSL) and tidal range values are calculated in AHD shown in **Table 3.2**. The exceptions to these are Lord Howe Island and Norfolk Island which are in local datum as there are no references to AHD in these locations. To convert the values in **Table 3.2** to local datum use the offsets provided in **Table 3.1.**

Table 3.2 Ocean and river entrance tide HAT and LAT values (m AHD*)

Site	Period 2001–2020			
	HAT	LAT	Range	MSL
Tweed Heads	1.09	-0.88	1.97	0.04
Brunswick Heads	1.18	-0.88	2.06	0.05
Ballina Breakwall	1.10	-0.84	1.94	-0.02
Yamba	1.11	-0.83	1.94	0.05
Coffs Harbour	1.23	-0.95	2.18	0.03
Port Macquarie	1.03	-0.74	1.77	0.02
Crowdy Head	1.19	-0.97	2.16	-0.02
Forster	0.88	-0.89	1.77	-0.03
Shoal Bay	1.16	-0.94	2.10	0.00
Patonga	1.17	-0.88	2.05	0.06
Sydney	1.15	-0.86	2.01	0.04
Port Hacking	1.20	-0.82	2.02	0.08
Crookhaven Heads	1.03	-0.77	1.80	0.04
Jervis Bay	1.14	-0.88	2.02	0.06
Ulladulla	1.08	-0.88	1.96	0.04
Princess Jetty	1.06	-0.78	1.84	0.06
Bermagui	1.02	-0.87	1.89	-0.02
Eden	0.98	-1.02	2.00	-0.09
Lord Howe Island*	2.32	-0.07	2.39	1.06
Norfolk Island*	2.00	0.08	1.92	1.01

*Results for Lord Howe Island and Norfolk Island are presented in local datum, as AHD is unavailable.

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

4 Significant tidal events 2021–2022

The data recovery statistics and comments on data losses are provided in **Table 4.1**.

Table 4.1 Data recovery July 2021 to June 2022

Data stream	Data recovery (%)	Comments
15-minute ocean tide data	99.25	Small percentage of data loss is mainly contributed by Ballina breakwall tide gauge. This gauge's orifice line was damaged by multiple swell events.
1-minute ocean tide data	98.87	
5-minute and 60-minute offshore data	36.00[2]	Tweed Heads: Major data loss with the primary logger memory failure (no data stored). Secondary pressure sensor failure and internal lithium battery failure. Port Macquarie: Major data loss with primary logger flat battery and inability to connect with available software. Secondary pressure sensor failure. Shoalhaven: No instruments were deployed from December 2021 due to unsuitable dive conditions during available dive windows and program budget. Batemans Bay: Major data loss with the primary logger memory failure (no data stored). Secondary sensor recorded corrupted data.

The 2021–2022 target data recovery rate of over 95% for the 15-minute ocean tide data (99.3%) was achieved. However, the offshore tide data recovery rate (36.0%) did not achieve the 95% recovery target primarily due to combined failure of the primary and secondary monitoring equipment at three of the four stations. The existing offshore gauges are now considered to have reached end of asset life, with over 10 years' and 30 years' reliable service, respectively.

Next generation offshore gauge trials started in 2020. The equipment must demonstrate reliable data capture between planned annual dives which may be extended by months when water conditions are unsuitable for available specialist dive teams. Secondary units are adopted as backup in case of a single gauge failure.

A complete new fleet of modern gauges (primary and secondary) has been procured. As of February 2023, all offshore primary and secondary gauges have been replaced with new equipment, except the Tweed Offshore site where the new primary gauge is supported by an original operational (at time of deployment) sensor/logger unit. This old unit will be replaced with a next generation gauge at the next planned dive.

[2] A replacement program designed to achieve the target data recovery rate post-new offshore gauge deployments is now underway.

The *2023 NSW Tide Charts* are available free of charge via download from the MHL public web page. The charts remain an authoritative reference for tides along the NSW coast (**Figure 4.1**). As for previous tide prediction publications, MHL adopts 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 through analysis of the tide levels recorded at gauges at each of the secondary locations (MHL 2001).

4.1 Tidal anomalies

Tidal anomalies in this report are calculated as the difference between the recorded data and the long-term epoch forecasts as discussed in **Section 3.4**.

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

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

The anomalies recorded on the NSW coast during the reporting period are compared across a selected group of stations in **Figure 4.2**. The major anomalies, which are classified as greater than ±0.25 m difference between recorded and forecast data, are identified on **Figure 4.2** and documented in more detail in **Figure 4.3** and **Figure 4.4**. Most are driven by ECLs or large high pressure systems. **Figure 4.5** to **Figure 4.8** show the tidal anomalies recorded at each station during the reporting period. **Figure 4.9** shows the anomalies for the four offshore tide stations.

The Bureau of Meteorology (BoM) recorded two Tropical Cyclones in Queensland that affected the NSW coast during the 2021–2022 reporting period.

- 9 to 15 December 2021, Tropical Cyclone Ruby formed in the Solomon Sea on 9 December, the tropical low moved slowly towards the south-east. It was upgraded to a Category 1 tropical cyclone on 12 December, intensifying into Category 2 on the same day. Ruby moved out of the Australian area of responsibility (160°E) and travelled over New Caledonia before weakening on 15 December. Tidal anomalies greater than 0.25 m are evident from Tweed Entrance South to Princess Jetty.
- 23 December 2021 to 7 January 2022, Tropical Cyclone Seth formed as a tropical low north of the Northern Territory in the eastern Timor Sea on 23 December. The tropical low was slow, moving south towards Dundee Beach, then started moving east on 27 December. It continued moving eastward and entered the Coral Sea on 30 December. The low was upgraded into a tropical cyclone by the BoM on 31 December, peaking at Category 2, and was then downgraded to Category 1 on 1 January. Seth was reclassified as a subtropical cyclone on 2 January, then slowly moved westward crossing the southern Queensland coast on 7 January. Before it weakened, it produced heavy rainfall which

caused severe flooding in south-east Queensland and hazardous surf and coastal inundation on southern Queensland and northern NSW coast. Tidal anomalies greater than 0.25 m are evident from Tweed Entrance South to Yamba.

4.2 Tsunami events

Table 4.2 lists the earthquake or volcano events that had associated tsunami events in the Pacific region for the period of time corresponding to the 2021–2022 data in this report. Earthquake events included in the list are those that have a magnitude of greater than or equal to 6 M_w.

Table 4.2 Recorded earthquake or volcano events July 2021 to June 2022

Date (UTC)	Event	Location	Observable on NSW tide recordings
11/08/2021	Earthquake (7.1 M_w)	Philippines – Mindanao Island	No
14/12/2021	Earthquake (7.3 M_w)	Indonesia – Flores Sea	No
13/01/2022	Volcano	Tonga – Tonga Islands	No
15/01/2022	Volcano	Tonga – Tonga Islands	Yes
16/01/2022	Volcano	Tonga – Tonga Islands	Yes
29/01/2022	Earthquake (6.5 M_w)	New Zealand – Kermadec Islands	No
16/03/2022	Earthquake (7.3 M_w)	Japan – Off Fukushima	No
30/03/2022	Earthquake (6.9 M_w)	New Caledonia – Loyalty Islands	No
31/03/2022	Earthquake (7.0 M_w)	New Caledonia – Loyalty Islands	No

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

The BoM and Geoscience Australia host the Joint Australian Tsunami Warning Centre (JATWC). The BoM collects specific tsunami data for issuing warnings, and the data can be requested from BoM for further use.

On Saturday afternoon 15 January 2022, an underwater volcano, called the Hunga Tonga-Hunga Ha'apai volcano located near Tonga and about 3,300 kilometres east of Australia erupted. The eruption generated pressure and surface waves that travelled across the globe, thick smoke and ash clouds could be seen in satellite images, as shown in **Figure 4.10**. The satellite imagery of the pressure wave and ensuing source wave is shown in **Figure 4.10** along with the measured BoM barometric pressure gauges across Australia as the wave travelled east to west. The generated tsunami waves triggered JATWC-issued tsunami warnings to Australia's east coast and islands.

It is possible to model both meteotsunami and tsunami waves using a shallow linear wave equation and the known epicentre of the eruption. **Figure 4.11** shows the modelled contour plotted arrival times for the Hunga Tonga eruption (Gareth Davies, Geoscience Australia). The model uses both a friction term and a constant wave speed of 320 m/s which is derived from the pressure maxima arrival times at gauges across Australia. The figure on the left shows the modelled shorter time period for the pressure wave meteotsunami arrival to the source or landslide-generated ocean tsunami waves. In contrast, below is the Tweed Entrance 1-minute data, residual and closest barometer (Coolangatta) measured data. The same frame of time reference has been created with the red line to indicate time of eruption and the yellow dotted line to show the initial pressure wave causing the meteotsunami in the water level (red circle). The subsequent tsunami wave then dominates the signal when arriving approximately 3 hours later. Tsunami wave periods range from 5 to 90 minutes making higher resolution one-minute and one-second[3] data sets better suited to analyse the tsunami waves as there is a descending relationship between measured wave height and energy to increasing time intervals for sampling (Rabinovich 2011).

The maximum overall tsunami waves recorded were in NSW trapped harbour embayments such as Coffs Harbour, Ulladulla and Crowdy Head. These experienced amplified water level oscillations due to the creation of a standing wave within the harbour boundaries. The maximum tsunami waves of these harbour embayments (obtained by getting the highest difference between actual 1-minute data and predicted tide) were 0.60 m, 0.74 m, and 0.97 m, respectively as shown in **Figure 4.12**. A comparison of embayment area and its effect on a trapped waves is also evident in **Figure 4.12**. Crowdy Head harbour detected the largest wave displacement. The size of Crowdy Head harbour is considerably smaller than Coffs Harbour and Ulladulla, which can be seen on the satellite images of these harbours. The effect of the harbour size is evident when the 1-minute data of Coffs Harbour, Ulladulla and Crowdy Head are plotted in one graph as shown in **Figure 4.13**. Coffs Harbour has a clearer sinusoidal wave compared to Crowdy Head, while Crowdy Head has more wave interference and approximately half the period. The resulting seiching is far more erratic inside Crowdy Head harbour. The size of Ulladulla is smaller than Coffs Harbour and larger than Crowdy Head, and it can be observed that it has more wave interference than Coffs Harbour but less than Crowdy Head.

Tide gauges in bays, such as Princess Jetty and Eden, experienced less wave oscillations because the areas of these bays are more open with different bathymetry and geomorphology compared to harbour embayments. However, the range of the tsunami waves at these open bay sites is comparable to that of Ulladulla Harbour, as shown in **Figure 4.13**. The comparison of tsunami wave effects was far less evident in open river gauges compared to harbours and open bays. The tsunami waves were dampened at more open river sites, such as Brunswick Heads and Ballina breakwall shown in **Figure 4.14**. At open river sites wave disturbances continued to travel upstream and the energy is not harnessed in a fixed boundary. Looking at the Yamba open river gauge that sits at the mouth of the Clarence river, the tsunami disturbance is measured in the 1-minute datasets from Yamba to Grafton which is over 50 km further upstream as shown in **Figure 4.14.** Wave shoaling can also account for the greater amplitudes inside open bays compared to open river gauges. The driving mechanism occurs when a wave enters shallow water and experiences force from the sea floor, resulting in a decrease in wave speed, decrease in wavelength and increase in wave height.

The pumping of ocean lake system water levels can occur during tsunami events. NSW has several large ocean lake systems including Lake Illawarra subject to anomaly pumping. Crookhaven Heads was measured with a maximum tsunami wave of 0.28 m. Water levels

[3] One second data is only available at select locations.

inside Lake Illawarra have been raised by a 0.1 m anomaly, with a maximum tsunami wave height of 0.18 m at Koonawarra Bay as shown in **Figure 4.15**. With a tidal range of 0.2–0.3 m inside Lake Illawarra, the 0.1 m anomaly can cause certain parts of the lake to inundate without warning.

Any impacts to marine infrastructure and water craft were minimal. This was a combination of timing of the event in the tidal cycle (neap) and the maxima energy of the seiche waves in embayments happening overnight. Long-term data and near real time data is essential for the State of NSW to manage these events in addition to supporting warning services by the BoM for public safety.

4.3 King tide events

Predicted king tides over the 2021–2022 financial year occurred on 06 December 2021, 03 January 2022, 17 May 2022 and 15 June 2022. The highest recorded actual water level associated with a spring tide in Sydney during the 2021–2022 financial year was 1.24 m AHD in July 2021. This was also the highest recorded water level at the Sydney gauge during the 2021–2022 financial year.

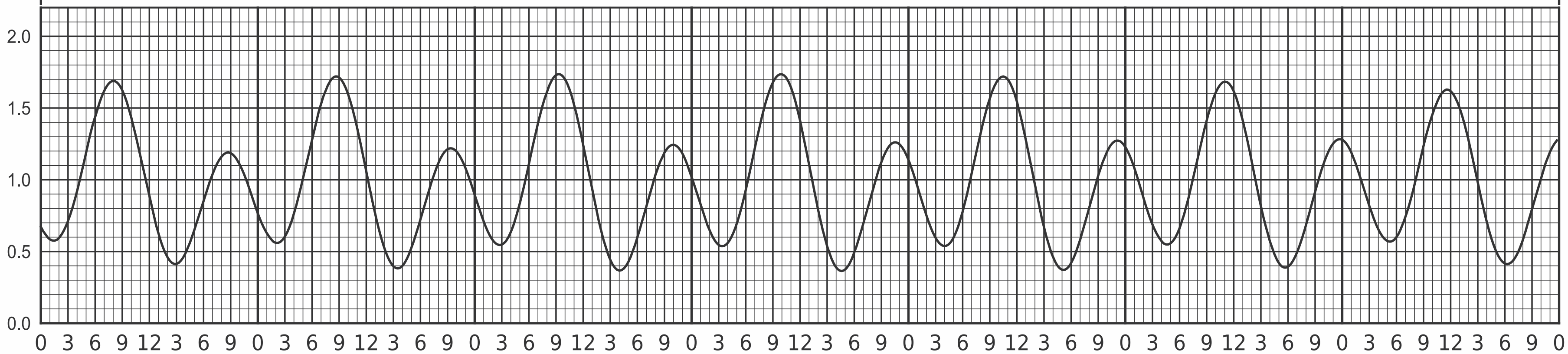
There were several events in 2021–2022 that created a high residual level (difference between actual and predicted tide) above 0.25 m at the Sydney gauge. The most sustained event during the financial year occurred during the March flooding event caused by a blocking high pressure system in the Tasman Sea resulting in a very humid environment along much of the coast. The combination of a spring tide, continual wave action and intense rainfall saw the residual in Sydney remain above 0.25 m from 4–11 March 2022 as shown in **Figure 4.16**. Localised coastal conditions on Sydney's northern beaches are also captured in **Figure 4.16**.

January 2023

Daylight Saving Time

Full Moon 7 Jan

5 Thursday	6 Friday	7 Saturday	8 Sunday	9 Monday	10 Tuesday	11 Wednesday
Sunrise: 05:50AM	Sunrise: 05:51AM	Sunrise: 05:52AM	Sunrise: 05:53AM	Sunrise: 05:53AM	Sunrise: 05:54AM	Sunrise: 05:55AM
Sunset: 08:09PM	Sunset: 08:09PM	Sunset: 08:09PM	Sunset: 08:09PM	Sunset: 08:09PM	Sunset: 08:09PM	Sunset: 08:09PM



5 Thursday		6 Friday		7 Saturday		8 Sunday		9 Monday		10 Tuesday		11 Wednesday	
1:26am	0.58m 1ft 11in	2:07am	0.56m 1ft 10in	2:46am	0.55m 1ft 9in	3:24am	0.54m 1ft 9in	4:01am	0.54m 1ft 9in	4:37am	0.55m 1ft 10in	5:15am	0.57m 1ft 10in
8:01am	**1.69m 5ft 6in**	**8:41am**	**1.72m 5ft 8in**	**9:17am**	**1.74m 5ft 8in**	**9:54am**	**1.74m 5ft 8in**	**10:28am**	**1.72m 5ft 8in**	**11:02am**	**1.68m 5ft 6in**	**11:37am**	**1.63m 5ft 4in**
2:52pm	0.41m 1ft 4in	3:29pm	0.38m 1ft 3in	4:02pm	0.37m 1ft 2in	4:35pm	0.36m 1ft 2in	5:09pm	0.37m 1ft 3in	5:43pm	0.39m 1ft 3in	6:17pm	0.41m 1ft 4in
8:41pm	**1.19m 3ft 11in**	**9:22pm**	**1.22m 4ft 0in**	**9:56pm**	**1.24m 4ft 1in**	**10:32pm**	**1.26m 4ft 2in**	**11:07pm**	**1.27m 4ft 2in**	**11:42pm**	**1.28m 4ft 3in**		

NSW TIDAL PREDICTIONS
EXTRACT FROM 'NSW TIDE CHARTS 2023'

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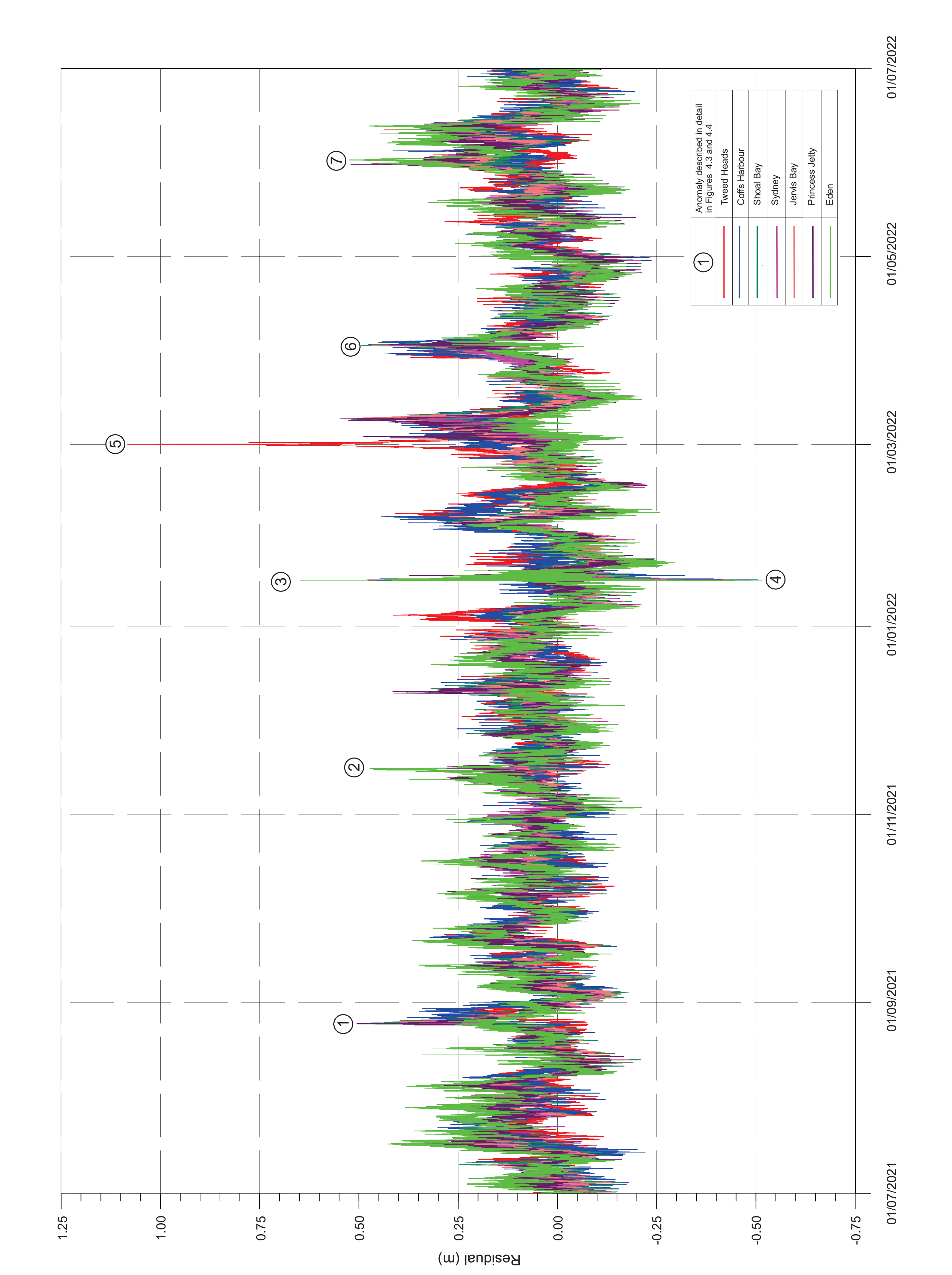
Figure

4.1

DRAWING 2907-04-01.cdr



NSW TIDAL ANOMALIES PLOT 2021–2022

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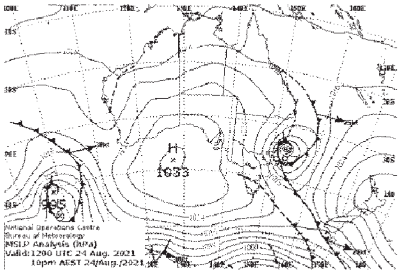
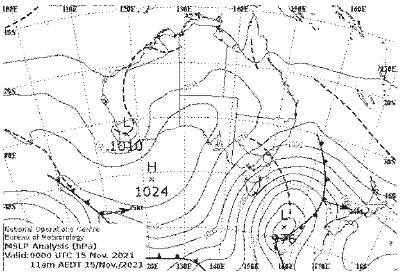
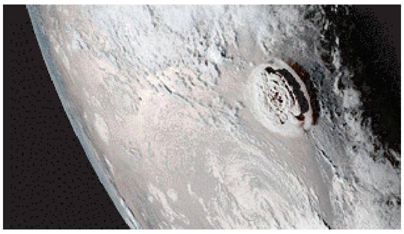
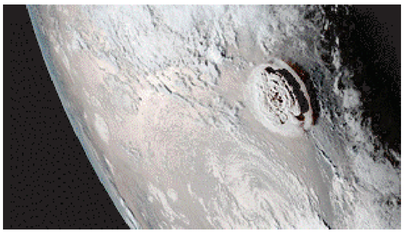
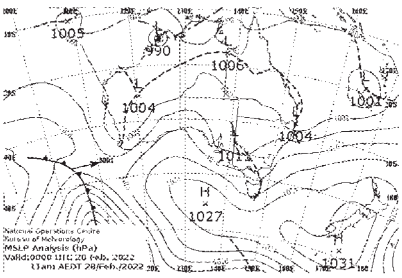
Figure 4.2

DRAWING 2907-04-02.cdr

Event number (see Figure 4.2)	Event period	BoM weather map* or satellite image#	Peak anomaly	Sites where anomaly > +/- 0.25m
1	24–28 August 2021	 East Coast Low	Site Ulladulla Date 25/08/2021 Time 1200 Peak value 0.763	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui
2	14–17 November 2021	 Low pressure system/flooding	Site Eden Date 15/11/2021 Time 2030 Peak value 0.473	Crowdy Head, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
3	15–17 January 2022	 Underwater volcanic eruption	Site Crowdy Head Date 15/01/2022 Time 2200 Peak value 0.703	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladullla, Princess Jetty, Bermagui, Eden
4	15–17 January 2022	 Underwater volcanic eruption	Site Crowdy Head Date 16/01/2022 Time 0000 Peak value -0.635	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladullla, Princess Jetty, Bermagui, Eden
5	28 February–6 March 2022	 February–March flooding	Site BrunswickHeads Date 28/02/2022 Time 1330 Peak value 2.251	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladullla, Princess Jetty, Bermagui

Satellite imagery of the Hunga Tonga volcano eruption (NOAA)

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TIDAL ANOMALY EVENTS JULY 2021–JUNE 2022

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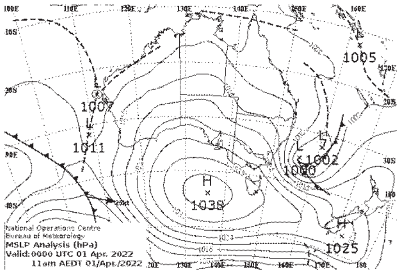
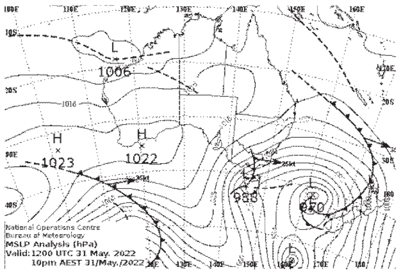
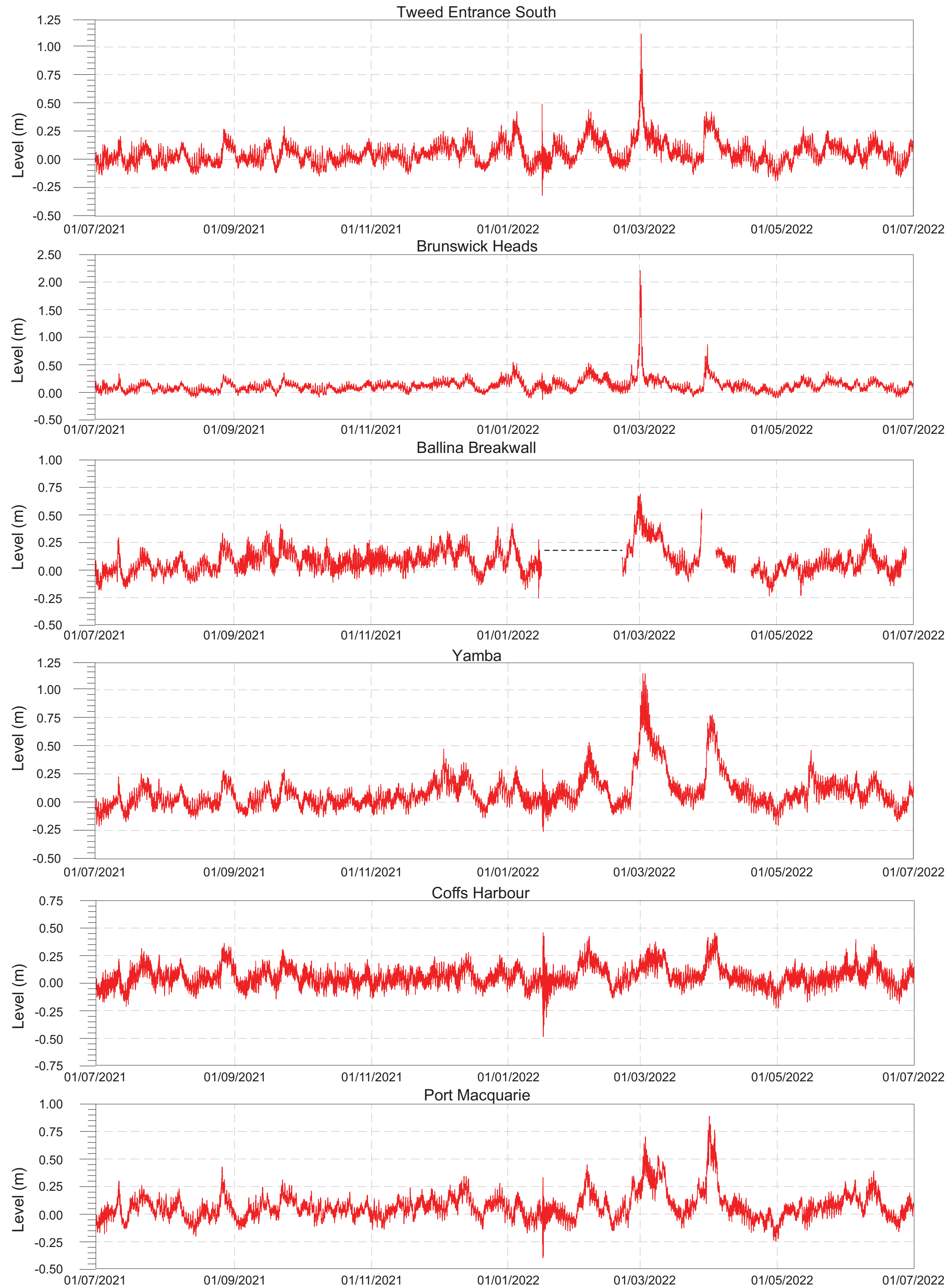
Figure 4.3

