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Engineering and Design
COMPREHENSIVE EVALUATION OF PROJECT DATUMS

Guidance for a Comprehensive Evaluation of Vertical Datums on Flood Control, Shore Protection, Hurricane Protection, and Navigation Projects

1. Purpose

This document provides guidance on the proper application of vertical datums used to reference protection elevations on flood control structures or excavated depths in navigation projects—hereinafter referred to as the Comprehensive Evaluation of Project Datums (CEPD) project. It describes specific procedural actions immediately required to evaluate the accuracy and adequacy of existing flood protection elevations or controlling navigation depths relative to federal datums established by the Department of Commerce and prescribed for government-wide use by the Federal Geographic Data Committee (FGDC). This guidance implements lessons learned from the Interagency Performance Evaluation Task Force (IPET) study conducted after Hurricane Katrina, as identified in Volume II (Geodetic Vertical and Water Level Datums) of the 1 June 2006 draft version of the Final IPET Report—see https://ipet.wes.army.mil. It is specifically intended to ensure that USACE project controlling elevations and datums are properly and accurately referenced to nationwide spatial reference systems used by other Corps Districts or Federal, state, and local agencies responsible for flood forecasting, inundation modeling, flood insurance rate maps, bathymetric mapping, and topographic mapping. It will be directly used in ERDC training sessions developed as a result of the IPET study. This document also implements and supersedes the interim guidance issued with a CECW-CE memorandum dated 4 December 2006, subject "Guidance for Establishing Primary Vertical Control on Flood Control Projects." This guidance also supports applicable portions of the National Levee Database (NLD) inventory project.

2. Applicability

This guidance applies to all USACE commands having responsibility for the project management, planning, engineering and design, operation, maintenance, and construction of civil works flood control, hurricane protection, shore protection, and navigation projects. This guidance is particularly applicable to hurricane and shore protection projects (HSPP) situated in coastal/tidal regions of the country, inland flood protection systems, and projects in areas with high rates of crustal subsidence or uplift.

3. Distribution

This publication is approved for public release; distribution is unlimited.

4. References

See Appendix A.

5. Scope

This guidance document distinguishes between inland and coastal projects. Appendix B contains guidance specific to upland or inland river flood control project elevations. Appendix C covers tide-based elevations on coastal navigation projects, shore protection projects, and hurricane protection structures. Appendix D provides guidance for documenting and web-based reporting to HQUSACE of each project's status. Appendix E references (but does not include) supplemental training material on geodesy, tidal models, and detailed examples of CEPD assessments for actual USACE projects. A copy of the Commanding General's 4 December 2006 directive memorandum is at Appendix F.

6. Discussion

A number of findings and lessons learned in the Hurricane Katrina IPET study (IPET 2006) revealed that hurricane protection structures were not designed and constructed relative to a vertical datum based on the most current hydrodynamic design model. In some cases, floodwall structures were mistakenly constructed relative to a terrestrial-based geodetic vertical datum instead of hydraulic/water-level referenced datums from which the structural protective elevations were designed. Often vertical datums specified for construction stakeout were based on older, superseded adjustments. Typically only a single benchmark was specified in the design documents, resulting in construction elevation uncertainties. Long-term land subsidence, seasonal tidal fluctuations, and sea level rise were not always fully compensated for in flood protection structure design or periodically monitored after construction. Aerial topographic mapping products were performed on a variety of datums and were inadequately ground-truthed. This caused difficulties in performing post-storm hydrodynamic surge modeling. In addition, navigation projects in tidal regions were often defined to a vertical reference datum that was not based on the latest tidal model for the region, or were defined relative to a datum that was inconsistent with recognized national or international maritime datums. The technical variations between geodetic, satellite-based (ellipsoidal), and water level datums, and their proper application on engineering and construction projects, were often misunderstood. These findings are outlined in detail in Volume II (*Geodetic Vertical and Water Level Datums*) of the referenced IPET Report. The following excerpt from the Report's Executive Summary synopsizes the need for this guidance:

> *A spatial and temporal variation was found to exist between the geodetic datums and the water level reference datums used to define elevations for regional hydrodynamic condition. Flood control structures in this region were authorized, designed, and numerically modeled relative to a water level reference datum (e.g., mean sea level).*

However, these structures were constructed relative to a geodetic vertical datum that was incorrectly assumed as being equivalent to, or constantly offset from, a water level datum. These varied datums, coupled with redefinitions and periodic readjustments to account for the high subsidence and sea level variations in this region, significantly complicated the process of obtaining a basic reference elevation for hydrodynamic modeling, risk assessment, and design, construction, and maintenance of flood control and hurricane protection systems ...[need to] refine the relationships between the various datums that are numerically compatible with the varied hydraulic, hydrodynamic, geodetic, and flood inundation models such as those used by the Federal Emergency Management Agency (FEMA).

The critical need to firmly establish the relationships between hydraulic and geodetic datums is highlighted in Figure 1 below, in which an I-wall type floodwall was constructed 2 ft below grade. Also indicated is the requirement to firmly connect design and construction reference benchmarks to both hydraulic and geodetic datums, and verify the adequacy of those connections prior to construction.

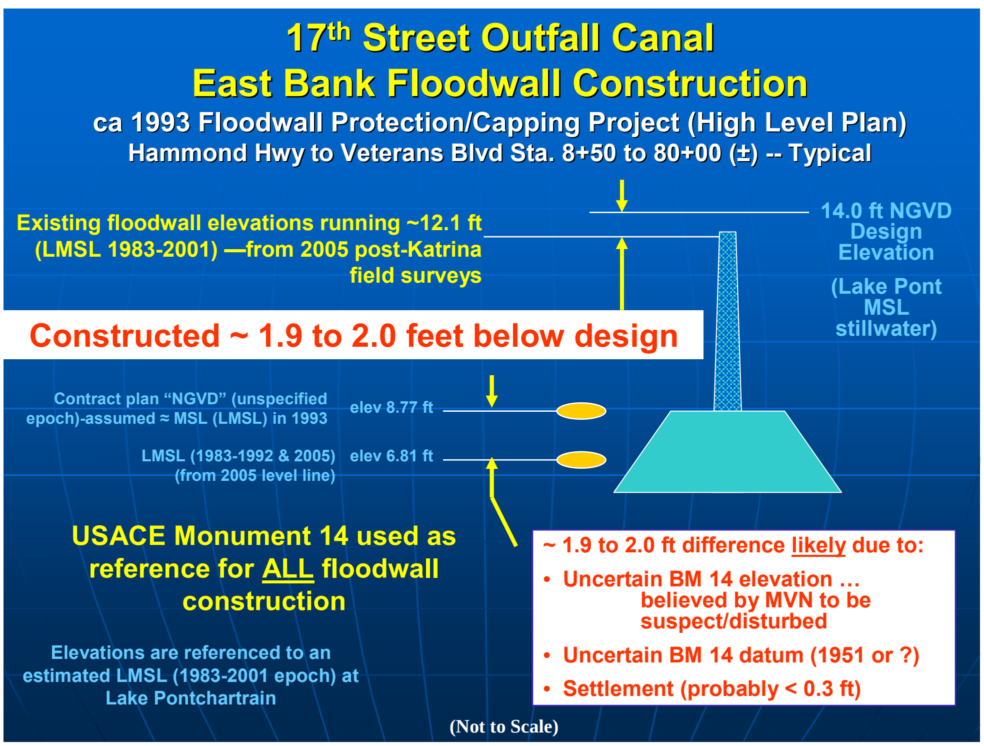

Figure 1. 17th Street Canal Floodwall Elevations—inconsistencies between geodetic and water level reference datums

The need for consistency on navigation project datums was also cited in the IPET report. The report cited a Water Resource Development Act (WRDA) 92 congressional action amending the Rivers and Harbors Appropriation Act of 1915. This amendment specifically required that navigation projects developed since the 1915 Act be referenced to a vertical mean lower low water datum (MLLW) defined by the Department of Commerce. The intent of WRDA 92 was to supersede older MLW datums on the Atlantic and Gulf Coasts or locally defined navigation datums. Subsequent guidance issued in 1993 to implement the provisions of WRDA 92 has not been universally followed as some projects are still on older tidal datums or epochs.

> SECTION 224: CHANNEL DEPTHS AND DIMENSIONS
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> Section 5 of the Act of March 4, 1915 (38 Stat. 1053; 33 U.S.C. 562), is amended -- (as indicated)
>
> Sec 5. 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.
>
> (Rivers and Harbors Appropriation Act of 1915)

7. Implementation Actions

Since vertical reference datum uncertainties and deficiencies described above are known to exist in other USACE regions, an assessment is needed of the accuracy of flood/hurricane protection elevations on existing flood control, reservoir, impoundment, or like projects. Authorized coastal navigation projects likewise need to be evaluated to ensure that maintained or constructed depths are based on the latest hydrodynamic tidal model. In addition, Commands need to ensure all geospatial surveying and mapping is performed on datums that are consistent with national and Federal standards. The guidance in this document provides sufficient detail for making a preliminary assessment of critical projects and preparing a budget estimate for programming corrective actions. During this review, special attention must be made to assess the following critical issues associated with a project's vertical reference:

- Flood control structure crest elevations were designed relative to hydraulic or hydrodynamic models that were based on reliable water-level gauge data.
- Permanent benchmarks for river, pool, reservoir, and tidal reference gauges are placed at an adequate density and are accurately connected to the Department of Commerce National Spatial Reference Network (NSRS) used by Federal and local interests.
- Hurricane protection structure elevations have been designed and/or periodically corrected to the latest tidal epoch (currently 1983-2001) defined by the Department of Commerce (NOAA), and that these corrections additionally reflect any sea level, settlement, or subsidence/uplift changes.
- Coastal navigation project depths are defined relative to Mean Lower Low Water (MLLW) datum, and are being maintained to this datum and the latest tidal epoch as

defined by the Department of Commerce; as required by Section 224 of WRDA 1992 (33 U.S.C. 562).

- That navigation project depths are designed, maintained, and measured relative to hydrodynamic tidal models that are based on, or calibrated to, up-to-date water-level gauge data, and that field survey techniques are adequately compensating for short-term phase and slope variations in the water surface.

8. General Background on the Definition and Use of Vertical Datums

Vertical datums typically represent a terrestrial or earth-based surface to which geospatial coordinates (such as heights, elevations*, or depths) are referenced. The vertical datum is the base foundation for nearly all civil and military design, engineering, and construction projects in USACE—especially those civil projects that interface with water. Elevations or depths may be referred to local or regional reference datums. These reference datums may deviate spatially over a region, due to a variety of reasons. They may also have temporal deviations due to land subsidence or uplift, sea level changes, crustal/plate motion, or periodic readjustments to their origin or to defined points on the reference surface.

In general, there are five types of vertical datums used to define USACE flood control and navigation projects.

- Orthometric (Geodetic) Datums: These datums are based on geopotential surfaces on some defined terrestrial origin—the geoid. Examples of orthometric datums include the National Geodetic Vertical Datum of 1929 (NGVD 29) and National Geodetic Vertical Datum of 1988 (NAVD 88). NAVD88 elevations are termed Helmert orthometric heights.

- Hydraulic Datums: These datums are found on inland river, lake, or reservoir systems, typically based on a low water pool or discharge reference point. Examples are the Mississippi River Low Water Reference Plane (LWRP 74 or LWRP 93) and the International Great Lakes Datum (IGLD 55 or IGLD 85). Hydraulic-based reference datums in inland waterways define stages of flood protection levees or floodwalls and navigation clearances. Dynamic height differences are often used in relating hydraulic datums. Dynamic heights, unlike orthometric heights, represent geopotential energy (hydraulic head) gradients in water surfaces (canals, rivers, lakes, reservoirs, hydropower plants, etc.) and thus have application to Corps hydraulic models.

- Tidal Datums: Tidal datums are used throughout all USACE coastal areas and are based on long-term water level averages of a phase of the tide. Mean Sea Level (MSL) datum is commonly used as a reference for hydrodynamic storm modeling. Depths of water in navigation projects in the United States are defined relative to Mean Lower Low Water (MLLW) datum. Tidal datums are essentially local datums and should not be extended more than a few hundred feet from the defining gauge without substantiating measurements or models.

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* "heights" and "elevations" are assumed synonymous in this guidance, recognizing that a physical distinction exists between these two terms.

- Space-Based (Ellipsoidal) Datums: These are three-dimensional, geocentric, equipotential ellipsoidal datums used by the Global Positioning System (GPS)—i.e., GRS 80 and WGS 84. Ellipsoid heights of points in CONUS represent elevations relative to the GRS 80 reference system. The geoid height represents the elevation of the GRS 80 ellipsoid above or below the geoid.

- Local Datums: Local datums are based on an arbitrary, unknown, or archaic origin. Often construction datums are referenced to an arbitrary reference (e.g., 100.00 ft). Some datums with designated origins may be local at distant points—e.g., Cairo (IL) Datum projected south to the Gulf Coast. Most hydraulic-based river datums and navigation MLLW tidal datums are actually local datums when they are not properly modeled or kept updated.

The relationship within and between the above datums may or may not be easily defined. More often than not, the relationship is complex and requires extensive modeling to quantify—see Meyer 2006. These relationships are especially critical on coastal hurricane protection and navigation projects where accurate hydrodynamic tidal modeling is essential in relating water level elevations to a datum that varies spatially and is time varying due to subsidence or sea level changes—see IPET 2006. Thus, there is no consistent, non-varying, vertical datum framework for most coastal areas—periodic survey updates and continuous monitoring are required for these projects.

Establishing a solid relationship between hydraulic/tidal datums and geodetic datums is critical in relating measurements of wave heights and water level elevations, high-resolution hydrodynamic conditions, water elevations of hydrostatic forces and loadings at levees and floodwalls, elevations of pump station inverts, and related elevations of flood inundation models deriving drainage volumes or first-floor elevations in residential areas. This is best illustrated by the following:

> *... the land-water interface depends on how water levels change in both space and time. To combine or compare coastal elevations (heights and depths) from diverse sources, they must be referenced to the same vertical datum as a common framework. Using inconsistent datums can cause artificial discontinuities that become acutely problematic when producing maps at the accuracy that is critically needed by Federal, state, and local authorities to make informed decisions (Parker 2003).*

The current use of GPS satellite-based ellipsoidal reference systems does provide a mechanism for establishing an external reference framework from which vertical datums can be related spatially and temporally. Various initiatives are underway by National Oceanic and Atmospheric Administration (NOAA), Federal Emergency Management Agency (FEMA), and other agencies to refine the models of some of the various vertical datums listed above—resulting in a consistent National Spatial Reference System that models and/or provides transformations between the orthometric, tidal, and ellipsoidal datums. Paramount in these efforts is the NOAA "National VDatum" project which is designed to provide accurately modeled transformations between orthometric and tidal datums.

Detailed technical background on geodetic reference systems is covered in the guidance documents listed below. Those charged with performing an assessment of project vertical datums shall acquire a detailed familiarity with the guidance in these reference documents.

IPET 2006, "Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System," Draft Final Report of the Interagency Performance Evaluation Task Force, US Army Corps of Engineers, 1 June 2006, Volume II--"Geodetic Vertical and Water Level Datums," (entire document)

EM 1110-1-1003, "NAVSTAR GPS Surveying," Chapter 4, "GPS Reference Systems."

EM 1110-2-1005, "Control and Topographic Surveying"
Chapter 5: Geodetic Reference Datums and Local Coordinate Systems
Section III (Vertical Reference Systems)
Appendix B: Requirements and Procedures for Referencing Coastal Navigation Projects to Mean Lower Low Water (MLLW) Datum
Appendix C: Development and Implementation of NAVD 88

Meyer 2006, "What Does Height Really Mean," Meyer, Roman, Zilkoski
Part I: Introduction
Part II: Physics and Gravity
Part III: Height Systems
Part IV: GPS Orthometric Heighting

NOS, 2001, "Tidal Datums and Their Applications," NOAA Special Publication NOS CO-OPS 1, NOAA/NOS, Center for Operational Oceanographic Products and Services, Silver Spring MD, February 2001.

EM 1110-2-1003, "Hydrographic Surveying," Chapter 5, "Project Control, Coordinate Systems, and Datums," Section 5-4 through 5-24.

EM 1110-2-1100, "Coastal Engineering Manual—Coastal Hydrodynamics (Part II)," Chapter 5, "Water Levels and Long Waves," Section II-5-4 (Water Surface Elevation Datums).

EM 1110-2-1100, "Coastal Engineering Manual—Coastal Hydrodynamics (Part II)," Chapter 6, "Hydrodynamics of Tidal Inlets."

9. National Spatial Reference System (NSRS)

The NSRS represents an independent framework system for long-term monitoring of the stability of project grades and flood protection elevations. This reference system has been adopted by most Federal agencies, including FEMA, USGS, EPA, and most state transportation departments (DOT). The NSRS is a national reference framework that specifies latitude, longitude, height (elevation), scale, gravity, and orientation throughout CONUS. Accordingly, USACE must ensure flood control projects and navigation projects are referenced to this NSRS system. This insures consistency in reporting elevations or grades between agencies and represents one of the primary purposes of this CEPD effort. In addition, incorporating Corps project control into the NSRS minimizes the need for maintaining independent databases at each District. It also ensures that Corps project control will be automatically updated when future updates to the NSRS are made. [*]

The NSRS is also a component of the National Spatial Data Infrastructure (NSDI) - [http://www.fgdc.gov/nsdi/nsdi.html] which contains all geodetic control contained in the National Geodetic Survey (NGS) database. This includes: A, B, First, Second and Third-Order horizontal and vertical control, geoid models, precise GPS orbits, Continuously Operating Reference Stations (CORS), and the National Shoreline as observed by NGS as well as data submitted by other Federal, State, and local agencies, academic institutions, and the private sector.

Permanent benchmarks or primary control points on USACE projects that are firmly connected to the NSRS shall be submitted to NGS for inclusion in the published NSRS. Details on this process are covered in Appendix B.

10. Minimum Criteria for Evaluating the Adequacy of Geodetic and Water Level Datums on Flood Control and Navigation Projects

A project-by-project assessment of the adequacy of the vertical reference network should be evaluated based on the general criteria described below. Projects that do not conform to these minimum standards are considered deficient and require remedial action following the guidance in Appendix B or C. The assessment items below should be addressed in the evaluation report for each project (Appendix D), as applicable. A more comprehensive checklist of CEPD assessment items is listed in Appendix D, including direct connection links with a web-based report to HQUSACE on critical items.

(1) Verify the existence of a permanent water level gauge network that adequately defines the spatially varying hydraulic or tidal datum in the project region. Existing or historical gauges should be established at a sufficient density such that the spatially varying hydraulic datum anomalies are (or were) modeled to an accuracy consistent with project requirements. USACE, NOAA, National Weather Service (NWS), Environmental Protection Agency (EPA), United States Geological Survey (USGS), State Department of Transportation (DOT), and other agency gauges may be utilized for this network. (Reference EM 1110-2-1100 (*Coastal Engineering Manual*), Section II-5 (Water Levels and Long Waves) and Section II-6 (Hydrodynamics of Tidal Inlets)).

(2) Verify that the original and/or periodic maintenance design documents (DM, GDM, P&S, etc.) indicate that constructed project grades (or excavated navigation depths) are based on direct hydraulic or tidal observations, and that the relationship between the hydraulic/tidal datum

[*] Note that the NSRS, and NAVD88 control therein, will be updated by NGS in the near future

and the geodetic datum used for construction (e.g., NGVD 29 or NAVD 88) was firmly established.

(3) Verify that coastal navigation projects were converted from Mean Low Water (MLW), Mean Low Gulf (MLG), or other local tidal datums, to MLLW as a result of the requirements in WRDA 92 (33 U.S.C 562) that superseded older tidal datums and epochs; and that these revisions are based on the latest NOAA tidal model and not on approximated or estimated translations. Projects still defined relative to undefined or superseded datums—e.g., "Mean Sea Level--MSL," "Mean Low Gulf," "Mean Tide Level," "Sea Level Datum--SLD," "NGVD," "MSL 1912," or "NGVD 29"—are considered deficient and in need of updating. There may be limited exceptions to this in OCONUS locales.

(4) Verify that reported elevations of coastal protection structures and maintained depths of navigation projects fully account for geological and climatological factors that may impact their integrity—e.g., sea level change, eustatic rise, crustal subsidence, tectonic uplift or downwarp, seismic subsidence, seasonal sea level biases, etc. See EM 1110-2-1100 (*Coastal Engineering Manual*), Section II-5-4-f (Tidal Datums).

(5) Verify USACE operated gauge networks are periodically inspected at adequate intervals to verify the gauge reference setting and other criteria. Gauge inspection and referencing procedures should be documented in a standards manual, or, at minimum, conform to gauge inspection criteria used by the Department of Commerce (NOAA). This also applies to gauges from other agencies that are used in USACE models.

(6) Verify USACE operated water level gauges are referenced to, at minimum, three (3) permanent benchmarks. Verify that each scheduled inspection visit connects the gauge reference mark to stable benchmarks by 3rd Order differential levels, and that these inspection records are properly archived.

(7) Verify that, at minimum, one benchmark at each flood control structure site, shore protection site, water level gauge, etc. is geodetically connected to the NAVD88 orthometric datum on the NSRS network maintained by the National Geodetic Survey (NGS), and that this benchmark(s) is published in the NSRS. In areas where subsidence or crustal uplift is known to exist, this connection must have been made periodically in order to monitor potential loss of flood protection or navigation grade. This may require establishment of vertical time-dependent networks—see IPET 2006.

(8) Verify that current project documents (or equivalent CADD databases) used in design or construction plans accurately describe the source and datum of any elevations or depths. Verify master project drawings have sufficient feature codes or metadata that notes the reference datum, source, location, adjustment epoch, and dates of tidal or hydraulic observations, etc.

(9) Verify all USACE operated and maintained projects have, at minimum, three up-to-date vertical control benchmarks identified in the most recent contract plans and specifications from which to stake out construction. Confirm these controlling benchmarks have dual elevations on the latest adjustments and/or epochs: (1) hydraulic/tidal and (2) NAVD88 (NSRS).

(10) Verify permanent benchmarks on navigation projects are at a sufficient density (i.e., spacing) needed to adequately model the water surface vertical datum for project maintenance, including controlling dredging grades and related measurement & payment/clearance survey; and that these benchmarks are directly referenced to NOAA tidal benchmarks.

(11) Verify permanent benchmarks shown on the most recent contract plans and specifications contain complete metadata descriptions—date, adjustment, epoch, monument description, etc.

(12) Verify hydraulic-based inland river reference datums (and reference benchmarks therefore) are firmly connected to river gauges and the NSRS. This includes various inland datums such as Low Water Reference Planes (e.g., LWRP74 and LWRP93), Minimum Regulated Pool, Flat Pool Level, Full Pool Level (for overhead clearance), Mean Sea Level 1912, International Great Lakes Datum (1985), and various other inland reference planes.

11. Corrective Actions Required for Projects Not Meeting Minimum Standards

Projects deemed to be deficient in any of the criteria outlined above will require corrective action. The amount of time and expense will vary considerably, depending on the geographical size of the project, risk assessments, the density and reliability of existing water level gauges, USACE or NOAA modeling support and capability, and various other factors. Coastal projects requiring updated tidal models may require the most effort. Updating river, pool, or reservoir gauge elevations will require minimal time and expense. The CEPD assessment report for each project should provide an estimate of the recommended corrective action. This estimate should be of sufficient detail to allow programming the action into the next budget cycle for the project. The guidance listed below is intended to support making this budget estimate for programming purposes.

a. Coastal Project Reference Datums. Projects in tidal areas that were not adequately updated to a current MLLW (or MSL) reference datum, or have outdated or unknown origin tidal modeling regimes (phase and range), or are on superseded epochs, will require initiating an effort to reliably update a model for the project. This may require setting one or more short-term tidal gauges to perform simultaneous comparison datum translations between an existing National Water Level Observation Network (NWLON) station and/or developing a tidal model utilizing the hydrodynamic modeling techniques which can be applied to develop the MLLW datum relationship over a project reach. Minimizing tidal phase errors may require mandated utilization of GPS (RTK) elevation measurement in lieu of extrapolated gauge elevations. Details are covered in Appendix C.

b. Water Level Gauge Upgrades. USACE-operated water level gauges that are used to reference elevations of flood control projects or tidal parameters on navigation projects must be rigorously maintained and documented. A primary benchmark for each gauge shall be surveyed and placed into the NSRS and continuously maintained in that file. District procedures should meet or exceed the standards set forth by the Department of Commerce (Center for Operational Oceanographic Products and Services—CO-OPS). USACE river gauges with insufficient reference benchmarks (i.e., minimum of three) must be upgraded. This can be accomplished with either hired-labor or contract forces. An assessment should evaluate existing District gauge inspection procedures against the following CO-OPS specifications:

> Specifications and Deliverables for Installation, Operation, and Removal of Water Level Stations. NOAA Special Publication NOS CO-OPS, NOAA/NOS, Center for Operational Oceanographic Products and Services, Silver Spring MD, February 2003.
>
> User's Guide for the Installation of Bench Marks and Leveling Requirements for Water Levels. National Ocean Service, Rockville, MD, October 1987.
>
> Standing Project Instructions and Requirements for the Coastal Water Level Stations. Center for Operational Oceanographic Products and Services, Silver Spring MD, October 2005.

The above specifications can be obtained at http://tidesandcurrents.noaa.gov/

c. Geodetic Control Survey Connections to the NSRS. River/tidal gauge primary benchmarks and primary reference benchmarks on dams, pools, lakes, reservoirs, or like projects requiring ties to the NSRS (i.e., NAVD88) can often be economically accomplished using GPS height transfer methods. Appendix B of these guidelines describes procedures for transferring orthometric elevations between points. Conventional differential leveling may be a more economical option, especially over short distances. Permanent benchmarks or primary project control points established or reestablished should be submitted to NGS for inclusion in the NSRS. Refer to Appendix B for details.

d. Projects on Non-Standard or Undefined Tidal Datums. Projects on antiquated or non-standard tidal datums must be converted to the MLLW datum established by NOAA used for coastal navigation and maritime charting in CONUS waters. This includes those projects that are still referenced to datums such as Mean Low Water (MLW), Mean Gulf Level (MGL), Mean Low Gulf (MLG), Gulf Coast Low Water Datum, Old Cairo Datum 1871, Delta Survey Datum 1858, New Cairo Datum 1910, Memphis Datum 1858 & 1880, Mean Tide Level, etc. Reference WRDA 92.

e. Mean Sea Level or NGVD Datums. Projects or benchmarks defined generically to "mean sea level" or "NGVD" without any definitive source data (metadata) probably have no firmly established relationship and need to be resurveyed. "NGVD 29" was once known a "Sea Level Datum of 1929." However, neither NGVD 29 nor the current NAVD 88 datums are related to "mean sea level." Resurveying entails establishing a hydraulic and NSRS geodetic reference, as applicable.

f. Permanent Benchmark Control Requirements for Dredging and Flood Control Structure Construction. Projects without a sufficient density (minimum number and spacing) of vertical control must be programmed for additional survey work—either by USACE or local sponsors, depending on the O&M status of the project. Additional permanent benchmarks (i.e., primary project control marks) should be added as necessary to control the project for conventional surveying methods, or preferably at a sparser density needed to accommodate GPS real-time kinematic construction control methods. These permanent benchmarks must be firmly connected to applicable hydraulic gauges and regional NSRS datums as described above and, where required (see Appendix B) should be submitted to NGS for inclusion into the NSRS.

g. Local Mean Sea Level Datum. For storm surge modeling, flood inundation models, and similar purposes, "Local Mean Sea Level" is distinguished from "Mean Sea Level" computed at a fixed water level gauge. As stated previously, sea level reference datums vary spatially depending on the tidal regime in the area. Therefore, "Local Mean Sea level" elevations should be assigned to monuments based on hydrodynamic models of the tidal regime in an area.

h. Projects Subject to High Subsidence Rates. Projects located in high subsidence areas may require special attention. This also applies to areas on the Northwest coast (e.g., Alaska) that may be subject to crustal uplift. Vertical elevations of reference benchmarks, water level gauges, and protection structures must be continuously monitored for movement and loss of protection. This monitoring can be accomplished using static GPS survey methods or conventional differential leveling. In high subsidence areas (portions of California, Texas, and Louisiana) independent local vertical control networks have been established for these purposes. These vertical networks are periodically resurveyed at intervals dependent on subsidence rates. In the New Orleans, LA area, control benchmarks on these monitoring networks are time-stamped to signify reobservation/readjustment epochs—e.g., BM XYZ (2004.65). Refer to IPET 2006 for additional details. Additional technical guidance for monitoring subsidence or uplift can be obtained from the Topographic Engineering Center (ERDC/TEC) and the NOAA National Geodetic Survey (NGS).

