Estimating Sea Level for Project Initiation Documents

Converting Tidal Datums to Project Elevations and Predicting Future Sea Levels

Office of Land Surveys,

Division of Right of Way and Land Surveys

Determining Sea Level for Project Initiation Documents

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http://www.dot.ca.gov/hq/row/landsurveys

1. Introduction

The purpose of this document is to become familiar with the tidal information available from the National Oceanic and Atmospheric Administration (NOAA), and instruct a Caltrans surveyor on the techniques to relate tidal datums to geodetic datums for initial project planning.

1.1 Governor's Executive Order S-13-08

Governor's Executive Order S-13-08[1] requires "all state agencies within my administration that are planning construction projects in areas vulnerable to sea level rise shall, for the purposes of planning, consider a range of sea level rise scenarios for the years 2050 and 2100 in order to assess project vulnerability…"

This order was addressed by the Caltrans document *Guidance on Incorporating Sea Level Rise- For use in the planning and development of Project Initiation Documents*[2] ,May 16, 2011, (hereafter *Guidance*). The *Guidance* requires a risk analysis of projects by determining the lifespan of the project, cost, and susceptibility to the effects of sea level rise (SLR).

As part of the analysis, Surveys is tasked with determining the relationship between tidal datums and the current geodetic elevation datum. By applying projected sea levels to those datums, the planner and engineer can perform a risk assessment in the PID phase for new projects.

1.2 Tidal Influence

Projects located near the ocean or tidal estuaries present special problems for planners, engineers, and surveyors. The rise and fall of tides are markedly different at each location. In bays and rivers, the shape of the estuary and the bathymetric (seafloor) surface can further accentuate the normal tide cycles, producing highs and lows several feet different from the tidal elevations along the ocean shoreline.

The elevation of mean sea level (MSL) isn't enough information to plan or design a project. For instance, the elevation of low and high tides are required to design drainage structures and rock slope protection. Also, the elevations of historical extreme events are needed to perform a risk analysis for the location of utilities, especially electrical equipment. Additionally, when working on or near tidal water, engineers must understand that the depths shown on nautical charts are based on a low tide, bridge height is based on or designed for a high tide, and neither is necessarily related to the geodetic elevation provided by Surveys for digital terrain mapping.

To further complicate matters, the height of the ocean isn't stable. In the City of San Francisco, sea level has been rising at an average of 0.66 feet per century[3]. The trend isn't consistent geographically. At the tide station at the North Spit of Humboldt Bay, the trend is 1.55 feet per century[4]. Another factor that must be taken into consideration during the design process is the existence or possibility, and historical magnitude and rate, of geological upheaval or subsidence.

Whether sea level changes are caused by the ocean rising or the land subsiding, the trend is real. Projects built today must be designed for the lifetime of the facility, and the future sea level height is one of many considerations to be addressed.

The Project Manager is responsible for requesting the elevation datums from Surveys. A request must be made when the project may be influenced by tidal actions. The request must include the sea level rise model to be used in the analysis, and any intermediate dates that would be included in the sea level rise scenario. A copy of any geotechnical analysis will be included, if available.

Surveys will provide the tidal datums, including Design High Tide, to the requestor. If the project is subject to sea level rise (SLR), Surveys will add the SLR projections and a graphic model of future possible inundation.

2. Vertical Datums and Sources

The surveyor must clearly communicate the relationship between the tidal and geodetic datums for each project influenced by a tidal body of water. The reader should be familiar with the geodetic and tidal datums as described in Appendix 1 of this paper, and Chapter 4 of the Surveys Manual, *Survey Datums.*
http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/04_Surveys.pdf

The *Highway Design Manual* (Sec. 873.2) uses a formula based on NOAA's tidal datums to determine the "Design High Tide". This formula should be used whenever the "Highest Observed Water Level" isn't published for a federal tide station.

2.1 Sources

The National Ocean Service (NOS) is part of the National Oceanic and Atmospheric Administration (NOAA) and tasked with determining tidal datums for the United States and territories. This work is performed by the Center for Operational Oceanographic Products and Services (CO-OPS)[5]. CO-OPS operates and maintains the system of tidal and water level stations for the United States. NOS has also created a computer modeling program, known as VDatum, for interpolating tidal data between tide stations.

The National Geodetic Service (NGS) is another office within the NOS, and maintains the National Spatial Reference System (NSRS). The NSRS is a consistent national coordinate system that specifies latitude, longitude, height, scale, gravity, and orientation throughout the nation, as well as how these values change with time. Relating tidal datums to geodetic datums requires a merging of the information available from both CO-OPS and NGS.

2.2 Primary Tide Stations

Primary stations are permanent structures that collect data for decades with a minimum span of one National Tidal Datum Epoch (NTDE), or 19 years. The latest NTDE is 1983-2001. A primary tide station monitors water levels and records data every six minutes. Each location yields independent data. There are relatively few primary tidal stations. They are often located at the mouths of major harbors. The shapes of local bays and estuaries can magnify or otherwise alter the intensity of the tides. For example, mid-ocean islands like Hawaii may have tidal changes of less than one meter in a day, whereas the Bay of Fundy in Canada has a tidal range of over 15 meters. Regardless of the range, the average of all hourly tide readings at each station is referred to as local mean sea level (MSL or sometimes LMSL).

2.3 Secondary Tide Stations

In areas not covered by primary stations, such as small harbors or inland waterways, secondary tidal stations can be established. There are many more secondary tide stations than primary stations. Secondary stations have collected data for more than one year, but less than one NTDE. Tidal datums and tide predictions for a secondary station are published in relation to an adjacent primary tide station. The secondary stations are often temporary, collecting data for months or years until the relationship with the primary station is established, then removed. There are also tertiary stations (those with less than one year of data). These are not identified as such on the CO-OPS website, but are listed with the secondary stations.

2.4 Tidal Bench Marks

CO-OPS has established a system of Tidal Bench Marks near each station it established. Elevation surveys (leveling) are conducted periodically to ascertain if there is local movement in the vicinity of the station. The tidal bench marks that have Permanent Identifications (PID’s) are part of the NGS bench mark data base. If the leveling is extended to bench marks on a geodetic level line, tidal datums can be readily correlated to the North American Vertical Datum of 1988 (NAVD88) datum.

Most of the tidal bench marks tied to primary stations are established by differential leveling. Next in order of accuracy are elevations established by high precision (e.g., Height Modernization) Global Positioning Satellite (GPS) techniques[6]. Least reliable are bench mark elevations converted from the National Geodetic Vertical Datum of 1929 (NGVD29) to NAVD88 using VERTCON modeling or Online User Position Service (OPUS) processing.

Primary and secondary stations with tidal bench marks can be seen on the CO-OPS Google™ map by selecting “Benchmark Sheets” in the “Require Data Type” menu. The NAVD88 datum shown in the table, which is relative to the MLLW datum, is derived from an average of several bench mark elevations at the tide station. As a result of this averaging, NAVD88 bench mark elevations computed indirectly from the tidal datums elevation table may differ slightly from NAVD88 elevations published for an individual bench mark in the NGS database. Computing the differences between the bench mark elevations and the tidal datums (which are usually not more than 3 mm) is a good way to check the calculations.

2.5 VDatum Models

VDatum is a free software tool developed jointly by NOAA's National Geodetic Survey (NGS)[7], Office of Coast Survey (OCS)[8], and CO-OPS[9]. VDatum is designed to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums - allowing users to convert data from a variety of horizontal/vertical datums into a common reference. VDatum is the preferred method for determining sea level datums when there are no primary or secondary tide stations with tidal bench marks or published vertical datums nearby.

Tidal datum transformations in VDatum extend only slightly inland of the mean high water (MHW) shoreline (1 or 2 km), but many applications seek to reference elevations to tidal datums further inland. The main reason that VDatum doesn't provide tidal datums inland is the fact that tidal datums have no physical meaning inland (until or unless that inland location becomes inundated by tides).

Spatial variations in tidal datums can influence the method of approximating their inland extension. Tidal datums can vary locally for many reasons, some of which include variable bathymetry, the presence of tidal flats, river interactions, presence of barrier islands, geographic/volumetric changes in the shoreline and associated embayments, and the presence of shoreline engineered structures. If tidal datums are relatively spatially uniform, extrapolation of the tidal datums can usually be made by assuming a constant datum difference which can be extended inland a limited distance.

3. Relating Tidal Datums to Geodetic Datums

Tidal datums can be related to geodetic datums in several ways. In order, the methods are:

1. Using the published tidal station data at primary tidal stations.
2. Using the published tidal station data at secondary tidal stations that have associated tidal bench marks.
3. Using the VDatum software to compute tidal datums.
4. Extrapolating data from tide stations in methods 1 and 2, above, into areas not covered by VDatum. This is a last resort, and is only to be used for early planning when no field surveys will be performed.

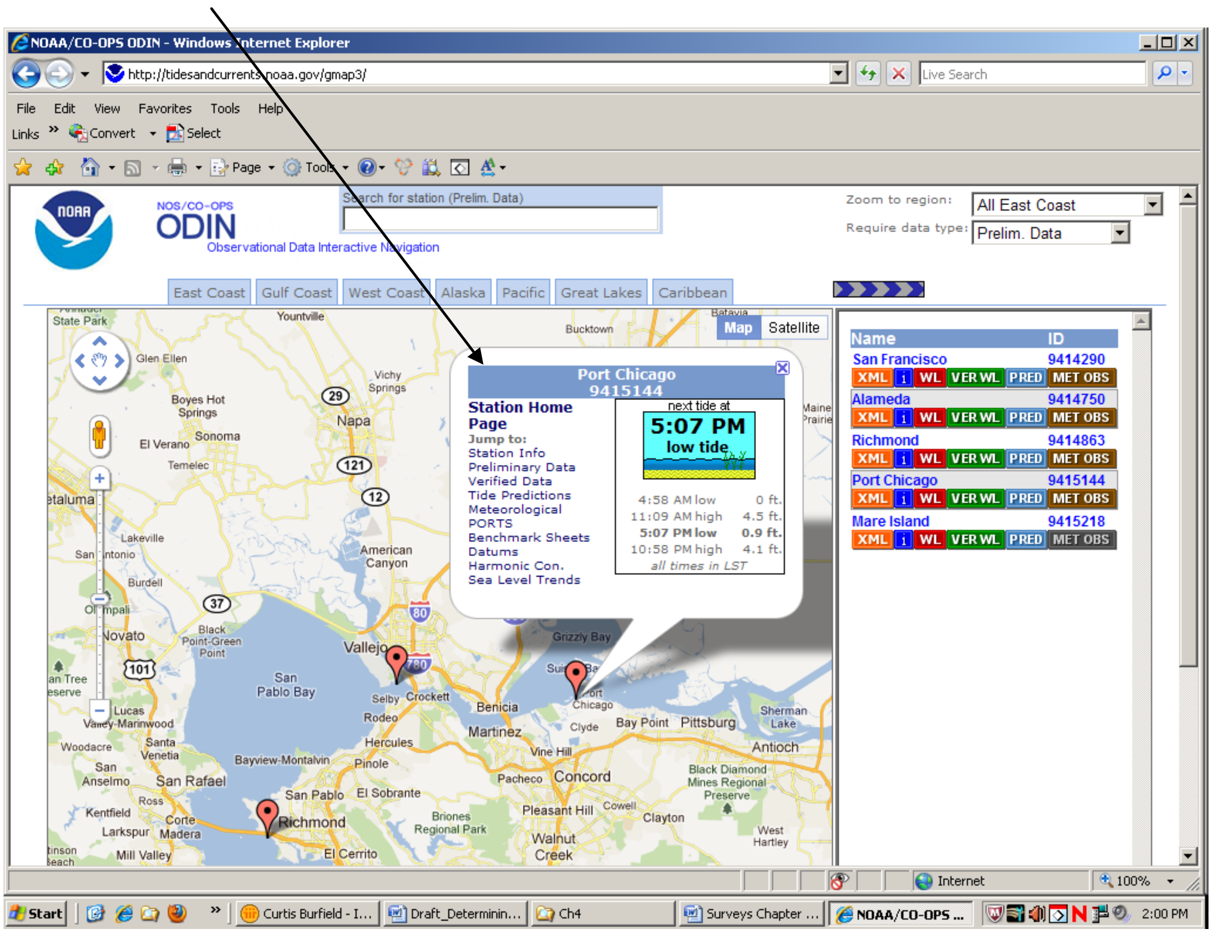
3.1 Tide Station Information

All information for tidal stations in the United States is on the CO-OPS website at http://tidesandcurrents.noaa.gov/index.shtml

In the center of the CO-OPS web page is a Google Map of the United States. By clicking on the map, users can zoom in to an area of interest. In the upper right corner of the map page is the "Require Data Types" pull down menu. Selecting the type for "Prelim Data" brings up 21 currently operating tide stations in California, of which 13 are primary stations. Tide Stations appear on the map as large red markers. The stations visible on the map will be listed on the right side of the page. Clicking on any station symbol will bring up the "Station Home Page" bubble.

The Station Home Page bubble has the current conditions on the right side, and detailed information on the left. You can click on the station name and go to the station home page, or jump to any listed information. The information available on the home page is the same as that available in the bubble.

Click on "Station Home Page" for detailed information about an individual station of interest.



The screen shot example above is for the Port Chicago Primary Tidal Station (9415144). Under "Station Home Page" are several options. Use the "Station Info" toggle to determine the location of the station in latitude and longitude, its installation history, and associated photographs.

The station description, tidal bench mark descriptions, and tidal datums are given under "Benchmark Sheets". Clicking on "Benchmark Sheets" brings up the file for the station. Scroll down to the "Tidal Datums" section for the relevant information. DO NOT choose the "Datums" page for the station, as those elevations are referenced to Station Datum and not to MLLW datum nor any tidal or geodetic datum.

The first item under “Tidal Datums” is the station name, time period the data was collected, and tidal epoch. For primary stations, the “Length of Series”, “Time Period” and “Tidal Epoch” should all show a 19-year time span. The term “Control Tide Station” is blank for a primary station. Secondary and tertiary stations will show a control tide station, to which their data are referenced.

