METHODOLOGY FOR DETERMINING MEAN HIGH WATER

1. INTRODUCTION

The purpose of this document is to describe the Rhode Island Coastal Resources Management Council (CRMC) guidelines and procedures required for the determination of an elevation of Mean High Water (MHW) at project areas in the coastal zone of the State of Rhode Island. The guidelines have been reviewed and approved by the National Oceanic and Atmospheric Administration (NOAA) and closely follow those prescribed by NOAA, National Ocean Service (NOS) that are used in their accepted procedures for national nautical charting, surveying and mapping missions.

Because of the effects of morphology and bathymetry and changes in the range and type of tide along the shore, the elevation of tidal datums, including Mean High Water (MHW), are not fixed, universal, elevations relative to the land, but vary depending on location. The procedures described in this document are for the determination of the elevation of MHW at specific locations. The tidal datum elevations at these fixed locations are then used as baseline points to interpolate or extrapolate the MHW line at intermediate or nearby points (to demarcate or survey a MHW line on the shore, for example).

Tidal datums are determined at specific locations using a four step process: 1) establishing a tide station at the desired location, 2) tabulating the tide and computing mean values from the observations, 3) computing datums from the observations by statistically comparing the mean values with an appropriate nearby long term control station, and 4) transferring the elevations of the tidal datums to the land.

General descriptions of each of these four steps are found in sections of this document. Detailed technical descriptions and specifications can be found in the referenced material in each section. The first section provides a glossary of the most important terms.

2. TERMINOLOGY

Full definitions of all terms can be found in the NOS Tide and Current Glossary (NOS 2000), (http://tidesandcurrents.noaa.gov/publications/glossary2.pdf). Only the specific terms required for determination of MHW in Rhode Island are discussed here.

A vertical datum is called a **tidal datum** when it is defined by a certain phase of the tide. Tidal datums are local datums and should not be extended into areas which have differing hydrographic characteristics without substantiating measurements. In order that they may be recovered when needed, such datums are referenced to fixed points known as bench marks.

Mean High Water (MHW) is a tidal datum determined from the arithmetic mean of the high water heights observed each tidal day.

The **Mean High Water Line** (MHWL) is the intersection of the plane of the MHW tidal datum with shore. The elevation of the MHWL is fixed for given time periods and does not change unless tidal datums are updated. The horizontal location of the MHWL may move landward with seasonal or long-term coastal erosion and may move seaward with shoreline accretion.

Mean Low Water (MLW) is a tidal datum determined from the arithmetic mean of the low water heights observed each tidal day.

Mean Tide Level (MTL) is a tidal datum which is determined from the average of the MHW and MLW tidal datum elevations.

Mean Range of Tide (Mn) is the difference in elevation between the tidal datums of MHW and MLW.

Mean Sea Level (MSL) is a datum defined as the arithmetic mean of observed hourly heights.

The **Relative Sea Level Trend** (**RSL**) is the rate of long-term change in the elevation of sea level at a particular location. There are two main components to the RSL at any given location. They are: 1) the global sea level change due to increased or decreased volume of water in the ocean, and 2) the local vertical motion of the land due to large scale or regional tectonic movement, local land subsidence, or isostatic rebound (due to melting glaciers). Global sea levels have been rising since the last ice age due to melting glaciers and ice sheets and thermal expansion of ocean waters. The estimated RSL using the NOAA tide gage records is 2.57 mm/yr for Newport and 1.88 mm/yr for Providence (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml), (Zervas, 2001).

A primary determination of a tidal datum is based directly on the average of observations over a 19 year period. For example, a primary determination of Mean High Water is based directly on the average of the high waters over a 19 year period. Specific 19-year periods are defined by NOAA as a **National Tidal Datum Epoch** (NTDE) and tidal datums must be specified with regard to a NTDE (Marmer, 1951). The 1983-2001 NTDE is currently in use by NOAA.. NTDE's are updated over time due to slowly varying changes in relative mean sea level. For stations with shorter series, a comparison of simultaneous observations is made with a primary control tide station in order to derive the equivalent of a 19-year value (Marmer, 1951 and NOS, 2000).

