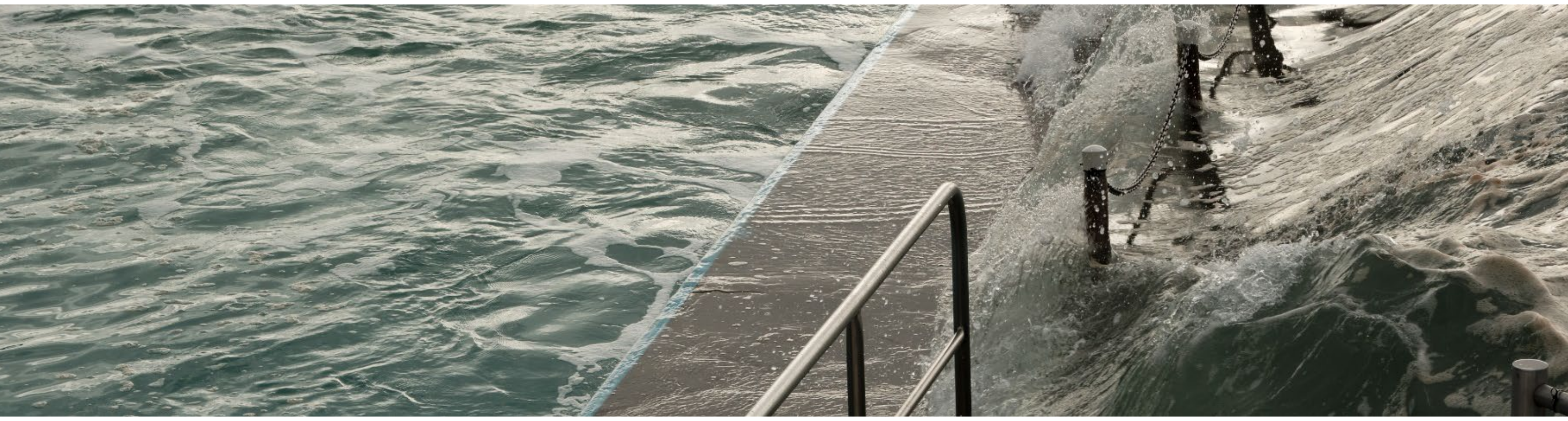

MEAN HIGH WATER LEVEL

2003-2022 AVERAGE OF THE HIGH TIDES AND HARMONIC ANALYSIS

Report MHL2902
March 2024

Prepared for:

Department of Climate Change, Energy, the Environment and Water-
Biodiversity and Conservation

Cover photograph: Dee Why ocean pool, Dee Why. Image by Mark Kulmar.

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Foreword

Manly Hydraulics Laboratory (MHL) on behalf of the Department of Climate Change, Energy, the Environment and Water - Biodiversity and Conservation (DCCEEW BC) monitors tides along the NSW coast through an extensive data network. MHL is a business unit within the Water Group of DCCEEW.

MHL was commissioned by DCCEEW BC to prepare a report of Mean High Water Level (MHWL) for 184 tidal water level stations using the calculation method of the average of the high tides and the harmonic method over a 19 year epoch (1 July 2003- 30 June 2022). Please note that both are valid methods of MHWL calculation, which can be used for multiple purposes including as an input to determining land parcel boundary definitions when tidal waters form part of the boundary[1].

---

[1] MHWL can be calculated from times series water level data using different methods and data currency, resulting in different MHWL values and measurement uncertainty ranges.

Executive summary

Mean High Water Level (MHWL) can be calculated from times series water level data using different methods and data currency, resulting in different MHWL values and measurement uncertainty ranges. The purpose of this report is to present the results of two MHWL calculation methods for DCCEEW BC owned stations on NSW's east coast that have a suitable degree of tidal influence.

This report provides the MHWL results using the average of the high tides and the harmonic analysis method over a 19 year epoch (1 July 2003 – 30 June 2022); and the associated uncertainty at a 95% confidence interval. There is a trend of the average of the high tides method displaying a higher MHWL value than that of the harmonic method. A sample comparison between the two MHWL methods for ocean, estuary and coastal lake environments indicates that the differences typically range between 0.01m and 0.05m on average. It is incumbent on the user of the data to determine which method is appropriate for their application.

