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TIDES AND MEAN SEA LEVEL

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1. Preface

The original Special Publications 9 Handbook – **The Australian Tides Manual** – was published in 1984 and a revised web enabled version followed in 2004. As the title suggests, it provided operating procedures to be followed by operators of tide gauges on the Australian "National Network" – those stations that provide data for tide predictions at standard ports. In the twenty years since it was published, there have been a number of changes in measurement technology, communications, and procedure, which now makes a new version of SP9 necessary.

Like the original SP9, this book is written for the Australian user. As various governments worldwide define legal boundaries differently, and have different procedural guidelines for tide gauge maintenance, datum control, etc., many of the procedures which are described herein may not be appropriate elsewhere.

This document brings together in a single, user-friendly form, a large number of existing sources of information on the measurement of tides and tidal currents. To some extent it is intended to enable the reader to quickly find the most relevant and up-to-date information.

This document contains numerous links to documents in html and PDF (Adobe reader required) formats, such links are blue and underlined. If the user already has Reader on their computer the document will be opened automatically, but otherwise, they will be prompted to obtain a (free) copy from Adobe.

2. Introduction

Our ability to predict the tidal levels and currents through coastal waterways is of great importance to a number of human activities. The beneficiaries of this information include commercial and recreational users, the Navy and a host of others. Sea level monitoring also provides key data for coastal authorities responsible for the determination of property boundaries, and for planners and engineers in the construction of waterfront buildings, bridges, and jetties.

It may be argued that for tidal prediction it is no longer necessary to continuously monitor sea level. Indeed, the greater parts of the tidal fluctuations are regulated so closely by clockwork-like astronomical variations that the tides can be predicted with a high degree of precision for many years into the future. Nonetheless, the monitoring of sea level and currents remains an essential task, even in tide prediction, which is only as good as the data on which it is based, and is continuously improved as the data set lengthens. One reason for this is that water level and currents are controlled by transient environmental factors as well as astronomical motions, and accurate records of both are often required in retrospect for legal, scientific, environmental, maritime safety, and planning purposes. From a broader perspective, we might consider that the global ocean, so closely tied to climate, is very sparsely sampled, and so we must do all in our power to maintain the best possible record of its variability at our shorelines.

Over the past several decades, sea level monitoring has taken on a new and important role in climate prediction, particularly for the El Niño Southern Oscillation (ENSO) and the estimation of long-term sea level variability. In the early 1990's, the advent of reliable satellite altimeter data, combined with numerical models, gave rise to the belief among some that conventional tide gauges would soon become obsolete. However, this has not proven to be the case. Tide gauges have proven to be the most reliable and accurate source of coastal sea level data, and have even turned the tables on satellite altimeters, providing evidence of drift in the latter technology.

3. Tides, Sea Level and Water Currents

3.1 Basic Theory

A brief introduction to the tidal forces is contained in “[Our restless Tides](#)”, by the National Oceanographic and Atmospheric Administration (NOAA) in the United States. The approach is fairly conventional, with basic graphics. An example of one such graphics is From "Our Restless Ties" NOAA:

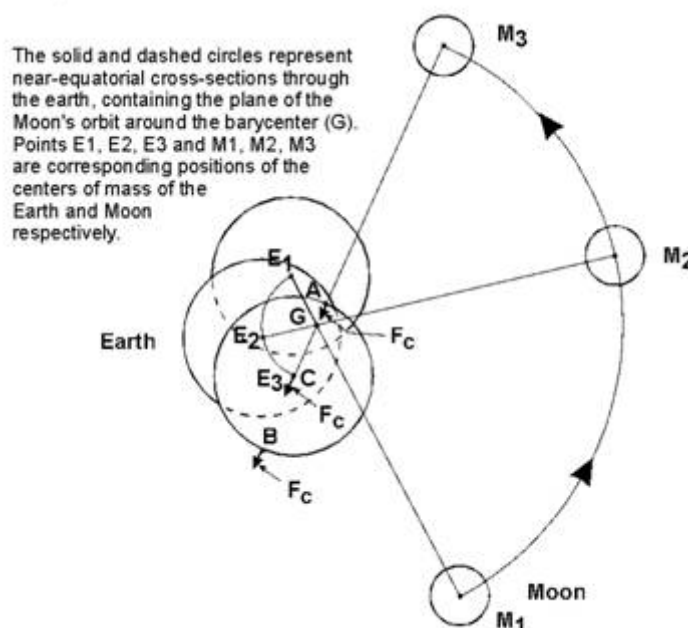


Figure 1 - Tidal forces

Figures such as the one above reproduced above serve an important purpose, but there are alternative approaches that some may find preferable, particularly with the easy availability of web-based animation software. A very informative on-line tutorial “Introduction to ocean tides” is available (after you register) through “Meted”, a cooperative online learning group. Another online introduction to tides that uses animated images is that of [Professor M. Tomczak of Flinders University](#).

Most introductions, including [Our Restless Tides](#) and [Professor Tomczak's website](#), explain tides in terms of a balance between gravitational and centrifugal forces. It is such an explanation that led to the figure below. Alternatively, introducing the concept of the “tidal potential” many of the complexities (such as illustrated in the figure above) of the force balance can be avoided. The [Canadian Tidal Manual](#) (Warren, 1983), online (in PDF format), discusses both approaches. This text requires slightly more advanced mathematical knowledge, but only by understanding the tidal potential can one understand the theoretical basis for the harmonic method of tidal analysis. It is more than twenty years old, but the theory has not gone out of date.

Finally, Pugh (1987) and Pugh (2004) have chapters on tidal theory written in a modern, textbook style.

3.2 Tidal Terminology

The National Tidal Centre hosts the comprehensive [NTC glossary](#) with an emphasis on Australian terms (for example, the tidal datums favoured in Australian jurisdictions). The [Australian Hydrographic Service \(AHS\) glossary](#), the [Manly Hydraulics Laboratory \(MHL; NSW Dept of Commerce\) glossary](#), and the [Maritime Safety Queensland](#) (MSQ; Queensland Department of Transport) site contain a number of pertinent definitions in an Australian context. The [Land Information New Zealand](#) (LINZ) site contains a concisely worded, but limited selection of tidal definitions, and NOAA's [tidal glossary](#) defines tidal terms in the context of US usage. It also defines a number of oceanographic terms, such as "Kuroshio Current". The International Hydrographic Organisation (IHO) [Hydrographic Dictionary](#), available for a fee, is a large compendium of all sorts of hydrographic and oceanographic terminology, including tidal.

3.3 Analysis and Prediction

The purpose of tidal analysis is to represent the water level or current time series by a set of harmonics, or sine waves, each of them having a specific amplitude and phase. The set of amplitudes and phases are known as the tidal constants. While the Australian National Tide Tables (ANNT) publishes 22 constants plus a mean level for each port, the official predictions created by the NTC uses 112 (given that there is at least one year of observations available for analysis). The definitions of four of the major constants are given below, these four constants can be used to classify the tidal character of a site (see section 1.3.3 Tidal Classification). There are two main methods for analysis: the harmonic method, and the response method. As the latter is used almost exclusively as a tool of scientific research, only the harmonic method will be discussed.

Table 1 - Major Tidal Constants

Constant	Definition
Major Diurnal Constants	
O ¹	Principle Lunar diurnal constituent
K ¹	Principle Lunisolar diurnal constituent
Major Semi-Diurnal Constants	
M ²	Principle Lunar semidiurnal constituent arising from the Earth with respect to the Moon
S ²	Principle Lunisolar semidiurnal constituent arising from the Earth with respect to the Sun

3.3.1 Tidal analysis

The harmonic method is based on the concept of the tidal potential (see above). It is difficult to find books that set out in detail the process of analysis for the tidal constants, which are based on a simultaneous linear regression for each of the amplitudes and phases (which may number over 100). Warren (1983) and Pugh (1987) both contain a brief overview. The **Manual for Tidal Heights Analysis and Prediction** (Foreman, 1977) is essentially the operating manual for the “Foreman package” of tidal analysis and prediction and is one of the best practical guides. The [PSMSL](#) site presents some of the finer points of tidal analysis in the “[Task-2000](#)” discussion, and refers the reader to the analysis method outlined in Murray (1964) which described the current PSMSL practice (which is also the basis for present-day NTC practice). The International Oceanographic Commission website “[Ocean Portal](#)”, which is devoted to the dissemination of ocean-related information, describes a number of tidal packages and invites the reader to review them.