NOAA uses specific NTDE periods of observations for nation-wide standardized datums for NOAA surveying and mapping and demarcation of maritime boundaries for federal purposes. The Rhode Island CRMC has chosen to use a modified tidal datum epoch for State purposes to ensure MHW uses the latest in MSL variations due to local sea level rise. NOAA has recommended that if this modified procedure is to be used, then the MSL should be estimated from the NOAA published sea level trend. The effective Rhode Island Modified Epoch uses the local sea level trend line from the 1930 -1999 time period for the Newport tide gage published by NOAA (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml) to estimate a tidal datum epoch value for MSL centered on the current year.

Other Vertical Datums and Their Relationship to Tidal Datums

In addition to tidal datums, other vertical datums are determined and employed for various applications. For example, MSL is the local mean sea level. It is a tidal datum (previously defined) and is often confused with the fixed datums of the National Geodetic Reference System, or the National Geodetic Vertical Datum (NGVD 1929) (previously referred to as the Sea Level Datum of 1929), or the North American Vertical Datum of 1988 (NAVD 88). These fixed geodetic datums (e.g., NGVD 1929 and NAVD 88) do not reflect the changes in sea level and because they represent a "best" fit over a broad area, their relationship to local mean sea level differs from one location to another. NGVD 1929 has been replaced by NAVD 88 and the National Geodetic Survey no longer supports the NGVD 1929 system.

When in doubt of the relationship of a tidal datum to a geodetic datum, establishment of a tide station and connection to geodetic datum using differential levels or GPS is recommended for most applications. NOS establishes geodetic connections at the tide stations through differential levels between tidal bench marks and geodetic bench marks. Use of GPS survey equipment to occupy tidal bench marks is the emerging state-of-the-art method for making the connections. See the NOS Web-sites at http://oceanservice.noaa.gov/ and www.ngs.noaa.gov for further information on geodetic and tidal datum elevations on bench marks.

3. ESTABLISHING A TIDE STATION

Tidal datums are computed from continuous observations of the water level over specified lengths of time. Observations are made at specific locations called tide stations. At a minimum, each tide station consists of a water level gage or sensor(s), a data collection platform or data logger, and a set of tidal bench marks established in the vicinity of the tide station. NOS collects water level data at 6-minute intervals. Various types of water level sensors and station configurations are possible. NOS specifications and appropriate references are found in Chapter 4 of the NOS Specifications and Deliverables document (April 2007).
(see http://chartmaker.ncd.noaa.gov/hsd/specs/specs.htm)

For tidal datum applications, it is important for gages and sensors to be carefully maintained with either frequent calibration checks or cycled swaps of calibrated sensors for long-term installations. The sensor "zero" must be precisely related to either a tide staff and/or the bench marks through staff/gage comparisons or direct leveling between the sensor and the bench marks. Vertical stability of the sensor "zero", both physically and internally, must be monitored and any movement taken into account in the data reduction and datum computation.

A network of bench marks is an integral part of every water level measurement station. A bench mark is a fixed physical object or mark (sometimes referred to as a monument) used as a reference for a vertical datum. For example, a tidal bench mark is a mark near a tide station to which the tidal datums are referenced. Since gage measurements are referenced to the bench marks, it follows that the overall quality of the datums is partly dependent on both the quality of the bench mark installation and the quality of the leveling between the bench marks and the gage. NOAA leveling and bench mark installation procedures are described in references from chapter 4 of the NOS Specifications and Deliverables Document (NOS, 2007).

4. DATA PROCESSING AND TABULATION OF THE TIDE

Data collected from the field must be processed before tidal datums are computed. NOS currently collects continuous water level data at 6-minute intervals at all NOAA tide stations.

Once the 6-minute interval data are processed, the derived products are computed. This processing includes QC, editing, gap filling. Data are plotted to examine the data quality and determine what kind of gap filling, if any, is required. If gaps are small, (< 4 hours), then an interpolation of the missing data points using curve-fitting techniques is usually adequate. If gaps are up to three days, then the gaps may be filled with back-up water level data, with predictions, or by comparison of data with a nearby station after amplitude and phase offsets are computed. Derived products from the 6-minute data include the tabulation of the times and heights of the high and low tide and the tabulation of hourly heights. Tidal parameters from these daily tabulations of the tide are then reduced to mean values, typically on a calendar month basis for longer period records or over a few days or weeks for shorter-term records. See the Manual of Tide Observations (1965) and the NOS Specifications and Deliverables (2007) documents for more information on tabulation of the tide and the computation of mean values.