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1 Introduction

The Mean High Water Level (MHWL) is an important input to determining property boundaries where land parcels meet tidal waters. The Surveyor General's Direction No. 6 Water as Boundary Procedures (Surveyor General of NSW, 2016) states that current tidal plane statistical data should be obtained from Manly Hydraulics Laboratory (MHL) and this publicly available report allows greater accessibility for requestors. This report offers two methods of MHWL calculation and users have a choice of which is fit for their purpose. The 183 Department of Climate Change, Energy, the Environment and Water - Biodiversity and Conservation (DCCEEW BC) water level monitoring stations have been selected based on their length of record and degree of tidal influence.

In 2021, MHL undertook a review of six selected methods for MHWL calculation at Fort Denison (MHL, 2019). The review recommended that an averaging window of 19 years should be used for MHWL determination and that the dataset with the minimum possible timestep be used to most accurately determine the high-tide values for each year. For this report, 15-minute interval water level data over an epoch of 19 years was used where possible. Stations with less than 10 years of continuous data were excluded from this report.

The following MHWL calculation methods were undertaken as part of this report:

1. Average of the high tides. Non-astronomical anomalies are removed from the recorded water level data. After anomalies are removed, the high tides each day are selected and averaged each year over the 19-year tidal epoch, where available.
2. Tidal harmonics using Foreman harmonic analysis method as described in MHL report 2786 (MHL, 2023). After removal of non-astronomical anomalies, the harmonic analysis transforms the tidal signal into its constituent astronomical components. The MHWL tidal plane equation uses the following constituents:

   $$MHWL = Z_0 + M_2$$

   Where Z_0 = mean sea level, that is the average of all filtered data points

   M_2 = semi-diurnal harmonic constituent.

2 MHWL methodology

All tidal characteristics identification for the purposes of harmonic analysis was completed in MHL report 2786 (MHL, 2023) and applied to the averaging of the high tides method. This includes the classification of applicable water level monitoring stations based on continuous astronomical influence. For the harmonic analysis method, if more than 180 days of data in any given year was missing or was non-tidal, then the data for that year is excluded from the analysis. This is because tidal range results vary with the length of record (MHL, 1995) and are therefore not necessarily representative for shorter periods. A similar selection criteria was applied for the average of the high tides method, where 50% of high tides were required for any year to be included in the calculation.

Both methods underwent the same anomaly removal technique described in MHL report 2786 (MHL, 2023). The 0.2m hindcast anomaly removal technique is used for all MHWL calculations whereby anomalies are identified by periods where residual values exceed a threshold of 0.2m.

2.1 Average of the high tides method

The average of the high tides method utilises every identifiable high tide in the dataset to calculate a representative high-water mark. The averages of all high-water observations were calculated over each financial year for the 2003-2022 epoch where only the highest value for each 6 to 7 hour tidal cycle period is selected, as shown in Figure 2-1. The blue trace is the monitored water level post anomaly removal, and the orange points indicate the selected high tide. This report only analyses NSW water level stations which have a semi diurnal tidal trace that generally produces two high tides of different amplitudes due to the orbit of the moon and earth around the sun.

