CHAPTER 4

Procedures for Referencing Datums and Dredging Grades on Coastal Navigation Projects

4-1. General. This chapter provides guidance on evaluating and establishing vertical reference grades on coastal navigation projects in tidal waters. It covers the procedures needed to ensure these projects are adequately referenced and modeled relative to the National Water Level Observation Network (NWLON) tidal datum and the National Spatial Reference System (NSRS) orthometric datum established by the Department of Commerce as outlined in Chapter 1 and ER 1110-2-8160. It also covers the tidal gaging and modeling methods used to define the varying MLLW datum plane at a project site, including NOAA's recently developed "VDatum" software tool that transforms vertical navigation datums throughout CONUS coastal regions. This chapter also discusses real-time GPS/RTN survey methods that are employed to measure the local water surface elevation relative to the MLLW datum. Much of the guidance in this chapter is also applicable to hurricane and shore protection projects covered in Chapter 5.

a. Scope. In coastal areas, and in coastal inlets, accurately modeling and measuring the varying tidal datum plane (e.g., LMSL or MLLW) relative to NAVD88 and the NAD83/GRS80 ellipsoid is the challenge. Measurement of the elevation of the actual water surface relative to the tidal reference datum must be done accurately in order to determine the acoustically surveyed depth/elevation of a point relative to the tidal datum. This water surface elevation varies temporally due to tidal phase latencies, tidal currents, and meteorological effects such as wind. This chapter provides procedural information and guidance to ensure survey and dredge positioning systems are effectively compensating for these tidal variations and other effects in coastal regions and inland rivers subject to fresh water flow and tidal influence. Non-tidal inland river, pool, reservoir, and lake datums are covered in Chapter 6.

b. Requirements to reference coastal navigation projects to NOAA MLLW datum. In accordance with the intent of Section 224 of WRDA 1992 and "The National Tidal Datum Convention of 1980" (NTDC 1980), navigation projects in coastal tidal areas must be defined relative to the datum shown on official NOAA navigation charts and NOAA tidal predictions for the project area. The WRDA 1992 amendment to Section 5 of the Rivers and Harbors Appropriation Act of 1915, which is excerpted below, supersedes previously authorized reference datums (e.g., Mean Low Water on Atlantic and Gulf coasts), and specifically directs that the datum defined by the U.S. Department of Commerce be used.

Section 5 of the Act of March 4, 1915 (38 Stat. 1053; 33 U.S.C. 562), is amended -- (as indicated). "That in the preparation of projects under this and subsequent river and harbor Acts and after the project becomes operational, unless otherwise expressed, the channel depths referred to shall be understood to signify the depth at mean lower low water as defined by the Department of Commerce for nautical charts and tidal predictions in tidal waters tributary to the Atlantic and Gulf coasts and at mean lower low water as defined by the Department of Commerce for nautical charts and tidal predictions in tidal

waters tributary to the Pacific coast and the mean depth for a continuous period of fifteen days of the lowest water in the navigation season of any year in rivers and nontidal channels, and after the project becomes operational the channel dimensions specified shall be understood to admit of such increase at the entrances, bends, sidings, and turning places as may be necessary to allow of the free movement of boats.

USACE projects that are still defined relative to non-standard or undefined legacy datums (e.g., Mean Low Gulf (MLG), Gulf Mean Tide, MSL, NGVD, MLW, COEMLW, etc.) should have technically valid transforms to the NOAA MLLW chart/tidal datum for the area. In isolated cases, the legacy datum may be retained as the reference grade provided its relationship to NOAA MLLW datum is accurately defined based on current gage data at the project site. In such projects, depth data furnished to NOAA and other project users must indicate the primary reference gage, along with the tidal datum epoch period and the relationship between the legacy datum, NOAA MLLW, and NAVD88. Legacy "Low Water" datums must be periodically updated for sea level change and regional subsidence using similar computational techniques established by NOAA for coastal waters. Refer to Appendix C for additional details on referencing coastal projects to the federal MLLW datum.

c. References. This chapter does not cover the detailed theory, principles, and computational procedures for establishing tidal datums from observed gage data, or for performing hydrodynamic tidal modeling of navigation projects. For more technical information on these topics consult the USACE and NOAA technical publications listed in Appendix A.

4-2. Overview of Procedures Needed to Reference Grades on Navigation Projects. Figure 4-1 illustrates the various datum relationships that will need to be established to ensure a navigation project complies with the requirements in ER 1110-2-8160. Actions to develop these relationships are summarized below. Subsequent sections in this chapter detail specific procedures for each of these actions.

a. Primary Project Control Point (PPCP) reference. Designate a NSRS published PPCP(s) needed to position survey and dredging operations over the project reach using RTK techniques. The PPCP shown in Figure 4-1 provides RTK coverage over the entire project reach. Alternatively, a RTN may be utilized, provided that it is "site-calibrated" to NSRS tidal bench marks. The PPCP should have horizontal coordinates (NAD83) of sufficient accuracy (< ± 2 ft relative to the NSRS) to position survey and dredging operations. As shown in the figure, the PPCP provides the relationship between NAVD88, NAD83/GRS80 ellipsoid, MSL, and the Geoid (geoid height), and perhaps a legacy datum such as NGVD29. Its vertical accuracy (< ± 0.25 ft relative to NAVD88) is usually adequate for RTK initialization; site calibration being performed relative to the NOAA tidal gage reference bench marks shown in Figure 4-1. Further details are covered in Section 4-3.

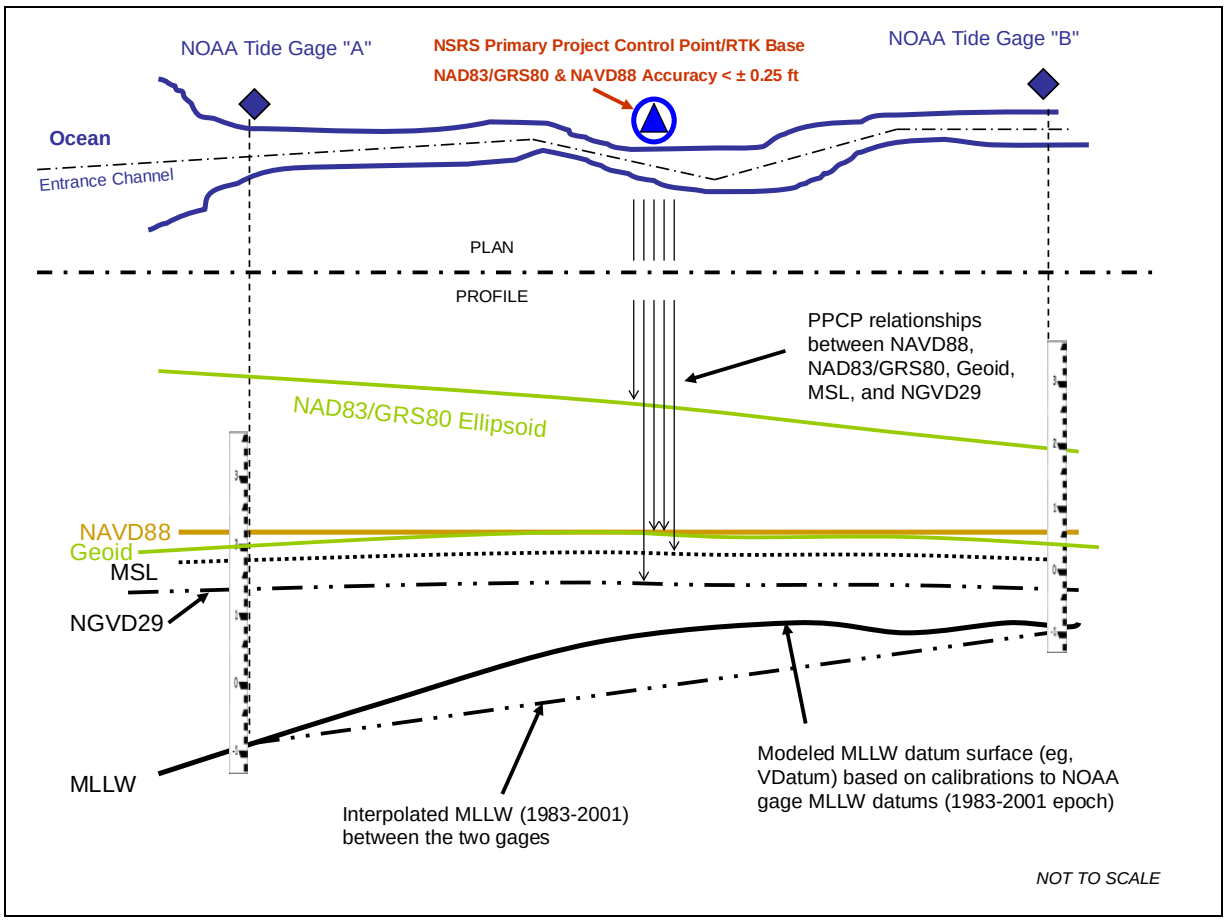

Figure 4-1. Geodetic and tidal datum relationships at a typical coastal entrance navigation project.

b. Tide gage and tidal bench mark references. Designate tide gages and tidal bench marks that reference the dredging datum for the project. These gage sites shall be used for calibrating RTN/RTK positioning systems to MLLW. Published MLLW elevation data for reference PBMs at these gages becomes the reference dredging datum for the project. Gages from any agency (e.g., NOAA, USACE, USGS, States, etc.) may be used; however, the MLLW reference datum must be current and referenced to the latest official NOAA National Tidal Datum Epoch NTDE). Depending on the size of the project and tidal characteristics, more than one gage may be required. The two gages shown in Figure 4-1 provide redundant RTK calibration points, at the entrance and upstream from the entrance. If only one gage at the entrance existed on this project (i.e., NOAA Tide gage "A") then the upstream gage "B" would have to be established in order to adequately model the reference MLLW surface. Further details on gage references are covered in Section 4-4.

c. Geoid model. Designate a geoid model for reducing observed RTK ellipsoid heights of the local water surface to the reference orthometric datum—NAVD88. As shown in Figure 4-1, the reference ellipsoid, geoid, and NAVD88 are not parallel and differ spatially over the project. The geoid (i.e., NGS "hybrid" Geoid XX) will match NAVD88 at some NSRS benchmarks but may deviate slightly away from those fixed points. GPS receivers and hydrographic survey

systems provide software to model and compute in real time the relationship between the NAD83/GRS80 ellipsoid and the geoid, as necessary to compute NAVD88 elevations at any point on the project. Further details are covered in Section 4-7.

d. MLLW tidal model. Designate a MLLW tidal model that provides the relationship between NAVD88 and the MLLW datum at any point on the project. As shown on Figure 4-1, the MLLW tidal model may be based on a simple interpolation between the gages, or by a hydrodynamic tidal model, such as "National VDatum," that refines the actual MLLW variations due to topographic and bathymetric effects. As shown in the figure, the tidal model must also be related to the current NTDE. Further details on tidal models and VDatum are covered in subsequent sections in this chapter.

e. Tidal phase and water surface elevation corrections. Designate procedures used to correct for tidal phase and hydrodynamic/meteorological effects on the water surface elevation throughout the survey area relative to the location of the reference gage. This correction is not shown in Figure 4-1; however, the magnitude of this correction can far outweigh errors in tidal modeling. Details on the use of RTN/RTK methods to correct surface elevation measurements are covered in Section 4-7.