12. Project Review, Certification, and Reporting

Designated coordinators responsible for reviewing and certifying the adequacy and accuracy of vertical control on a given project must have a solid background in surveying, mapping, and geodesy, and especially must have knowledge of the latest GPS technology used for extending vertical control and real-time construction layout. These project reviews are to be conducted and submitted to HQUSACE using a web-based tool developed and designed for this effort. Once the review is completed, the designated coordinator is to print out the report and have it signed by the District Commander. This signed copy is to be sent to HQUSACE. The submitted report to HQUSACE should contain clear findings and delineate any remedial surveying actions that may be required for each project—including a budget cost and time estimate to rectify any identified vertical reference deficiencies. Additional details are contained in Appendix D, “Documentation and Reporting for Comprehensive Evaluation of Project Datums."

13. Programming Evaluation and Implementation Actions

In general, Districts will fund the CEPD review of flood control and hurricane protection projects operated and maintained by non-federal sponsors within the Inspection of Completed Works (ICW) account. CEPD review of Corps-maintained projects, including navigation projects, will be funded from existing O&M accounts associated with those projects.

Mechanisms for funding the initial CEPD assessment and programming subsequent corrective actions are detailed in Appendix D.

14. Technical Assistance and Training

This technical guidance was developed by the Topography, Imagery, & Geospatial Research Division of the U.S. Army Engineer Research and Development Center—Topographic Engineering Center (TEC). That office is also responsible for developing a joint USACE-NOAA training course on vertical reference datums that is intended to supplement evaluation actions in this guidance. Designated coordinators for this assessment action should contact TEC for technical assistance and interpretations regarding this guidance. The point of contact at TEC is Mr. James Garster (CEERD-TR-A), e-mail James.K.Garster@usace.army.mil. An alternate technical point of contact is Mr. David Robar (CESAJ-EN-D), e-mail David.J.Robar@saj02.usace.army.mil. An Additional technical point of contact for hydrodynamic tidal modeling at ERDC Coastal Hydraulics Laboratory is Kevin Knuuti (CEERD-HN-CE), email Kevin.Knuuti@usace.army.mil. Technical points of contact at NOAA/NOS include:

NGS: Mr. Ronnie Taylor Ronnie.Taylor@noaa.gov

OCS/CSDL/VDatum Group: Ms. Maureen Kenny Maureen.Kenny@noaa.gov

CO-OPS: Mr. Jerry Hovis Gerald.Hovis@noaa.gov

15. Periodic Reassessments of Controlling Reference Elevations

Subsequent periodic reevaluations of project reference elevations and related datums covered in this document will likely be included as an integral component in the various civil works inspection programs of completed projects—see IPET 2006. The frequency that these reevaluations will be needed is a function of estimated magnitude of geophysical changes that could impact flood protection or navigation grades. Project elevations and dredging grades that are referenced to tidal datums will have to be periodically coordinated with and/or reviewed by NOAA to ensure the latest tidal hydraulic effects are incorporated and that the project is reliably connected with the NSRS. In all cases, a complete reevaluation of the vertical datum should be conducted at each scheduled periodic inspection—e.g., NTE 5 years. Shallow-draft navigation projects may have different criteria. Any uncertainties in protection levels that are identified during the inspection will also need to be incorporated into any applicable risk/reliability models developed for the project—see EM 1110-2-1619 (*Risk Based Analysis for Flood Damage Reduction Studies*). Details on these periodic reevaluations will be provided in subsequent guidance.

16. Proponency and Waivers

The HQUSACE proponent for this interim guidance is the Engineering and Construction Division, Directorate of Civil Works. Waivers to this guidance should be forwarded through MSC to HQUSACE (ATTN: CECW-CE).

FOR THE COMMANDER

JAMES C. DALTON, P.E.
Chief, Engineering and Construction
Directorate of Civil Works

7 Appendices
Appendix A – Reference Documents
Appendix B – Guidance, Standards, and Specifications for Referencing Levee Systems and Related Flood Control Projects to the National Spatial Reference System (NSRS) and to the North American Vertical Datum of 1988 (NAVD88)
Appendix C – Guidance, Standards, and Specifications for Referencing Coastal Navigation Projects, Hurricane Protection Projects, and Shore Protection Systems to National Water Level Observation Network Datums
Appendix D – Documentation and Reporting for Comprehensive Evaluation of Project Datums
Appendix E – List of Supplemental Training Material to Accompany this Guidance Document
Appendix F – CEPD Directive Memorandum

APPENDIX A
Referenced Documents

WRDA 1992
Water Resources Development Act (WRDA) of 1992 (Rivers and Harbors Appropriation Act of 1915 (38 Stat. 1053; 33 U.S.C. 562))

WRDA 92
Water Resources Development Act of 1992, Section 224, Channel Depths and Dimensions

NTDC 1980
The National Tidal Datum Convention of 1980, US Department of Commerce.
Federal Register, Vol. 45, No. 207, Notices, 70296-70297, Thursday, October 23, 1980

ER [EP] 500-1-1
Civil Emergency Management Program—[Procedures]

ER 1110-1-8156
Policies, Guidance, and Requirements for Geospatial Data and Systems.

ER 1110-2-100
Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures

ER 1130-2-530
Flood Control Operations & Maintenance Policies

EM 1110-1-1002
Survey Markers and Monumentation

EM 1110-1-1003
NAVSTAR Global Positioning System Surveying

EM 1110-1-2909
Geospatial Data and Systems

EM 1110-1-1005
Control and Topographic Surveying

EM 1110-2-1003
Hydrographic Surveying.

EM 1110-2-1009
Structural Deformation Surveying

EM 1110-2-1100
Coastal Engineering Manual—Coastal Hydrodynamics (Part II).
Chapter 5, "Water Levels and Long Waves"
Chapter 8, "Hydrodynamic Analysis and Design Conditions"

EM 1110-2-1416
River Hydraulics

EM 1110-2-1601
Hydraulic Design of Flood Control Channels

EM 1110-2-1607
Tidal Hydraulics

EM 1110-2-1614
Design of Coastal Revetments, Seawalls, and Bulkheads

EM 1110-2-1913
Design and Construction of Levees

EM 1110-2-1619
Risk Based Analysis for Flood Damage Reduction Studies.

HEC 1986
Hydraulic Engineering Center RD-26 "Accuracy of Computed Water Surface Profiles"

FEMA 2003
Guidelines and Specifications for Flood Hazard Mapping Partners
Appendix A "Guidance for Aerial Mapping and Surveying)

FGDC 1998
FGDC "Geospatial Positioning Accuracy Standards, PART 1: Reporting Methodology," Federal Geographic Data Committee, FGDC-STD-007.1-1998
FGDC "Geospatial Positioning Accuracy Standards, PART 2: Standards for Geodetic Networks," Federal Geographic Data Committee, FGDC-STD-007.2-1998
FGDC "Geospatial Positioning Accuracy Standards, PART 3: National Standard for Spatial Data Accuracy," Federal Geographic Data Committee, FGDC-STD-007.3-1998

IJC 1995
Establishment of International Great Lakes Datum (1985), International Joint Commission Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, December 1995

IPET 2006
"Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System," Draft Final Report of the Interagency Performance Evaluation Task Force, US Army Corps of Engineers, 1 June 2006. (Volume II--"Geodetic Vertical and Water Level Datums") https://ipet.wes.army.mil .

Jacksonville District 2005
"Use of Real Time Kinematic Elevation References on Dredge Payment & Clearance Surveys in Coastal Navigation Projects," 2005 Hydrographic Society of America Conference Workshop.

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Technical Report NOS/NGS 50, Rates of Vertical Displacement at Benchmarks in the Lower Mississippi Valley and the Northern Gulf Coast, NOAA, NGS, July 2004.

NGS 2005
Accuracy of OPUS Solutions for 1- to 4-h Observing Sessions

NOAA 1994
"Input Formats and Specifications of the National Geodetic Survey Data Base," NOAA, National Geodetic Survey, September 1994.

NOAA 1997
NOAA Technical Memorandum NOS NGS-58, Zilkoski, D.B., D'Onofrio, J. D., and Frankes, S. J. (Nov 1997) "Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)," Version 4.1.3. Silver Spring, Maryland.

NOAA 2005
Guidelines for Establishing GPS Derived Orthometric Heights (Standards: 2cm and 5cm) version 1.4, National Geodetic Survey 2005 DRAFT NOS NGS 59; Zilkoski, Carlson, and Smith, NOAA, NOS, NGS.

NOS 2000
Tide and Current Glossary

NOS 2001
Tidal Datums and Their Applications, NOAA Special Publication NOS CO-OPS 1, NOAA/NOS, Center for Operational Oceanographic Products and Services, Silver Spring MD, February 2001.

NOS 2003
Computational Techniques for Tidal Datums Handbook, NOAA Special Publication NOS CO-OPS 2, NOAA/NOS, Center for Operational Oceanographic Products and Services, Silver Spring MD, September 2003.

Brennan 2005
The Design of the Uncertainty Model for the Tidal Constituent and Residual Interpolation (TCARI) Method for Tidal Correction of Bathymetric Data
LT Richard T. Brennan, OCS/NOS/NOAA - Center for Coastal and Ocean Mapping – Joint Hydrographic Center, UNH; Dr. Lloyd Huff, Center for Coastal and Ocean Mapping – Joint Hydrographic Center, UNH; Kurt Hess, Steve Gill, NOS/NOAA, The Hydrographic Society of America, 2005.

Myers 2005
Review of Progress on VDatum, a Vertical Datum Transformation Tool (7 pages, pdf). Marine Technology Society / IEEE OCEANS Conference, Washington, D.C., September 19-23, 2005.

Meyer 2006
"What Does Height Really Mean," Meyer, Roman, Zilkoski; University of Connecticut
Part I: Introduction
Part II: Physics and Gravity
Part III: Height Systems
Part IV: GPS Orthometric Heighting

NRC 2004
"A Geospatial Framework for the Coastal Zone--National Needs for Coastal Mapping and Charting," National Research Council, The National Academies Press 2004
http://books.nap.edu/catalog/10947.html.

Parker 2003
Parker, B., Hess, K. W., Milbert, D. G., and Gill, S., 2003: A National Vertical Datum Transformation Tool. *Sea Technology*, Volume 44, Number 9, pp. 10-15, September 2003.

APPENDIX B
Guidance, Standards, and Specifications for Referencing Levee Systems and Related Flood Control Projects to the National Spatial Reference System (NSRS) and to the North American Vertical Datum of 1988 (NAVD88)

B-1. Purpose

This Appendix provides Corps-wide guidance on evaluating and establishing region-wide vertical reference control on levee systems and related flood control projects It describes preliminary evaluation actions necessary to determine if flood control structures are adequately connected to the National Spatial Reference System (NSRS) established by the Department of Commerce (National Geodetic Survey); and in particular, the North American Vertical Datum of 1988 (NAVD88) elevation component of the NSRS. For those projects that are not adequately connected to the NSRS, specific procedural actions required to effect this connection are outlined herein.

B-2. Scope

The guidance in this section primarily applies to vertical datums and elevations on inland flood control systems, including levees, floodwalls, reservoir impoundment structures, river navigation locks & dams, and other river control structures. It also applies to controlling elevations on certain hurricane and shore protection projects (HSPP) covered in Appendix C. It is only applicable to nationwide or region-wide connections with the NSRS that are necessary to meet project-specific hydrologic and hydraulic design accuracy requirements. It is not a geodetic survey network densification or height modernization guidance document. The geodetic survey procedures contained in this guidance are specifically tailored to the accuracy tolerances of hydraulic engineering applications required for flood control projects. The geodetic survey procedures described in this document are intended for performing accurate survey connections with nearby benchmarks on the NSRS. The required precision of these geodetic survey connections to the NSRS will vary depending on local conditions, e.g., low relief flood plains, high subsidence areas, high head dams, etc. These survey guidelines do not apply to local topographic survey or construction survey standards needed for design, construction, operation, maintenance, and NLD inventories of a particular local levee segment, floodwall, and related controlling structures. Topographic and construction survey procedures needed to set levee stationing control monuments, or profile/cross-section levee grades, are detailed in EM 1110-1-1005, "Control and Topographic Surveying" (01 Jan 07).

B-3. Definitions

The following definitions apply to flood control projects covered in this Appendix.

- **Geodetic Surveying.** Survey measurements performed to relate project features to a nationwide reference datum, typically using static GPS observations over long baselines or precise geodetic differential leveling methods. Geodetic surveys in this guidance are performed for general geospatial reference purposes only; they are not used for local design & construction.

- **Topographic or Engineering & Construction Surveying.** Surveys used to set project control monuments on levees and related flood control structures, topographic surveys for planning & design, stake out construction, levee cross-sections, levee profiling, etc. Engineering & construction surveys are performed using total stations, differential levels, and/or RTK methods; following the techniques outlined in EM 1110-1-1005. Procedures and accuracies generally follow "Third-Order" methods described in that manual. These surveys, or fixed control monuments/benchmarks established therefrom, are usually not included in the NSRS; however, there may be exceptions.

- **North American Vertical Datum of 1988**. The current nationwide vertical datum to which features on USACE flood control projects shall be referenced. (It is anticipated that the NAVD88 reference system will be superseded in the future).

- **National Spatial Reference System.** The NSRS includes those nationwide reference points or monuments published by the National Geodetic Survey. It includes the primary horizontal and vertical reference datums—NAD83 and NAVD88.

- **National Water Level Program**. The NWLP, administered by the Department of Commerce, includes a database of water level elevation data on benchmarks near gauges operated by that agency. Many (but not all) of these gauge benchmarks are linked to orthometric or ellipsoidal elevation data on the NSRS.

- **Primary Project Control Monuments**. Monuments (benchmarks) set on or near a project that are connected with and published in the NSRS, and are used to densify local project control monuments or develop project features. These NSRS benchmarks may be established by the NGS, USACE, or other agencies. Each USACE project should have at least one primary control monument.

- **Local Project Control Monuments**. Monuments (or benchmarks) used to reference project features, alignment, elevations, or construction. Monuments may be atop levees (e.g., PIs) or offset to the alignment. Typically monuments will have X, Y, & Z coordinates along with local project station-offset coordinates. Project control monuments are usually not part of the published NSRS; however, they should be directly connected with a primary project control monument described above.

- **Project Network Accuracy** (NSRS connection accuracy). Spatial accuracy of a project control monument relative to points (benchmarks) in the nearby NSRS region. NSRS regional network accuracy is not significant to local project construction. Required network elevation accuracies may range from ± 0.1 ft to ± 1 ft. (NOTE: This is NOT the same as "network accuracy" defined by the National Geodetic Survey).

- **Local Network Accuracy** (Engineering & construction accuracy). Spatial accuracy of a local project control monument or project features relative to nearby local reference monuments on the project. Local project accuracy is critical for construction with X-Y-Z tolerances typically < ± 0.05 ft. Local accuracy tolerances are always much smaller than network accuracy tolerances. (NOTE: This is NOT the same as "local accuracy" defined by the National Geodetic Survey).

- **Survey Standards**. Target positional accuracy tolerances for project control monument/benchmark or other project feature (e.g., top of floodwall, inverts, and ground shots).

- **Survey Specifications**. Survey procedures and equipment requirements.

- **Target Network Accuracy**. The intended accuracy of a point relative to the NSRS. May or may not be achieved.

B-4. Development of Standards and Specifications

The accuracy standards and observing specifications detailed in this Appendix were developed based on the following constraints and caveats.

- Accuracy standards have been developed based on the hydraulic engineering and design requirements of flood control projects, not existing geodetic survey capabilities.

- There is no rigid or fixed accuracy standard that will fit all USACE flood control projects. Varying river slope profiles, flood inundation topography, land subsidence, and numerous other factors will govern the required survey accuracy.

- The target NSRS network connection and local accuracy standards proposed in this guidance should be considered as nominal for most USACE levee and flood control projects.

- Primary project control benchmarks and primary river gauge benchmarks will be input to and continuously maintained in the NSRS.

- VERTCON conversions from NGVD29 to NAVD88, although of sufficient accuracy in some places, cannot be used as an elevation in the NSRS.

- Actual statistical accuracies of primary project control benchmarks will be posted to the published NSRS regardless of whether they fall within or outside the targeted accuracy standard. This is in accordance with the FGDC "National Standard for Spatial Data Accuracy" (NSSDA) criteria—see FGDC 1998.

- Current USACE and NGS guidance documents, i.e., EM 1110-1-1003 (NAVSTAR GPS Surveying) and NOAA Technical Memorandum NOS NGS-58 (Guidelines for

Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm), and NGS "Guidelines for Establishing GPS-Derived Orthometric Heights," were used in developing the survey specifications in this guidance. These specifications are designed to achieve high-order network accuracies intended to densify and support development of the NSRS for use by a variety of applications requiring more exacting tolerances than the projects included under this guidance. Thus, the observing criteria were scaled down to meet the standards for this project. However, in areas of high subsidence or low slope profiles, these more refined guidelines may be required.

- For most populated regions of CONUS, GPS connections with the NGS's Continuously Operating Reference System (CORS) stations are expected to provide sufficient accuracy to meet the NSRS horizontal and vertical network connection and engineering accuracy standards in this guidance. The enhanced use of CORS stations is intended to reduce the number of GPS observation sessions while still meeting the target NSRS accuracy standards.

As with any guidance standards and specification there will be exceptions. In some cases the target NSRS network accuracy standard in this guidance may be too high or low, depending on many technical factors associated with the river system. The GPS session observing times may prove too short to achieve the target accuracy and may have to be extended. CORS stations may be too remote is some CONUS locations. Levees or floodwalls in high subsidence regions may require more precise tolerances. In such instances, this guidance will have to be modified to meet those unique local requirements.

In future years, as GPS Real Time Networks (RTN) or Virtual Reference Networks (VRN) are expanded in CONUS, this guidance may become largely obsolete in that accurate NSRS positioning (elevations) will be available without a nearby NSRS reference benchmark. If, by chance, a DOT-established (or other agency) VRN network currently exists over a USACE levee sector, its direct use should be considered; assuming the VRN is adequately connected with the NSRS.

PROJECT ACCURACY REQUIREMENTS

B-5. Development of Elevation Accuracy Requirements

A critical distinction must be made between:

(1) The regional "geodetic" survey process of referencing USACE project elevations to NAVD88 or NAD83 relative to nearby points on the NSRS (i.e., Project Network Accuracy), and

(2) Engineering and construction surveying requirements necessary to design, align, stake out, and construct a local flood control structure (i.e., Local Network Accuracy).

Figure B-1 below illustrates the distinction between network and local accuracies. The "Primary" benchmark has been connected to other adjacent points in the NSRS to an accuracy of ± 0.22 ft. This "network accuracy" is based on the adjustment statistics from the point's connection—e.g., GPS baseline connections, differential leveling loop closures, etc. The adjusted NSRS elevation of 298.72 ft is assumed absolute and is used to establish elevations on the two PIs (Local Project Control Points) shown in the figure. These PI elevations may be determined by various topographic survey methods—levels, GPS, total station. Assuming differential levels were run from the Primary NSRS benchmark to the two PIs, NAVD88 elevations are transferred to the PIs. These elevations have a slightly larger NSRS "network" accuracy than the Primary NSRS benchmark. However, their "Local Network Accuracy" of ± 0.03 ft is based on the accurate level line closures between the three points. The Local Project Control Points (PIs) have both a local (relative) accuracy needed for construction and a regional (NSRS) accuracy needed for regional engineering purposes.

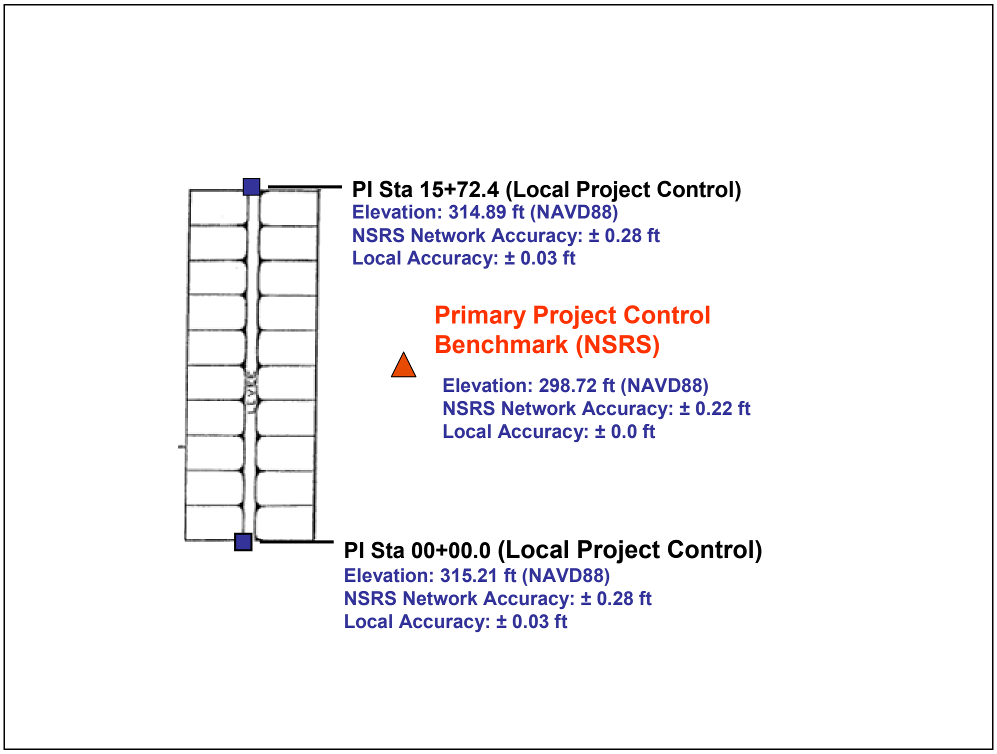


Figure B-1. Distinction between Primary Project Control and Local Project Control--Network and Local Accuracies

If the above distinction between local and network project accuracies is not clearly understood, then unnecessary USACE resources (O&M, ICW, project, or NLD) may be expended performing higher accuracy "geodetic" surveys to achieve elevation accuracies that have no hydrologic or hydraulic engineering requirement; either within USACE or in conjunction with other agencies.

It is also essential that the required survey accuracy be derived from realistic engineering applications associated with the flood control system or project. This is best summarized in Appendix A of the FEMA "Guidelines and Specifications for Flood Hazard Mapping Partners" (FEMA 2003) which emphasizes the need for establishing reasonable accuracy and resolution specifications for flood insurance studies:

> *The specified accuracy of FIRM work maps produced by Mapping Partners must be sufficient to ensure that the final FIRMs produced by FEMA can be reliably used for the purpose intended. However, the accuracy and resolution requirements of a mapping product must not surpass that required for its intended functional use. Specifying map accuracies in excess of those required results in increased costs, delays in project completion, and reduction in the total numbers of new or revised products that the Mapping Partner may generate. Mapping accuracy requirements must originate from functional and realistic accuracy requirements.*

The above statement makes it imperative that the project's functional and realistic accuracy requirements be defined by hydraulic engineers based on the requirements of a flood system model, not by USACE surveyors or geodesists. Once the functional accuracy requirement is defined, USACE surveyors can then define the appropriate survey specifications needed to meet that accuracy. Therefore, the above FEMA guidance is equally applicable to the USACE CEPD and NLD projects included under these instructions (Paragraph 1--Purpose).

The required NSRS network accuracy of a primary or local project control point (and indirectly to any topographic feature on the project—e.g., levee crest, floodwall cap, pump station invert, etc.) is also determined by the engineering requirement for regional consistency between these points. These regional network accuracy requirements relative to the NSRS may be contingent on compliance with one or all of the following:

- USACE, USGS, FEMA, or other agency hydrologic or hydraulic analyses/models/water surface profiles between and within large river reaches/basins and river stage gauges.
- USACE/FEMA/other flood inundation mapping study accuracies.
- Consistency with FEMA flood insurance study accuracies performed under FEMA's National Flood Insurance Program (NFIP)—e.g., Flood Hazard Maps, Flood Insurance Rate maps (FIRM/DFIRM), etc.
- Consistency with Federal mapping accuracy standards in the project area—e.g., USGS.

In addition, projects must be geospatially referenced such that they are:

- Consistent with Federally mandated vertical datums (NAVD88)
- Consistent with Federally mandated horizontal datums (NAD83)

To meet the above requirements, elevation accuracies need to be around the ± 1 to ± 2 ft level and horizontal positions around ± 10 ft to ± 20 ft--to be consistent with FEMA flood study (FEMA 2003) or USGS mapping requirements—see references in the following paragraphs. USACE regional hydraulic requirements are typically around the ± 0.5 ft level. Conforming to these regional mapping and flood control system accuracy requirements is not particularly difficult and can be easily accomplished when GPS satellite positioning techniques are employed. The nominal targeted NSRS network accuracy standards for USACE projects in these guidelines will be within these general requirements. Again, it is emphasized that these are regional NSRS network accuracy standards, not local engineering/construction accuracies.

B-6. Guidance on Developing Survey Accuracies in EM 1110-1-1003 (NAVSTAR GPS Surveying)

The following is excerpted from Section 8-3 (Project Control Function and Accuracy) of EM 1110-1-1003 (NAVSTAR GPS Surveying). This manual's guidance is applicable to CEPD and NLD projects envisioned under this document.

> *a. Project functional requirements.* Project functional requirements must include planned and future design, construction, and mapping activities. Specific control density and accuracy are designed from these functional requirements.

(1) Density of control within a given project is determined from factors such as planned construction, site plan mapping scales, master plan mapping scale, and dredging and hydrographic survey positioning requirements.

(2) The relative accuracy for project control is also determined based on mapping scales, design/construction needs, type of project, etc., using guidance in Table […] ... Most site plan mapping for design purposes is performed and evaluated relative to FGDC or American Society of Photogrammetry and Remote Sensing (ASPRS) standards--see references in Appendix […]. These standards apply to photogrammetric mapping, total station mapping, and site plan mapping performed with GPS RTK techniques. Network control must be of sufficient relative accuracy to enable hired-labor or contracted survey forces to reliably connect their supplemental mapping work.

b. Minimum accuracy requirements. Project control surveys shall be planned, designed, and executed to achieve the minimum accuracy demanded by the project's functional requirements. In order to utilize USACE resources most efficiently, control surveys shall not be designed or performed to achieve accuracy levels that exceed the project requirements. For instance, if a Third-Order, Class I accuracy standard (1:10,000) is required for dredge/survey control on a navigation project, field survey criteria shall be designed to meet this minimum standard.

c. Achievable GPS accuracy. As stated previously, GPS survey methods are capable of providing significantly higher relative positional accuracies with only minimal field observations, as compared with conventional triangulation, trilateration, or EDM traverse. Although a GPS survey may be designed and performed to support lower accuracy project control requirements, the actual results could generally be several magnitudes better than the requirement. Although higher accuracy levels are relatively easy to achieve with GPS, it is important to consider the ultimate use of the control on the project in planning and designing GPS control networks. Thus, GPS survey adequacy evaluations should be based on the project accuracy standards, not those theoretically obtainable with GPS.

(1) For instance, an adjustment of a pair of GPS-established points may indicate a relative distance accuracy of 1:800,000 between them. These two points may be subsequently used to set a dredging baseline using 1:2,500 construction survey methods; and from 100-ft-spaced stations on this baseline, cross sections are projected using 1:500 to 1:1,000 relative accuracy methods (typical hydrographic surveys). Had the GPS-observed baseline been accurate only to 1:20,000, such a closure would still have easily met the project's functional requirements.

(2) Likewise, in topographic (site plan) mapping or photogrammetric mapping work, the difference between 1:20,000 and 1:800,000 relative accuracies is not perceptible at typical USACE mapping/construction scales (1:240 to 1:6,000), or ensuring supplemental compliance with ASPRS Standards. In all cases of planimetric and topographic mapping work, the primary control network shall be of sufficient accuracy such that ASPRS Standards can be met when site plan mapping data are derived from such points. For most large-scale military and civil mapping work performed by USACE, Third-Order relative accuracies are adequate to control planimetric and topographic features within the extent of a given sheet/map or construction site ...

(3) In densifying control for GIS databases, the functional accuracy of the GIS database must be kept in perspective with the survey control requirements. Performing 1:100,000 accuracy surveys for a GIS level containing 1-acre cell definitions would not be cost-effective; sufficient accuracy could be obtained by scaling relative coordinates from a US Geological Survey (USGS) quadrangle map.

d. Vertical accuracy. Establishing primary (i.e. monumented) vertical control benchmarks using carrier phase differential GPS methods requires considerable planning if traditional vertical accuracy standards are to be met. Since most Corps projects involve hydraulic flow of water in rivers, streams, pools, wetlands, etc., precise vertical control is essential within a project area; especially if construction is planned. Densification of vertical elevations with GPS requires sufficient control checks using conventional differential leveling, along with accurate geoid modeling. Therefore, an early evaluation needs to be made to determine if GPS-derived elevations will be of sufficient accuracy to meet project needs. Usually, a combination of GPS and conventional differential spirit leveling will be required. GPS standards and specifications needed to establish and densify vertical control network points are discussed in a later section of this chapter.