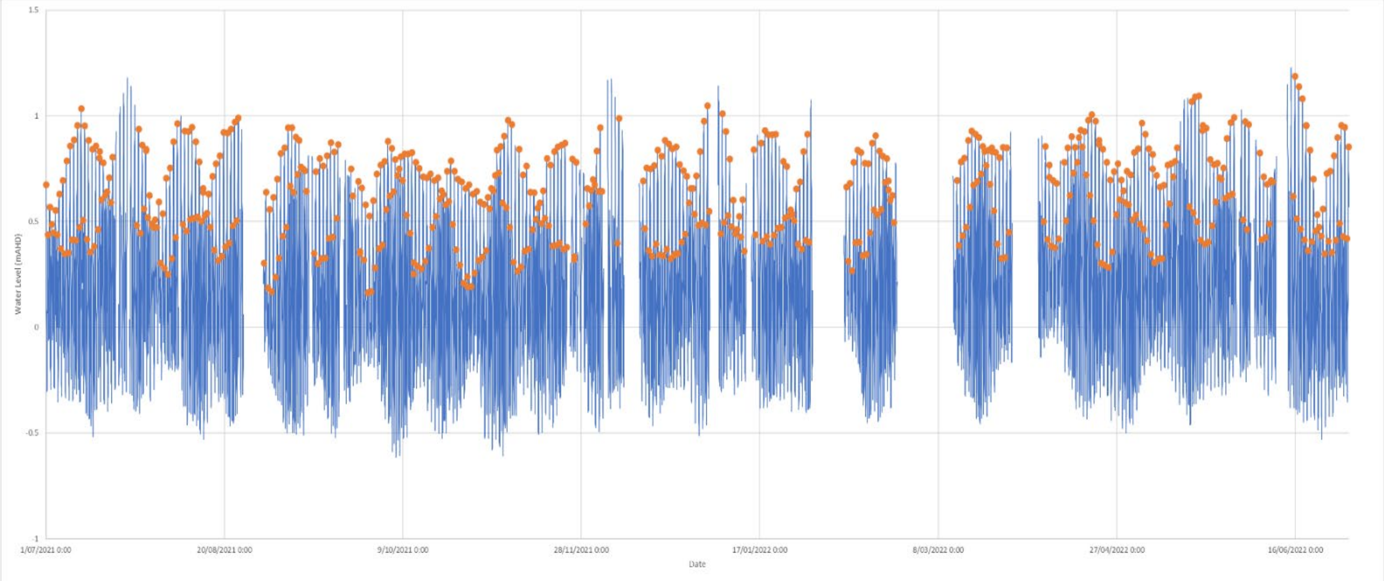

Figure 2-1 An example of high tides for averaging over a single financial year

To avoid including false high-water values in the dataset, a detailed identification and filtering methodology was developed. The method employs the following steps:

1. All local maxima are extracted for each year of data.
2. Filtering to remove erroneous results which occur within 8 hours of each other.
3. Any days which do not have 2 high tides are then identified for further refinement.
4. Each of these days is analysed individually using slightly relaxed maxima checking to try and find the second peak (using the maximum daily value as the first).
5. Should a second peak still be unable to be resolved the whole day is discarded to prevent skewing of the results.

The number of high tides analysed for each yearly block are provided in the analysis results in Appendix A . The flood removal process may already have potentially removed some high tides. Other methods of theoretical tide loss include:

- water level station failure
- MHL water level data quality coding procedure, where data points with an uncertainty of >+/-50mm are removed prior to the anomaly removal process
- noisy data where local maxima could not be reliably identified
- more than 10% of a data is missing in a 24-hour period.

For the purposes of this report if the percentage of high tides used is below 50% then the analysis for that year's block is voided which is consistent with the harmonic methods procedure in MHL report 2786 (MHL, 2023):

$$\%\, tides\ used = (No.of\ high\ tides\ used\ in\ a\ year)/(Theoretical\ no.high\ tides\ that\ year)$$

2.2 Harmonic analysis method

The tidal harmonic constituents determined for each station using the Foreman tidal height analysis and prediction program. MHL has incorporated the Foreman Versatile Tide method into its standard analysis routines which is outlined in MHL report 2786 (MHL, 2023). This method is an improved version of the original method completed by Foreman in 2007 (MHL, 2012) where improvements include the possibility to analyse records over the full tidal epoch and better handling of missing data allowing the analysis of sparsely sampled data. It also includes a more accurate nodal correction, inference, and astronomical argument adjustments due to the incorporation of the least square analysis instead of post analysis as in MHL report 2053 (MHL, 2012).

The MHWL harmonic analysis method is calculated per financial year over the 2003-2022 epoch.

2.3 Uncertainty

The methodology for uncertainty calculations undertaken by MHL for each water level station where MHWL has been determined is given in MHL report 2786 (Appendix C), an excerpt of the contributing uncertainty components is given in Table 2-1.