Prospective tidal analysts should be aware that a set of constants derived using one analysis package may not provide accurate results with all prediction packages. This problem was discussed in [Interpretation of tidal constituent Sa](#) as well as in the Task-2000 report.

3.3.2 Tide prediction packages

Given a set of amplitudes and phases for a particular port from an analysis, the prediction of sea level is much simpler than the analysis that created them. The [Scripps](#) website listed above lists dozens of software packages that perform this function. Most generally contain a limited default set of constants for ports in the region covered, and it is also fair to say that most or all of those on the Scripps site

are limited in the total number of constants they can accept (and hence limited in accuracy). For tidal information at Australian regional ports, Seafarer Tides, from the AHS (CD available [online](#)), is useful, having tabulated predictions for high and low water each day of the year for over 80 standard ports in Australia, PNG, Solomon Islands and East Timor. It incorporates a graphical representation of the tidal curves and predictions at 20 minute intervals for each location.

3.3.3 Tidal classification

The characteristic features of tides, such as whether there are two or only one high and low per day, vary widely around Australia. Various classification schemes have been developed, and one of the most common of these is the “form factor”, F , defined by $F = (K1 + O1)/(M2 + S2)$, see section 1.3 for definitions the four major constants. The ANTT describes the classification of tidal types as follows:

“All tides are composed of both semi-diurnal and diurnal components, the latter introducing inequality in successive heights of high or low water and also in the times. When this diurnal inequality reaches a certain limit, it becomes more informative to list the average heights of the higher and lower high and low waters rather than the average spring and neaps values. The division between diurnal and semi-diurnal tides is arbitrary. In these tables the following criterion is used:

When $(K1 + O1)/(M2 + S2)$ is less than or equal to 0.5, the tide is considered to be semi-diurnal. When $(K1 + O1)/(M2 + S2)$ is greater than 0.5, the tide is considered to be diurnal. In some areas these formulae are unsatisfactory and a more detailed study of the harmonic constants is necessary to determine tidal characteristics”.

3.3.4 Analysis of tidal currents

Tidal currents are analysed in terms of their separate (east-west and north-south) components. An introduction to [tidal currents](#) can be found on the NOAA website, and the NOAA [glossary](#) gives further detailed definitions, such as the meaning of “rotary” versus “rectilinear” currents. Many users find it useful to distinguish between the terms “tidal currents” and “tidal streams”, with the latter being used to imply the major axis of flow denoted on nautical charts. Warren (1983) and Pugh (1987) give additional details.

3.3.5 Long term sea level variability

Long-term sea level changes are an important reason for the necessity of permanent continuous tide gauge installations. The topic of sea level rise in the context of the “enhanced greenhouse effect” is nicely summarised, with good illustrations, in the United States Environmental Protection Agency’s (EPA) booklet [Greenhouse Effect and Sea Level Rise: A Challenge for this Generation](#), available in PDF format online. The potential impacts in the Australian region are discussed in Chapter 2 of [Climate Change: An Australian Guide to the Science and Potential Impacts](#), available online on the Australian Greenhouse Office website in PDF format. The CSIRO also has an

online [fact sheet](#), and finally, Wikipedia's entry for [sea level](#) contains useful information and good graphics.

3.4 Environmental Effects on Sea Level

Water levels at the coast are governed by environmental (weather related, ocean wave, etc.) effects as well as by the astronomical tides. Perhaps the most familiar and dramatic example along the coasts of Australia is the storm surge, a large volume of water driven up to the coast by the combined effects of wind and atmospheric pressure. The effects of wind and atmospheric pressure are described in [Section 2.3](#) of the IOC (Intergovernmental Oceanographic Commission) Training Manual Vol. I (1985). This section also discusses the difference between tropical and extra-tropical surges.

3.4.1 Weather-related effects

The appendices of the [NSW Coastline Management Manual](#) contain descriptive reviews of coastal processes and the effects on beaches of storms and other weather-related events. The climate-related information is primarily focused on NSW, but the majority of the information is more general. Warren (1983) (Chapter 4) describes wind set-up of sea level at the coast, wind-driven currents, atmospheric pressure effects, storm surges, seiches, precipitation, and runoff, written for the purposes of the tidalist. Pugh (1987) also covers most of those topics. Some nice illustrations and discussion of coastal processes can be found in [Chapter 4](#) of *Shelf and Coastal Oceanography* by Prof. M. Tomczak.

What starts out as a storm surge, can under certain conditions become a free wave known as a coastally trapped wave (CTW) or continental shelf wave. In Australia such waves were intensively studied in the 1980's as part of the Australian Coastal Experiment, which focused on the continental shelf of southeastern Australia. However, the largest and most prevalent CTWs in Australia occur along the southern Western Australia coast and along the Great Australian Bight.

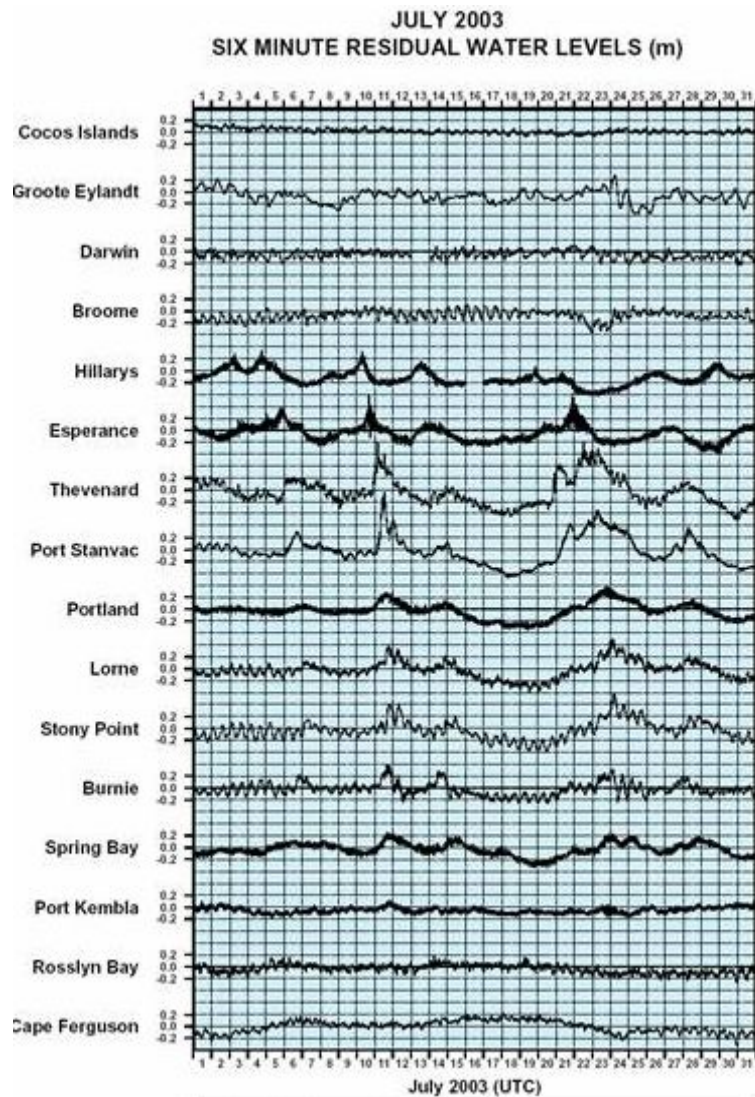


Figure 2 - Sea level residuals.

Above is an example of sea level residuals based on data from SEAFRAME stations of the Australian Baseline Array

The effect of CTWs on coastal sea level is clearly visible in the preceding figure. A typical case begins somewhere in the vicinity of Hillarys, WA on 10 July. Onshore winds with peak gusts of 25 m/s (about 50 knots) drove water forward onto the shelf, sending sea levels at the tide gauge to about 30 cm above the predicted tidal value and initiating a CTW. CTWs travel along coastlines over the continental shelf. In the southern hemisphere the direction of travel is such that the coastline is to the left of the wave, so the CTW propagated southwards from Hillarys. It was evidently reinforced over the following days by onshore or north-westerly winds. The wave rounds the southwest corner of Australia, then turns to the east, successively raising sea levels by a half-metre or so at Esperance, Thevenard, Port Stanvac (Adelaide), Portland, and Lorne, finally entering Bass Strait a day or two after leaving Hillarys. A second CTW appears to be generated in the Bight itself on the 21st, with large residuals observed first at Esperance, and then stations to the east.