B-7. Hydrological and Hydraulic Accuracy Requirements

In order to best define the governing accuracy standard required for connecting primary project control monuments to the regional NSRS, it is necessary to understand the hydraulic engineering applications for such connections. Evaluation of CEPD projects will require close coordination with District H&H personnel in order to develop elevation accuracy criteria. These criteria can be developed from a number of USACE publications, such as:

EM 1110-2-1416 (River Hydraulics)
EM 1110-2-1411 (Standard Project Flood Determinations)
EM 1110-2-1619 (Risk-Based Analysis for Flood Damage Reduction Studies)
EM 1110-2-1601 (Hydraulic Design of Flood Control Channels)
EM 1110-2-1913 (Design and Construction of Levees)
Hydraulic Engineering Center (HEC) RD-26 "Accuracy of Computed Water Surface Profiles"

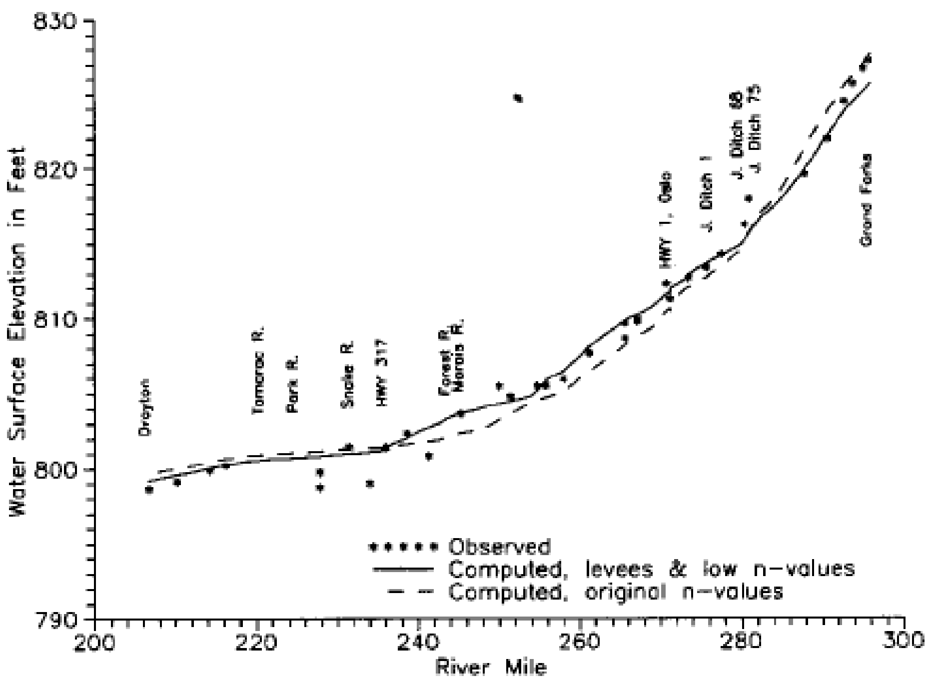


Figure B-2. Profile calibration to high water marks (HEC RD-26) from EM 1110-2-1416, 15 Oct 93

Region-wide hydraulic accuracy requirements can be derived using the guidance in HEC RD-26. Figure B-2 above illustrates the requirement for regional NSRS connections (and implied relative NSRS accuracies) between disparate locations on a river system. Using an observed 815 ft profile elevation at river mile 280 and an 800 ft elevation at river mile 220, a 15 ft elevation difference exists over this 60-mile reach. If the 15 ft elevation difference needs to be accurate to ± 1 ft (i.e., relative accuracy), then the river gauge reference benchmark elevations at each end of the 60 mile line would require (roughly) a ± 0.7 ft relative NSRS regional accuracy—i.e., $(0.7^{2} + 0.7^{2})^{½} = \pm 1$ ft.

HEC RD-26 also assessed the survey accuracy required to achieve desired profile accuracies, as illustrated in the following table (Figure B-3) taken from that publication:

TABLE 6.7

SURVEY ACCURACY REQUIREMENTS[1]
FOR SPECIFIED PROFILE ACCURACIES
(Hydraulic Depth is 5 Feet)

		Manning's n-value Reliability - Nr = 0		Manning's n-value Reliability - Nr = 1	
Stream Slope (ft./mi.)	Profile Accuracy Emean[2] (feet)	Aerial Survey Contour Interval	Topo Map Contour Interval	Aerial Survey Contour Interval	Topo Map Contour Interval
1	.1	10 foot	N.A.	N.A.	N.A.
1	.5	10 foot	5 foot	N.A.	N.A.
1	1.0	>10 foot	10 foot	10 foot	2 foot
1	1.5	>10 foot	10 foot	10 foot	5 foot
1	2.0	>10 foot	10 foot	>10 foot	10 foot
10	.1	2 foot	N.A.	N.A.	N.A.
10	.5	10 foot	5 foot	N.A.	N.A.
10	1.0	10 foot	5 foot	10 foot	N.A.
10	1.5	>10 foot	10 foot	10 foot	2 foot
10	2.0	>10 foot	10 foot	10 foot	5 foot
30	.1	2 foot	N.A.	N.A.	N.A.
30	.5	10 foot	2 foot	N.A.	N.A.
30	1.0	10 foot	5 foot	10 foot	N.A.
30	1.5	>10 foot	10 foot	10 foot	2 foot
30	2.0	>10 foot	10 foot	10 foot	5 foot

[1]Denotes maximum survey contour interval to produce desired accuracy.
[2]Emean is mean absolute reach error.

The Hydrologic Engineering Center
December 1986

Figure B-3. Survey accuracy for various profile accuracies

Given the allowable error in a water surface profile, and considering other hydraulic factors, the required accuracy of topographic data (e.g., stream cross-sections) can be estimated. (Topographic survey accuracies in this older publication are defined relative to National Map Accuracy Standard (NMAS) contour interval accuracy. These can be converted to NSSDA 95% confidence standards—see below). This document should be reviewed in order to appreciate the impact (or often lack thereof) of survey accuracy on computed water surface profiles. For example, if a hydrological or hydraulic water surface profile model is sensitive to cross-sectional accuracy at the ± 2 ft (NSRS) level, then there would be no point in requiring control points for surveying these sections to be accurate at the ± 0.1 ft (NSRS) level.

B-8. Regional NSRS Network Accuracy for Levees and Related Flood Control Projects

Figure B-4 outlining the MVS Bois Brule Levee & Drainage District represents a typical main-stem Mississippi River levee system. The river slope drops approximately 8 ft over this 12-mile reach, or over ½ ft per mile. Given the magnitude of the elevation change over this 12-mile distance, the design levee grades between each end of the system would not need a high level of relative accuracy. A ±0.25 ft to ±0.5 ft relative accuracy between the northwesterly and southeasterly limits would be adequate for most engineering purposes. These levels of accuracy can be easily achieved with GPS or conventional differential leveling methods.

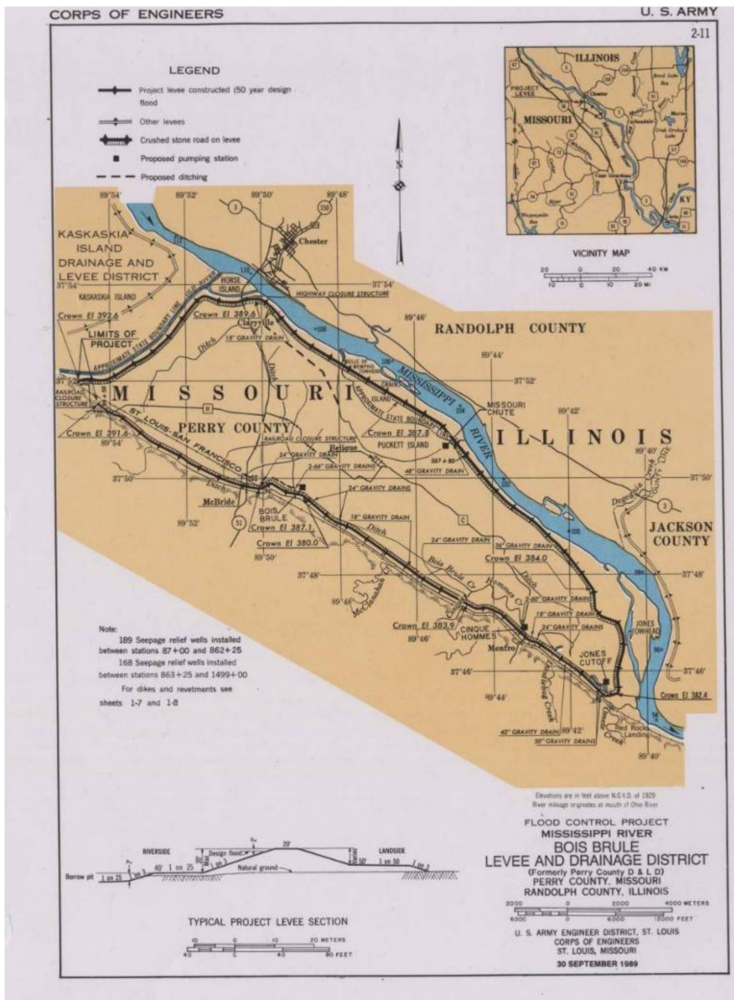


Figure B-4. Bois Brule Levee & Drainage District

Region-wide NSRS connections are also illustrated in the Figure B-5. This Central and Southern Florida Flood Control Project contains a vast network of levees, canals, control gates, pump stations, and other flood control structures in southeast Florida. Assume the elevation of a water control structure reference benchmark at Lake Okeechobee may need to be known (for hydraulic engineering purposes) to the nearest ± 0.25 ft relative to a levee or canal gauge reference control point 80 miles south in Miami. Geodetic control surveys can be designed to achieve this accuracy; such that points throughout the C&SF region are connected to the NSRS to such an accuracy with a 95% confidence estimate. Regional NSRS benchmarks spaced, say at 15 to 20 mile intervals, would provide such coverage in that supplemental topographic/construction densification surveys from these benchmarks would provide NSRS elevations (NAVD88) at feature points.

However, for local construction purposes, a control benchmark point on a levee two miles to the south of the Lake Okeechobee control structure may need to be accurate to ± 0.1 ft relative to the Lake Okeechobee benchmark; and ± 0.025 ft in a 500 ft x 500 ft construction area. Benchmarks set in this small project area would have NAVD88 elevations relative to the regional NSRS but would be locally accurate to ± 0.025 m or ± 0.1 ft levels needed for construction. These project benchmarks, and any other local topographic features, would be surveyed using conventional "Third Order" topographic surveying techniques outlined in EM 1110-2-1005—e.g., differential leveling, total stations, or RTK GPS.

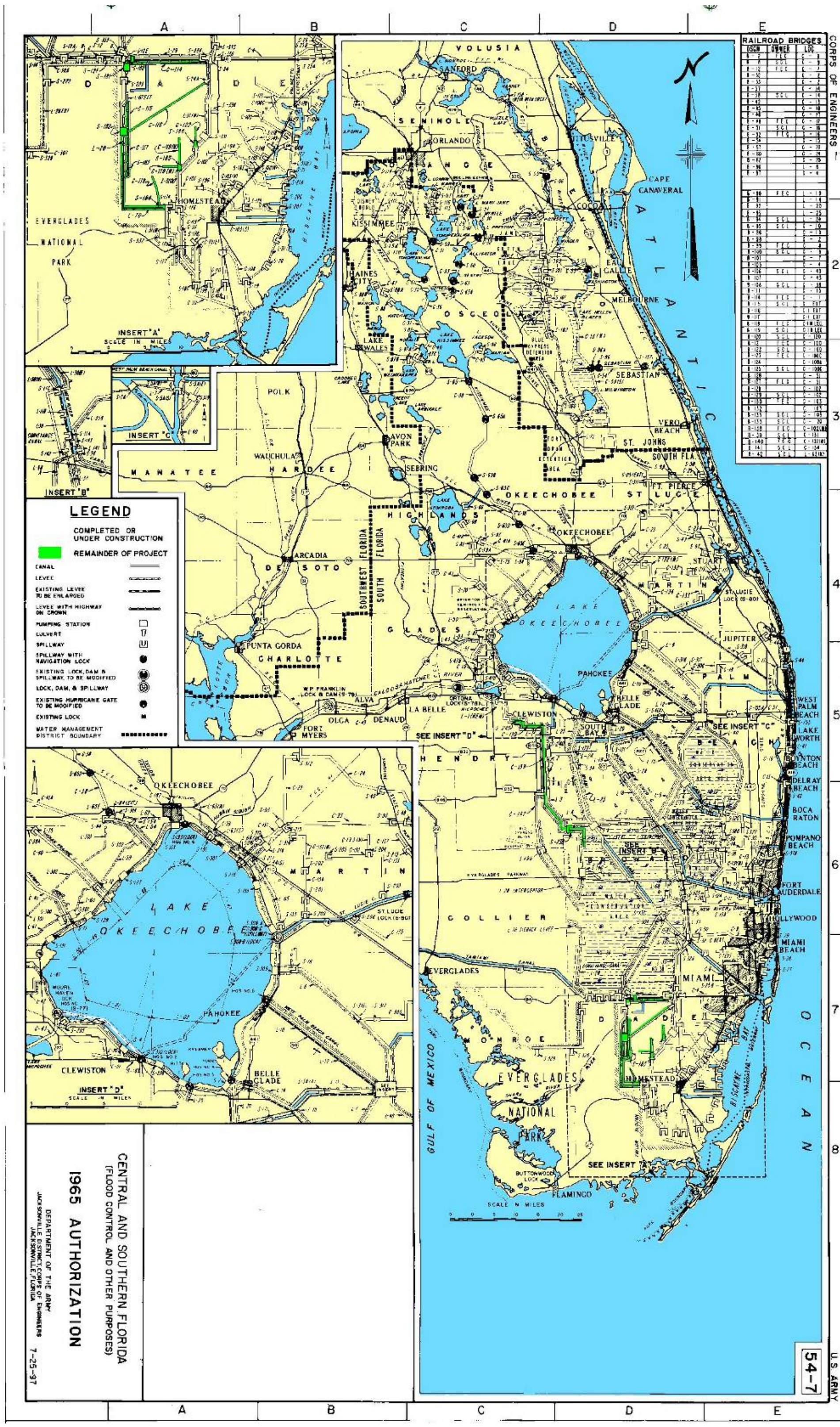


Figure B-5. Central & Southern Florida Flood Control Project

Local accuracy requirements will also vary significantly depending upon the type of control structure. The guidance below excerpted from EM 1110-2-1009 (Structural Deformation Surveying) illustrates the high relative accuracies needed in and around a structure site.

> The following table provides guidance on the accuracy requirements for performing deformation surveys. These represent either absolute or relative movement accuracies on target points that should be attained from survey observations made from external reference points. The accuracy by which the external reference network is established and periodically monitored for stability should exceed these accuracies. Many modern survey systems (e.g., electronic total stations, digital levels, GPS, etc.) are easily capable of meeting or exceeding the accuracies shown below. However, it is important that accuracy criteria must be defined relative to the particular structure's requirements, not the capabilities of a survey instrument or system. As an example to distinguish between instrument accuracy and project accuracy requirements, an electronic total station system can measure movement in an earthen embankment to the ±0.005-foot level. Thus, a long-term creep of say 3.085 feet can be accurately measured. However, the only significant aspect of the 3.085-foot measurement is the fact that the embankment has sloughed "3.1 feet" -- the ±0.001-foot resolution (precision) is not significant and should not be observed even if available with the equipment. As another example, relative crack or monolith joint micrometer measurements can be observed and recorded to ±0.001-inch precision. However, this precision is not necessarily representative of an absolute accuracy, given the overall error budget in the micrometer measurement system, measurement plugs, etc. Hydraulic load and temperature influences can radically change these short-term micrometer measurements at the 0.01 to 0.02-inch level, or more. Attempts to observe and record micrometer measurements to a 0.001-inch precision with a ±0.01-inch temperature fluctuation are wasted effort on this typical project.

EM 1110-2-1009 Table 2-1. [*Local*] Accuracy Requirements for Structure Target Points (95% RMS)

Concrete Structures Dams, Outlet Works, Locks, Intake Structures:	
Long-Term Movement	± 5-10 mm
Relative Short-Term Deflections Crack/Joint movements Monolith Alignment	± 0.2 mm
Vertical Stability/Settlement	± 2 mm
Embankment Structures Earth-Rockfill Dams, Levees:	
Slope/crest Stability	± 20-30 mm
Crest Alignment	± 20-30 mm
Settlement measurements	± 10 mm
Control Structures Spillways, Stilling Basins, Approach/Outlet Channels, Reservoirs	
Scour/Erosion/Silting	± 0.2 to 0.5 foot

The above accuracies are local within the immediate area of a structure. For example, a monitoring plug on a concrete monolith may have a local vertical accuracy of ± 0.001 ft relative to the adjacent monolith plug, and perhaps ± 0.003 ft relative to the external monitoring network 500 to 1,000 ft distant (see Figure B-6). Since most monitoring points are on local vertical datums, a monolith plug's elevation may be 104.678 ft ± 0.003 ft, where one of the external monitoring points has been given an arbitrary elevation of 100.000 ft. The absolute NSRS elevation (e.g., NAVD88) for this same monolith point might be 784.2 ft ± 0.3 ft. This NSRS elevation may have been obtained from static GPS baseline observations to NSRS points 5 to 10 miles distant, and/or CORS points 50 to 150 miles distant.

For most earth-rockfill and concrete dams, only one external monitoring point needs to be tied in to the NSRS—NSRS elevations for all other monitoring points can be computed from the latest periodic inspection report.

This CEPD project is not intended to modify local deformation vertical datums—only to add a reliable NSRS reference to these structure points.

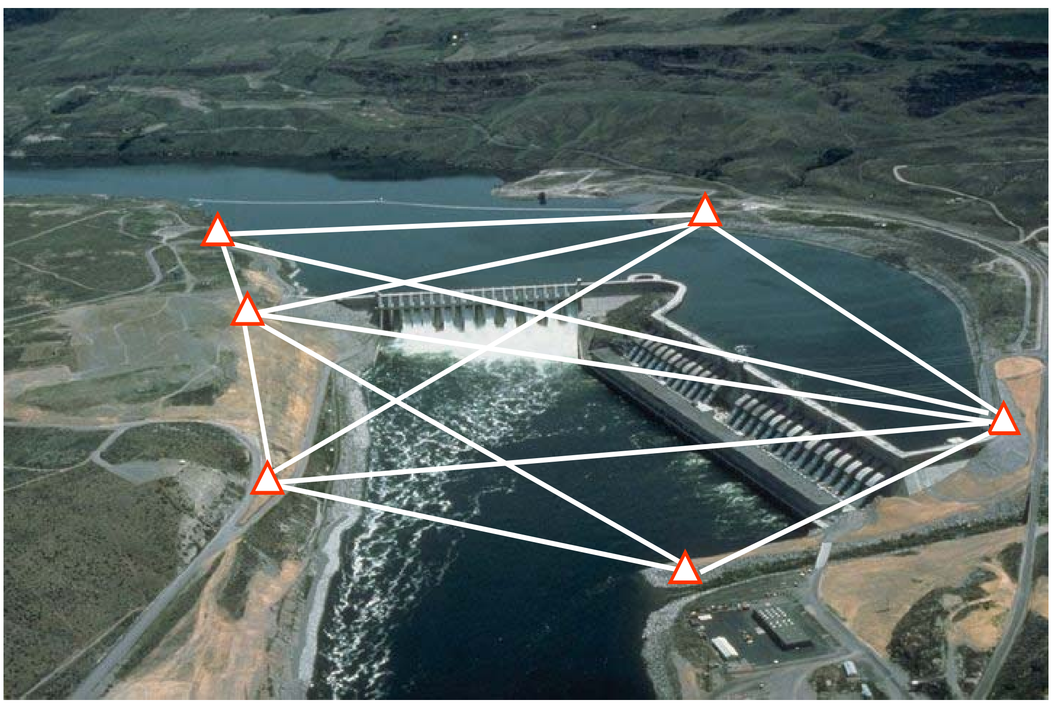


Figure B-6. Structural deformation monitoring network at a hydropower project

B-9. FEMA Accuracy Standards for Flood Insurance Rate Maps

Since regional conformance with FEMA NFIP studies is an essential goal of any USACE flood control project and/or study, both USACE and FEMA must be on the same vertical datum—i.e., NSRS NAVD88. FEMA standards and specifications clearly detail this intent. The following table from Appendix A (Guidance for Aerial Mapping and Surveying) of the FEMA "Guidelines and Specifications for Flood Hazard Mapping Partners" illustrates the required FIRM/DFIRM accuracy requirements relative to the NSRS. In summary, FEMA NSRS regional elevation accuracy standards are:

- Standard 2-foot equivalent contour interval accuracy ($Accuracy_z$ = 1.2 foot) appropriate for flat terrain
- Standard 4-foot equivalent contour interval accuracy ($Accuracy_z$ = 2.4 foot) appropriate for rolling to hilly terrain

(Note that vertical accuracies are reported relative to the NSSDA 95% confidence level)

Guidelines and Specifications for Flood Hazard Mapping Partners [April 2003]

Table A-2. Comparison of Vertical Accuracy Standards

NMAS Contour Interval	NMAS VMAS 90% confidence level	NSSDA $Accuracy_z$ 95% confidence level	NSSDA $RMSE_z$	ASPRS 1990 Class 1/2/3 Limiting $RMSE_z$
2 feet	1 foot	1.2 feet	0.6 foot 18.5 centimeters	0.7 foot (Class 1) 1.3 feet (Class 2) 2.0 feet (Class 3)
4 feet	2 feet	2.4 feet	1.2 feet 37.0 centimeters	1.3 feet (Class 1) 2.7 feet (Class 2) 4.0 feet (Class 3)

Guidelines and Specifications for Flood Hazard Mapping Partners [April 2003]

Table A-1. Comparison of Horizontal Accuracy Standards

NMAS Map Scale	NMAS CMAS 90% confidence level	NSSDA $Accuracy_r$ 95% confidence level	NSSDA $RMSE_r$	ASPRS 1990 Class 1/2/3 Limiting $RMSE_r$
1" = 500'	16.7 feet	19.0 feet	11.0 feet	7.1 feet (Class 1) 14.1 feet (Class 2) 21.2 feet (Class 3)
1" = 1,000'	33.3 feet	38.0 feet	22.0 feet	14.1 feet (Class 1) 28.3 feet (Class 2) 42.4 feet (Class 3)
1" = 2,000'	40.0 feet	45.6 feet	26.3 feet	28.3 feet (Class 1) 56.5 feet (Class 2) 84.9 feet (Class 3)

In effect, USACE flood control structure elevations should have relative NSRS regional network accuracies at or better than the above levels in order to be consistent with FEMA flood insurance studies, FIRMS, DFIRMS, etc. The USACE control survey standards and specifications in this guidance document will yield NSRS network accuracies well within these FEMA NSRS accuracy standards. These more precise USACE accuracy standards result from more rigorous hydraulic engineering and levee design requirements than those needed for NFIP studies.

The above referenced FEMA guidance document should be thoroughly reviewed by those involved with USACE vertical datum updates under CEPD or NLD. The FEMA "Map Modernization" project should also be reviewed.

B-10. Conformance with USGS National Map Accuracy Standards

USGS topographic maps at 1:24,000 (1" = 2,000 ft) are generally designed to be accurate to 1/2 the contour interval on the map. Thus, for a typical 2 ft contour map, the estimated vertical accuracy is ± 1 ft (at a 90% confidence). The horizontal accuracy is specified at 1/30th of the scale, or ± 67 ft for a 1 " = 2,000 ft 7.5 minute quadrangle. The targeted NSRS network accuracy standards performed under this guidance will easily exceed these USGS mapping accuracy standards, and therefore makes USACE geospatial data consistent with USGS mapping requirements.

ACCURACY STANDARDS FOR PRIMARY AND LOCAL PROJECT CONTROL

B-11. Recommended USACE Accuracy Standards for Primary Project Control Benchmarks Set Relative to the NSRS Network

The following accuracy standards in Table B-1 apply to USACE "primary project control" benchmarks that are newly established relative to a regional NGS NSRS network—e.g., those points connected by differential leveling and/or GPS baselines to nearby NSRS or CORS points. These connections will be submitted to NGS for inclusion in the NSRS. These are nominal standards and are believed adequate for typical USACE flood control systems and levees along the major inland waterways. **As stated previously, they do not apply to supplemental (local) levee or flood control structure control surveys, or topographic and construction surveys, established from these points.**

Table B-1. Nominal or Target Accuracy Standards for Connecting USACE Flood Control Projects to the NSRS Network—Primary Project Control Points

	Relative Accuracy (95%)	Reference Datum
Vertical Accuracy	± 0.25 ft (± 8 cm)	NAVD88
Horizontal Accuracy	± 2 ft (± 60 cm)	NAD83

Accuracies are relative to points published by NGS on the NSRS—both nearby and/or CORS.

Accuracies are based on a constrained adjustment of GPS observations to CORS (CORS-Only Solutions) and/or nearby NSRS points.

The absolute network accuracy of non-CORS NSRS points is not factored in this standard—all observed NSRS points will be fully constrained in a weighted adjustment. Actual NSRS network and local accuracies may be subsequently computed/estimated by NGS.

These target NSRS network accuracy standards at the ±0.25 ft level are believed to be representative of the nominal accuracy requirements for the vast majority of USACE levee systems and related flood control projects. These accuracies should support flood forecasting models, stage-discharge relationships, flood inundation modeling, flood control channel design, levee freeboard design, risk assessment, and related river hydraulics work.

As stated previously, there may be river segments where these standards are either too rigid or perhaps require tightening, as might be the case in high subsidence regions. This decision on the required project accuracy should be left to those performing hydrology and hydraulics studies over a watershed or flood control region. (As stated previously, USACE surveyors will develop performance specifications to meet those standards). If such technical guidance is not available from H&H, then these criteria may be used by default. If more rigid accuracy standards are required, then refer to the guidance at the end of this Appendix (Higher Accuracy Survey Standards).

NSRS network horizontal accuracies (±2 ft) are obviously not critical for the above hydraulic engineering purposes. This nominal horizontal standard can be exceeded with minimal observation times using CORS-only control. This would be done in cases where existing NGS benchmarks are recovered that do not have a horizontal position. When static GPS observations are conducted at a point for elevation determination, horizontal accuracies relative to the NSRS will typically fall below the ±0.15 ft levels.

B-12. Local Topographic, Engineering, and Construction Survey Accuracy Standards

Local levee alignment benchmarks (e.g., PIs, PTs, PCs, gauge references, etc.) and topographic features (levee profiles, cross-sections, etc.) will be positioned relative to the nearest primary project control benchmark that has been controlled relative to the NSRS. This primary NSRS point(s) may be a published NGS benchmark or a USACE monument that has been connected to (and input into) the NSRS. These local project control surveys will typically be performed over short distances—e.g., less than 3 to 5 miles from a RTK base station or comparable differential leveling or total station lengths). Field survey procedures will follow 3rd Order engineering and construction guidelines in EM 1110-1-1005 (Control and Topographic Surveying).

Table B-2. Recommended Local Project Accuracies for Flood Control Project Features

	Relative Accuracy (95%)	Reference Datum
Levee or floodwall control benchmarks:	± 0.15 ft (± 5 cm)	NAVD88/NAD83/local
Hard topographic features:	± 0.3 ft (± 9 cm)	NAVD88/NAD83/local
Ground shots:	± 0.5 ft (± 15 cm)	NAVD88/NAD83/local
Construction stake out	± 0.01 to 0.05 ft	Local site

Local project control will typically have two horizontal references: (1) a local SPCS system, and (2) the construction station/chainage-offset system.

Note: the above accuracies are not relative to the regional NSRS but are for local topographic and construction purposes—e.g., that which may be required for construction or to populate the NLD. Elevations are reported relative to NSRS vertical datum.

Geoid03 (or a later version published by NGS) will be used to estimate and correct local geoid undulations for all topographic densification using RTK methods. At longer distances greater than 3 miles from the RTK base, frequent calibration check points are recommended if a standard RTK site calibration/localization process is not feasible—see EM 1110-2-1005.

Local horizontal accuracies should generally be within the above tolerances for vertical accuracies shown in Table B-2. When using RTK methods, the horizontal accuracies will be slighter better—and over typical RTK application distances, a ± 0.1 ft (± 3 cm) local relative accuracy should be achieved at any type of point located (assuming appropriate RTK site calibration procedures are followed). For example, the horizontal distance between two levee PIs 2,000 ft apart will be accurate horizontally to the ± 0.1 to 0.2 ft level when these points are connected using either RTK or total station EDM observations, and usually better than ± 0.05 ft vertically when 3rd-Order differential levels are run. These local (relative) accuracy levels are sufficient for any levee stationing stake out needed for construction or maintenance grading. Thus a PI monument will have a local project stationing-offset and elevation coordinate for maintenance and construction, and will also be referenced to the NSRS (NAD83 & NAVD88) for regional mapping orientation (and CEPD certification) purposes.