Table 2-1 Summary of uncertainty components

Source	Raw uncertainty ranges	Estimation component
Survey reference Benchmark	±0.003m to ±0.220m Based on MHL survey practices	(NSW Government Spatial Services, 2021)
Survey resolution	±0.001m	Scale resolution
Survey mis-close	±0.000m to ±0.005m	MHL survey books
Instrument resolution	Assumed ±0.010m for all instrumentation types	Lowest resolution of the environmental database – resolution varies from 0.010 (pre 2010) to 0.001m.
Instrument calibration uncertainty	Assumed ±0.004m for all instrumentation types and tidal ranges.	DPI 610 IS Portable pressure calibrator calibration certificate from manufacturer.
Water density uncertainty	Dependant on instrument type and estuary type	(UNESCO, 1981) Salinity is not being measured so we are assuming based on a classification.
Variation between quality controlled data and field observations	MHL quality controlled database for each station.	MHL field observations
Gauge post reading resolution	±0.003m	Scale resolution (1/3 of the gauge plate 10mm marks)
Sea level change – Not included.	Based on the Fort Denison tide record 1914 – 2004 there is a linear trend of sea level rise of 0.94mm/year.	(MHL, 2011) – Not included in the calculation.
Hydrologic input removal technique	Assumed ±0.033m for all station locations	Refer to methodology on anomaly removal technique in MHL report 2786.

Source	Raw uncertainty ranges	Estimation component
Foreman analysis uncertainty	Station specific. Based on this report ranges between ±0.150m to ±0.330m	Assumption is that for the tidal constituents their associated uncertainty is the same as the mean value (prediction) i.e., the standard deviation.

The MHWL harmonic (Foreman) method uncertainty values published in MHL report 2786 (MHL, 2023) have also been adopted in this report, rounding up uncertainty estimates from three to two decimal places to allow for any differences using the latest available tidal data between 2003 to 2022[2].

The Foreman analysis uncertainty is the most significant contributor to the uncertainty budget. The contribution of survey mis-closes and variation between field observations and quality controlled data is negligible to the overall uncertainty calculation. Six stations from different types of NSW water level systems were tested to confirm the rounding sufficiently encompassed the change in uncertainty.

Estimates of uncertainty for the average of the high tides MHWL methodology are based on the same uncertainty components as for the Foreman analysis approach, except that the Foreman analysis (model) uncertainty component no longer applies. The average high tides methodology introduces additional uncertainty components related to missing high tides and high tides not captured due to the observation timing interval. The potential impacts of these two uncertainty components were tested using the full 2003-2022 epoch comparing 1 minute and 15 minute interval datasets. In each individual year the difference between the two available time series datasets MHW values were found to be less than 1mm. As such, these two uncertainty components are not significant for the MHWLs presented in this report, and overall uncertainty for the average of the high tides MHWL definition has reduced uncertainty at all stations compared to the Foreman analysis MHWL definition.

---

[2] MHL report 2786 (MHL. 2023) MHWL estimates are based on data from 2001 to 2020.

3 Results

Results of the MHWL calculations are presented from north to south in Appendix A. Each catchment on the east coast of NSW has a location map showing DPE operated stations that were eligible for analysis. A 2D MHWL longitudinal plot is provided for major river and coastal lake systems showing the results of both methods. The results for each water level station include:

- yearly average of the high tide's method MHWL for each financial year over the 2003-2022 epoch
- number and percentage of available high tides used for each yearly average of the high tides
- yearly harmonic analysis method MHWL for each financial year over the 2003-2022 epoch
- an averaged MHWL value over the 2003-2022 epoch for each method
- an uncertainty value at the 95% confidence interval for each calculation method (rounded to two decimal places)
- plotted comparison of the yearly values to highlight trends in the datasets
- web link to each station's metadata and previously calculated tidal planes (MHL, 2023).

All results are presented in metres Australian Height Datum (1971).

4 Discussion

The results outlined in Appendix A have a general trend of the average of the high tides method displaying a higher MHWL value than that of the harmonic method. Users of MHWL information may choose a method which is fit for purpose based on entrance conditions, bathymetry or tidal limits.

The following tables present the results from a sample of water level stations which measure levels in varying types of hydraulic systems. These sample stations are grouped in Table 4-1 to Table 4-4 and show a comparison between the epoch MHWL value for each method.

Table 4-1 MHWL for both methods in selected sample ocean tide stations

Station	MHWL mean of the high tides (m AHD)	Harmonic analysis MHWL (m AHD)	Difference (m)
Tweed	0.525	0.511	0.014
Coffs Harbour	0.590	0.563	0.027
Sydney	0.572	0.546	0.026
Jervis bay	0.574	0.548	0.026
Eden	0.405	0.377	0.028
Average			**0.024**

Table 4-2 MHWL for both methods in selected sample estuary stations

Station	MHWL mean of the high tides (m AHD)	Harmonic analysis MHWL (m AHD)	Difference (m)
Hexham Bridge	0.625	0.584	0.041
Taree	0.444	0.409	0.035
Byrnes Point	0.523	0.497	0.026
Wauchope	0.486	0.457	0.029
Picnic Point Downstream	0.664	0.615	0.049
Average			**0.036**