3.4.2 Shallow water effects

As the tide enters shallow waters, the tides associated with one or another of the major components often interact to produce “compound tides”. Another effect is in the lagging of the tide wave through friction. Murray (1964) wrote:

“Ports which are situated in shallow water may have distorted tidal profiles, and this distortion may take many forms. In some cases, the distortion takes the form of a short period of rising tide and a long period of ebb, and at some places this can take the extreme form of a bore, particularly at spring tides. At other ports, the shallow water effects may cause double high or low waters, or perhaps a stand of tide lasting several hours; again the effect can vary considerably between spring and neap tides.”

An introductory-level discussion is contained in Warren (1983). Many, but not all, shallow water effects on tides can be accounted for by use of the full 112-constituent analysis.

When tidal waters flow into coastal lagoons, or other partially impounded water bodies, the return flow frequently takes on a different character. For example, the flood currents are often more vigorous and the rise of water level in the lagoon more rapid than its fall. The connection of the lagoon to the ocean often takes the form of a long, narrow channel, which acts like a low-pass filter, reducing the amplitude of the higher tidal frequencies and the tidal effects within the lagoon. The time of high and low waters in the lagoon is also phase-lagged behind that of the ocean. The more restricted the connecting channel, the longer the hydrodynamic turn-over time, or residence time, within the lagoon. More restricted lagoons also tend to have greater salinity variations due to river input, which fluctuate with rainfall, and they also tend to be more prone to problems with sedimentation, pollution, and eutrophication. Consequently, there have been many instances of channel deepening and widening worldwide. These frequently have led to improved water quality, fish breeding, and other positive effects; however, careful study is required to predict the full ecological consequences in advance.

Tsunamis are well-known for their destructive impacts on many coastal areas.

These also are essentially shallow-water phenomena since the generating wave is barely discernible in the open ocean. Recordings of tsunami are rare in Australian waters, but not unknown (see the Geoscience Australia [factsheet](#)). IOC [Vol.1](#) states:

“A tsunami is a wave generated by seismic activity and as such falls outside the two categories of forces responsible for normal sea level changes, tides and the weather. Not all submarine earthquakes produce tsunami. The important element is a vertical crustal movement which displaces the sea bed. The tsunami wave characteristics will depend on the amplitude of the displacement and the dimensions of the sea bed involved. Horizontal displacements of the seabed will be relatively ineffective. The waves travel at a speed given by $(\text{water depth} \cdot \text{gravitational acceleration})^{1/2}$. Amplitudes in deep water are small, probably not more than 1 metre. The Pacific Ocean and its coastlines are the most vulnerable to tsunami because of the seismically active surrounding plate boundaries. As the wave approaches shallow coastal waters its amplitude increases and there are multiple reflections and

refractions which combine to give very large local amplitudes. A network of reporting tide gauges in the Pacific enables warnings of tsunami arrival to be given some hours in advance.”

3.5 Tidal Datum Epoch

The tidal datum epoch (TDE) is the interval recommended for the calculation of datums. It is normally longer than 18.6 years in order to include a full lunar nodal cycle. The Permanent Committee for Tides and Mean Sea Level (PCTMSL) recommended that a 20-year TDE, 1992-2011 inclusive, be adopted for the determination of Lowest Astronomical Tide and Highest Astronomical Tide (LAT and HAT). The MSQ document “[Tidal Reference Frame for Queensland](#)”, details the implementation of the epoch in Queensland.

Internationally, there are different but equivalent ways of defining the epoch. For example, to account for slow variations of sea level relative to land, NOAA intends to re-compute the U.S. National TDE (NTDE) every 20-25 years. (The "current" epoch is the 19-year period ending 31 December 2001) The NTDE is used in the US for the computation of not only LAT and HAT, but also mean sea level and most other tidal datums. The NOAA [site](#) gives additional information.

3.6 Tidal Planes and Levels

The terms “tidal planes”, “tidal datums”, and “tidal levels” will be used interchangeably, although some authors draw a distinction - for example, a “plane” implies a two-dimensional surface extending over a given region.

3.6.1 Harmonics-based definitions

The following definitions, based on the tidal harmonics, are taken from the ANTT. The harmonic definitions can be considered convenient simplifications. The Intergovernmental Committee on Surveying and Mapping (ICSM), Tidal Interface Working Group (TIWG), has produced a 103-page [compendium](#) of terms related to the legal definition of the land-sea boundary in Australia. It can also be found as a [summary](#). In the following, Z_0 represents the mean sea level, and the other symbols are the usual harmonic constants.

For semi-diurnal ports:

$$\text{Mean High Water Springs: MHWS} = Z_0 + (M_2 + S_2)$$

$$\text{Mean High Water Neaps: MHWN} = Z_0 + |M_2 - S_2|$$

$$\text{Mean Low Water Springs: MLWS} = Z_0 - (M_2 + S_2)$$

$$\text{Mean Low Water Neaps: MLWN} = Z_0 - |M_2 - S_2|$$

For diurnal ports:

$$\text{Mean Higher High Water: MHHW} = Z_0 + (M_2 + K_1 + O_1)$$

$$\text{Mean Lower High Water: MLHW} = Z_0 + |M_2 - (K_1 + O_1)|$$

$$\text{Mean Higher Low Water: MHLW} = Z_0 - |M_2 - (K_1 + O_1)|$$

$$\text{Mean Lower Low Water: MLLW} = Z_0 - (M_2 + K_1 + O_1)$$

3.6.2 Observations-based definitions

The harmonic-based definitions are not universally accepted, in part because they assume that M2, S2, O1, and K1 are the dominant four components, which is not always the case. For this reason, many authorities (e.g., MSQ and NOAA) adhere strictly to observation-based definitions of the tidal planes. The TIWG list of standard terms in the table below gives observation-based definitions from the Australian Hydrographic Office tidal glossary. Variations of the definitions may apply in current legislation.

Table 2 - Tidal Planes

Plane/Level	Purpose	definition
HAT	Landward limit of the tidal interface. Chart datum for high tide (Clearances). Limit of landward extent of tidal water under normal atmospheric circumstances.	Highest Astronomical Tide: the highest level of water which can be predicted to occur under any combination of astronomical conditions.
MHWS (and MHHW)	Tidal datum for cadastral (boundary) purposes for some jurisdictions (e.g. New Zealand, Queensland)	Mean High Water Springs (MHWS): the average of all high water observations at the time of spring tide over a period of time (preferably 19 years). Applicable in semi-diurnal waters only. Mean Higher High Water (MHHW): the mean of the higher of the two daily high waters over a period of time (preferably 19 years). Applicable in mixed and diurnal waters.

Plane/Level	Purpose	definition
MHW	<p>Common law datum for cadastral (land boundary) purposes. Used in Australia unless amended by legislation (as in Queensland for example).</p> <p>Frequently used as the coastal limit on topographic mapping.</p>	<p>Mean High Water (MHW): the average of all high waters observed over a sufficiently long period.</p>
MSL	<p>Average limit of the tides.</p>	<p>Mean Sea Level (MSL): the arithmetic mean of hourly heights of the sea at the tidal station observed over a period of time (preferably 19 years).</p>
MLWS (and MLLW)		<p>Mean Low Water Springs (MLWS): the average of all low water observations at the time of spring tide over a period of time (preferably 19 years). Applicable in semi-diurnal waters only.</p> <p>Mean Lower Low Water (MLLW): the mean of the lower of the two daily low waters over a period of time (preferably 19 years). Applicable in mixed and diurnal waters.</p>
MLW	<p>Has been used as the limit of Australian States as the definition of “low water”</p>	<p>Mean Low Water (MLW): the average of all low waters observed over a sufficiently long period.</p>
LAT	<p>Chart low water datum</p> <p>Baseline for the purposes of defining Australia’s maritime boundaries in compliance with the UN Convention on the Law of the Sea.</p>	<p>Lowest Astronomical Tide (LAT): the lowest tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions.</p>

4. Tide Gauges

To comply with regulatory or other requirements, tide gauges on the national network (in particular those used as "standard ports" in the ANTT) must meet with certain standards for accuracy and reliability, as well as being subjected to regular maintenance schedules. This ensures the integrity of the database on which the tidal predictions are based.