DRAWING 2907-04-03.cdr

Event number (see Figure 4.2)	**Event period**	**BoM weather map***	**Peak anomaly**	**Sites where anomaly > +/- 0.25m**
6	30 March–7 April 2022	 March–April flooding	Site: Brunswick Heads Date: 30/03/2022 Time: 1245 Peak value: 0.863	Tweed, Brunswick, Ballina, Yamba, Coffs Harbour, Port Macquarie, Crowdy Head, Forster, Shoal Bay, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden
7	30 May–5 June 2022	 South coast low pressure system	Site: Eden Date: 01/06/2022 Time: 0645 Peak value: 0.524	Yamba, Coffs Harbour, Port Macquarie, Patonga, Sydney, Bundeena, Crookhaven Heads, Jervis Bay, Ulladulla, Princess Jetty, Bermagui, Eden



NSW GOVERNMENT

TIDAL ANOMALIES 2021–2022
TWEED ENTRANCE SOUTH TO PORT MACQUARIE

Manly Hydraulics Laboratory

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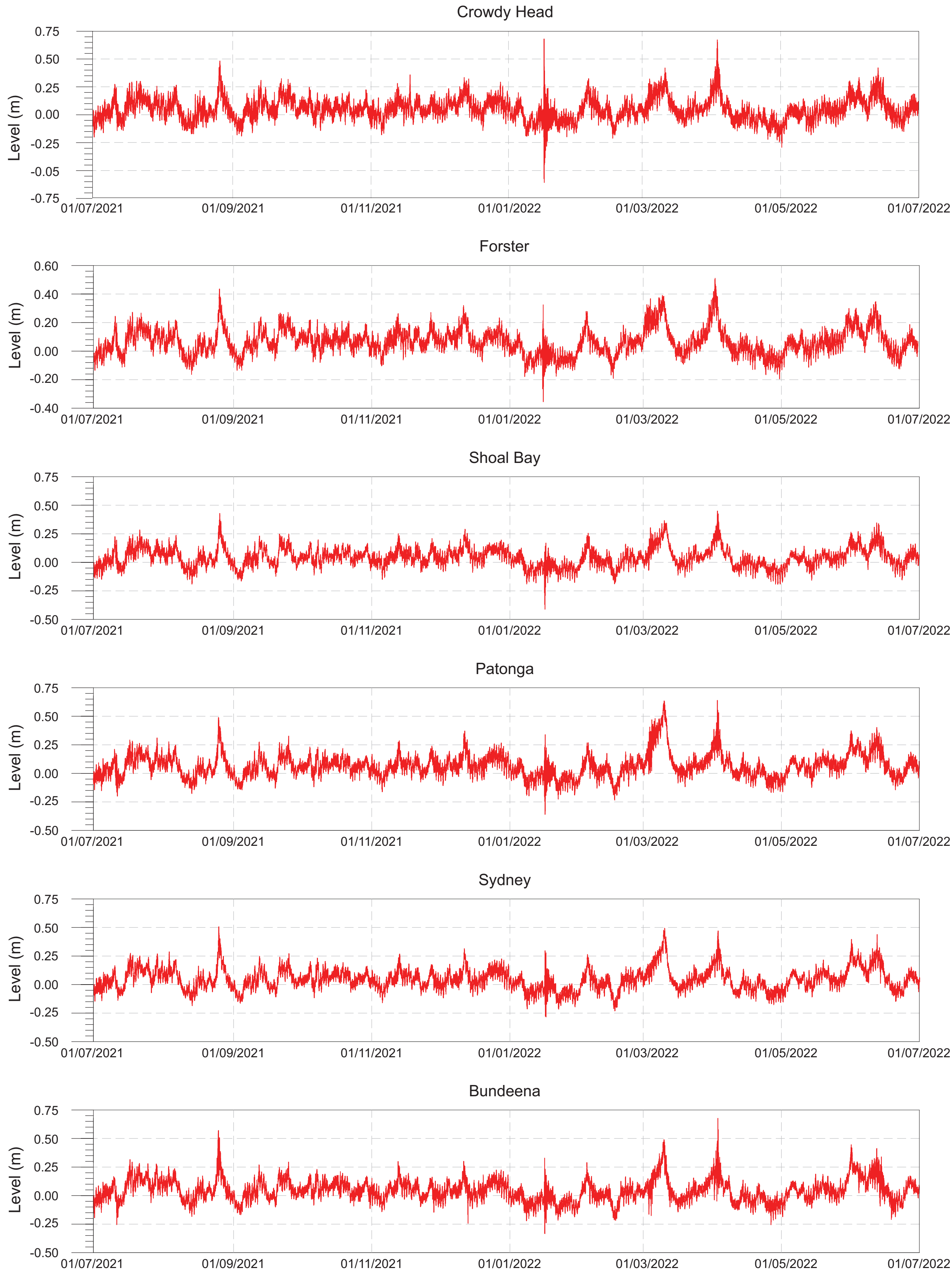
Figure
4.5

DRAWING 2907-04-05.cdr



NSW GOVERNMENT

TIDAL ANOMALIES 2021–2022
CROWDY HEAD TO BUNDEENA

Manly Hydraulics Laboratory

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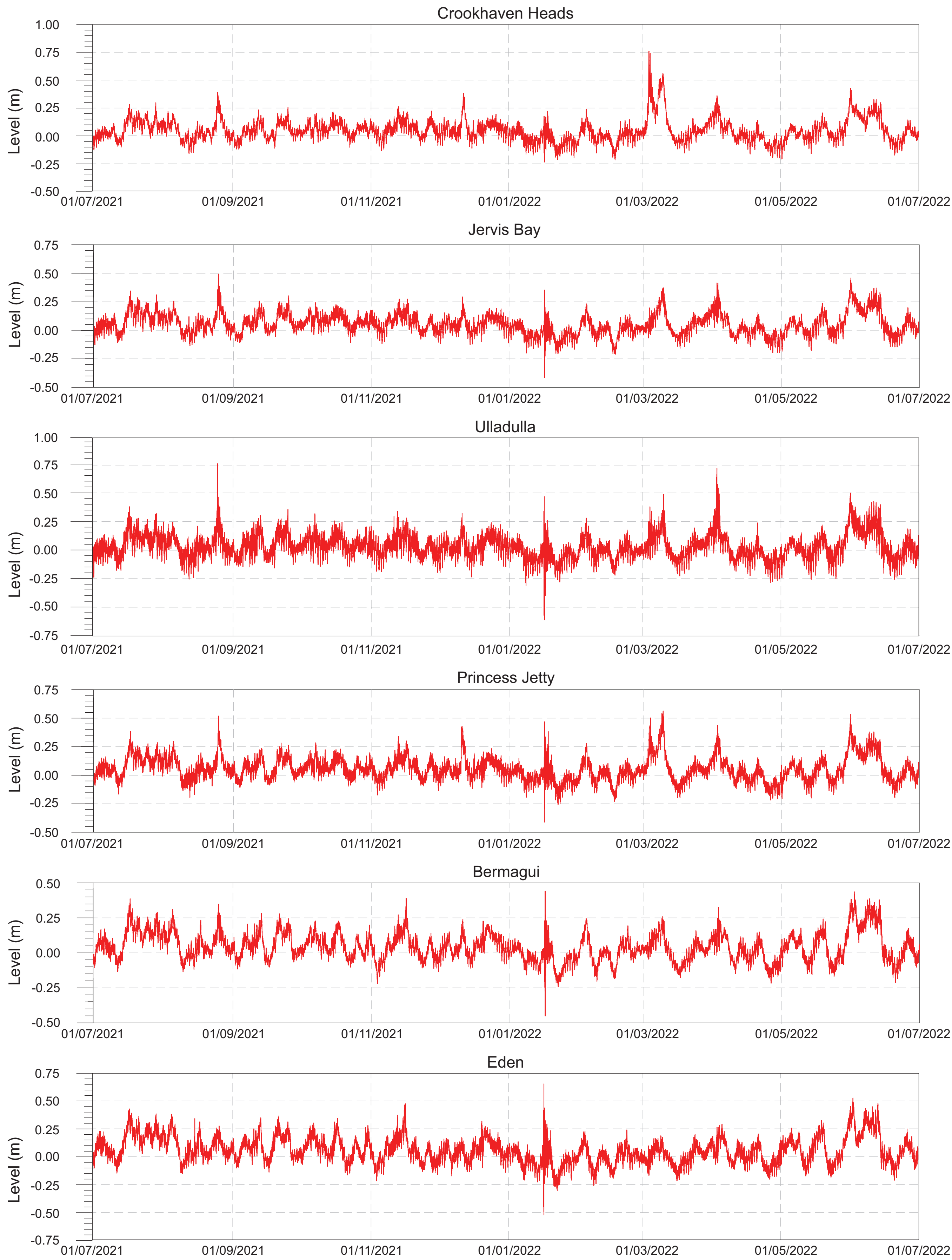
Figure 4.6

DRAWING 2856-04-06.cdr



NSW GOVERNMENT

TIDAL ANOMALIES 2021–2022
CROOKHAVEN HEADS TO EDEN

Manly Hydraulics Laboratory

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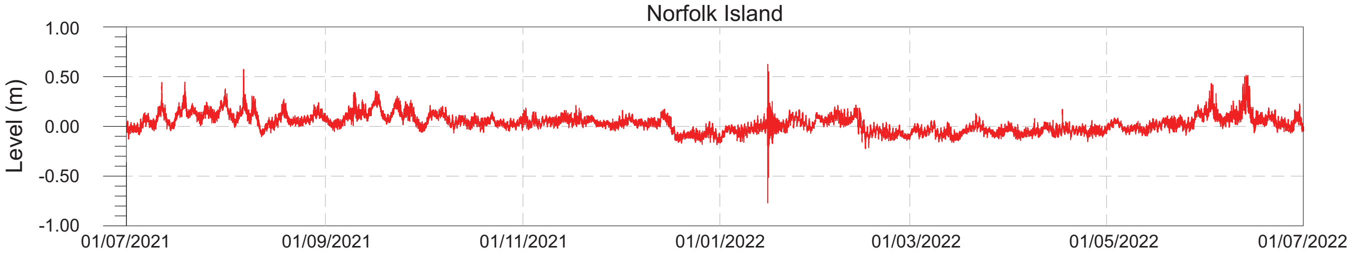
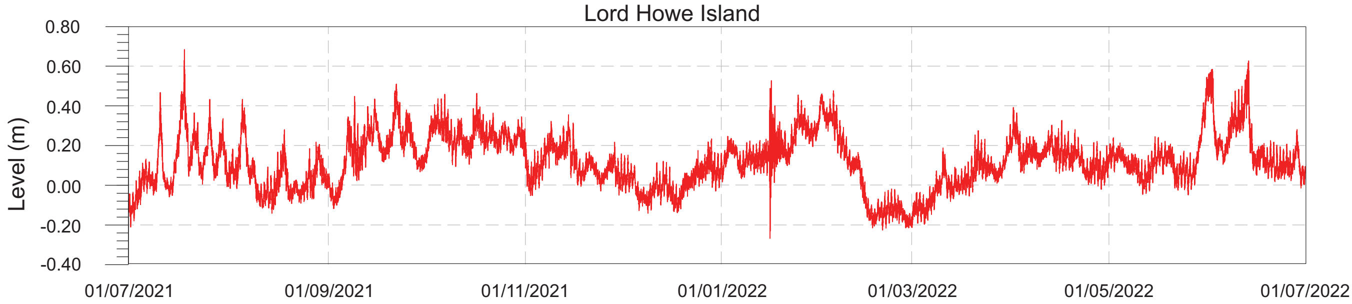
Figure

4.7

DRAWING 2856-04-07.cdr





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

TIDAL ANOMALIES 2021–2022
NORFOLK ISLAND AND LORD HOWE ISLAND

NSW GOVERNMENT

Manly Hydraulics Laboratory

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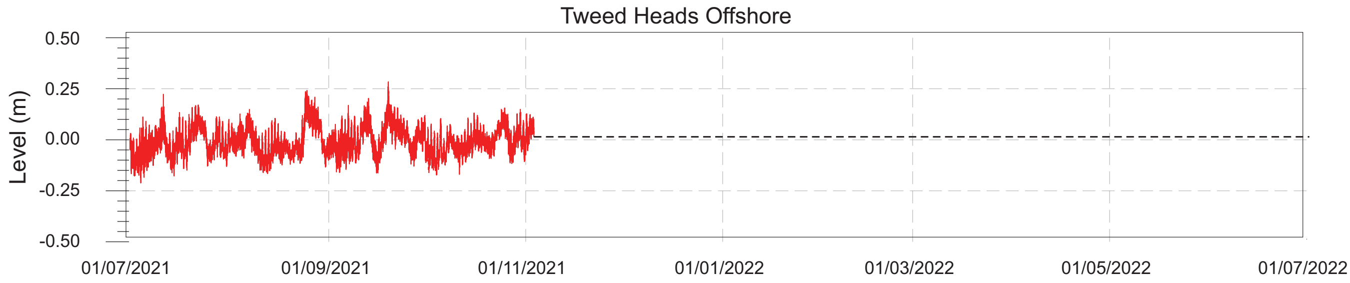
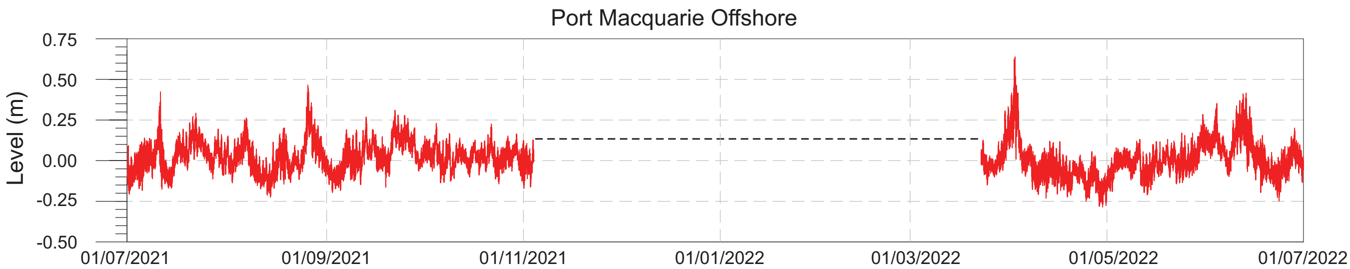
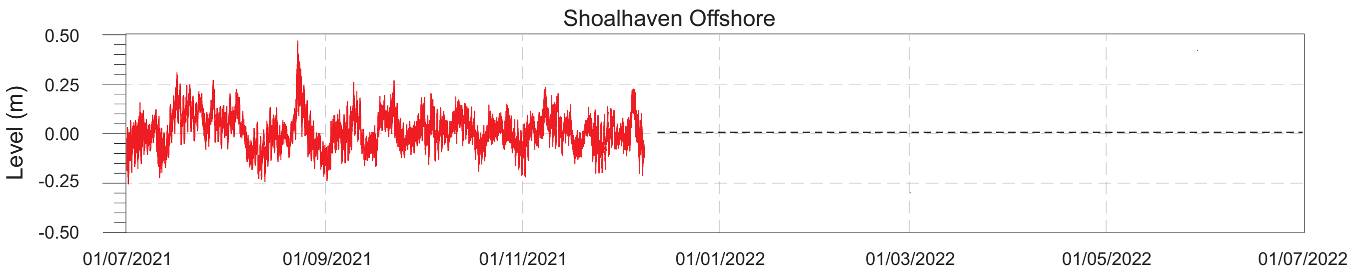
Figure

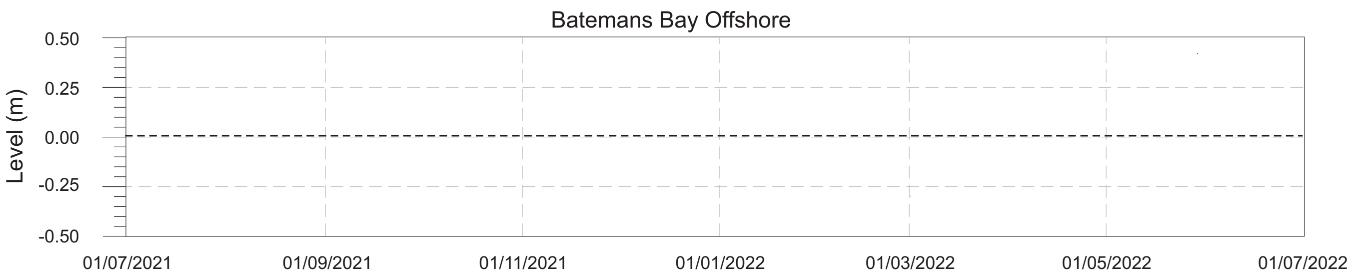
4.8

DRAWING 2907-04-08.cdr









NSW GOVERNMENT

TIDAL ANOMALIES 2021–2022
OFFSHORE TIDE GAUGES

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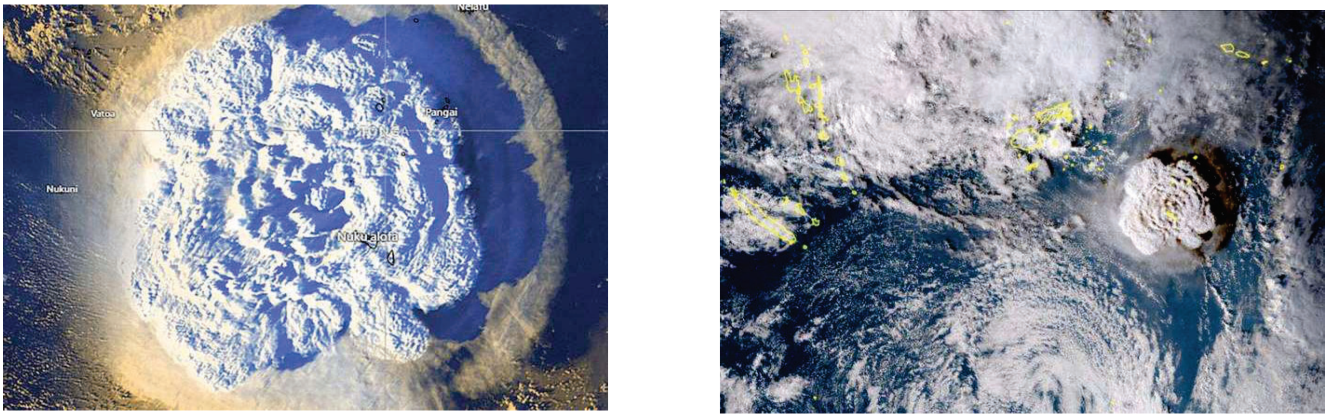
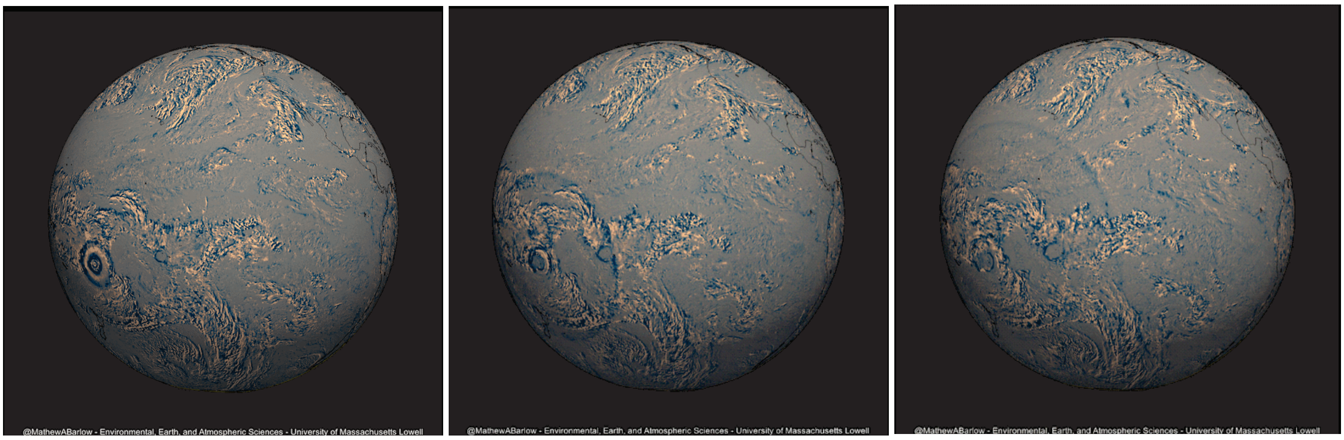
Figure
4.9

DRAWING 2907-04-09.cdr



Satellite image of the volcano eruption taken by Tonga Meteorological Services and Himawari-8, respectively. Courtesy of 7news



Satellite infrared observations captured the shockwave caused by the volcano eruption propagating around the world.
Image credit: Mathew Barlow, University of Massachusetts Lowell. Courtesy of Space.com

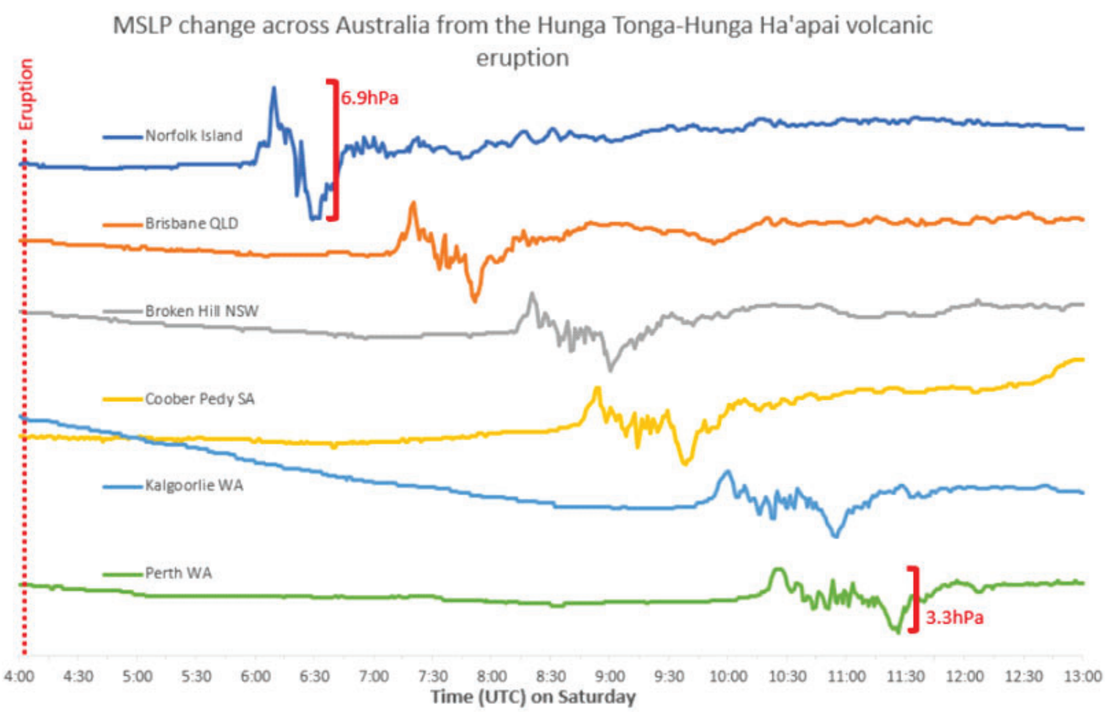


Image courtesy of BoM © Commonwealth of Australia, Bureau of Meteorology

NSW GOVERNMENT

EFFECT OF THE VOLCANO ERUPTION
ON ATMOSPHERIC PRESSURE

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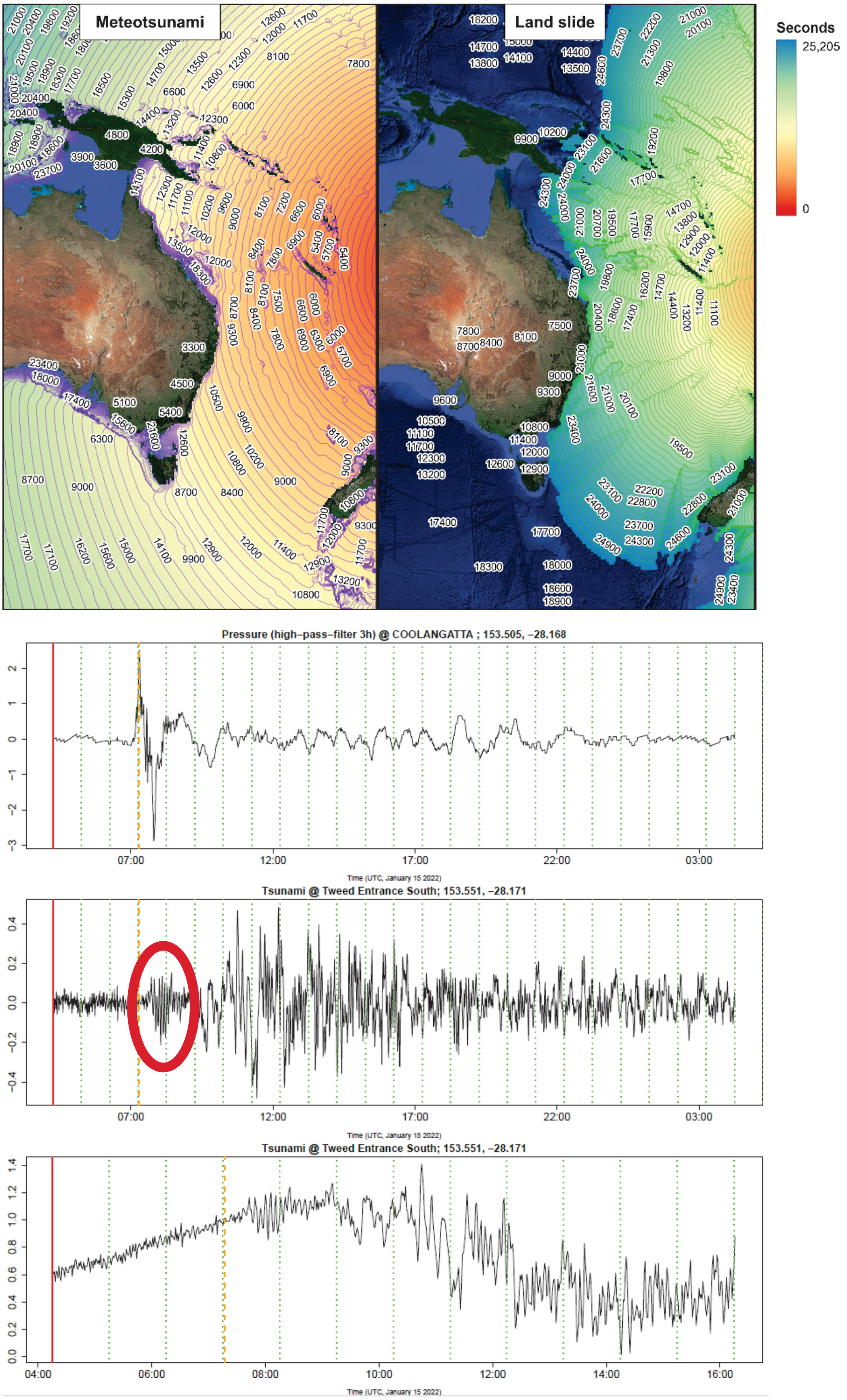
Figure