Table 4-3 MHWL for both methods in selected sample coastal lake stations

Station	MHWL mean of the high tides (m AHD)	Harmonic analysis MHWL (m AHD)	Difference (m)
Belmont	0.144	0.136	0.008
Marmong Point	0.166	0.158	0.008
Cudgeree Bay	0.238	0.230	0.008
Average			**0.008**

Table 4-4 MHWL for both methods in selected sample tidal boundary stations

Station	MHWL mean of the high tides (m AHD)	Harmonic analysis MHWL (m AHD)	Difference (m)
Murwillumbah Bridge	0.578	0.526	0.052
Coraki	0.427	0.396	0.031
Rogans Bridge	0.507	0.480	0.027
Windsor	0.735	0.671	0.064
Belmore Bridge	0.570	0.499	0.071
Average			**0.049**

The maximum difference in MHWL between the two methods across all reported sites does not exceed 0.075m. In all cases the 95 percentile measurement uncertainty bands for the two methods overlap with each other. This provides confidence in both sets of MHWL estimates and the methodologies adopted.

Using the overall average for each group of hydraulic systems in NSW, it is possible to see a trend in Figure 4-1 where the average of the highs has a consistently larger MHWL when moving from ocean and estuary entrance further up toward the tidal limit. Coastal lake systems' tidal ranges are too small to bear out any discernible difference in the methods.

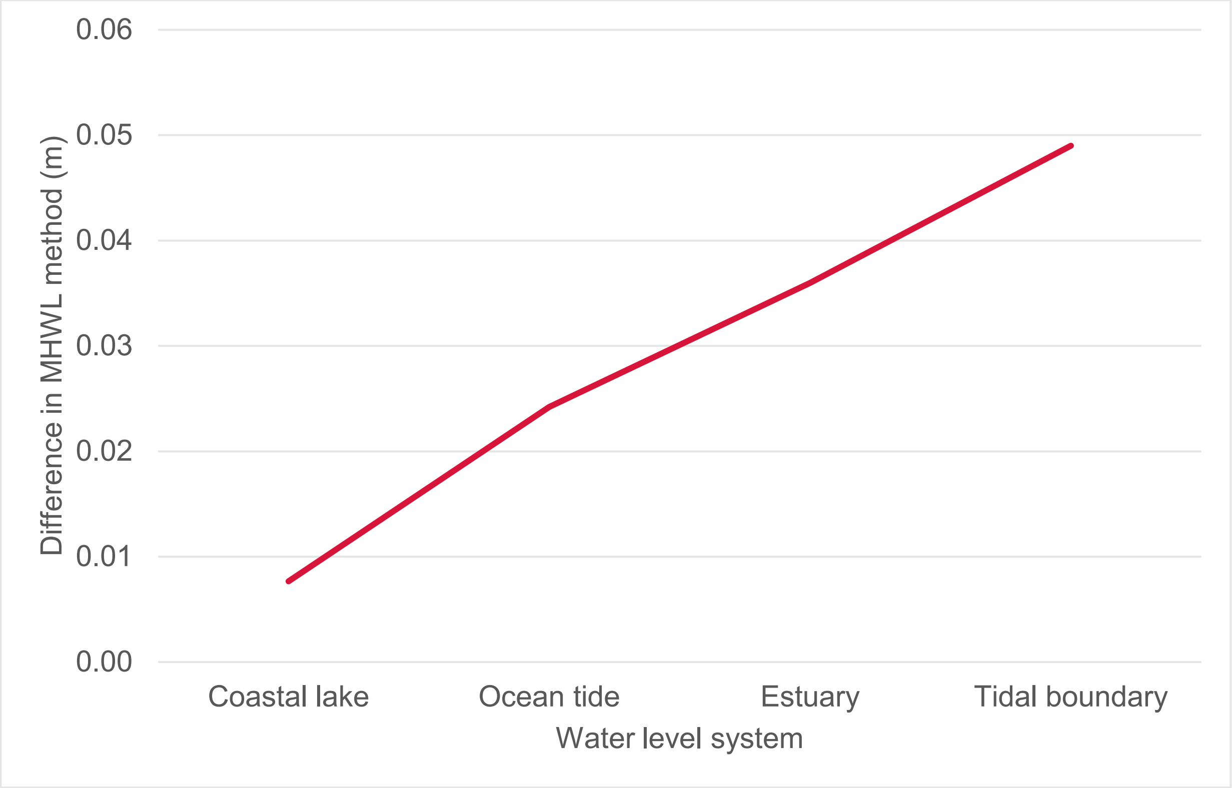

Figure 4-1 An average sample trendline when comparing MHWL method calculation for certain NSW coastal systems