4-3. Establishing Primary Project Control Point (PPCP) References. This section provides guidance on establishing PPCPs needed to reference excavation grades on a navigation project.

a. Orthometric and tidal datum relationships. As outlined in Chapter 1, it is essential that the relationship between geodetic, tidal, and ellipsoidal datums be firmly established at a navigation project. This relationship is essential for determining the water surface elevation using RTK survey methods.

(1) Figure 4-2 illustrates the relationship between these datums at a PPCP and a tide gage. The tidal bench mark PBM A “000 9999 A” is used to reference the gage and contains only the elevation relationship between the gage zero and the various computed tidal datums. It does not have any geodetic datum elevation, which is common at many historical NOAA tide gage sites.

(2) In Figure 4-2, a nearby, published NSRS geodetic bench mark (PBM B “USED 123”) has established orthometric (NAVD88) and ellipsoidal heights, based on precise geodetic leveling and long-term static GPS observations to surrounding NSRS points. In cases where the NSRS mark has not been connected by precise geodetic leveling, the NAVD88 orthometric height may have been computed based on a GPS ellipsoid height observation coupled with the estimated geoid height, as was illustrated in Chapter 2.

(3) PPCP "USED 123" would likely be used as a reference base for RTK surveys of the project, and the tidal bench mark "000 9999 A" would be used to "site-calibrate" the RTK system to the reference dredging datum (e.g., MLLW and/or LWRP). The relationships between the datums at each PBM can be obtained by field leveling or GPS surveys connecting the two bench marks. This field survey effectively establishes the datum relationships at both PBMs.

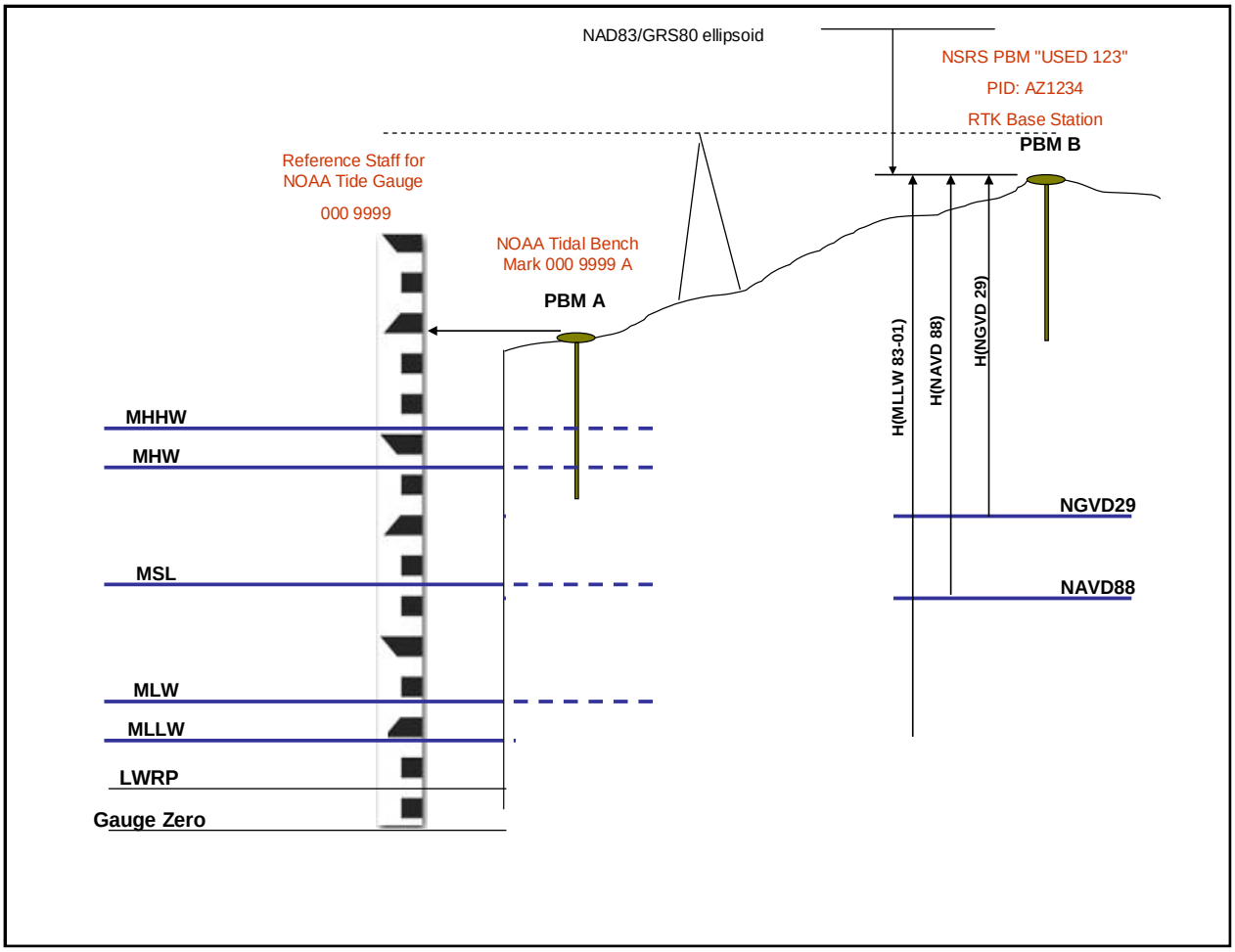

Figure 4.2. Establishing the relationships between orthometric datums and tidal datums at a gage site.

(4) If this gage in Figure 4-2 were located in a river transition area, a hydraulic Low Water Reference Plane (LWRP) stage, or a specified river datum such as the Columbia River Datum, is also defined at the gage site. Both tidal and non-tidal low water (or low flow) datums overlap at this site. See Chapter 6 for additional details on non-tidal river (low water) reference planes.

b. Establishing RTK base stations. RTK base stations on a PPCP can utilize either an existing NSRS PBM near the project site or a USACE PBM that is connected to the NSRS. In most CONUS coastal locations, CORS/OPUS observations are suitable and recommended for establishing a new PPCP or establishing an NAVD88 elevation on a published NSRS point with only horizontal control. Rarely would a long-term static GPS observation network be required to establish a new PPCP. The nominal PPCP accuracy standard of ± 0.25 ft (X-Y-Z) should be adequate for an RTK base, noting that the "Z" (MLLW) calibration is performed relative to a tidal PBM, not the PPCP elevation determined from a CORS/OPUS observation.

(1) RTK or RTN coverage in the project area must be assessed to determine the number of PPCPs needed to reach the project limits. In areas beyond reliable real-time data links, post-processed kinematic (PPK) procedures may be an option. In large open bays, and beyond reliable single-base RTK positioning limits, a PPK solution may be a necessity.

(2) In areas covered by government or commercial RTNs, an NSRS PBM is required near the project site to perform RTN site calibration.

(3) If static GPS network observations are needed to establish NSRS control on a PPCP or tidal PBM, then the procedures outlined in Chapter 3 should be followed. This may be necessary in isolated project areas or in OCONUS.

c. Connecting NOAA tide gage reference bench marks to the NSRS (NAVD88). It is desirable to reference MLLW datums at tidal bench marks to NAVD88. In order to support NOAA's program to update tidal bench mark elevations to NAVD88, tidal bench marks may be positioned using the CORS/OPUS methods described in Chapter 3. These GPS elevation observations will be input into the NSRS using the procedures described in Chapter 3. Recovery notes and updated descriptions on CO-OPS tidal bench marks not yet published in the NSRS (but published in the NWLON database without a NGS "PID" link) should be transmitted directly to CO-OPS.

(1) In some cases, NOAA tidal bench marks may be used as a PPCP for an RTK base if they are more suitable than the NSRS PPCP. In Figure 4-2, survey connections by differential leveling from the NSRS PBM "USED 123" to the tidal bench mark "000 9999 A" would provide adequate X-Y-Z control on the tidal bench mark to be used as the RTK base.

(2) If the NOAA tidal bench mark is distant from the nearest NSRS PPCP, then CORS/OPUS observations at the tidal bench mark are recommended; establishing $< \pm 0.25$ ft horizontal and vertical accuracy on this point which is adequate for initializing RTK observations.

d. Summary. Figure 4-3 outlines the decision flow process involved in establishing and designating a PPCP used for RTK control on a navigation project.

4-4. Designating a Primary Tidal Reference Gage for a Navigation Project. All navigation projects must have one or more primary tidal bench marks that are directly referenced to an established tide gage. The gages must adequately model the project area and be suitable for RTK calibration purposes. A gage's computed reference datum (e.g., MLLW or LMSL) shall be based on relatively current observations and shall be referenced to the latest NTDE established by NOAA. The gage shall also have a sufficient number of tidal reference bench marks. The procedures for computing the reference MLLW datum at the gage shall be consistent with NOAA standards and specifications. This section describes the process for evaluating the adequacy of existing gage data at a project site, and if deemed inadequate, the steps needed to establish a new reference datum.

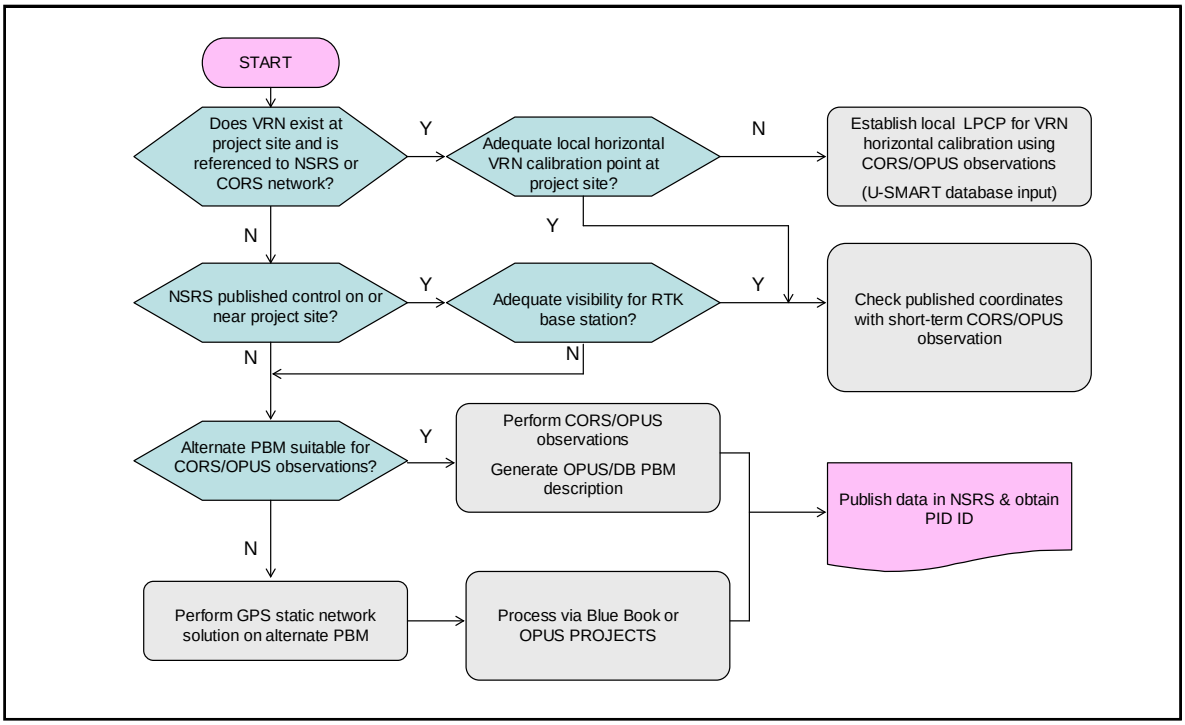

Figure 4-3. General decision process for establishing a navigation project PPCP.

a. Assessing the quality of existing tide gages and computed water level datums. The NWLON is the NOAA nation-wide network of permanently operating tide gages with accepted tidal datums and published bench mark elevations. It also includes the network of historical NOAA tide gage locations that have published tidal datum elevations relative to the latest NTDE. The navigation reference datum on a project site must be adequately connected with this NOAA NWLON network. This implies using either a NOAA gage site that is on, or is connected with, the NWLON, or a locally operated gage that conforms to NOAA/CO-OPS specifications. Isolated bench marks (those of USACE or any other agency) that purport MLLW or MSL reference elevations should be considered highly suspect unless their connection with a NWLON gage site can be firmly established. These connections are usually performed by simultaneous comparison methods, direct differential levels, or static GPS connections to a NOAA tidal bench mark. Any such marks must also contain an NTDE designation attached to their elevation that signifies it has been adjusted to the current NOAA tidal epoch.