4.10

DRAWING 2907-04-10.cdr



Source: Gareth Davies, Geoscience Australia

MODELLED AND MEASURED TSUNAMI WAVE ARRIVAL TIMES TO NSW COASTAL GAUGES

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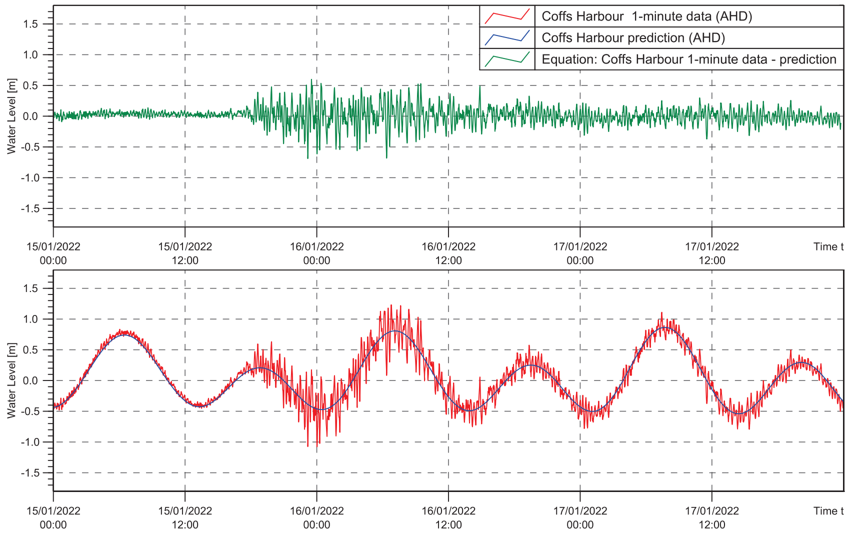
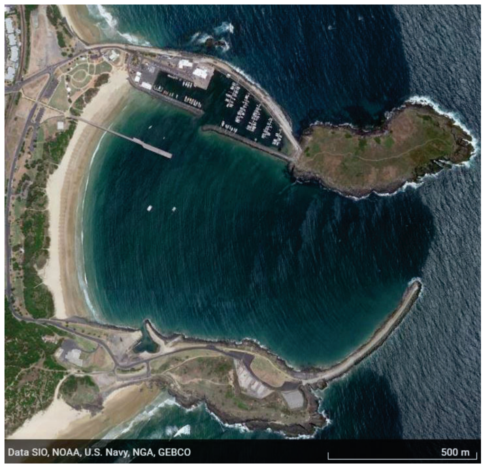
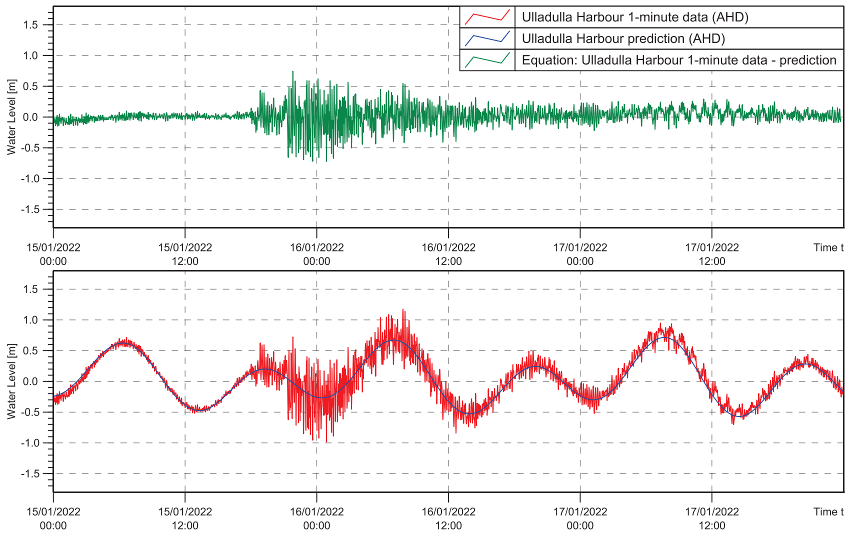
Figure 4.11

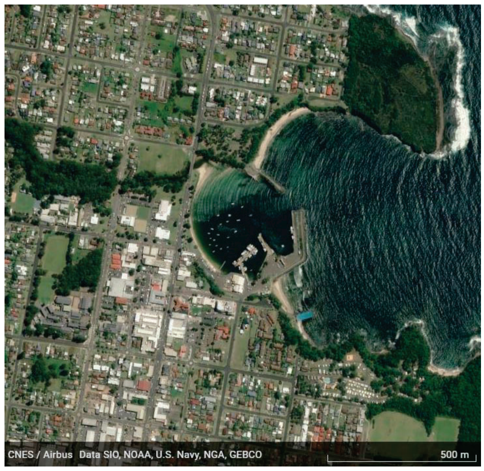
DRAWING 2907-04-11.cdr



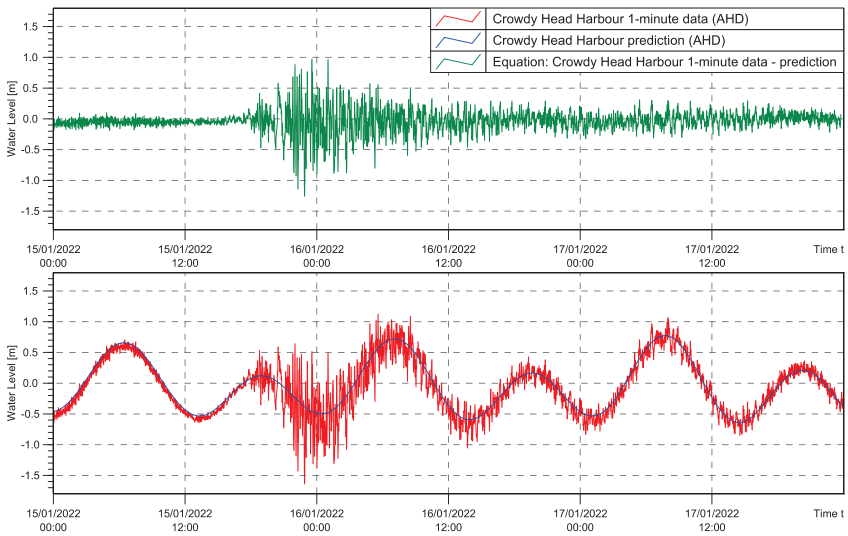


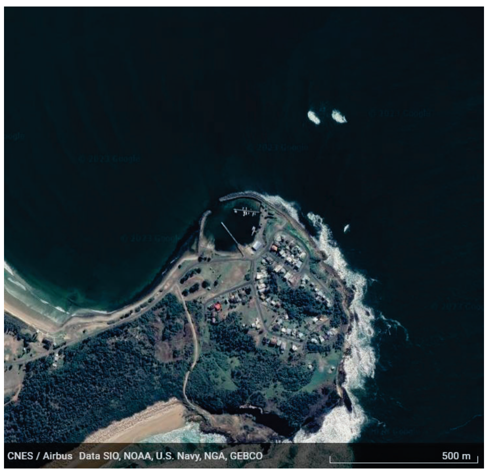
Source: Google Earth





Source: Google Earth





Source: Google Earth

NSW GOVERNMENT

MAXIMUM TSUNAMI WAVES AND EMBAYMENT AREAS OF COFFS HARBOUR, ULLADULLA AND CROWDY HEAD

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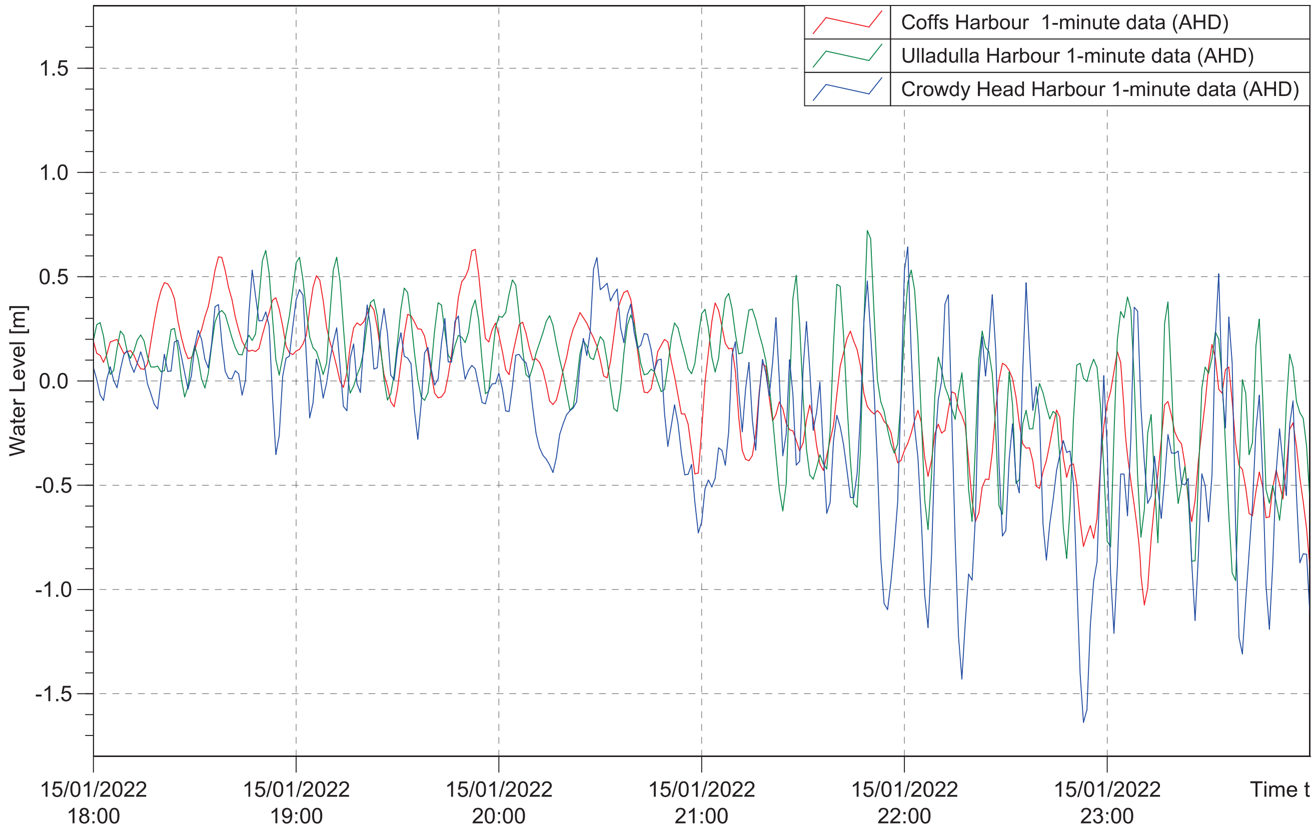
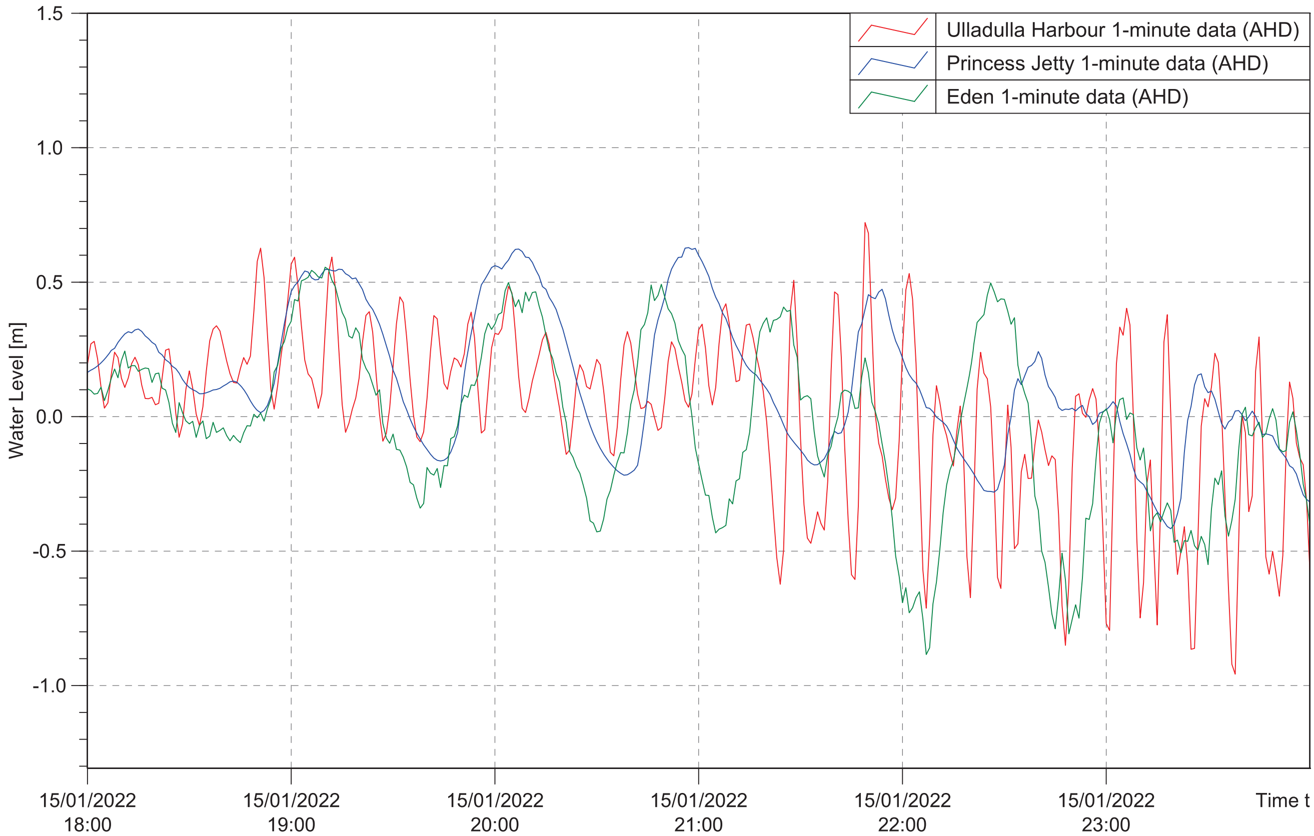
Figure 4.12

DRAWING 2907-04-12.cdr





NSW GOVERNMENT

COMPARISON OF TSUNAMI WAVE EFFECTS
IN NSW COASTAL HARBOURS AND BAYS

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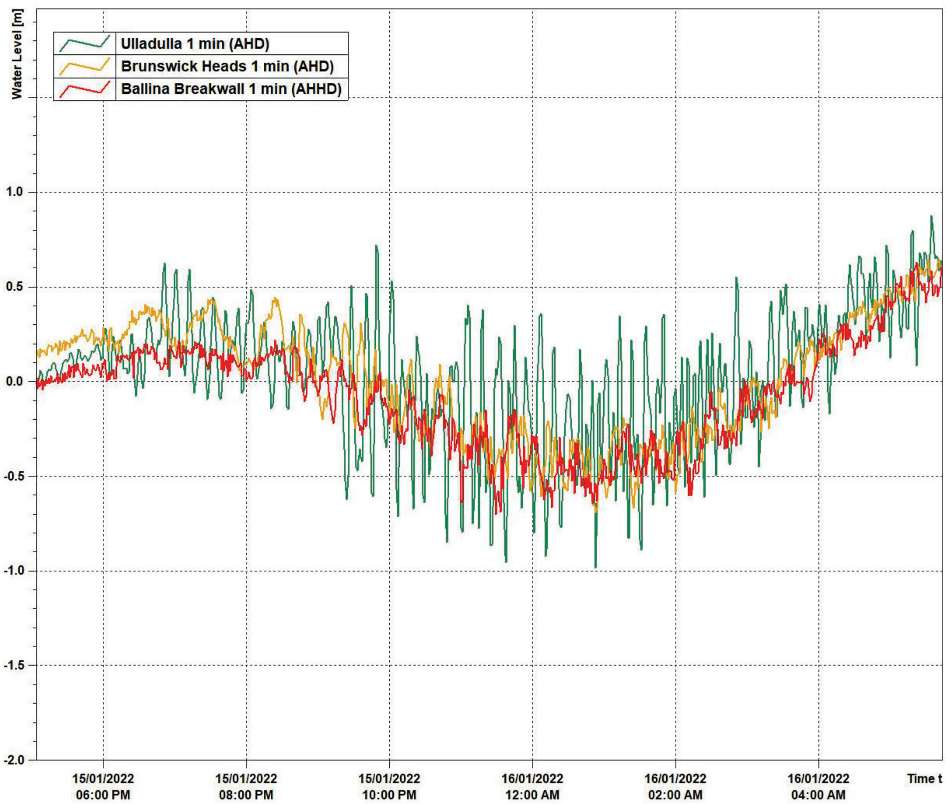
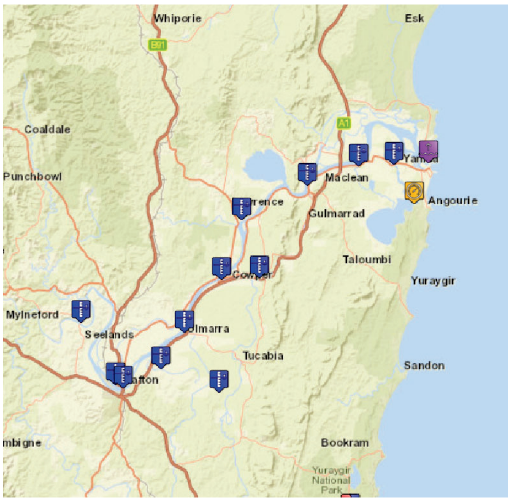
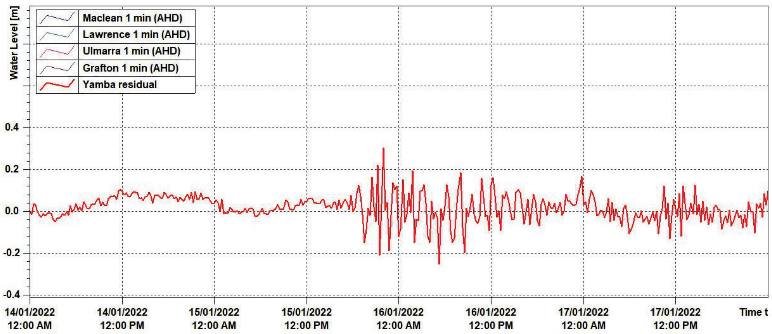
Figure

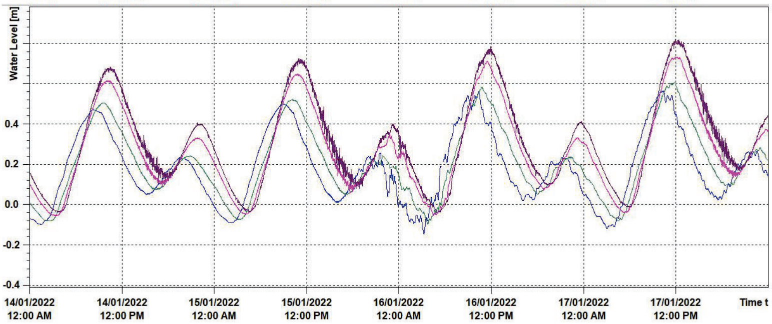
4.13

DRAWING 2907-04-13.cdr









NSW GOVERNMENT

COMPARISON OF TSUNAMI WAVE EFFECTS
IN NSW COASTAL OPEN RIVERS

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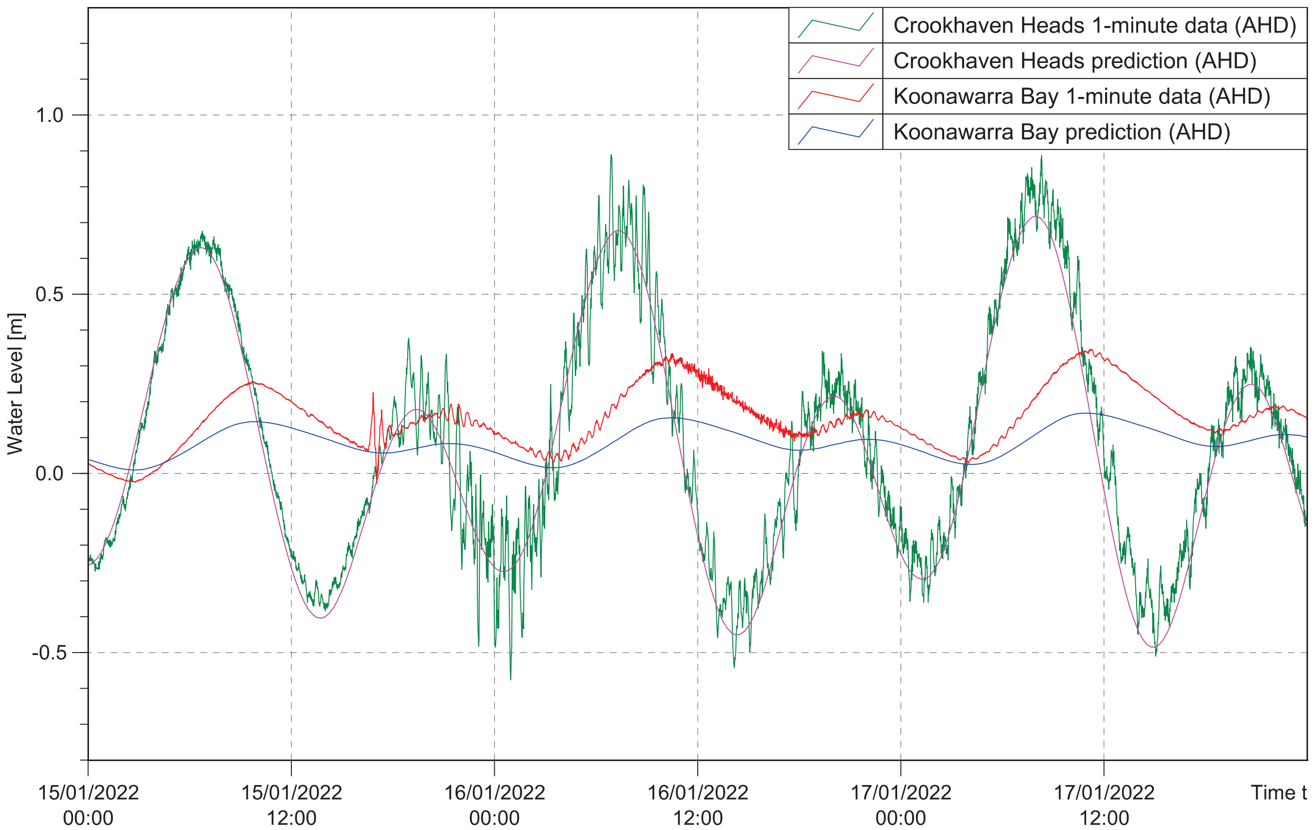
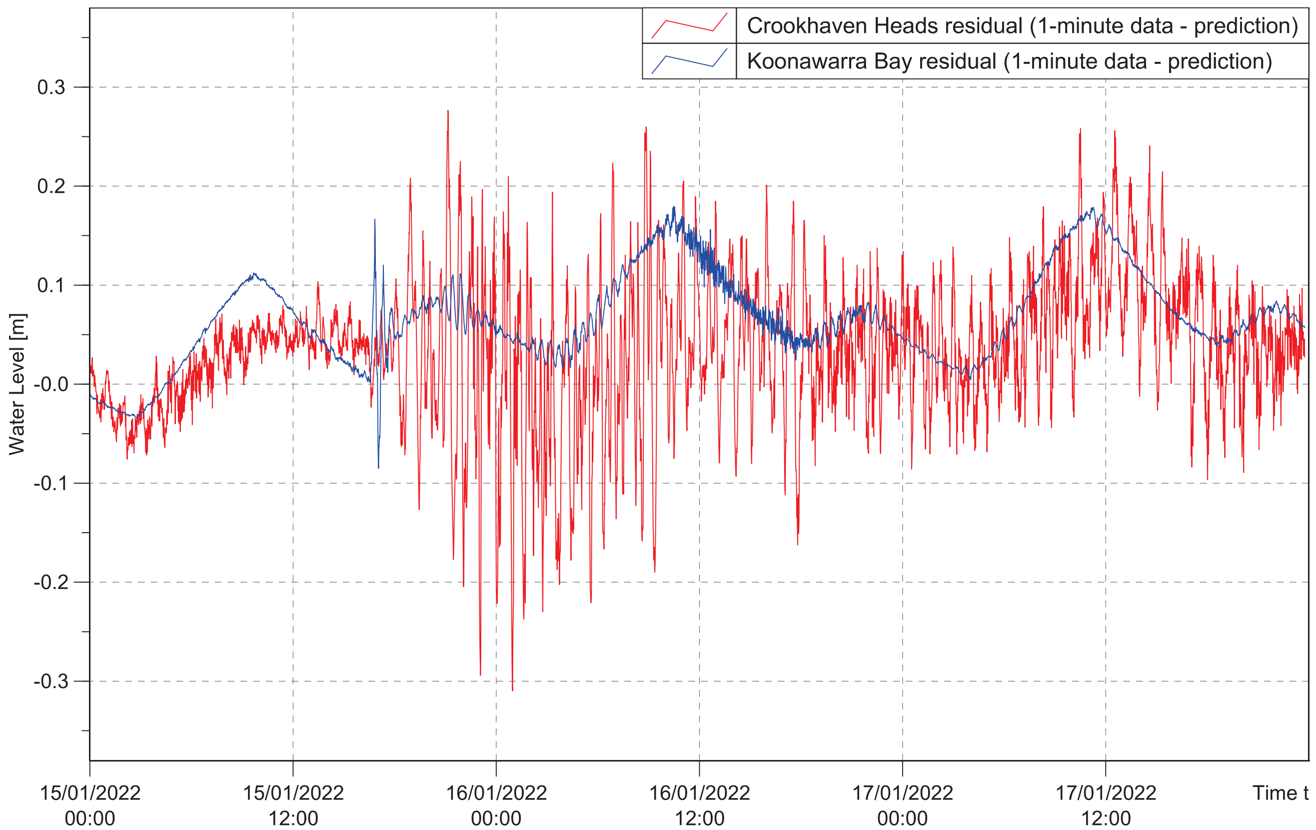
Figure

4.14

DRAWING 2907-04-14.cdr





NSW GOVERNMENT

COMPARISON OF TSUNAMI WAVE EFFECTS
IN NSW COASTAL LAKES

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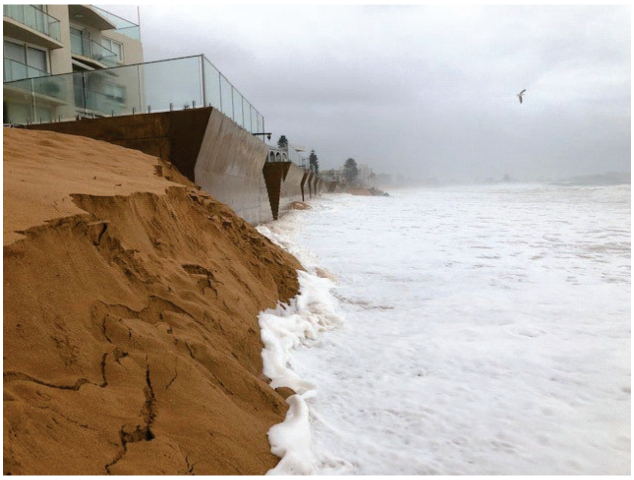
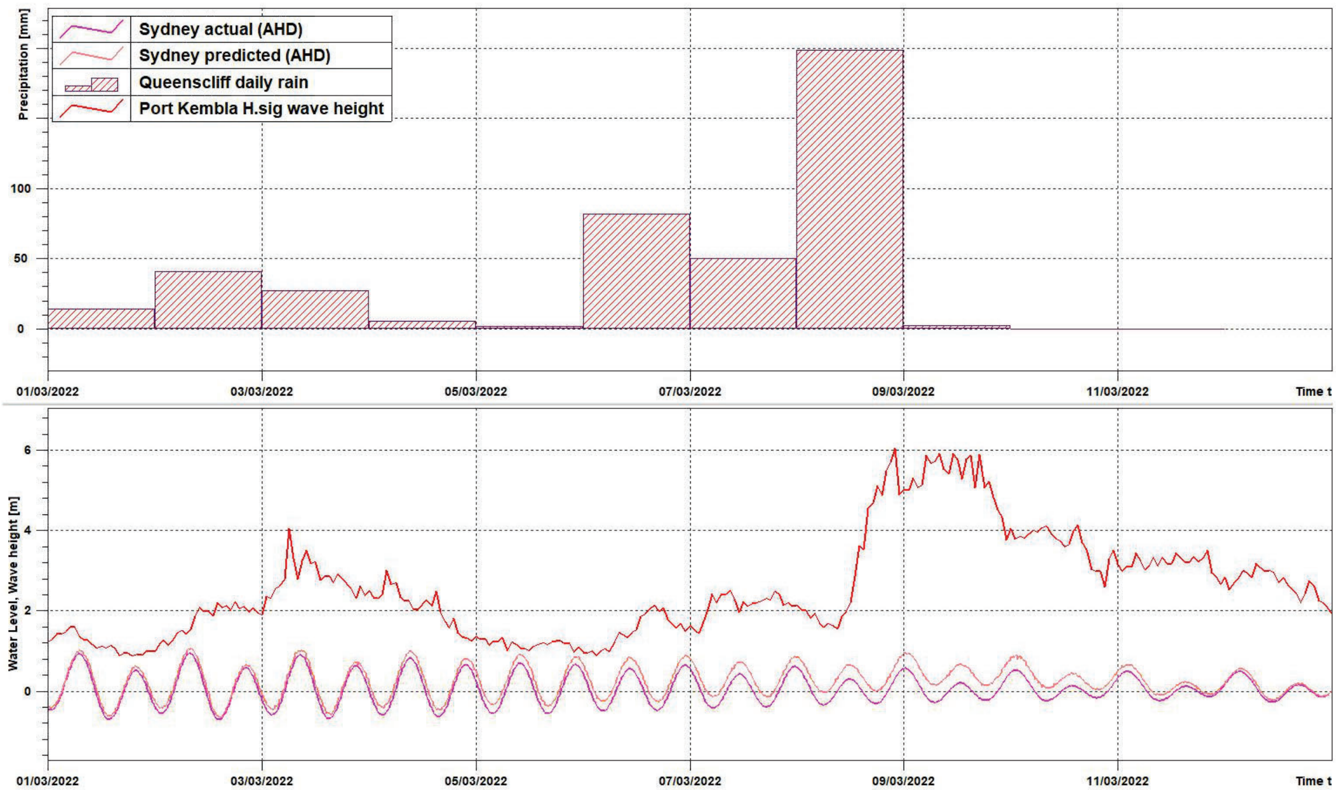
Figure

4.15

DRAWING 2907-04-15.cdr



Photos courtesy of Sam Maddox (MHL) and Ben Short (public)



NSW GOVERNMENT

SYDNEY COASTAL CONDITIONS DURING THE MARCH 2022 EAST COAST LOW

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Report MHL2907

Figure

4.16

DRAWING 2907-04-16.cdr

5 Air pressure program summary 2021–2022

5.1 Data capture

During 2021–2022 the overall data recovery for all barometer stations was 100%. Monthly data recovery during the 2021–2022 year is shown in **Table 5.1**. **Appendix B** provides plots of measured air pressure at each site.