4.1 Description

A standard tide gauge installation consists of the following.

1. A data recording (short term storage) device. Tide gauges at all Australian primary ports use a digital recording device.
2. At least one water level sensor.
3. A means of communicating the readings to users - a direct connection to the recorder, a broadcast, polled or on-demand interrogation device.
4. Some means of independently checking the height and time recorded (e.g. a tide staff, the operator to maintain a clock set to standard time)
5. A station height datum above/below which heights are measured, recorded, and stored.
6. A TGBM (tide gauge benchmark) of known elevation relative to the station height datum.
7. Several recovery benchmarks in the event the TGBM is damaged.
8. A clock set to a standard time zone for recording.
9. Performance specifications: station to comply with a given set of requirements, e.g. the GLOSS (Global Sea Level Observing System) requirements found in IOC Training Manual I [Appendix 1](#), or the Queensland requirements, documented in [MSQ specifications](#).
10. Documentation in accordance with levelling procedures outlined in Section 5 below.

4.2 Types of Water Level Sensors

The main types of water level sensors in use in standard ports in Australia are the microwave (radar), acoustic and pressure sensors. Also used, but less common are laser ranging and ADCP current meters. The IOC Training Volumes provide a very comprehensive source of information on tide gauge types (see links below). Bear in mind that there are substantial gaps in time between the three manuals, published in 1985, 1994, 2002 and 2006 so that the latest manual is far more up to date than the original.

The pros and cons of the main types are given in IOC Vol. III, [Table 2.1](#). This table has been updated in [IOC Vol IV](#) Table 3.1 describes the merits and drawbacks of

each tide gauge technology, including radar gauges. Several studies have been undertaken since 2006 that evaluate the major tide gauge types in use, copies of these can be found on the PSMSL website [Tide Gauge Experiences](#).

The radar instrument is a freestanding, portable unit which sends a microwave pulse downward through free air and measures the return time. Radar gauges are easy to operate with no parts in the water and give a direct measurement of water level with no dependency on air temperature. Descriptions of radar type gauges are given in [IOC Vol. IV](#). The radar sensor can also be setup to operate within a stilling well. A cable must be installed down the centre of the well to guide the microwave pulse.

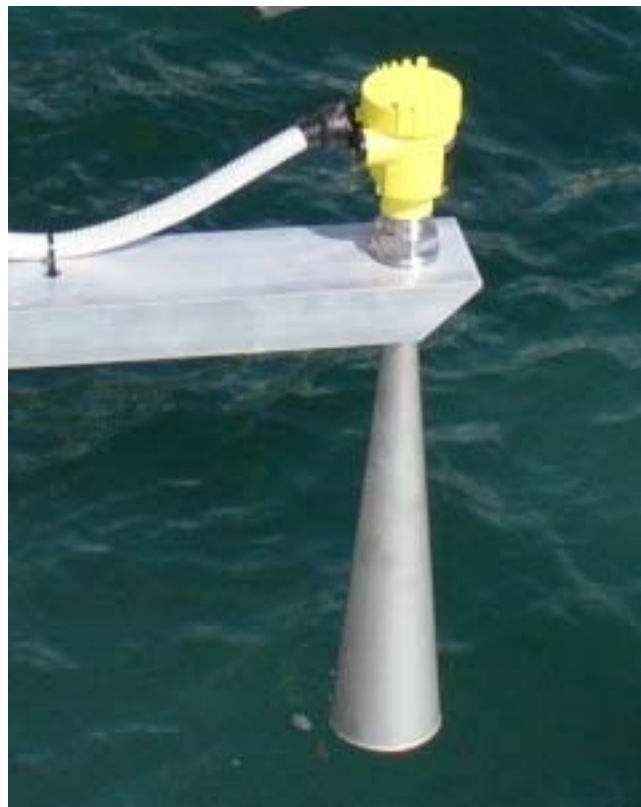


Figure 3 - Typical Microwave radar sensor used at many Australian Ports. This particular unit is a Vega Puls 63 on a wharf in Gladstone harbour.

Descriptions of pressure-type tide gauges (including bubbler systems) are given in [SP9 1984](#), IOC Training Manual Vol. I [Section 2.4](#) and Vol. III [Section 2.2](#).

Descriptions of acoustic tide gauges are given in IOC [Vol. II](#) and IOC [Vol. III](#).



Figure 4 - Tide gauge at Hillarys, Western Australia.

Figure 4 is a "SEAFRAME" station, one of thirteen installed by NTC to monitor long-term sea level changes around Australia. The water level is measured by sending an acoustic pulse down a small pipe within the environmental tube.

These instruments measure return time, sending an acoustic pulse down a 13 mm (internal diameter) ABS sounding tube. The return travel time through the air between a transmitter/receiver and the water surface below is converted to sea level. A calibration hole, drilled into the tube at a set distance from the transmitter, causes a secondary reflection which is used to correct the sound velocity (which changes with temperature and other factors). Most acoustic instruments are very lightly damped in comparison to the 1:10 ratio of float gauges. For example, the acoustic instruments of the Australian Baseline are damped only 1:3. The mechanical damping is replaced by digital filtering of the return signals. A pulse is sent down the tube every second for three minutes. The arithmetic mean of the return times is then recorded. The standard deviation of the levels is also recorded, as it is used to eliminate outliers and can be related to the significant wave height (SWH), both of which can be of significant advantage.

Descriptions of float gauges are given in IOC Training Manual Vol. 1 Section 3.2, Vol. II Section 2.1 and Vol. III Section 2.3. The [Queensland Environment and Resource Management website](#) has a description of the float gauges which, until recently were used in their "storm tide" network, primarily to detect storm surges.

The most recent newcomer to the field of sea level measurement is the laser ranging wave gauge (LRWG). These were developed for application to wave measurement but are also capable of application to measuring water level. For a comparison of the LRWG and other sensor types see the Canadian Hydrographic comparison of sensors. The ability to measure sea level and wave heights with one instrument makes the EWS and LRWG attractive options for port operations.



Figure 5 - Laser wave ranging gauge in operation at Hay Point.

The instrument is a WTS-1 non-contact laser from Harbour and Marine Engineering. Photo is courtesy of North Queensland Bulk Ports.

4.3 Recording Devices

Modern tide gauge installations automatically record the water level data. For a mechanical system such as a float device, the distance travelled by the float was, until recently, usually recorded directly on a chart recorder, but nowadays more commonly is converted to an electrical pulse for recording on a digital medium. Acoustic systems use a transducer to convert the acoustic wave to an electrical signal.

4.3.1 Chart recorder operating procedures

As chart recorders are nearly obsolete at Australian ports, we refer the reader, if necessary, to Vol. 1 of the IOC training manuals, and [SP9 1984](#), which contains a check sheet for operational water level checks to the tide staff.



Figure 6 - A chart recorder

4.3.2 Digital recorder operating procedures

Chart recorders are gradually being replaced by some form of shaft encoder coupled with a digital recording device. A pulley attached to the float (see diagram below) causes the encoder shaft to rotate in response to vertical motion of the float.