(1) Use of active or historical NOAA gages. Published NOAA tidal bench marks are found on or near the vast majority of USACE deep-draft and many shallow-draft projects. These tidal PBMs may be referenced to an active NOAA gage or a historical NOAA gage with archived tidal data. Since few of USACE's 900+ navigation projects have actively operating NOAA gages, the adequacy of historic gage data must be evaluated. This would include assessing the period of record, the age of the data, subsequent channel deepening or realignment, inlet changes, jetty or breakwater modifications, etc. These physical changes may have modified the tidal characteristics since the gage data were recorded. For example, datums at a site computed from a 30-day series in 1970 may be suspect, particularly if subsequent construction or other physical changes have modified the tidal characteristics in the area. NOAA has dropped

published bench marks sheets from historical short-term stations that were established prior to the 1970's. In such cases, a new gaging program to update the reference datum may be warranted. Procedures for establishing tidal datums using short-term gage observations are described in "*Computational Techniques for Tidal Datums Handbook*" (NOAA 2003).

(2) Tidal bench mark recovery at historical NOAA gage sites. Tidal bench marks at historical NOAA gage sites are often lost or impossible to recover due to dated descriptions. Ideally, at least two tidal PBMs should be recovered to have confidence in the stability of these marks and their reference MLLW datum. Third-Order leveling procedures are considered adequate for this purpose. Additional tidal PBMs should be set such that a total of three to five reference marks are available at the gage site. One of the tidal bench marks should be designated as the primary "PPCP" tidal datum reference for the project and placed in the NSRS.

(a) If only one tidal PBM is recoverable, then the long-term stability of that PBM must be assessed if it is to be used as a primary reference. If no PBMs are recoverable, then a new gaging program would likely be warranted to reestablish the tidal datum—especially on deep-draft projects.

(b) Exceptions to the above may exist at less critical shallow-draft projects with reliable VDatum coverage. In such cases, the VDatum estimate of the NAVD88-MLLW difference may be used. The NOAA Coast Survey Development Laboratory (CSDL) "VDatum Team" should be consulted before making this determination.

(3) Use of other agency tide gages. Many other local, state, and Federal agencies including USACE operate tide gages that may be used to reference navigation datums. As with NOAA gages, the quality of the gage data (e.g., datum computation) and reference bench marks must be assessed. Often these gages are referenced to only one bench mark. The stability and quality of this single reference bench mark must be evaluated. If this gage is to be used as a project reference, then additional reference PBMs should be set with at least one PBM in the NSRS. In any case, for hydrographic survey tidal control, a current NTDE MLLW elevation must be established.

(a) Figure 4-4 illustrates NAVD88 orthometric connections to tide gages from other agencies that may be in the vicinity of the project area. Static GPS baselines are observed from published NSRS control points in the region to a local LPCP set near the gage site. Gage reference PBMs and staff zeros are leveled in from the LPCP. The gage datum relationship to NAVD88 is documented as shown in the figure. Additional gage reference PBMs are set in the vicinity of the gage.

(b) Figure 4-5 shows a case where the original gage reference point is updated and a new reference LPCP PBM is set. The primary reference PBM should be documented in the NSRS and additional gage reference PBMs established. Gage reference points must be clearly documented as shown in the figure.

Figure 4-4. Gage reference elevations (USGS and Orleans Levee District gages at I-10 and Inner Harbor Navigation Canal (IHNC)—from IPET 2007).

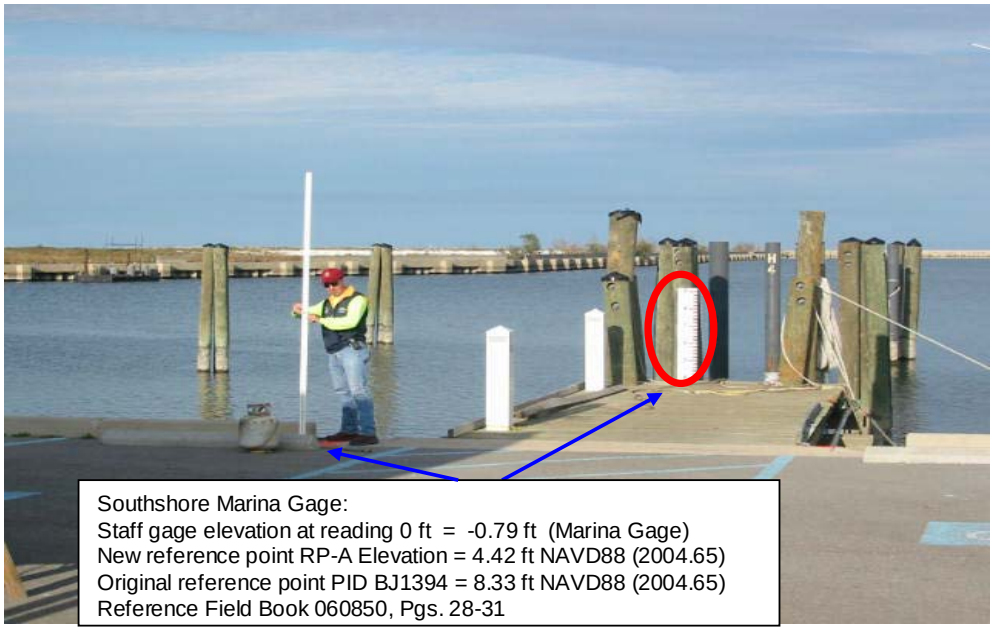

Figure 4-5. Revised gage reference points and elevations. The above photo shows location of PBM "RP-A" and red circle shows staff gage.
(Orleans Levee District gage at Southshore Marina, Lake Pontchartrain--from IPET 2007)

b. Projects with inadequate reference gages or undefined datums. Many USACE navigation projects, particularly isolated shallow-draft projects, do not have tidal datum references that can be reliably related to the current NOAA NWLON gage network. Typically, these projects have been referenced to a local datum or a legacy NGVD29 reference. These legacy reference datums may or may not be referenced to any tide gage. In other cases, the density of gages is inadequate to model the tidal regime over the project, or VDatum coverage may not extend to the head of the maintained navigation channel. This may occur on intracoastal waterways or on projects where the head of maintained navigation is distant from the coastal entrance. A number of options exist to bring these projects into compliance with ER 1110-2-8160, all of which are dependent on status and use of the project, commercial traffic, and related funding availability. These options may include:

(1) In coordination with NOAA CO-OPS, install a short-term tide gage to develop an updated reference datum using simultaneous comparison techniques relative to NOAA NWLON primary or secondary gages (see NOAA 2003). A 30-day observation period will suffice for most USACE navigation projects; however, 90-days are preferred by NOAA for QC purposes and to minimize datum errors. Longer gage observations (e.g., 3 to 12 months) may be required on more critical deep-draft projects. Less critical shallow draft projects may be effectively referenced to the NWLON with 7-day simultaneous gage observations where datum errors are not deemed critical to the project.

(2) If the project area is covered by a NOAA VDatum model, use this model to estimate the tidal datum relationship relative to NAVD88 on an established PPCP used for referencing RTN surveys. Check with NOAA CO-OPS as to the reliability of the VDatum model in the area. This would represent an interim solution for non-critical shallow draft projects with no maintenance funding. The NOAA VDatum model must be calibrated at existing or historic gage sites—see Appendix D. If no historic tide gage data exists for the project, then a gage may need to be established to calibrate the VDatum model.

(3) Maintain a legacy tidal datum reference noting the uncertainty of this reference on all published data for the project. VDatum may be used to estimate the datum relationships at the project site. This option may be applicable for inactive, soft-bottom, shallow draft projects that have not had any significant funding or maintenance activity in decades (i.e., funding a $50,000 to $100,000 tidal gaging and modeling program could not be economically justified).

c. Navigation project tide gage and modeling options. Figure 4-6 illustrates five of the more common cases of tide gage and tidal model coverage found on USACE navigation projects. The following sections outline possible corrective actions needed to bring the project into compliance with ER 1110-2-8160. Larger projects may require more than two gages to calibrate VDatum models for referencing hydrographic surveys and dredging operations—e.g., Tampa Harbor, Florida as illustrated in Appendix D.