Note that the simultaneous tabulations and monthly means from the NOAA control stations should be obtained from the NOAA website so that the two time series can be statistically compared.

5. COMPUTE TIDAL DATUMS

Due to time and resource constraints, primary determinations of tidal datums (i.e. using 19 years of data) are not practical at every location along the entire coast where tidal datums are required. At intermediate locations, a secondary determination of tidal datums can usually be made by means of observations covering much shorter periods than 19 years if the results are corrected to an equivalent mean value by comparison with a suitable control tide station (Marmer, 1951 and NOS, 2000).

Conceptually, the following steps need to be completed in order to compute equivalent NTDE tidal datums at short term stations using the method of comparison of simultaneous observations:

1) Select the time period over which the simultaneous comparison will be made.

2) Select the appropriate control tide station for the subordinate station of interest.

.3) Obtain the simultaneous data from subordinate and control stations and obtain or tabulate the tides and compute monthly means, as appropriate.

4) Obtain the accepted NTDE values of the tidal datums at the control station from

NOS via the CO-OPS Website (http://tidesandcurrents.noaa.gov/nwlon.html)

5) Compute the mean differences and/or ratios (as appropriate) in the tidal parameters between the subordinate and control station over the period of simultaneous comparison.

6) Apply the mean differences and ratios computed in step 5, above, to the accepted values at the control station to obtain equivalent or corrected NTDE values for the subordinate station.

Range-Ratio Method. This method is generally used for the East Coast stations with semidiurnal types of tide. For calculation of mean high water (MHW), values needed are mean tide level (MTL), mean range of tide (Mn), and mean low water (MLW) as determined by comparison with an appropriate control. From these, the following are computed:

$$MLW = MTL - (0.5 \times Mn)$$
$$MHW = MLW + Mn$$

The **computational procedure** for the simultaneous comparison discussed in 5) and 6) above is a three step process.

1) It starts with the determination of the accepted datum of Mean Tide Level (MTL_{acs}) for the tidal datum epoch of interest at the short-term station. This is done by comparing the differences in MTL between the short-term (MTL_s) and the control station (MTL_c) for a simultaneous time period (minimum one month).

$MTL_s - MTL_c = MTL_{difference.}$

This difference is then applied to the accepted NTDE value for MTL at the long-term control station (MTL_{acc}) to compute the equivalent long term value at the short-term station.

$MTL_{difference} + MTL_{acc} = MTL_{acs}$

2) The accepted mean range of tide at the short-term station (Mn_{acs}) then must be determined. This is computed by forming a range ratio between the ranges of tide at the short-term and the control station for simultaneous time period (minimum one month).

$Mn_s / Mn_c = Mn_{ratio}$

This ratio is then applied to the accepted NDTE value for Mn at the long-term control station (Mn_{acc}) to compute the equivalent long-term value at the short-term station.

$Mn_{ratio} \times Mn_{acc} = Mn_{acs}$

3) The accepted datum of Mean High Water at the short-term station (MHW_{acs}) is then computed by first subtracting ½ of the value of the accepted Mean Range (from step 2) at the short-term station from the Mean Tide Level at the short-term station (from step 1) to get MLW_{acs} and then adding the Mn_{acs} to the MLW_{acs} to get MHW_{acs}:

$$MLW_{acs} = MTL_{acs} - \tfrac{1}{2} Mn_{acs}$$

$$MHW_{acs} = MLW_{acs} + Mn_{acs}$$

6. COMPUTE BENCH MARK ELEVATIONS

Once the tidal datums are computed from the tabulations, the elevations are transferred to the bench marks established on the land through the elevation differences established by differential leveling between the tide gage sensor “zero” and the bench marks during the station operation (NOS Specifications and Deliverables, 2007). The bench mark elevations and descriptions for NOAA stations established in Rhode Island are disseminated through a published bench mark sheet for each station (http://tidesandcurrents.noaa.gov/nwlon.html). Connections between tidal datum elevations and geodetic elevations are obtained after leveling between tidal bench marks and geodetic network benchmarks. Traditionally, this has been accomplished using differential leveling, however GPS surveying techniques can also be used (NGS, 1997; NOS Specifications and Deliverables, 2007).