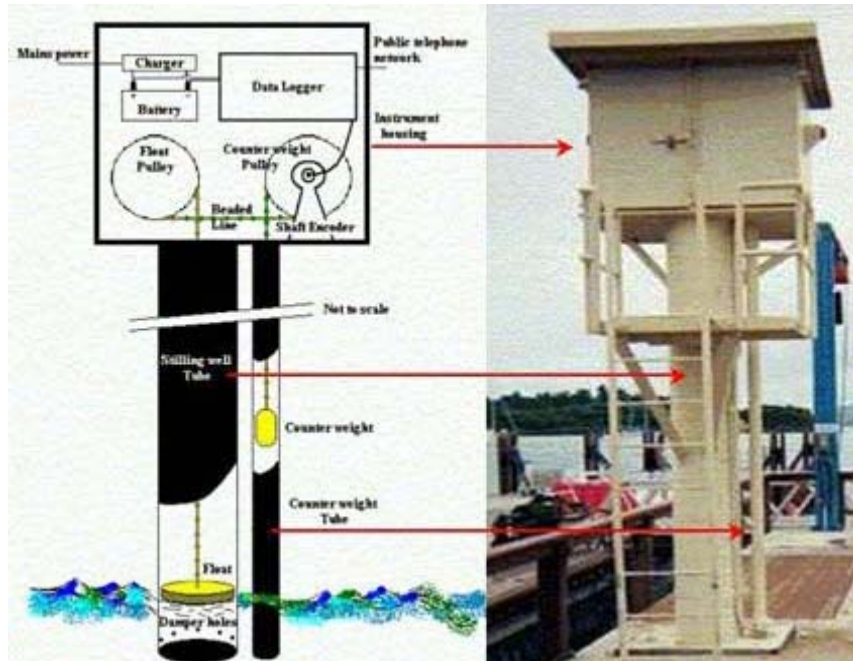


Figure 7 - Diagram of tide gauge with shaft encoder and data logger, from the Queensland EPA website.

There are many types of shaft encoder; however they all convert the vertical displacement of the float to a digital or analog electrical signal. Some employ a quadrature device that picks up the motion of a rotating disk and sends out two digital pulses, out of phase by 90°. This requires a second device to interpret the edges of the pulses “increase or decrease of voltage” as either upwards or downwards motion. Another type uses a transducer to send out a 16 bit parallel code which again requires interpretation by an electrical sensor. Other types include potentiometers “voltage level output” and counters “these send out a “motion” pulse plus an “up/down” signal”.



Figure 8 - An incremental shaft encoder

The operating procedures for digital recording devices are outlined in [SP9 1984](#), in which may be found a check sheet for operational water level checks to the tide staff.

4.4 Tide Gauge Specification

4.4.1 Precision, accuracy and resolution

Accuracy and precision are frequently confused, despite having quite distinct technical definitions. A simple way to think of the difference is in terms of a target. Consider a cluster of five arrows shot into a small area above and to the right of the bulls-eye. The archer's accuracy would be measured by the distance from the bulls-eye to the centre of the cluster, while his or her precision would be measured by the tightness of the cluster. Precision is a measure of repeatability, or how closely repeated measurements of the same quantity agree with each other. Accuracy is a measure of reliability - how close are the measured values, as a whole, to the true or accepted value?

Resolution is usually defined as the smallest interval of change that can be measured by a particular instrument.

4.4.2 Requirements for accuracy and placement

Tide gauges used for standard port predictions in Australia have the same requirement for accuracy as tide gauges on the GLOSS network, i.e., one centimetre accuracy in all weather (see IOC Vol. III [Section 1.3](#)). Likewise, it is important that should an instrument be replaced, there should be a period of overlap in which the two operate in parallel to ensure accuracy and to pinpoint the mean level. The GLOSS implementation plan suggests that the period be one decade, but acknowledges that this will be impractical.

Many tide gauges, such as the SEAFRAME instruments operated as part of the Australian Baseline Array, are intended to monitor sea level trends over the least

possible period of time. Compared to the port and storm surge gauges, these are subject to more rigorous requirements in accuracy and precision, as well as datum control.

4.5 Measurement System Defects

A discussion of the errors common to stilling wells and chart recorders is given in IOC Training Manual Vol. I (see [Section 4.2](#)), and a diagram of the amplitude attenuation as a function of wave height is shown in [Figure 3.3](#) of the same volume.

A summary of possible systematic errors in the acoustic measurement system can be found in [Section 2.1.1](#) of IOC Vol. III. The most serious problem commonly cited is with temperature gradients along the flight path of the acoustic pulse, as can happen, for example, when the sun shines only on the part of the “environmental tube” which encloses the inner sounding tube. Such errors can be quite substantial. These can be avoided to a large extent by providing even solar exposure of the environmental tube to the direct rays of the sun.

[Section 2.4](#) of IOC Vol. III discusses possible sources of systematic errors in pressure gauges. One of these is barometric pressure, which can be avoided either by simultaneous air pressure monitoring, or by using a gauge vented to the atmosphere. With pressure gauges in deep water, changes in water temperature or salinity may need to be considered. Another problem discussed on Section 2.4 is that of datum control with pressure gauges, particularly in light of the general tendency of the transducers to drift. A means of overcoming this is given, by use of a second pressure gauge at approximate mean sea level.

4.6 Calibration

From the 1984 Special Publication 9 on tide gauges:

Many tide records show unexplained jumps in datum, bad overlaps on charts, time errors, and other discrepancies which have no connection with the tidal movement which the gauge is required to monitor.

The fact that a gauge is in error is not necessarily a reflection on the attention of the operator. No gauge is perfect or trouble-free and errors are to be expected from time to time. Our main concern is that the user of the records should be able to see at once whether any correction to the records is necessary.

Perhaps the main requirement to enable the tide gauge records to be correctly processed is the availability of independent checks. From these checks the performance of the gauge can be assessed and any necessary corrections made before putting the records into the national data base. It is therefore most essential that accurate and true comparisons be made between the gauge time and a standard clock and also between the recorded height and the height as read from the tide staff.

The preceding words from SP9 1984 are still true, except that the independent checks now often take the form of a second instrument, either temporarily or permanently installed alongside the primary gauge.



Figure 9 - Calibrating an Aquatrak sensor in a calibration rig.

A description of stilling well test calibration and maintenance may be found in IOC Training Manual Vol. 1 [Section 3](#). A description of the Van de Castele test may also be found in the IOC Training Manual Vol. I [Section 3.2](#). These checks should be carried out yearly or more often if biological fouling of the sensors is a problem, and always after a change of any of the components of the system.



Figure 10 - Biological fouling is a real problem, especially in near shore tropical waters.

The picture shows a side view of the circular copper plates normally bolted to the bottom of the acoustic sensor, and the brass damping cone that sits just above them inside the environmental tube. The tide gauge is located in Kiribati, and shows the accumulation of about five years' growth. Photo credit: Allan Suskin.

There must be frequent independent water level checks, with time and height recorded. The tide staff and TGBM, and its supporting marks must be re-surveyed at least yearly and at any change to the board.

Precise datum control for pressure gauges is outlined in [IOC Vol. II](#)

5. Survey and Levelling

5.1 Site Selection

The criteria set out in the establishment of the Australian Baseline Array provide a useful guide to the selection of sites for high precision tidal recording equipment. They may be found in the PCTMSL [Site Specification](#) document. Additional guidelines are given in IOC Training Manual Vol. I [Section 3.1](#), updated in Vol. II [Section 2.5](#).



Figure 11 - Example of a benchmark.

The tide gauge benchmark for the SEAFRAME at Port Vila known as "Van 14", installed by the Royal Australian Navy is shown above. The benchmark is the small knob on which the hammer is resting. A raised mark at the top of the knob is the precise level. A chunk of concrete below the benchmark fell off during a recent earthquake.

5.2 Levelling Procedures

This is a topic that has undergone tremendous change in the past decade due to improved technologies. For a thorough discussion of modern geodetic surveying procedures and definitions (including "class" as a measure of survey accuracy), the ICSM publication SP1, ["Standards & Practices for Control Surveys"](#) is recommended. The Australian Height Datum (AHD)(see section 3.3) and related topics are defined in the Geodetic Datum of Australia ["GDA Technical Manual"](#).

A review of levelling for tide gauges was presented in the PCTMSL document [Tide gauge survey instructions](#), October 2003. Topics included in this document are:

1. Work to be carried out at each site

2. Calibration of automatic recorders
3. Tide gauge details sheets
4. Bench marking
5. Levelling to the zero of tide staffs
6. Connection to the National Levelling Survey
7. Photographic record of each site
8. Plan of gauge installation
9. Discussion with owners and operators
10. Notification of PCTMSL
11. Tide gauge details form
12. Tide gauge calibration form
13. Photographic exposure record form

Procedures for establishing benchmarks for differential levelling and GPS surveys were defined in some detail in a [report](#) by the National Tidal Facility in 1992, in the early stages of the South Pacific Sea Level and Climate Monitoring Project (which used SEAFRAME stations to monitor sea level).