As was shown back on Figure B-1, NSRS network accuracies of any local benchmark or feature point will typically be slightly larger than the accuracy of the controlling (primary) NSRS benchmark—due to error propagation. For example, if an RTK base is set over a NGS NSRS network point with an established (estimated or published) NSRS “network” accuracy of ± 0.3 ft (± 10 cm), and a local project benchmark atop the levee on a PI is shot in with an estimated RTK “precision” of ± 0.1 ft, then the estimated (propagated) accuracy of the PI benchmark is roughly ± 0.32 ft—i.e., $(0.3^2 + 0.1^2)^{1/2} = \pm 0.32$ ft. If this PI point is later occupied with an RTK base to cut in hard levee features or levee crest ground profiles, then the estimated (propagated) accuracy of these elevations would be roughly ± 0.34 ft relative to the regional NSRS—i.e., $(0.32^2 + 0.1^2)^{1/2} = \pm 0.34$ ft. This will still be well within most regional engineering or CEPD certification accuracy requirements.

EVALUATION OF EXISTING FLOOD CONTROL PROJECT ELEVATION CONNECTIONS WITH THE NSRS

B-13. General Assessment Criteria

General guidance for evaluating the acceptability and reliability of vertical datums on individual flood control projects is outlined in paragraph 10 of this guidance document and further expanded in Appendix D. In summary, the main issues to be evaluated for each flood control project include:

- The protection grade elevations are referenced to NAVD88 based on primary project control benchmarks published in the NSRS.

- River gauges owned and operated by (or other agency gauges used by) the Corps are referenced to NAVD88 based on control benchmarks published in the NSRS, and that the relationship between the geodetic and hydraulic datums at the gauge are firmly established and documented.

- Project drawings, CADD files, and related documents, contain full and complete metadata on primary project control benchmarks.

Upon completing an evaluation for each project, it may be determined that no additional fieldwork is required for connection to the NSRS. This would include:

(1) Projects that have been recently connected to the NSRS, e.g., were included in a Height Modernization project.

(2) Projects with control firmly surveyed on NGVD29 and directly leveled to NSRS points that were subsequently readjusted to NAVD88.

(3) Projects that were recently connected to the NSRS by local sponsors, levee boards/districts, State DOT, or other local agency, but connections were not published in the NSRS.

If the initial CEPD assessment finds that a project datum requires updating, and a required accuracy tolerance is developed by H&H personnel, then the amount of effort involved will be largely governed by the following factors:

(1) Availability, acceptability, and accessibility of existing (published or unpublished) vertical control in the region.

(2) If GPS survey observations are required, the ability to use a CORS-Only/OPUS elevation determination in lieu of observing extensive GPS static baseline networks.

(3) Availability of expedited procedures for submitting benchmark descriptions and elevation data into the published NSRS (OPUS DB or OPUS PROJECT).

The following sections provide guidance on estimating the field survey scope required that will be needed to update a project datum to NAVD88 and, where applicable, publish the primary benchmark(s) for a project on the NSRS. These estimates will be incorporated into a project report following the guidance in Appendix D.

B-14. Prioritization of Projects Requiring Datum Updates

This CEPD assessment should program field surveys to update project control based on some form of risk assessment. Risk assessment criteria for a project might include (1) protected population areas, (2) known insufficient datums, (3) known settlement problems, (4) known subsidence, (5) District or sponsor priority, (6) type for flood protection structure, or (7) structure height. Numerous other factors might also be considered. Deauthorized projects will not be evaluated nor will non-Federal levee systems within the Rehab and Inspection Program (RIP) or non-Federal hurricane/shore protection projects—see ER 500-1-1.

B-15. Field Reconnaissance during the Evaluation Process

It is not intended that the initial CEPD assessment effort will require any field reconnaissance. Time and cost estimates will be based on professional judgment and local knowledge of the projects. However, once the CEPD evaluation identifies a project that requires a datum update, then a field reconnaissance may be necessary to refine the rough CEPD cost estimate. In order to develop a firm contract scope of work (SOW), it may be necessary to recover existing NGS NSRS benchmarks in the project area. This should be done with USACE hired-labor forces. Based on this recovery, a more detailed SOW can be developed that will better estimate the number of required new benchmarks as opposed to potential use of existing NGS NSRS control. This will also provide a more solid cost estimate for the remaining survey work.

UTILIZING EXISTING NSRS CONTROL FOR PRIMARY PROJECT CONTROL BENCHMARKS

If existing (published) NGS vertical control (2nd-Order or better) are available on or near a levee system or flood control structure, and at a density (spacing) adequate for supplemental topographic surveying purposes (e.g., 15 to 20 miles), then there is effectively no need to establish a new NSRS primary project control reference point. Existing NSRS benchmarks can be used to delineate NAVD88 elevations on local control points on the levee—typically using standard topographic survey methods, e.g., short-term static GPS baseline observations, differential leveling, total station traverse. The published NGS data will be accepted as reliably connected to the NSRS after checks into two (2) surrounding NSRS points. In effect, benchmarks published by NGS on the NSRS will be accepted (trusted) at "face value." If the NSRS benchmark does not have a horizontal position, this can be quickly obtained by a short-term (1 hour) CORS/OPUS observation. General criteria are shown in Table B-3 below.

Table B-3. General Criteria Needed when Utilizing Existing (Published) NSRS Control as the Primary Elevation Benchmark at a Project

NGS pre-approval required	No
Check validity of published elevation	Yes
Minimum number of NSRS check points	2
Survey check methods	RTK, differential levels, total station
NSRS input of check surveys	No
Check survey tolerance between NSRS benchmarks	±0.05 ft to ±0.10 ft
Recovery note on NSRS benchmark	Required—submit on-line to NGS

A recovered NGS NSRS benchmark will have some elevation uncertainty relative to the nationwide NSRS (i.e., "Network Accuracy" and "Local Accuracy"—see NGS Pub 58). Given limited resources, it is not the intent of these standards and specifications to investigate and minimize these NSRS benchmark inaccuracies. It should be noted that existing NSRS benchmark elevations may have a greater relative inaccuracy that an elevation determined by height reductions based on current CORS observations. In time, it is anticipated that benchmark elevations will be observed and monitored relative to the nationwide CORS network.

To illustrate a case where existing NSRS control can be used, Figure B-7 shows a published NSRS line of levels running through a levee segment. In this case, the published NGS benchmark elevations will be accepted as the primary project reference point, and will be directly used for referencing NAVD88 elevations to supplemental local project control points on the levee. No long-term static GPS observations will be required to adjacent points on the NSRS or CORS, other than a quick tolerance check indicated in Table B-3.

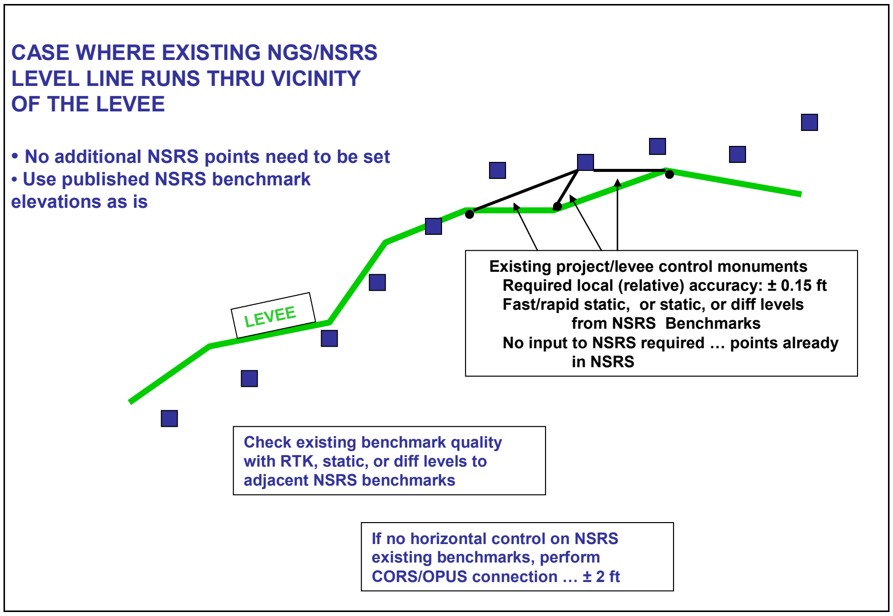


Figure B-7. Existing NSRS control within a levee project

The first step in evaluating NSRS coverage in a levee system is to access the NGS database and search for existing benchmarks. This can be done graphically as shown in the screen capture in Figure B-8 below. If a USACE levee system is located along the river system parallel with the NGS level line running diagonal SW to NE in the figure, then any of these benchmarks can be directly used to provide NSRS (NAVD88) control on levee points—and only short-term RTK checks would be performed to confirm NSRS control accuracy and validity of the marks used as control. Per Table B-3, a tolerance check between benchmarks of ±0.05 ft to ±0.1 ft would be considered reasonable.

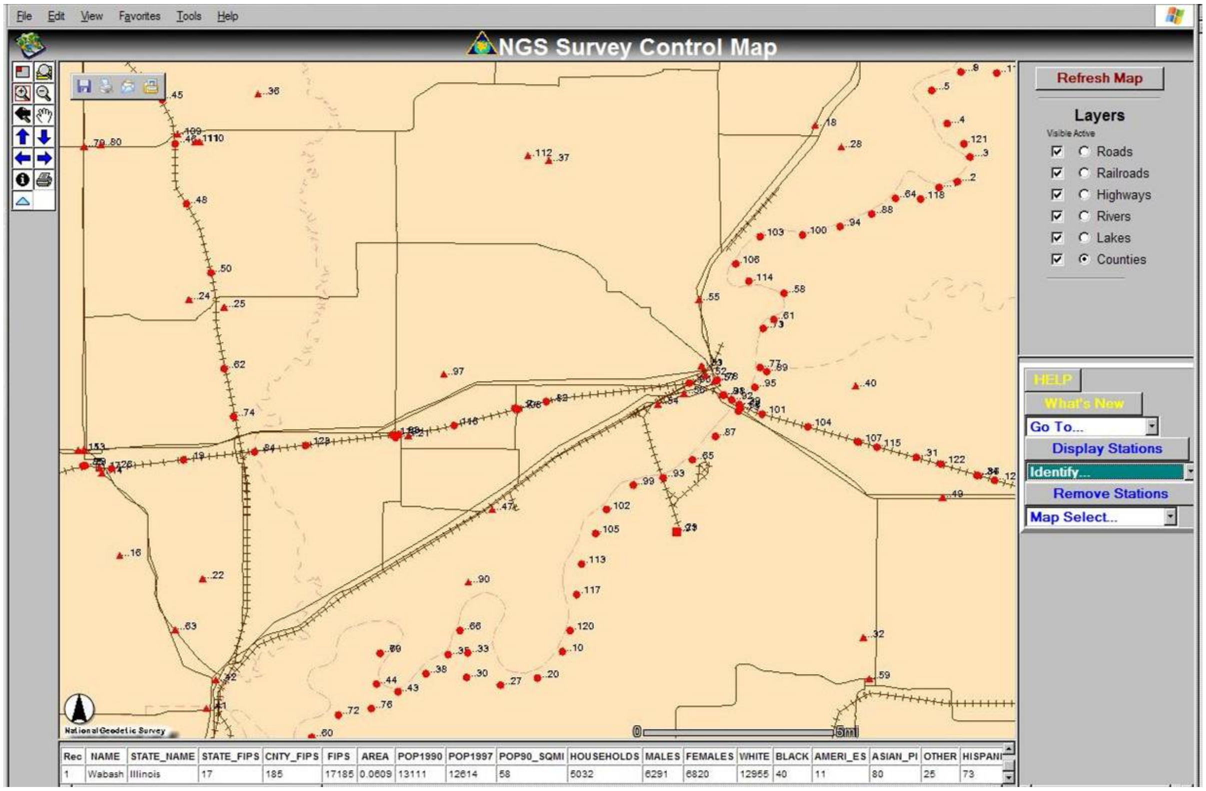


Figure B-8. NGS Control Map on Web Site

An evaluation and search for any unpublished vertical control should also be made. Any number of State or local agencies may have performed precise GPS control surveys in and around the project. Even other District elements may have done this. It is possible that this work can be directly used and input into the NSRS.

Figure B-9 illustrates a NSRS control search that included specialized vertical control in the New Orleans region. In this high subsidence region, only NGS updated time-dependent vertical control can be used for connecting levee/floodwall systems to the NSRS—e.g., NAVD88 (2004.65). Previous adjustments of NAVD88 cannot be used in this region, and the current adjustment (NAVD88 (2004.65)) will be superseded in 2007.

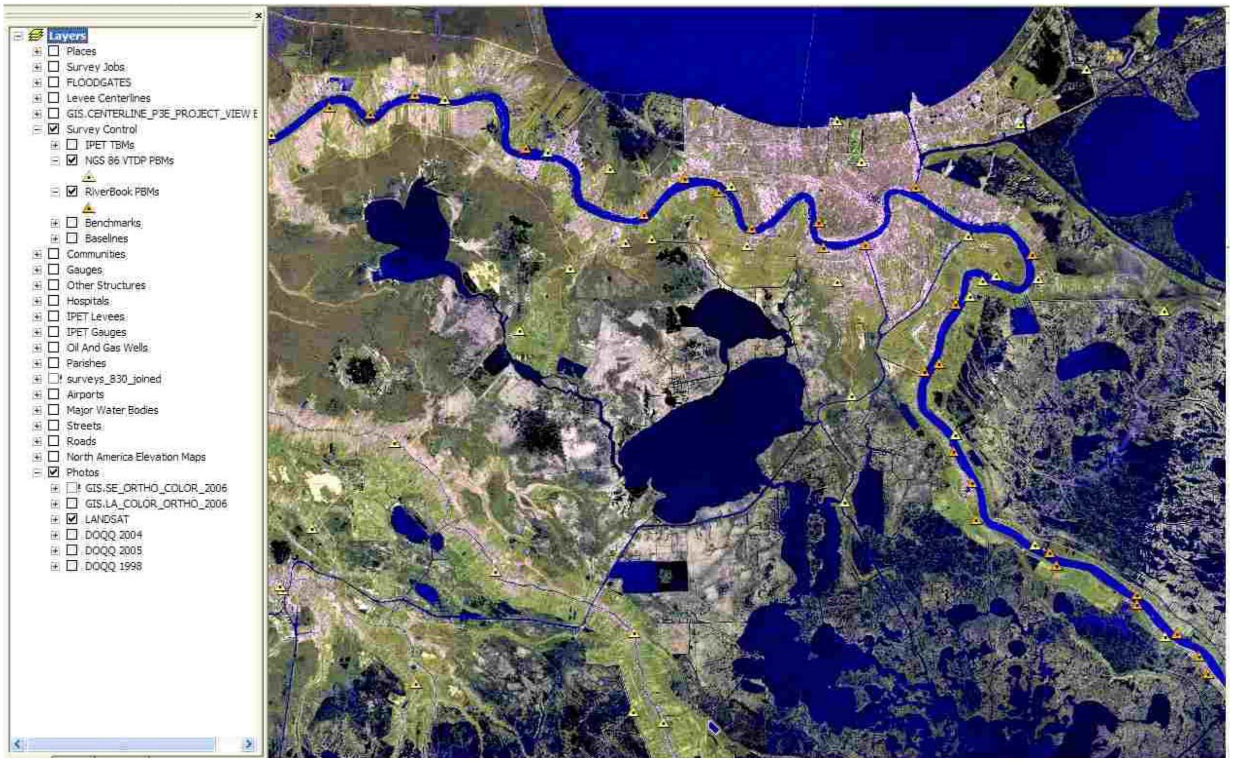


Figure B-9. New Orleans area vertical control network—NAVD88 (2004.65)

The following project from Albuquerque District (Figure B-10) is typical of a remote flood control project in New Mexico. In this case, a search of the NSRS database yielded little vertical control within 15 miles of the project, and much of the control listed had not been recovered for 50 or more years. This would be a case for checking all sources (internal District, local, DOT) for any recently established control points that may be in the process of being published by the NGS.

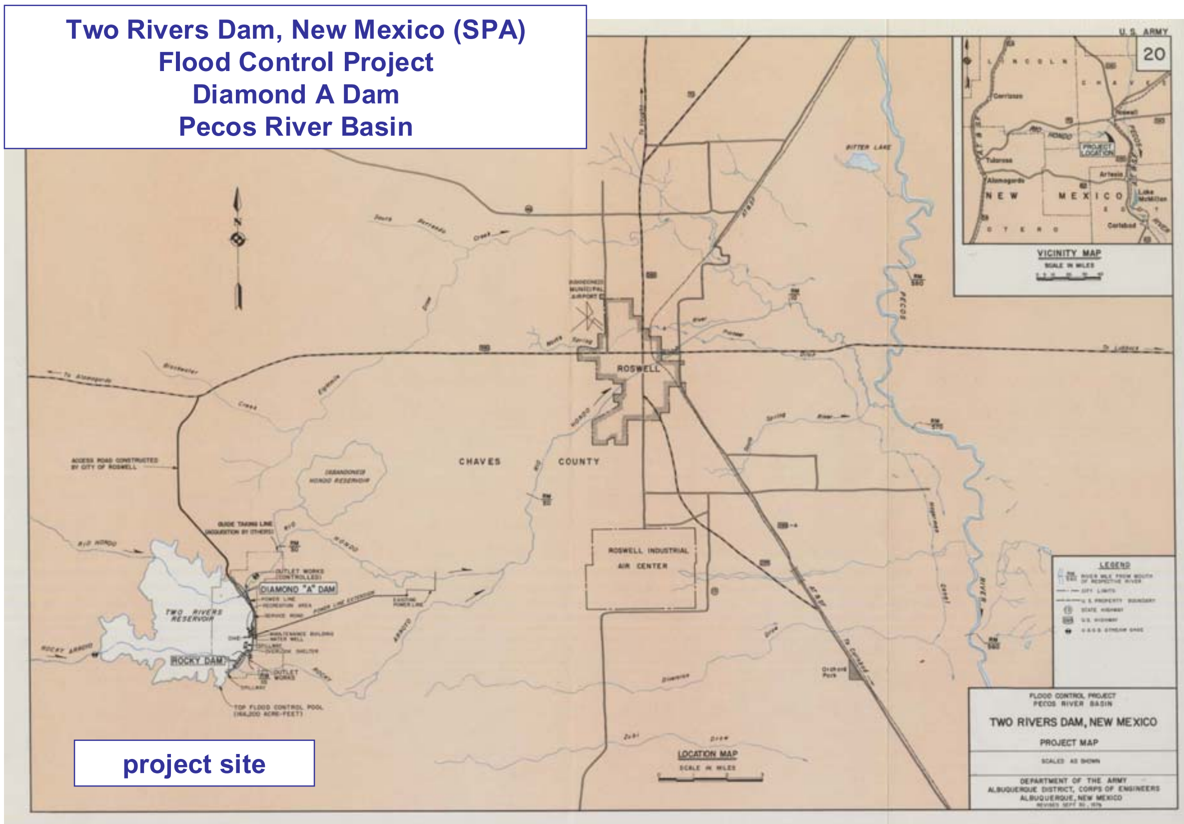


Figure B-10. Two Rivers Dam, New Mexico

The following levee district project in Illinois (Figure B-11) appears to have sufficient NSRS control such that no major GPS densification surveys will be required to bring NAVD88 control into the project. Some of the NSRS benchmarks are on the levee crown. It is also possible that the local District has already re-referenced the primary or local project control to NAVD88—this should be checked internally within the District.

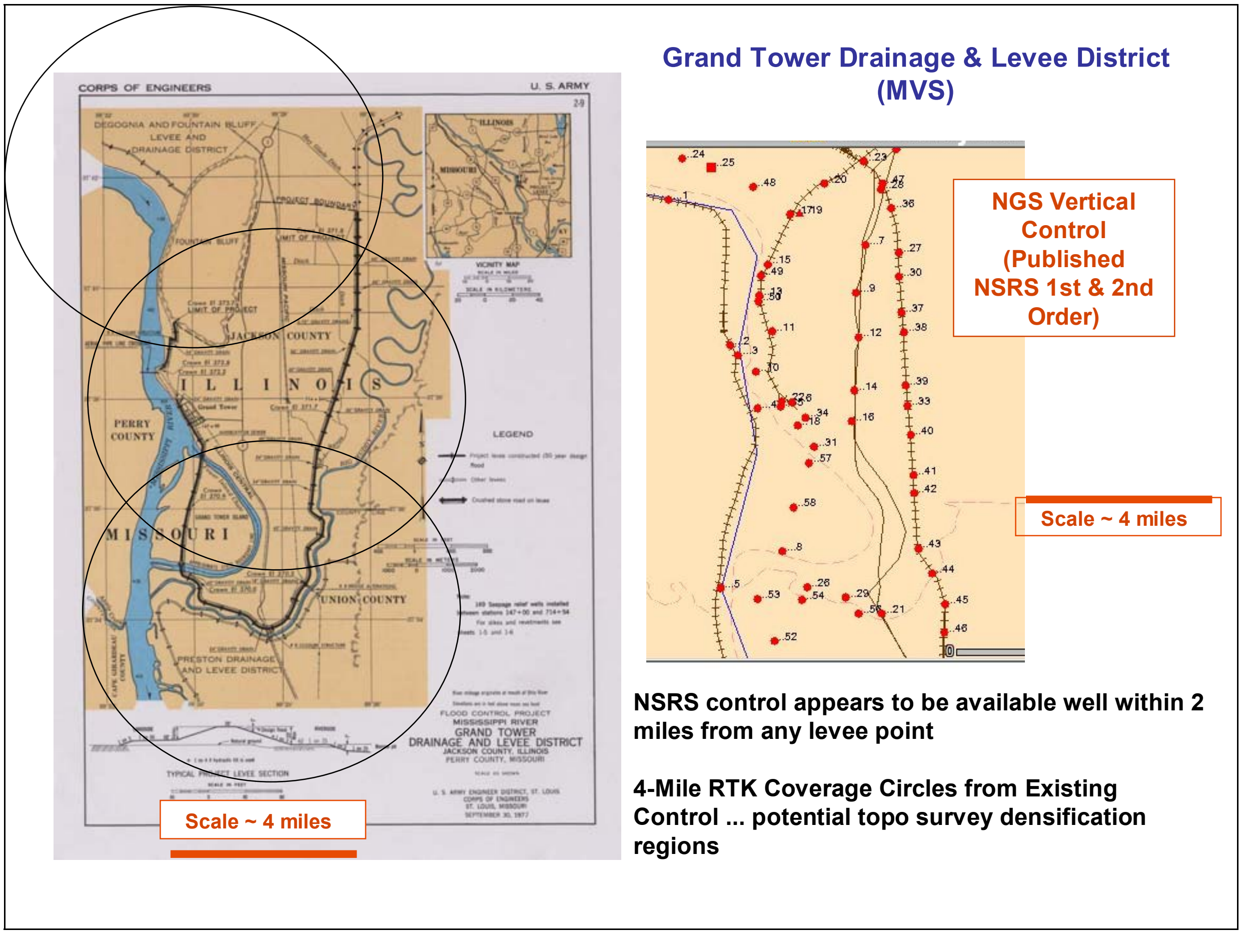


Figure B-11. Grand Tower Levee District, IL

SURVEY SPECIFICATIONS FOR ESTABLISHING NEW PRIMARY PROJECT CONTROL (±0.25 ft Accuracy)

B-16. Criteria for Establishing New Primary Benchmarks Relative to the NSRS

When no existing NSRS vertical control is available near the project, new primary project control benchmarks must be set to some established density, accuracy, and observing specification. This control must also be published in the NSRS by forwarding geodetic observations and descriptive data to the NGS. The primary purpose for establishing this control is to provide assurance that the flood control structure is adequately referenced to the NSRS (NAVD88) in accordance with CEPD initiatives. It is not intended for detailed design or construction purposes.

A variety of survey procedures may be used to establish a new primary project control point. These include, by general order of preference:

Table B-4. Preferred Survey Methods for Establishing New Primary Project Control Benchmarks Relative to the NSRS

Preference Order	Survey Method	NSRS Input Method	Notes
1	Use existing NSRS control	not applicable	NSRS check surveys only
2	GPS: CORS-Only OPUS	OPUS DB	Restricted to CORS within 200 miles
3	GPS: Networked baselines to nearby NSRS benchmarks if CORS-Only/OPUS solutions cannot be performed	ADJUST Blue Book or OPUS PROJECT	Include any CORS baselines in adjustment
4	Differential Leveling from NSRS points (3rd Order)	Blue Book OPUS Levels (future)	Setting primary points at levees or gauges

The above order of preference is somewhat dependent on the mechanism for inputting data to the NSRS—item (2) being the simplest and (4) being the most difficult at the present time.

The survey method chosen from the above table will have a major impact on the amount of field effort (and cost). A CORS-Only/OPUS method (Preference 2) at a new primary control point can be performed for less than $1,500 using a one-man survey crew (using OPUS DB to input the data to the NSRS). Positioning this same point by NSRS networked baseline connections (Preference 3) would require a 3 to 4-man survey crew. If ADJUST/Blue Book techniques are used to input this data into the NSRS, the total cost for the point could exceed $5,000.

Differential leveling ties (Preference 4) will be cost-effective only over short lines where 3rd Order closure tolerances can be maintained. They will also require connections with at least two or more published NSRS benchmarks. Higher-order instrumentation and procedures will also be required over longer lines, significantly increasing field effort. Inputting level line data into the NSRS also requires significant administrative effort—Blue Book—the administrative cost of which will typically exceed the cost of the field work. NGS is working on a potential solution (OPUS Levels) to this problem.

The density, or spacing, of primary project control points that are directly connected to the NSRS will vary with the geographic extent of the project. Each project should have at least one published primary control benchmark within 10 miles of the project and a published reference benchmark a short distance from a river gauge. Any suitable existing levee control monument may be used as a new primary control point. For extensive levee segments, primary control points spaced every 15 to 20 miles will provide adequate coverage from which to perform any non-NSRS supplemental control observations needed to establish NAVD88 elevations on a levee—i.e., by observing fixed GPS baselines of some 7 to 10 miles.

From the above, it is obvious that the major effort in the CEPD and NLD projects should be to locate and utilize existing NGS NSRS vertical control as the "primary project control" points—and establish as few as possible new points. When new primary points must be set, use of CORS-Only/OPUS methods should be used to the maximum extent possible.

Specifications for performing the above surveys are detailed in the following sections. These specifications will be used to estimate the time and cost for programming budgets to implement the datum update.

B-17. Survey Specifications for Connecting USACE Primary Project Control Benchmarks to the NSRS (±0.25 ft Accuracy)

The following specifications describe field observing procedures needed to establish primary project control suitable for defining flood control structure elevations relative to the NRSR. These primary control points will be submitted to the NGS for inclusion in the NSRS. They are based on the previously defined nominal target accuracy standard of ± 0.25 ft (± 8 cm) relative to the published NSRS. The following general criteria apply to these specifications:

- Recognize that the nominal levee elevation tolerances ± 0.25 ft (± 8 cm) are not as demanding as those developed by NGS for densifying and maintaining a nationwide NSRS control system.

- Accuracies exceeding the intended (target) ± 0.25 ft (± 8 cm) NAVD88 elevation relative to the NSRS network will not necessarily be rejected by USACE, depending on their magnitude, the levee project, and other factors. If vertical accuracies excessively exceed the target tolerances (e.g., > ± 0.33 ft or ± 10 cm), then the GPS observing specifications and related network connections may have to be modified accordingly.

- Reference benchmarks need to be set near each water level gage associated with a flood control project. These benchmarks will be designated as "primary control" points and will be connected to the NSRS using any of the methods in Table B-4 above. Level ties to the gauge reference point are also required and elevation differences and associated metadata will be included in the benchmark description in the NSRS.

- Differential leveling, where performed to either check NSRS control or densify vertical control along levee control monuments, will conform to USACE 3rd Order engineering survey standards outlined in EM 1110-1-2909 (Geospatial Data and Systems) and EM 1110-1-1005 (Control and Topographic Surveying). This implies double-run level loop closure tolerances of NTE $0.05 \cdot \sqrt{M}$ ft, where M is in miles. For level lines greater than one (1) mile, more precise procedures should be considered, such as three-wire leveling or digital leveling.

- Benchmark construction for new NSRS points will follow the guidance in EM 1110-1-1002 (Survey Markers and Monumentation). Type C (USACE disk set in existing concrete structure) marks are preferred. Geodetic quality mark stability is not required given the CEPD and NLD project tolerances; thus, Type F and Type G marks (disk attached to shallow rod or rebar) are acceptable as benchmarks.

- Each flood control project should have at least one (1) primary benchmark that has been connected to the NSRS. On large levee projects, primary project control benchmarks connected to the NSRS should be spaced NTE 15 to 20 mile intervals. These primary control points should then be interconnected with static GPS baseline observations. On large levee projects, adjacent primary project control points should be interconnected as shown in Figure B-12.

- In cases of small detached levee segments (or other structures), then local project control connections with the primary (NSRS) control point could be made as shown in Figure B-13. Note again that only one primary project control point needs to be connected and incorporated into the NSRS.