Table 5.1 New South Wales air pressure: 2021–2022 data capture

Water level / barometer site	Data capture (%)												Total year
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
Tweed Heads / Kingscliff	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Yamba / Lake Wooloweyah	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Port Macquarie / Settlement Point	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Newcastle / Stockton Bridge	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Sydney / Narrabeen Bridge	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Jervis Bay / Currarong Creek	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Tuross Head / Tuross Head	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Eden / Wonboyn Lake	100	100	100	100	100	100	100	100	100	100	99.6	100	**100**

6 References

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

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

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

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

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

MHL 2020, *Review of NSW OEH Automatic Water Level Recorder Network*, MHL Report 2546, March 2020.

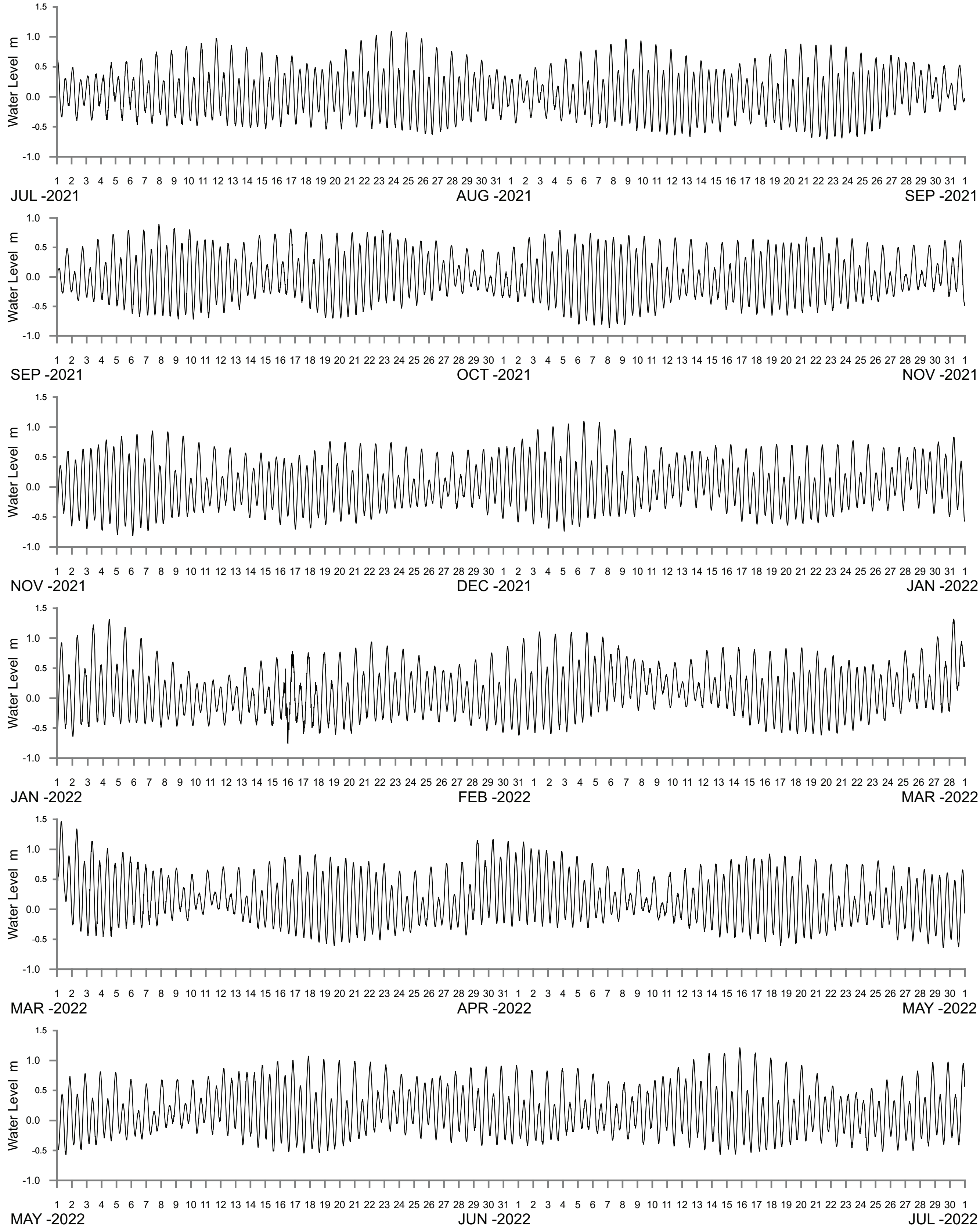
MHL 2022, *NSW Estuary and River Water Levels Annual Summary 2020-2021*, MHL Report 2855, April 2022.

MHL 2023a, *NSW Tidal Planes Analysis 2001-2020 Harmonic Analysis*, MHL Report 2786, April 2023.

MHL 2023b, *NSW Estuary and River Water Levels Annual Summary 2021–2022*, MHL Report 2906, May 2023.

Rabinovich, Candella 2011, 'Energy Decay of the 2004 Sumatra Tsunami in the World Ocean', *Pure and Applied Geophysics*, vol. 168, pp. 1919–1950.

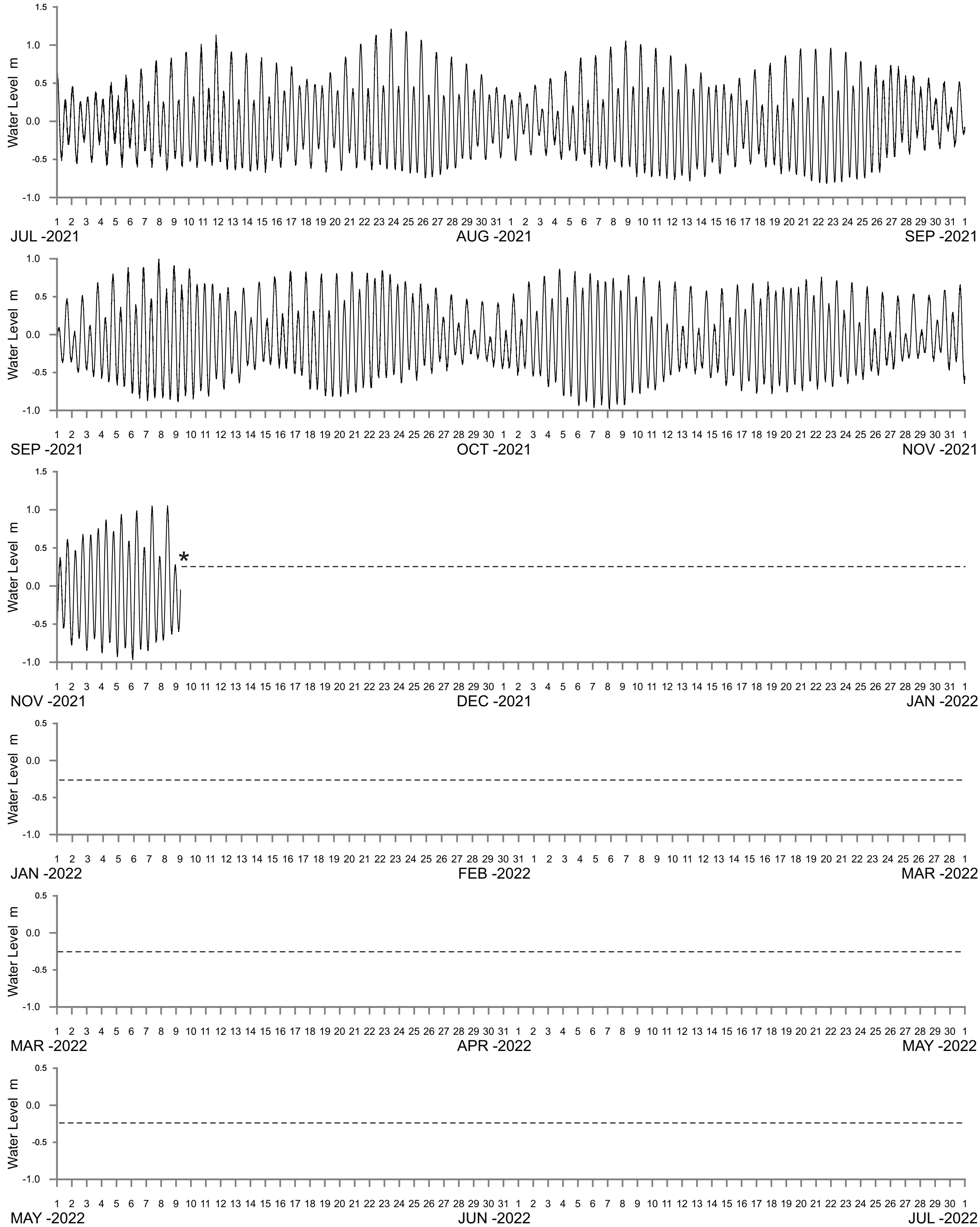
Appendix A Annual tidal data station summaries



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

NSW GOVERNMENT	TWEED ENTRANCE SOUTH DATA SUMMARY 2021–2022	Manly Hydraulics Laboratory Report MHL2907 Figure A1 DRAWING 2907-A1.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

– – – – – DATA LOSS

*Data loss due to failure of primary and secondary sensor

NSW GOVERNMENT

TWEED HEADS OFFSHORE DATA SUMMARY
2021–2022

Manly Hydraulics Laboratory

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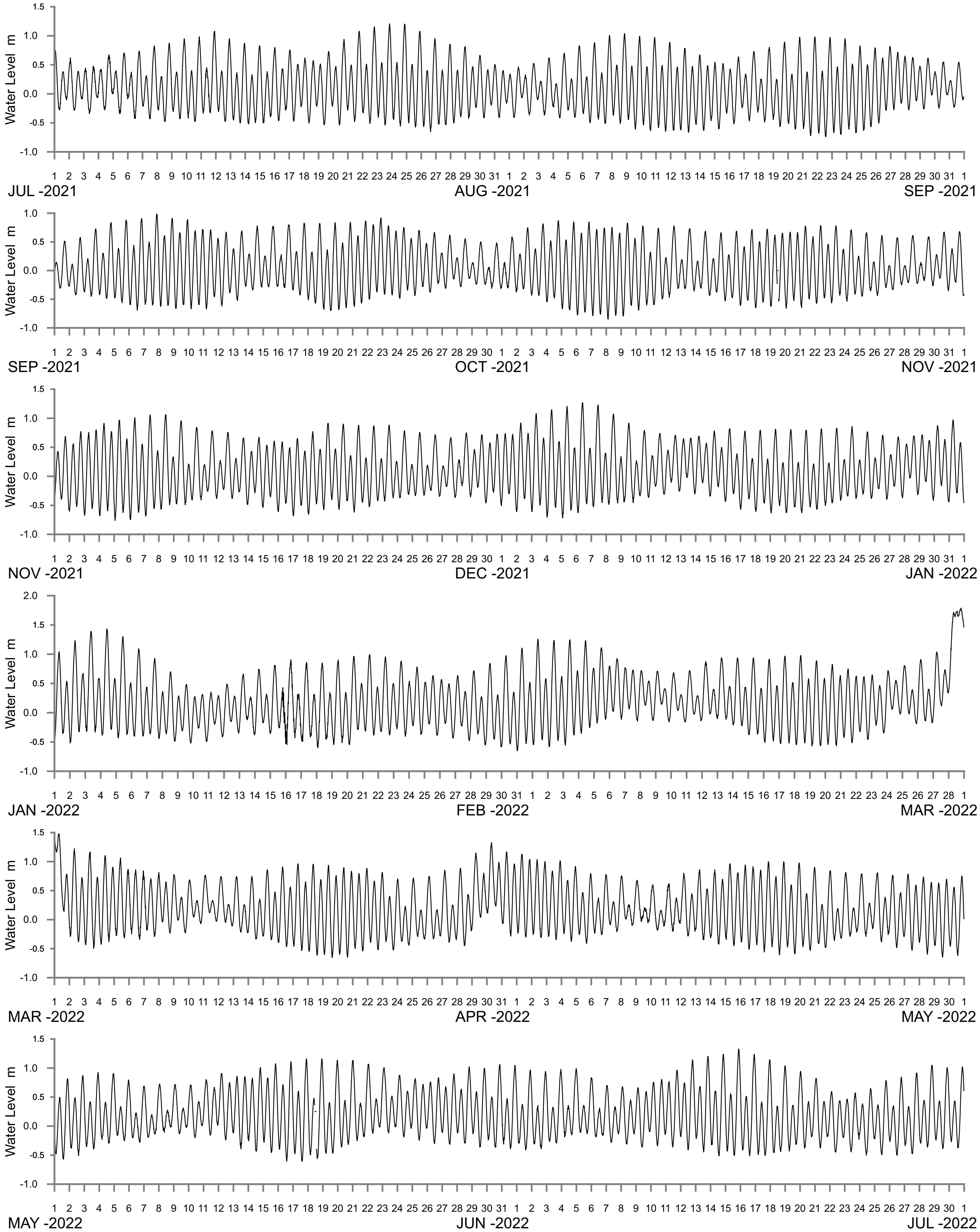
Figure

A2

DRAWING 2907-A2.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

NSW GOVERNMENT

BRUNSWICK HEADS DATA SUMMARY
2021–2022

Manly Hydraulics Laboratory

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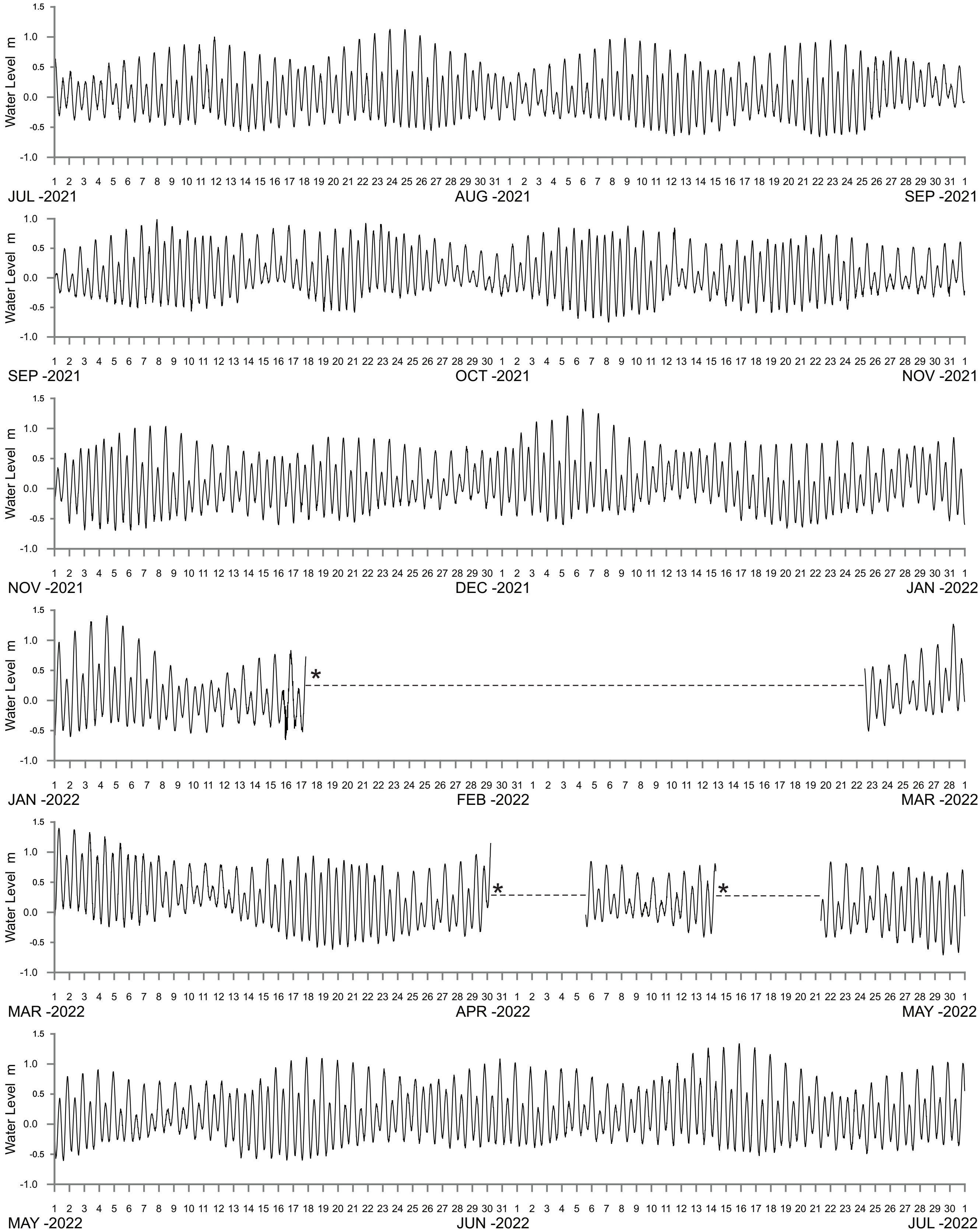
Figure

A3

DRAWING 2907-A3.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

- - - - - DATA LOSS

*Data loss due to failure of primary and secondary sensor

NSW GOVERNMENT

BALLINA BREAKWALL DATA SUMMARY
2021–2022

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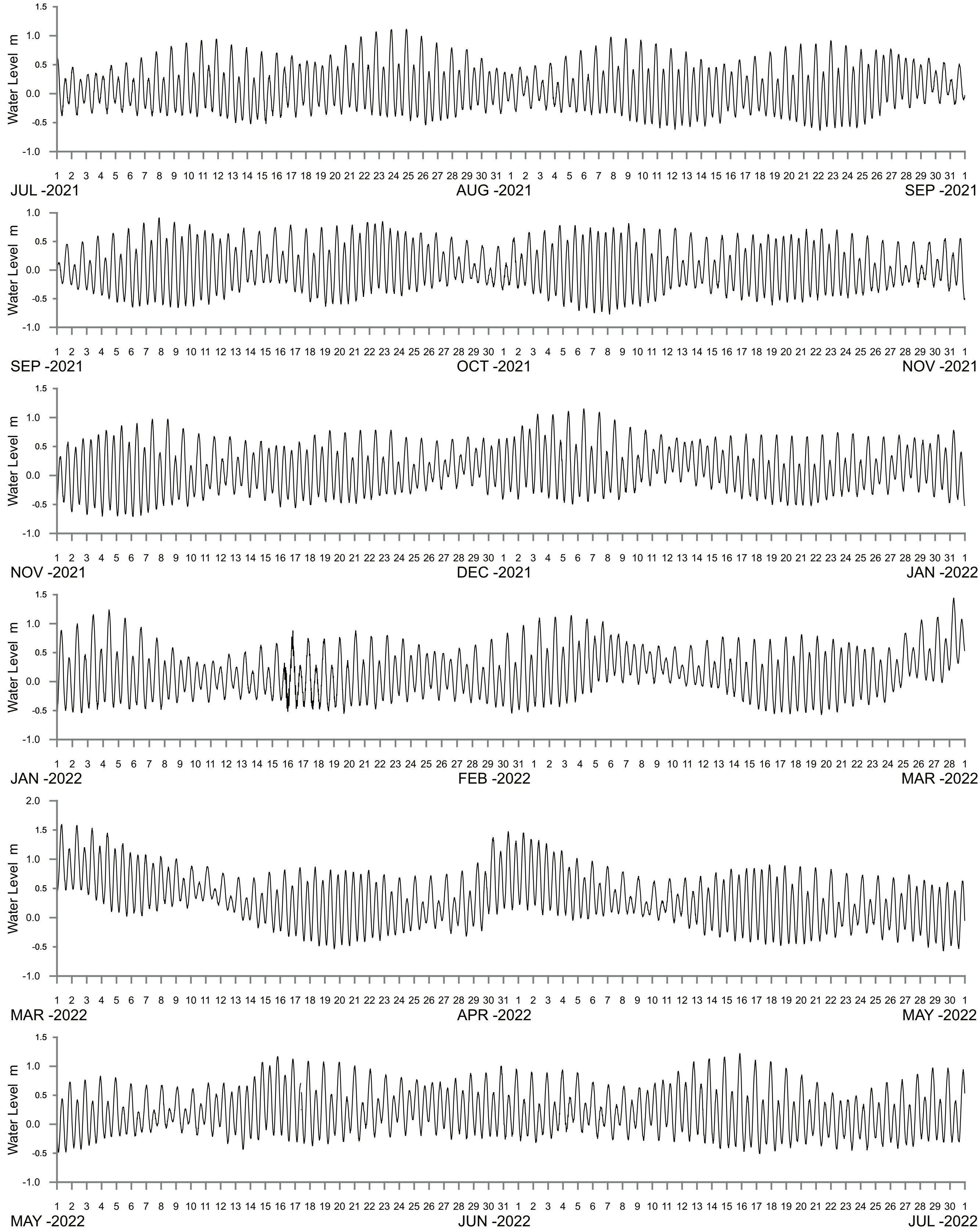
Figure