The longitudinal plotting in Appendix A, on major NSW estuaries, demonstrates the changes in MHWL values for both methods from left to right moving downstream towards the ocean. The location markers on the X axis with associated distances are calculated based on river length, not straight line distance. This is done in graphical software and gives a truer reflection of how far tidal waters are traveling between the ocean entrance and the tidal limit of an estuary. The longitudinal plot gives the reader a brief overview of how the MHWL methods may slightly diverge with distance upstream for their interested estuary.

The average of the high tides method can be more sensitive to hydraulic condition changes during the selected data time series period than the Foreman analysis. For example, Figure A161 shows MHWL results deviate at Freemans Reach on the Hawkesbury River after flood events change river bathymetry in 2011 and 2012.

Both methods still rely on there being a sufficient tidal signal to calculate MHWL. The Office of the Surveyor-General is currently undertaking a review of Direction No. 6 Water as a Boundary (Surveyor General of NSW, 2016) to consider advice to surveyors where limited tidal data is available.

5 Conclusion

This report presents two valid methods of calculating MHWL for NSW coastal systems and estuaries from data collected by stations managed by MHL. The analysis epoch was set to 2003 to 2022 to best reflect the most current datasets. The anomaly removal, harmonic analysis and average of the high tides methods have been scripted and automated to allow efficient and timely updates of the results into the future. These results are publicly available in this report and on the MHL website within each individual monitoring station's metadata to maximise discoverability for the general public (Figure 5-1).

The mean high water mark is often used to determine the boundary line for properties which lie adjacent to tidal waterways. Historically this has been performed using harmonic analysis of the tidal record over a 19-year tidal epoch (where data is available). Recent work has shown that this harmonic value will often underrepresent the mean high water mark as calculated by averaging all high water values over the same period. Therefore, the values for the mean high water mark as calculated by *both* methods are presented below for reference and appropriate usage. Further information can be found in the 2003-2022 Mean High Water Level Report.

The overall MHW values, in AHD, for **Sydney** have been calculated to be:

Mean of Highs: **0.572m** Harmonic: **0.546m**

Figure 5-1 Sample of individual station MHWL results available on the MHL public website

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Appendix B Glossary of terms

Amplitude (H)	One-half the range of a constituent tide. By analogy, it may be applied also to the maximum speed of a constituent current.
Automatic water level recorder	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.
Australian Height Datum (AHD)	The Australian Height Datum is a geodetic datum for altitude measurement in Australia. According to Geoscience Australia, "In 1971 the mean sea level for 1966-1968 was assigned the value of zero on the Australian Height Datum at thirty tide stations 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 as the datum to which all vertical control for mapping (and other surveying functions) is to be referred.
Bathymetry	Geomorphology mapping of underwater sea beds, lake floors or river floors
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.
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.
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.
Entrance conditions	The interface between any lake or estuarine system with the ocean where this may be dynamic and change or permanently open to ocean influence.

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.
Harmonic analysis	Process of measuring or calculating the relative amplitudes and frequencies of all the significant harmonic components present in a given wave form.
ICOLL	Intermittently closed or open (coastal) lakes and lagoons
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 Level (MHWL)	A tidal datum. The average of all the high waters observed over the National Tidal Datum Epoch. For stations with shorter periods of record, simultaneous observational comparisons are made with a control tide station to derive the equivalent datum.
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.
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.
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.
Tidal anomaly	The difference between the recorded and predicted tide level generally representative of the non-astronomical factors influencing coastal water levels such as storm surge.
Tidal characteristics	Principally, those features relating to the time, range, and type of tide.
Tidal limit	That point along a tidal estuary above which there is no tidal influence

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.
Z_0	Symbol recommended by the International Hydrographic Organisation to represent the elevation of mean sea level above chart datum.

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