Appendix 2 contains full copies of the bench mark sheets for the Port Chicago (primary) and Rio Vista (secondary) Stations.

```
T I D A L   D A T U M S


Tidal datums at PORT CHICAGO, SUISUN BAY based on:

     LENGTH OF SERIES:       19 YEARS
     TIME PERIOD:            January 1983 - December 2001
     TIDAL EPOCH:            1983-2001
     CONTROL TIDE STATION:


Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in
METERS:

     HIGHEST OBSERVED WATER LEVEL (12/03/1983)     =  2.415
     MEAN HIGHER HIGH WATER (MHHW)                 =  1.498
     MEAN HIGH WATER (MHW)                         =  1.343
     MEAN TIDE LEVEL (MTL)                         =  0.785
     MEAN SEA LEVEL (MSL)                          =  0.781
     MEAN LOW WATER (MLW)                          =  0.226
     MEAN LOWER LOW WATER (MLLW)                   =  0.000
     NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)     = -0.335
     LOWEST OBSERVED WATER LEVEL (01/08/1989)      = -0.447
```

Here (in metric units) are the elevations of tidal datums for this station referenced to the MLLW datum (0.000 m). Note that there is an NAVD88 datum. This table relates NAVD88 and the other tidal datums to MLLW datum at this location.

3.2 Using Primary Stations to Determine Datum Relationships

In the example above, the NAVD88 datum of -0.335 m MLLW means that the NAVD88 elevation of 0.00 is 0.335 meters below the MLLW datum at this station. Or, the MLLW datum at this tide station has an NAVD88 elevation of positive 0.335 meters. To convert datums from metric to feet, first apply the metric offset from the tidal datum to NAVD88 (+0.335m), and then convert the metric data to feet.

Conversion of Port Chicago Tidal Datums to NAVD88 Feet.

Datum	MLLW Metric	NAVD88 Metric	NAVD88 Feet
HOWL*	2.415	2.750	9.02
MHHW	1.498	1.833	6.01
MHW	1.343	1.678	5.51
MTL	0.785	1.120	3.67
MSL	0.781	1.116	3.66
MLW	0.226	0.561	1.84
MLLW	0.000	0.335	1.10
NAVD88	-.335	0.000	0.00
LOWL	-.447	-.112	-.37

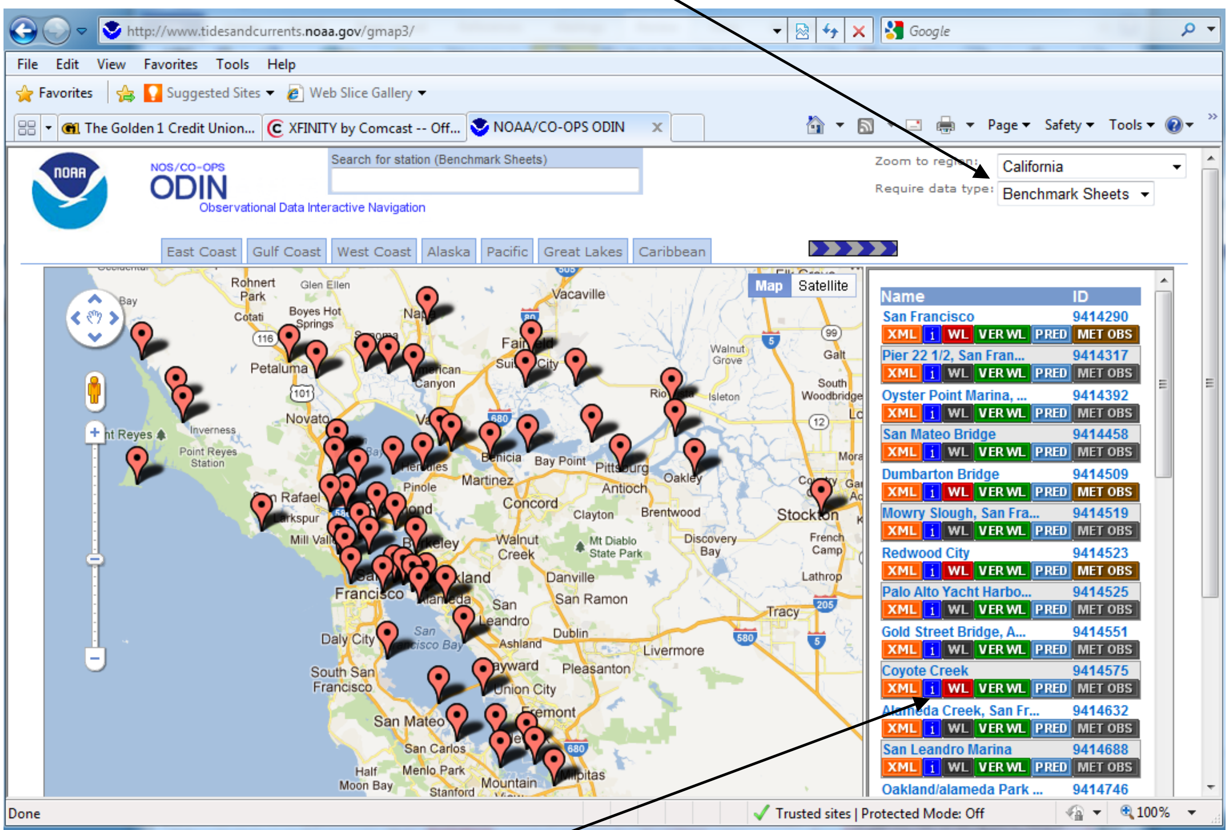
For a project close to a primary station, this conversion would provide the proper tidal datums, referenced to NAVD88, to be given to the planner. "Close to" would be determined by analyzing distance from project location to other tide stations, similarity of coastline shape and bathymetric (seafloor) surface between the project location and the tide station. If NGVD29 elevations are needed, apply VERTCON to the above values. Document all steps—all conversions among datums and/or metric/feet-- and provide to the planner. Their requirements may change but if they already have the other data at hand, Surveys would not need to do it again.

* The *Highway Design Manual Sec.872.3* bases all designs on the Design High Water (DHW) or Design High Tide (DHT). The DHW is the highest expected water level for any body of water: lake, river, or ocean. The Design High Tide is the highest expected water level on tidal influenced bodies. The DHT is defined as "the *Highest Tide* in its relationship to an extreme –tide cycle and to a hypothetical average tide cycle." The HOWL is therefore equal to the DHT at tide stations with HOWL data. The DHT at each project must be included in the report, as it is the elevation used for shore protection calculations. See Appendix 4 for instructions on how to determine the DHT for stations without a published HOWL.

3.2 Using Secondary Stations with Tidal Bench Marks

The relationship between tidal datums and NAVD88 elevations can be directly calculated at any tide station with a tidal bench mark in the NAVD88 adjustment. To find the station nearest to a project, change the data type on the CO-OPS map to Benchmark Sheets.

Set "Require Data Type" to "Benchmark Sheets" to see all Stations with Tidal Bench Marks.



The letters "WL" highlighted in RED indicates currently active stations.

In the upper right corner of the map is the Rio Vista station. This is where S.R. 12 crosses the Sacramento River. Below are excerpts from the Rio Vista Bench Mark Sheet

```
                PRIMARY BENCH MARK STAMPING:  A 904 1957
                        DESIGNATION:          A 904

MONUMENTATION:          Bench Mark disk                           VM#:    11925
AGENCY:                 US Coast and Geodetic Survey (USC&GS)     PID#:  JS1921
SETTING CLASSIFICATION: Concrete foundation


The bench mark is a disk set in the concrete sidewalk on the north side of C.
Wasak Warehouse on the abandoned Rio Vista Army base, 3.90 m (12.8 ft) east of
the east side of the sliding door on the north face of the building, 0.30 (1 ft)
north of the north wall, and set at the ground level.
```

The Bench Mark designation A904 has a PID of JS1921. There is a hyperlink to the NGS Data Sheet.

```
JS1921  TIDAL BM     -  This is a Tidal Bench Mark.
JS1921  DESIGNATION -  A 904
JS1921  PID          -  JS1921
JS1921  STATE/COUNTY-  CA/SOLANO
JS1921  USGS QUAD    -  RIO VISTA (1993)
JS1921
JS1921                         *CURRENT SURVEY CONTROL
JS1921  ___________________________________________________________________
JS1921* NAD 83(1986)-  38 08 42.     (N)     121 41 39.     (W)     SCALED
JS1921* NAVD 88      -         5.37   (+/-2cm)       17.6    (feet)  VERTCON
JS1921  ___________________________________________________________________
JS1921  GEOID HEIGHT-          -32.26  (meters)                      GEOID09
JS1921  VERT ORDER   -  FIRST     CLASS II (See Below)
```

The Data Sheet shows an NAVD88 elevation of 5.37 meters, as determined by applying a VERTCON shift value to the NGVD29 height, which is found further down the data sheet under “Superseded Survey Control.” The accuracy of +/- 2cm for the conversion to NAVD88 is acceptable for initial studies during the PID phase unless there is reason to believe that the bench mark is unstable, e.g., is likely to be in a subsidence area.

Here are the tidal datums at Rio Vista:

```
     LENGTH OF SERIES:       5 MONTHS
     TIME PERIOD:            August 1996 - December 1996
     TIDAL EPOCH:            1983-2001
     CONTROL TIDE STATION:   9415144 PORT CHICAGO, SUISUN BAY


Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

     MEAN HIGHER HIGH WATER                    MHHW   =  1.243
     MEAN HIGH WATER                           MHW    =  1.098
     MEAN SEA LEVEL                            MSL    =  0.649
     MEAN TIDE LEVEL                           MTL    =  0.639
     MEAN LOW WATER                            MLW    =  0.179
     MEAN LOWER LOW WATER                      MLLW   =  0.000

North American Vertical Datum (NAVD88)

Bench Mark Elevation Information               In METERS above:

     Stamping or Designation                   MLLW        MHW

     A 904 1957                                 4.477    3.379
     PRC 149                                    7.789    6.691
     5316 A 1996                                7.867    6.769
     5316 B 1996                                7.301    6.203
```

The bench mark sheet for Rio Vista shows the elevation of A 904 is 4.477 meters above MLLW, and 3.379 meters above MHW.

5.370 - 4.477= 0.893 MLLW

5.370 – 3.379= 1.991 MHW

1.991 – 0.893= 1.098 = Difference between MHW and MLLW on tidal datums chart

Applying those differences to the Rio Vista tidal datums yield the following chart:

Datum	MLLW Metric	NAVD88 Metric	NAVD88 Feet
DHT*	2.027	2.920	9.58
MHHW	1.243	2.136	7.01
MHW	1.098	1.991	6.53
MSL	0.649	1.542	5.06
MTL	0.639	1.532	5.03
MLW	0.179	1.072	3.52
MLLW	0.000	0.893	2.93

*DHT based on data from May 1978- March 1997. See Appendix A-4

3.3 Relating Datums Using VDatum Model

Determining tidal datum information using tide stations should only be used relatively near the tide station. The farther the project is from the tide station, the greater the need to interpolate the data. NOAA CO-OPS has developed a computer program called VDatum that can perform the necessary interpolations.

VDatum isn't as accurate as the use of tide stations with tidal bench marks, but VDatum is preferred over the use of tide stations without bench marks. This method is also a good way to independently check the information at a specific tide station. For example, the VDatum software calculates a NAVD88 elevation of 1.0 ft MLLW at the Latitude/ Longitude of the Port Chicago Tide Station. This verifies that the 1.10 ft elevation calculated from the tide station information is acceptable.

VDatum has the ability to interpolate between tide stations and both NGVD29 and NAVD88 elevations. It uses the VERTCON program developed by NGS to convert between NGVD29 and NAVD88. There are documented limitations in the VERTCON program, and the accuracy varies by location. Before using the VDatum program, the user should read the "Estimation of Vertical Uncertainties in VDatum" published on the NOAA website[10] and take those limitations into consideration when relating datums. Before downloading the VDatum software, the user must indicate that they have read and understood this important document.

3.4 Instructions for Determining Sea Level using VDatum

1. The VDatum program is available for downloading at http://vdatum.noaa.gov/download.html. The file consists of the actual program, and separate transformation grid datasets. The datasets are large, and thus it will be more efficient to download the regional set for just your area. . California is covered by 4 regional datasets.

2. Determine the latitude and longitude of the proposed project. For larger projects, the Lat/Long at each location where the information is needed. Google Earth™ or other mapping software has adequate accuracy for this information.

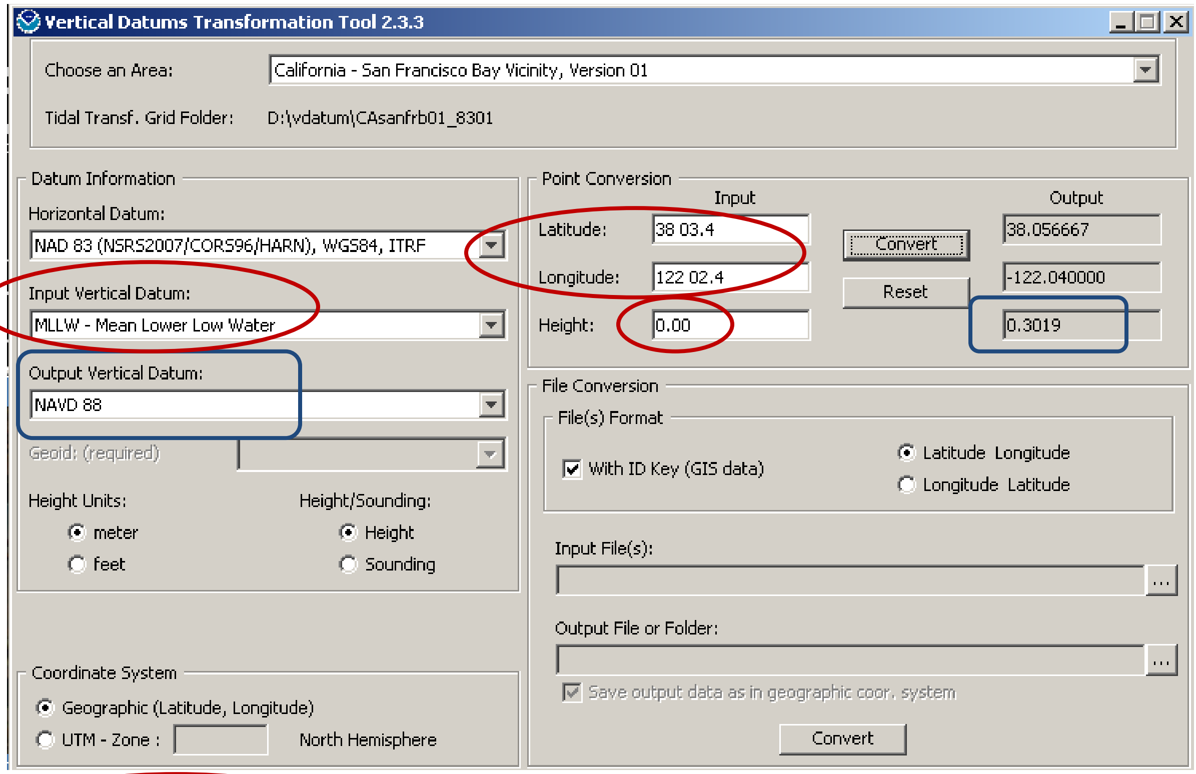
3. Open the VDatum software. For the top field in VDatum, select one of the 4 regional coverage areas associated with California that is relevant to your project. On the left side, check that the default horizontal datum (NAD83), is appropriate or change accordingly. Still on the left side, choose the vertical datum MLLW from the pick list, and in the next line, select an output vertical datum, i.e., the project datum (e.g., NAVD88). Decide whether you want the output in meters, which is the default, or in feet, which you would have to select. Ensure that the "Height" dot is selected, and not "Sounding" or your conversion answers will be in the wrong 'direction'.