A4

DRAWING 2907-A4.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

- - - - - DATA LOSS

NSW GOVERNMENT

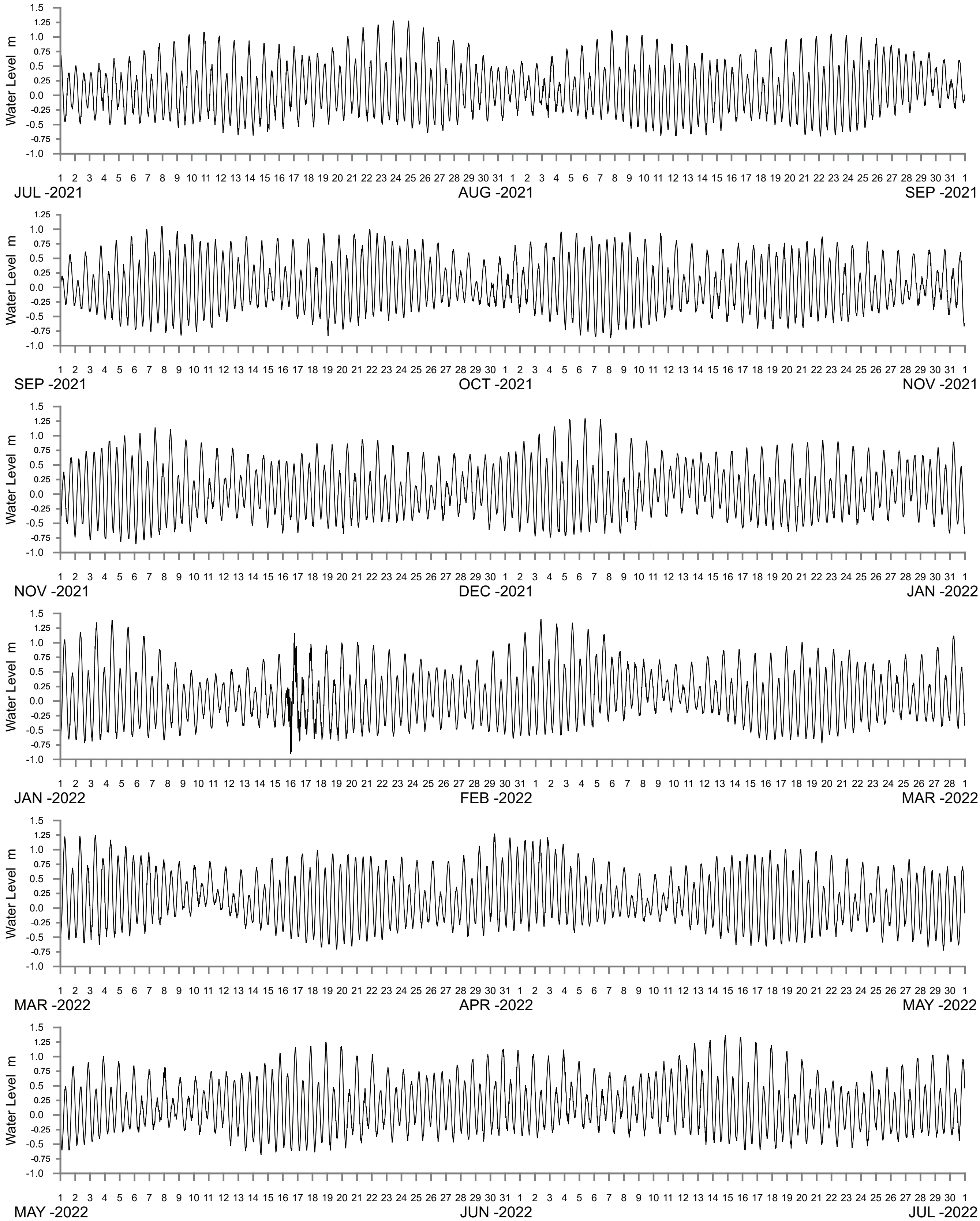
YAMBA DATA SUMMARY 2021–2022

Manly Hydraulics Laboratory

Report MHL2907

Figure A5

DRAWING 2907-A5.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

NSW GOVERNMENT

COFFS HARBOUR DATA SUMMARY
2021–2022

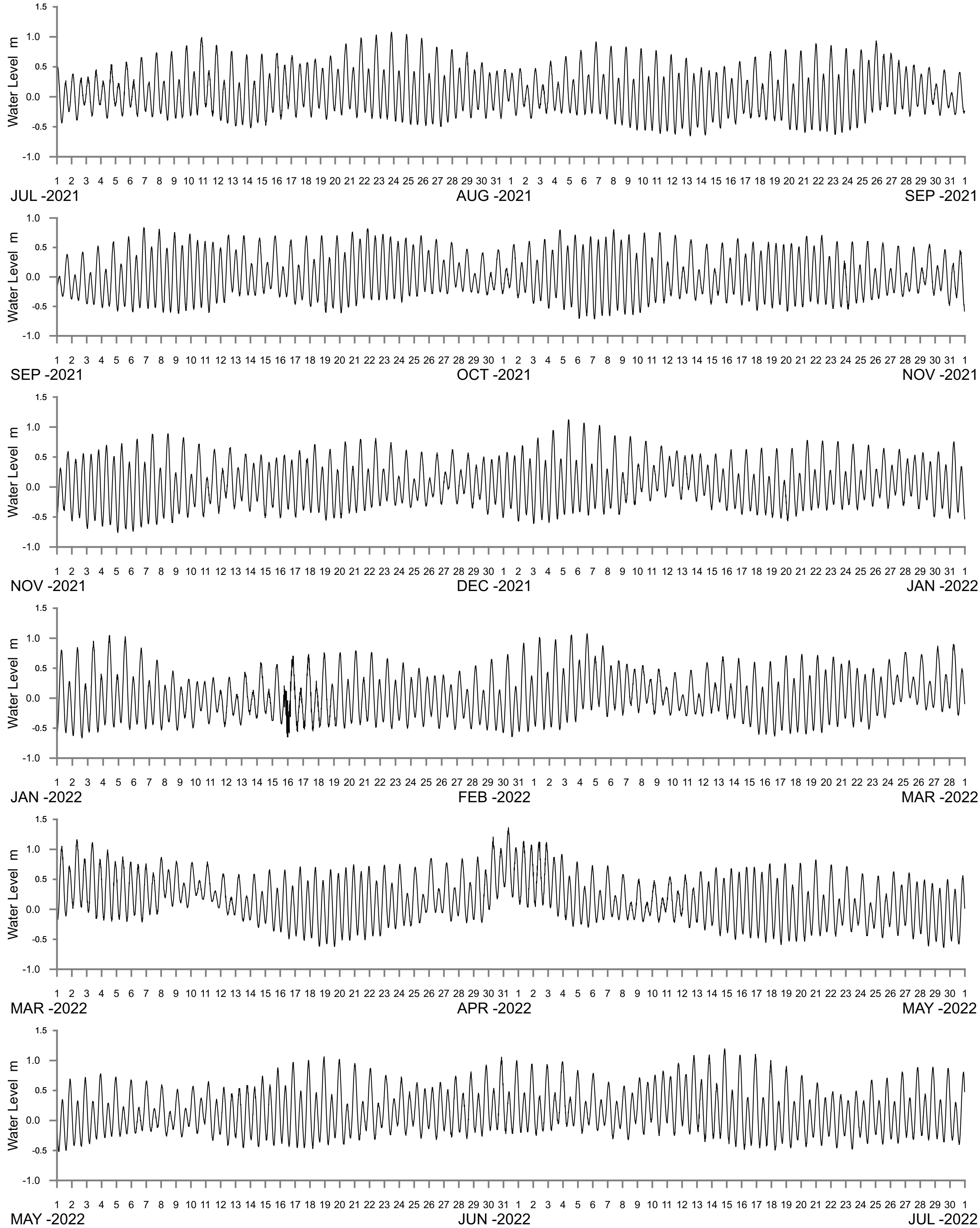
Manly Hydraulics Laboratory

Report MHL2907

Figure

A6

DRAWING 2907-A6.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

PORT MACQUARIE DATA SUMMARY
2021–2022

Manly Hydraulics Laboratory

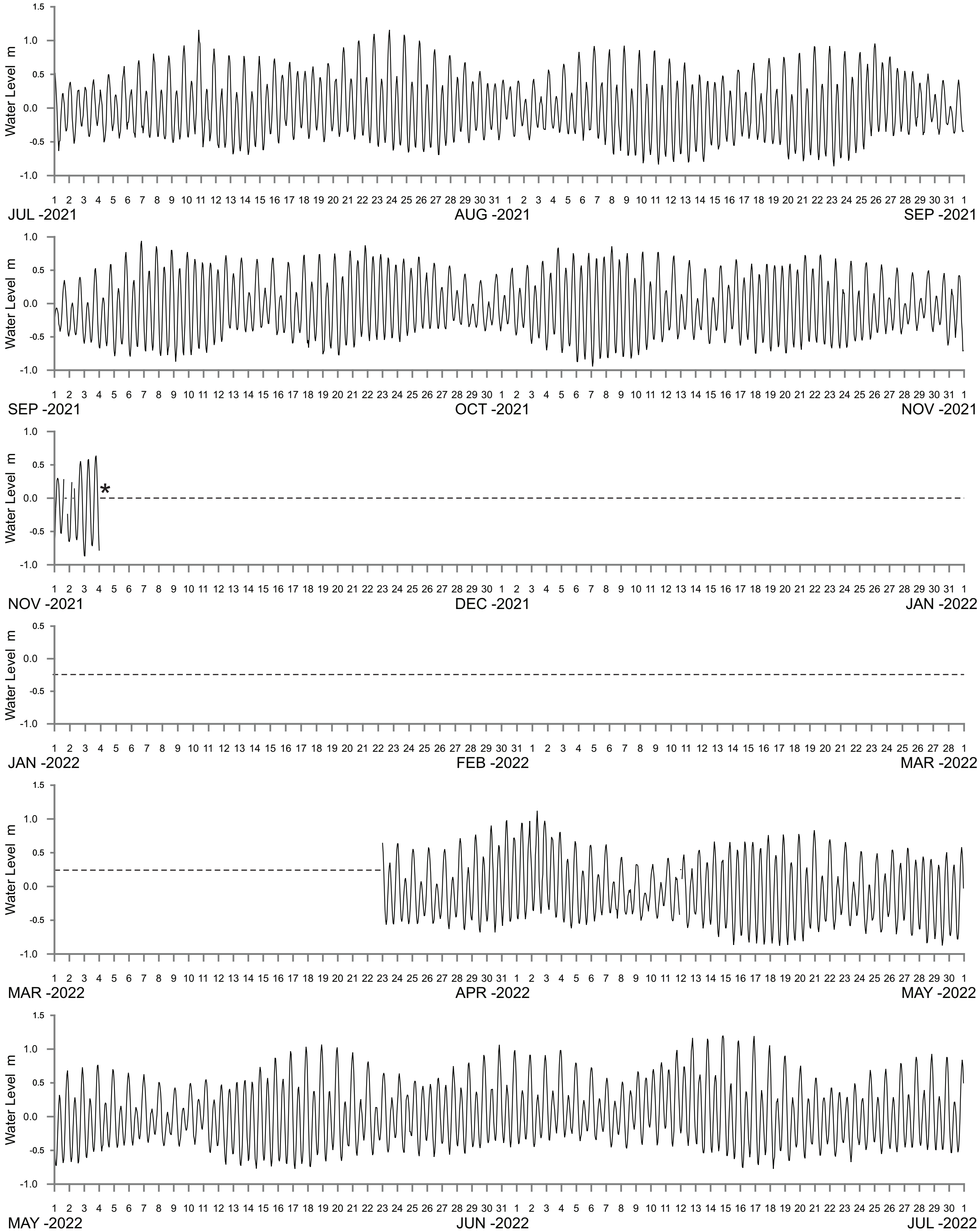
Report MHL2907

Figure

A7

DRAWING 2907-A7.cdr

NSW GOVERNMENT



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

– – – – – DATA LOSS

*Data loss due to failure of primary and secondary sensor

PORT MACQUARIE OFFSHORE DATA SUMMARY
2021–2022

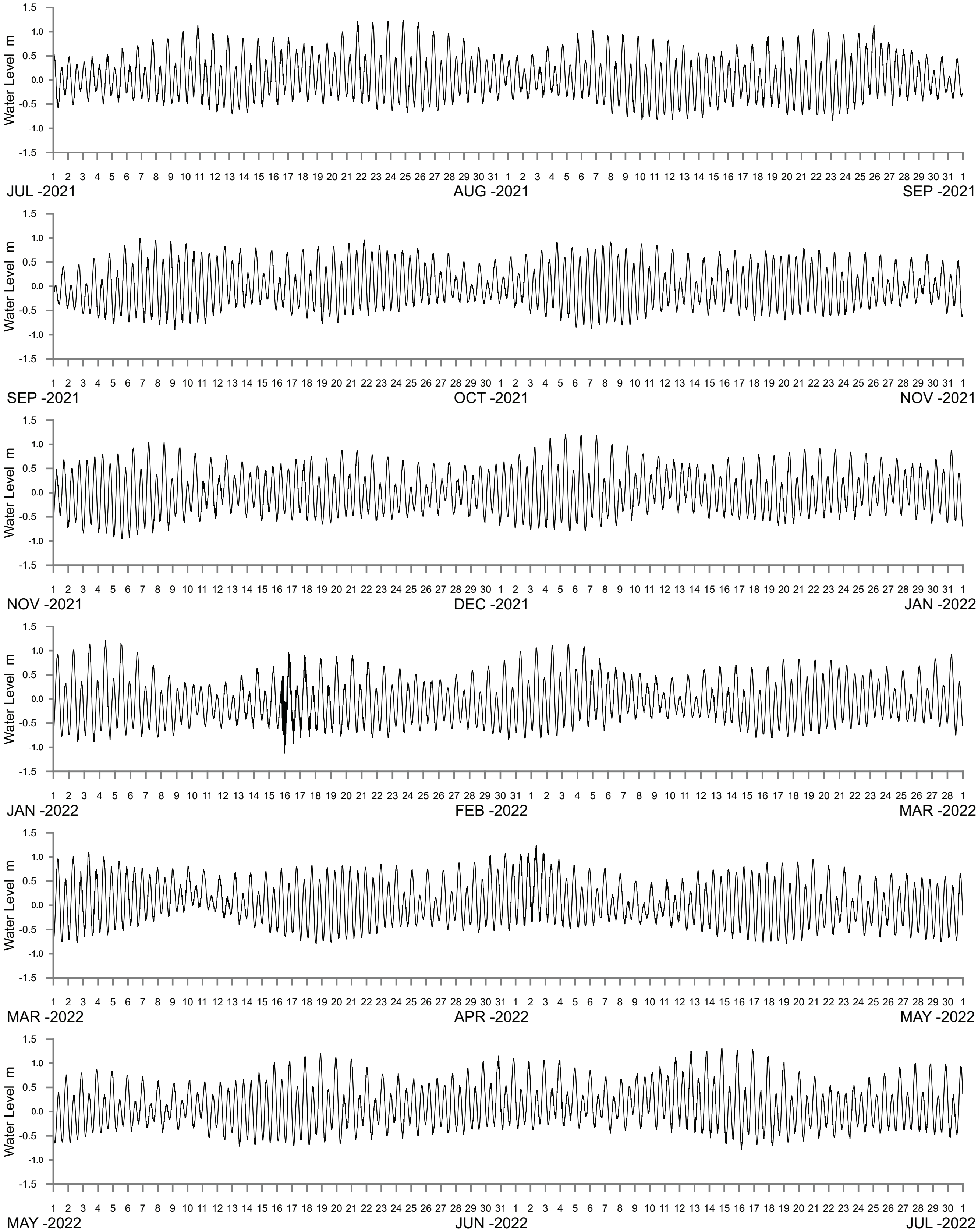
Manly Hydraulics Laboratory

Report MHL2907

Figure

A8

DRAWING 2907-A8.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

NSW GOVERNMENT

CROWDY HEAD DATA SUMMARY
2021–2022

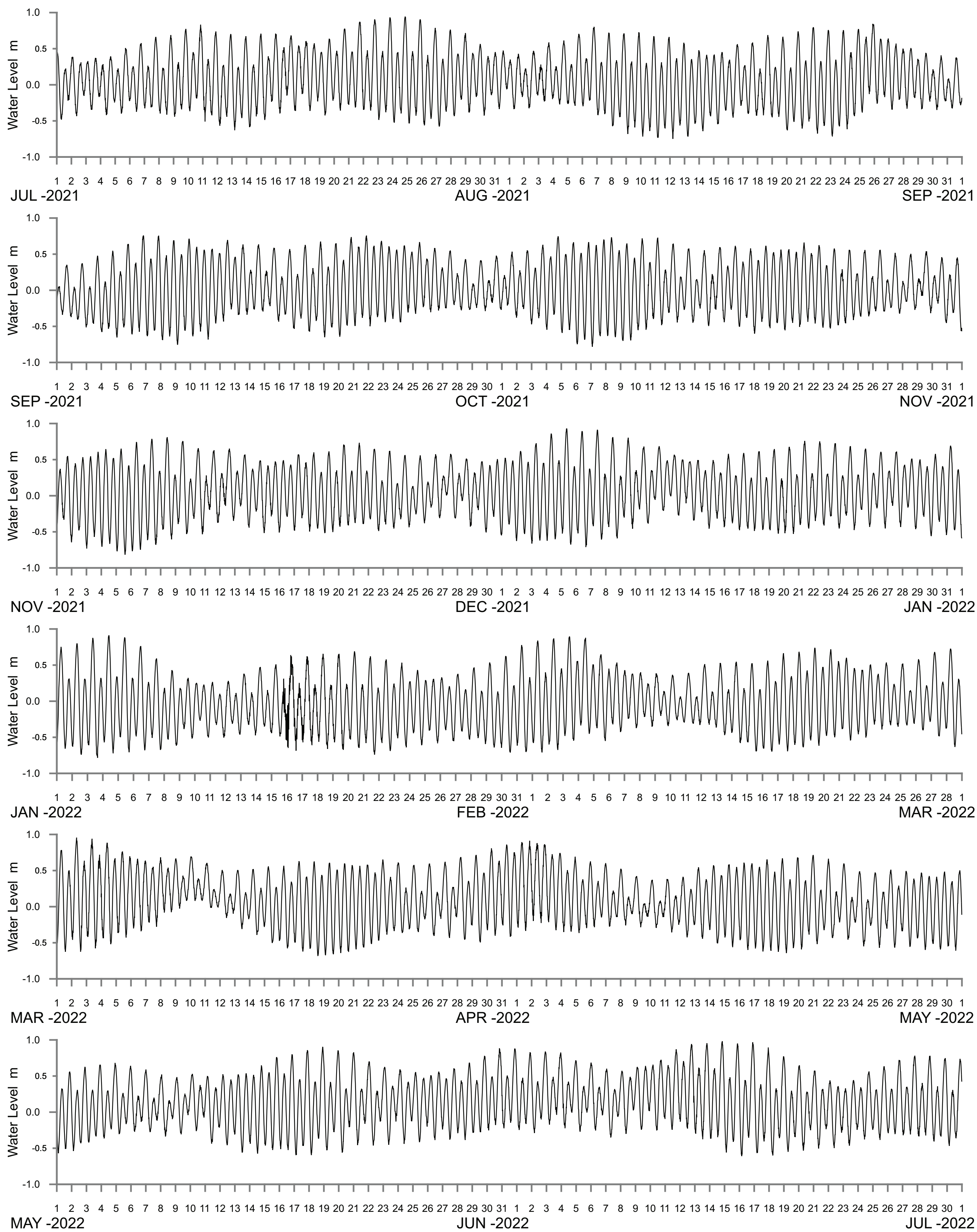
Manly Hydraulics Laboratory

Report MHL2907

Figure

A9

DRAWING 2907-A9.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

- - - - - DATA LOSS

FORSTER DATA SUMMARY
2021–2022

NSW GOVERNMENT

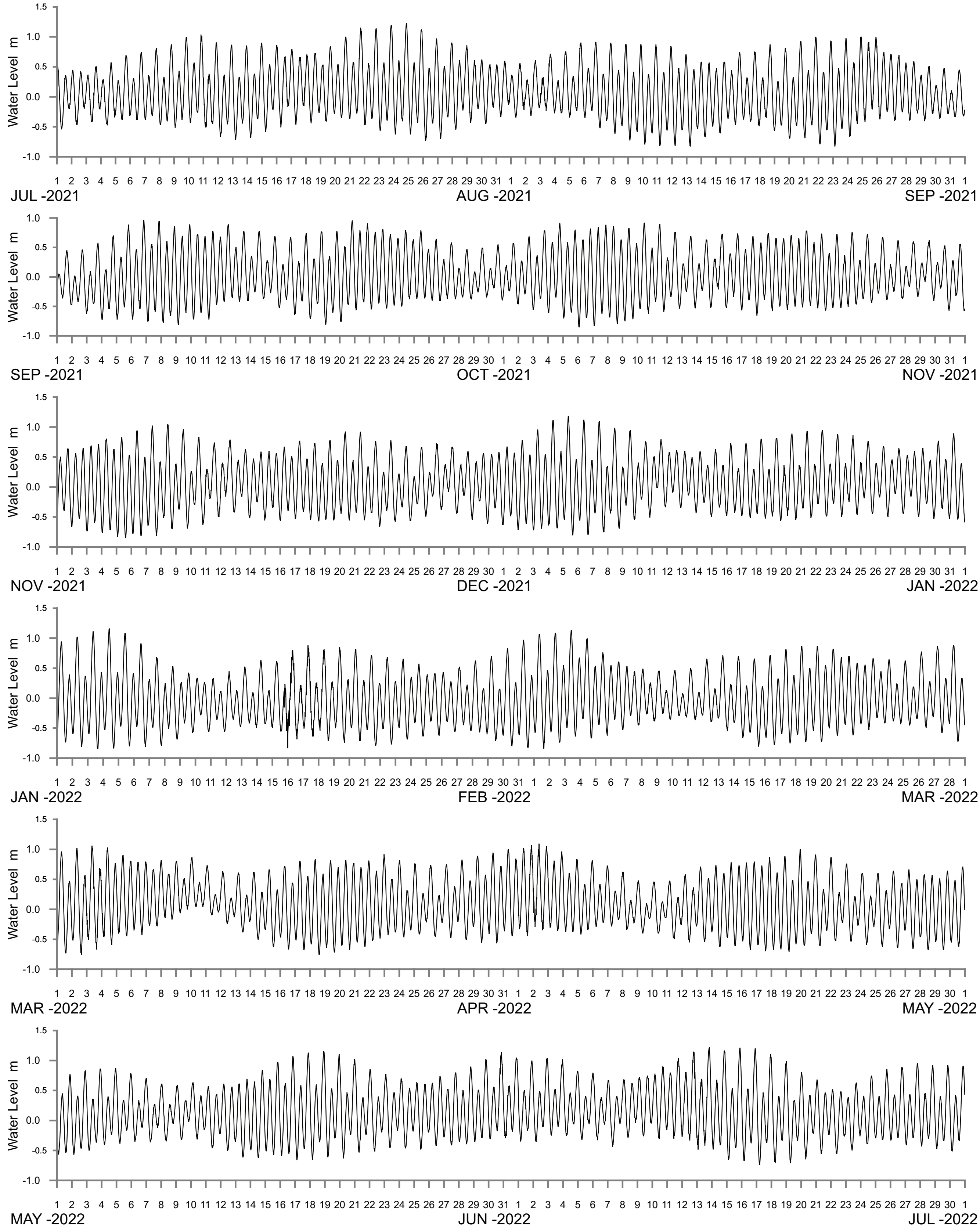
Manly Hydraulics Laboratory

Report MHL2907

Figure

A10

DRAWING 2907-A10.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

- - - - - DATA LOSS

SHOAL BAY DATA SUMMARY
2022–2023

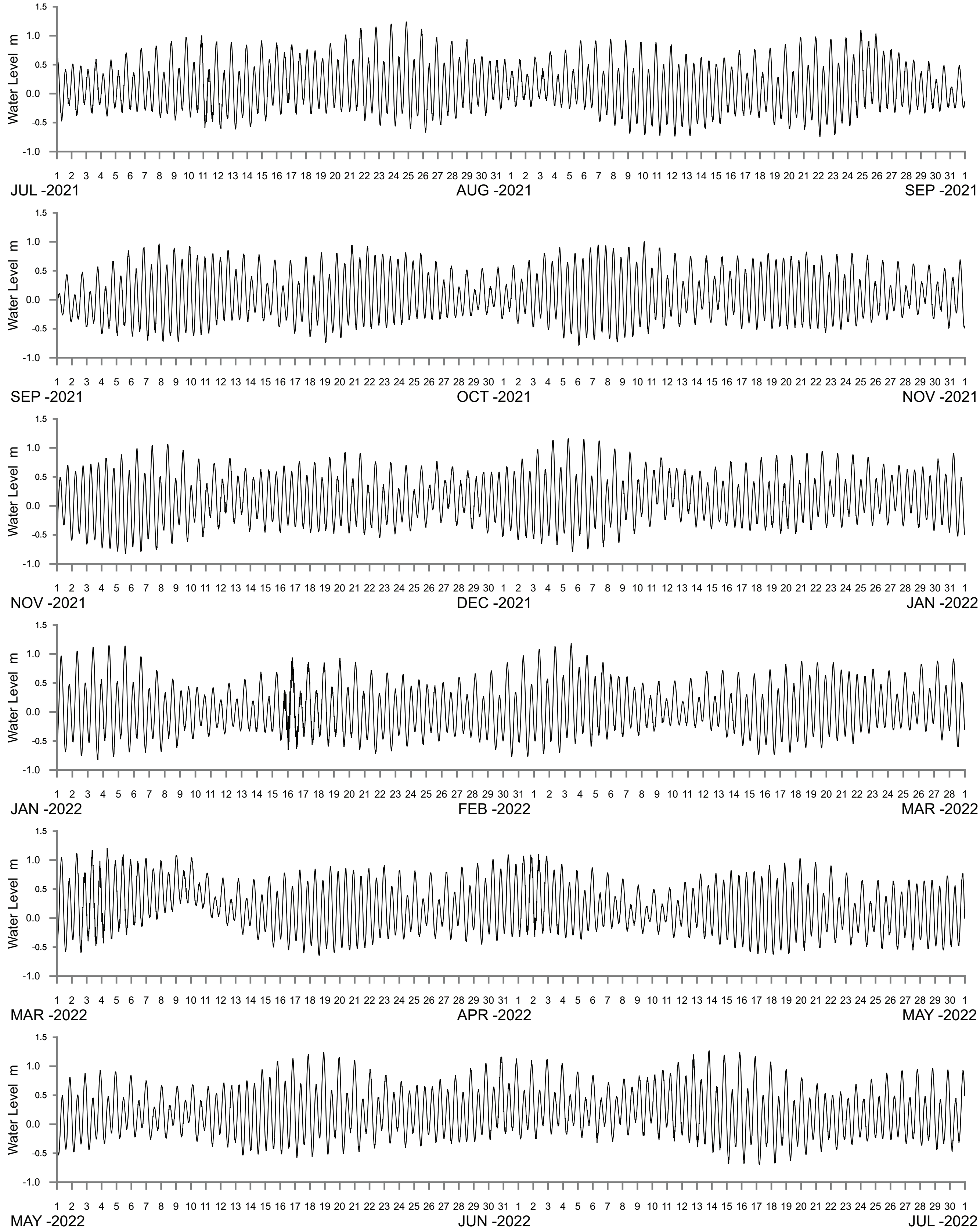
Manly Hydraulics Laboratory

Report MHL2907

Figure

A11

DRAWING 2907-A11.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

NSW GOVERNMENT

PATONGA DATA SUMMARY
2021–2022

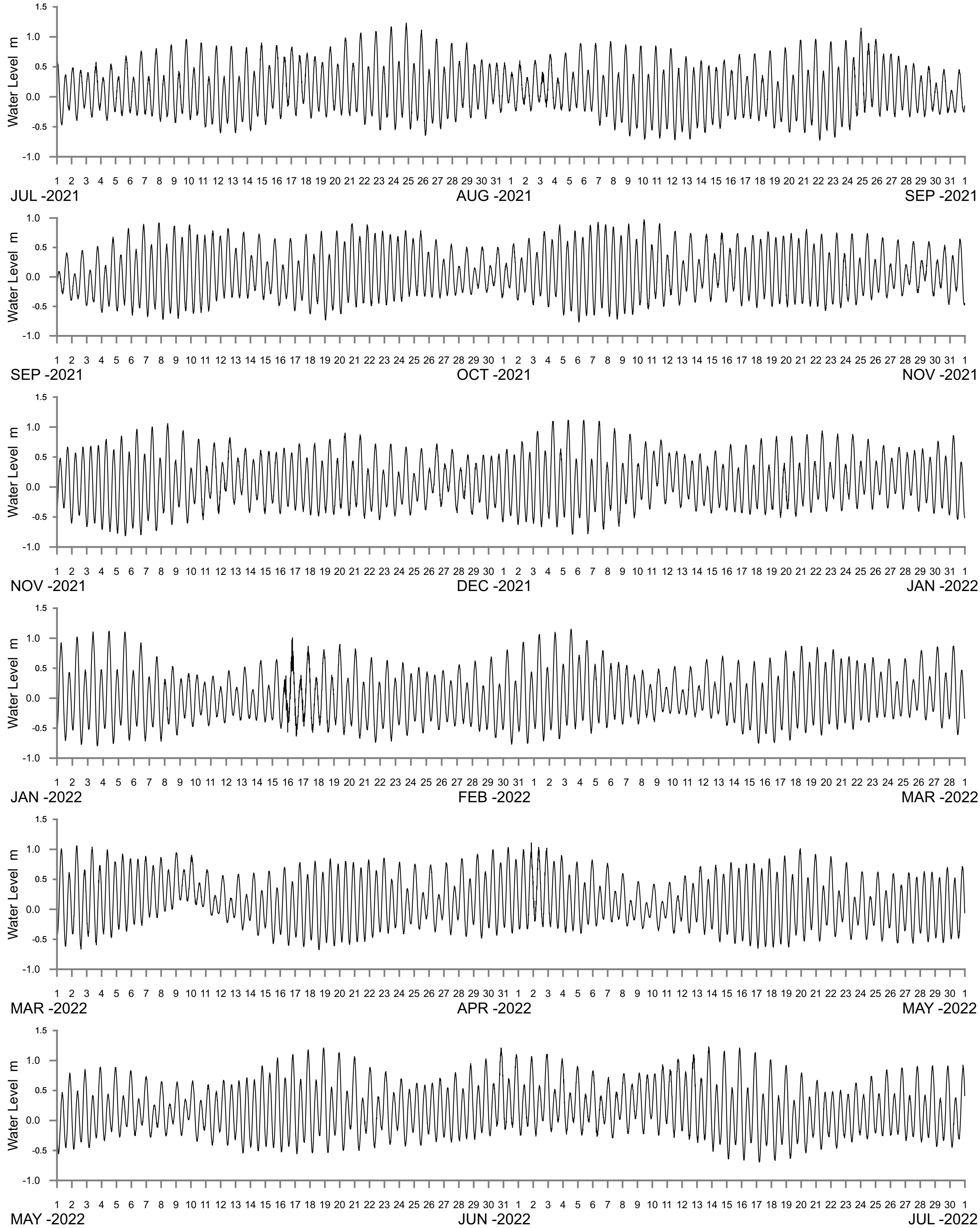
Manly Hydraulics Laboratory

Report MHL2907

Figure

A12

DRAWING 2907-A12.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

NSW GOVERNMENT

SYDNEY DATA SUMMARY
2021–2022

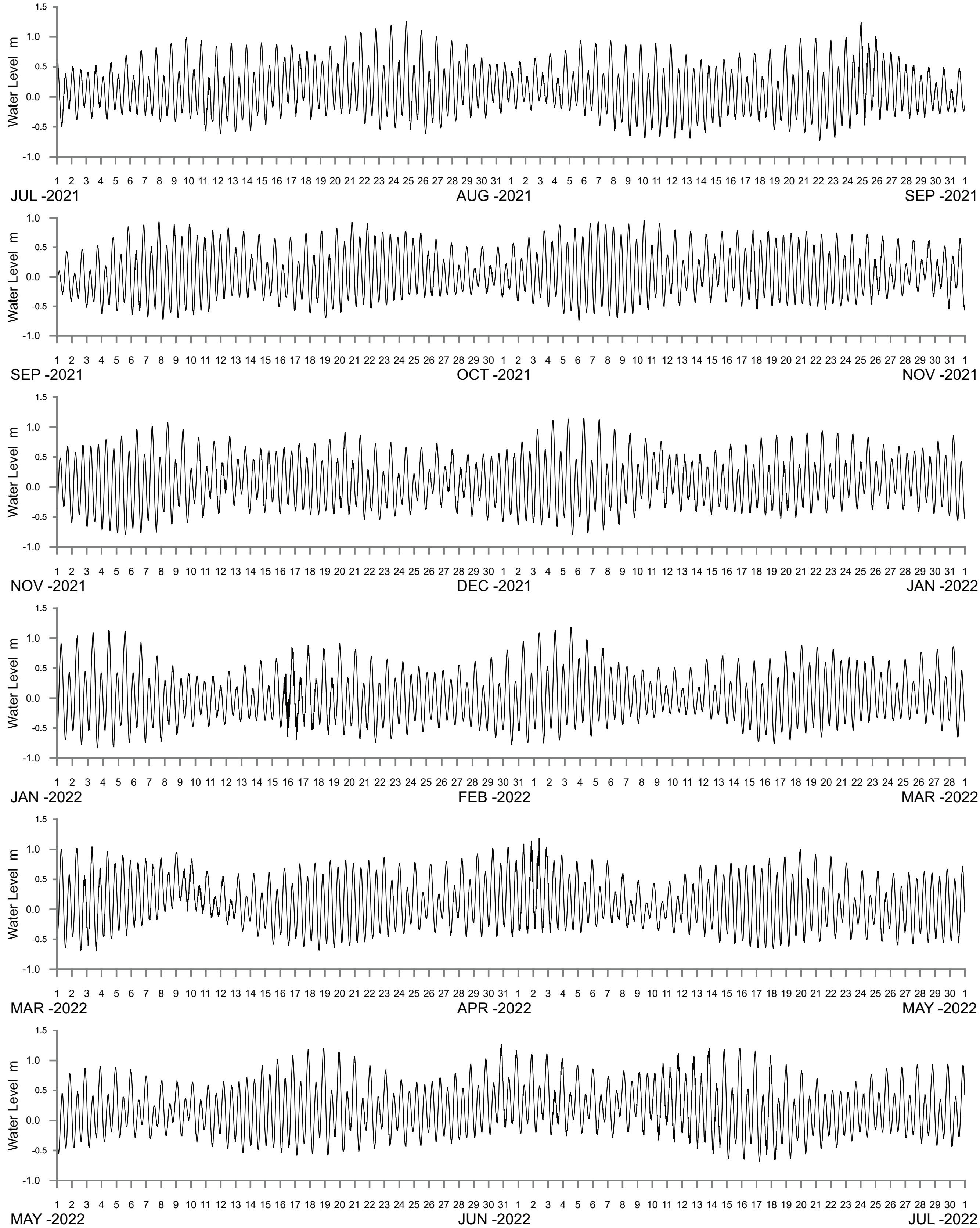
Manly Hydraulics Laboratory

Report MHL2907

Figure

A13

DRAWING 2907-A13.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

BUNDEENA DATA SUMMARY
2021–2022

NSW GOVERNMENT

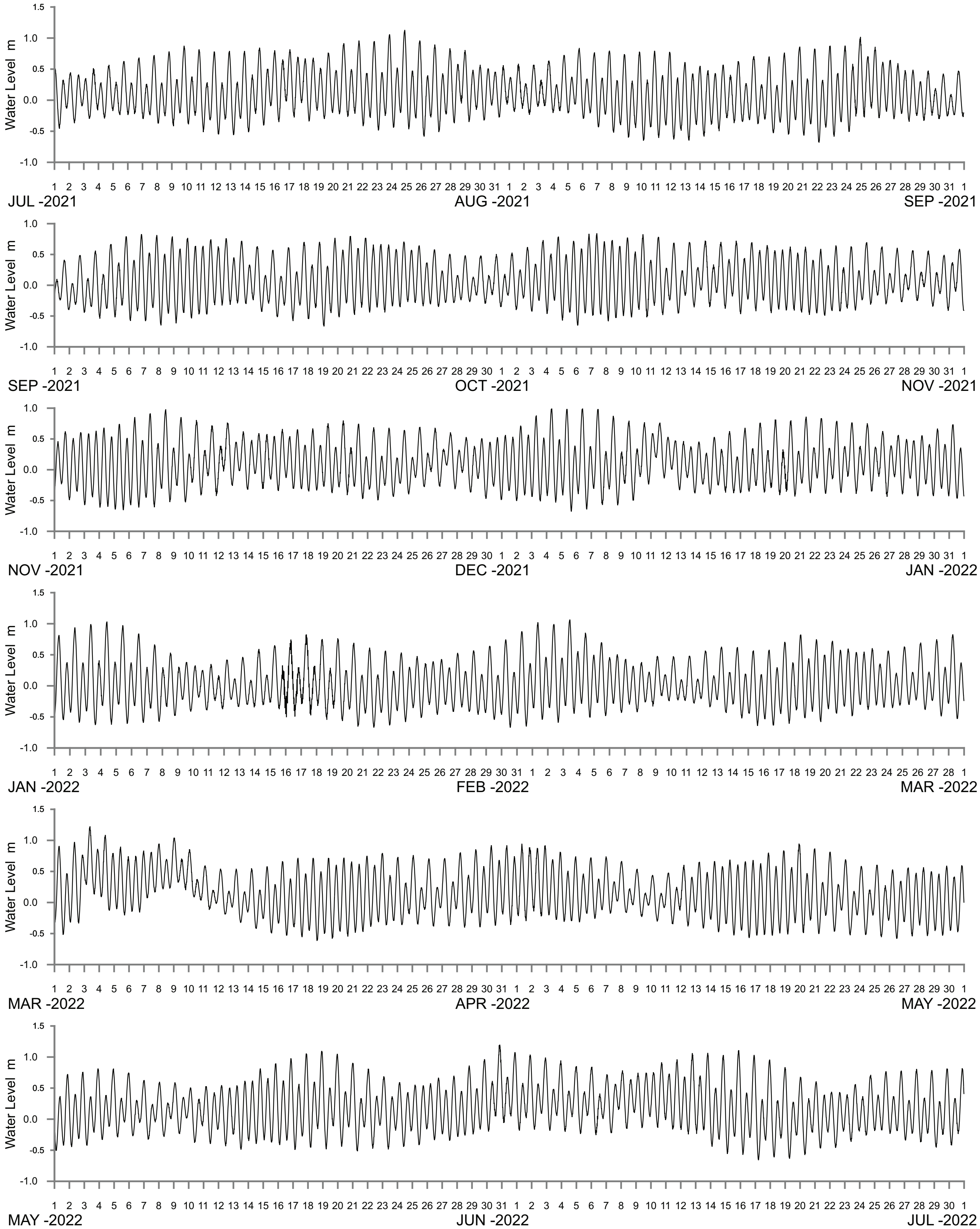
Manly Hydraulics Laboratory

Report MHL2907

Figure

A14

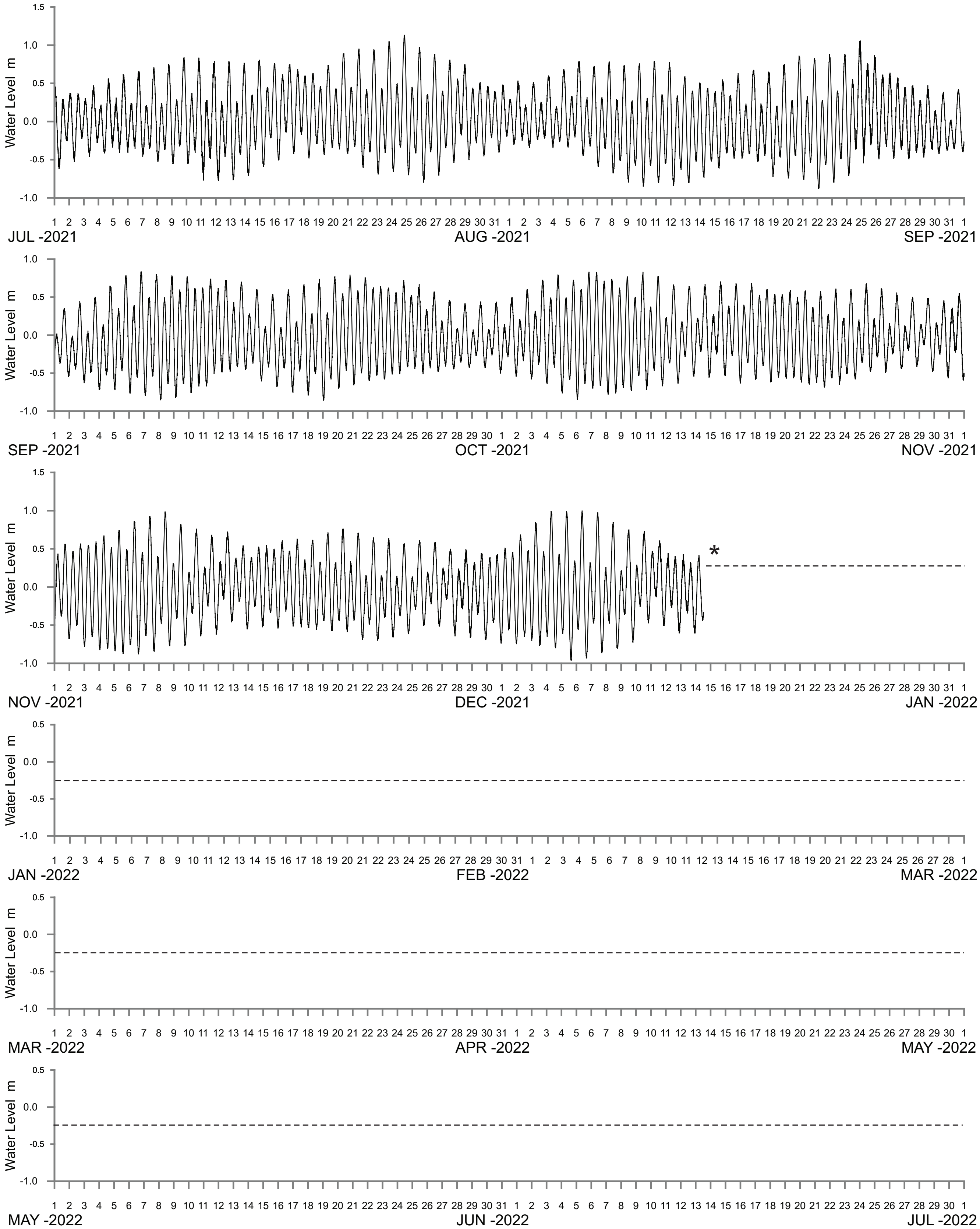
DRAWING 2907-A14.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

- - - - - DATA LOSS

NSW GOVERNMENT	CROOKHAVEN HEADS DATA SUMMARY 2021–2022	Manly Hydraulics Laboratory Report MHL2907 Figure A15 DRAWING 2907-A15.cdr