Geodetic Connections to Tide Gauge at Thevenard

RESULTS OF OPTICAL LEVELLING

Bench Mark Name	AHD Ht (m) Aug 1991	AHD Ht (m) Mar 1992	AHD Ht (m) Apr 1994	AHD Ht (m) May 1995	AHD Ht (m) Jun 1995	AHD Ht (m) Jun 1999	AHD Ht (m) Sep 2002	Comments
BM 1153	2.9350	-	2.9351	-	-	-	-	Datum for AHD heights.
BM 1476	4.4787	4.4787	4.4787	4.4787	4.4787	4.4787	4.4787	Primary Coastal array BM.
BM 1478	4.7812	4.7813	4.7811	4.7814	4.7815	4.7828	4.7828	Coastal array BM.
BM 1479	11.7187	11.7189	11.7186	11.7185	11.7182	11.7184	11.7186	Coastal array BM.
BM 1487	15.9773	15.9780	15.9779	15.9779	15.9778	15.9780	15.9790	Coastal array BM.
5633/1581	4.211	-	4.212	4.212	-	-	-	Seafloor Sensor Recovery Mark.
5633/1591	4.4977	4.4979	4.4500	4.4995	4.5001	4.4995	4.4999	Seafloor Sensor BM
5633/1680	-	-	-	16.5410	16.5410	16.5409	16.5422	Coastal array Pillar #

Note 5633/1680 levelled to top of 5/8" threaded stub that is 14mm above the surface of the pillar plate. Ratcliff B, email 2002.

Figure 12 - Log sheet example of successive levelling surveys.

Figure 13 above shows the recording sheet for successive optical levelling surveys at Thevenard, South Australia. The AHD benchmark is BM 1153. BM 1476 is the primary TGBM. The five surveys indicate that the TGBM has retained the constant value of 4.4787 with respect to the AHD benchmark.

In 2000, this subject was reviewed in detail in the IOC Training Manual Vol. III, Section 4, "[Datums and datum connections at tide gauges](#)". For convenience, the topics from Section 4 are listed below:

- 4.1 Some definitions (key terms such as Tide Gauge Benchmark defined)
- 4.2 Levelling between local benchmarks
- 4.3 Levelling between wider area marks
- 4.4 Geodetic fixing of tide gauge benchmarks
 - 4.4.1 Introduction
 - 4.4.2 Geodetic Coordinates of Tide Gauge Benchmarks and Monitoring of Vertical Land Movements at Tide Gauges
 - 4.4.3 GPS measurements
 - 4.4.4 DORIS Measurements
 - 4.4.5 Absolute gravity measurements
- 4.5 Geodetic contact points

Section 4.1 describes the expanding use of Global Positioning System (GPS) benchmark arrays. Australian practice permits spirit levelling of the TGBM and its supporting recovery benchmarks to an array of GPS–heighted benchmarks.

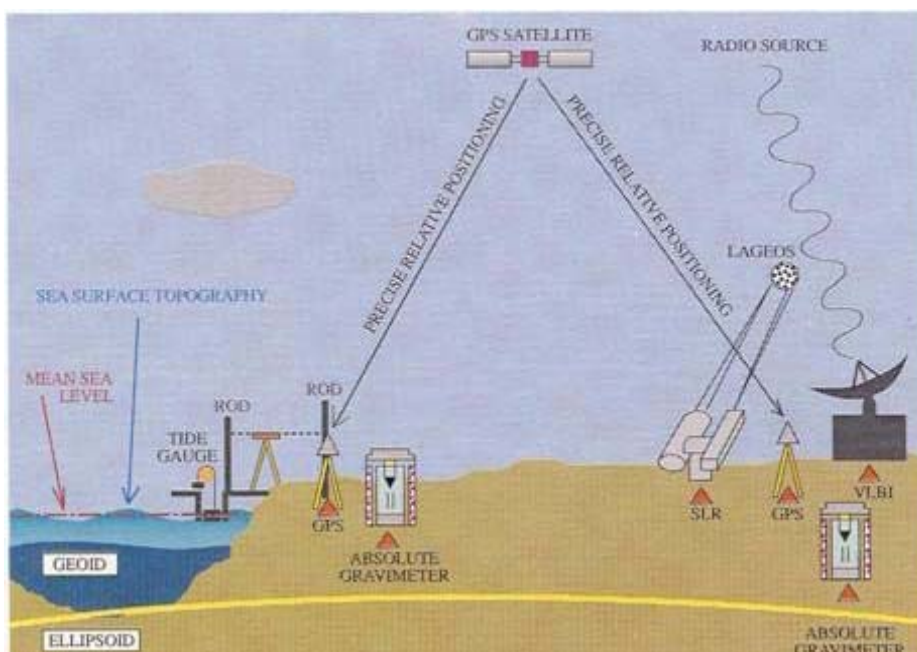


Figure 13 - Some technologies for measuring absolute level.

Many tide gauges are connected to Continuous GPS sites in order to identify vertical land movement in the sea level records.

5.3 The Australian Height Datum

In Section 3.2, mention was made of the AHD, described in detail in the [GDA Technical Manual](#). For convenience, several key paragraphs are reproduced below:

On 5 May 1971 the then Division of National Mapping, on behalf of the National Mapping Council of Australia, carried out a simultaneous adjustment of 97,230 kilometres of two-way levelling. Mean sea level for 1966-1968 was assigned the value of zero on the Australian Height Datum at thirty tide gauges around the coast of the Australian continent.

The resulting datum surface, with minor modifications in two metropolitan areas, has been termed the Australian Height Datum (AHD) and was adopted by the National Mapping Council at its twenty-ninth meeting in May 1971 as the datum to which all vertical control for mapping is to be referred. The datum surface is that which passes through mean sea level at the thirty tide gauges and through points at zero AHD height vertically below the other basic junction points.

The AHD is an imperfect realisation of mean sea level because some of the tide gauges used for its definition were not well sited; the mean sea level determination was for a limited period and a particular epoch and no allowance was made for sea surface topography. The difference between AHD and mean sea level, which may be of the order of several decimetres, is not significant for conventional propagation of AHD, which is relative to existing AHD bench marks, but may be important if connecting AHD to a recent determination of mean sea level.

6. Current Meters

6.1 General References

Warren (1983) contains a review of current meter practice relevant to hydrographers.

US Bureau of Reclamation [Water Measurement Manual](#) is a useful reference, particularly Chapter 10.

6.2 Types of Current Meter

Most current meters operate on one of the following principles: propeller or rotor with flow vane, acoustic Doppler, electromagnetic, or tilt. Manufacturer's websites are often the best source of up-to-date information. The following list is a guide only and is not intended to promote any individual manufacturer.

The propeller-type [current meter](#) shown below is normally mounted inline in a moored array. The large cylinder contains the A/D conversion and recording electronics. A small red propeller sits above the cylinder. A large vane keeps the instrument facing into the current. The instrument as a whole is mounted on the gimbled vertical rod that is attached to the mooring riser.



Figure 14 - The Aanderaa doppler current meter

The Aanderaa [doppler current meter](#) meter is superficially similar to the propeller-type metre above, aside from the latter's vane, which is not required as the Doppler meter uses an acoustic Doppler method to measure water velocity at the instrument's depth. The Aanderaa document describes the Doppler principle, which is based on the change in frequency of reflected sound waves - the change in frequency is proportional to the relative speed of the reflecting particle or air bubble. A simple diagram of a moored array of two meters and a release is shown below. More information about this type of meter can be found in the [Manual](#). UCM also manufactures doppler current meters for currents in three dimensions. The manual describing the [UCM-60](#) gives further information.

Acoustic Doppler current profilers (ADCPs) are designed to simultaneously measure currents at a range of distances or levels. A [data sheet](#) describes the range of modes in which such profilers can be operated. The diagram below shows a bottom-mounted instrument for vertical profile.