4. On the right hand side, in the location fields, type or insert the geodetic coordinates. Input an elevation of 0.00, and then click the "Convert" button on the right side. This returns the MLLW elevation referenced to the NAVD88 datum. Repeat for MLW, MSL, MHW, and MHHW, always using 0.00 as the input elevation. The results will be the NAVD88 elevations for each tidal datum.

5. On the CO-OPS site, determine the nearest tidal bench mark station, and click on the station home page. Relate the LOWL and HOWL elevations for the station to the MSL elevation from step 3 to calculate the Design High Tide referenced to NAVD88 . See Appendix 4 on determining DHT.

6. (Optional) Go back to VDatum and input an NGVD 29 elevation of 0.00, with a conversion to NAVD88. The elevation difference will be the correction factor between the NGVD29 elevations (Sometimes referred to as MSL on older project plans) and NAVD88 elevations. It is possible that MSL on older documents really means MSL from the nearest tide station (perhaps at a previous tidal epoch). This is not the recommended method. Direct measurements using the latest vertical control is preferred, but not required, during the PID phase.

Here is an example of using VDatum to convert from MLLW at the Port Chicago Tide Station to NAVD88 elevations.



Input Datum and Elevation

Output Datum and Elevation

See Appendix A-5 for a step-by-step example of determining tidal datums using VDatum.

3.5 Calculating Tidal Datums in Areas with Poor Control

VDATUM will not return results when there is insufficient data to produce results that meet the error bounds associated with the modeling. The data gap could relate to tidal datums, geodetic elevations, or bathymetric and topographic data. If the VDATUM software will not convert at a given location, the following notation will appear: “Invalid input: Input/Output file names are empty”. Or you may see a -99999 (many nines) in the ‘Output’ field.

The Sacramento-San Joaquin Delta is one notable area that does have tidally influenced water levels but where VDATUM does not work. There are several alternatives which could be employed that utilize non-primary station data. Datums can be interpolated between two acceptable tidal stations, or extrapolated inland for a short distance from a single station. This should only be performed during the project initiation phase of a project, and used for risk assessment only. Further elevation studies would be needed as part of the final design process.

Although tidal datums can be extrapolated upstream past existing tide stations, Surveys is only tasked with determining tidal datums. 100-year or 200-year flood predictions aren't a part of the tidal datum study. Where river flood elevations are needed, the project engineer is responsible for any studies. At this time, we don't have any methodology for predicting the effect of sea level rise on river floods.

3.5.1 Interpolating Data

Where the project site is located between two tidal stations with benchmarks, the tidal datums may be interpolated between them. There are a few locations along the coast where VDatum doesn't function. In those areas, the surveyor should interpolate between tidal stations. Here are tidal datums, referenced to the coastal primary stations, in NAVD88 metric:

Station	MLLW(M)	MHHW(M)	HOWL(M)	MLLW(Ft)	MHHW(Ft)	HOWL(Ft)
San Diego	-0.132	1.613	2.349	-0.43	5.29	7.71
La Jolla	-0.058	1.566	2.277	-0.19	5.14	7.47
L.A. Out Harbor	-0.062	1.612	2.352	-0.20	5.29	7.72
Port San Luis	-0.024	1.599	2.307	-0.08	5.25	7.57
Monterey	0.043	1.669	2.444	0.14	5.48	8.02
San Francisco	0.018	1.798	2.658	0.06	5.90	8.72
Point Reyes	-0.008	1.750	2.596	-0.03	5.74	8.52
N. Spit, Humb	-0.103	1.987	2.910	-0.34	6.52	9.55
Crescent City	-0.116	1.979	3.084	-0.38	6.49	10.12
Mean	-0.049	1.730	2.553	-0.16	5.68	8.38

For most of the coast, the tidal datums are very stable. Secondary stations with tidal benchmarks located between primary stations can be used to improve data resolution.

3.5.2 Extrapolating Inland Areas

There are finite limits to any tidal study. Even in areas that may be under some tidal influence, if there is no information, there can be no tidal assessment. On the CO-OPS Google search map, all tidal stations (primary, secondary, and tertiary) will be displayed if the "Required Data Type" is set to "Tide Predictions". Some of the stations shown may indicate "Tide Predictions are not available for this station". Predicting tidal datums near these stations requires some judgment on the part of the surveyor. As a general rule, don't extrapolate very far beyond secondary stations. Tertiary stations (less than one year of data) may not have enough data to be used for sea level rise studies, but may indicate the limits of tidal studies performed by NOAA.

4. Sea Level Rise

Per the Executive Order and the *Guidance* documents, Caltrans must not only determine the tidal datums for projects along tidal waters, but must also perform a risk assessment of project vulnerability due to sea level rise. A final table of tidal datums, with sea level rise projections and adjusted for local geotechnical conditions, shall be prepared for each project. A preliminary assessment of local land subsidence or uplift, as determined in the preliminary Geotechnical Design Report, may be included as part of the risk analysis when available.

The sea level rise projections are based on "Global sea level linked to global temperature", *Proceedings of the National Academy of Sciences,* Martin Vermeer and Stefan Rahmstorf, published December 7, 2009. The *Proceedings* paper is based on a compilation of sea level rise papers from around the world. The State is contracting for a state-specific study, combining sea level and geotechnical data, which will apply to specific regions in the state. The new figures will be used when the study is adopted.

The *Proceedings* projections have been adopted for statewide use, but each agency may decide on a particular model, Low, Medium, or High. The Caltrans *Guidance* recommends using the medium model, but a consensus must be reached among all of the project partners as part of the initial planning.

Sea-Level Rise Projections using 2000 as a Baseline

Year		Average of Models	Range of Models
2030		7 in (18 cm)	5-8 in (9-17 cm)
2050		14 in (36 cm)	10-17 in (26-43 cm)
2070	**Low**	23 in (59 cm)	17-27 in (43-70 cm)
	Medium	24 in (62 cm)	18-29 in (46-74 cm)
	High	27 in (69 cm)	20-32 in (51-81 cm)
2100	**Low**	40 in (97 cm)	31-50 in (78-128 cm)
	Medium	47 in (121 cm)	37-60 in (95-152 cm)
	High	55 in (140 cm)	43-69 in (110-176 cm)

Executive Order S-13-08 requires a risk assessment for the years 2050 and 2100. The Caltrans *Guidance* document recommends using an assumption of linear progression for dates between those listed in the Table (e.g. 2037 or 2080).

California rivers can be influenced by tides for miles inland. There will be a transition area upstream where water levels are controlled by river flow rather than tidal influence. The location of these transition areas may significantly change, depending on the profile of the river and its relationship to low and high tide conditions.

4.1 Example of Sea Level Rise Projections

Port Chicago Tide Station – Average/ Medium Models

PORT CHICAGO – Data based on 1983-2001 Tidal Epoch

Datums	Tide Datums Metric Existing	NAVD88 Metric Existing	NAVD88 Feet Existing	NAVD88 Feet 2050	NAVD88 Feet 2100
HOWL/DHT	2.415	2.750	9.02	10.19	12.94
MHHW	1.498	1.833	6.01	7.18	9.93
MHW	1.343	1.678	5.51	6.68	9.43
MTL	0.785	1.120	3.67	4.84	7.59
MSL	0.781	1.116	3.66	4.83	7.58
MLW	0.226	0.561	1.84	3.01	5.76
MLLW	0.000	0.335	1.10	2.27	5.02
NAVD88	-.335	0.000	0.00	0.00	0.00
LOWL	-.447	-.112	-.37	0.80	3.55

If additional time frames are requested, they can be inserted into the chart. For example, a structure with a 75-year lifespan, to be completed in the year 2015, may need a projected set of datums for the year 2090. Use a linear interpolation between the years 2070 and 2100 in the Sea Level Rise protection table to report a sea level projection for the year 2090.

4.2 Graphic Display of Data

Step 3 of the *Guidance on Incorporating Sea Level Rise – For use in the planning of development of Project Initiation Documents* calls for generating a plot of the data calculated in the chart above. The most precise method is to use a photogrammetric or digital terrain model of the project site. The projected SLR can then be displayed as a contour line. The NOAA digital elevation map of the coastline developed from LIDAR data was published in February 2012. That mapping may be used for large scale mapping to predict where a SLR risk assessment will be needed. NOAA also plans to produce SLR animations utilizing that data by the end of 2012.

The coastal Lidar Data is available on the NOAA Digital Coast website at

http://www.csc.noaa.gov/digitalcoast/data/coastallidar/index.html

The coastal data is from multiple surveys performed from 1997 to present. Different surveys are available in different formats. Formats include ASCII XYZ, DEMS, GeoTIFF, DXF, and various shapefiles. The shapefiles and raster data (GeoTIFF and JPEG) can be imported into most standard GIS software. The DXF files are native to Civil 3D software, and can be imported into Microstation. The ASCII information can be imported into CAiCE and Civil 3D to create digital terrain models (DTM’s).

4.2.1 Inundation Mapping Accuracy

It is critical that all people creating and using the SLR mapping understand the accuracy, or lack thereof, of all the data sources.

The following illustration is Fig 2.16 from the NOAA NOS Technical Report "*Technical Considerations for Use of Geospatial Data in Sea Level Change Mapping and Assessment*".[11]

Elevation Data Source	Vertical accuracy: RMSE	Vertical accuracy: linear error at 95-percent confidence	Minimum sea-level rise increment for inundation modeling
1-foot contour interval map	9.3 cm	18.2 cm	36.4 cm
Lidar	15.0 cm	29.4 cm	58.8 cm
2-foot contour interval map	18.5 cm	36.3 cm	72.6 cm
1-meter contour interval map	30.4 cm	59.6 cm	1.19 m
5-foot contour interval map	46.3 cm	90.7 cm	1.82 m
10-foot contour interval map	92.7 cm	1.82 m	3.64 m
20-foot contour interval map	1.85 m	3.63 m	7.26 m

Sea level rise can only be accurately modeled if the accuracy of the mapping will support the sea level rise increment for the inundation modeling.

Considering that a one foot contour map has a Root Mean Square Error (RMSE) of 9.3 cm (0.3 ft), the 95% confidence level would be 18.2 cm (0.6 ft). The minimum sea level rise that can be confidently mapped is twice (1.96 x) that of the 95% confidence interval. So the minimum increment that can accurately be shown is 36.4 cm (1.19 ft) for a one foot contour map.

Since the Sea Level Rise Projection Table shows a projected rise of 36 cm in 2050, which would be the minimum rise that could be shown on a 1-foot contour map. Mapping at any larger scale is not accurate enough to show the inundation modeling for 2050.

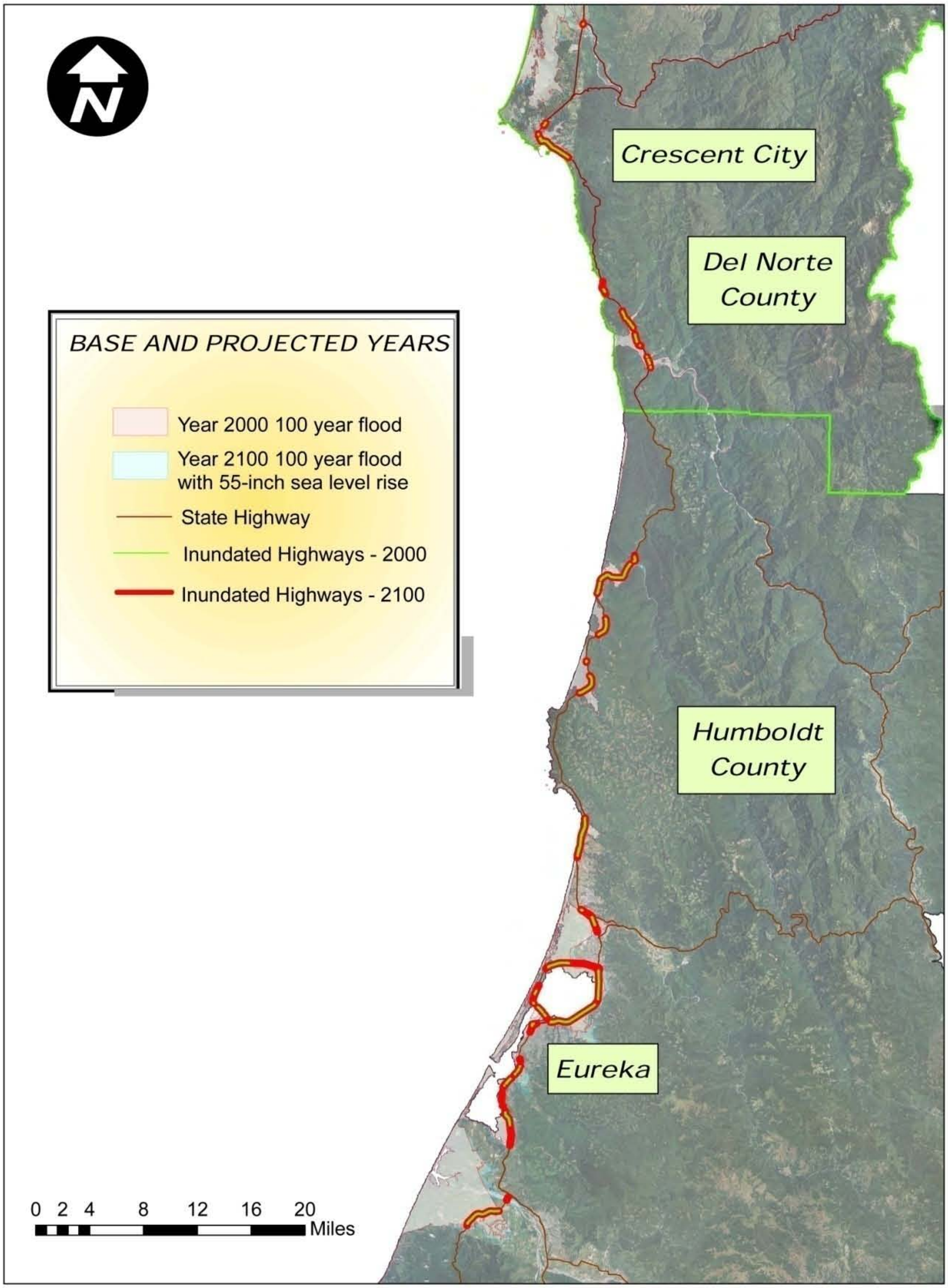
If accurate base mapping isn't available, new mapping must be completed before preparing inundation maps. An explanation of the relative accuracies should be provided to the user of inundation maps. The rough estimate is that the contour interval has to be equal or less than the sea level rise increment.