WATER LEVEL REFERENCED TO MEAN SEA LEVEL

– – – – – DATA LOSS

*No instrument deployed due to unsafe diving conditions

NSW GOVERNMENT

SHOALHAVEN OFFSHORE DATA SUMMARY
2021–2022

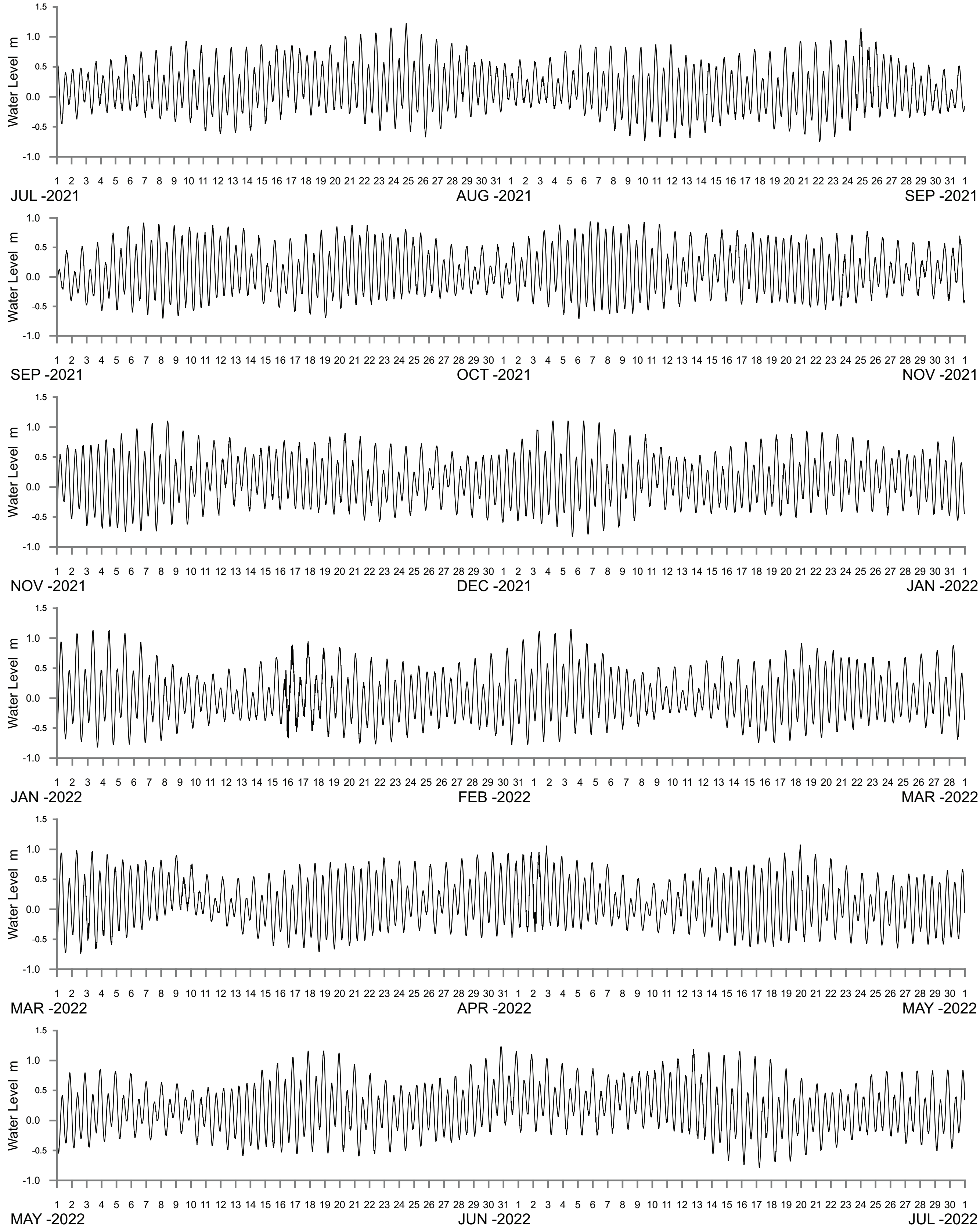
Manly Hydraulics Laboratory

Report MHL2907

Figure

A16

DRAWING 2907-A16.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

NSW GOVERNMENT

JERVIS BAY DATA SUMMARY
2021–2022

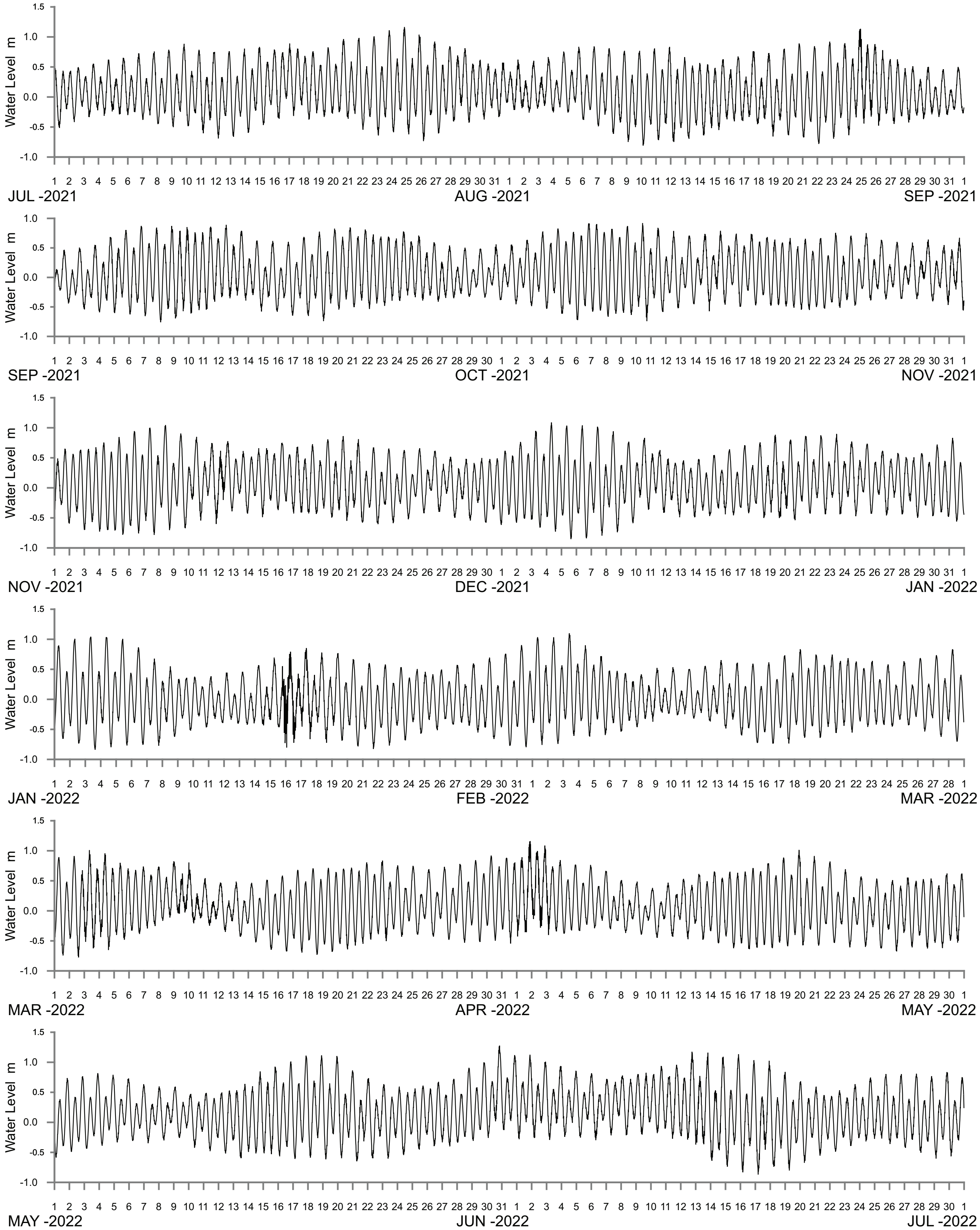
Manly Hydraulics Laboratory

Report MHL2907

Figure

A17

DRAWING 2907-A17.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

- - - - - DATA LOSS

NSW GOVERNMENT

ULLADULLA DATA SUMMARY
2021–2022

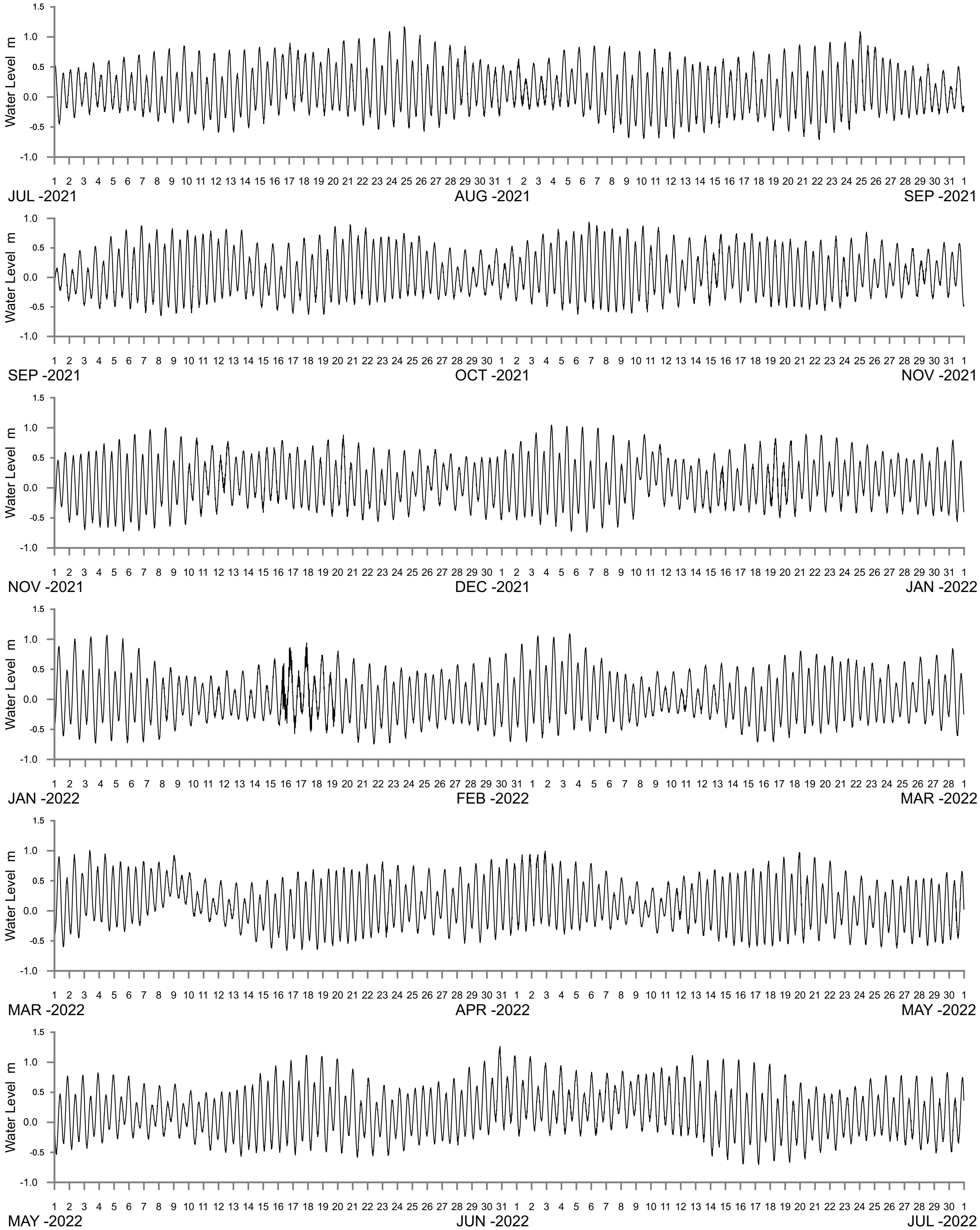
Manly Hydraulics Laboratory

Report MHL2907

Figure

A18

DRAWING 2907-A18.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

NSW GOVERNMENT

PRINCESS JETTY DATA SUMMARY
2021–2022

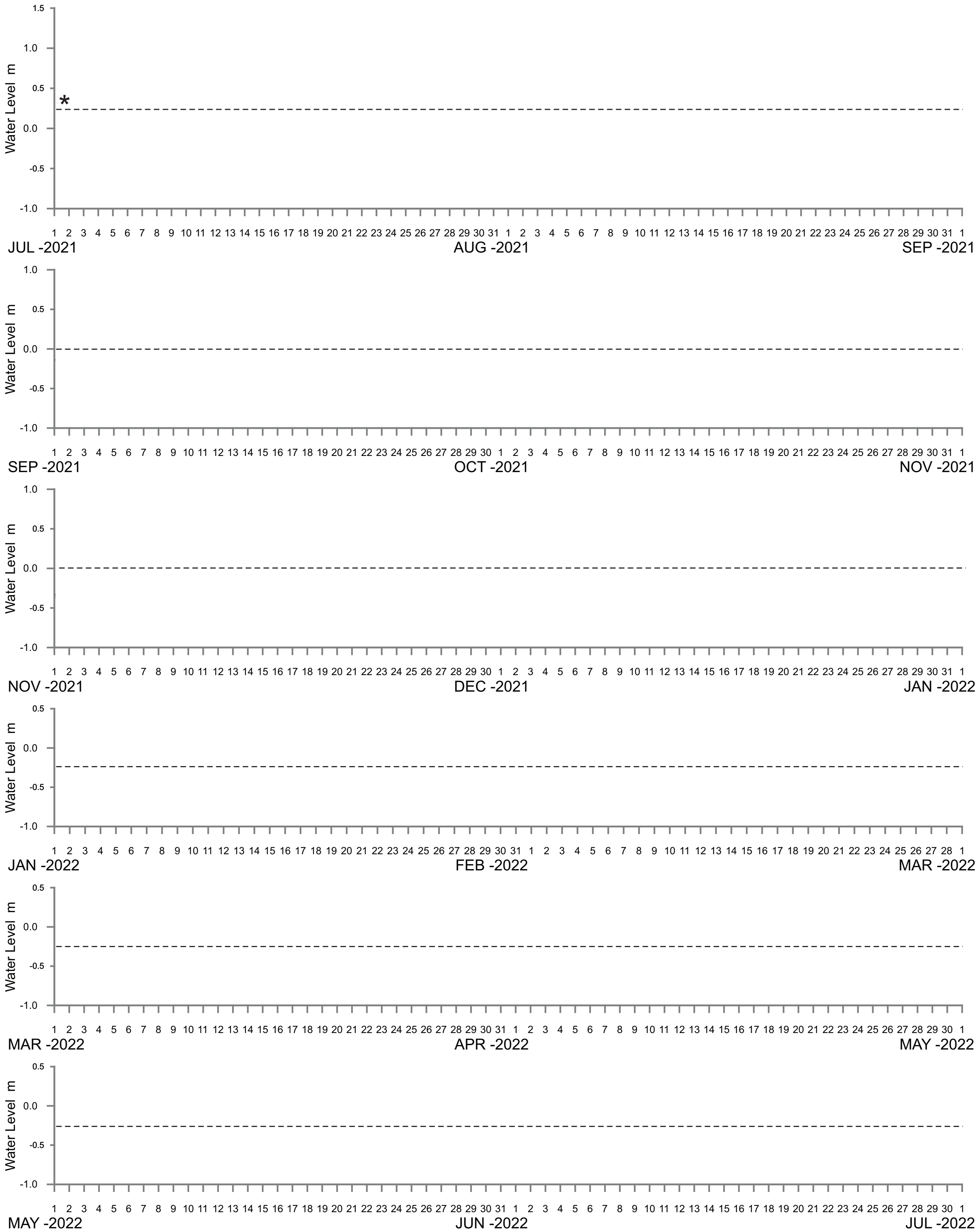
Manly Hydraulics Laboratory

Report MHL2907

Figure

A19

DRAWING 2907-A19.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

– – – – – DATA LOSS

*Data loss due to failure of primary and secondary sensor

NSW GOVERNMENT

BATEMANS BAY OFFSHORE DATA SUMMARY
2021–2022

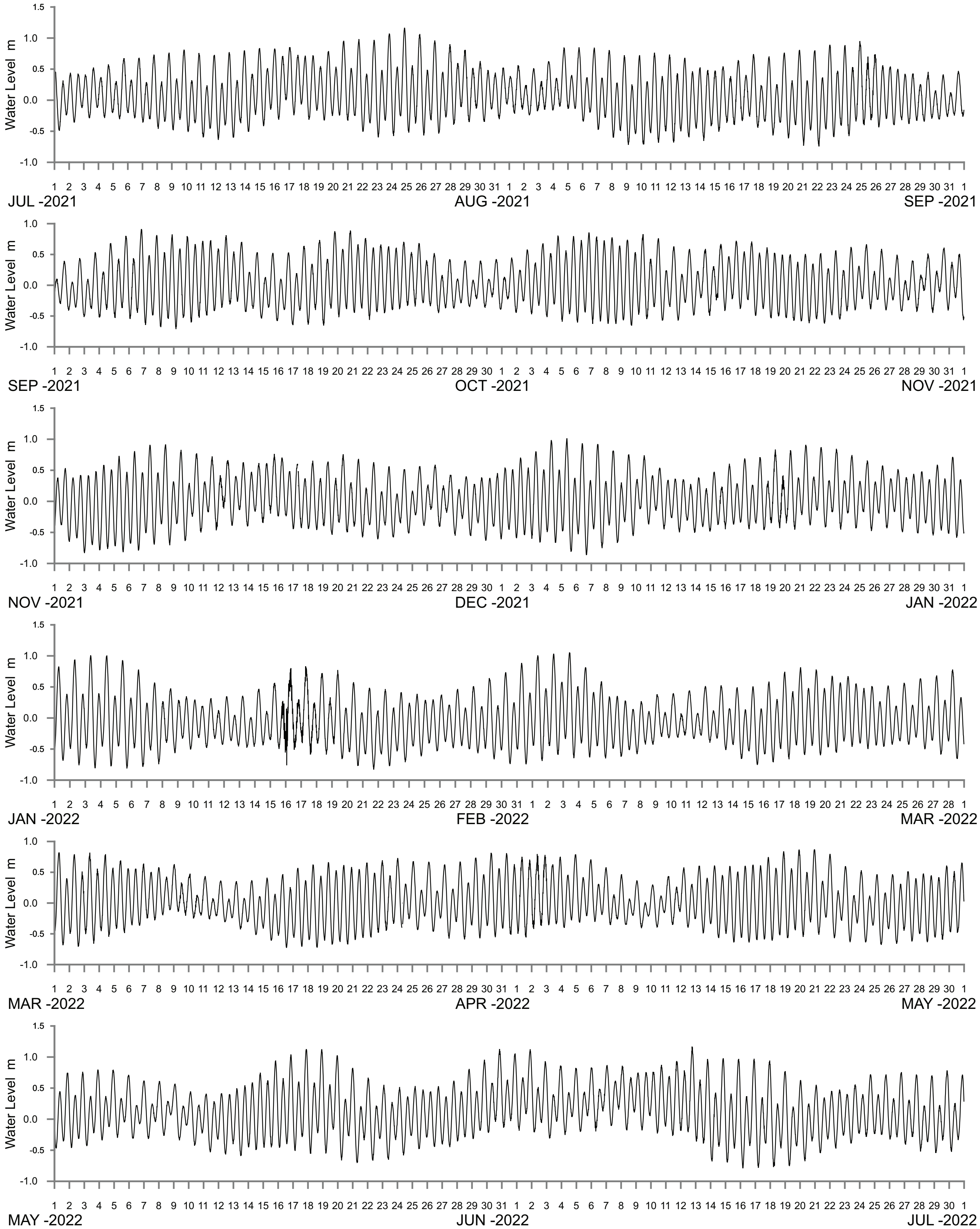
Manly Hydraulics Laboratory

Report MHL2907

Figure

A20

DRAWING 2907-A20.cdr



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

- - - - - DATA LOSS

BERMAGUI DATA SUMMARY
2021–2022

Manly Hydraulics Laboratory

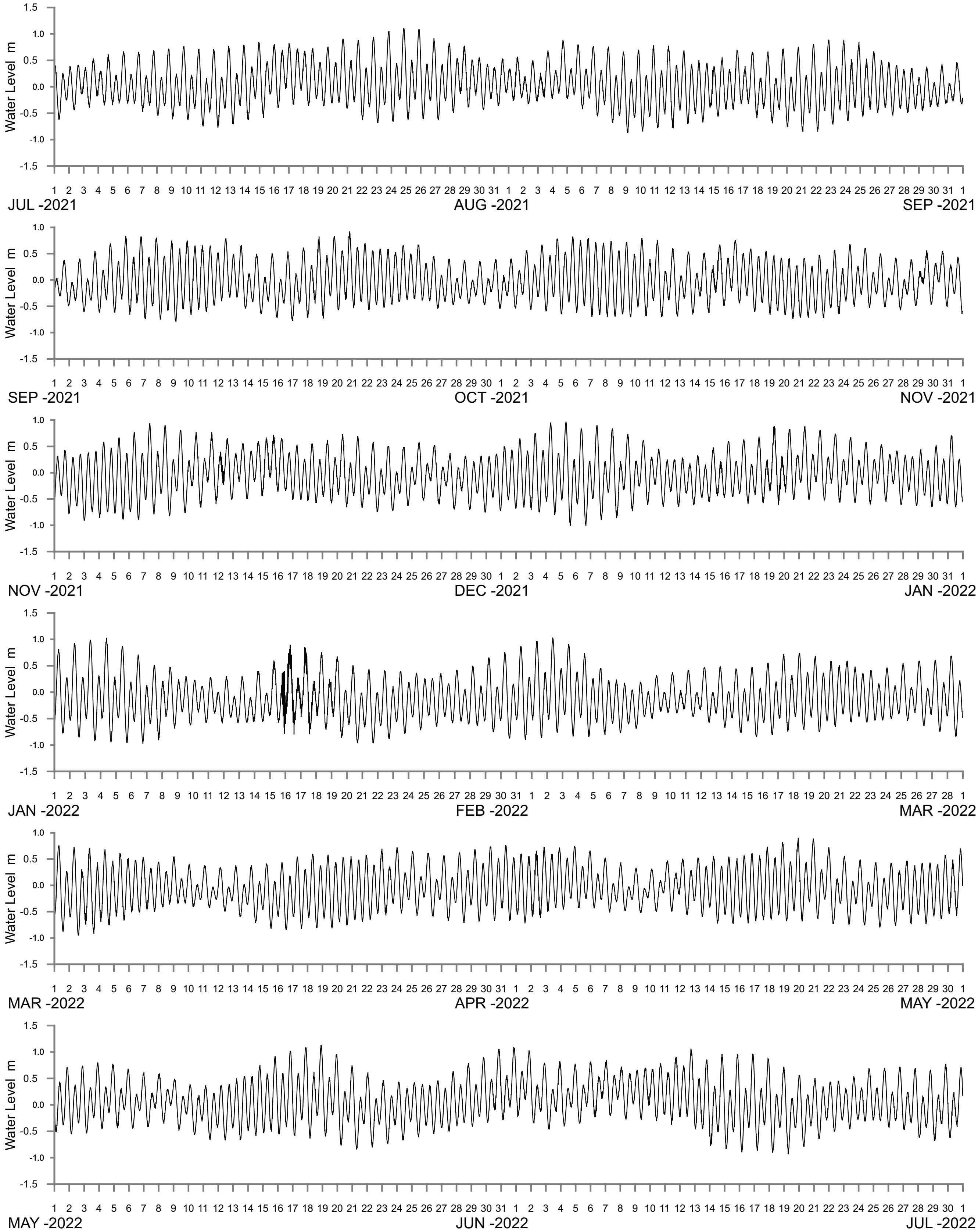
Report MHL2907

Figure

A21

DRAWING 2907-A21.cdr

NSW GOVERNMENT



WATER LEVEL REFERENCED TO AUSTRALIAN HEIGHT DATUM

- - - - - DATA LOSS

EDEN BOAT HARBOUR DATA SUMMARY
2021–2022

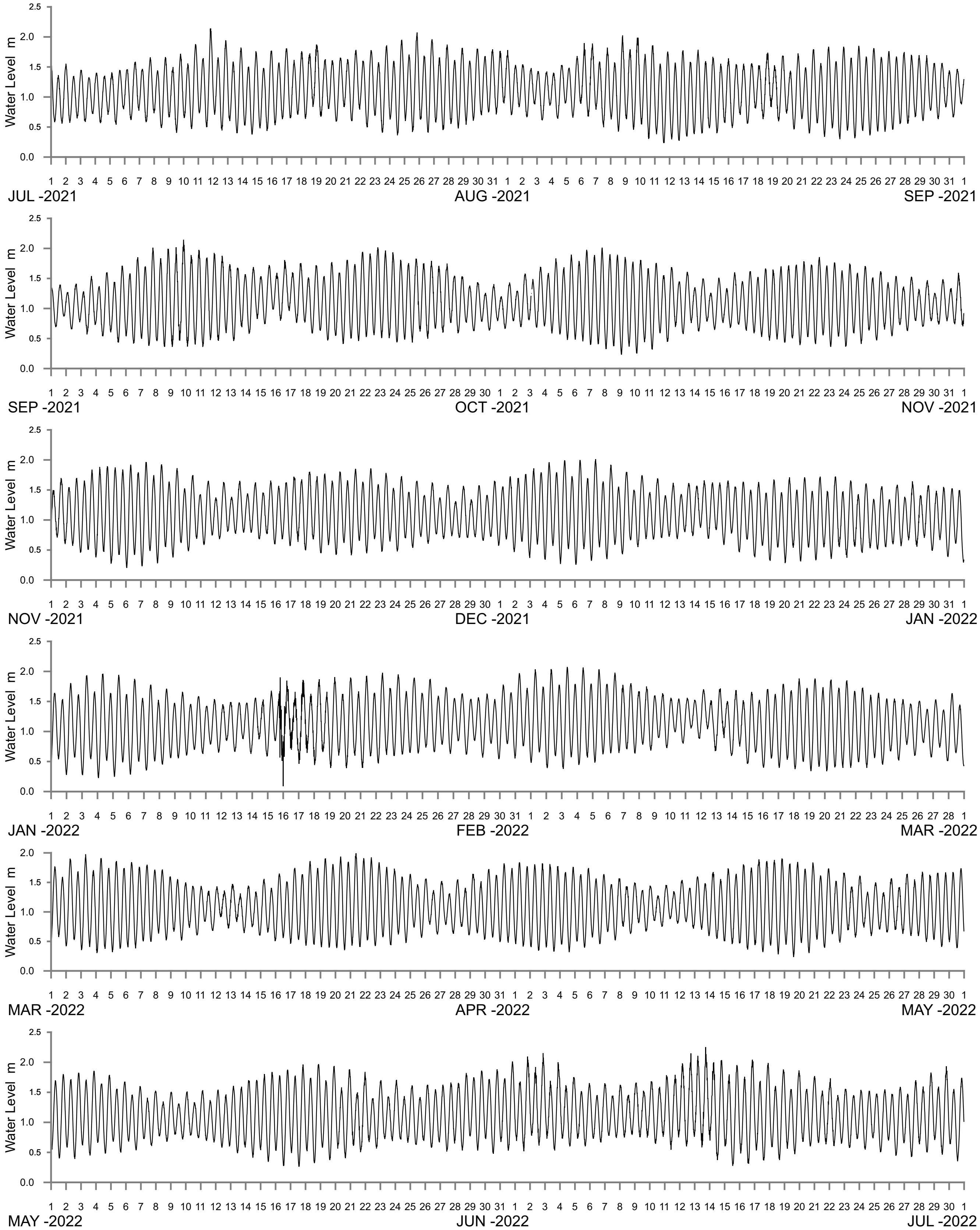
Manly Hydraulics Laboratory

Report MHL2907

Figure

A22

DRAWING 2907-A22.cdr



WATER LEVEL REFERENCED TO LOWEST ASTRONOMICAL TIDE

– – – – – DATA LOSS

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

NSW GOVERNMENT

NORFOLK ISLAND DATA SUMMARY
2021–2022

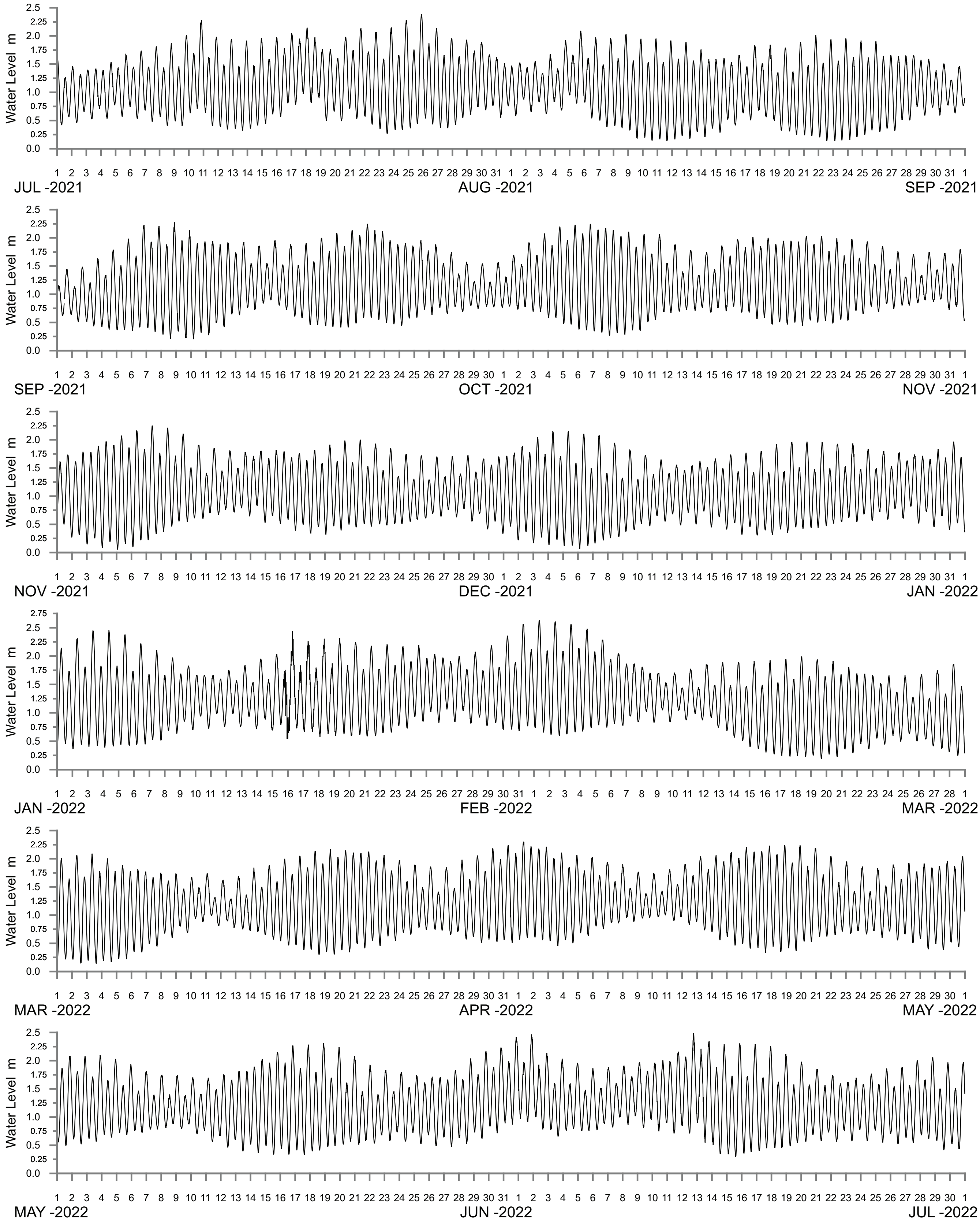
Manly Hydraulics Laboratory

Report MHL2907

Figure

A23

DRAWING 2907-A23.cdr



WATER LEVEL REFERENCED TO LORD HOWE ISLAND TIDAL DATUM

– – – – – DATA LOSS

NSW GOVERNMENT

LORD HOWE ISLAND DATA SUMMARY
2021–2022

Manly Hydraulics Laboratory

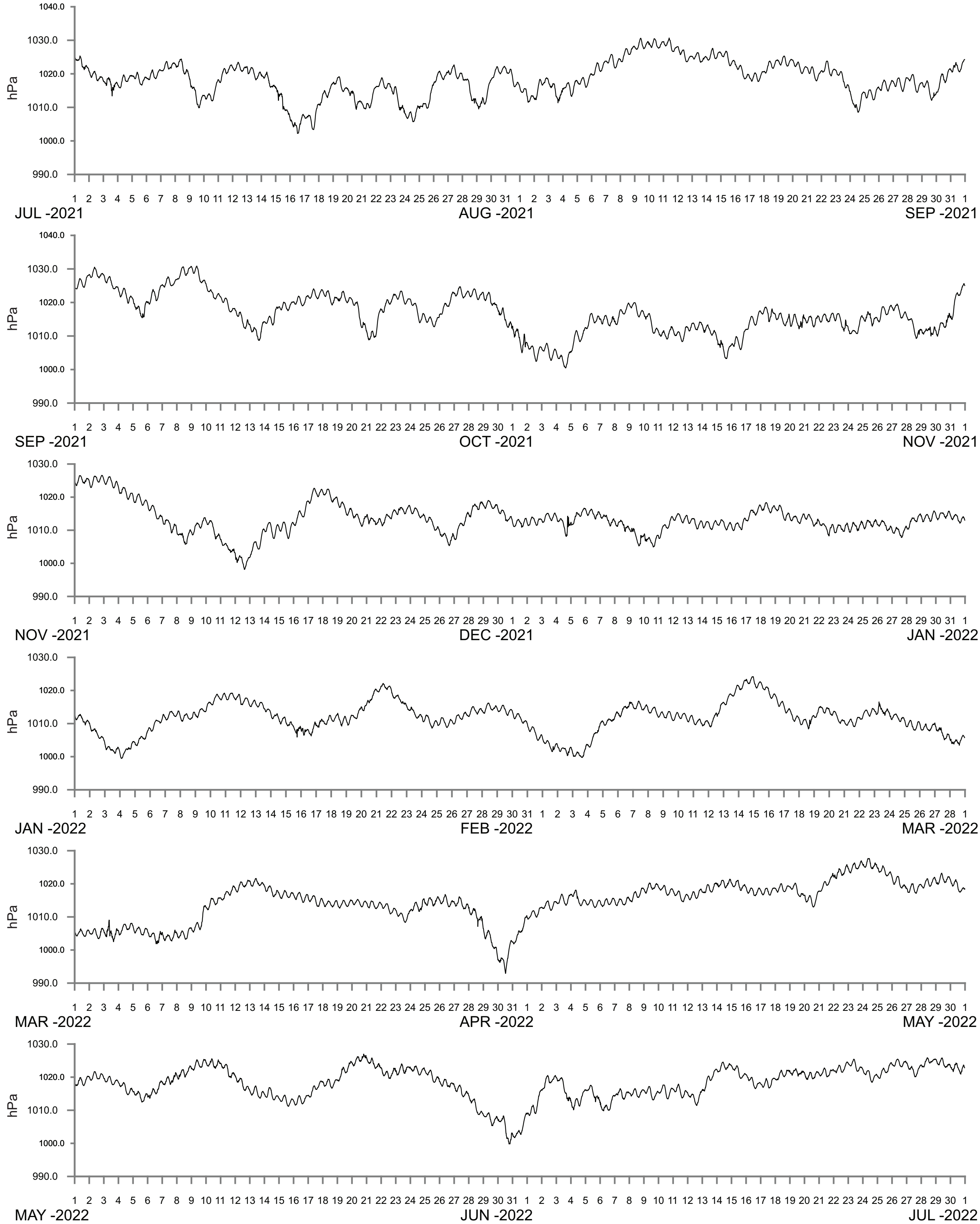
Report MHL2907

Figure

A24

DRAWING 2907-A24.cdr

Appendix B Annual barometric data station summaries



BAROMETRIC PRESSURE REFERENCED TO MEAN SEA LEVEL

– – – – – DATA LOSS

NSW GOVERNMENT

KINGSCLIFF DATA SUMMARY
2021–2022

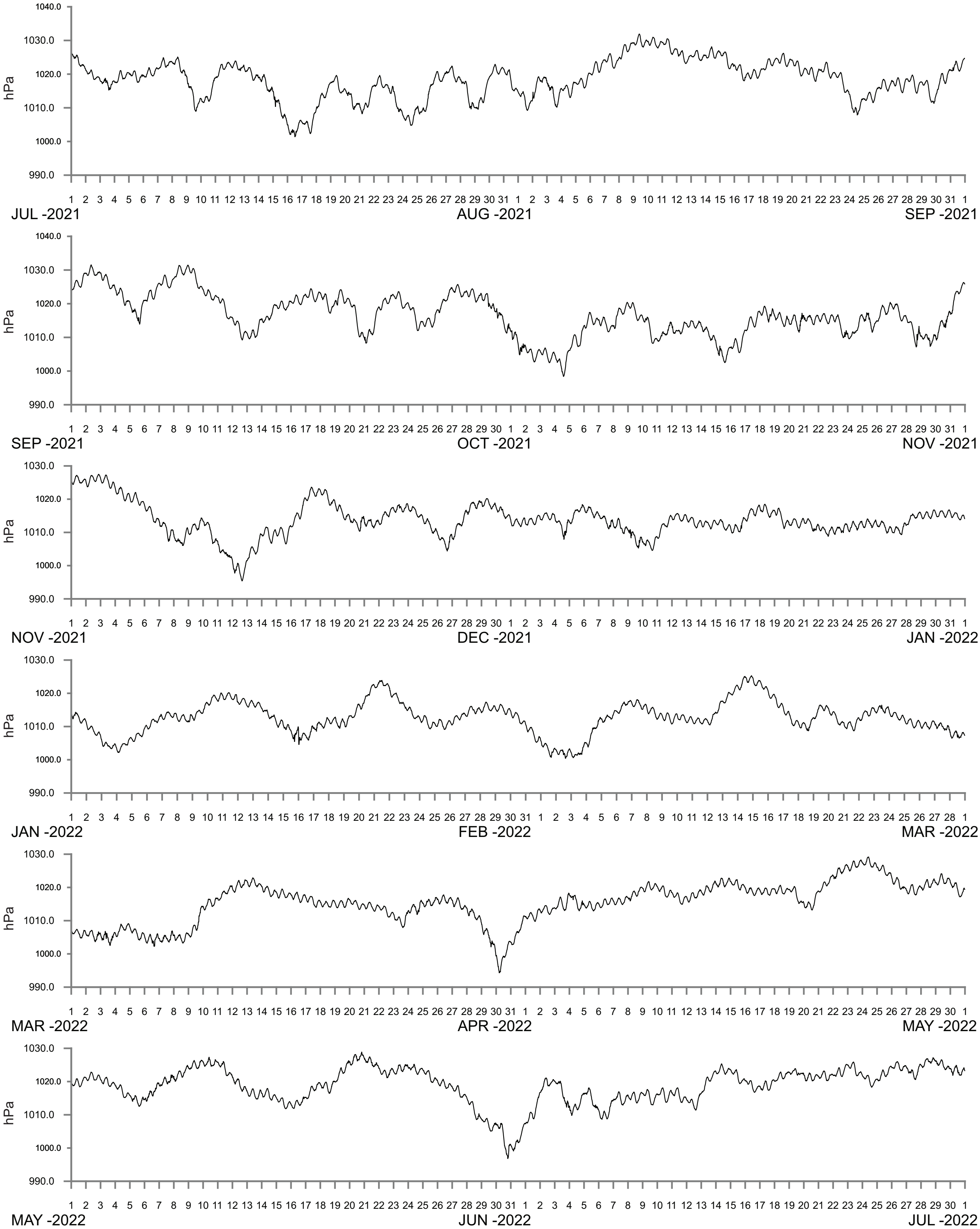
Manly Hydraulics Laboratory

Report MHL2907

Figure

B1

DRAWING 2907-B1.cdr



BARROMETRIC PRESSURE REFERENCED TO MEAN SEA LEVEL

– – – – – DATA LOSS

NSW GOVERNMENT

LAKE WOOLOWEYAH DATA SUMMARY
2021–2022

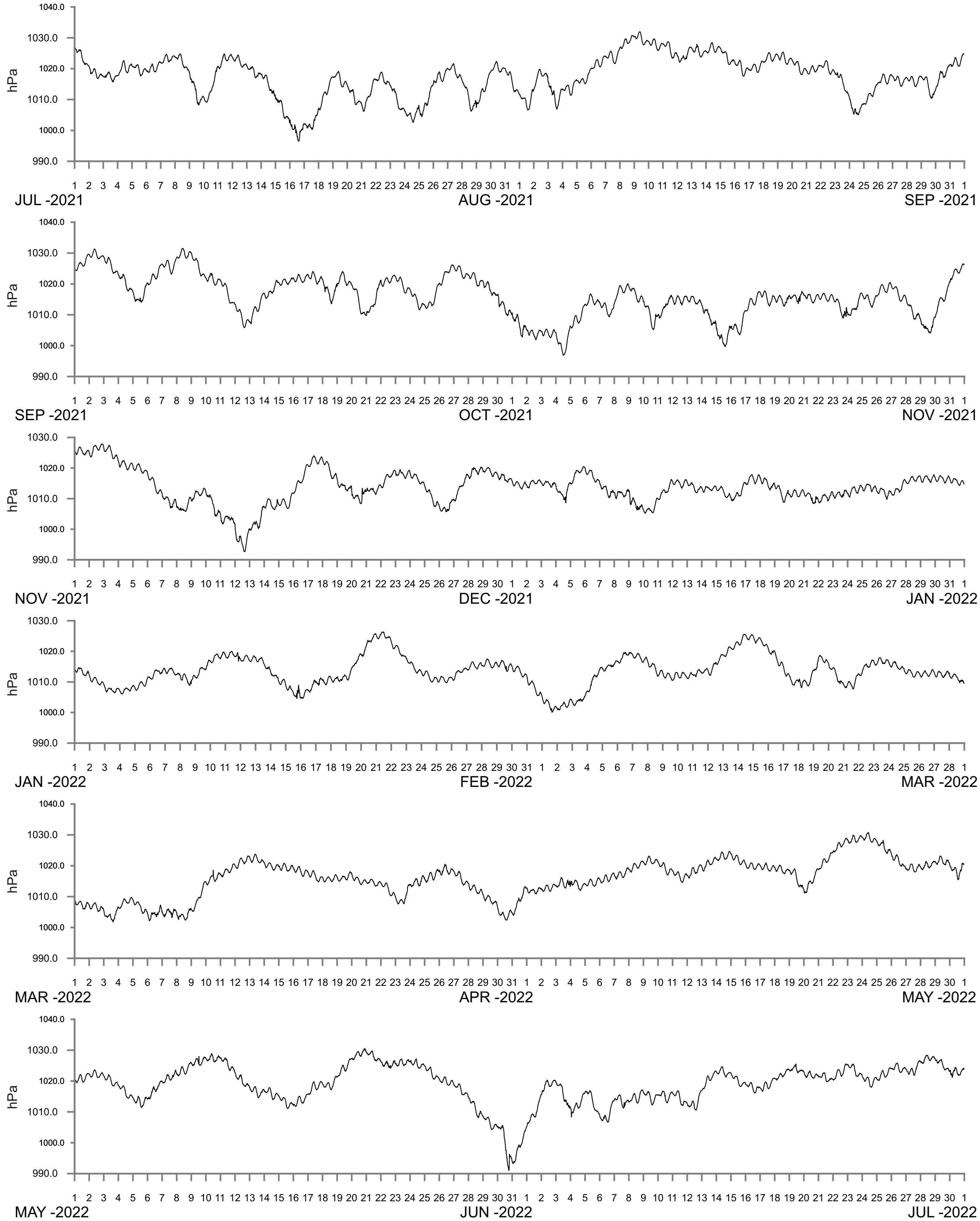
Manly Hydraulics Laboratory

Report MHL2907

Figure

B2

DRAWING 2907-B2.cdr



BAROMETRIC PRESSURE REFERENCED TO MEAN SEA LEVEL

- - - - - DATA LOSS

NSW GOVERNMENT

SETTLEMENT POINT DATA SUMMARY
2021–2022

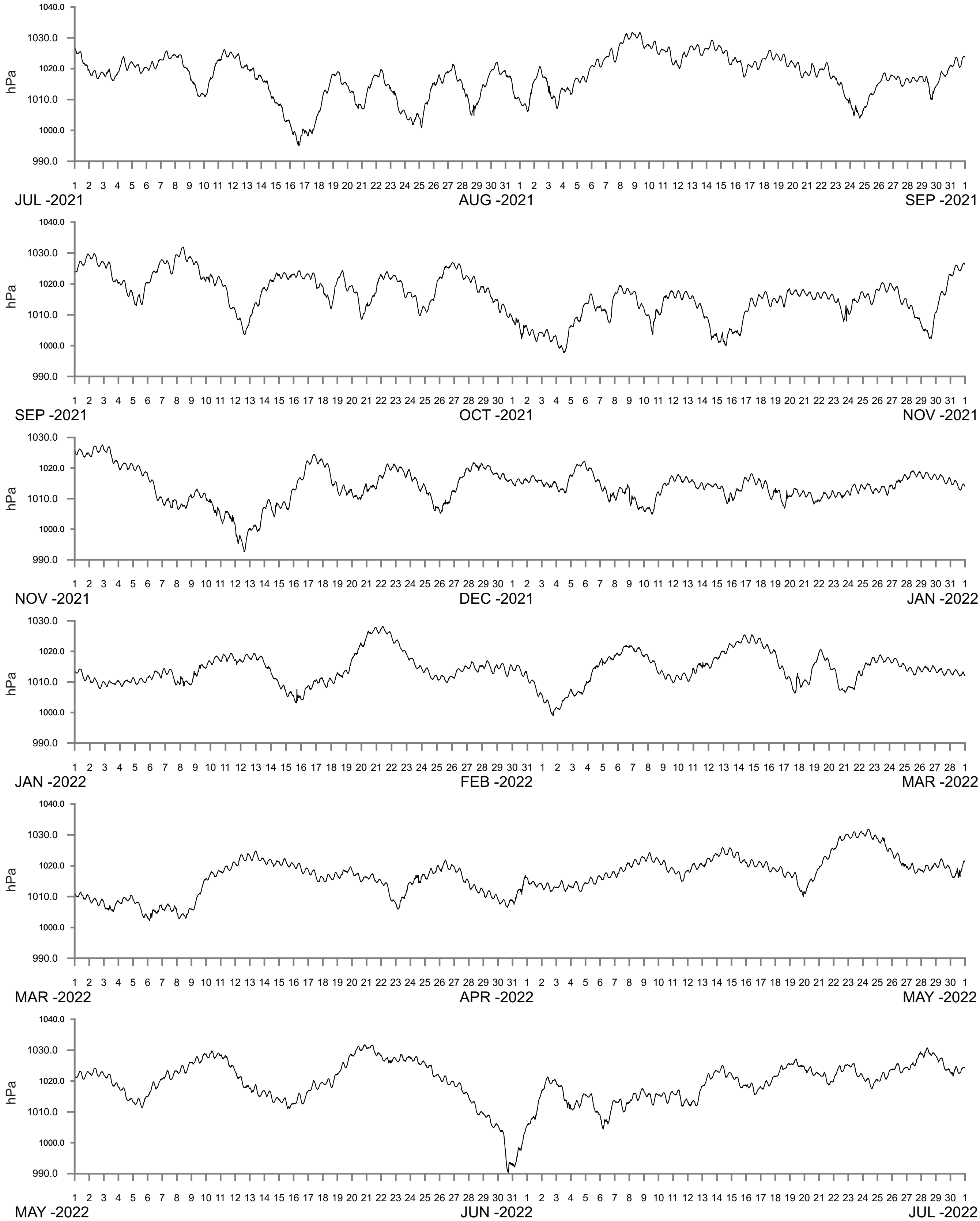
Manly Hydraulics Laboratory

Report MHL2907

Figure

B3

DRAWING 2907-B3.cdr



BAROMETRIC PRESSURE REFERENCED TO MEAN SEA LEVEL

– – – – – DATA LOSS

NSW GOVERNMENT

STOCKTON BRIDGE DATA SUMMARY
2021–2022

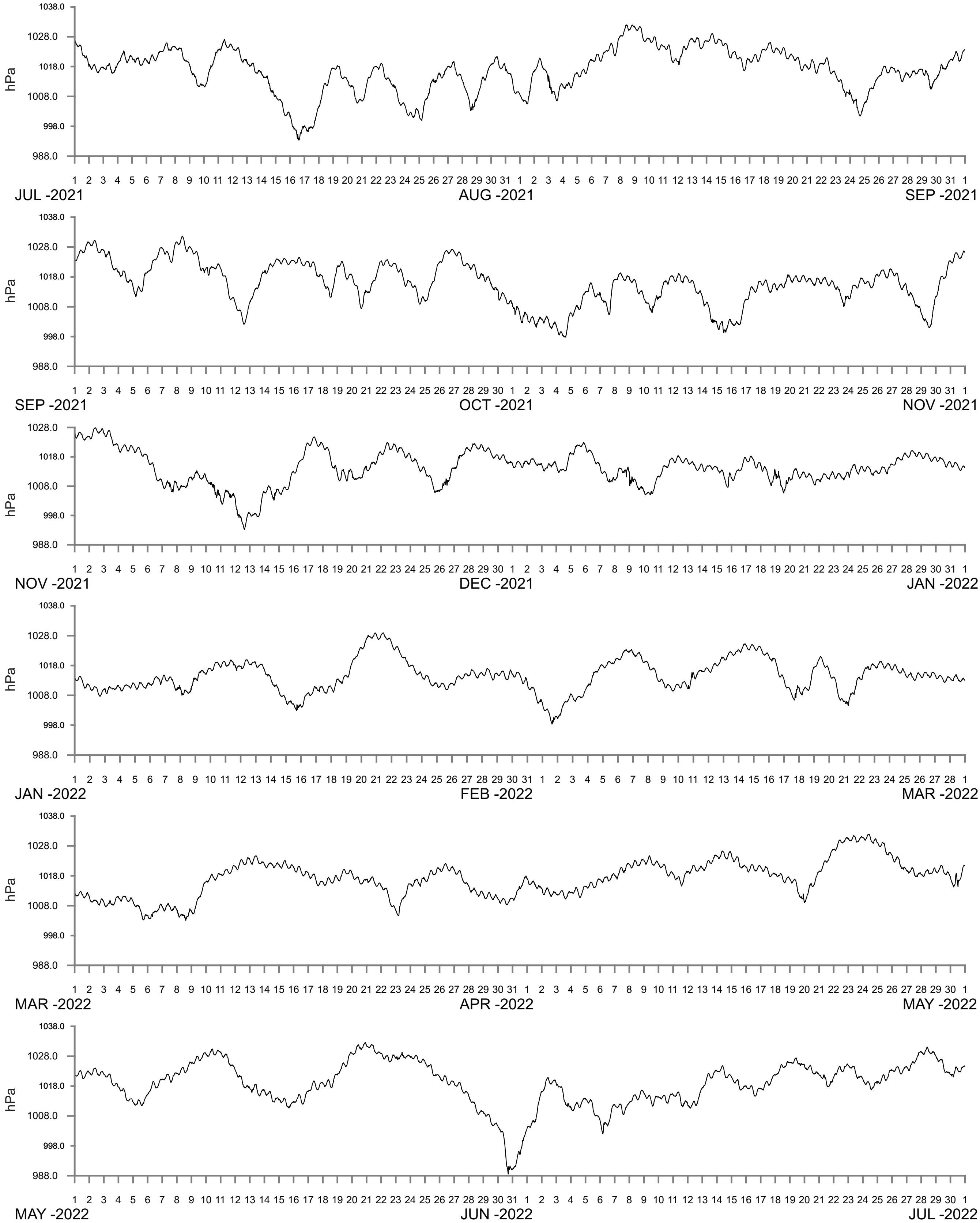
Manly Hydraulics Laboratory

Report MHL2907

Figure

B4

DRAWING 2907-B4.cdr



BAROMETRIC PRESSURE REFERENCED TO MEAN SEA LEVEL

– – – – – DATA LOSS

NSW GOVERNMENT

NARRABEEN BRIDGE DATA SUMMARY
2021–2022

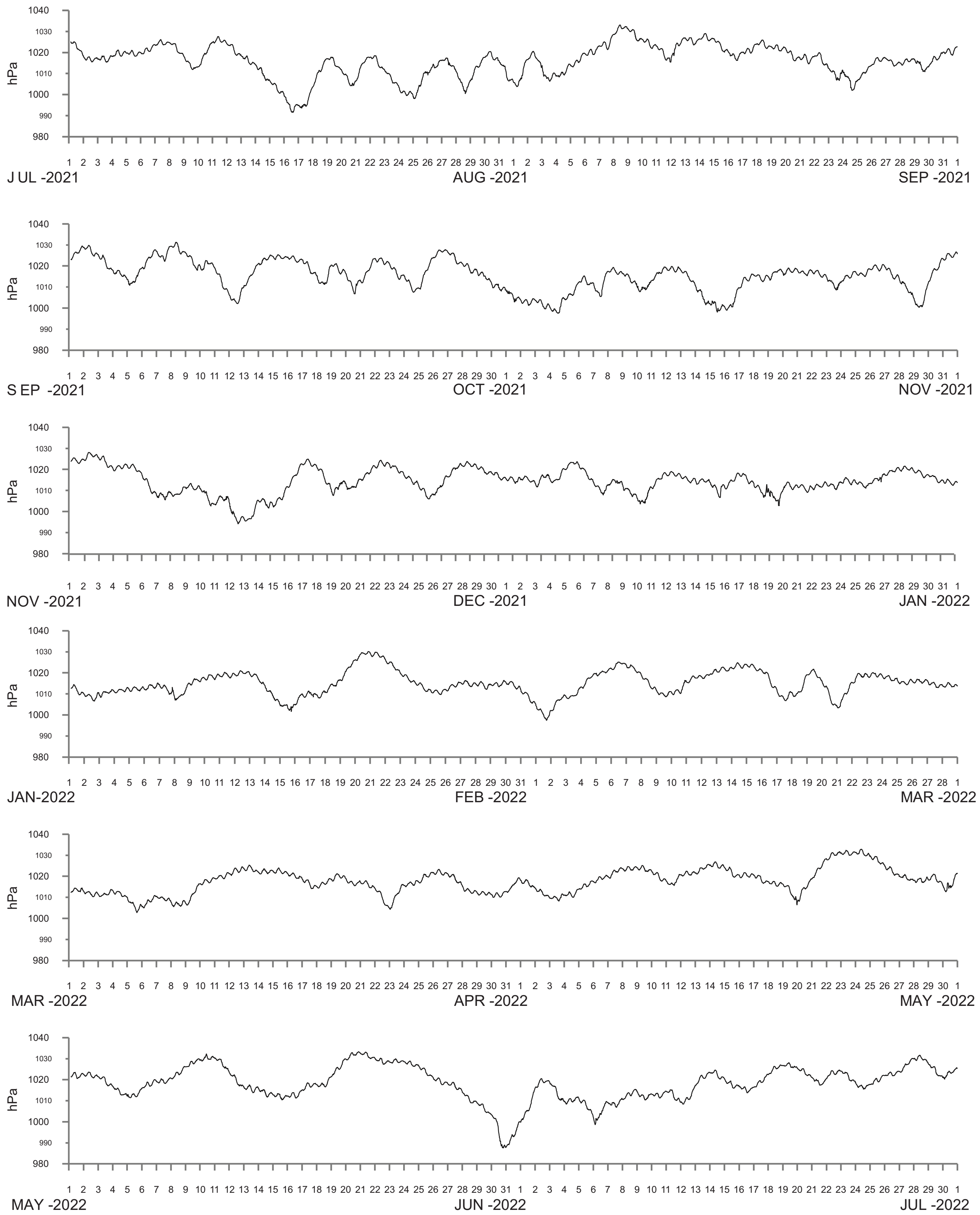
Manly Hydraulics Laboratory

Report MHL2907

Figure

B5

DRAWING 2907-B5.cdr



BAROMETRIC PRESSURE REFERENCED TO MEAN SEA LEVEL

– – – – – DATA LOSS

NSW GOVERNMENT

CURRARONG CREEK DATA SUMMARY
2021–2022

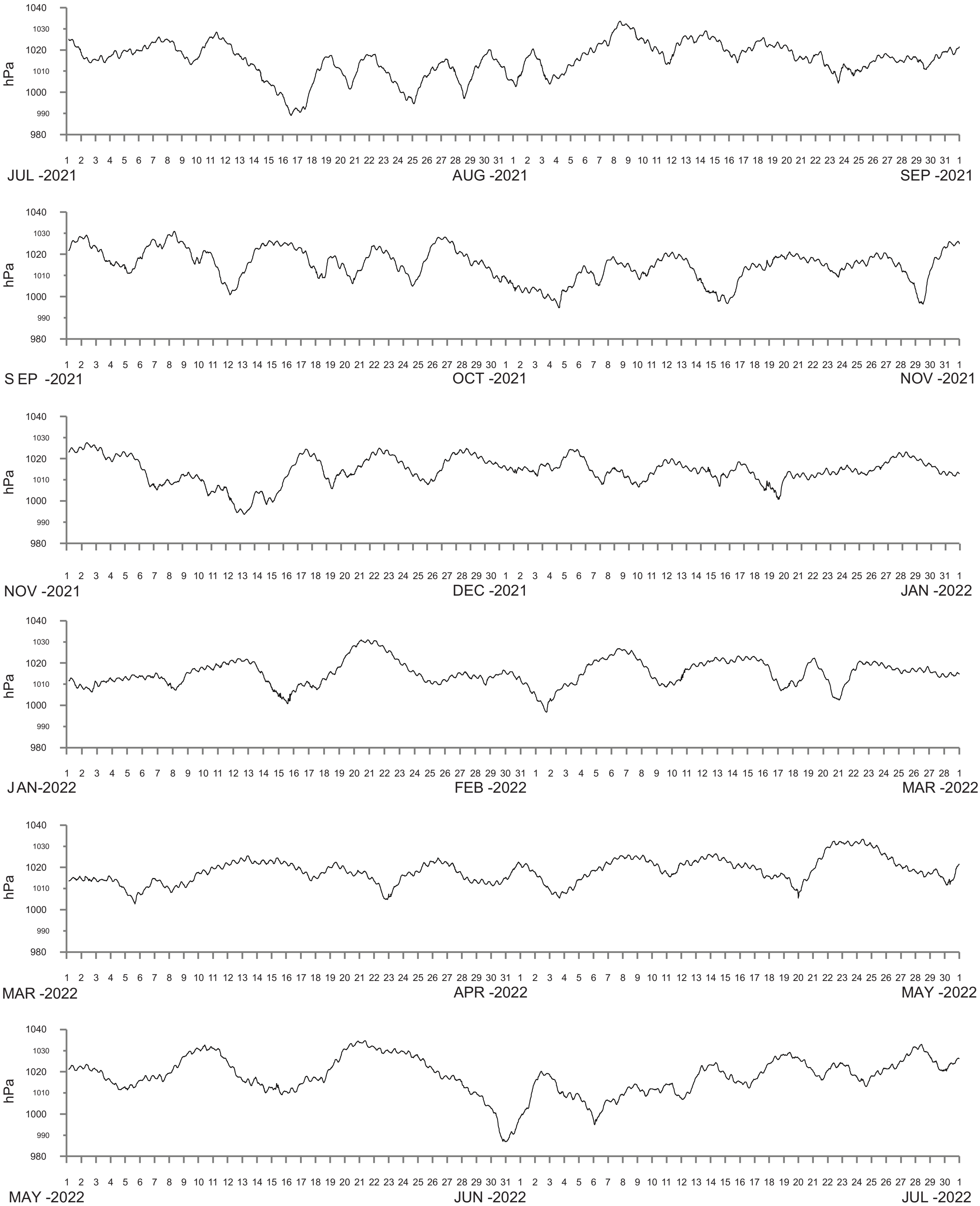
Manly Hydraulics Laboratory

Report MHL2907

Figure

B6

DRAWING 2907-B6.cdr



BAROMETRIC PRESSURE REFERENCED TO MEAN SEA LEVEL

– – – – – DATA LOSS

NSW GOVERNMENT

TUROSS HEAD DATA SUMMARY
2021–2022

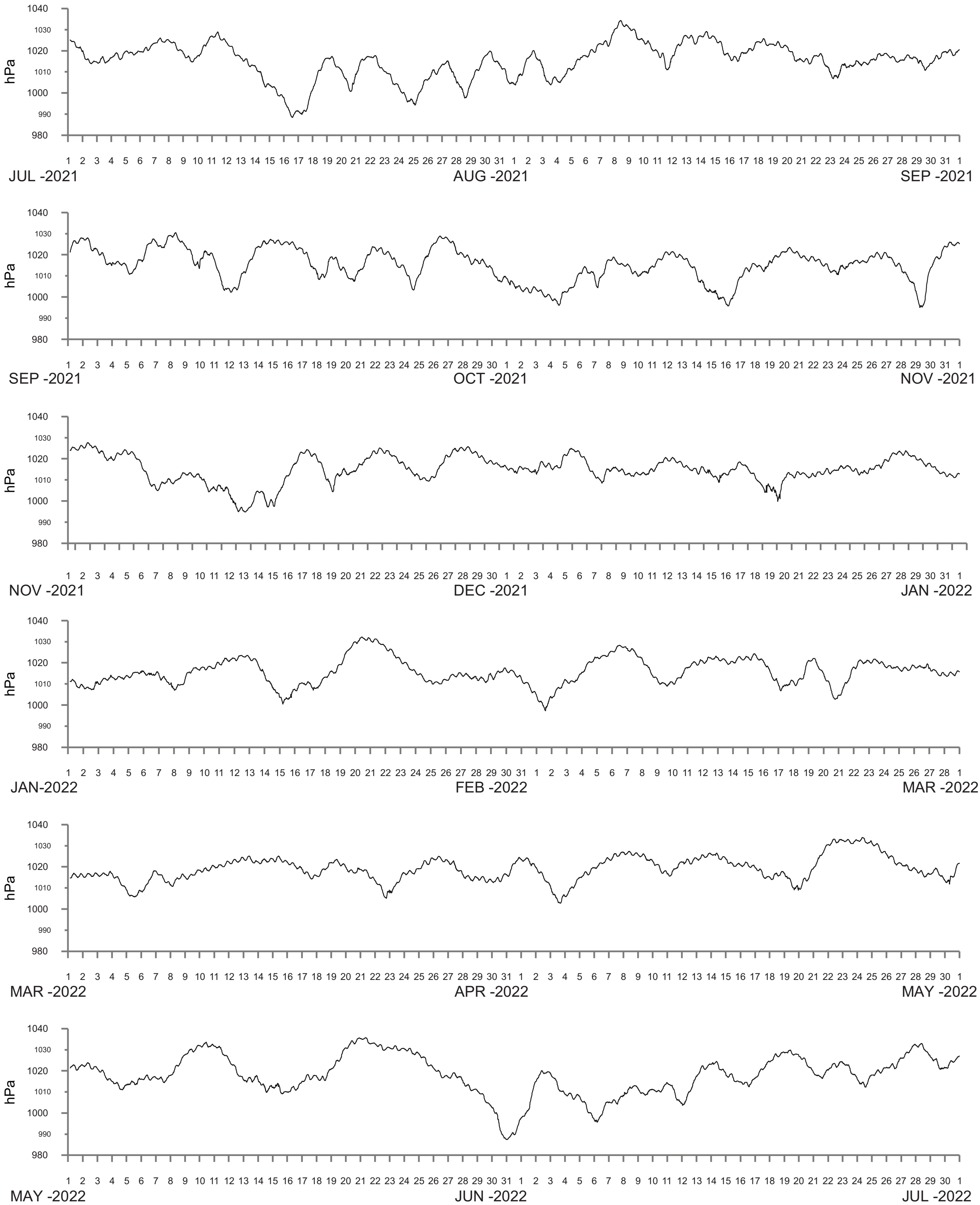
Manly Hydraulics Laboratory

Report MHL2907

Figure

B7

DRAWING 2907-B7.cdr



BAREOMETRIC PRESSURE REFERENCED TO MEAN SEA LEVEL

- - - - - DATA LOSS

NSW GOVERNMENT	WONBOYN LAKE DATA SUMMARY 2021–2022	Manly Hydraulics Laboratory Report MHL2907 Figure B8

DRAWING 2907-B8.cdr

Appendix C Current tidal station data

Table C.1 Current station digital data

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

[1] Station has changed location during data period

Appendix D Historical tide data

Table D.1 Historical tide data

Station Name	Location	Period of record	Location
Tweed Regional	North Breakwater	Feb 1987–Apr 2015	Online
Tweed Regional	Breakwater 201470	1978–1980	Online
Richmond River	Breakwater 202471	1889–1912	HiLos online
Richmond River	Ballina	1959–1963	Microfiche MHL
Ballina 202470	Half Tide Breakwater	Apr 1986–May 2011	Online
Clarence River	Yamba	1900–1924	HiLos online
Yamba Offshore	Yamba 204450	Jun 1987–Sep 2009	Online
Clarence River	Iluka 204437	1956–1961	Online
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	Online
Coffs Harbour	Outer harbour	1953–56, 1957–60	Microfiche MHL
Coffs Harbour	Water Police Jetty Inner Harbour 205470	1990–1996	Online
Macleay River	Entrance 206477	1901–1913	HiLos online
Crowdy Head	CSIRO 208470	1985–1986	Online
Tomaree	Hospital Jetty 209471	Oct 1985–Apr 2014	Online
Tomaree	Hospital Jetty	1967–1969	HiLos State Archives
Newcastle	Boat harbour 210461	1899–1921	HiLos online
Newcastle	Breakwater	1946–1961	HiLos State Archives
Port Hacking	Hungry Point	Nov 1987–Feb2015	Online
Port Jackson	Fort Denison 60370	1914–2021	Online
Port Kembla	Harbour	1957–1965	Microfiche State Archives