7. TIDAL DATUM EPOCHS

To calculate the Rhode Island Modified Tidal Datum Epoch the local sea level trend line is used to estimate a tidal datum epoch value for MSL centered on the current year. For the Newport tide gage the sea level trend line from the 1930 -1999 time period is 2.57 mm/year (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml). Accepted values of the tidal datums for the NOAA control stations in Rhode Island and the equivalent values determined by the Rhode Island modified sea-level trend method are listed below. All values are in meters. NOAA uses modified epoch periods for MSL calculation purposes only when extreme sea level trends (> 0.10 mm/yr) are present.

Newport 8452660

	1983-2001	RI-Modified 1998-2016
MSL	1.106m	1.145m
MTL	1.148m	1.187m
Mn	1.057m	1.057m
MHW	1.676m	1.716m

The NOAA published trend in MSL at Newport from the 1930-1999 data is 2.57 mm/yr with a standard error of 0.11 mm/yr

The following provides details of the calculation of accepted values of the tidal datums for Newport. The same procedure for Providence would be used.

RI-Modified accepted values are computed using MSL calculated from 19 years of the estimated MSL values for 1998-2016 and centered on 2007, using the estimated sea level trend computed from the 1930-1999 time period. This procedure provides for a MSL value that estimates a 19-year mean value in 2007. MTL is estimated using the relationship of MSL and MTL from the NOAA 1983-2001 NTDE:

For Newport:

MTL - MSL (1983-2001) = 1.148m - 1.106m = 0.042m
MTL RI- Modified = 1.145m + 0.042m = 1.187m

and MHW is estimated from this MTL and using the Mn from the NOAA 1983-2001 Epoch as well:

MLW = MTL-1/2 Mn = 1.187m - ½ 1.057m = 0.659m
MHW = MLW + Mn = 0.659m + 1.057m = 1.716m

8. TIDE STATIONS AND DATUM ACCURACY

Types of Tide Stations:

Primary control tide stations are generally those which have been operated for 19 or more years, are expected to continuously operate in the future, and are used to obtain a continuous record of the water levels in a locality. Control tide stations are sited to provide datum control for national applications. There are two long-term NOAA National Water Level Observation Network stations in Rhode Island located at Newport and Providence, which provide primary control for shorter-term tide stations. Data, tabulations, accepted tidal datums and bench mark information can be found at http://tidesandcurrents.noaa.gov/nwlon.html.

Secondary water level stations are those which are operated for less than 19 years but more than 1 year, and have a planned finite lifetime. Secondary stations provide control in bays and estuaries where localized tidal effects are not realized at the nearest primary control station. Observations at a secondary station are not usually sufficient for a precise independent determination of tidal datums, but when reduced by comparison with simultaneous observations of monthly means at a suitable control tide station very satisfactory results may be obtained

Tertiary water level stations are those which are operated for more than a month but less than 1 year. Tertiary stations may have their data reduced to equivalent 19-year tidal datums through mathematical comparison of simultaneous observations from a nearby control station or an appropriate secondary station. Comparisons make use of either tide-by-tide (TBYT) comparisons (if less than a full calendar month of data are available) or comparisons of monthly means (NOS, 2000).

Short-term water level stations are those which are operated for less than one-month, but longer than three days and may have their data reduced to equivalent 19-year tidal datums through comparison of simultaneous observations with a nearby primary control or secondary stations. These comparisons require the use of TBYT comparison procedures. (NOS, 2000 and Manual of Tide Observations, 1965)

Data, tidal datums, and bench mark elevations for historical and existing secondary and tertiary stations can be found at http://tidesandcurrents.noaa.gov/nwlon.html

Accuracy:

Generalized accuracies (Swanson, 1974) for datums computed at secondary or tertiary stations based on one standard deviation error for the length of the record are summarized in Table 1. The accuracies of the secondary and tertiary datums can be interpreted as known to within plus or minus the appropriate value in Table 1. That is, the values in Table 1 are the confidence intervals for the tidal datums based on one standard deviation.

Table 1. Generalized accuracy of tidal datums for East Coast tide stations when determined from short series of record and based on one standard deviation.

Series Length (months)	East Coast (cm)	(ft.)
1	3.96	0.13
3	3.05	0.10
6	2.13	0.07
12	1.52	0.05

Note that accuracies for short-term stations less than one-month could have standard deviations much greater than 0.13 foot.

8. REFERENCES

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