4.2.2 Inundation Mapping Examples

One method of inundation mapping is to use an area chart, showing areas of concern. The second method is to provide detail sheet for a proposed project where photogrammetric or digital terrain modeling is available.

For the first example (next page), this map shows an inundation of 1.4 m (55 in). The base mapping used for this information would have to be a 1 meter contour or less to display this accuracy at the 95% confidence level.

The second example uses the detail sheet method to map the areas of inundation using a 0.5 meter contour interval. That is approximately the same accuracy as the LIDAR mapping (15.0 cm RMSE). The map shows inundation for the year 2050 (36 cm). Since the mapping standards don't support the SLR increment shown in this example, this map would have to be redone to a larger scale to achieve a 95% confidence level, before it is delivered to the planner or engineer.

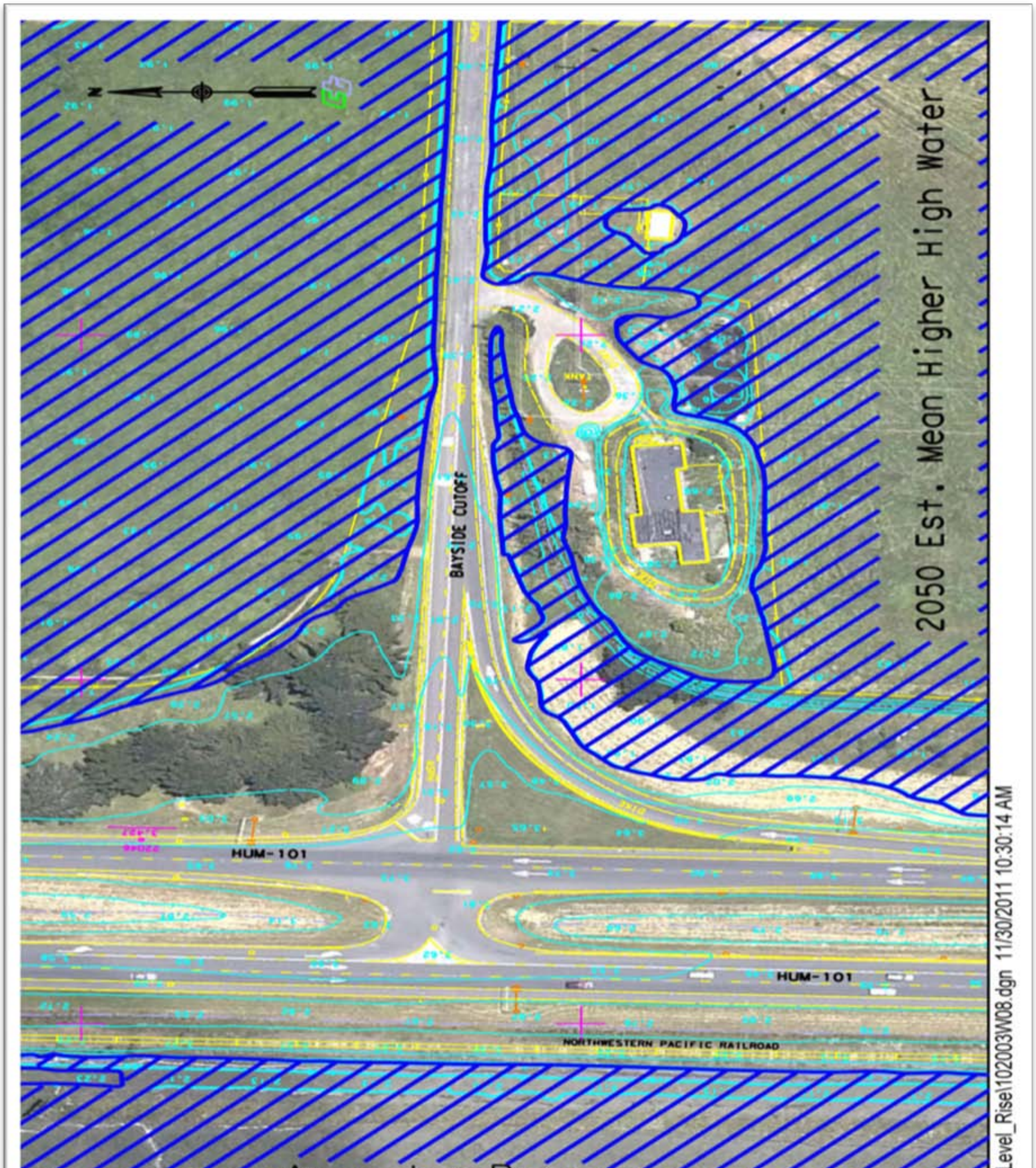


Northern Humboldt and Del Norte Counties
State Highway Inundation, 100-year flood,2000, and
100-year flood with a 1.4 meter sea-level rise, 2100

DATA SOURCE - PACIFIC INSTITUTE

PACIFIC INSTITUTE

dsc 11/08/2010


2050 Est. Mean Higher High Water
BAYSIDE CUTOFF
HUM-101
HUM-101
NORTHWESTERN PACIFIC RAILROAD
Arcata Bay
...\Sea_Level_Rise\1020003W08.dgn 11/30/2011 10:30:14 AM

4.3 Creating a Preliminary Assessment Report

A complete initial report delivered to the planners, project managers, and engineers must be complete enough that it can be used without any additional research or rework. As a minimum, the basic information in this report should include:

1. Project ID
2. Co-RTE- PM
3. Project Name (if known)
4. Project Horizontal Datum – including epoch
5. Vertical Datum
6. Datum of existing As-Builts (if needed)
7. Controlling (Nearest) Primary Tide Station
8. Nearest Secondary Tide Station (if needed)
9. Datums related using:
    a. Tidal Bench marks (provide NGS Bench mark information), or
10. VDatum (provide Latitude/ Longitude used for conversion)
11. Chart showing existing tidal datums converted to project datum (NAVD88)
12. Does the project require a Sea Level Rise Assessment?
    a. Does the project adjoin the coast or tidal estuary?
    b. Are the project elevations low enough to be impacted by SLR?
    c. Is the design life of the project beyond the year 2030?
13. If a SLR assessment is required, provide a chart of predicted SLR elevations as requested (low, medium, or high)
    a. The chart will not be adjusted for geologic movement unless requested, and the adjustment data provided by requestor
14. Graphic illustrations of SLR impacts will only be provided when requested, and when the unit performing the assessment has all of the required resources.

4.4 Sample Tidal and Sea Level Rise (SLR) Assessment

Continuing with the example two detail sheets mapping above, the following tidal and sea level rise assessment report was prepared:

Project ID: 0100000127

Project Name: Eureka-Arcata Route 101 Corridor Improvement Project

Co/RTE/PM: Hum/101/79.9-86.3

1. Is the project located on the coast or a tidal estuary? ☒ Yes ☐ NO
   If NO, no further action required

2. Will the project be impacted by the stated SLR? ☒ Yes ☐ NO
   If NO, No further action required
3. Is the design life of the project beyond year 2030? ☒ Yes ☐ NO
   If NO, No further action required
   If YES, Complete Sea Level Rise Projections

Project Horizontal Datum: ☒ NAD 83, Epoch 2007.00, ☐ Other ____________
Project Vertical Datum: ☒ NAVD88, ☐ NGVD29, ☐ Other ____________
Current As-built Vertical Datum: ☐ NAVD88, ☒ NGVD29, ☐ Other ____________

Nearest Primary Tidal Station - (Number): Humboldt Bay- North Spit (9418767)

Table 1 Exist. Epoch 1983-2001	Primary Tide Station Datums			
Datums	**ABBR.**	**Tidal Metric**	**NAVD88 Metric**	**NAVD88 FEET**
Highest Observed Water Level	HOWL	2.693	2.590	8.50
Mean Higher High Water	MHHW	2.090	1.987	6.52
Mean High Water	MHW	1.874	1.771	5.81
Mean Sea Level	MSL	1.129	1.026	3.37
Mean Low Water	MLW	0.384	0.281	0.92
North American Vertical Datum	NAVD88	0.103	0.000	0.00
Mean Lower Low Water	MLLW	0.000	-0.103	-0.34
Lowest Observed Water Level	LOWL	-0.883	-0.986	-3.23

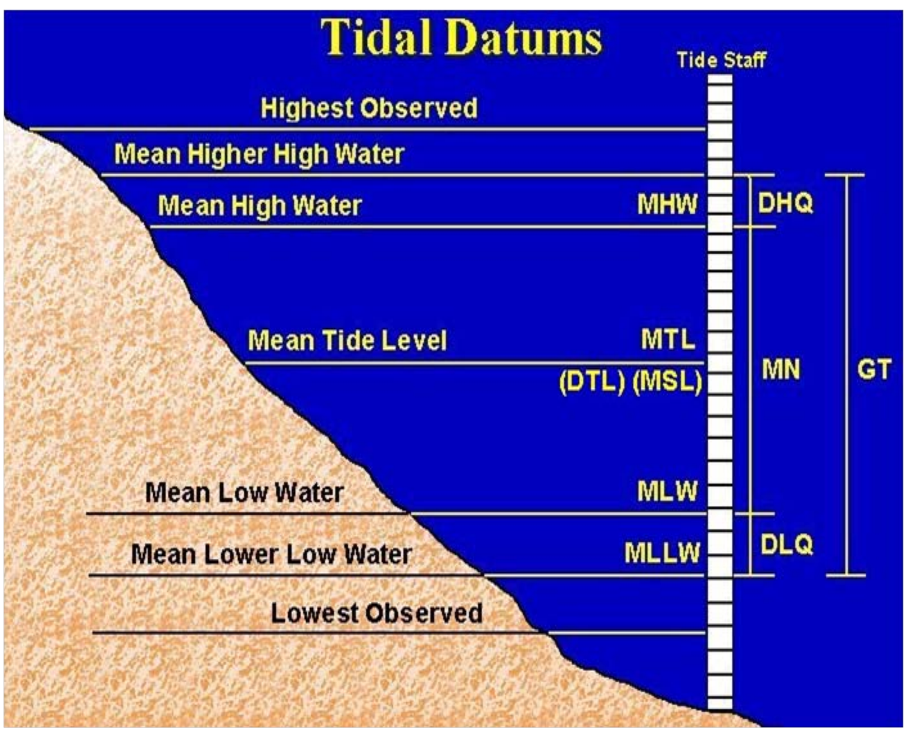
PAGE 1

Project ID: 0100000127

Datum Conversion based on: ☐ Tidal Bench mark ☒ VDATUM
Project Latitude: 40° 50’ N., Longitude: 124° 05’ W.

Table 2			
Project Datums Relative to Primary Station			
Datums (FEET)	**Primary Station Tidal**	**Primary Station NAVD88**	**Project Location NAVD88**
DHT			9.08
HOWL	8.84	8.50	
MHHW	6.86	6.52	6.61
MHW	6.15	5.81	5.89
MSL	3.70	3.37	3.21
MLW	1.26	0.92	0.37
NAVD88	0.34	0.00	0.00
MLLW	0.00	-0.34	-0.97
LOWL	-2.90	-3.23	

To convert as-built elevations (NAVD29) to Project Datum (NAVD88): Add 3.34 feet to As-built elevations.



Projected Sea Level Rise Table

Year		Average of Models	Range of Models
2030		7 in (18 cm)	5-8 in (9-17 cm)
2050		14 in (36 cm)	10-17 in (26-43 cm)
2070	**Low**	23 in (59 cm)	17-27 in (43-70 cm)
	Medium	24 in (62 cm)	18-29 in (46-74 cm)
	High	27 in (69 cm)	20-32 in (51-81 cm)
2100	**Low**	40 in (97 cm)	31-50 in (78-128 cm)
	Medium	47 in (121 cm)	37-60 in (95-152 cm)
	High	55 in (140 cm)	43-69 in (110-176 cm)

Sea level rise projections based on Average/ Medium models.

Model doesn't include geologic movements.