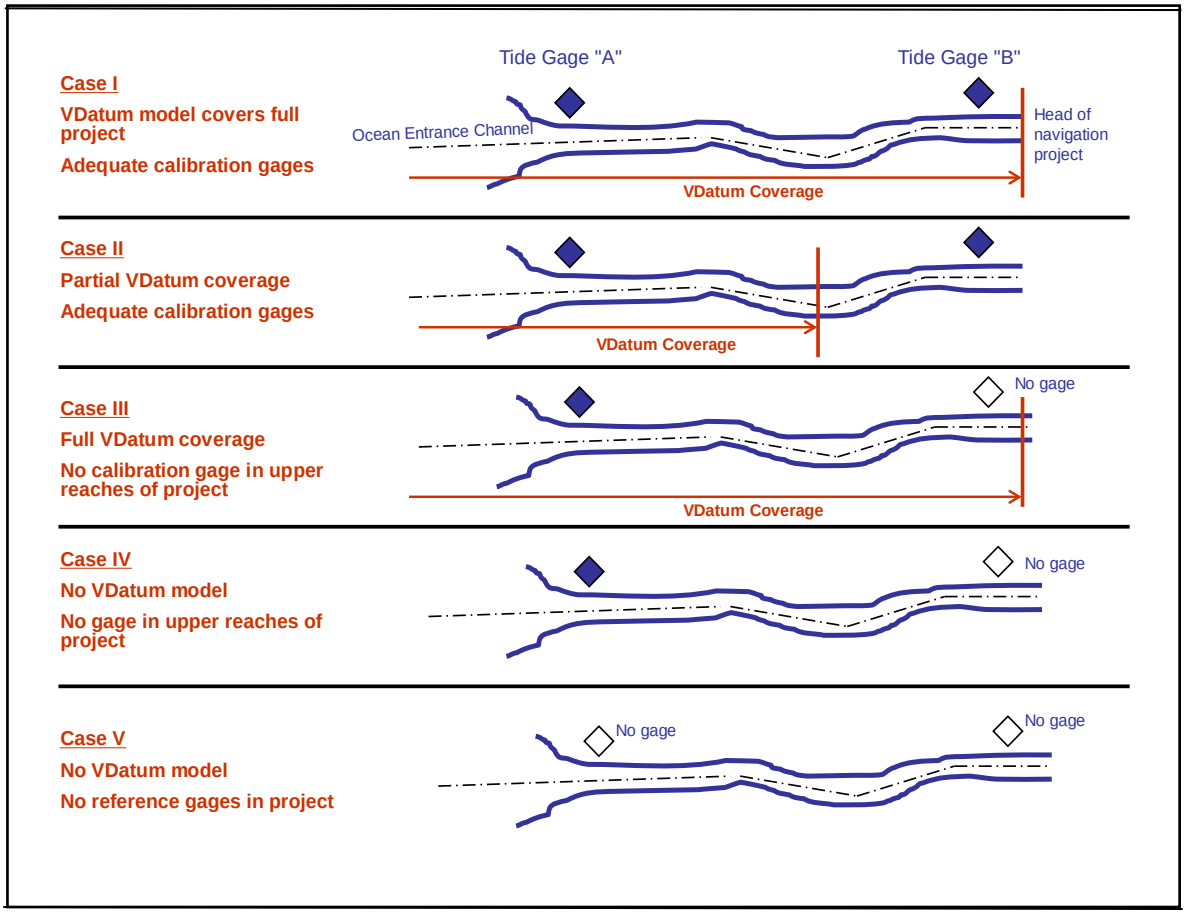

Figure 4-6. Tide gage and VDatum coverage cases that may exist at a navigation project. RTK/RTN surface elevation measurement is assumed. Tide gages are referenced to NOAA NWLON network.

(1) Case I. This case has adequate gage and MLLW datum model coverage to calibrate and reference RTK/RTN surveys over the entire project.

(2) Case II. Although existing tide gages are sufficient to reference the project, VDatum coverage does not extend over the entire project. In this case, the MLLW datum model would have to be interpolated between the VDatum model limit and the upstream gage.

(3) Case III. This case is an example of inadequate gage coverage to calibrate the VDatum model in the upstream reaches, and to reference surveys in these upper reaches. The VDatum model may adequately depict the MLLW reference surface throughout the project but reliance on one calibration gage at the entrance may be problematic if the distance upstream and tidal range variation is significant. For small, shallow draft projects, a single calibration/reference gage may be adequate. Likewise, small deep-draft projects only a mile or two inland from the entrance can be covered by a single gage. For projects of extended lengths upstream, an additional reference gage needs to be established. To correct this case, a short-term tidal comparison relative to the

entrance gage would be performed. This may entail establishing a temporary gage for a comparison period of 3, 7, or 30 days, depending on the tidal characteristics in the area.

(4) Case IV. This case is similar to Case III except there is no VDatum model covering the project. As in Case III, an upstream tide gage would need to be established to perform a datum comparison with the entrance gage. The MLLW reference plane between the two gages could be modeled by spatial interpolation methods. The offshore entrance channel datum relationship would have to be extrapolated from the entrance gage, unless other tidal data are available. More robust tidal modeling methods described in Section 4-6 would better model the river and offshore entrance channel.

(5) Case V. This is a "worst case" condition—no existing or historic gages at the project. Depending on various funding and maintenance levels, a full gaging program would be needed to model the project. Two short-term gages would be established for periods of 30 days or more, from which datum comparisons are made with nearby NOAA NWLON stations. The MLLW model would be developed using one of the methods described in Section 4-6.

d. NOAA requirements for short-term tide gages needed to update tidal models at a navigation project. When historical NOAA tide gage sites are occupied, or additional gaging data are needed to model the tidal regime at a navigation project, NOAA requires the following minimum standards in order for the site to be included in the CO-OPS database.

(1) Types of recording gage. At a new site, any NOAA approved type of temporary gage that can measure recorded water levels at 6-minute intervals is suitable. The gage must be firmly tied in and referenced to the local tidal bench marks at the site.

(2) Location of temporary gage. As needed to cover the navigation project and survey calibration. To be coordinated with NOAA CO-OPS.

(3) Length of record. Minimum of 30 days. Longer term if required by NOAA CO-OPS. A shorter term—3 to 7 days—may be used for adding gages within projects for use in calibrating hydrodynamic models and referencing RTK/RTN hydrographic surveys.

(4) Tidal bench marks. Five bench marks are required around the gage site. Follow mark construction requirements outlined in EM 1110-1-1002 (*Survey Markers and Monumentation*). No deep driven rods are required. Type C, F, and G marks are acceptable.

(5) Data format and submittal. Follow NOAA CO-OPS submittal requirements.

(6) Datum transfer computations. Follow NOAA CO-OPS simultaneous comparison standards—see NOAA 2003. NOAA CO-OPS will check datum transfer computations if they are performed in-house or by an A-E.

(7) Third-Order leveling between tidal bench marks. Follow standard procedures in EM 1110-1-1005 (*Control and Topographic Surveying*) for both new and existing gage sites.

(8) Primary tidal bench mark elevation. Tidal bench marks at both new and existing sites will be referenced to and input to the NSRS using CORS/OPUS input methods outlined in Chapter 3.

Detailed procedures for establishing tide gages and computing tidal datums at navigation projects can be found in Section 4 (*Tides and Water Level Requirements*) of "*NOS Hydrographic Surveys Specifications and Deliverables*" (NOAA 2009).

e. Referencing projects to the current tidal epoch. USACE projects must be referenced to the current NTDE defined by NOAA. NOAA periodically updates the tidal datums throughout CONUS and OCONUS to account for sea level change (rise or fall), local land settlement of tidal gage PBMs, and other factors. These periodic apparent sea level adjustments can be significant—ranging from 0.2 ft to 0.5 ft over the last 19-year update period (1983-2001) on the Atlantic East Coast. Projects not updated since the 1940s would have significantly larger differences—note the upward "apparent" sea level trend at Annapolis, MD shown in Figure 4-7. These adjustments represent systematic changes to the local reference datum (e.g., MSL or MLLW). They also represent systematic biases in navigation project depths or shore protection structure elevations.

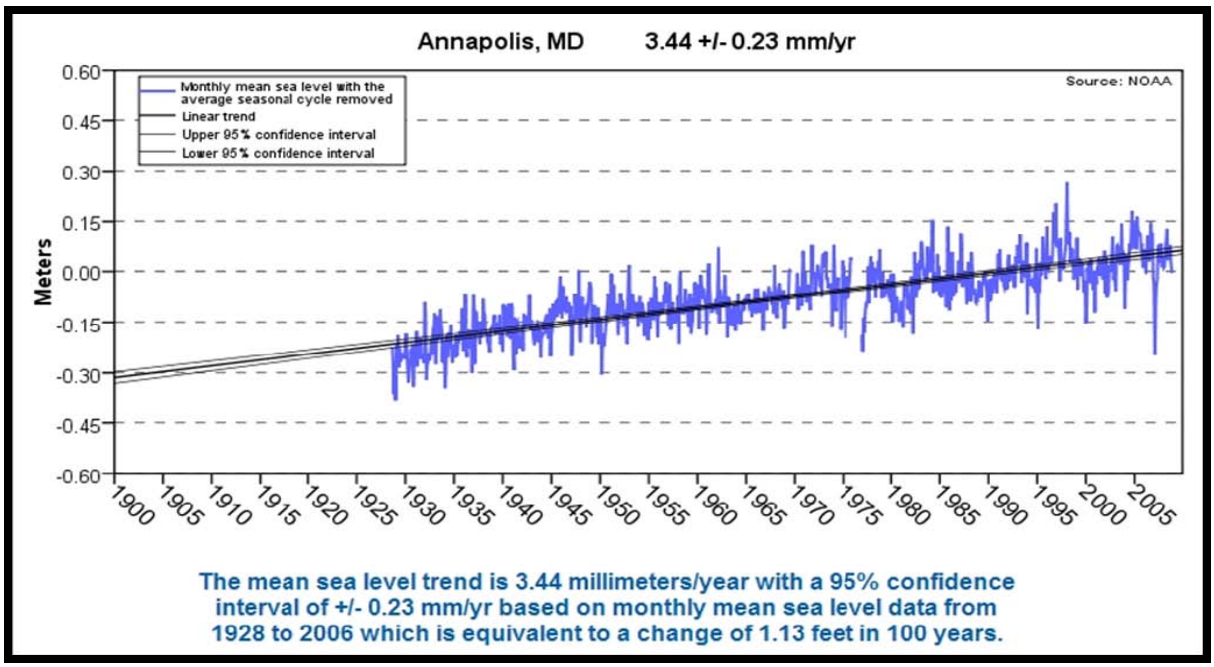

Figure 4-7. Sea level trends at Annapolis, Maryland.

(1) Sea level change impacts on tidal datums. Generally, on most CONUS East and Gulf Coast locations, sea level rise results in maintaining deeper navigation projects than were authorized, and overdredging if the sea level rise is not accounted for. Conversely, on shore protection structures, sea level rise results in less protection than originally designed, assuming this predicted rise was not factored into the design. Numerous USACE, NOAA, and academic technical publications provide guidance on estimating future sea level change for use in the

design of project grades. USACE technical guidance on assessing sea level change recommends that potential relative sea-level change must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence ... and that fluvial studies (such as flood studies) that include backwater profiling should also include potential relative sea-level change in the starting water surface elevation for such profiles, where appropriate. Sea level change projection uncertainties must be coupled with the uncertainties in the reference datum relating the projected sea level parameters. Refer to Chapter 9 for uncertainties associated with reference datums.

(2) Impact of tidal epoch changes on dredge clearance surveys. Figure 4-8 illustrates the impact of a tidal epoch change on a project that was dredged relative to the superseded 1960-1978 tidal epoch. Adjustment to the latest epoch (1983-2001) significantly reduced the number of strikes above grade that would have required additional dredging had the superseded epoch been held. Of importance is that the required dredging grade of 36.0 ft on the 1960-1978 epoch was 36.22 ft on the 1983-2001 epoch—the project was overdredged by 0.22 ft.