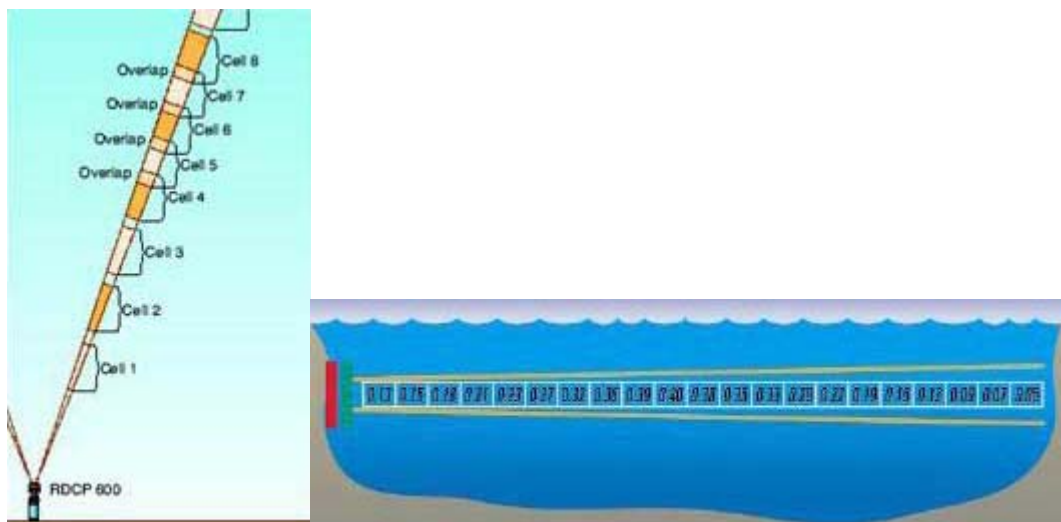


Figure 15 - A) Bottom-mounted ADCP instrument for vertical profile B) Side-viewing ADCP

A horizontal profiler of current is often required for straits and channels. In such cases, a [side-viewing ADCP](#) may be used. The range may be up to several hundred meters.

Most modern current meters and ADCPs come with a software interface for processing and visualisation, for example [WinADCP](#). Electromagnetic current meters are able to detect the velocity of the surrounding water by setting up a magnetic field and measuring the voltage induced in a pair of electrodes by the water flowing past it. Additional [description](#) and [theory](#) can be found in the linked documents. The diagram below shows several different modes in which electromagnetic current meters may be deployed.

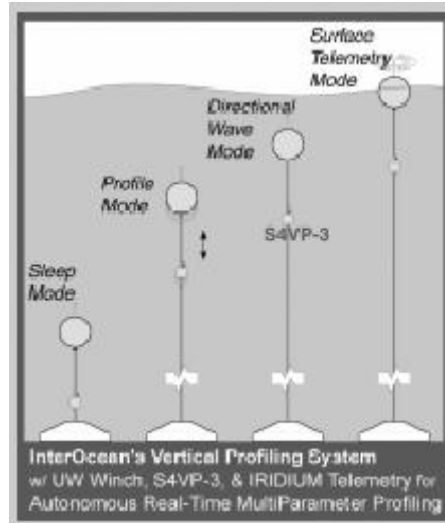


Figure 16 - InterOcean's Vertical Profiling System

There are a number of current meter manufacturers, and again their inclusion here is not intended as an endorsement. Manufacturers' brochures, such as the [Monitoring Brochure](#) and [Systems Brochure](#) are an invaluable source of information which can be applied to any system, not just that of the manufacturer.

7. Australian Standard Ports

7.1 Selection Criteria

A standard port (also known as a "primary port", particularly in North America) is one for which sufficient data is available in order for a set of official predictions to be produced. By contrast, a secondary (or "subordinate") port is one for which predictions are required, but due to insufficient data, they may be less reliable. In some cases, at secondary ports, certain constants are inferred on the basis of relationships taken from the nearest standard port.

7.2 Standard Port Tidal Stations that have Permanent Operating Recorders as of 2011

A standard port (also known as a "primary port", particularly in North America) is one for which sufficient data is available in order for a set of official predictions to be produced. By contrast, a secondary (or "subordinate") port is one for which predictions are required, but due to insufficient data, they may be less reliable. In some cases, at secondary ports, certain constants are inferred on the basis of relationships taken from the nearest standard port.

*Standard port: A place for which independent daily predictions are given in the tide or stream tables, from which corresponding predictions are obtained for other locations, known as secondary ports, by means of differences or factors.

Table 3 - List of Australian Standard Ports

Name	Sensor Type	Owner/ Operator
New South Wales		
Eden	Radar/Pressure	MHL
Newcastle	Acoustic/Float	NPC
Port Kembla	Acoustic/Pressure	NTC
Sydney (Fort Denison)	Acoustic	SPC
Yamba	Pressure	MHL
Northern Territory		
Centre Island†	No operating gauge	
Darwin	Acoustic/ Pressure	NTC

Name	Sensor Type	Owner/ Operator
Gove Harbour	No operating gauge	
Milner Bay	Acoustic	NTC
Queensland		
Abbott Point	No operating gauge	
Booby Island	Acoustic	AMSA
Brisbane Bar	Radar	MSQ
Bugatti Reef	No operating gauge	
Bundaberg	Radar	MSQ
Cairns	Guided wire microwave	DERM
Gladstone	Radar	MSQ
Gold Coast Seaway†	No operating gauge	
Hay Point	Gas purge / Radar	MSQ
Ince Point	Acoustic	AMSA
Jubilee Reef	No operating gauge	
Karumba	Radar	MSQ
Leggatt Island	No operating	
Lucinda	Guided wire microwave	DERM
Mackay	Radar	DERM
Mooloolooba	Radar (Shaft encoder)	EPA
Mourilyan Harbour	Guided wire microwave	DERM
Mornington Island†	Guided wire microwave	DERM
Noosa Head†	No operating gauge	
Port Alma	Guided wire microwave	DERM
Poll Island	No operating gauge	

Name	Sensor Type	Owner/ Operator
Port Douglas	Acoustic	MSQ
Shute Harbour	Guided wire microwave	DERM
Turtle Head	Acoustic	AMSA
Twin Island	No operating gauge	
Urangan	Radar	DERM
Waddy Point	No operating gauge	
Weipa	Radar	DERM
South Australia		
Port Adelaide	Purge Bubbler	FP
Port Giles	Float	FP
Port Lincoln	Purge Bubbler	FP
Port Pirie	Purge Bubbler	FP
Thevenard	Acoustic/pressure	NTC
Victor Harbor	Float	FP/Transport SA
Wallaroo	Purge Bubbler	FP
Whyalla	Acoustic	FP/OneSteel
Tasmania		
Burnie	Acoustic	NTC
Devonport	Acoustic	Tasports
Georgetown	No operating gauge	
Hobart	Acoustic	Tasports
Spring Bay†	Acoustic/ Pressure	NTC
Stanley	No operating gauge	
Low Head	Acoustic	Tasports

Name	Sensor Type	Owner/ Operator
Victoria		
Geelong	Acoustic	Vic Channels Auth.
Melbourne	Acoustic	PoM
Port Philip Heads (Lonsdale)	Acoustic	PoM
Portland	Acoustic	NTC
Port Welshpool	Acoustic	Gippsland Ports
Western Port (Stony Point)	Acoustic	NTC/TOLL
Western Australia		
Albany	Float	Albany Port
Bouvard (Dawesville)∇	Float	DoT
Bremer Bay	Float	DoT
Broome	Acoustic/Pressure	NTC
Bunbury	Float	DoT
Busselton	Float	DoT
Caddadup (Dawesville)∇	Float	DoT
Cape Lambert	Float	Rio Tinto
Carnarvon	Float	DoT
Derby Jetty	Float	DoT
Esperance	Acoustic/Pressure	NTC
Esperance	Float	DoT
Exmouth	Float	DoT
Fremantle – Fishing Boat Harbour	Float / Radar	DPI

Name	Sensor Type	Owner/ Operator
Fremantle	Float	Fremantle Ports
Geraldton	Float	Geraldton Port
Harvey Estuary (Dawesville) ^γ	Float	DoT
Jurien	Float	DoT
King Bay	Float	Woodside / Rio Tinto
Mandurah	Float	DoT
Mangles Bay	Float	DoT
Onslow (Beadon Ck.)	Float	DoT
Onslow (Onslow Salt)	Float	Onslow Salt
Peel Inlet (Dawesville) ^γ	Float	DoT
Perth (Barrack St.)	Float	DoT
Point Sampson ^γ	Pressure	DoT
Port Hedland (Bn3)	Float	Port Hedland Port
Two Rocks	Float	DoT
Useless Loop Jetty	TBA	Shark Bay Resources
Wyndham	Float	DoT
Antartica		
Casey†	Pressure	AAD
Davis†	Pressure	AAD
Mawson†	Pressure	AAD
Australian Territories		
Cocos Island	Acoustic/Pressure	NTC
Macquarie Island†	Acoustic/Pressure	AAD
Norfolk Island	Float	MHL

†Ports marked with this symbol are "standard ports" in AusTides, but not ANTT.