Port Kembla	Harbour 214480	1987–1992	Online
Jervis Bay	HMAS Creswell 216471	1914–1919	HiLos online
Jervis Bay	Huskisson 216472	1987–1993	Online
Batemans Bay Offshore	Snapper Island 216451	1986–1990	Online
Batemans Bay Offshore	Offshore 216452	1987–1988	Online (MHL556)
Moruya River	Moruya Heads 217403	1951–1952	HiLos State Archives
Moruya River	Entrance	1951–52, 1987–88	Online
Eden	Snug Cove 220470	1978–1990	Online
Eden	Snug Cove	1954–1956	Microfiche State Archives
Norfolk Island	Kingston Jetty	1994-2015	Online

Fort Denison data courtesy of Sydney Ports Corporation and BoM National Tidal Unit.
Data for Norfolk Island since 2015 provided by Bureau of Meteorology's National Tidal Unit (NTU).

Appendix E Glossary of terms

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

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

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

K1	Lunisolar diurnal constituent. This constituent, with O1, expresses the effect of the moon's declination. They account for diurnal inequality and, at extremes, diurnal tides. With P1, it expresses the effect of the sun's declination. Speed = T + h = 15.041,068,6° per solar hour.
King Tide	A non-scientific term used to describe especially high tide events occurring twice a year around early January and early July. They occur when the earth, sun and moon are in alignment and when the sun is closest and furthest from the earth (perihelion and aphelion respectively).
Lambda	Smaller lunar evectional constituent. This constituent, with V_2, U_2, and (S_2), modulates the amplitude and frequency of M_2 for the effects of variation in solar attraction of the moon. This attraction results in a slight pear-shaped lunar ellipse and a difference in lunar orbital speed between motion toward and away from the sun. Although (S_2) has the same speed as S_2, its amplitude is extremely small. Speed = 2T - s + p = 29.455,625,3° per solar hour.
Low water (LW)	The minimum height reached by a falling tide. The low water is due to the periodic tidal forces and the effects of meteorological, hydrologic, and/or oceanographic conditions. For tidal datum computational purposes, the minimum height is not considered a low water unless it contains a tidal low water.
Lower high water (LHW)	The lowest of the high waters of any specified tidal day due to the declination A_l effects of the moon and sun.
Lower low water (LLW)	The lowest of the low waters (or single low water) of any specified tidal day due to the declination A_l effects of the moon and sun.
Lowest Astronomical Tide (LAT)	The lowest level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions; this level will not be reached every year. LAT is not the extreme level which can be reached as storm surges may cause considerably lower levels to occur.
Lunar tide	That part of the tide on the earth due solely to the moon as distinguished from that part due to the sun.
M_2	Principal lunar semi-diurnal constituent. This constituent represents the rotation of the Earth with respect to the Moon. Speed = 2T - 2s + 2h = 28.984,104,2° per solar hour.
Mean high water (MHW)	A tidal datum. The average of all the high water heights observed over the National Tidal Datum Epoch. For stations with shorter series, simultaneous observational comparisons are made with a control tide station in order to derive the equivalent datum.

Mean low water springs (MLWS)	A tidal datum. Frequently abbreviated spring low water. The arithmetic mean of the low water heights occurring at the time of spring tides observed over the National Tidal Datum Epoch. It is usually derived by taking an elevation depressed below the half-tide level by an amount equal to one-half the spring range of tide, necessary corrections being applied to reduce the result to a mean value.
Mean Sea Level (MSL)	The arithmetic mean of the water level heights at the tidal station observed over a period of time (preferably 19 years).
Modem	A device allowing a computer to be accessed over a telephone line.
Neap tides	Tides of decreased range or tidal currents of decreased speed occurring semi-monthly as the result of the moon being in quadrature. The neap range (Np) of the tide is the average range occurring at the time of neap tides and is most conveniently computed from the harmonic constants. It is smaller than the mean range where the type of tide is either semi-diurnal or mixed and is of no practical significance where the type of tide is predominantly diurnal. The average height of the high waters of the neap tide is called neap high water or high water neaps (MHWN) and the average height of the corresponding low waters is called neap low water or low water neaps (MLWN).
O_1	Lunar diurnal constituent. See K_1. Speed = T - 2s + h = 13.943,035,6° per solar hour.
Phase	1. Any recurring aspect of a periodic phenomenon, such as new moon, high water, flood strength, etc. 2. A particular instant of a periodic function expressed in angular measure and reckoned from the time of its maximum value, the entire period of the function being taken as 360°. The maximum and minimum of a harmonic constituent have phase values of 0° and 180°, respectively.
Pressure sensor	A pressure transducer sensing device for water level measurement. A relative transducer is vented to the atmosphere and pressure readings are made relative to atmospheric pressure. An absolute transducer measures the pressure at its location. The readings are then corrected for barometric pressure taken at the surface.