Projected SLR at Project - NAVD88 Feet					
DATUM	**Current**	**2030**	**2050**	**2070**	**2100**
SLR	**+0.0**	**0.58**	**1.17**	**2.00**	**3.92**
DHT	9.08	9.66	10.25	11.08	13.00
MHHW	6.61	7.19	7.78	8.61	10.53
MHW	5.89	6.47	7.06	7.89	9.81
MSL	3.21	3.79	4.38	5.21	7.13
MLW	0.37	0.95	1.54	2.37	4.29
MLLW	-0.97	-0.39	0.20	1.03	2.95
LOWL	-3.87	-3.29	-2.70	-1.87	0.05

DHT based on HOWL and LOWL at the Humboldt Bay- North Spit tidal station.
DHT= (HOWL-LOWL) / 2 + MSL
Current Highest Observed Water Level is 8.84 feet above MLLW at Primary Tide Station.
Current Lowest Observed Water Level is 2.90 feet below MLLW at Primary Tide Station.

See Attached Maps for projected inundation*

**See Maps used in example 4.2.2, above*

Appendices

Tables, Graphs, and Definitions Courtesy of the National Oceanic and Atmospheric Central Library Photo Collection.

A-1 Geodetic Datums

Caltrans uses two primary geodetic datums for vertical control on its projects, NGVD29 and NGVD88. Most state highways were built using the National Geodetic Vertical Datum of 1929 (NGVD29). NGVD29 was officially replaced in 1991 by the North American Vertical Datum of 1988 (NAVD88) as the national standard geodetic reference for heights. NGVD29 and NAVD88 are fixed geodetic datums whose elevation relationships to local MSL and other tidal datums determined at tide stations differ from one location to another.

A-1.1 NGVD29 Datum

This is a fixed datum adopted as a national standard geodetic reference for heights but is now superseded. NGVD29 is sometimes referred to as Sea Level Datum of 1929 or simply as Mean Sea Level on some earlier mapping. NGVD29 was based on first order leveling surveys between the 26 tidal stations in North America. MSL at each tidal station was fixed, and all leveling surveys adjusted to fit the master stations. In California, crustal motion and other geologic issues eventually degraded the network to the point that where many bench marks became untrustworthy.

A-1.2 NAVD88 Datum

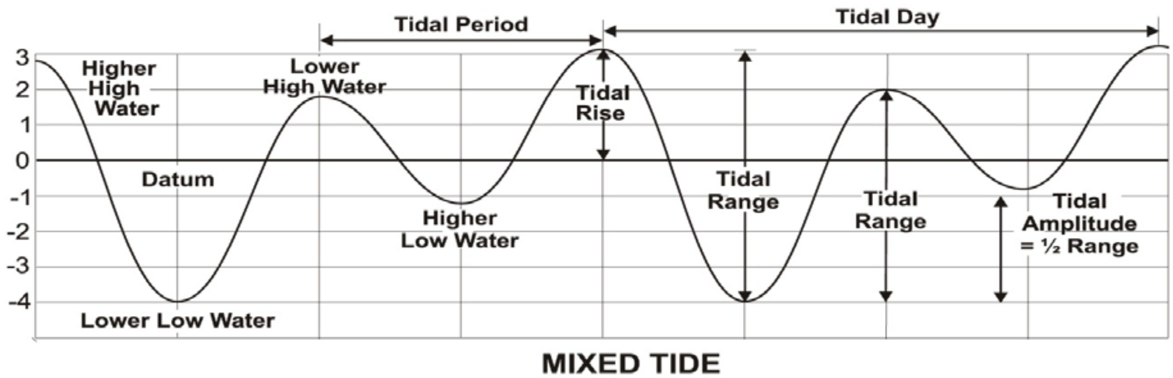
NAVD88 is a fixed datum derived from a simultaneous, least squares, minimum constrained adjustment of Canadian/Mexican/United States leveling observations. Local mean sea level observed at Father Point/Rimouski, Canada was held fixed as the single initial constraint. Bench mark elevations relative to NAVD88 are available on the National Geodetic Survey[12] (NGS) website. The NGS is an office within the National Ocean Survey (NOS), which is within the National Oceanic and Atmospheric Administration (NOAA), and maintains the National Spatial Reference System, of which NAVD88 is a part.

A-2 Tidal Datums

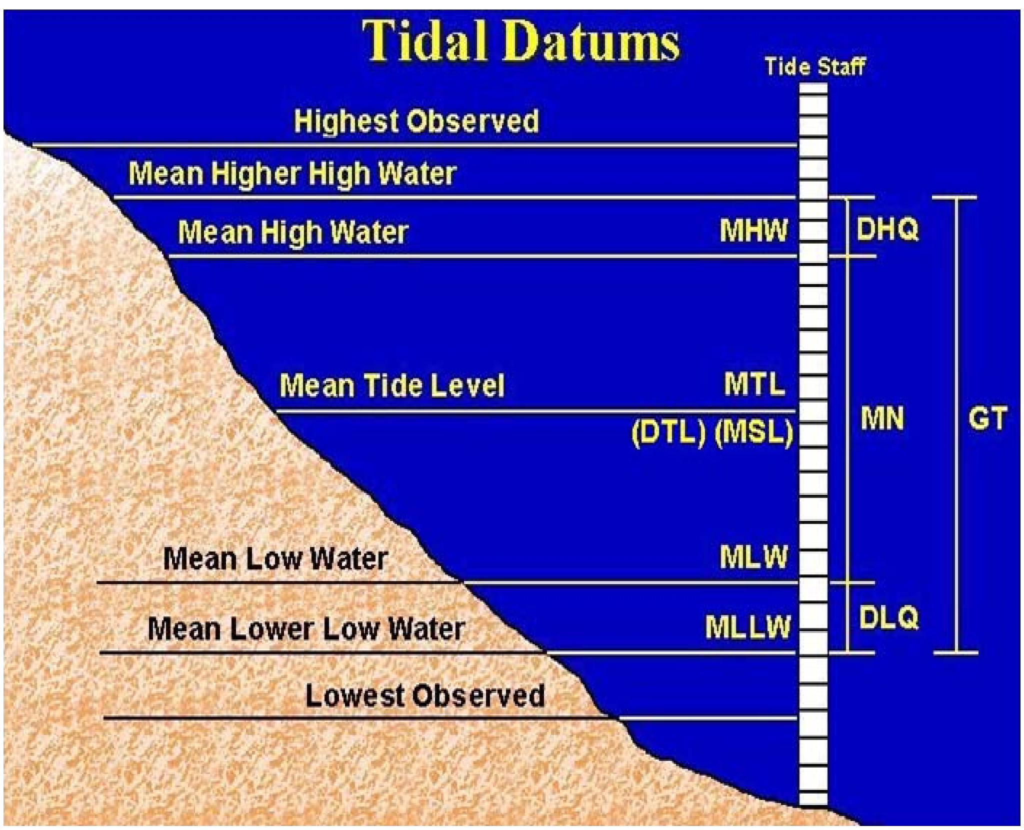
The NOS is tasked with determining tidal datums for the United States and territories. This work is performed by the Center for Operational Oceanographic Products and Services (CO-OPS)[13]. CO-OPS operates and maintains the system of tidal stations for the United States.

A-2.1 Tide Graphs

There are two high tides and two low tides each day on the west coast. This is called a “mixed semi-diurnal tide” because each high and low tide differs in its height.



The more extreme tides are called the Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW)[14].



A-2.2 Definitions

Before making any tidal assessment, the surveyor must understand common terminology and definitions used to collect and report tide data.

Mean Lower Low Water (MLLW) = Average of the lowest of the two low tides each day. *This is the elevation of 0.00 at each tide station datasheet. It is also the datum used in nautical charts for depth soundings. A chart depth of 12 feet is 12 feet below MLLW.*

Mean Low Water (MLW) = Average of all low tides. *In the state of California, this is the lower limit of state-owned tidelands.*

Mean Sea Level (MSL) = The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. *The latest 19-year epoch for California is 1983-2001.*

Mean Tide Level (MTL) = The arithmetic mean of mean high water and mean low water. *The MTL value is usually very close (± 0.1 ft) to Mean Sea Level.*

Mean High Water (MHW) = Average of all high tides. This is the datum used in nautical charts to compute bridge clearances. *In California, this is the upper limit of state-owned tidelands.*

Mean Higher High Water (MHHW) = Average of the higher daily high tides.

Highest Observed Water Level (HOWL) = Also called the extreme high water. The highest elevation reached by the sea as recorded by a tide station during a during the latest tidal datum epoch*, i.e., the highest recorded level of inundation. The high tide line for design purposes per the Highway Design Manual 872.3.*

Lowest Observed Water Level (LOWL) = The lowest water level recorded at a tide station during a during the latest tidal datum epoch. *The Lowest and Highest Observed Water Levels aren't actually datums, but single observations representing the greatest range within the latest epoch. The difference between HOWL and LOWL is the maximum tidal range (Rm) per HDM 872.3.*

North American Vertical Datum of 1988 (NAVD88) = *This is the elevation of NAVD88 relative to the tidal station. This information is only provided at tidal stations that have associated tidal bench marks directly tied to the station. The tidal bench marks are jointly maintained by CO-OPS and the National Geodetic Survey.*

A-3 Bench Mark Sheet Examples

9415144 Port Chicago Primary Tidal Station Bench Mark Sheet

9415316 Rio Vista Secondary Tidal Station Bench Mark Sheet

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Ocean Service

Station ID:	9415144	PUBLICATION DATE:	11/23/2010
Name:	PORT CHICAGO, SUISUN BAY CALIFORNIA		
NOAA Chart:	18656	Latitude:	38° 3.4' N
USGS Quad:	VINE HILL	Longitude:	122° 2.4' W

To reach the tidal bench marks, take Highway 4 east to Port Chicago Highway, Naval Weapons Station exit, proceed north 2 km (1 mi) to the Naval Weapons Center gate on the right, obtain a pass to the tide gauge area, get back on the main road towards the railroad crossing and fork left through guarded gate, follow the railroad tracks on base for 3 km (2 mi) to just past a bridge and bear left at a fork onto Johnson Road, then follow Johnson Road 2 km (1 mi) to the water. The bench marks are in the vicinity on the Naval Weapons Center property. The tide gauge is on the SE end of the Tug Pier.

T I D A L   B E N C H   M A R K S

PRIMARY BENCH MARK STAMPING: 5144 H 1976
DESIGNATION: 941 5144 H

MONUMENTATION:	Tidal Station disk	VM#:	994
AGENCY:	National Ocean Survey (NOS)	PID#:	AH7472
SETTING CLASSIFICATION:	Stainless steel rod		

The primary bench mark is a disk set on a rod located at the SE corner of Johnson Road and White Road, about 96.9 m (317.9 ft) SE of the inshore end of Port Chicago barge pier where the tide station is located, 49.68 m (163.0 ft) east of the centerline of Johnson Road, 30.18 m (99.0 ft) west of the westerly corner of Building A16, 30.18 m (99.0 ft) south of the centerline of White Road, 26.82 m (88.0 ft) NE of the NE corner of Building A14, 14.63 m (48.0 ft) NE of the most easterly railroad track, and 1.37 m (4.5 ft) south of a 4-inch square witness post. The bench mark is set 3 cm (0.1 ft) above ground level, crimped to a stainless steel rod driven 9.80 m (32.2 ft) to refusal, and encased in a 4-inch PVC pipe.

Station ID:	9415144	PUBLICATION DATE:	11/23/2010
Name:	PORT CHICAGO, SUISUN BAY CALIFORNIA		
NOAA Chart:	18656	Latitude:	38° 3.4' N
USGS Quad:	VINE HILL	Longitude:	122° 2.4' W

T I D A L   B E N C H   M A R K S

BENCH MARK STAMPING: HARLEY 1954
DESIGNATION: HARLEY 1954
ALIAS: HARLEY 1982

MONUMENTATION:	Triangulation Station disk	VM#:	996
AGENCY:	US Coast and Geodetic Survey (USC&GS)	PID#:	JT2039
SETTING CLASSIFICATION:	Concrete sidewalk		

The bench mark is a disk set flush in the concrete sidewalk on the west side of the Taylor Boulevard Bridge over the Southern Pacific Railroad, located at the crest of the bridge across from the painted number "34" which is on the east guard rail, 171.3 m (562.0 ft) south of Bench Mark CT 26, 4.30 m (14.1 ft) west of the centerline of Taylor Boulevard, 0.53 m (1.7 ft) east of the west guard rail, 0.06 m (0.2 ft) west of the curb edge, and 0.3 m (1 ft) above road level in center of white painted cross.

BENCH MARK STAMPING: 5144 F 1976
DESIGNATION: 941 5144 F

MONUMENTATION:	Tidal Station disk	VM#:	997
AGENCY:	National Ocean Survey (NOS)	PID:	
SETTING CLASSIFICATION:	Concrete foundation		

The bench mark is a disk set flush and horizontally in a 0.76 m (2.5 ft) square concrete base, located 35.05 m (115.0 ft) WNW of the center of the intersection of Johnson and Wilson Roads, 13.72 m (45.0 ft) SSW of the northern pole supporting three transformers, 13.26 m (43.5 ft) NW of the north face of Building A3, 8.84 m (29.0 ft) north of the centerline of Wilson Road, 3.78 m (12.4 ft) NE of the railroad track switch, 3.35 m (11.0 ft) north of northern rail of a single railroad track, 0.09 m (0.3 ft) west of the NE corner of the concrete base, and 0.12 m (0.4 ft) above ground.

Station ID:	9415144	PUBLICATION DATE:	11/23/2010
Name:	PORT CHICAGO, SUISUN BAY CALIFORNIA		
NOAA Chart:	18656	Latitude:	38° 3.4' N
USGS Quad:	VINE HILL	Longitude:	122° 2.4' W

T I D A L   B E N C H   M A R K S

BENCH MARK STAMPING: 5144 G 1976
DESIGNATION: 941 5144 G

MONUMENTATION:	Tidal Station disk	VM#:	998
AGENCY:	National Ocean Survey (NOS)	PID:	
SETTING CLASSIFICATION:	Concrete loading dock		

The bench mark is a disk set flush in the extreme SE corner of a concrete loading dock on the south side of Transfer Building A177, 82.30 m (270.0 ft) west of the center of the intersection of Johnson and Pickett Roads, 17.37 m (57.0 ft) north of the centerline of Pickett Road, 6.34 m (20.8 ft) SE of the SE corner of building, and 1.83 m (6.0 ft) north of the northern-most rail of the three railroad tracks that run parallel to the south side of the building.