∩ Ports marked with this symbol are not listed in AusTides or ANTT.

Acronyms:

AMSA: Australian Maritime Safety Authority

AAD: Australian Antarctic Division

BPA: Bundaberg Port Authority

DERM: Department of Environment and Resources Management (Queensland)

DoT: Department of Transport (Western Australia)

FP: Flinders Ports Pty Ltd

MHL: Manly Hydraulics Laboratory

MSQ: Maritime Safety Queensland

NTC: National Tidal Centre (Bureau of Meteorology)

PoM: Port of Melbourne Corporation

SPC: Sydney Ports Corporation

All gauges listed in the table of standard ports are fitted with digital recording devices (there are no chart recorders).

8. Digital Data Handling

8.1 Storage and Archiving

Data to be archived should be corrected for documented instrumental and datum errors only. No gap-filling is to be applied to archived data - this is to be left to the individual later undertaking post-processing of the data.

"A sea level agency should aim to not only operate gauges to its best ability, but also to provide proper documentation, data processing and archiving functions. Documentation has already been alluded to in previous sections. All tide gauge operations (equipment change notes, calibration records, maps, photographs etc.) must be documented within an overall, preferably computerised system so that the information is not lost to future analysts. The tide gauge data themselves must be checked (and if necessary corrected) for their quality and properly documented before being passed to scientists in the wider community."

– IOC Training Manual Vol. III

8.2 Quality Control

Quality control of the data prior to archiving consists of several checks. If more than one gauge is in operation at the site, subtraction of the two time series may reveal abrupt changes in reference level (a gauge from a nearby port may also serve). Comparison with a tide staff, though less precise, is an equivalent check.

A second check consists of subtraction of a time series of predicted tides from the data. What remains are the tidal "residuals". Inspection of the residuals can reveal timing errors, datum shifts, out-of-range values, and other errors not apparent in the original data. If possible, such errors are to be resolved and removed from the data prior to archiving. If an error such as a datum shift is evident, but its exact location in time can not be identified, the problem must be fully documented in the metadata. The quality assessment practices vary between different institutions. The University of Hawaii's [UHSLC QA system](#) fully documents the quality assessment process and provides full metadata for their "research quality sea level data".

8.3 Post-processing

These procedures were described in IOC Training Manual Vol. II [Section 5](#). A revised and updated version was presented in Vol. III [Section 5](#), however the earlier volume contains some valuable details not included in the latter. Volume III also discusses tide analysis, filtering to remove tides, and the computation of extremes.

8.4 Data Exchange Formats

A protocol for data exchange was laid out in IOC Training Manual Vol. III [Section 6](#). In Australia, the PCTMSL ([May 2004 report](#)) has acknowledged the existence of several

international formats and affirmed the need for a minimum set of metadata. These are: Identification (Station Name and Geographical Co-ordinates); Measurement Units; Details of Owner/Custodian and Contact details; Date of Supply; Quality Assessment; Instrumentation. This information is sufficient to enable the user to seek further information from the data provider.

8.5 Data Banks

International sea level centres and information required to submit data to them, are listed in the IOC Training Manual Vol. II Section 6. The GLOSS station Handbook has a more comprehensive set of metadata for ports - for example see Fremantle. The Australian stations on the GLOSS database are listed below (note that the port numbers are active only if online).

Table 4 - Australian Gloss Stations

Australian Gloss Stations				
061	Booby Is.	Australia	10° 36'S	141° 55'E
058	Brisbane (West Inner Bar)	Australia	27° 22'S	153° 10'E
040	Broome	Australia	18° 00'S	122° 13'E
059	Bundaberg	Australia	24° 46'S	152° 23'E
052	Carnarvon	Australia	24° 54'S	113° 39'E
278	Casey	Australia	66° 17'S	110° 32'E
047	Christmas Is.	Australia	10° 25'S	105° 40'E
046	Cocos Is. (Keeling)	Australia	12° 07'S	096° 53'E
062	Darwin	Australia	12° 28'S	130° 51'E
277	Davis	Australia	68° 35'S	077° 58'E
054	Esperance	Australia	33° 52'S	121° 54'E
053	Fremantle	Australia	32° 03'S	115° 43'E
148	Lord Howe Is.	Australia	31° 31'S	159° 04'E
130	Macquarie Is.	Australia	54° 30'S	158° 56'E
022	Mawson	Australia	67° 36'S	062° 52'E
124	Norfolk Is.	Australia	29° 04'S	167° 57'E

Australian Gloss Stations				
051	Port Hedland	Australia	20° 19'S	118° 34'E
055	Portland	Australia	38° 20'S	141° 36'E
056	Spring Bay	Australia	42° 33'S	147° 56'E
057	Sydney, Fort Denison	Australia	33° 51'S	151° 14'E
308	Thevenard	Australia	32° 10'S	133° 40'E
060	Townsville	Australia	19° 16'S	146° 50'E

9. Contact List, Useful Links and Biography

ICSM Permanent Committee on Tides and Mean Sea Level (PCTMSL)

Follow this [link to a current listing of the members of PCTMSL](#)

9.1 Useful links

[ANTT "Seafarer Tides"](#)

[Australian Hydrographic Office Glossary](#)

[Intergovernmental Committee on Surveying and Mapping](#)

[Canada Fisheries and Oceans glossary](#)

[Flinders Ports Pty. Ltd.](#)

[ICSM \(Tidal Interface Working Group\): Compendium of Terms \(103 pages\)](#)

[Intergovernmental Oceanographic Commission \(IOC\)](#)

IOC training manuals "Manual on sea level measurement and interpretation":

[Volume 1: Basic Procedures](#)

[Volume 2: Emerging Technologies](#)

[Volume 3: Reappraisals and Recommendations as of the year 2000](#)

[Volume 4: An update to 2006](#)

[Land Information New Zealand glossary](#)

[Manly Hydraulics Laboratory](#)

[Manly Hydraulics Laboratory glossary](#)

[Maritime Safety Queensland \(Home\)](#)

[Maritime Safety Queensland \(Tides\)](#)

[National Tidal Centre](#)

[NOAA Publications](#)

[NOAA glossary](#)

[NOAA "Our Restless Tides"](#)

[Permanent Service for Mean Sea Level - Training Information](#)

[Ports Australia - Members](#)

9.2 Further reading

Anonymous, 1994 Hydrographic Dictionary, International Hydrographic Organization, Special Publication No. 32, 1994

Forrester, W.D., 1983 Canadian Tidal Manual, Department of Fisheries and Oceans, Ottawa. 138 pages.

Discusses many tide-related topics, such as how tides propagate as waves, the tide-generating potential (an alternate way of thinking about the forces behind tidal motions), the harmonic analysis of sea levels and tidal streams, environmental influences on sea level, and vertical datum control. Of particular relevance are chapters on the establishment of tide gauge sites (including levelling), transferring datums between two water level time series, and current meters. Unfortunately it is now more than twenty years old and some of the technology discussed is virtually obsolete in Australia. Chapters on tidal theory, tidal specification, tidal cycles, analysis and prediction, sea level observations, tidal terminology, and tables of harmonics.

Murray, M.T., 1964 A general method for the analysis of hourly heights of the tide. International Hydrographic Review, 41(2), 91-101.

Pugh, D.T. 1987 Tides, Surges, and Mean Sea-Level, John Wiley and Sons, Chichester, 472 pages.

This book is out of print but still worth noting. There are useful chapters on observations (summarising the main methods for monitoring levels and currents), tidal forces, analysis and prediction, tidal dynamics, storm surges, shallow water dynamics, tidal engineering, mean sea level, geological processes, and biological processes associated with tides.

Pugh, D.T. 2004 Changing sea levels. Effects of tides, weather and climate. Cambridge University Press, 280pp. Contains some of the material from Tides, Surges, and Mean Sea-Level, but updated and with much new information.