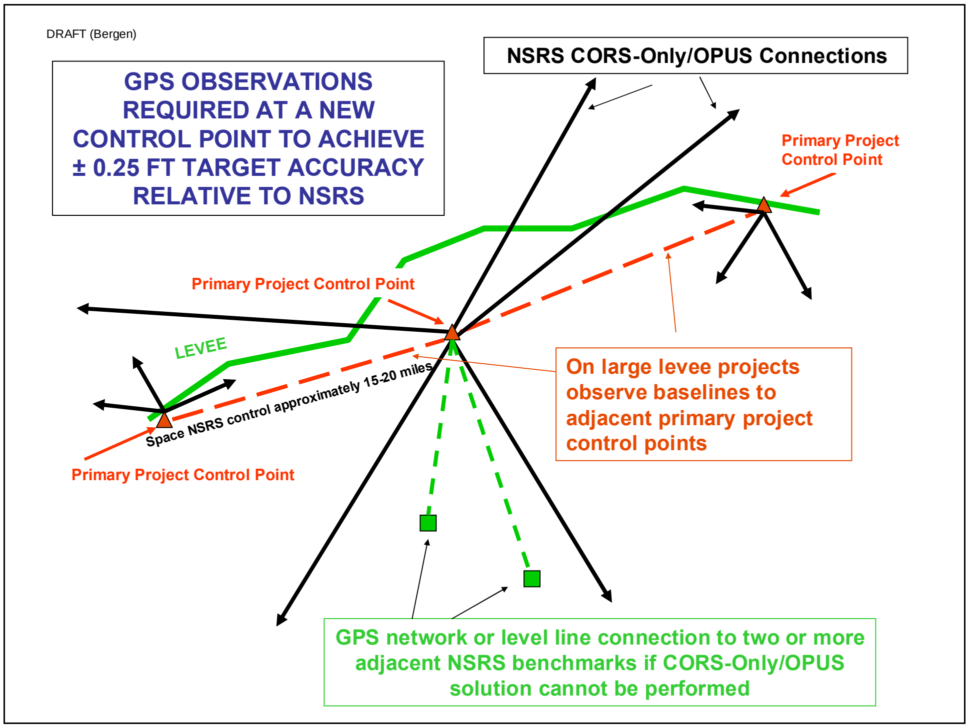


Figure B-12. Primary project control connections to the NSRS on extensive levee systems

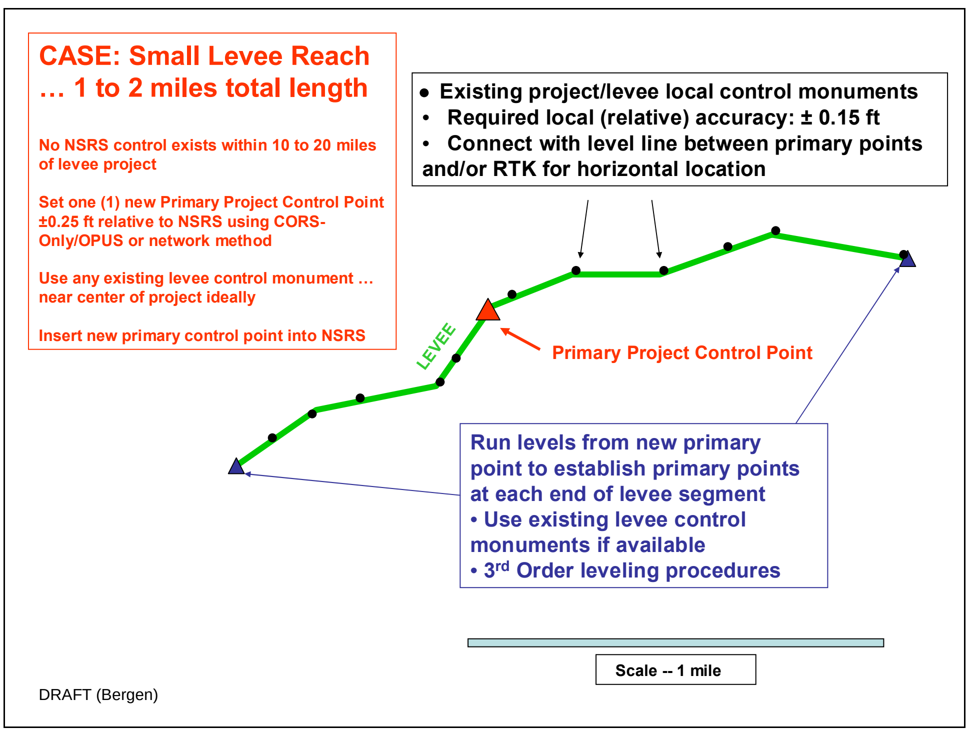


Figure B-13. Requirement for a single primary control point on small levee projects

B-18. CORS-Only/OPUS Solutions for Primary Project Control Benchmark Elevations (±0.25 ft Accuracy)

When CORS-Only/OPUS solutions are made to establish NAVD88 orthometric elevations on a primary control point, the following guidelines shall be followed. CORS-Only/OPUS solutions are a practical and efficient method of establishing primary project control to an accuracy of ±0.25 ft (± 8 cm), provided the following NGS observing guidelines are rigidly followed. In most populated regions of CONUS (see Figure B-14), CORS-Only/OPUS coverage is adequate for establishing NAVD88 orthometric elevations on primary project control points. These elevations can be obtained in one day with a one-man survey crew and the resulting data can be efficiently input into the NSRS using newly developed OPUS DB procedures that "automatically Blue Books" the dataset.

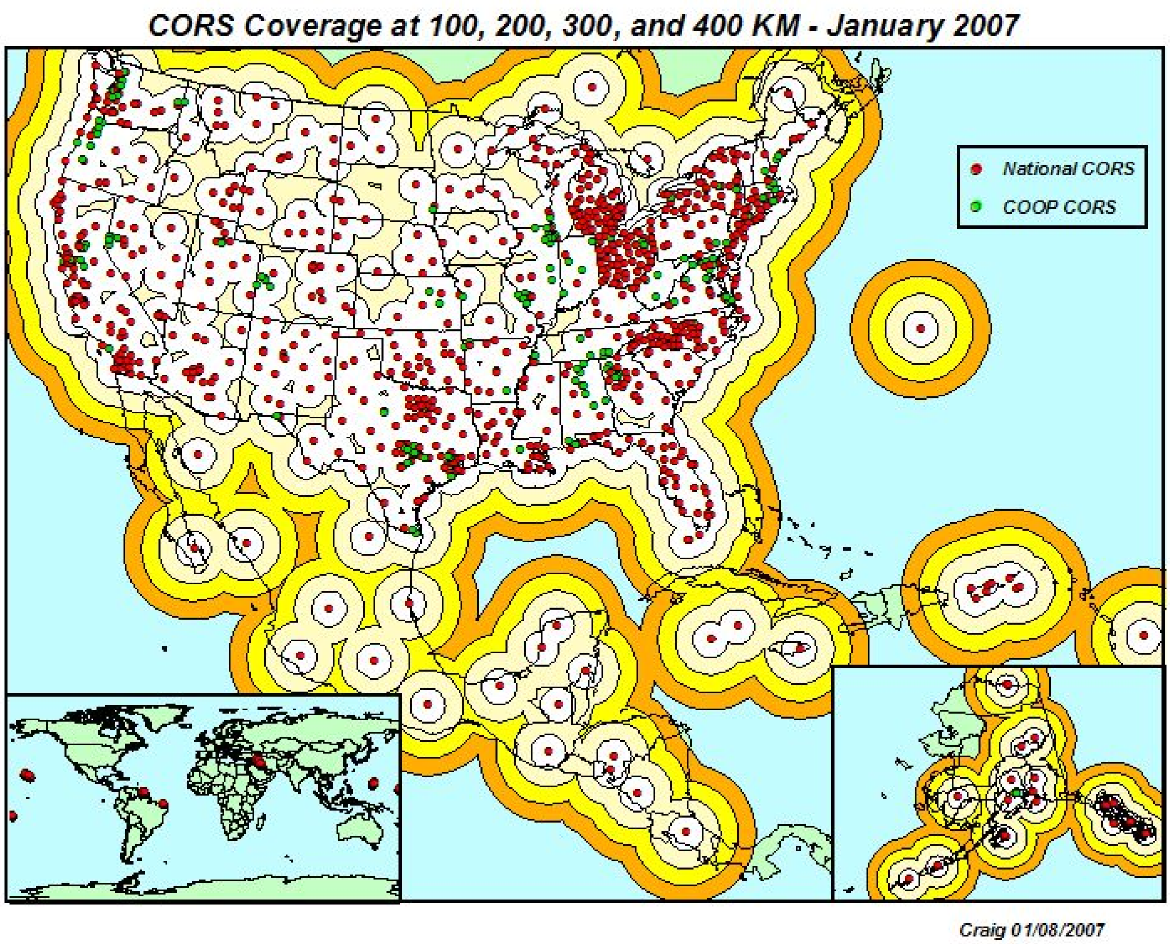


Figure B-14. CORS coverage as of January 2007

Table B-5. Recommended Specifications for CORS-Only/OPUS Ellipsoidal Elevation Measurements (Primary Project Control Points--± 0.25 ft Orthometric Accuracy)

NGS Pre-approval required:	No (check w/NGS on geoid model)
Minimum number of CORS Stations within 200 miles:	3
Minimum session time:	4 hours
Number of sessions:	2 -- 8 hours on same day with reset at 4 hours
HI measurements:	3 required – different units
Ephemeris—preliminary check:	any
Ephemeris—final:	wait 36 hours after observations
Geoid model:	(OPUS determined)
Geoid model--estimated accuracy at site:	NTE 3 cm (check w/NGS)
Data processing and NSRS input:	OPUS DB

The specifications in Table B-5 must be followed in order to meet NGS's QC and QA criteria for inputting benchmarks to the NSRS. CORS-Only/OPUS observations for targeted ±0.25 ft (±8 cm) accuracies to the NSRS do not need to be pre-approved by the NGS; however, one should verify with NGS that the local geoid model is adequate to use to convert ellipsoidal heights to orthometric heights. In most populated regions of CONUS where the NSRS vertical network is fairly dense, the geoid model should be adequate. In these areas, the geoid model accuracy is typically less than ± 3 cm (and often close to ±1 cm)—errors in the ellipsoidal-orthometric conversion will not be significant. In mountainous areas or in high-subsidence regions, this may not be the case and NGS should be consulted in advance.

In arriving at the estimated accuracy of a CORS-Only/OPUS solution for an orthometric elevation, the error budget consists of (1) estimated accuracy of the geoid model, (2) the ellipsoid height measurement accuracy, and (3) base CORS station elevation accuracy. In many USACE Districts, ±5 cm orthometric accuracies are being achieved.

The estimated accuracy of the CORS-Only/OPUS ellipsoid height solution varies with the observation time, approximately:

$$\sigma \approx 3.7/\sqrt{T}$$

where σ is the estimated accuracy of ellipsoid height in cm (one standard deviation)
T is observation time in hours

i.e., at a 4 hour session, $\sigma = \pm 1.8$ cm, or ±3.6 cm at 95%
(multiply by 1.96 to obtain 95% estimated vertical accuracy)

The above estimated accuracy does not account for geoid model errors. For projects with differing accuracy requirements (e.g., say only ± 0.5 ft accuracy is required), or project control not requiring input to the NSRS, the above formula may be used to estimate minimum observation times. Note that the USACE specifications in Table B-5 require a minimum of two 4-hour sessions to meet NGS criteria for OPUS DB input to the NSRS.

B-19. GPS Specifications for Networking Primary Control Point Connections to the NSRS (±0.25 ft Accuracy)

This section describes specifications to be used when CORS-Only/OPUS solutions cannot be made. Table B-6 below outlines the GPS observing specifications needed to determine NAVD88 elevations relative to the NSRS based on a target accuracy of ± 0.25 ft (± 8 cm). The following statements apply to these networking specifications.

- Static (networked) GPS baseline connections may be required in cases where the current geoid model has unacceptable accuracies in a particular region (sparsely NSRS controlled mountainous areas), or where CORS stations are too distant—greater than 200 miles. Regardless, CORS baselines will be used in the adjustment if available.

- GPS network connection procedures will require considerably more field effort and must follow the guidelines in Table B-6. Inputting networked GPS observation data into the NSRS will also require "Blue Booking,"—see NOAA 1994. However, it is expected that an alternate "Blue Booking" method will soon be available for "automatically" inputting this traditional networked data into the NSRS—"OPUS PROJECT." (Details on OPUS PROJECT will be provided by ERDC/TEC when these procedures are finalized by NGS—estimated before the end of FY07).

- At least two (2) baselines tied to (or "networked" with) nearby NSRS points should be observed. These local baselines will be adjusted along with CORS baselines, and input to the NSRS using either ADJUST/Blue Book or OPUS PROJECT when it becomes available.

- Proposed observation schemes for networked baseline observations to nearby NSRS points shall be pre-approved by NGS. Pre-approval may be obtained from the local NGS geodetic advisor or from designated NGS HQ staff—see paragraph 14 in this guidance. The format for submitting proposed schemes should follow the "Project Proposal Form" available on the NGS web site www.ngs.noaa.gov/PROJECTS/proposals/project1.shtml

- The GPS static baseline observing specifications for network connections in Table B-6 are largely tailored around current USACE EM 1110-1-1003 (NAVSTAR GPS Surveying) and NGS orthometric height guidelines for 2/5 cm accuracy orthometric network densification. These GPS orthometric guidelines for network densification have been significantly modified to fit the nominal ±0.25 ft accuracy requirements of the CEPD and NLD projects under these guidelines.

- Actual NSSDS positional accuracies resulting from a rigorous weighted adjustment will be reported to (published in) the NSRS.

Table B-6. Guidelines for Establishing GPS-Derived ± 0.25 ft Accuracy Orthometric Elevations Using Connections to Existing NSRS Benchmarks (Primary Project Control Benchmarks)

Occupation time based on baseline distance to nearest two NSRS benchmark(s):

Distance	Time
< 20 km	30 min
20-40 km	60 min
40-60 km	180 min
60-80 km	240 min
80-100 km	300 min
> 100 km	> 5 hours

NGS pre-approval required	Yes (local NGS advisor, HQNGS, or NGS web site)
Number of days station occupied:	1 day (perform interim break-down and reset)
Dual-frequency receiver required:	Yes
Geodetic quality antenna with ground plane required:	Yes
Minimum number of observations per baseline:	1
Fixed-height tripods/poles:	Required
Measure antenna height:	2 to 3 times (different units)
Satellite altitude mask angle (minimum):	10 degrees (collect) 15 degrees (process)
Maximum allowable VDOP:	5
Precise ephemeris:	Recommended, but not required
Geoid model:	Geoid 03 (or most recent)
Add CORS baselines to adjustment	Yes
Maximum distance to CORS points	No restriction—weight accordingly with local NSRS baselines
NSRS input	ADJUST/Blue Book or OPUS PROJECT (future)

The above network connection specifications are intended to achieve the target accuracy for primary project control. This is not to say that they will work in all cases, or in all locations, due to a variety of factors too numerous to list here. They are based on actual observations made in some USACE Districts, including during the New Orleans Katrina IPET study. The bottom line is that on site baseline reduction and processing software should readily (i.e., same or next day) identify the quality of the results from a constrained network adjustment statistical summary.

B-20. Summary of Standards and Specifications

The standards and specifications for establishing primary project control on a levee segment, along with related local accuracy tolerances, are summarized in figures B-15 and B-16:

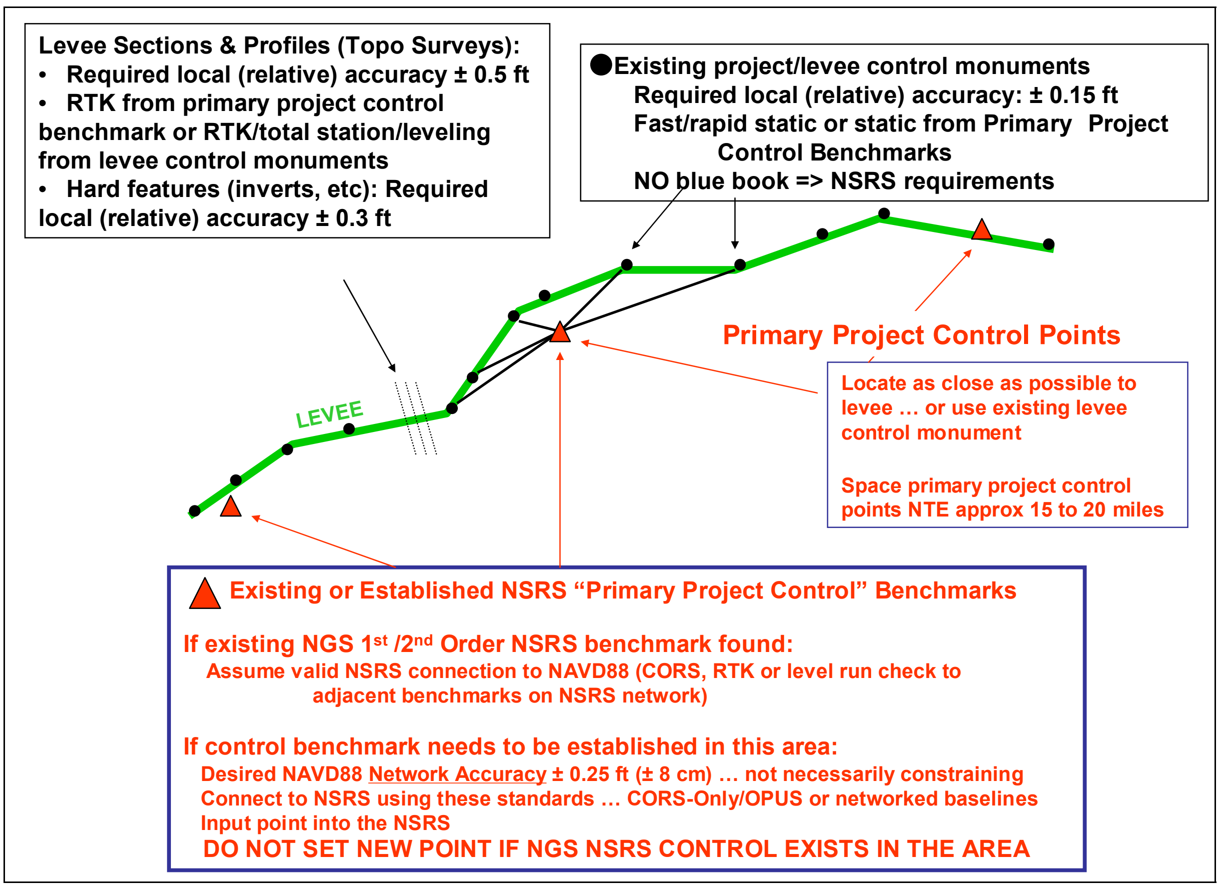
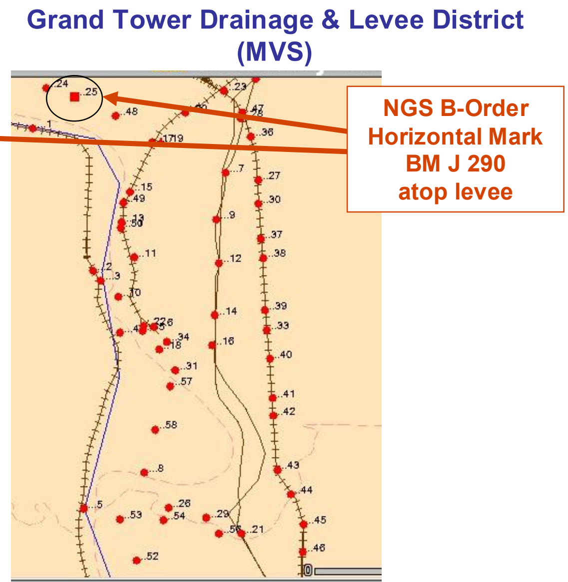


Figure B-15. Summary of vertical control standards & specifications



HORIZONTAL CONTROL
If horizontal control relative to the NSRS needs to be updated (ie, project still on NAD27 reference):
- **use CORPSCON, or**
- **30 to 60 min OPUS, or**
- **GPS from BM J 290 (#25)**

Note geospatial reference of ± 2 ft is adequate

Horizontal Tie for NSRS Reference Only
Does not supersede local levee control

Figure B-16. Summary of horizontal control requirements for NSRS levee reference points—for general reference only

B-21. OPUS DB and OPUS PROJECT Data Submittal to NGS

A preliminary field adjustment is recommended to verify the adequacy of the GPS baselines, the resultant estimated accuracy of the point relative to the NSRS, and/or the reliability of recovered NSRS benchmarks that are tied in. This can be done using any COTS network adjustment software, such as Trimble Geomatics Office (TGO), Waypoint/GrafNet, etc. An OPUS solution may also be used as a preliminary QC check.

CORS-Only OPUS derived data will be submitted to the NSRS using automated OPUS DB procedures. This system adjusts the GPS data similarly to OPUS but also effectively incorporates the final positional and descriptive data directly into the NSRS—thus avoiding the traditional Blue Booking methods. (Specific OPUS DB procedures are currently being developed by the NGS Products & Services Division. Details on OPUS DB will be available by the end of April 2007.)

OPUS PROJECT is also being developed by the NGS Product and Services Division. It is intended to support networked GPS baseline connections to local NSRS points. It will provide similar automated adjustment and NSRS input capabilities as does OPUS DB—thus eliminating the traditional Blue Book process. Details on OPUS PROJECT should be available from NGS before the end of FY07.

B-22. Data Submittal to NSRS via Blue Book Procedures

When the above OPUS DB or OPUS PROJECT submittal methods cannot be utilized, GPS observations and leveling observations to newly established primary control points must be adjusted and submitted to the NSRS using NGS procedures—i.e., the Blue Book—"Input Formats and Specifications of the National Geodetic Survey (NGS) Data Base." The Blue Book—NOAA 1994—is a guide for preparing and submitting geodetic survey data for incorporation into the NSRS database. Volume I, Annex L, "Guidelines for Submitting GPS Relative Positioning Data" (http://www.ngs.noaa.gov/FGCS/Blue Book/), provides overall instructions and a checklist for submitting raw data, vector solutions, project and station data, station descriptions, horizontal and vertical connections (if applicable), least squares adjustments, a project sketch, and a project report. Additional guidance, tutorials, and required software are referenced therein with web addresses for downloading.

It is recommended that the A-E performing the field surveys work directly with A-E firms that have an established record for producing accepted Blue Book submittals to ensure proper procedures and documentation are followed throughout the project. Firms with a known history of acceptable submissions for GPS projects include, but are not limited to:

> Maptech, Inc.
> Chris A. King, PLS
> Tel: 601-664-1666
> www.maptech-survey.com
>
> GCY, Inc.
> George C. "Chappy" Young, Jr. PSM
> Tel: 800-386-1066
> www.gcyinc.com

B-23. Reporting NSRS Positional Accuracy

Appendix A of FEMA "Guidelines and Specifications for Flood Hazard Mapping Partners" (FEMA 2003) describes the FGDC standards for reporting the positional accuracies of points on a map or in a database. These standards are excerpted below as taken from the FEMA guidance. These reporting standards are only applicable to USACE primary project control benchmarks that are newly established relative to a regional or nationwide NGS NSRS network.

> **A.2 Industry Geospatial Standards [February 2002]**
> In 1998, the Federal Geographic Data Committee (FGDC) published *Geospatial Positioning Accuracy Standards*, which replaced both the *United States National Map Accuracy Standards* (NMAS) published by the Office of Management and Budget in 1947 (Office of Management and Budget, 1947) and the American Society for Photogrammetry and Remote Sensing (ASPRS) *ASPRS Accuracy Standards for Large-Scale Maps* (ASPRS, 1990). Designed specifically for digital spatial data products, this new FGDC standard has three parts:

- Part 1, Reporting Methodology (FGDC-STD-007.1-1998)
- Part 2, Standards for Geodetic Networks (FGDC-STD-007.2-1998); and
- Part 3, National Standard for Spatial Data Accuracy (FGDC-STD-007.3-1998)

FGDC-STD-007.1-1998 provides a common methodology for reporting the accuracy of horizontal and vertical coordinate values of digital geospatial products. Specifically, the reporting standard in the horizontal component ($Accuracy_r$) is the radius of a circle of uncertainty, such that the true or theoretical location of the point falls within that circle 95 percent of the time. The reporting standard in the vertical component ($Accuracy_z$) is a linear uncertainty value, such that the true or theoretical location of the point falls within plus or minus of that linear uncertainty value 95 percent of the time. It also defines the meanings of "local accuracy" and "network accuracy" and other terms used in the FGDC standard. Part 1 of the *Geospatial Positioning Accuracy Standards* is available online at: www.fgdc.gov/standards/documents/standards/chapter1.pdf.

FGDC-STD-007.2-1998 provides a common methodology for determining and reporting the accuracy of horizontal and vertical coordinate values for geodetic control points represented by survey monuments, such as brass disks and rod marks. It provides a means to directly compare the accuracy of coordinate values obtained by one method (e.g., a classical line-of-sight traverse) with the accuracy of coordinate values obtained by another method (e.g., a Global Positioning System [GPS] geodetic network survey) for the same point. It explains how "network accuracy" is achieved by properly connecting survey and mapping data to control points in the National Spatial Reference System (NSRS). Part 2 of the *Geospatial Positioning Accuracy Standards* is available on the FGDC website at www.fgdc.gov/standards/documents/standards/chapter2.pdf.

FGDC-STD-007.3-1998 implements a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to georeferenced ground positions of higher accuracy. If errors have a normal distribution and if systematic errors have been eliminated as best as possible, the National Standard for Spatial Data Accuracy (NSSDA) uses root-mean-square error (RMSE) to estimate positional accuracy of x, y and z coordinates ($RMSE_x$, $RMSE_y$ and $RMSE_z$ respectively). FGDC-STD-007.3-1998 defines RMSE as the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points and it defines (horizontal) radial accuracy in terms of $RMSE_r$ computed as a function of $RMSE_x$ and $RMSE_y$. FGDC-STD-007.3-1998 provides NSSDA testing guidelines, it relates $Accuracy_r$ and $Accuracy_z$ (horizontal and vertical accuracies at the 95-percent confidence level) to $RMSE_r$ and $RMSE_z$, and it documents the statistical relationship between the NSSDA and the prior National Map Accuracy Standard (NMAS) and ASPRS 1990 standards. FGDC-STD-007.3-1998 is available online at www.fgdc.gov/standards/documents/standards/chapter3.pdf.

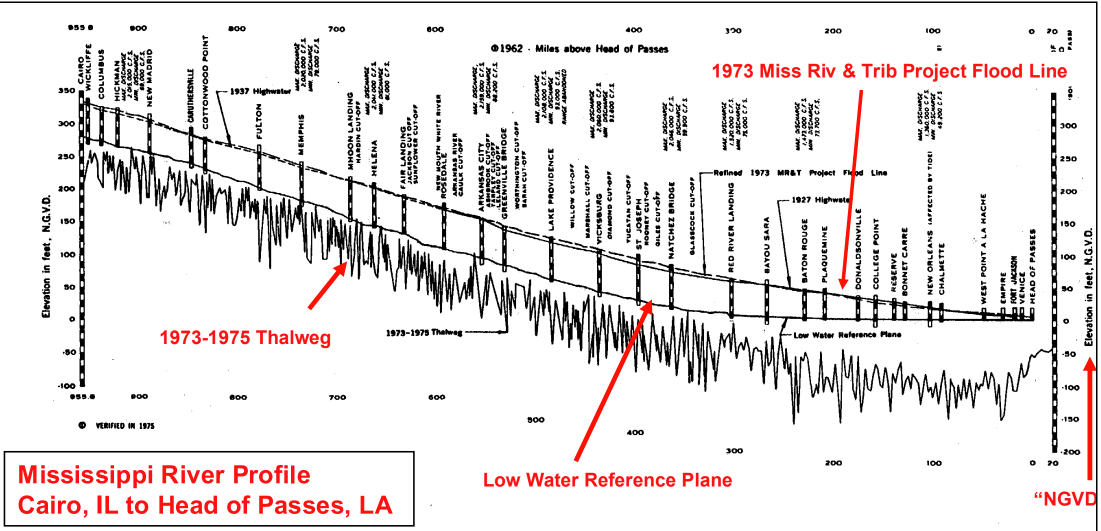
Vertical accuracies relative to the NSRS are reported in accordance with Table 2.1 in Part 2 of the standards, as shown below. Therefore, a benchmark with a resultant network accuracy of ± 8 cm would be reported or classified with a network accuracy of "One Decimeter." Its "local accuracy" may be reported at the 1-or 2-centimeter level, depending on the local connections.

Table 2.1 -- Accuracy Standards
Horizontal, Ellipsoid Height, and Orthometric Height

Accuracy Classification	95-Percent Confidence
	Less Than or Equal to:
1-Millimeter	0.001 meters
2-Millimeter	0.002 "
5-Millimeter	0.005 "
1-Centimeter	0.010 "
2-Centimeter	0.020 "
5-Centimeter	0.050 "
1-Decimeter	0.100 "
2-Decimeter	0.200 "
5-Decimeter	0.500 "
1-Meter	1.000 "
2-Meter	2.000 "
5-Meter	5.000 "
10-Meter	10.000 "

B-24. River Gauge Connections to the NSRS

As part of the CEPD project, river gauge references and reference benchmarks need to be evaluated to verify they are directly connected to the NSRS (NAVD88). This is intended to insure these gauges are on the same regional (nationwide) vertical datum used for hydrologic and hydraulic studies, both USACE and other agencies. Currently, most gauges on the Lower Mississippi River are relative to a Low Water Reference Plane (LWRP) which is referenced to the older (and superseded) “NGVD” datum, as indicated in Figure B-17 below.