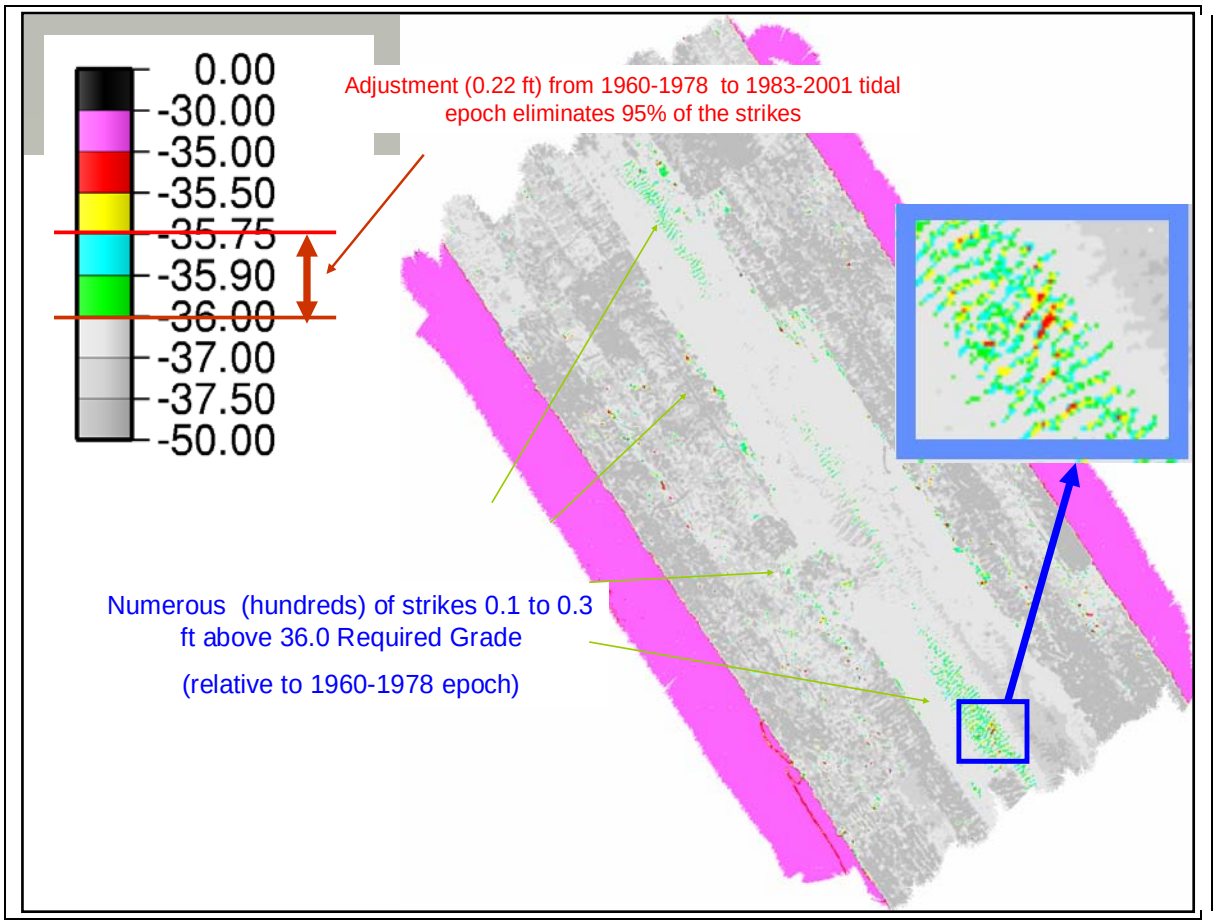

Figure 4-8. Impact of tidal epoch updates dredging strike detection and clearance grades.

(3) Epoch updates are averages from long-term estimates. The adjusted sea level or MLLW datum elevation is based at the midpoint of the epoch. Thus, the current epoch (1983-2001) is averaged about 1993. Tidal epoch adjustments are easily corrected by ensuring projects

are updated when NOAA completes a periodic epoch change. In areas with significant rates of sea level changes or subsidence, NOAA CO-OPS should be consulted to assess the need for shorter 5-year modified tidal datum epochs. NOAA has introduced modified 5-year tidal datum epoch procedures in areas of Louisiana and Texas (due to rapid subsidence) and Alaska (due to rapid land uplift).

4-5. Tidal Datum Uncertainty Estimates. Tidal datums used to reference USACE navigation projects contain two major error sources. These include (1) The regional accuracy of the MLLW datum computed at the project reference gage relative to 19-year NWLON stations, and (2) The local or relative spatial accuracy of the MLLW datum model relative to the project's reference tide gage and the reference orthometric datum (currently NAVD88). If RTN or RTK survey techniques are performed, then the uncertainties in the ellipsoid height measurement and geoid model must be factored into the overall "tidal-geoid" model covering the navigation project. If RTN or RTK surface elevation measurements are not used (i.e., tide readings from a gage are extrapolated to the project site without phase or range correction) then no readily defined accuracy estimate can be made, other than assuming that "worst case" tidal range, tidal phase, and hydrodynamic meteorological conditions occur between the gage and project site.

a. Estimates of NOAA tidal datum regional accuracies. Computed accuracies of tidal datums at a navigation project gage site refer to the uncertainties of the established reference datum at a gage site, such as MLLW or MSL. These estimates have application when a tide gage must be installed at a USACE project to reestablish the reference datum.

(1) Datum errors. The total error of computed tidal datums at a NOAA gage has the following component errors.

(a) Gage measurement error. The measurement error is a combination of the gage/sensor and processing error to refer the measurements to a station datum.

(b) Datum comparison error. The error in computation of equivalent 19-year tidal datums from short-term tide stations. The shorter the time series, the less accurate the datum, i.e., the larger the error. The closer the subordinate station is in geographic distance and in tidal difference to a control station, the more accurate the datum. Estimated maximum errors of an equivalent tidal datums based on one month of data is 0.26 ft for the Atlantic and Pacific coasts and 0.36 ft for the coast in the Gulf of Mexico (at the 95% confidence level).

(2) Tidal datum uncertainties at NOAA gages. Table 4-1 lists the estimated accuracy (i.e., uncertainty) of computed tidal datums for various lengths of gage observation periods. It indicates that, in general, tide stations with at least 3 months record have determined a tidal datum to within ± 0.15 ft. If a NOAA historical gage has some 12 months of record (which is common) then the accuracy of the computed MLLW datum at that point is better than ± 0.1 ft. Refer to NOAA 2001 (*Tidal Datums and Their Applications*) for more details.

Table 4-1. Generalized Estimated Uncertainties of Tidal Datums for East, Gulf and West Coasts when Determined from a Short Series of Record – at 95% Confidence levels.
(from Table 2, NOAA 2001)

Series length (months)	East Coast	Gulf Coast	West Coast
1	± 0.26 ft	± 0.36 ft	± 0.26 ft
3	± 0.20 ft	± 0.30 ft	± 0.22 ft
6	± 0.14 ft	± 0.24 ft	± 0.16 ft
12	± 0.10 ft	± 0.18 ft	± 0.12 ft

(3) Computed tidal datum error. The estimates in Table 4-1 are regional generalized uncertainties and should only be used for planning purposes. Instead of the regionalized approach in the above table, the following relationships may be used to estimate tidal datum uncertainties for each individual subordinate tide station. Specifically, the tidal datum uncertainty is determined from the relationship of the subordinate tide station to the control tide station to which the simultaneous comparison is being made. Assuming most subordinate tide stations for NOS hydrographic surveys are operated for less than one-year durations, the regression equations for mean low water for one-standard deviation ("s") estimates are of the form:

$$s_{1\ month} = 0.0068\ ADLWI + 0.0053\ SRGDIST + 0.0302\ MNR + 0.029$$

$$s_{3\ months} = 0.0043\ ADLWI + 0.0036\ SRGDIST + 0.0255\ MNR + 0.029$$

$$s_{6\ months} = 0.0019\ ADLWI + 0.0023\ SRGDIST + 0.207\ MNR + 0.030$$

$$s_{12\ months} = 0.0045\ SRSMN + 0.0128\ MNR + 0.025$$

where:

ADLWI is the absolute difference (in hours) in low water time intervals between subordinate and control stations.

SRGDIST is the square root of the geodetic distance between the control and subordinate stations, measured in nautical miles.

MNR is the mean range ratio that is computed from the absolute value of the difference in

mean range of tide between control and subordinate tide stations divided by the mean range of tide at the control station.

SRSMN is the square root of the sum of the mean ranges computed by adding the mean ranges of the control and subordinate stations and then taking the square root of this sum.

For stations with series longer than one-year in length, the datum errors can be time-interpolated between the estimate at that station for a one-year series and the zero value at 19 years. Errors in tidal datums for accepted datums from 19-year control tide stations are zero by definition. Using these formulas, estimates of the datum error can be uniquely computed in the planning process for each subordinate tide station being used for the hydrographic survey using historical and accepted tidal datums on file.

(4) Recommended observation periods for USACE projects. When a gage is installed at a USACE project, the above NOAA accuracy estimates may be used to assess the required observation period. Based on Table 4-1, 30 days of simultaneous gage observations should usually be adequate to develop a reliable reference datum at the ± 0.25 ft level on most East Coast and West Coast projects. Deep-draft projects with critical keel clearance issues may warrant 3 to 12 months of observations. All gage installations, observation periods, and datum computations should be closely coordinated with, and approved by, NOAA CO-OPS.

b. Local or relative tidal datum accuracy. It is important to emphasize that the above uncertainties in the computed datum at a tide gage do not necessarily factor into the relative, or local, accuracy of an established tidal datum on a project. The computed/established reference datum at the gage is considered "fixed" for referencing dredging grades. Thus, for the purposes of defining dredging grades on navigation projects, errors in the "global" or regional determination of the reference datum are not usually an issue, other than providing regional uncertainty estimates of tidal datums for storm surge monitoring or like purposes. If a NOAA tidal PBM is used to reference grades at a project site, then both USACE channel clearance surveys and NOAA charts will be referenced to the same "local" MLLW datum.

(1) For small navigation projects with only one reference tide gage, the reference datum at the gage is the designated reference for the entire project, and RTK calibrations are performed to tidal PBMs at this gage. For larger projects with two or more tide gages, calibration discrepancies between the gages may result due to the absolute (regional) datum uncertainties between the tide gages. These calibration differences may or may not be significant. If significant, then a zoned calibration reference should be designated for each project reach—e.g., specify the tide gage to be used for specific channel reaches. The following Table 4-2 is an example of a zoned gage reference on a large 67-mile length project with VDatum coverage. In this example, VDatum model calibrations were made using a regional RTN network, resulting in 0.1 to 0.2 ft variations at the calibration gages. Construction survey plans in a given channel reach are fixed ("zoned") to the gages in the table—i.e., all users must calibrate RTN systems to MLLW at these specific gages for a given channel reach.

Table 4-2. Zoned Reference Gages for Tampa Harbor Channel Reaches.