BENCH MARK STAMPING: 5144 J 1976
DESIGNATION: 941 5144 J

MONUMENTATION:	Tidal Station disk	VM#:	999
AGENCY:	National Ocean Survey (NOS)	PID#:	AE7867
SETTING CLASSIFICATION:	Stainless steel rod		

The bench mark is a disk located 0.5 km (0.3 mi) SE along Johnson Road from the barge pier, 32.61 m (107.0 ft) NW of fire hydrant #216, 20.42 m (67.0 ft) SW of the most westerly track, 17.68 m (58.0 ft) SE of utility pole #1181, 11.58 m (38.0 ft) SW of the centerline of Johnson Road, and 0.90 m (3.0 ft) SE of a witness post. The bench mark is set 6 cm (0.2 ft) above ground level, crimped to a stainless steel rod driven 9.80 m (32.2 ft) to refusal, and encased in a 4-inch PVC pipe.

Station ID: 9415144 PUBLICATION DATE: 11/23/2010
Name: PORT CHICAGO, SUISUN BAY
CALIFORNIA
NOAA Chart: 18656 Latitude: 38° 3.4' N
USGS Quad: VINE HILL Longitude: 122° 2.4' W

T I D A L B E N C H M A R K S

BENCH MARK STAMPING: 5144 K 1976
DESIGNATION: 941 5144 K

MONUMENTATION:	Tidal Station disk	VM#:	1000
AGENCY:	National Ocean Survey (NOS)	PID:	
SETTING CLASSIFICATION:	Stainless steel rod		

The bench mark is a disk located 0.8 km (0.5 mi) SE along Johnson Road from the barge pier, 23.47 m (77.0 ft) NW of most westerly track at centerline of where track crosses Johnson Road, 10.21 m (33.5 ft) SW of the centerline of Johnson Road, 7.77 m (25.5 ft) north of a street-light utility pole #1142, 3.99 m (13.1 ft) west of railroad crossing sign, and 1.0 m (3.3 ft) SE of a witness post. The bench mark is set 3 cm (0.1 ft) above ground level, crimped to a stainless steel rod driven 18.29 m (60.0 ft) to refusal, and encased in a 4-inch PVC pipe.

BENCH MARK STAMPING: 5144 M 1982
DESIGNATION: 941 5144 M

MONUMENTATION:	Tidal Station disk	VM#:	1001
AGENCY:	National Ocean Survey (NOS)	PID:	
SETTING CLASSIFICATION:	Concrete loading dock		

The bench mark is a disk set flush in the top of the SE corner of a loading dock on the east side of Building A31, 28.04 m (92.0 ft) SW of the centerline of Johnson Road between Bench Marks 5144 J 1976 and 5144 K 1976, 3.29 m (10.8 ft) SW of the NE edge of the loading dock, 1.28 m (4.2 ft) NW of the SE edge of the loading dock, 0.40 m (1.3 ft) NE of the building, and 1.13 m (3.7 ft) above ground level.

Station ID:	9415144	PUBLICATION DATE:	11/23/2010
Name:	PORT CHICAGO, SUISUN BAY CALIFORNIA		
NOAA Chart:	18656	Latitude:	38° 3.4' N
USGS Quad:	VINE HILL	Longitude:	122° 2.4' W

T I D A L   B E N C H   M A R K S

BENCH MARK STAMPING: 5144 N 1982
DESIGNATION: 941 5144 N

MONUMENTATION:	Tidal Station disk	VM#:	1002
AGENCY:	National Ocean Survey (NOS)	PID:	
SETTING CLASSIFICATION:	Concrete loading dock		

The bench mark is a disk set flush in the top of the SE corner of the railroad concrete loading dock on the south side of Building S47SH, 14.02 m (46.0 ft) NW of the centerline of Holmes Road, 3.26 m (10.7 ft) east of the center of a set of double doors leading into the building, 1.71 m (5.6 ft) north of the south edge of the loading dock, 0.40 m (1.3 ft) west of the east edge of the loading dock above the stairs, 0.12 m (0.4 ft) south of Building S47SH, and 1.19 m (3.9 ft) above ground level.

BENCH MARK STAMPING: CT 26
DESIGNATION: 26 USN
ALIAS: 14 1948

MONUMENTATION:	Bolt	VM#:	1003
AGENCY:	US Army Corps of Engineers (USE)	PID#:	JT0383
SETTING CLASSIFICATION:	Concrete sidewalk		

The bench mark is the rounded head of a 1-inch brass bolt set in the top at the north end of the west concrete sidewalk of the Taylor Boulevard bridge over the Southern Pacific Railroad, 4.72 m (15.5 ft) west of the centerline of Taylor Boulevard, 2.44 m (8.0 ft) SE of easterly railroad support trestle, 0.46 m (1.5 ft) east of west side of bridge-fac, and about 0.30 m (1.0 ft) above the level of the road.

Station ID:	9415144	PUBLICATION DATE:	11/23/2010
Name:	PORT CHICAGO, SUISUN BAY CALIFORNIA		
NOAA Chart:	18656	Latitude:	38° 3.4' N
USGS Quad:	VINE HILL	Longitude:	122° 2.4' W

T I D A L   B E N C H   M A R K S

BENCH MARK STAMPING: 5144 P 1990 RESET 1997
DESIGNATION: 941 5144 P RESET

MONUMENTATION:	Tidal Station disk	VM#:	13892
AGENCY:	National Ocean Survey (NOS)	PID:	
SETTING CLASSIFICATION:	Concrete foundation		

The bench mark is a disk set flush in the concrete base of a flag pole at the head of the tug pier, 14.83 m (48.6 ft) east of the east side of a telephone booth near the tug office, 3.81 m (12.5 ft) SE of the southern end of a guard rail which leads to pier, and 0.49 m (1.6 ft) SW of the flag pole.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service

Station ID: 9415144 PUBLICATION DATE: 11/23/2010
Name: PORT CHICAGO, SUISUN BAY
CALIFORNIA
NOAA Chart: 18656 Latitude: 38° 3.4' N
USGS Quad: VINE HILL Longitude: 122° 2.4' W

T I D A L D A T U M S

Tidal datums at PORT CHICAGO, SUISUN BAY based on:

LENGTH OF SERIES:	19 YEARS
TIME PERIOD:	January 1983 - December 2001
TIDAL EPOCH:	1983-2001
CONTROL TIDE STATION:	

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

HIGHEST OBSERVED WATER LEVEL (12/03/1983)		= 2.415
MEAN HIGHER HIGH WATER	MHHW	= 1.498
MEAN HIGH WATER	MHW	= 1.343
MEAN TIDE LEVEL	MTL	= 0.785
MEAN SEA LEVEL	MSL	= 0.781
MEAN LOW WATER	MLW	= 0.226
MEAN LOWER LOW WATER	MLLW	= 0.000
North American Vertical Datum	NAVD88	= -0.335
LOWEST OBSERVED WATER LEVEL (01/08/1989)		= -0.447

North American Vertical Datum (NAVD88)

Bench Mark Elevation Information In METERS above:

Stamping or Designation	MLLW	MHW
5144 H 1976	2.994	1.651
HARLEY 1954	12.306	10.963
5144 F 1976	3.742	2.399
5144 G 1976	4.491	3.148
5144 J 1976	2.253	0.909
5144 K 1976	2.672	1.329
5144 M 1982	4.341	2.998
5144 N 1982	4.615	3.271
CT 26	5.753	4.410
5144 P 1990 RESET 1997	3.605	2.262

Station ID: 9415144 PUBLICATION DATE: 11/23/2010
Name: PORT CHICAGO, SUISUN BAY
CALIFORNIA
NOAA Chart: 18656 Latitude: 38° 3.4' N
USGS Quad: VINE HILL Longitude: 122° 2.4' W

D E F I N I T I O N S

Mean Sea Level (MSL) is a tidal datum determined over a 19-year National Tidal Datum Epoch. It pertains to local mean sea level and should not be confused with the fixed datums of North American Vertical Datum of 1988 (NAVD88).

NAVD88 is a fixed datum derived from a simultaneous, least squares, minimum constraint adjustment of Canadian/Mexican/United States leveling observations. Local mean sea level observed at Father Point/Rimouski, Canada was held fixed as the single initial constraint. NAVD88 replaces NGVD29 as the national standard geodetic reference for heights. Bench mark elevations relative to NAVD88 are available from NGS through the World Wide Web at National Geodetic Survey.

NGVD29 is a fixed datum adopted as a national standard geodetic reference for heights but is now considered superseded. NGVD29 is sometimes referred to as Sea Level Datum of 1929 or as Mean Sea Level on some early issues of Geological Survey Topographic Quads. NGVD29 was originally derived from a general adjustment of the first-order leveling networks of the U.S. and Canada after holding mean sea level observed at 26 long term tide stations as fixed. Numerous local and wide-spread adjustments have been made since establishment in 1929. Bench mark elevations relative to NGVD29 are available from the National Geodetic Survey (NGS) data base via the World Wide Web at National Geodetic Survey.

NAVD88 and NGVD29 are fixed geodetic datums whose elevation relationships to local MSL and other tidal datums may not be consistent from one location to another.

The Vertical Mark Number (VM#) and PID# shown on the bench mark sheet are unique identifiers for bench marks in the tidal and geodetic databases, respectively. Each bench mark in either database has a single, unique VM# and/or PID# assigned. Where both VM# and PID# are indicated, both tidal and geodetic elevations are available for the bench mark listed.

The NAVD88 elevation is shown on the Elevations of Tidal Datums Table Referred to MLLW only when two or more of the bench marks listed have NAVD88 elevations. The NAVD88 elevation relationship shown in the table is derived from an average of several bench mark elevations relative to tide station datum. As a result of this averaging, NAVD88 bench mark elevations computed indirectly from the tidal datums elevation table may differ slightly from NAVD88 elevations listed for each bench mark in the NGS database.

Station ID: 9415316 PUBLICATION DATE: 09/05/2003
Name: RIO VISTA, SACRAMENTO RIVER CALIFORNIA
NOAA Chart: 18661 Latitude: 38° 8.7' N
USGS Quad: RIO VISTA Longitude: 121° 41.5' W

To reach the tidal bench marks from State Highway 12, exit southwest on Main Street, then take a right on Second Street and follow signs to the Coast Guard Base. The tidal bench marks are located on and near the Base. The tide gauge was located on the Finger Pier of the Marine Railway at the north end of the Base.

T I D A L B E N C H M A R K S

PRIMARY BENCH MARK STAMPING: A 904 1957
DESIGNATION: A 904

MONUMENTATION: Bench Mark disk VM#: 11925
AGENCY: US Coast and Geodetic Survey (USC&GS) PID#: JS1921
SETTING CLASSIFICATION: Concrete foundation

The bench mark is a disk set in the concrete sidewalk on the north side of C. Wasak Warehouse on the abandoned Rio Vista Army base, 3.90 m (12.8 ft) east of the east side of the sliding door on the north face of the building, 0.30 (1 ft) north of the north wall, and set at the ground level.

BENCH MARK STAMPING: PRC 149
DESIGNATION: PRC 149

MONUMENTATION: Bench Mark disk VM#: 11927
AGENCY: California State Lands Commission PID:
SETTING CLASSIFICATION: Concrete post

The bench mark is a disk set on a 10" concrete monument underneath a large sign marking P.E. & E pipeline crossing, 21.64 m (71.0 ft) west of the edge of the embankment, 5.64 m (18.5 ft) north of a chainlink fence which is north of the marine railway, and 0.30 m (1 ft) above grade,

Station ID: 9415316 PUBLICATION DATE: 09/05/2003
Name: RIO VISTA, SACRAMENTO RIVER
CALIFORNIA
NOAA Chart: 18661 Latitude: 38° 8.7' N
USGS Quad: RIO VISTA Longitude: 121° 41.5' W

T I D A L B E N C H M A R K S

BENCH MARK STAMPING: 5316 A 1996
DESIGNATION: 941 5316 A TIDAL

MONUMENTATION: Tidal Station disk VM#: 13128
AGENCY: National Ocean Service (NOS) PID:
SETTING CLASSIFICATION: Concrete footing

The bench mark is a disk located on Rio Vista Coast Guard Base in the foundation for a met tower on the north side of the main building, 4.88 m (16.0 ft) NE of the NW corner of the building, 1.52 m (5.0 ft) NW of the NE corner of the building, and 0.61 m (2.0 ft) south of the south curb of the road along the north side of the building.

BENCH MARK STAMPING: 5316 B 1996
DESIGNATION: 941 5316 B TIDAL

MONUMENTATION: Tidal Station disk VM#: 13129
AGENCY: National Ocean Service (NOS) PID:
SETTING CLASSIFICATION: Concrete pad

The bench mark is a disk set in a 3.05 m x 4.57 m (10.0 ft x 15.0 ft) concrete pad for a gasoline tank on the Rio Vista Coast guard base, 4.57 m (15.0 ft) south of the NE corner of the pad, 3.05 m (10.0 ft) east of the SW corner of the pad, and 1.83 m (6.0 ft) north of the north side of the road leading to the pier.

Station ID: 9415316 PUBLICATION DATE: 09/05/2003
Name: RIO VISTA, SACRAMENTO RIVER
CALIFORNIA
NOAA Chart: 18661 Latitude: 38° 8.7' N
USGS Quad: RIO VISTA Longitude: 121° 41.5' W

T I D A L D A T U M S

Tidal datums at RIO VISTA, SACRAMENTO RIVER based on:

LENGTH OF SERIES:	5 MONTHS
TIME PERIOD:	August 1996 - December 1996
TIDAL EPOCH:	1983-2001
CONTROL TIDE STATION:	9415144 PORT CHICAGO, SUISUN BAY

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

MEAN HIGHER HIGH WATER	MHHW	=	1.243
MEAN HIGH WATER	MHW	=	1.098
MEAN SEA LEVEL	MSL	=	0.649
MEAN TIDE LEVEL	MTL	=	0.639
MEAN LOW WATER	MLW	=	0.179
MEAN LOWER LOW WATER	MLLW	=	0.000

North American Vertical Datum (NAVD88)

Bench Mark Elevation Information In METERS above:

Stamping or Designation	MLLW	MHW
A 904 1957	4.477	3.379
PRC 149	7.789	6.691
5316 A 1996	7.867	6.769
5316 B 1996	7.301	6.203

Foot Notes:

CAUTION: Tidal datums at Rio Vista may be subject to change over time due to land subsidence.