Range of tide	The difference in height between consecutive high and low waters. The mean range is the difference in height between mean high water and mean low water. The great diurnal range or diurnal range is the difference in height between mean higher high water and mean lower low water. For other ranges see spring, neap, perigean, apogean, and tropic tides; and tropic ranges.

Relative mean sea level change	A local change in mean sea level relative to a network of benchmarks established in the most stable and permanent material available (bedrock, if possible) on the land adjacent to the tide station location. A change in relative mean sea level may be composed of both an absolute mean sea level change component and a vertical land movement change component, together.
S_2	Principal solar semi-diurnal constituent. This constituent represents the rotation of the Earth with respect to the Sun. Speed = 2T = 30.000,000,0° per solar hour.
Seiche	A stationary wave usually caused by strong winds and/or changes in barometric pressure. It is found in lakes, semi-enclosed bodies of water, and in areas of the open ocean. The period of a seiche in an enclosed rectangular body of water is usually represented by the formula: Period (T) = 2L / square root (gd) in which L is the length, d the average depth of the body of water, and g the acceleration of gravity.
Semi-diurnal	Having a period or cycle of approximately one-half of a tidal day. The predominant type of tide throughout the world is semi-diurnal, with two high waters and two low waters each tidal day. The tidal current is said to be semi-diurnal when there are two flood and two ebb periods each day. A semi-diurnal constituent has two maxima and two minima each constituent day, and its symbol is the subscript 2.
Shallow water constituent	A short-period harmonic term introduced into the formula of tidal (or tidal current) constituents to take account of the change in the form of a tide wave resulting from shallow water conditions. Shallow water constituents include the overtides and compound tides.
Slack water (slack)	The state of a tidal current when its speed is near zero, especially the moment when a reversing current changes direction and its speed is zero. The term also is applied to the entire period of low speed near the time of turning of the current when it is too weak to be of any practical importance in navigation. The relation of the time of slack water to the tidal phases varies in different localities. For a perfect standing tidal wave, slack water occurs at the time of high and of low water, while for a perfect progressive tidal wave, slack occurs midway between high and low water.
Solar tide	1. The part of the tide that is due to the tide-producing force of the sun. 2. The observed tide in areas where the solar tide is dominant. This condition provides for phase repetition at about the same time each solar day.
Solid State	An electronic device composed of components with no moving parts – in this instance, using the electronic properties of solids, as in transistors, semi-conductors and integrated circuits.

Spring high water	Same as mean high water springs (MHWS). See spring tides.
Spring low water	Same as mean low water springs (MLWS). See spring tides.
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 Epoch	Has been set in Australia as a 20–year period (based on the Lunar Cycle of 18.6 Earth years) over which all recordings of tidal variations and influences are analysed and reviewed.
Tidal Plane	A level of water (often defined by tidal constituents) from which water depths and heights of tides are referenced.

Tide	The periodic rise and fall of the water resulting from gravitational interactions between sun, moon and earth. The vertical component of the particulate motion of a tidal wave. Although the accompanying horizontal movement of the water is part of the same phenomenon, it is preferable to designate this motion as tidal current.
Tide curve	A graphic representation of the rise and fall of the tide in which time is usually represented by the abscissa and height by the ordinate. For a semi-diurnal tide with little diurnal inequality, the graphic representation approximates a cosine curve.
Tide (water level) gauge	An instrument for measuring the rise and fall of the tide (water level).
Tide Tables	Tables which give daily predictions of the times and heights of high and low waters. These predictions are usually supplemented by tidal differences and constants through which predictions can be obtained for numerous other locations.
Tsunami	A shallow water progressive wave, potentially catastrophic, caused by an underwater earthquake or volcano.
Universal time (UTC)	Same as Greenwich mean time (GMT).
Z_0	Symbol recommended by the International Hydrographic Organisation to represent the elevation of mean sea level above chart datum

Appendix F Publications of interest

Data reports

MHL annual ocean tide levels summaries available from 1986–87 to 2019–2020
MHL Report Nos. 515 (86–87), 544 (87–88), 563 (88–89), 585 (89–90), 602 (90–91), 628 (91–92), 658 (92–93), 697 (93–94), 732 (94–95), 777 (95–96), 876 (96–97), 947 (97–98), 1013 (98–99), 1069 (99–00, 1129 (00–01), 1205 (01–02), 1277 (02–03), 1347 (03–04), 1423 (04–05), 1512 (05–06), 1764 (06–07), 1848 (07–08), 1933 (08–09), 2010 (09–10), 2089 (10–11), 2158 (11–12), 2219 (12–13), 2292 (13–14), 2384 (14–15), 2475 (15–16), 2574 (16–17), 2618 (17–18), 2693 (18–19), 2770 (19–20), 2856 (20–21).

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Manly Hydraulics Laboratory 2023, *NSW Tidal Planes Analysis: 2001–2020 Harmonic Analysis*, MHL Report 2786, April 2023.

Mean sea level

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

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