Tampa Harbor Channel Reach	NOAA Gage	Station ID
Egmont Cuts Mullet Key Cut	Egmont Key Mullet Key	872 6347 or 872 6364
Cut A, Cut B, and Cut C	Port Manatee	872 6384
Cut D, Cut E, and Cut F	St. Petersburg	872 6520
Gadsden Point Cut to PI Cut A & C (HB) and Cut G (PT)	Gadsden Point	872 6573
Cut C (HB) and Alafia River Channel	Long Shoal-MacDill AFB	872 6604
Davis Island, Seddon Island Port Sutton, & McKay Bay Channels	Ballast Point Hooker Point Davis Island	872 6639 or 872 6668 or 872 6657
Cut J (PT) & Cut K (PT)	Port Tampa	872 6607

(2) Regardless of the absolute accuracy of a tidal datum for a project, the relative accuracy (i.e., "repeatability") is most critical for survey and dredging operations. In general, a local tidal datum relative accuracy of ± 0.1 ft should be achievable at most navigation projects where an established tide gage exists. RTN calibrations are performed at this gage and a VDatum type model is used to correct for local MLLW variations.

c. Dredging measurement & payment survey repeatability. As stated above, for USACE tidal datum modeling purposes, and subsequent maintenance dredging and construction of projects, the accuracy of a NOAA gage datum, (or acceptable datums from another agency's long-term gages) will be assumed as absolute—i.e., they will be assumed to have “zero error” ("zero uncertainty") irrespective of the actual computed datum uncertainties at a particular gage. This assumption is valid in that the final developed MLLW tidal model for the project (e.g., NAVD88-MLLW differences in VDatum) will also be considered fixed for project construction purposes. This fixed local VDatum model, when used with RTK, provides repeatability between users (surveyors, dredges, etc.), limited mainly by the precision of the RTK solution and the site calibration. This repeatability is critical for equitable dredge payment surveys. If RTK is not used, and zoning estimates relative to a water level gage are used, then repeatability will be dependent on tidal range and phase variations.

d. Tidal datum accuracies for navigation projects. Table 4-3 represents the desired accuracy of a navigation project model, considering the total propagated uncertainties (TPU) in both the MLLW datum and the geoid.

Table 4-3. Recommended Accuracies for Tidal Reference Datums on Navigation Projects with VDatum Coverage.

	Accuracy (95%)	Relative to Datum
Absolute accuracy of tidal datum relationship at gage	± 0.25 ft	MLLW Regional NWLON
Relative accuracy of local tidal model	± 0.2 ft	Local MLLW at PPCP Gage

Tidal-geoid model numerical resolution:	nearest 0.01 ft
Model 1D or 2D density in navigation channel:	100 to 500 ft (varies with tidal range)
Geoid model:	use latest available at time of study (currently Geoid 09)
Tidal-geoid model format:	1D or 2D (1D for linear navigation channels)

NOTE: The above standards are believed representative for most CONUS navigation projects. Exceptions may exist in extreme tide ranges or in parts of Alaska. See VDatum uncertainty models on NOAA VDatum web site.

In general, a full tidal-geoid model absolute accuracy of < ± 0.25 ft should be achievable at most deep-draft navigation projects where NOAA calibration gage data exists. Local (relative) model accuracy should be better than ± 0.1 ft on such a project—i.e., that accuracy relative to one or more local NOAA gages where VDatum coverage exists. Regardless of the resultant absolute accuracy of a tidal model for a region, the relative ("repeatable") accuracy is most critical.

4-6. Tidal Modeling Methods to Define Local MLLW Datums on Coastal Projects. Defining the MLLW datum tidal model on a navigation project requires the following basic actions: (1) ensure tidal datum reference planes (MLLW) are defined relative to published NOAA gages and tidal benchmarks, (2) ensure the latest tidal epoch adjusted by NOAA is used, (3) model the MLLW reference plane and geoid throughout the geographic extent of the project, (4) verify/calibrate the MLLW model at gage sites, (5) publish/disseminate the tidal-geoid model for

users—e.g., a Kinematic Tidal Datum (KTD) file, (6) determine the NAVD88-MLLW datum relationship at tidal benchmarks, and (7) submit any field GPS or gage data to NOAA for their use in expanding the nationwide VDatum. Actions (1) and (2) are easily achieved as long as an existing or historical gage exists at the navigation project. This will likely be the case for the majority of the Corps' deep-draft navigation projects. If not, then a short-term gaging program will have to be developed in order to establish a tidal datum at a project. Any such effort must be coordinated with NOAA in order to ensure the project becomes included in the NOAA CO-OPS gage inventory. Project modeling—actions (3) through (7)—will require close coordination with District H&H elements, ERDC/CHL, and/or NOAA. In small tide ranges, or in survey areas that are small geographically and hydrodynamically simple, linear interpolation of the MLLW model will often be sufficiently accurate and economically developed. By 2012, VDatum models may already have been developed for most projects.

a. Modeling techniques. A number of techniques can be employed to model the variations in tidal datums on a coastal navigation project. These models reflect the changes in mean or diurnal tide ranges that occur on the project. They are configured to relate the difference between NAVD88 and MLLW spatially over the project since RTK observations of ellipsoid heights are reduced to a NAVD88 elevation of the local water surface. These models may be simple or complex depending on the project use and maintenance activity—ranging from assumed constant NAVD88-MLLW differences throughout the project to a full hydrodynamic tidal model of varying NAVD88-MLLW differences based on multiple gages in the project area. These various modeling options include:

(1) Constant NAVD88-MLLW model. Assumes no significant tidal range or phase differences occur between the reference gage and project site—i.e., a "tide correction" at a reference gage is extrapolated to the project site. This "model" is only applicable when the gage is close to a confined project site with a small tide range—i.e., minimal potential phase and wind effects between the gage and the site. The water level elevation ("tide correction") and the NAVD88-MLLW difference at the gage are assumed the same throughout the project. If RTK positioning is used under such conditions, variations in geoid heights must still be applied.

(2) Spatial interpolation model between tide gages. A simple linear or TIN spatial interpolation of the variations NAVD88-MLLW differences between tide gages. Examples of spatial interpolation modeling methods are shown in Appendix E.

(3) NOAA tidal zoning estimates. Tidal zoning models are estimates of tidal ranges and tidal phases at an offshore project site. Tidal zoning is used extensively by NOAA but only on isolated USACE projects (e.g., Chesapeake Bay). A further discussion on tidal zoning is at Appendix E.

(4) NOAA Tidal Constituent And Residual Interpolation (TCARI) model—a NOAA/CO-OPS spatially interpolated model. Incorporated in, and being replaced by, NOAA VDatum models.

(5) Hydrodynamically generated tidal models. Hydrodynamically generated tidal models that spatially develop the tidal regime and MLLW datum variations over the project.

b. Tidal datum models. Figure 4-9 illustrates a tidal datum model for a coastal inlet navigation project. As shown on the figure, the existing MLLW datum model is based on a straight-line interpolation between the gages. A hydrodynamic tidal model, such as VDatum, would fit (calibrate) the induced astronomical tide to the MLLW datums at each gage, as shown by the curved MLLW profile in the figure.

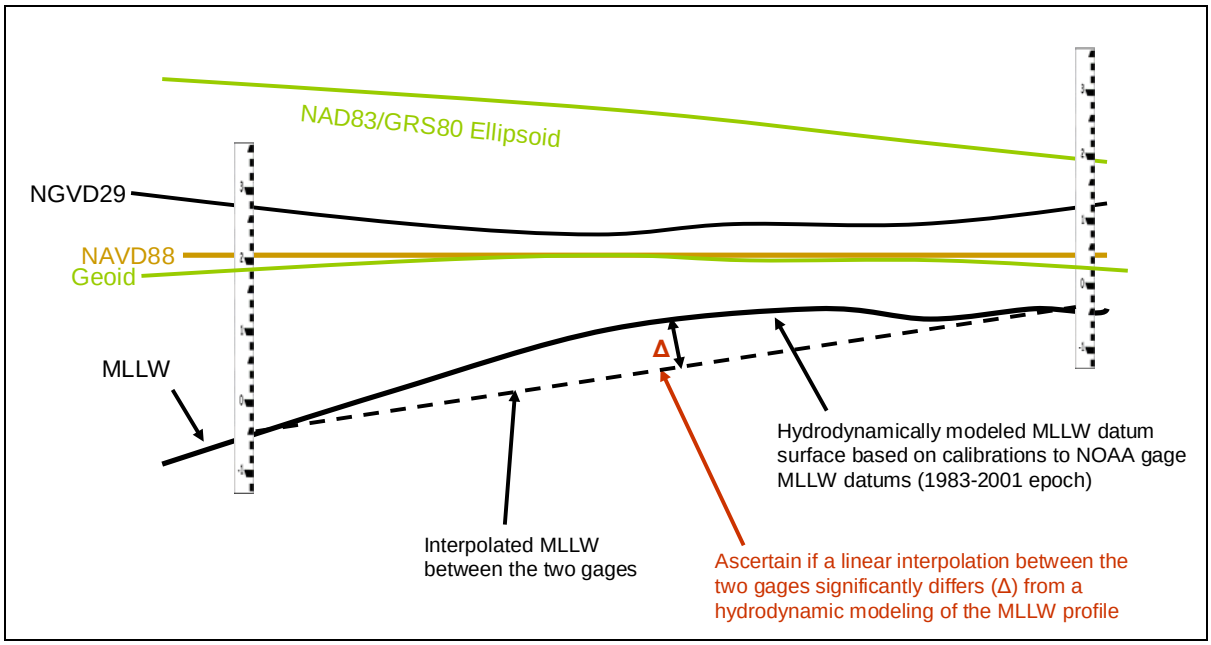

Figure 4-9. Modeled versus interpolated MLLW datums.

(1) Interpolated tidal models. Of significance is whether this project can be just as effectively modeled using a simple straight-line interpolation between the gages as opposed to running a full hydrodynamic model. In lower tide ranges, or with dense gage data, this would be the case. In general, if the estimated variation between a model and straight-line interpolation does not exceed 0.1 ft, then the straight-line interpolation would be acceptable. This variation is indicated by "Δ" in Figure 4-9. The use of validated VDatum models is recommended in lieu of linear interpolation.

(2) Geodetic reference datums. Figure 4-9 also depicts the relationship between other geodetic reference datums. The local geoid model would provide the undulation shown relative to NAVD88, and indirectly relative to MLLW. NOAA's VDatum model includes the transformations between all these datums.

c. Example of a spatially interpolated project. Appendix F contains an example of a Jacksonville District project (Canaveral Harbor) where spatial interpolations of the MLLW reference datum were estimated from NOAA gage data; both in the offshore Entrance Channel and in a semi-controlled pool. These estimates were made prior to receipt of VDatum model data which will supersede these estimates.

4-7. National Vertical Datum Transformation Software (VDatum). VDatum is a vertical datum transformation software tool developed by NOAA for coastal areas that allows users to transform geospatial data among a variety of geoidal, ellipsoidal, and tidal vertical datums. VDatum is important to coastal applications that rely on vertical accuracy in bathymetric, topographic, and coastline data sets, many of which may be produced on different reference datums but need to be merged for hydrodynamic surge models. VDatum has application to most, if not all, USACE coastal navigation projects. It also represents a defined datum reference for USACE projects.

a. Transformation datums. Currently the VDatum software is designed to convert between over 30 geodetic datums, including full continuous models of NAVD88 and MLLW, which are especially applicable to most USACE navigation projects. Various geoid models are also included. Figure 4-10 depicts the variety of datum transforms currently available in VDatum. Only the NAD83/NSRS2007 ellipsoidal datum is utilized on CONUS projects.