Station ID: 9415316 PUBLICATION DATE: 09/05/2003
Name: RIO VISTA, SACRAMENTO RIVER
CALIFORNIA
NOAA Chart: 18661 Latitude: 38° 8.7' N
USGS Quad: RIO VISTA Longitude: 121° 41.5' W

D E F I N I T I O N S

Mean Sea Level (MSL) is a tidal datum determined over a 19-year National Tidal Datum Epoch. It pertains to local mean sea level and should not be confused with the fixed datums of North American Vertical Datum of 1988 (NAVD88).

NAVD88 is a fixed datum derived from a simultaneous, least squares, minimum constraint adjustment of Canadian/Mexican/United States leveling observations. Local mean sea level observed at Father Point/Rimouski, Canada was held fixed as the single initial constraint. NAVD88 replaces NGVD29 as the national standard geodetic reference for heights. Bench mark elevations relative to NAVD88 are available from NGS through the World Wide Web at
National Geodetic Survey.

NGVD29 is a fixed datum adopted as a national standard geodetic reference for heights but is now considered superseded. NGVD29 is sometimes referred to as Sea Level Datum of 1929 or as Mean Sea Level on some early issues of Geological Survey Topographic Quads. NGVD29 was originally derived from a general adjustment of the first-order leveling networks of the U.S. and Canada after holding mean sea level observed at 26 long term tide stations as fixed. Numerous local and wide-spread adjustments have been made since establishment in 1929. Bench mark elevations relative to NGVD29 are available from the National Geodetic Survey (NGS) data base via the World Wide Web at
National Geodetic Survey.

NAVD88 and NGVD29 are fixed geodetic datums whose elevation relationships to local MSL and other tidal datums may not be consistent from one location to another.

The Vertical Mark Number (VM#) and PID# shown on the bench mark sheet are unique identifiers for bench marks in the tidal and geodetic databases, respectively. Each bench mark in either database has a single, unique VM# and/or PID# assigned. Where both VM# and PID# are indicated, both tidal and geodetic elevations are available for the bench mark listed.

The NAVD88 elevation is shown on the Elevations of Tidal Datums Table Referred to MLLW only when two or more of the bench marks listed have NAVD88 elevations. The NAVD88 elevation relationship shown in the table is derived from an average of several bench mark elevations relative to tide station datum. As a result of this averaging, NAVD88 bench mark elevations computed indirectly from the tidal datums elevation table may differ slightly from NAVD88 elevations listed for each bench mark in the NGS database.

A-4 Determining Design High Tide

Chapter 870 of the *Highway Design Manual* is *Channel and Shore Protection*. Surveyors should review Section 873.2 – *Design High Water and Hydraulics* before calculating the Design High Tide (DHT) datum. In the *HDM,* the term DHT refers to tidal influenced waters and Design High Water to all shorelines (lakes, rivers, or ocean).

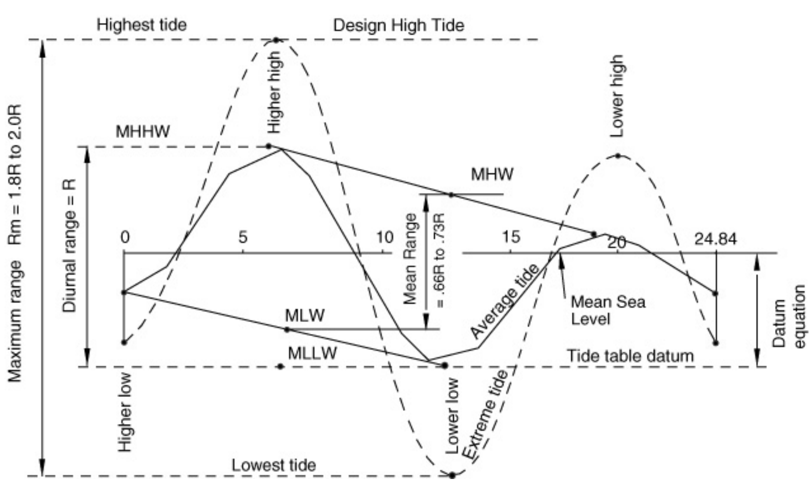
“The most important, and often the most perplexing obligation, in the design of bank and shore protection features is the determination of the appropriate design high water elevation to be used. The design flood stage elevation should be chosen that best satisfies site conditions and level of risk associated with the encroachment…

Except for inland tidal basins affected by wind tides, floods and seiches, **the static or still-water level used for design of shore protection is the highest tide**. In tide tables, this is the stage of the highest tide above "tide-table datum" at MLLW.”

In Figure 873.2A, the highest tide is the same as the Design High Tide. This work well when the tidal data is directly tied to a Primary Tidal Station, with published HOWL.

Figure from *Highway Design Manual - 2010*

Figure 873.2A
Nomenclature of Tidal Ranges



Because of the great variation of tidal elements, Figure 873.2A was not drawn to scale.

The elevation of the design high tide may be taken as mean sea level (MSL) plus one-half the maximum tidal range (Rm).

For primary tidal stations, and active secondary stations, the maximum tidal range (Rm) as described in Fig. 876.2 is the difference between the published HOWL and LOWL at the station.

When determining the HOWL and LOWL for an active secondary station, identify the station on the CO-OPS page, and then click on "Datums". This information isn't tied to any tidal or geodetic datums, so the raw data must be extracted and added to the station MSL as computed in VDatum.

On the "Datums" page for the San Mateo Bridge (Station 9414458) the following information will be at the center of the page:

```
Maximum     25.42       Highest Observed Water Level
Max Date 19830127       Highest Observed Water Level Date
Max Time    00:00       Highest Observed Water Level Time
Minimum     11.82       Lowest Observed Water Level
Min Date 19880119       Lowest Observed Water Level Date
Min Time    19:12       Lowest Observed Water Level Time
```

Data is in feet

The difference between the extreme high and low water levels is computed, and half of the difference added to the VDatum MSL to obtain the Design High Tide.

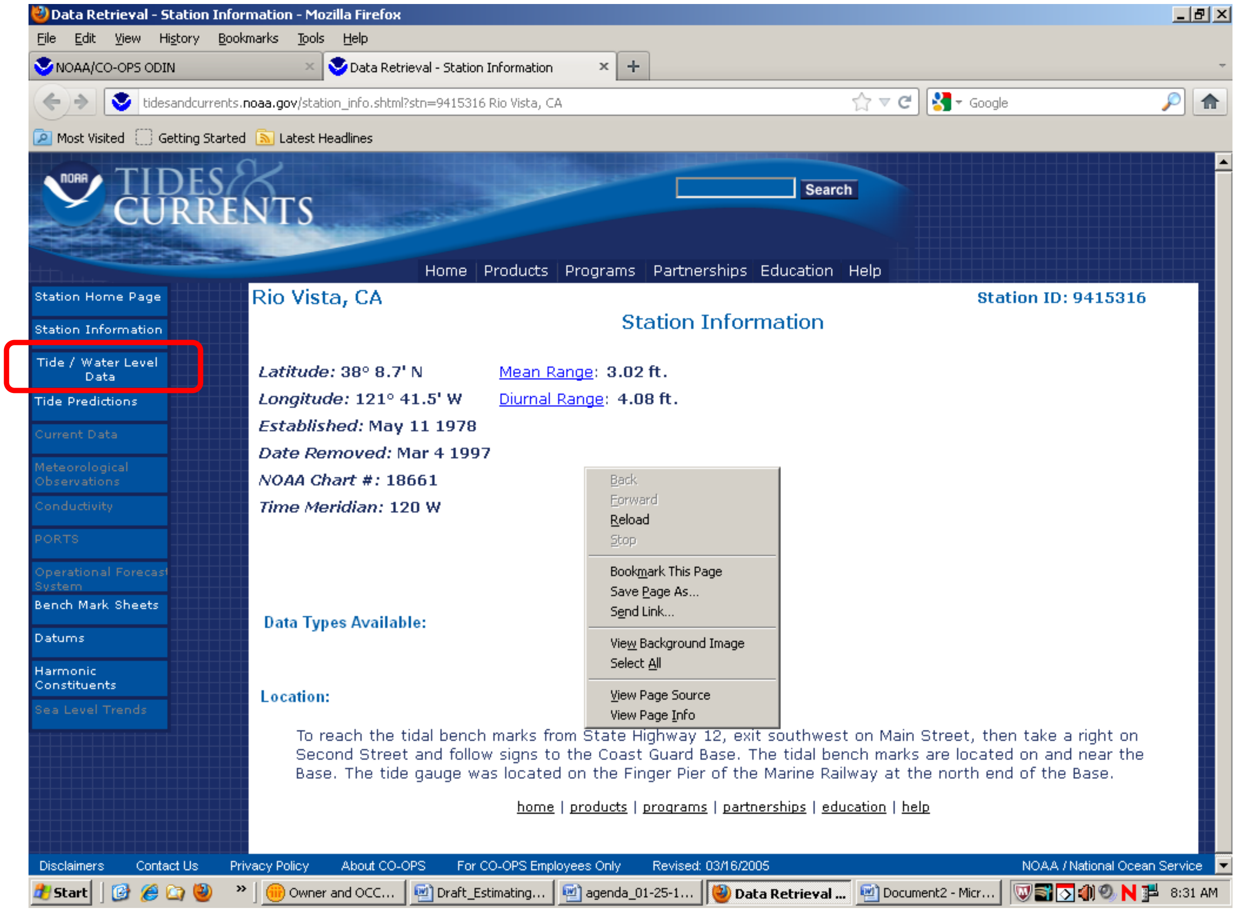
$$DHT = \frac{HOWL - LOWL}{2} + MSL$$

$$DHT = \frac{25.42 - 11.82}{2} + MSL$$

For inactive secondary stations without published HOWL and LOWL data, the record of the extreme water levels must be obtained from the historical station data published by CO-OPS.

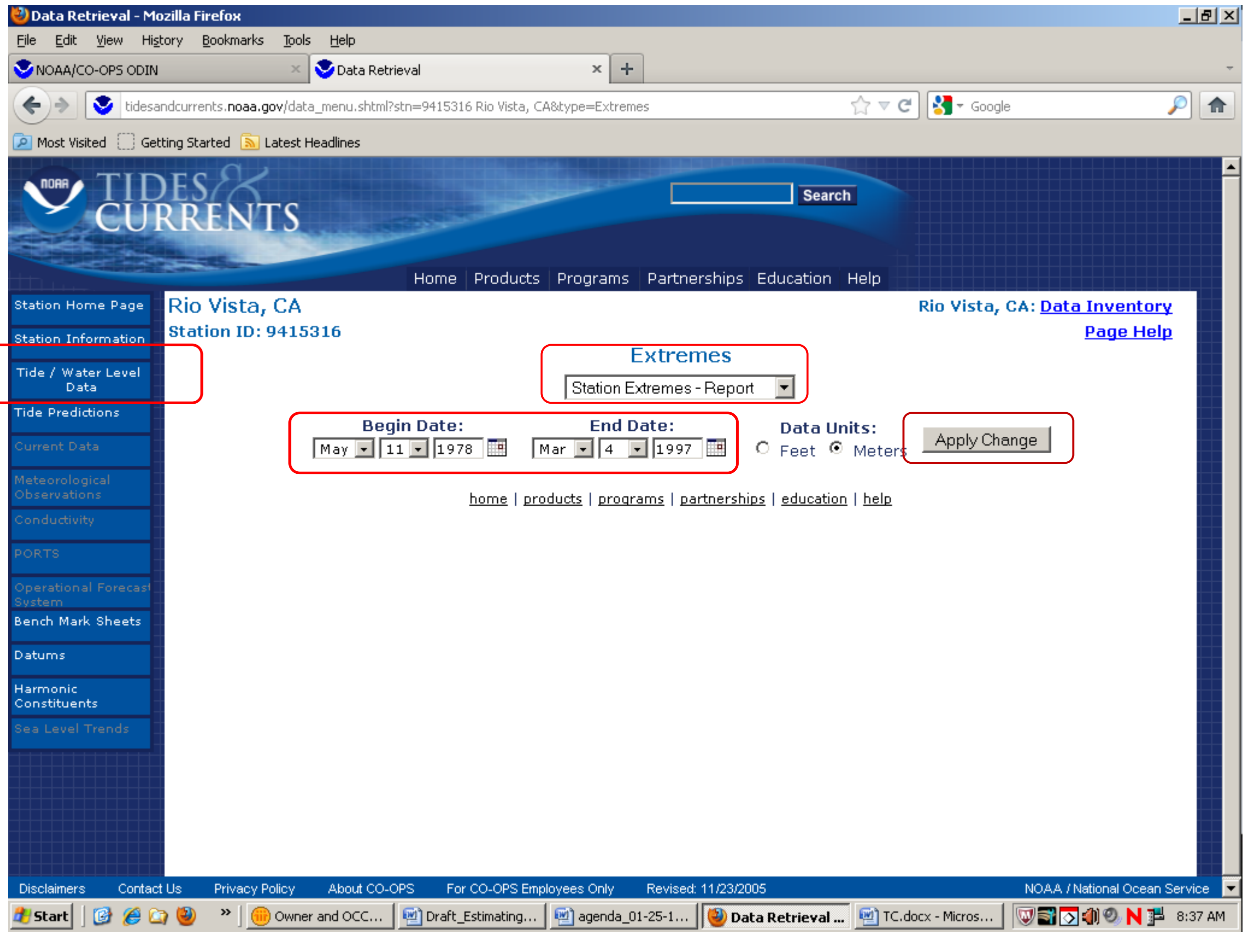
Here is the example of determining DHT at the Rio Vista Tide Station:

1. Determine the dates of the station data. Using the procedures shown in section 3.1, bring up the Station Home page and click on "Datums". The following page will appear:



The Station Information page will show the dates that the station was established (May 11, 1979) and removed (March 4, 1997). This information will be used in the next step.