PROFILE CAIRO, ILL., TO GULF OF MEXICO
VIA
SOUTHWEST PASS, MISSISSIPPI RIVER

PREPARED UNDER THE DIRECTION OF
PRESIDENT, MISSISSIPPI RIVER COMMISSION
VICKSBURG, MISS.

GAGE	①1962 MILES A.H.P.	GAGE ZERO FT. NGVD	GAGE READING - FT. HIGHEST	LOWEST	BANKFULL	* LWRP
CAIRO, ILL. (OHIO RIVER)	953.8	270.47	59.51	−1.0	44	9.6
WICKLIFFE, KY. (A)	951.5	269.12	58.18	4.95	42	10.2
COLUMBUS, KY.	937.2	266.38	54.54	0.05	43	7.8
HICKMAN, KY. (B)	922.0	264.73	51.5	−0.4	37	3.4
NEW MADRID, MO.	889.0	255.48	47.97	−0.60	40	2.7
CARUTHERSVILLE, MO.	846.4	235.49	46.0	−0.72	35	4.0
COTTONWOOD POINT, MO.	832.7	230.18	44.4	−3.9	36	3.1
FULTON, TENN.	778.2	208.61	47.25	−7.7	34	−3.1
MEMPHIS, TENN.	734.7	183.91	48.7	−5.35	34	−2.8
MHOON LANDING, MISS.	687.5	161.22	53.2	−8.85	35	−3.9
HELENA, ARK.	663.0	141.70	60.21	−3.0	41	4.1
FAIR LANDING, ARK. (C)	632.5	132.20	55.6	−4.8	40	−0.9
ROSEDALE, MISS.	592.2	100.73	50.4	−2.05	44	3.0
ARKANSAS CITY, ARK.	554.1	96.66	59.2	−5.3	44	0.2
GREENVILLE (BRIDGE), MISS.(D)	531.5	74.92	58.2	6.7	48	11.3
LAKE PROVIDENCE, LA.	487.2	80.71	50.7	−7.7	37	
VICKSBURG (CANAL), MISS.	437.6	46.25	58.4	−6.8	42	—

GAGE	①1962 MILES A.H.P.	GAGE ZERO FT. NGVD	GAGE READING - FT. HIGHEST	LOWEST	BANKFULL	* LWRP
VICKSBURG, MISS.	435.7	46.23	53.24	−7.0	43	0.1
ST. JOSEPH, LA.	396.4	33.12	55.3	−10.7	40	0.0
NATCHEZ, MISS.	363.3	17.28	58.04	−2.7	48	6.1
RED RIVER LANDING, LA.	302.4	0.00	60.94	2.89	46	10.6
BAYOU SARA, LA.	265.4	0.00	55.46	0.96	36	5.25
BATON ROUGE, LA.	228.4	0.00	47.28	−0.07	29	2.57
PLAQUEMINE, LA.	208.8	0.00	43.04	−0.9	25	1.7
DONALDSONVILLE, LA.	175.4	0.00	36.01	−0.39	23	1.33
COLLEGE POINT, LA.	157.4	0.00	32.32	−0.6	17	1.06
RESERVE, LA. (B)	138.7	0.00	26.0	−0.1	15	0.70
BONNET CARRE, LA. (C)	128.0	0.00	23.79	−0.62	14	0.68
NEW ORLEANS, LA.	102.8	0.00	21.27	−1.6	11	0.48
CHALMETTE, LA.	91.0	0.00	17.58	−0.52	8	0.08
WEST POINTE A LA HACHE, LA.	48.7	0.00	15.25	−1.06	3	0.06
EMPIRE, LA. (G)	29.5	0.00	10.92	−0.74	1	−0.21
FORT JACKSON, LA.	18.6	0.00	14.3	−2.67	2	−0.40
VENICE, LA. (F)	10.7	0.00	9.11	−0.73	1	−0.36
HEAD OF PASSES LA. (E)	−0.6	0.00	12.03	−0.85	1	−0.36

Figure B-17. Mississippi River LWRP profile relative to superseded NGVD29 datum

A minimum of 3 benchmarks should be (or should have been) established around a river gauge. Only one of these points needs to be connected to the NSRS using either CORS observations, or differential levels (3rd Order), or short-term static GPS baseline observations (e.g., static or fast/rapid static methods). The remaining river gauge benchmarks can be surveyed using 3rd Order differential leveling methods. Data for the primary gauge benchmark connections shall be incorporated into the NSRS database.

Figure B-18 depicts a typical river gauge connection on the Middle Mississippi. In this simulated example, a river gauge on LWRP and a presumed "NGVD" reference is connected with the regional NAVD88; thus, providing an external (i.e., ellipsoidal and orthometric) reference for the gauge, along with the LWRP hydraulic profile reference. The relationship between the orthometric height, ellipsoidal height, geoid height, and the hydraulic elevation is shown in Figure B-19.

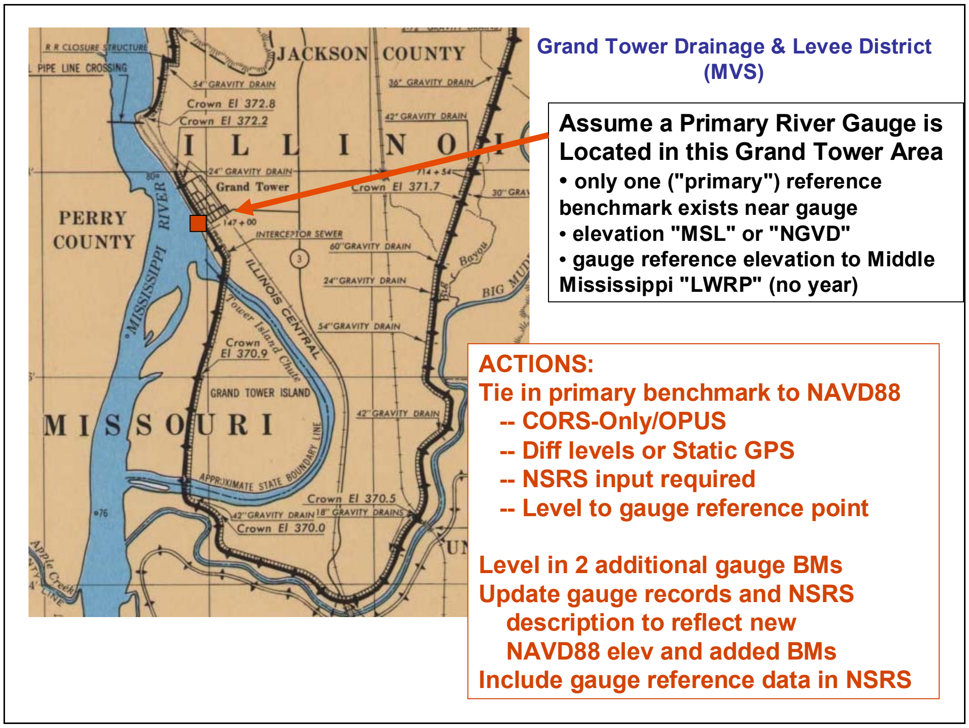


Figure B-18. River gauge NSRS connection requirements

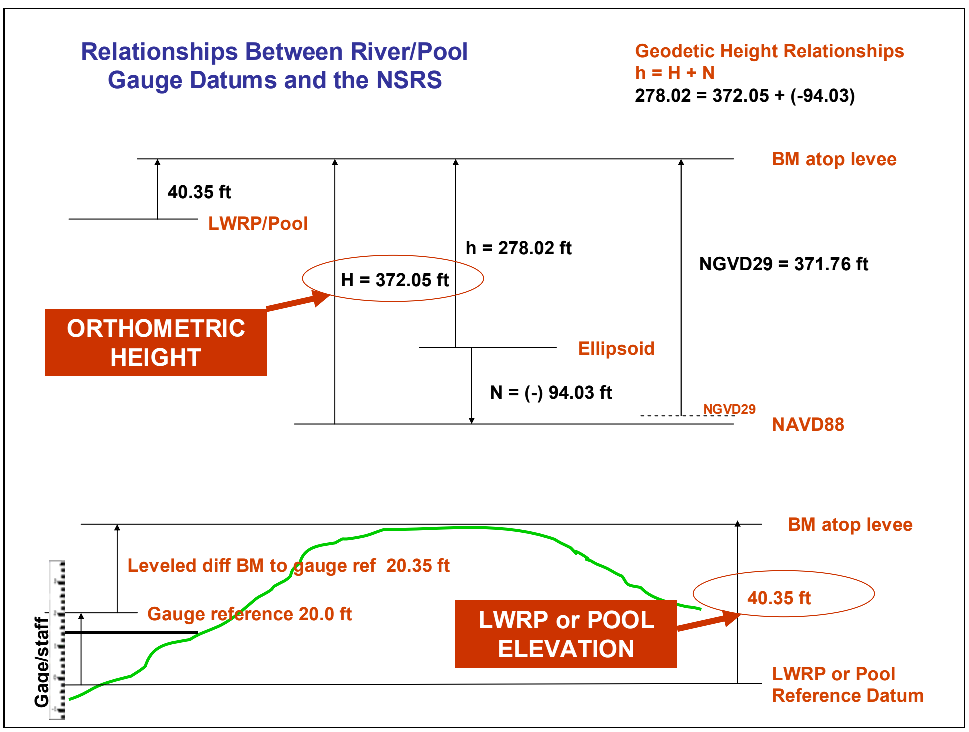


Figure B-19. Orthometric height and hydraulic reference datum relationships

The NSRS description for the primary gauge benchmark must contain, in addition to the standard description, full metadata associated with that benchmark and river gauge. For example:

Benchmark:	USED RIVER GAUGE 12345 1955
River Gauge:	[River gauge name/file designation]
Elevation:	419.63 ft NAVD88 ±0.22 ft [2008 03 21 adjustment]
Elevation:	40.35 ft above LWRP 20XX [2008 03 21]
Elevation:	20.35 above river gauge zero reference [2008 03 21]
Elevation:	3.38 ft above 12345 RM 1 [2008 03 21]
Elevation:	0.97 ft below 12345 RM 2 [2008 03 21]
Position:	[SPCS X & Y location/accuracy/date]
Source:	[specify NGS "PID" and District file number]

Subsequent benchmark Recovery Notes Made at periodic gauge inspections should also update the gauge reference and adjacent reference benchmark connections. The following is a simulated (and much abbreviated) NSRS description and recovery note made for a water level gauge reference benchmark. Not all NSRS descriptive details are shown, e.g., method by which the NAVD88 elevation was established and estimated accuracy. What is intended to be shown is the use of the NSRS in maintaining periodic gauge inspection reference elevations.

```
 ***********************************************************************
XX999  DESIGNATION -  12345
XX999  PID         -  XX999
XX999  STATE/COUNTY-  MO/C OF ST LOUIS
XX999  USGS QUAD   -  GRANITE CITY (1998)
XX999
XX999                       *CURRENT SURVEY CONTROL
XX999  ___________________________________________________________________
XX999* NAD 83(1986)-  38 00 00.     (N)    090 00 00.     (W)     OPUS
XX999* NAVD 88     -       127.903  (meters)     419.63   (feet)  ADJUSTED
XX999  ___________________________________________________________________
XX999  GEOID HEIGHT-         -31.08  (meters)                      GEOID03
XX999  DYNAMIC HT  -         127.821 (meters)     419.36  (feet)  COMP
XX999  MODELED GRAV-     979,991.3   (mgal)                        NAVD 88
XX999
XX999  VERT ORDER  -  FIRST     CLASS II
XX999
XX999_U.S. NATIONAL GRID SPATIAL ADDRESS:
XX999_MARKER: DB = BENCH MARK DISK
XX999_SETTING: 38 = SET IN THE ABUTMENT OF A LARGE BRIDGE
XX999_SP_SET: CONCRETE PIER
XX999_STAMPING: GAUGE REF BM 12345 (2008)
XX999_MARK LOGO: COE
XX999_STABILITY: B = PROBABLY HOLD POSITION/ELEVATION WELL
XX999
XX999  HISTORY     - Date     Condition        Report By
XX999  HISTORY     - 20080321 MONUMENTED       USACE
XX999  HISTORY     - 20090605 GOOD             USACE
XX999  HISTORY     - 20100705 GOOD             USACE
XX999
```

```
XX999                          STATION DESCRIPTION
XX999
XX999'DESCRIBED BY USAED ST LOUIS 2008 03 21 (R MESKO)
XX999'
XX999'IN ST LOUIS, 1.35 KILOMETERS (0.85 MILE) SOUTH ALONG THE FLOOD WALL OF
XX999'THE MISSISSIPPI RIVER FROM THE GOLDEN ARCH BRIDGE OVER THE RIVER, SET
XX999'VERTICALLY IN THE EAST END OF THE ONLY LARGE SOLID PIER OF A RAILROAD
XX999'OVERPASS THAT LEADS WEST OVER THE TRACKS THAT PARALLEL THE FLOOD WALL,
XX999'AND 19.21 METERS (63.0 FEET) WEST OF THE WEST FACE OF THE FLOOD WALL.
XX999'THE MARK IS THE PRIMARY REFERENCE POINT FOR COE RIVER GAUGE NO. 12345
XX999'WHICH IS APPROX 30 FT NORTH OF THE MARK.
XX999'THE MARK IS 1.04 METERS N FROM A WITNESS POST.
XX999'THE MARK IS 1.12 M ABOVE GROUND.
XX999'
XX999'RIVER GAUGE NO 12345 LEVELING REFERENCES RUN 2008 03 21
XX999'THE MARK IS 20.35 FT ABOVE THE ZERO GAUGE REFERENCE POINT
XX999'THE MARK IS 40.35 FT ABOVE LWRPXX
XX999'THE MARK IS 3.38 FT ABOVE 12345 RM 1, A COE DISC LOCATED ON THE
XX999'FLOODWALL 45.6 FT NORTH.
XX999'THE MARK IS 0.97 FT BELOW 12345 RM 1, A COE DISC LOCATED ON THE
XX999'FLOODWALL 89.4 FT SOUTH.
XX999'
XX999
XX999                          STATION RECOVERY (2009)
XX999
XX999'RECOVERY NOTE BY USAED ST LOUIS 2009 06 05 (R MESKO)
XX999'RECOVERED MARK AND RM1 AND RM2 IN GOOD CONDITION, AS DESCRIBED.
XX999'RELEVELING RESULTS FROM 2009 06 05 GAUGE INSPECTION:
XX999'THE MARK IS 20.34 FT ABOVE THE ZERO GAUGE REFERENCE POINT
XX999'THE MARK IS 40.34 FT ABOVE LWRPXX
XX999'THE MARK IS 3.39 FT ABOVE 12345 RM 1, A COE DISC LOCATED ON THE
XX999'FLOODWALL 45.6 FT NORTH.
XX999'THE MARK IS 0.97 FT BELOW 12345 RM 1, A COE DISC LOCATED ON THE
XX999'FLOODWALL 89.4 FT SOUTH.
XX999'
XX999
XX999                          STATION RECOVERY (2010)
XX999
XX999'RECOVERY NOTE BY USAED ST LOUIS 2010 07 05 (R MESKO)
  ...
***********************************************************************
```

In addition to narrative NSRS descriptions of gauge inspection location and elevation data, photographs of the gauges and related reference marks should be made, as shown in Figure B-20 and Figure B-21 below.

USGS Gage at I-10 and IHNC
Elevation taken on Iron directly over transducer pipe = 10.09' NAVD88(2004.65)
Bk. 060855, Pg.36

Orleans Levee District Staff Gage
10' Mark = 9.62' NAVD88(2004.65)
Bk. 060855, Pg.36

Figure B-20. Typical gauge reference elevations (USGS and Orleans Levee District Gages at I-10 and Inner Harbor Navigation Canal (IHNC)—from IPET 2006)

Southshore Marina Gage Staff Gage elevation at reading 0’ = -0.79’, New reference point RP-A Elevation = 4.42’, Original reference point PID BJ1394 = 8.33’ NAVD88(2004.65), Bk. 060850, Pgs. 28-31

The above photo shows location of RP-A and red circle shows staff gauge.

Figure B-21. Revised gauge reference points and elevations (Orleans Levee District gauge at Southshore Marina--from IPET 2006)

CEPD PROGRAM ESTIMATES FOR NSRS CONNECTIONS

B-25. Cost Estimating Guidance

The following is a guideline for developing budget estimates for updating flood control project datums to NAVD88. These office estimates are for future programming purposes only. They are based on the best judgment and experience of the individual in the District preparing the estimate. It is assumed this individual has a general familiarity with the projects, along with a solid surveying background which is needed to estimate production rates for a survey crew; otherwise, preparing such a reliable estimate will be difficult or impossible. These planning/budgeting estimates are not to be used for contract/task order IGE in that site conditions have not been investigated.

B-26. Estimated Cost of CEPD Evaluation

The CEPD evaluation effort will vary widely from District to District. The number of flood control projects and their geographical range will be major factors.

Hired-labor rates in (man-days) MD will include all burdens (overheads). Thus a typical GS-12 will cost out at around $800 to $1,000/MD, depending on local burden rates. Similar rates will apply to A-E technical staff.

Assuming 4 to 8 hours to evaluate each project (assume 6 hours), and 50 flood control projects in a District, the CEPD evaluation will total approximately $30K (0.75 MD x $800/MD x 50). This represents 37 MD effort.

B-27. Budget Estimate to Establish NSRS (NAVD88) Connections

The following factors need to be considered in developing a budget estimate for each project that requires additional survey ties to connect the reference datum to NAVD88. The units of measure (UM) are either Man Day [MD] or Crew Day [CD]. In general, a survey crew consists of 3 persons, fully equipped with levels, GPS receivers, and total stations. Regional A-E contract rates (burdened) for such a crew in travel status can vary considerably in CONUS and OCONUS, from $1,500 to over $3,000 per CD. Obviously not all the factors listed below will be applicable on all projects.

Contract Administration

USACE hired-labor, technical S&A (prepare A-E SOW, IGE, etc.—these costs can vary considerably depending on the size of the project and the amount of remedial work needed)

USACE hired-labor, CT admin charges ($5K to $10K per task order typical—lump SOWs into one task order to minimize costs)

USACE hired-labor & travel—field recon if needed to develop A-E SOW—probably should include if published NSRS control is old. Will not need if performing CORS-Only/OPUS.

A-E Contract Line Items

Mob/demob to project site [CD]

Recon for existing NSRS or USACE project control if not in SOW [CD]

GPS, static baseline observations to NSRS/CORS [CD]

Differential leveling surveys—miles/day [CD]

RTK connections to local project control or features [CD]

River gauge reference ties to NAVD88—levels or GPS [CD]

Setting additional benchmarks at project site and/or river gauge [CD]

Data Processing and Reporting

Input Data to NSRS (Blue Book) & coordinate w/NGS —A-E contract line item—use 3.0 MD per point typical [MD]. Less if using OPUS DB or OPUS PROJECT

USACE hired-labor and/or A-E labor to update district documents & files (e.g., DPN, DGN, etc.) upward web-based reporting CEPD to HQUSACE [MD]

Contingencies

Add percentage to all of above costs to allow for uncertainties, inflation, lack of CEPD field recon, etc.

The following is a sample budget estimate for a typical levee segment. This estimate assumes one primary point will be established using a networked scheme (CORS-Only/OPUS option not used). 3rd Order levels will be run to tie in the reference benchmark at a river gauge. The MD and CD rates shown are for illustrative purposes only.

Contract Administration

USACE hired-labor, technical S&A
10 MD @ $800/MD $8000
USACE hired-labor, CT admin charges
$7500
USACE hired labor & travel (recon)
2 MD @ $800/MD $1600
(add Travel if applicable)

TOTAL $17,100

A-E Contract Line Items

Mob/demob to project site [CD]
2 CD @ $2500 $5000
Recon for existing NSRS or USACE project control
1 CD @ $2500 $2500
GPS, static baseline observations to NSRS/CORS [CD]
(incl in RTK)
Differential leveling surveys—miles/CD [CD]
1 CD @ $2500 $2500
RTK connections to local project control or features [CD]
2 CD @ $2500 $5000
River gage reference ties to NAVD88—levels or GPS [CD]
1 CD @ $2500 $2500
Setting additional benchmarks at project site [CD]
(incl in above)
TOTAL $17,500

Data Processing and Reporting

Input Data to NSRS (Blue Book) & coordinate w/NGS —
A-E contract line item—
use 3 MD per point typical [MD] $2400

Input Level Line data to gauge into NSRS (Blue Book) 2 MD $1600

USACE hired-labor and/or A-E labor to update district documents & files
2 MD @ $800 $1600

TOTAL $5600

Summary

Contract Administration	$17,100
A-E Contract Line Items	$17,500
Data Processing and Reporting	$ 5,600
Subtotal	$40,200
Contingencies @ 20%	$ 8,040
TOTAL BUDGET ESTIMATE	$48,240

use $48K for program estimate

HIGHER ACCURACY SURVEY STANDARDS

B-28. Recommended NSRS Connection Accuracy Standards for High Subsidence Regions, Dams, Embankments, and other Critical Flood Control Structures

Based on H&H assessments, some projects may require more precise vertical tolerances than the nominal ±0.25 ft specified for levee systems. For example, a high head dam or reservoir embankment may require intake structure gauge elevations to be accurate relative to the large impoundment pool perimeter. Or the dam or spillway crest elevations need to have high relative accuracies relative to points downstream. Likewise, accurate relative elevations may need to be known between navigation lock & dams and their pool reference datum, or in canals with low head differences. In some cases, precise differential levels may be needed when elevation difference accuracies exceed those achievable with GPS.

As with the case of standard earthen levees, special care must be taken not to specify NSRS network accuracy connections to more exacting tolerances than are actually required to support hydraulic models. A high-head concrete hydropower dam or high subsidence region does not simply (or automatically) demand high precision connections to a regional NSRS network. In high subsidence areas, concrete floodwall cap elevations may be monitored to ±0.05 ft levels but earthen levees in these areas need only be monitored to ±0.25 ft levels—each structure or area must be assessed relative to actual hydraulic or geotechnical requirements. If additional freeboard allowance was applied for subsidence or settlement during design, then the required measurement accuracy may not be as critical.

Measuring subsidence (or subsidence rates) to ±0.01 ft or ±0.05 ft network accuracy standards and specifications may not be necessary when absolute NSRS subsidence elevations are only needed to the level which can be readily obtained with less demanding (and far less costly) specifications (e.g., repeated CORS-Only/OPUS observations). Local subsidence or settlement rates can be monitored from these project control points to high accuracy levels. The overall regional subsidence is not needed to as high an accuracy—periodic GPS connections with the NSRS can effectively monitor any regional subsidence. (In coastal areas, connections to tidal datums at long-term gauges will provide similar subsidence rates).

In a subsidence area, or on levees subject to settlement, the relative accuracy of this subsidence/settlement is the key to determining whether higher accuracy survey standards and specifications are needed. For example, a monitored 10-year subsidence/settlement on an earthen embankment may yield elevation drops of either "-2.3 ±0.05 ft" or "-2.1 ±0.25 ft", depending on the precision of the measurement. Either method indicates "over a 2 foot" subsidence/settlement. However, obtaining this "2 foot" answer to ±0.05 ft may cost 5 to 10 times the cost of obtaining a ±0.25 ft precision.

The following table contains recommended accuracy tolerances on primary project control benchmarks that may be used for special cases where ±0.1 ft (±3 cm) accuracies are required.

Table B-7. Accuracy Standards for Connecting USACE Flood Control Projects to the NSRS Network—High Subsidence Regions, Reservoirs, and Dams (Primary Project Control Benchmarks)

	Relative Accuracy (95%)	Reference Datum
Vertical Accuracy	± 0.1 ft (± 3 cm)	NAVD88
Horizontal Accuracy	± 2 ft (± 60 cm)	NAD83

NOTES
In general, follow NGS 2 cm/5 cm guidelines (NOAA 1997 & NOAA 2005)
NGS must pre-approve the proposed observing scheme
Input data to NSRS using Blue Booking procedures—NOAA 1994

Use of the above standards is evaluated on a case-by-case basis, considering risk and other factors. In addition, Second-Order or better differential/digital leveling specifications may be needed in some low elevation difference pools or canals where less than ± 0.1 ft accuracies are required.

B-29. NSRS Survey Connections in Special Cases where Higher Accuracy Standards are Required

In such cases, guidance specifications from NOAA 2005 and EM 1110-1-1003 may be utilized. The EM 1110-1-1003 specifications were designed to achieve local network accuracies of ±0.1 ft, or ±3 cm, and were largely derived from NGS 2cm/5cm specifications. Specifications to meet these accuracy standards are contained in Sections 8-10 thru 8-13 of EM 1110-1-1003. Table 8-4 from EM 1110-1-1003 is copied below for general reference. Note that higher accuracy observation schemes must be pre-approved by NGS and all data submitted to NGS via the Blue Book process—i.e., NOAA 1994.

EM 1110-1-1003 Table 8-4. Guidelines for Establishing GPS-Derived ± 3 cm Accuracy Orthometric Elevations (Revised 2007)

Occupation time for each baseline occupation (minimum):

Distance	*Time*	*Update rate*
< 10 km	*30 min*	*5 sec intervals*
10-20 km	*60 min*	*10 sec intervals*
20-40 km	*120 min*	*15 sec intervals*
40-60 km	*180 min*	*15 sec intervals*
60-80 km	*240 min*	*15 sec intervals*
80-100 km	*300 min*	*15 sec intervals*
> 100 km	*> 5 hours*	*15 sec intervals*

Proposed observing scheme pre-approved by NGS	*Yes*
Dual-frequency receiver required:	*Yes*
Geodetic quality antenna with ground plane required:	*Yes*
Minimum number of existing benchmarks required:	*2 or 3 (preferred)*
Minimum number of observations per baseline:	*2*
Fixed-height tripods/poles:	*Required*
Measure antenna height:	*2 to 3 times*
Satellite altitude mask angle:	*15 degrees*
Maximum allowable VDOP:	*5*
Number of days station occupied:	*2 days*
Over 40 km baselines:	*3 days*
Nominal distance between project and fixed, higher-order benchmarks:	*within 20 km radius*
Maximum distance between same or higher-order benchmarks:	*50 km*
Collect meteorological data:	*Required*
Precise ephemeris baseline reduction required:	*Yes*
Recommended geoid model:	*Geoid 03 (or most recent)*
Fixed integers required for all baselines:	*Yes*
Baseline resultant RMS less than:	*2.5*
NSRS submittal:	*ADJUST/Blue Book*

Source: Table 1 of (NOAA 1997) with USACE revisions

APPENDIX C
Guidance, Standards, and Specifications for Referencing Coastal Navigation Projects, Hurricane Protection Projects, and Shore Protection Systems to National Water Level Observation Network Datums

C-1. Purpose

This Appendix provides guidance on evaluating and establishing vertical reference control on coastal navigation, hurricane protection, and shore protection projects. It describes preliminary evaluation actions necessary to determine if coastal navigation projects and related protective structures are adequately connected and modeled relative to the National Water Level Observation Network (NWLON) tidal datum and the National Spatial Reference System (NSRS) established by the Department of Commerce. For those projects that are not adequately connected to these reference systems, specific procedural actions required to effect this connection are outlined herein.

C-2. Applicability

This guidance applies to all projects in coastal areas that are referenced, modeled, designed, constructed, and maintained relative to a sea level datum. This includes all coastal navigation projects referenced to Mean Lower Low Water (MLLW) datum, and shore protection or hurricane protection projects referenced to MLLW, Mean Sea Level (MSL), Mean Tide Level (MTL), Mean High Water (MHW), or any other local tidal datum. It also applies to all projects that are not firmly referenced to a tidal datum determined relative to the National Water Level Observation Network (NWLON) network. To a limited extent, navigation projects in the Great Lakes and connecting channels are included. Navigation projects in non-tidal inland waterways are excluded.

C-3. Definitions

National Water Level Observation Network. The NWLON is composed of the continuously operating long-term primary and secondary control tide stations of the National Ocean Service. This Network provides the basic foundation for the determination of tidal datums for coastal and marine boundaries and for chart datum of the United States.

National Water Level Program. The NWLP, administered by the Department of Commerce, includes the NWLON and includes a database of water level elevation data and benchmark elevation data form historical long-term and short-term operated by that agency for various surveying and mapping projects.

National Tidal Datum Epoch. The specific l9-year period NTDE adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. Special NTDEs are adopted for local areas with extreme relative sea level change due to significant land subsidence (Louisiana) or land rebound (SE Alaska) are partly based on a more recent 5-years of Mean Sea Level.