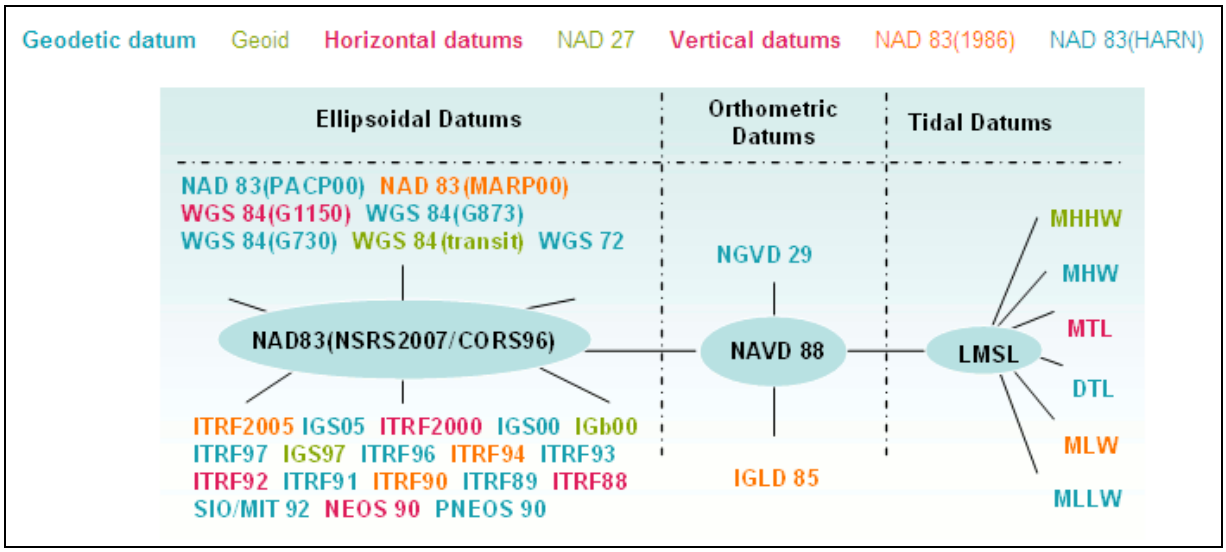

Figure 4-10. Primary VDatum transforms between ellipsoidal, orthometric, and tidal datums.

b. VDatum coverage. Figure 4-11 shows VDatum coverage as of 2010. It is anticipated that complete CONUS coverage will be available in or after 2012. Coverage of some OCONUS areas is in progress. In many cases, VDatum coverage extends up to the head of navigation on deep-draft harbors and ports.

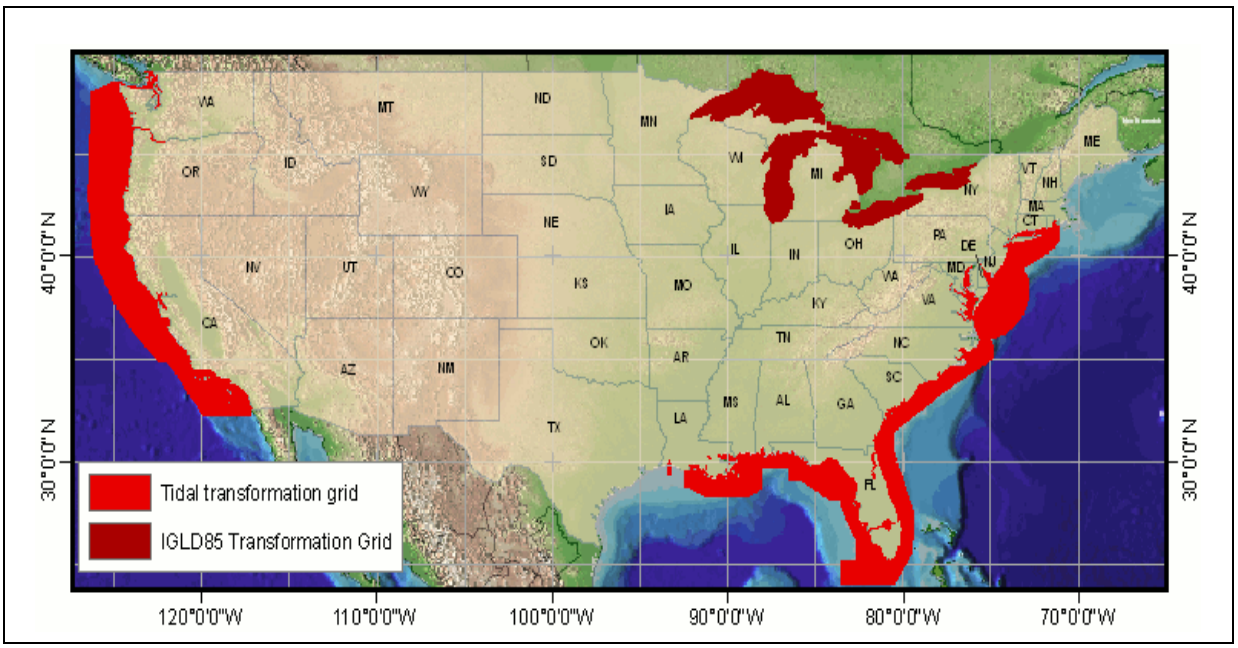

Figure 4-11. VDatum coverage in CONUS as of April 2010 (NOAA).

c. Use of VDatum for surveying and dredging applications. Most USACE applications will involve incorporating VDatum transforms with observed real-time GNSS satellite observations to obtain the elevation of the water surface relative to the local construction datum (e.g., MLLW, LMSL, IGLD85, etc). This water surface elevation, often resolved as a "tide correction" in RTN/RTK hydrographic positioning and orientation systems, is then applied to a measured depth to obtain a "corrected depth." The applicable VDatum ellipsoid-NAVD88-construction datum transforms in a project area are normally output to a 2D TIN model of the project area. This TIN model can then be input into surveying and dredging positioning/orientation software for real-time datum conversions at any point on the project. An example of this is the HYPACK "KTD" file. Future developments in survey and dredge positioning/orientation software will include a seamless input of VDatum transform models.

d. Site calibration. VDatum models of navigation projects need to be "site calibrated" (i.e., verified) prior to use in dredging measurement & payment or clearance surveys. This entails comparing observed water surface elevations at a reference NOAA tide gage/staff to those reduced through VDatum on a RTN/RTK survey positioning/orientation system on the vessel. Given the resolution of tide staff readings and RTK accuracy, tolerances approaching ± 0.2 ft would be expected. Uncertainty estimates for the various VDatum transformations are provided on NOAA's VDatum web site. An example of a VDatum site calibration is shown in Appendix D.

e. Further information on VDatum. Additional technical details on VDatum applications are available from the NOAA Coast Survey Development Laboratory "VDatum Team" web site and from "*Review of Progress on VDatum, a Vertical Datum Transformation Tool*" (Myers 2005).

4-8. Tidal Phase and Water Surface Elevation Variations over a Navigation Project. The major correction in the depth measurement survey of a navigation project is for tidal phase (latency) variations between the reference tide gage and the location of the dredge or survey vessel at the project site. Local hydrodynamic and meteorological effects (e.g., wind set up) changes the water surface elevation profile in the project. These variations due to tidal phase, along with other hydrodynamic or meteorological effects, increase with the distance from the tide gage. These systematic differences can exceed 1 to 2 ft in moderate range projects, and higher on projects with large tide ranges (over 10 ft) or experiencing adverse weather conditions. They are most pronounced during periods of full ebb and flood tide. Many dredging measurement & payment survey disputes and claims arise over lack of adequate compensation/correction for tidal phase and meteorological set up throughout a project site—see EM 1110-2-1003 (*Hydrographic Surveying*) for details..

a. Tidal phase latency variations. EM 1110-2-1003 and EM 1110-2-1100, (*Coastal Engineering Manual*), Part II-6, "*Hydrodynamics of Tidal Inlets*" have numerous examples of the tidal phase and MLLW range variations that typically occur between the ocean and bay at a typical coastal inlet. These tide curves do not include any hydrodynamic or meteorological effects which could, at times, exceed the basic phase variations. Modeling and correcting these tidal phase variations throughout the project is critical.

b. Water surface elevation measurements using RTK techniques. Tidal phase errors and weather/sea surface set up are effectively eliminated by using RTK surface elevation measurement techniques, coupled with inertial measurement and orientation systems. Local water level variations can be measured in real-time using these RTK techniques, either from a local RTK base station set at a PPCP or from a regional RTN system. RTK methods effectively measure the local water surface elevation relative to the ellipsoid; thus, providing direct corrections relative to a MLLW datum at a modeled offshore construction site.

(1) Dredging measurement & payment surveys performed using RTK methods will usually employ a combined tidal-geoid model from which to correct observed ellipsoid heights measured relative to the water surface; to obtain a surface elevation relative to the tidal MLLW model at the project site. Thus, the measured ellipsoidal height of the water surface at any point is corrected for (1) geoid model undulations, and (2) tidal range variations based on hydrodynamic models of the tide in the region. The RTK measurement process is illustrated in Figure 4-12. The actual offshore water surface level above local MLLW (i.e., a "tide correction") is thereby measured at every observation (typically 1 to 10 Hz) made by a survey vessel, dredge, or commercial vessel employing RTK methods; and an average surface level above local MLLW computed using filters and/or an inertial measurement unit (IMU) over a 30 to 120+ second filter period. As long as every user (vessel) employs the same tidal-geoid model for the region, then full repeatability of surface elevation measurements will be achieved. The relative accuracy of the RTK measured surface elevation and tide level will fall around ± 0.05 ft level. The tidal-geoid model developed for the project is considered as absolute.

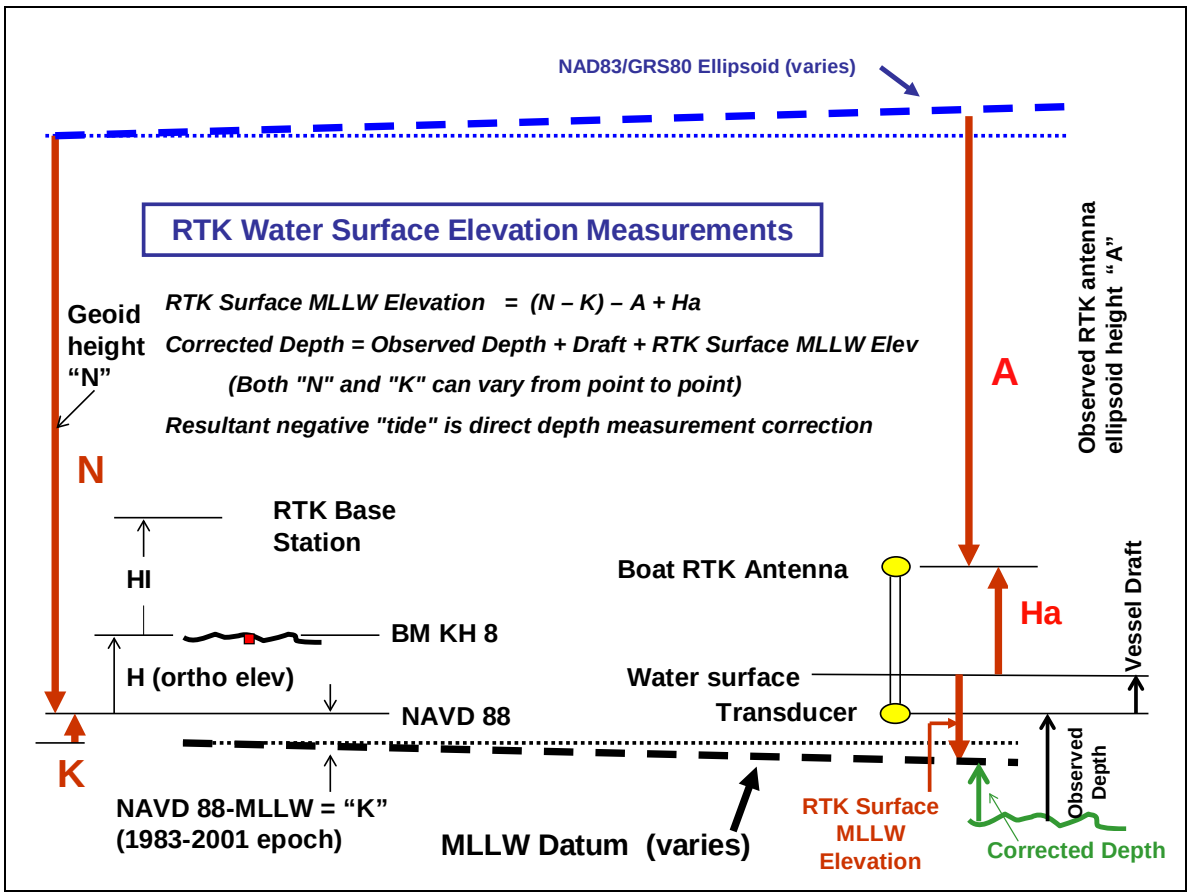

Figure 4-12. RTK Ellipsoid-Tidal-Geoid parameters for water surface elevation measurements. (Note: coordinate system is positive up)