2. Look up the extreme water level data. On the left side of the Station Information Page is a column of links to other station information. Clicking on “Tide / Water Level Data”, Then “Extremes” will lead to page below:

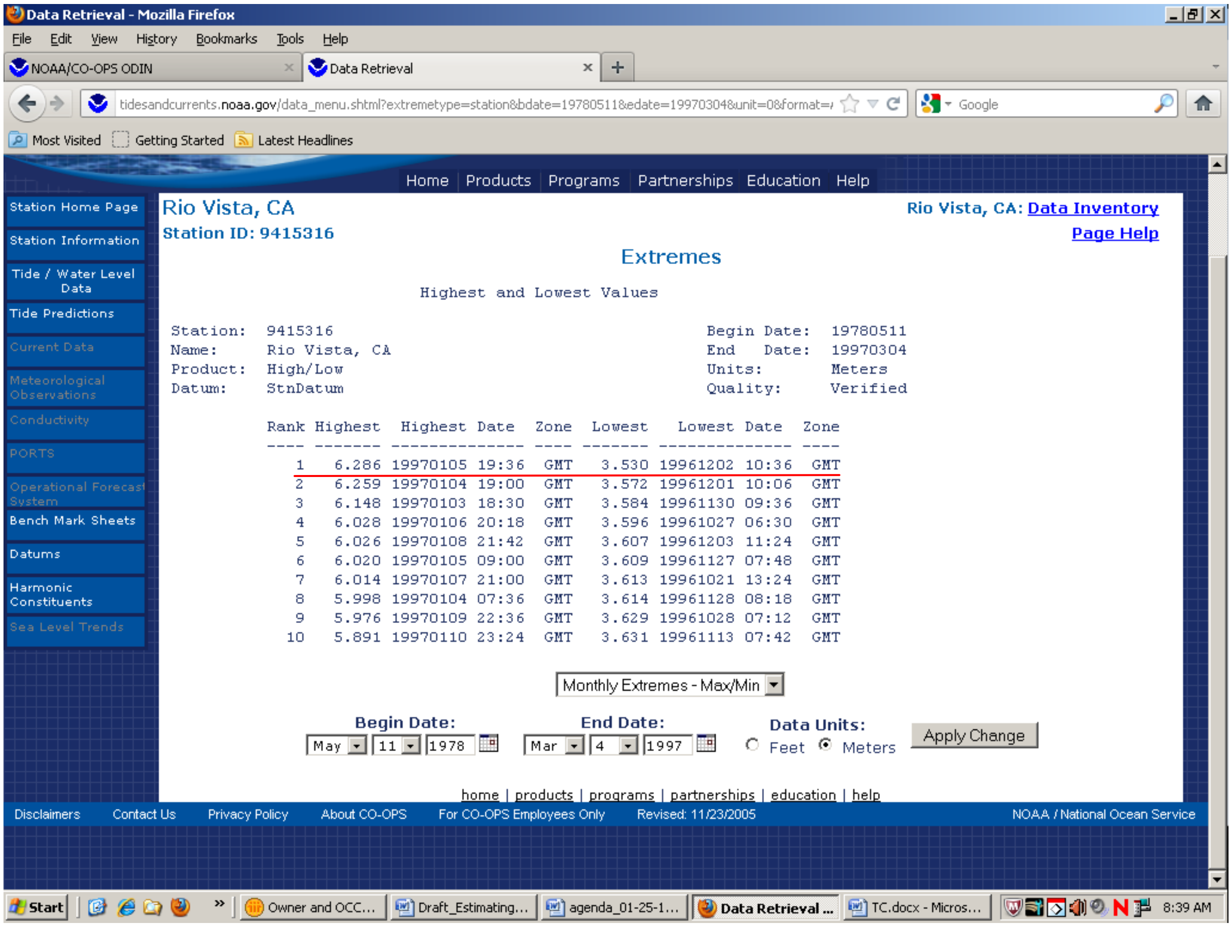


By Selecting “Station Extremes- Report”, entering the dates that the station was operational, and then clicking on “Apply Change”, the record high and low water levels will be displayed.

$$DHT = \frac{HOWL - LOWL}{2} + MSL$$

The Extremes report will show the highest and lowest ten recorded values for the selected time period. The information is in the “Station Datums”, or the raw, uncorrected values. These aren’t the same as the Benchmark Sheets datums, which have been corrected to MLLW.

3. Calculate maximum tidal range. This page shows that the single highest recorded water level was 6.286 m above the station datum, recorded January 05, 1997. The lowest recorded level was 3.530 m, dated December 02, 1996. The difference between these two levels is the maximum tidal range (Rm) used to calculate the Design High Tide elevation.



$= - +$

$$DHT = \frac{6.286 - 3.530}{2} + 0.649 = 2.027 \text{ m}$$

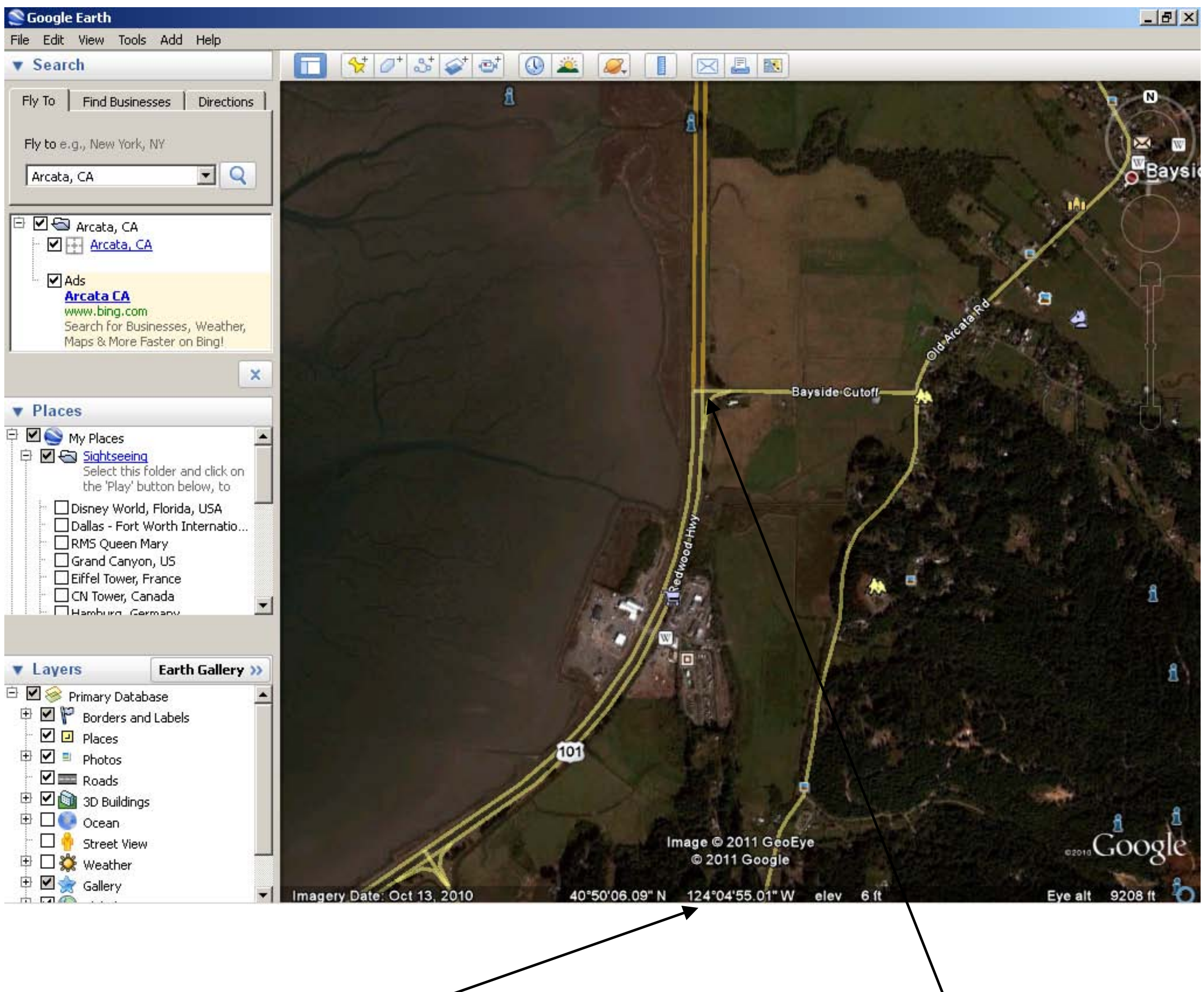
The DHT of 2.027 m is entered into the station chart for the Rio Vista station in section 3.2

For projects using VDatum, determine the Rm of the nearest tide station with a bench mark sheet, and then the differential is applied to the local MSL as determined by VDatum to calculate the DHT.

A-5 Example of using VDatum to convert datums

The easiest way to locate a project on VDATUM is by using latitude and longitude to input your project location into the system. The surveyor can calculate the latitude and longitude for the middle of the project limits or use Google Earth and read the latitude and longitude coordinates generated at the bottom of the computer screen.

As an example, look at 1-HUM-101-84.0, at the intersection with the Bayside Cutoff Road. This is just south of Arcata, along Arcata Bay. Google Earth shows the Lat/ Long of 40° 50’ 00” N, 124° 06’ 00” W and an elevation of six feet. Record the latitude and longitude coordinates for input into the VDATUM system.



Latitude / Longitude/ Elevation

Site Location

Open the VDatum software by clicking on the vdatum.jar file in the VDatum directory. Then use the following steps to generate baseline tidal information for the project:

1. Choose an area by using the pull-down menu and selecting “Oregon/ California – Punta Gorda to Cape Blanco”. This is one of the four areas associated with California.

2. On the right side, under “Point Conversion”, input the Latitude, Longitude, and a height of 0.00. The degrees, and minutes are separated by spaces. The North and West aren’t entered, as they are presumed for North America.

3. On the left side, Under “Datum Information”, verify the default horizontal datum is NAD83. Then pull down the “Input Vertical Datum” and select “MHHW- Mean Higher High Water”. Under “Output Vertical Datum”, select “MLLW- Mean Lower Low Water”. Then select “Feet” if you don’t wish to use the default “Meters”, and ensure that the “Height” option button is marked (not Soundings)..

4. Create a chart of the relative tidal datums at the project location. Under “Point Conversion”, Input a height of “0.00” and click “Convert”. The output is the relative height of MHHW to MLLW, or 7.58 feet. Repeat this step, using the “Input Vertical Datums” for MHW, MLW, NAVD88, and local mean sea level (LMSL), *ALWAYS* inputting a tidal datum height of 0.00. This will result in the following chart:

VERTCON Project Datums			
Datums	**Tide Datums Metric**	**Tide Datums Feet**	
DHT	3.063	10.04	
MHHW	2.310	7.58	
MHW	2.089	6.86	
LMSL	1.275	4.18	
MLW	0.407	1.33	
NAVD88	0.295	0.97	
MLLW	0.000	0.00	
LOWL	-0.513	-1.68	

Note that the DHT and LOWL Datums are in red. The reason is because there is no direct datum in VERTCON for these figures, so the differences from the nearest primary station are used. See the tidal datums for Humboldt Bay – North Spit in Section 4.4.

5. Convert the Mean Lower Low Water to the NAVD88 elevation at the selected location. Enter MLLW into “Input Vertical Datum and NAVD88 into “Output Vertical Datum”. Go to the “Point Conversion” section and click on “Convert”. If you selected feet, you should get a NAVD88 elevation of -0.9690. If you selected meters, it should read -0.2941. This is the MLLW in NAVD88 at the site location. Repeat this step for MLW, MSL, MHW, and MHHW. Always use 0.00 as the “Input” for a tidal datum height of

0.00. For a check, the MHHW of 0.00 is the NAVD elevation of 6.61 ft. Alternatively, you could enter a MLLW datum of 7.58 (the difference between 6.61 and -0.97), which also gives a NAVD88 elevation of 6.61.

6. The VERTCON Data will allow you to add NAVD88 elevations to the data in Project Datums table above to complete the table as shown below:

VERTCON Project Datums			
Datums	**Tide Datums Metric**	**Tide Datums Feet**	**Project NAVD88 Feet**
DHT	3.063	10.04	**9.07**
MHHW	2.310	7.58	**6.61**
MHW	2.092	6.86	**5.89**
MSL	1.275	4.18	**3.21**
MLW	0.407	1.33	**0.37**
NAVD88	0.295	0.97	**0.00**
MLLW	0.000	0.00	**-0.97**
LOWL	-0.513	-1.68	**-2.65**

7. To confirm the DHT and LOWL elevations, log on to the NOAA Tides and Currents website at http://tidesandcurrents.noaa.gov/index.shtml .Zoom in to the Eureka/ Arcata area, in the upper right hand corner, and choose Require Data Type labeled "Tide Predictions". Look at both the primary and nearby secondary tide stations. Select a nearby secondary station and check which tide station it uses as a reference. By clicking on the Arcata Wharf icon and the words "Tide Predictions" under "Jump to", we can see that the primary tide station is "Humbolt Bay – North Spit" and the difference between Arcata Wharf and North Spit is +0.10 feet for the Low, and +0.10 for the High. The project is approximately half way between the two tidal stations, so the HOWL and LOWL data from North Spit is accurate enough to use to calculate the DHT for this location. Large gaps between station datums would require interpolation by the surveyor to estimate DHT elevations.

A-6 End Notes

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[1] http://gov.ca.gov/news.php?id=11036

2http://www.dot.ca.gov/hq/tpp/offices/orip/Updated_Climate_Change/Documents/Sea_Level_Guidance_May2011.pdf

[3] See Mean Sea Level Trend- San Francisco
http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9414290

[4] See Mean Sea Level Trend – North Spit
http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9418767

[6] [6] NOAA Technical Memorandum NOS NGS 59 http://www.ngs.noaa.gov/PUBS_LIB/NGS592008069FINAL2.pdf

[7] http://www.ngs.noaa.gov/

[8] http://www.nauticalcharts.noaa.gov/

[9] http://tidesandcurrents.noaa.gov/

[10] http://VDatum.noaa.gov/docs/est_uncertainties.html .

[11] http://www.csc.noaa.gov/digitalcoast/inundation/_pdf/SLC_Technical_Considerations_Document.pdf