Mean High Water (MHW). The average height of all high waters at a place, covering a 19-year period. Heights of bridges over navigable waterways and legal coastal shoreline boundaries are typically referred to this datum. Coastal shorelines shown on navigation charts typically (but not always) depict MHW whereas depths on the same chart are referred to Mean Lower Low Water. Exceptions to this are found in Corps of Engineers inland navigation charts.

Mean Tide Level (MTL) and Diurnal Tide level (DTL). A plane often confused with LMSL that lies close to LMSL. MTL is the midpoint plane exactly between the average of MHW and MLW at a tide station. Hydraulic design manuals sometimes refer to MTL as being synonymous with Mean Sea Level. DTL is the midpoint exactly between the average Mean Higher High Water and Mean Lower Low Water.

Mean Sea Level (MSL) or Local Mean Sea Level (LMSL). The average height of the surface of the sea at a tide station for all stages of the tide, typically (but not always) covering a 19-year period which is usually determined from hourly height readings measured from a fixed and predetermined reference level.

Mean Lower Low Water (MLLW). The average height of the lower of the two low waters occurring in a day, at a tide gage over a 19-year period. Coastal navigation projects are referred to this datum. This datum superseded Mean Low Water (MLW) which was previously used as the navigation reference datum for the East Coast CONUS.

Mean Low Gulf (MLG). A low water tidal datum unique to Gulf Coast Districts, used as a navigation (and construction) reference datum in coastal waterways such as the Gulf Intracoastal Waterway (GIWW), the Mississippi River Gulf Outlet (MRGO). Derived from Mean Gulf Level.

Mean Gulf Level (MGL). A Gulf tidal datum established ca 1899 from which Mean Low Gulf (MLG) is derived and defined to this day. Presumed to be Mean Sea Level (MSL) at 1899 origin in Biloxi, MS.

Range of Tide. The difference in height between consecutive high and low waters. The mean range is the difference in height between mean high water (MHW) and mean low water (MLW) tidal datums. The great diurnal range or diurnal range is the difference in height between mean higher high water (MHHW) and mean lower low water (MLLW) tidal datums.

See NOS 2000 (Tide and Current Glossary) for additional definitions.

C-4. Scope

This guidance details the CEPD process for assessing the adequacy of referenced water level elevations on coastal projects. It provides technical options for correcting any determined deficiencies in existing project datums, including preparing programming budget estimates for implementing corrective actions. The primary emphasis is on navigation projects in that the evaluation of hurricane/shore protection projects (HSPP) will roughly parallel the flood protection structures covered in Appendix B. Guidance on hydrodynamic tidal modeling will be referenced to existing Corps publications—e.g., EM 1110-2-1100 (Coastal Engineering Manual).

C-5. General

The Corps uses a variety of water level datums to reference flood control, hurricane protection, navigation, and shore protection projects. Figure C-1 below depicts some of these reference planes. In coastal areas, and in coastal inlets, accurately modeling the sloping MLLW datum plane shown in the figure is the challenge. Additionally, the elevation of the actual water surface above the MLLW reference must be accurately measured in order to determine the elevation of a point relative to the MLLW datum. This water surface temporally varies due to tide, currents, wind, and other effects. On shore/hurricane protection projects, other sea level based datums may be required (e.g., MSL, MHW, MLW), along with their relationship to the NSRS (NAVD88).

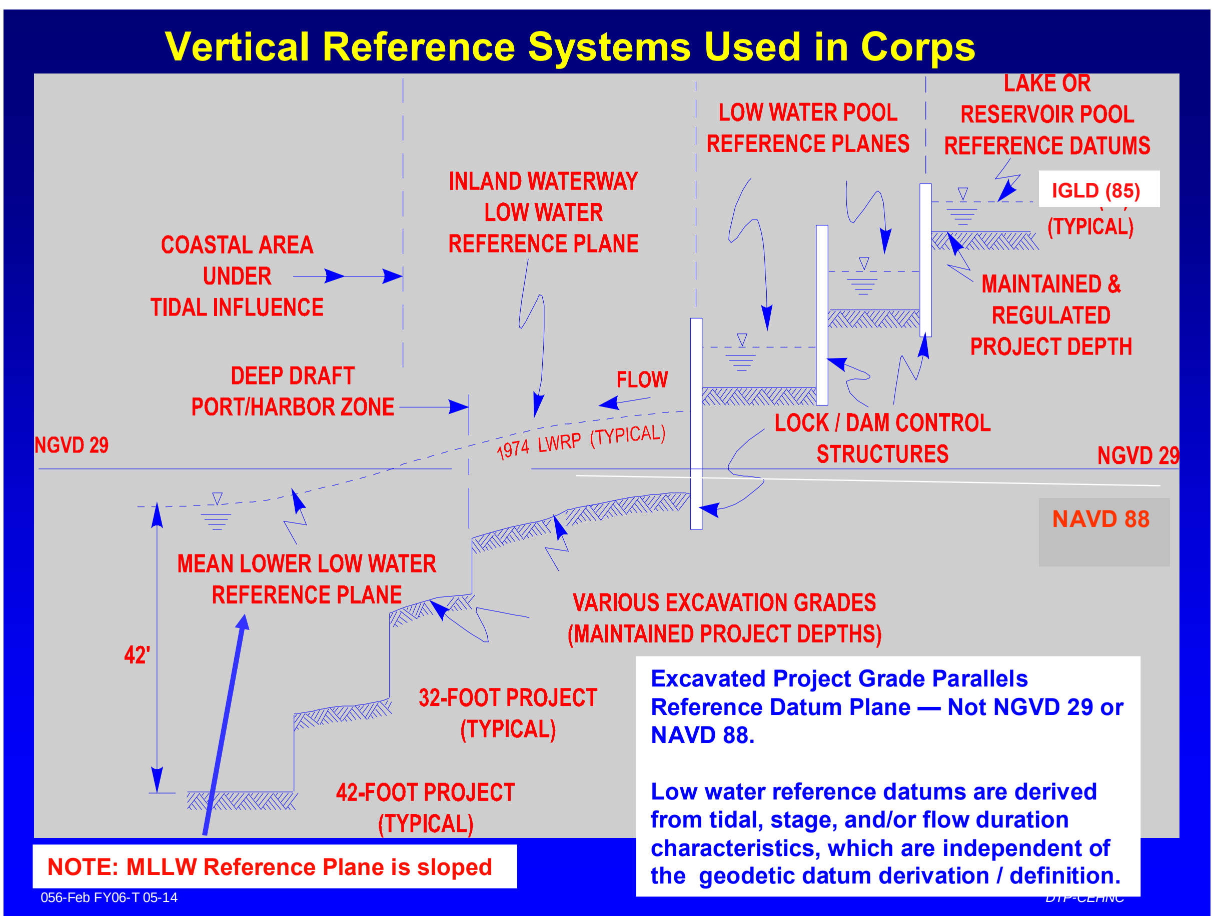


Figure C-1. Tidal and Inland Vertical Reference Datums

The overall effect of conditions at tidal inlets is best summarized in the following excerpt from EM 1110-2-1100 (Part II-6).

> "Hydrodynamic conditions at tidal inlets can vary from a relatively simple ebb-and-flood tidal system to a very complex one in which tide, wind stress, freshwater influx, and wind waves (4- to 25-sec periods) have significant forcing effects on the system … Flow enters the bay (or lagoon) through a constricted entrance, which is a relatively deep notch (usually 4 to 20 m at the deepest point). Entrance occurs after flow has traversed over a shallow shoal region where the flow pattern may be very complex due to the combined interaction of the tidal-generated current, currents due to waves breaking on the shallow shoal areas, wind-stress currents, and currents approaching the inlet due to wave breaking on adjacent beaches …. Particularly during stormy conditions with strong winds, flow patterns may be highly complex. Also, the complicated two-dimensional flow pattern is further confounded because currents transverse to the coast tend to influence the propagation of waves, in some cases blocking them and causing them to break … Final complications are structures such as jetties, which cause wave diffraction patterns and reflections. In inlets with large open bays and small tidal amplitudes, flows can be dominated by wind stress. In such cases, ebb conditions can last for days when winds pile up water near the bay side of the inlet, or long floods can occur when winds force bay water away from the inlet. Most inlet bays, however, are small and some are highly vegetated, so wind stress is not a dominant feature, except under storm conditions ... Although many bays do not receive much fresh water relative to the volume of tidal flow, substantial freshwater input due to river flow can sometimes create vertically stratified flows through a tidal inlet. Typically, however, well-mixed conditions exist for most inlets."

C-6. Requirements for Accurately Modeled Tidal Reference Datums

The need for accurate tidal datums on USACE projects surfaced in the IPET study following Hurricane Katrina, and is outlined in the beginning sections of this guidance document. Lack of accurate tidal datums can have significant impacts on project design and cost. For example, inadequately modeled navigation projects can result in millions of dollars of overdredging, along with increased construction disputes and claims. Erroneous reference datums on hurricane or shore protection projects can result in significant freeboard reductions.

Figure C-2 illustrates the impact of tidal elevation biases on dredging measurement and payment surveys. The tidal modeling bias in this single 1,600 ft acceptance section at Key West, FL resulted from tidal datum and phase errors, in addition to inherent survey biases. Minimizing these errors (and resultant construction costs) is a primary goal of this CEPD assessment.

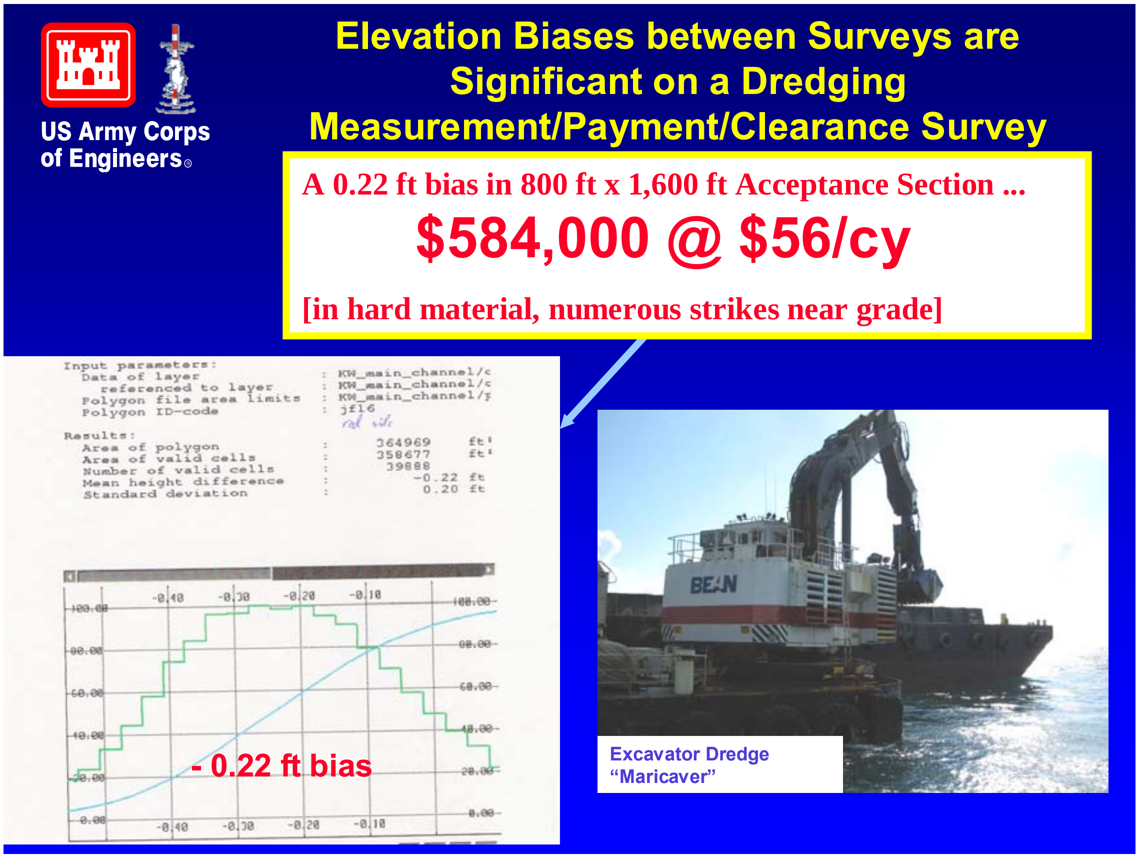


Figure C-2. Impact of elevation biases on measurement & payment

The primary factors that need to be considered in evaluating tidal datums include the following:

(1) Tidal phase variations over the project reach.

(2) Tidal range variations over the project reach.

(3) Tidal epoch adjustments for sea level or land subsidence changes.

(4) Quality of reference tidal gauge datum determinations

Tidal reference datums vary both spatially and temporally. Thus, the water surface elevation at a shore-based gauge is adequate only for that specific location and time. The height of the tidal wave will be significantly different between two points around an inlet, due to varying times and weather conditions. Likewise the MLLW datum will vary with the tidal range variations, which are modified by the topography of an inlet or coastal region. This MLLW datum cannot be extrapolated to another location without some modeled correction. It is also subject to long-term variation due to sea level rise, subsidence, or other factors. This requires periodic updating of tidal datums based on NOAA's latest National Tidal Datum Epoch (NTDE), which is currently 1983-2001 for most areas.

Current USACE practice for dredging and related payment surveys of navigation projects involves extrapolation of a water (tide) level gauge to the construction area. This assumes both the water surface level and reference datum range are constant over the extrapolated distance—i.e., assumes no tidal phase or range variations exist. This distance may range from a few hundred feet to over 10 miles. These assumptions of linearity in water surface levels and datum degrade with distance from the reference gauge. At low tidal ranges, longer extrapolations may be possible. At higher ranges (> 2 ft), extrapolations greater than ½ mile to 1 mile may be invalid and inaccurate. In addition, local weather conditions may further degrade the distance which a tide reading can be reliably extrapolated from a gauge. Sea surface setup due to strong winds can significantly alter the surface model. Approximate modeling methods ("tidal zoning") are used in some Districts, with mixed accuracy results—these methods do not account for local weather conditions. Figure C-3 depicts some of the geographical and physical factors that need to be considered in assessing the reliability of a tidal model for a coastal inlet project.

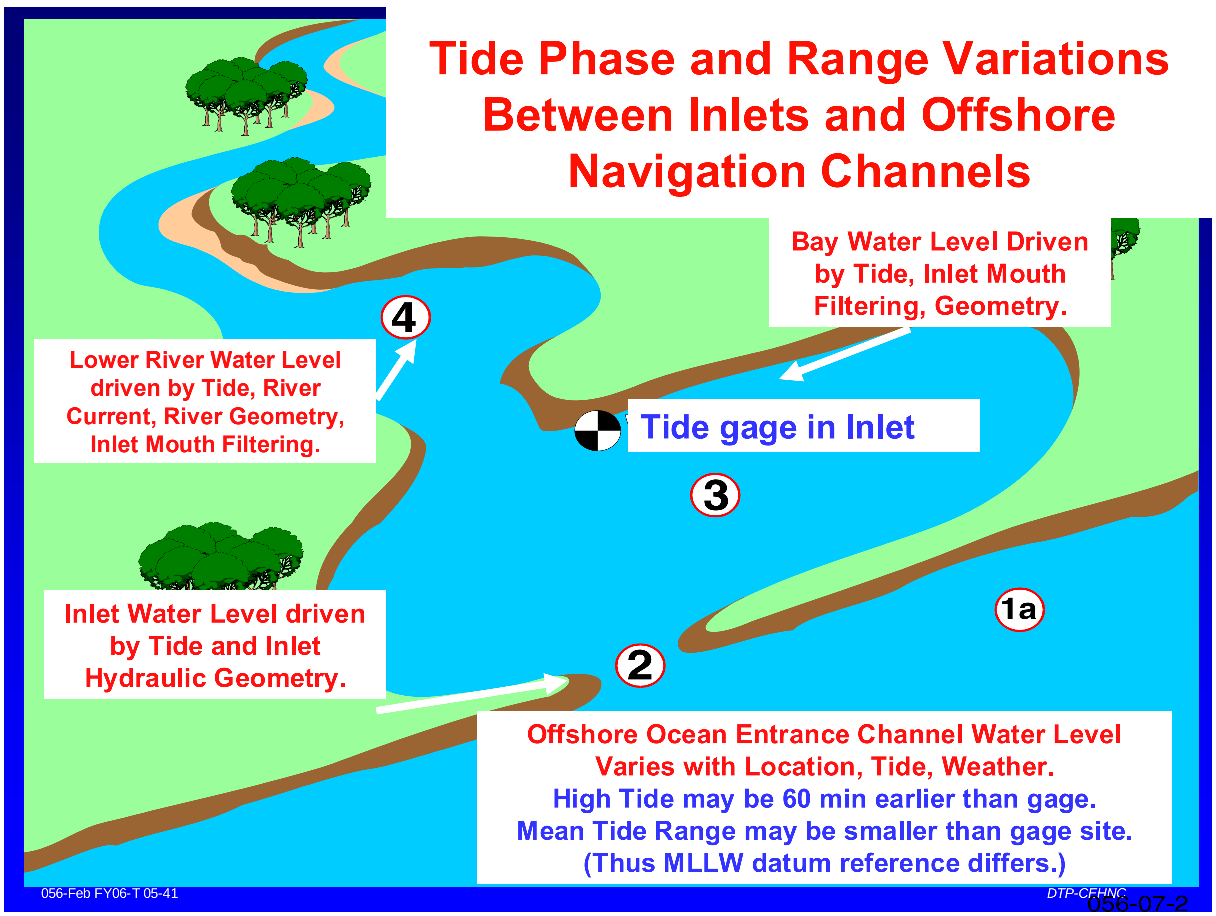


Figure C-3. Tide phase & range variations at an inlet

Figure C-4 from EM 1110-2-1100 (Part II-6, "Hydrodynamics of Tidal Inlets") clearly illustrates the tidal phase and range variation occurring between the ocean and bay at a typical coastal inlet.

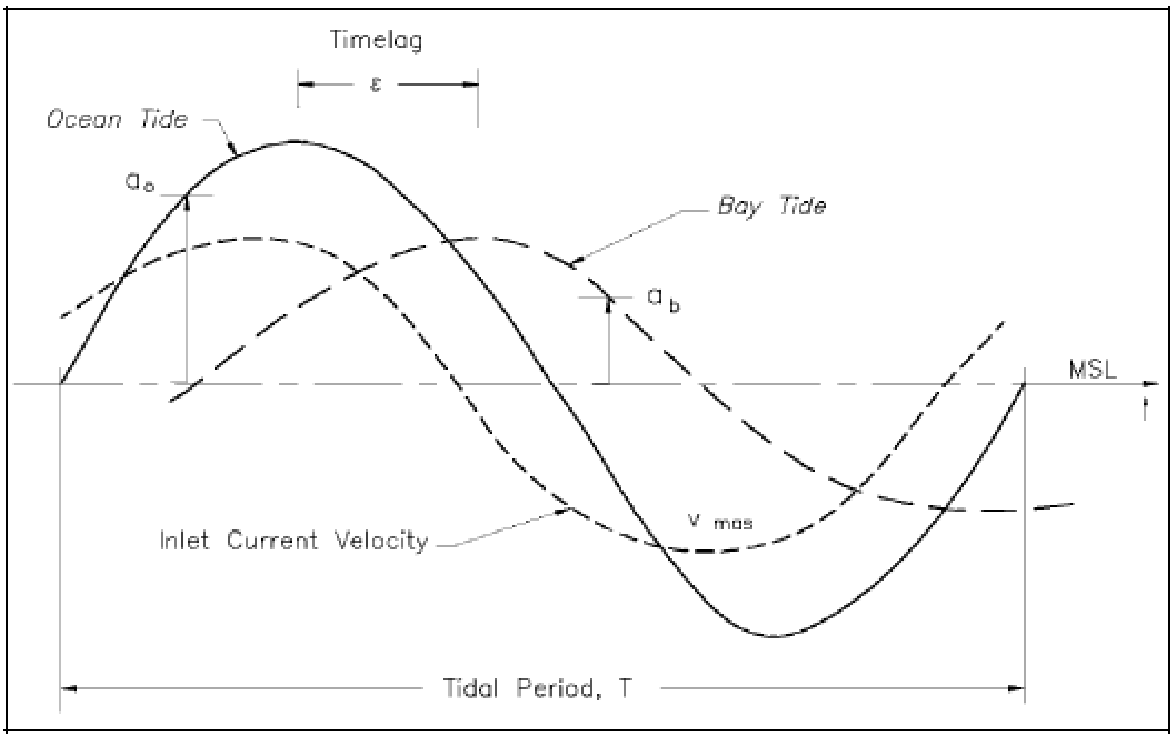


Figure C-4. Tide phase & range variations between ocean and bay from EM 1110-2-1100 (Part II), 30 Apr02

C-7. Tidal Phase Variations

The major error in the depth measurement of a navigation project is caused by tidal phase (time lag) variations between the gauge and the extrapolated location of the dredge or survey vessel at the project site. Local weather (winds) further varies the tidal profile in the region, as detailed in EM 1110-2-1100 (Part II-6). These phase and weather errors increase with the distance from the gauge and the topographic constrictions in an inlet. These systematic errors can exceed 1 to 2+ ft in moderate range projects—as depicted in Figure C-5. Most dredging measurement & payment disputes and claims arise over lack of adequate tidal phase modeling in a project. (See EM 1110-2-1003 for additional details on tidal phase errors.)

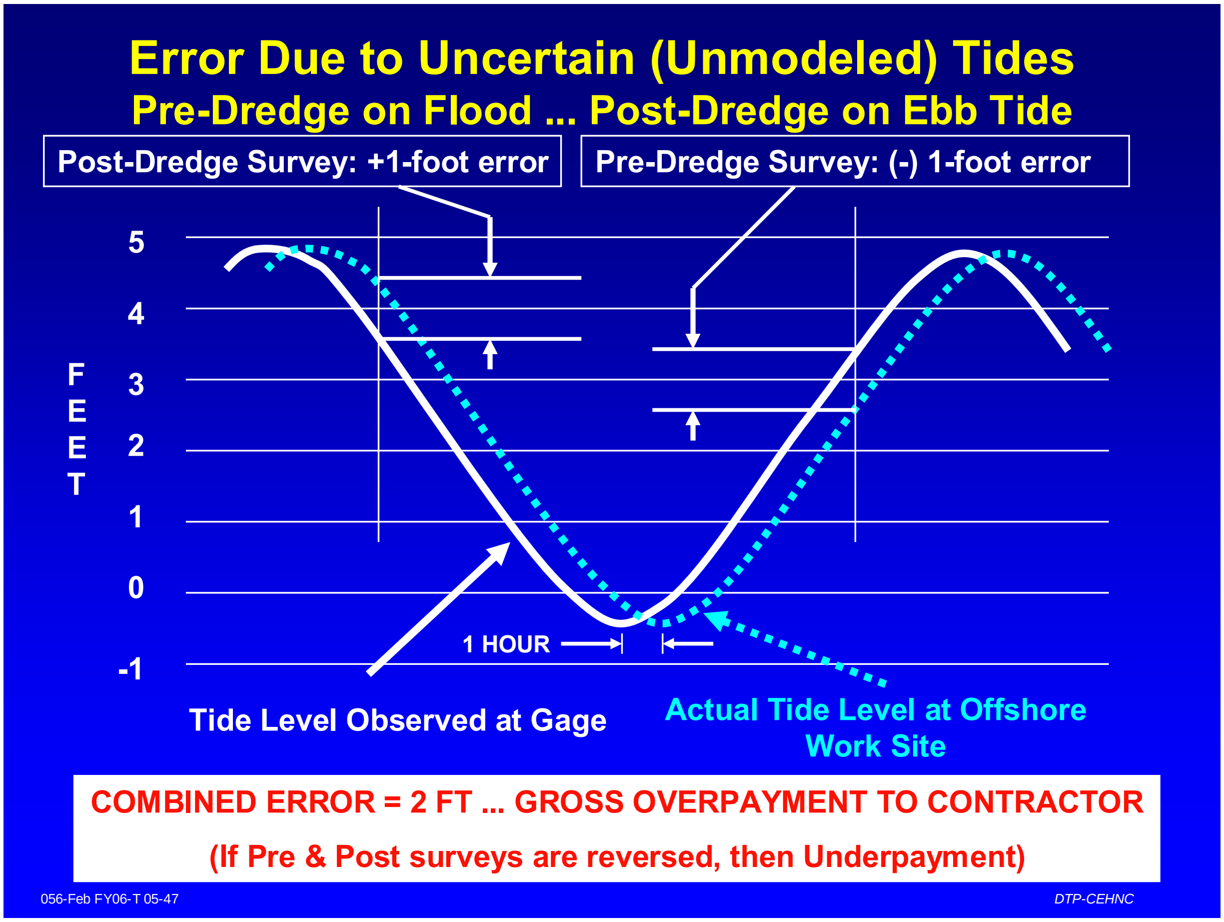


Figure C-5. Tide phase difference errors due to lag, wing, or other factors

Tidal phase lag errors (and weather/sea surface set up) are now effectively eliminated by using GPS-based surface elevation measurement techniques—i.e., RTK. USACE commands must endeavor to require RTK elevation measurement in lieu of tide gauge observations where tidal phase errors are significant. Figure C-6 illustrates the application of using GPS 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 bias is generated at a point only 3 miles distant from the gauge. This bias is significant given the tide range at this project is only about 2 ft. As shown in the figure, the RTK-determined elevation of the sea surface at the dredging site was accurate to approximately ±0.05 ft, which effectively minimized the tidal phase and weather errors. 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 (see next section). This typically requires GPS survey connections to operating or historical tide station benchmarks.

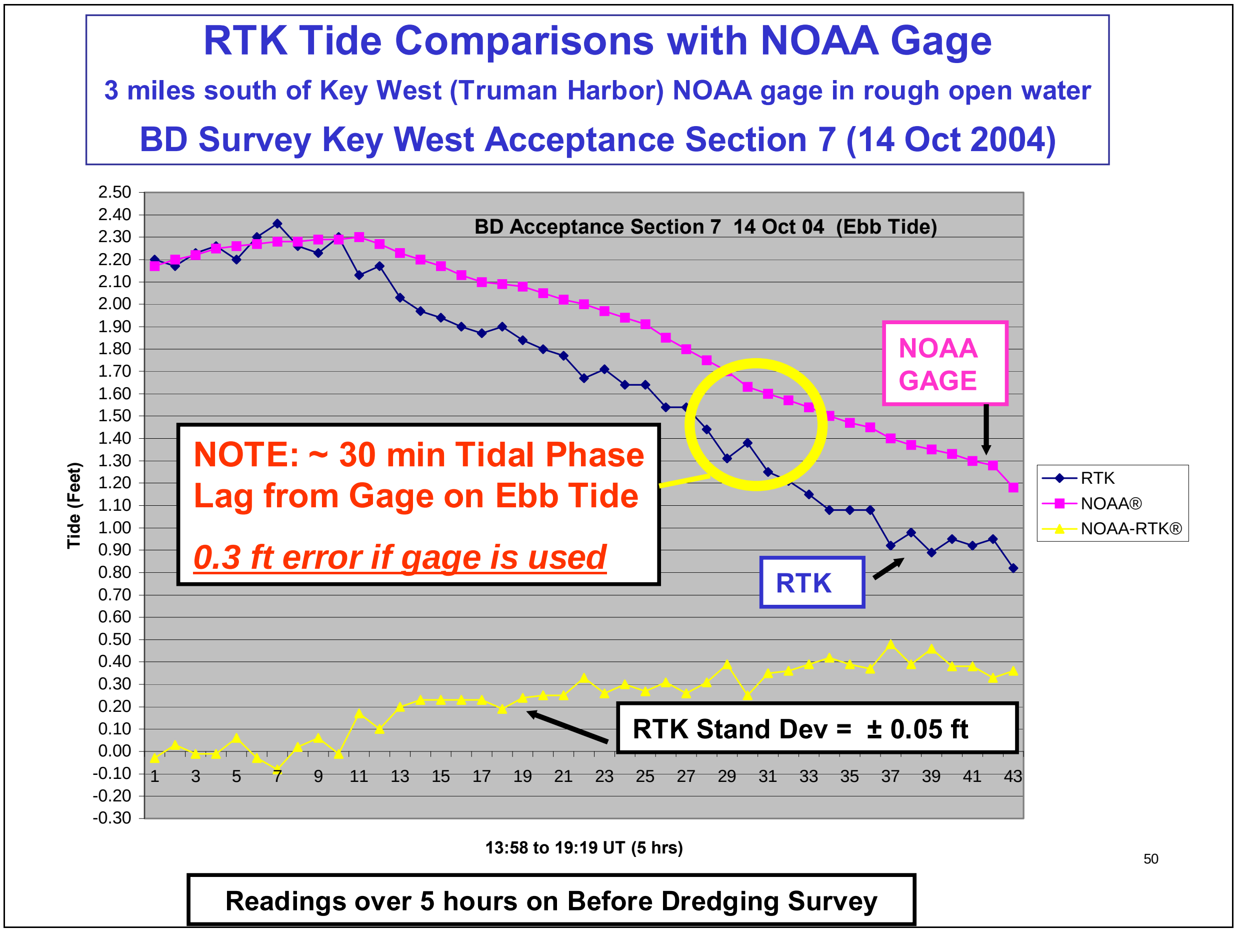


Figure C-6. Gauge v RTK comparisons

C-8. Tidal Range Variations

Variations in tidal range (i.e., undulations in MLLW datum relative to MSL or to geodetic datum) within a project must also be accounted for. This requires developing some model of the tidal hydrodynamic characteristics throughout the project.