Using the parameters shown in Figure 4-12, the following is an example of RTK observations and vessel depth measurements that derive a "corrected depth" on the MLLW reference datum. Note that observed depths and drafts are shown as positive values in Figure 4-12. Observed depths and corrected depths are shown as positive downward values.

RTK Parameters	Vessel Observations
N = (-) 71.29 ft	Observed Depth: + 40.0 ft
K = + 1.76 ft	Vessel Draft: + 3.0 ft
A = (-) 45.00 ft	
H_a = + 22.05 ft	

RTK Surface MLLW Elevation = (- 71.9 - 1.76) – (- 45.0) + 22.05 = (-) 6.0 ft

Corrected Depth = = + 40.0 + 3.0 + (- 6.0) = 37.0 ft

(2) Geoid model accuracy is a function of the location and density of NSRS vertical control and gravity data in the area. The predicted geoid undulation from the latest geoid model will be

used for offshore entrance channels—areas that obviously have no vertical control but have geoid height estimates using other techniques (airborne gravity). NGS should be contacted to confirm the accuracy of the predicted geoid model does not exceed reasonable tolerances. Likewise, the predicted tidal range in offshore entrance channels 3 to 10 miles seaward may have to be based on established regional models of the ocean tides. In such cases, the estimated accuracy of these regional models may be verified by contacting ERDC/CHL or NOAA. Alternatively, these offshore tidal ranges, and indirectly the geoid model, can be easily confirmed by observing long-term RTK data recorded during the course of a survey in the area.

(3) It is emphasized that the tidal-geoid model developed for each project must be published and disseminated to all users. This may be a simple ASCII file in the form of a gridded difference between NAVD88 and MLLW (NAVD88-MLLW), such as a “KTD” file used by commercial navigation dredging software (HYPACK®). Since most USACE navigation projects are linear, only a 1D model may be required—e.g., a tidal-geoid correction every 100-ft station down the channel centerline. This is adequate to cover the areal extent of a 100 ft to 1,000 ft wide channel. This file may periodically be updated if the MLLW tidal model for the region is significantly modified by NOAA. Thus, the file must clearly identify (metadata) the source of the data. Care must be taken in that in some navigation/dredging processors, the geoid correction may be performed separately by the GPS receiver from the MLLW tidal model correction—i.e., two distinct corrections. Thus the KTD file may contain only the tidal datum correction (NAVD88-MLLW or "K" in Figure 4-11) or may combine both the tidal datum correction "K" and the geoid correction "N." Users must also be advised that RTK, like any measurement system, must be periodically checked (and site calibrated/localized if necessary) against a physical recording tide gage or staff gage.

c. RTK versus gage surface elevation measurement. Figure 4-13 illustrates the application of using GPS/RTK elevation measurement for removing tidal phase and wind-induced errors on a Jacksonville District dredging project at Key West, FL. In this example, a constant 0.3 ft phase bias (and perhaps some wind setup bias) is generated during ebb tide at a point only 3 miles distant from the gage. This phase bias is significant given the tide range at this project is only about 2 ft. Had the NOAA tide gage been used to correct depth measurements during this survey, a 0.3 ft bias would have been translated to the quantity measurements in this Acceptance Section. As shown in Figure 4-13, the RTK-determined elevation of the sea surface at the dredging site was estimated to be accurate to ± 0.05 ft, effectively minimizing the tidal phase and potential meteorologically induced errors at this offshore project site. RTK operations are only successful if the MLLW to ellipsoidal difference are correctly modeled and understood prior to the survey as these two reference planes have slopes relative to each other.

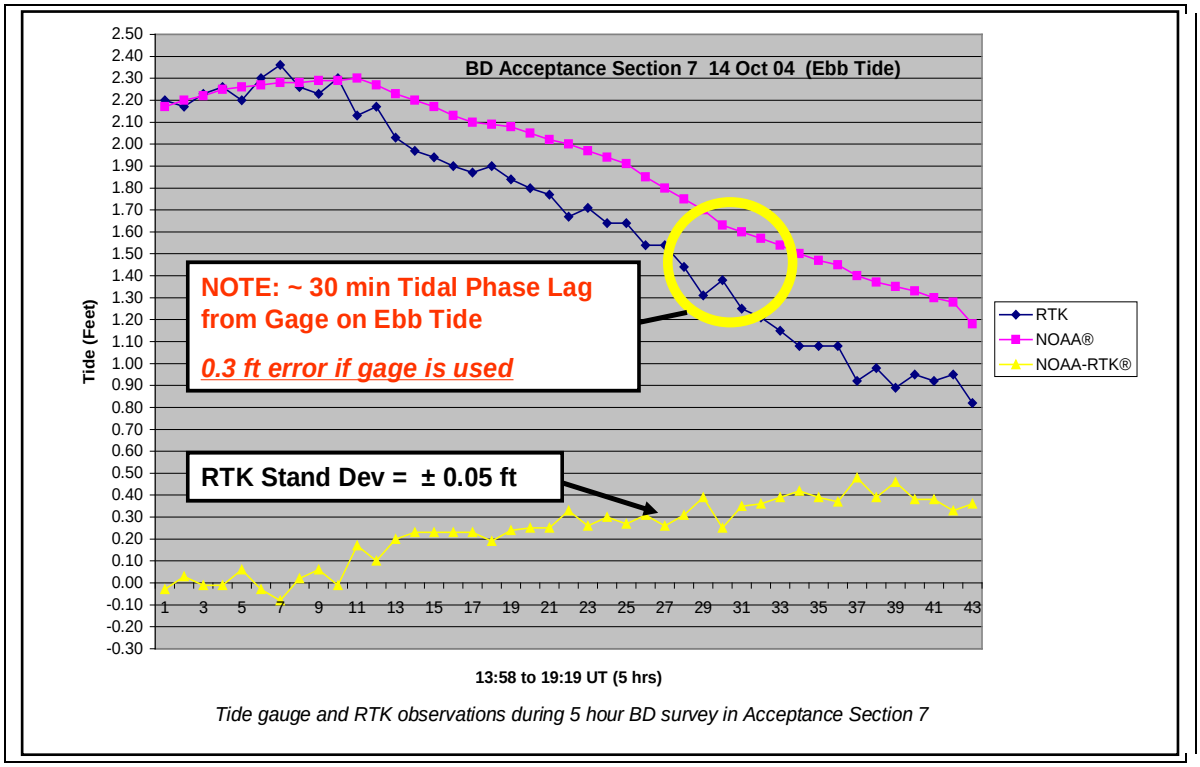

Figure 4-13. Offshore RTK tide comparisons with an onshore NOAA tide gage. (Key West Harbor, FL Acceptance Section 7—3 miles south of Key West in open water)

d. RTK survey procedure references. See EM 1110-2-1003 for additional details on the impacts of tidal phase errors on dredging measurement & payment surveys. Refer to EM 1110-1-1003 (*NAVSTAR GPS Surveying*), EM 1110-1-1005, and hydrographic survey system user manuals for detailed RTK survey procedures.

4-9. Channel Control Framework Drawing Notes for Navigation Projects. Detailed datum metadata are required on drawing notes for plans and specifications surveys, channel condition surveys, and measurement & payment surveys. It is especially critical that bid documents for dredging projects contain the essential horizontal and vertical datum parameters, gages, and transformation models that will be used during construction. See Appendix D for an example of drawing notes used on a Jacksonville District project with VDatum and partial RTN coverage.

4-10. Summary of Evaluation Factors for Determining a Reference Tidal Datum on a Navigation Project. Table 4-4 outlines a general decision flow process for determining the reference tidal datum for a navigation project, based on the issues discussed above.

Table 4-4. Tidal Reference Evaluation Factors.

I. Existing Tide Gage Data

Does project have an existing tide gage that is adequate to define the tidal datum?
If NO, go to IV.

Is gage data based on relatively recent observations? If NO, go to IV.

Is gage observation series length adequate based on project use? If NO, go to IV.

Is gage datum based on or can be updated to current tidal epoch? If NO, go to IV.

Have physical modifications to project possibly impacted historical gage datum data?
If YES, go to IV.

Does gage location and density adequately model the entire project? If NO, go to III.

II. Reference Tidal Bench Marks

Were two or more tidal bench marks recovered at existing gage station?
Only one tidal bench mark recovered: Evaluate stability & reliability
No tidal bench marks recovered? If YES, go to IV.

Are tidal bench marks stable based on field level checks? If NO, perform checks.

Does existing gage site contain 3 or more reference PBMs? If NO, add PBMs as required.

Do any tidal reference bench marks need to be published in the NSRS?

III. Tidal Modeling

Does NOAA VDatum model adequately cover project to head of authorized navigation?
If NO, contact NOAA CO-OPS for possible extension of VDatum.

Has VDatum model been site calibrated/verified in the field?
If NO, perform field site calibrations.

If no VDatum coverage exists: Evaluate use of spatially interpolated model or NOAA TCARI model.

Has NAVD88-MLLW model file been generated for project?

Table 4-4 (Concluded). Tidal Reference Evaluation Factors.

IV. New Gaging Program Required to Develop Datum

Evaluate (with NOAA CO-OPS) options for using VDatum NAVD88-MLLW relationships
If not an option install a new gage to reestablish datum

Determine length of series requirements in coordination with NOAA CO-OPS	30 days most projects 90 to 360 days on critical clearance deep-draft projects

Were new reference tidal PBMs established and furnished to NOAA CO-OPS?

Do new reference PBMs need to be placed in the NSRS?

V. Hydraulic or Legacy Tidal Datums

Are legacy datums adequately referenced to the current MLLW datum?
If not, is estimated uncertainty documented?

In junctions between river and tidal datums, is the hydraulic low water plane adequately referenced to the NSRS and tidal datums?

Are local flood stages referenced to MLLW and NSRS?