Figure C-7 illustrates this MLLW variation over a Jacksonville District deep-draft coastal inlet project (St Johns River—Ocean to Jacksonville, FL). The MLLW datum relative to MSL varies from the ocean through the entrance jetties and up river. MSL also varies relative to NAVD88. The figure also depicts that NGVD29 and NAVD88 are not parallel datums. The MSL-MLLW datum variation may also be impacted by fresh water flow into the tidal area.

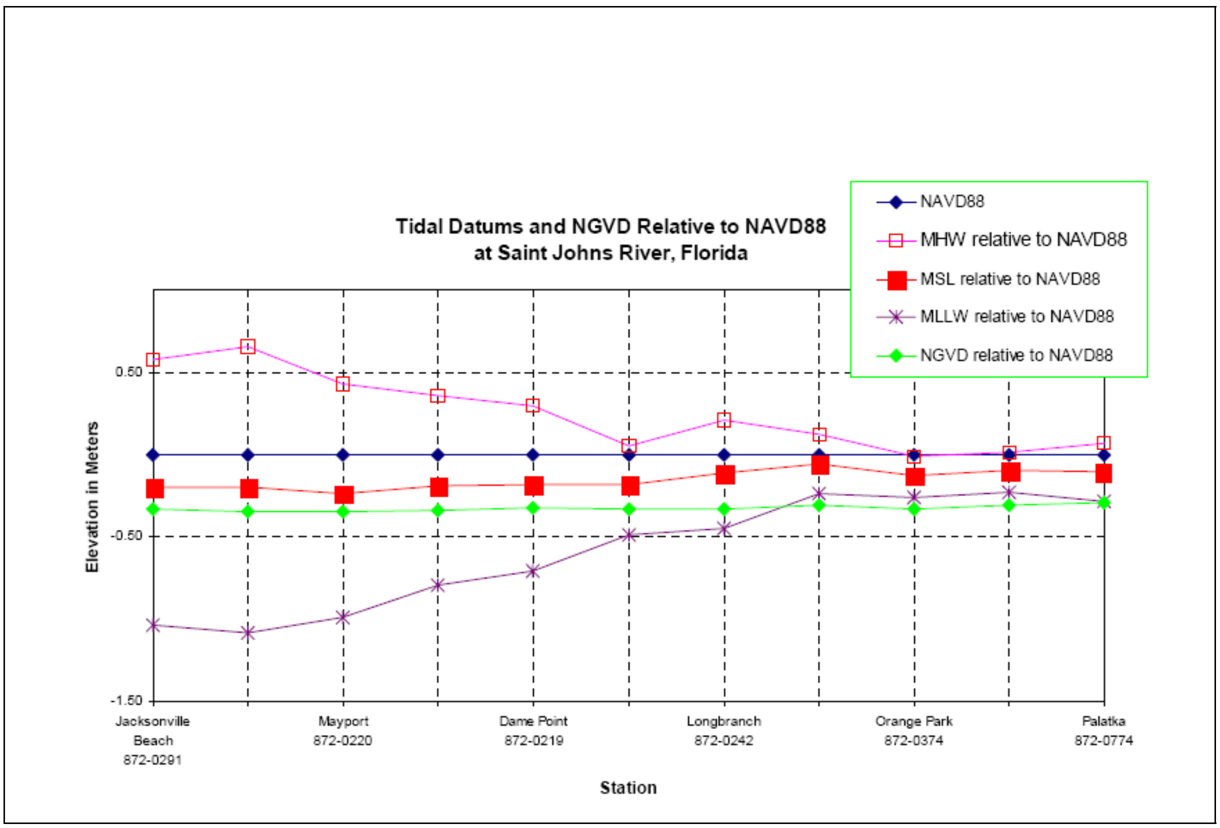


Figure C-7. Tidal range variation at a coastal inlet

Modeling the MLLW datum through a navigation project requires an adequate density of tide gauges from which the model can be calibrated, and intermediate datum variations between the gauges can be modeled. In the Figure C-7 above, the roughly 5.6 ft tide range at the ocean narrows down to 1.6 ft over a 25-mile navigation project. Although the gauges in the above figure are spaced at about every 5 to 10 miles, they should be of sufficient density to calibrate a hydrodynamic tidal model for this project. The lineal interpolations between the gauges shown on this figure represent only a crude tidal model of the MLLW reference plane—a full hydrodynamic tidal model would be represented by a smooth curve. In many cases with small tidal range variations, or with a dense gauge network, a linearly interpolated model may prove adequate. That may be the case for portions of the above project where the variation between gauges is not large.

Figure C-8 illustrates the tidal range variation over seven miles of a shallow draft project on the East Coast. There would appear to be a sufficient density of gauge data to model the MLLW datum plane for this project—including updating the older MLW and NGVD29 references shown in the figure.

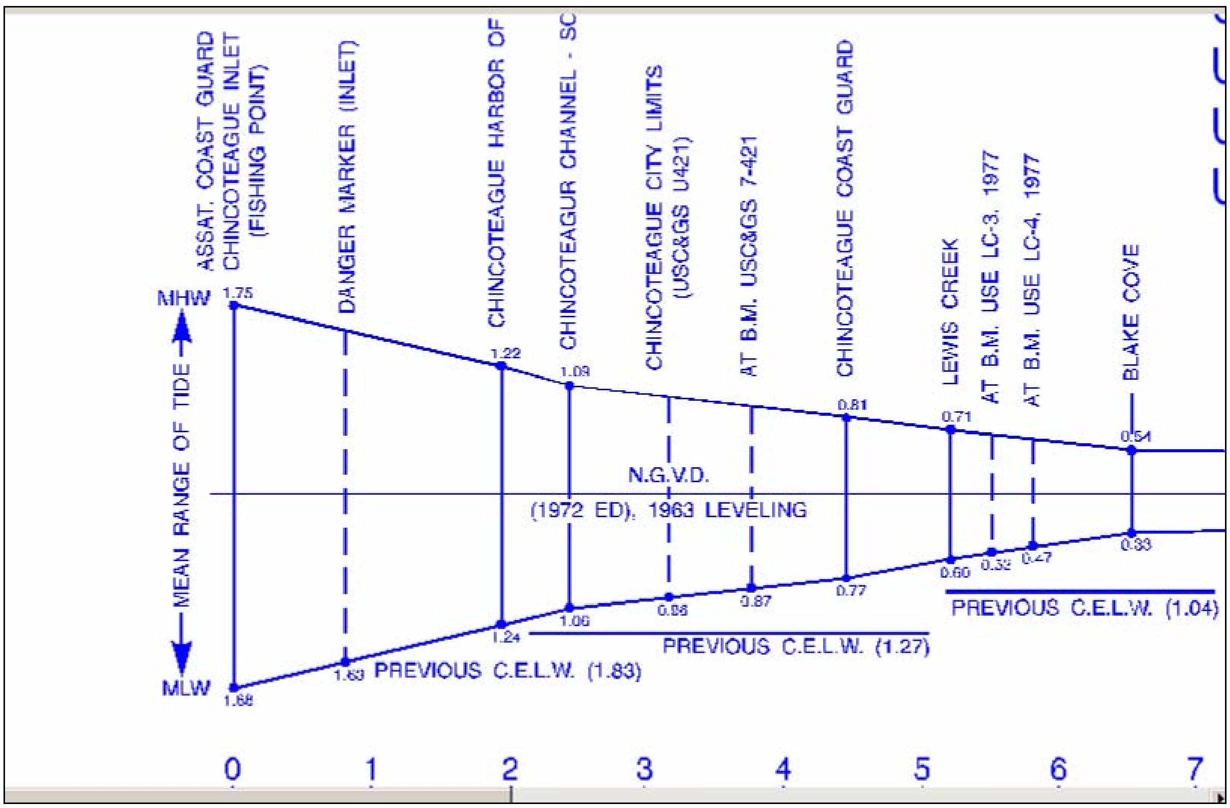


Figure C-8. Tidal range variation at Chincoteague Inlet, VA

C-9. Tidal Epoch Variations

NOAA periodically updates the tidal datums throughout CONUS and OCONUS to account for sea level rise, local land settlement, and other factors. These periodic adjustments can be significant—ranging from 0.2 ft to 0.5 ft over the last 19-year update period (1983-2001). Projects not updated since the 1940s would have significantly larger differences—see Figure C-9. 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 hurricane protection project elevations. Typically, on most CONUS locations, the 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.

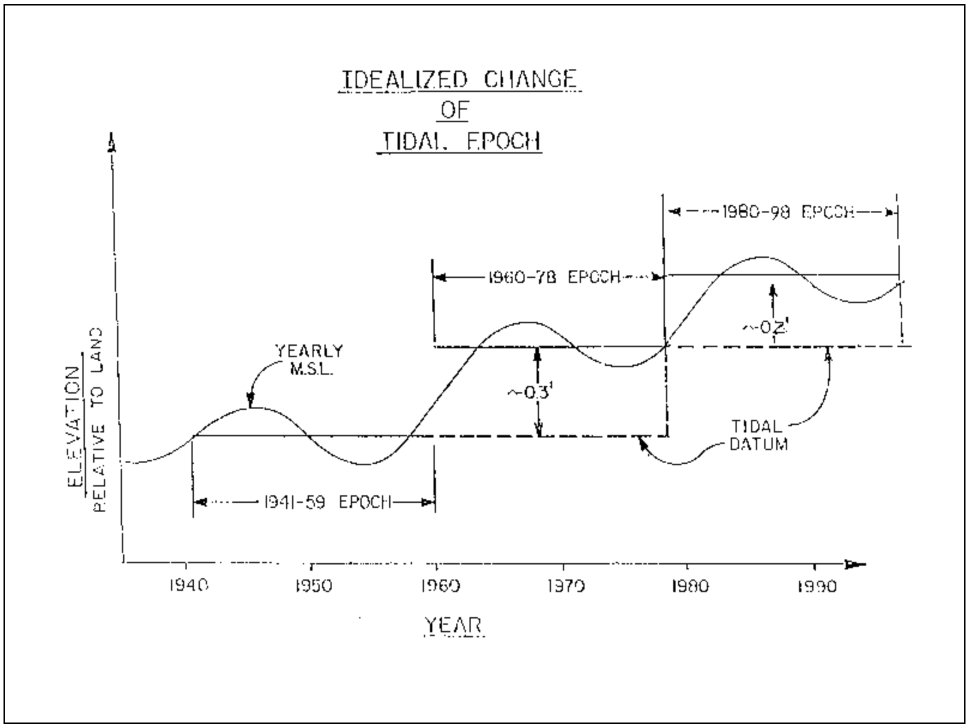


Figure C-9. Sea level rise 1940 to 1998 (Note that latest epoch is 1983-2001)

Tidal epoch adjustments are easily corrected by ensuring projects are updated when NOAA completes a periodic epoch change.

Figure C-10 illustrates the impact of a tidal epoch change on a project being dredged relative to the superseded 1960-1978 epoch. The adjustment to the latest epoch (1983-2001) significantly reduced the number of strikes above grade that would have required additional dredging.

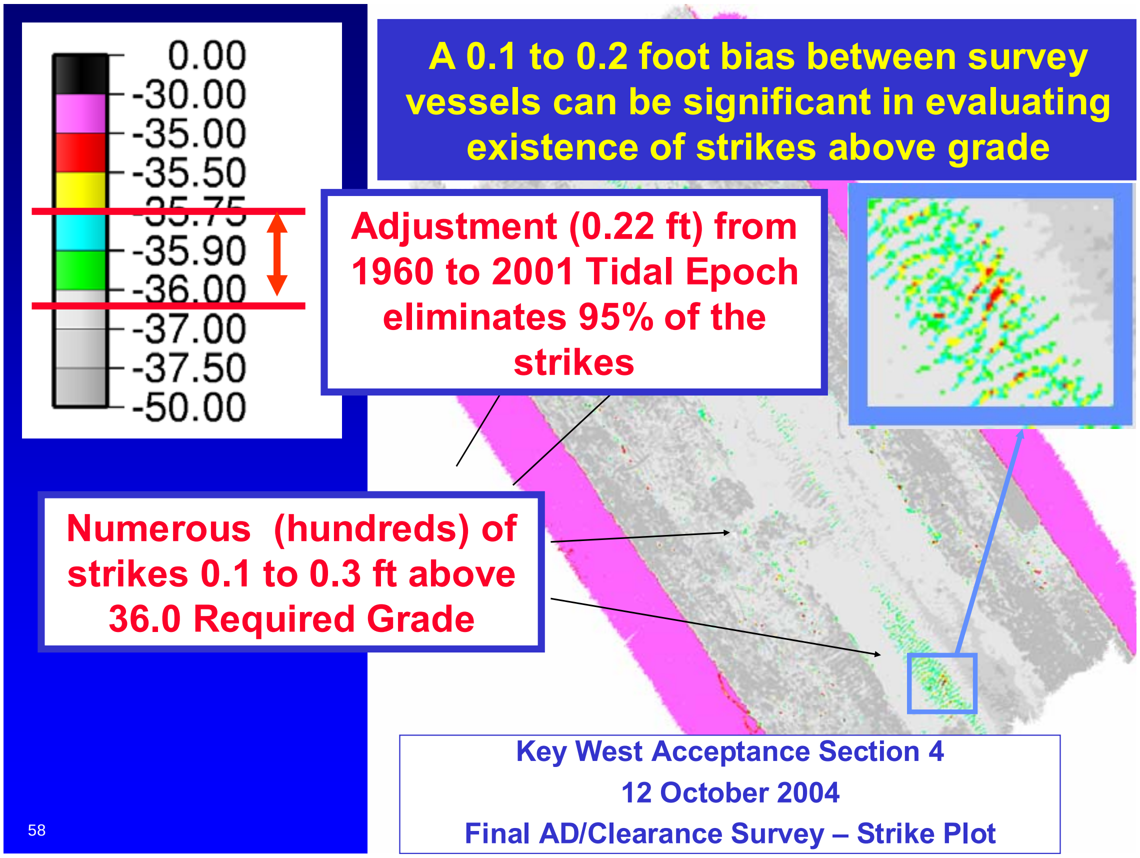


Figure C-10. Tidal epoch variation on dredging grade

Epoch updates are only 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. See NOAA 2001 and NOAA 2003 for additional details on the periodic computation and adjustment of tidal epochs.

C-10. Quality of Reference Tidal Gauge and Computed Water Level Datum

The MLLW datum at a gauge site (either existing or historic) must be adequately connected with the NOAA NWLP network. This implies using either a NOAA gauge site that is on or is connected with the NWLP, or a locally operated gauge that meets with NOAA connection specifications. Isolated benchmarks (those of USACE or any other agency) that purport MLLW or MSL reference elevations should be considered highly suspect unless their connection with a NWLP gauge site can be firmly established (i.e. direct differential level or static GPS connections to a NOAA tidal benchmark). Any such marks must also contain an epoch designation attached to their elevation that signifies it has been adjusted to the current tidal epoch. For example, the elevations at a benchmark should have, at minimum, the following type of metadata in order to be considered acceptable as a reliable reference for controlling USACE projects:

Benchmark: USED INLET 1957
Elevation: 8.29 ft (NAVD88 [adjustment epoch as appropriate])

Elevation: 7.21 ft (above MLLW—1983-2001 epoch)
Source: [specify NGS "PID" or NOAA CO-OPS tide station designation number]

USACE benchmarks set near NOAA gauges should be leveled in using standard 3rd Order survey procedures. These marks should be entered into the NSRS if they are going to be used as a primary vertical control point for the project—e.g., setting a tide calibration staff or as a RTK base.

If a complete tidal-geoid model has been developed for a project, then this model designation—and date—should also be included as primary metadata with a benchmark used to control construction dredging.

When in doubt about the quality of an existing USACE benchmark, always hold to gauges/benchmarks published on the NOAA reference network—either currently operating or historical.

C-11. Requirements to Reference Coastal Navigation Projects to MLLW Datum

Some USACE projects are still defined relative to non-standard or undefined reference datums (e.g., Mean Low Gulf, Gulf Mean Tide, MSL, NGVD, MLW, etc.). In accordance with the intent of Section 224 of WRDA 1992 (33 U.S.C 562) and The National Tidal Datum Convention of 1980 (NTDC 1980), navigation projects (channel depths and dimensions) in coastal tidal areas must be defined relative to the MLLW. This WRDA 92 amendment to Section 5 of the Rivers and Harbors Appropriation Act of 1915 overrides and supersedes previously authorized reference datums, 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 …"*

As previously stated, the MLLW reference plane is not a flat surface but slopes as a function of the tidal range in the area. Tidal range can increase or decrease near coastal entrances; thus the MLLW must be accurately modeled throughout the navigation project. The required grade at all points on the navigation project is dependent on tidal modeling--requiring determination of the elevation of the MLLW datum plane from a series of gauge and/or modeled observations at each point. Guidance on performing this conversion was first issued as ETL 1110-2-349 on 1 Apr 93 *(Requirements and Procedures for Referencing Coastal Navigation Projects to Mean Lower Low Water Datum).* This guidance was subsequently incorporated into engineering manuals—EM 1110-1-1005 and EM 1110-2-1003 and is also included as an appendix in the IPET 2006 Report.

C-12. Accuracy Standards for Tidal Datums

The total error of tides and water levels for application to hydrographic surveys can be considered to have component errors of:

(1) the measurement error is a combination of the gauge/sensor and processing error to refer the measurements to station datum. The measurement error, including the dynamic effects of waves and currents, should not exceed 0.10 m at the 95% confidence level. The processing error also includes interpolation error of the water level at the exact time of the soundings (water levels are recorded every 6-minutes). An estimate for a typical processing error is 0.10 m at the 95% confidence level.

(2) 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 0.08 m for the Atlantic and Pacific coasts and 0.11 m for the coast in the Gulf of Mexico (at the 95% confidence level).

(3) the error in application of tidal zoning. Tidal zoning is the extrapolation and/or interpolation of tidal characteristics from a known shore point(s) to a desired survey area using time differences and range ratios. The greater the extrapolation/interpolation, the greater the uncertainty and error. These are correlated with geographic distance and the difference in tidal characteristics. Estimates for typical errors associated with tidal zoning are 0.20 m at the 95% confidence level. However, errors for this component can easily exceed 0.20 m if tidal characteristics are very complex, or not well defined, and if there are pronounced differential effects of meteorology on the water levels across the survey area.

For both (2) and (3) above, the tidal difference is a function of the difference in time of tide, range of tide, and type of tide (shape of the tide curve).

(Note that the use of RTK elevation measurement, coupled with a fixed MLLW datum model, effectively minimizes or eliminates the above errors.)

Datum Error:

Refer to NOS 2001 (Tidal Datums and Their Applications) for more details. The following table from this reference illustrates the accuracy of tidal datums for various lengths of record.

Table 2. Generalized accuracy of tidal datums for East, Gulf, and West Coasts when determined from short series of record and based on +/- sigma. From Swanson (1974).

Series Length (months)	East Coast (cm)	(ft.)	Gulf Coast (cm)	(ft.)	West Coast (cm)	(ft.)
1	4.26	0.13	5.91	0.18	4.26	0.13
3	3.28	0.10	4.92	0.15	3.61	0.11
6	2.30	0.07	3.94	0.12	2.62	0.08
12	1.64	0.05	2.95	0.09	1.97	0.06

The above table indicates that in general, tide stations with at least 3 months record have determined a datum to within ± 0.2 ft. If a NOAA historical gauge has some 12 months of record (which is typical) then the accuracy of the computed MLLW datum at that point is around ± 0.1 ft at 95%.

These maximum estimates are no longer being used operationally by NOS to estimate datum uncertainties from tide stations. Instead of the regionalized approach in the above table, the following relationships are being used to estimate tidal datums 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 (NOS 2003). Assuming most subordinate tide stations for NOS hydrographic surveys are operated for less than one-year durations, the Bodnar regression equations for mean low water for one-standard deviation ("s") estimates are of the form:

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

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

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

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

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.

Tidal Zoning Error:

Discrete tidal zones are constructed based on knowledge of the tide at shore-based historical stations and estimated positions of co-tidal lines for range and time of tide. For most NOAA applications the resolution of the zoning has been to construct a zone polygon for every 0.2-foot change in range and every 0.3-hour change in time of tide. For many tidally complex areas (such as around Key West for instance) tide zones with higher resolution are used. Tidal zoning errors are considered random errors although they have a certain periodic nature and not a normal statistical distribution. Zoning errors also are characterized by two components: a time correction and a range ratio correction to observations from a nearby tide station. Maximum zoning errors for each project are estimated by simultaneously comparing tide curves constructed from time and range corrections to historical tide station observations. Statistics of the residuals are then analyzed to estimate the error in the zoning for the entire project.

Zoning	Estimate	Error Type
Typical Areas	~ 0.10m	s - random
Complex Areas	~ 0.20m	s- random

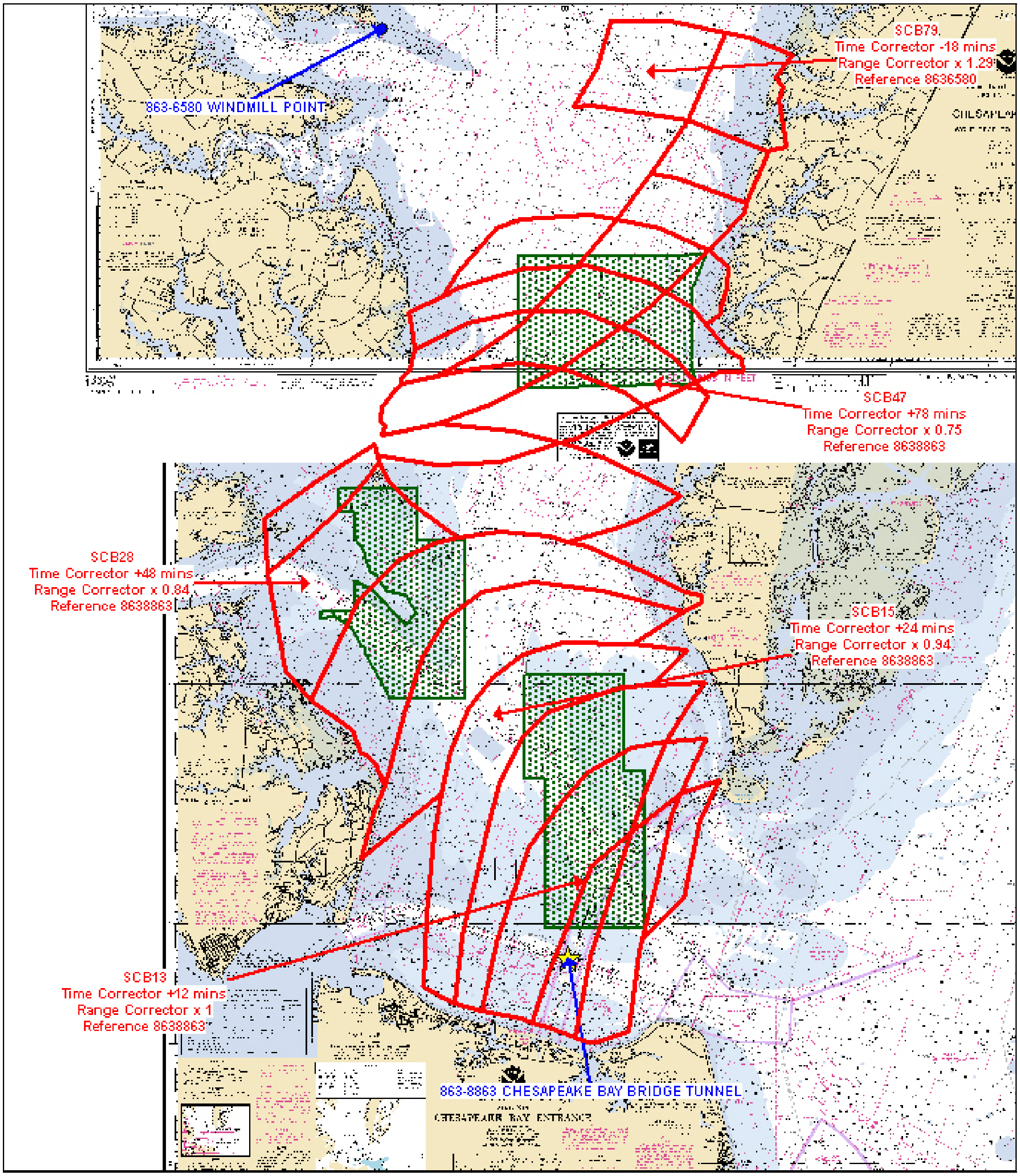


Figure C-11. The discrete tidal zones constructed from the co-tidal lines and the survey areas in lower Chesapeake Bay

There are inherent errors in application of discrete tidal zoning: 1) discontinuities at the edge of the zones; 2) resolution in areas of complex tidal characteristics, where the location and number of zones is not adequate to describe the changes in the tide over the survey area; 3) where large time corrections and large range ratios are required; and 4) the fact that placement of the zones becomes subjective when the co-tidal lines are based upon inconsistent or inadequate source data.

Figure C-11 above illustrates an application for tidal zoning in Chesapeake Bay—in particular for areas in the middle of the bay where no RTK or VRS coverage is available. Where RTK/VRS coverage is available only the corange model would have application.

Discussion of Applications to CEPD:

The major contributors to the tides error budget are the datum error which contributes as a systematic bias and the tidal zoning error which contributes as a random error. In practice the datum error is reduced with longer data series. Errors can be very significantly if less than 30-days of data are observed. Substantial reductions in error from those of a 30-day series are not realized until one-year of data are collected. For CEPD tidal modeling purposes, NOAA gauge datums, (or acceptable datums from another agency's long-term gauges) will be assumed as absolute—no effort will be considered in improving the accuracy of existing datums by extending gauge periods. The tidal zoning error can be reduced by lessening the amount of time and range correction needed by establishing more tide stations for use in direct control of the survey. Use of the Tidal Constituent and Residual Interpolation (TCARI) (discussed in later sections on models) can also reduce tidal zoning errors. Project planning an implementation are focused on finding the practical balance between the number of tide stations required and the amount of tidal zoning required. This in turn depends upon the complexities of the tidal characteristics in the area and the resources and logistics required to establish and maintain tide stations. Calibrated tide gauges that are configured and installed to minimize dynamic errors result in the measurement errors usually being minor contributors to the tides error budget. The estimated total tides error can then be root-summed-squared with all of the other hydrographic survey error sources to estimate the total survey error budget.

As stated above, for USACE tidal modeling purposes, and subsequent maintenance dredging and construction of projects, the accuracy of a NOAA gauge datum, (or acceptable datums from another agency's long-term gauges) will be assumed as absolute—i.e., they will be assumed to have “zero error.” This assumption is valid in that the final developed MLLW-geoid model will also be considered fixed, and containing minimized errors based on the developed model. This fixed model, when used with RTK, provides near absolute 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 gauge are used, then repeatability will be dependent on all the errors discussed in the above paragraphs. Future events (i.e., updated epochs, major projects construction or deepening, etc.) will require periodic modifications to the tidal model; however, these will be few and far between—perhaps only every 19 years.

USACE EM 1110-2-1003 Accuracy Standards:

USACE hydrographic surveying accuracy standards for water surface accuracy are defined in Table 3-1 of EM 1110-2-1003 (Hydrographic Surveying)—excerpted below.

EM 1110-2-1003 Table 3-1. Minimum Performance Standards for Corps of Engineers Hydrographic Surveys (Mandatory)

PROJECT CLASSIFICATION		Navigation & Dredging Support Surveys Bottom Material Classification		Other General Surveys & Studies (Recommended Standards)
		Hard	Soft	
RESULTANT ELEVATION/DEPTH ACCURACY (95%)				
System	Depth (d)			
Mechanical	(d<15 ft)	± 0.25 ft	± 0.25 ft	± 0.5 ft
Acoustic	(d<15 ft)	± 0.5 ft	± 0.5 ft	± 1.0 ft
Acoustic	(15>d<40 ft)	± 1.0 ft	± 1.0 ft	± 2.0 ft
Acoustic	(d>40 ft)	± 1.0 ft	± 2.0 ft	± 2.0 ft
MAXIMUM ALLOWABLE BIAS		± 0.1 ft	± 0.2 ft	± 0.5 ft
WATER SURFACE MODEL ACCURACY		[½ depth accuracy standard]		½ depth accuracy

> EM 1110-2-1003 Section 3-12. Tidal or Water Level Surface Modeling Accuracy
>
> These standards refer to the accuracy by which the water surface elevation is determined at the point a depth measurement is observed. Tide or stage uncertainty can often be the major error component in the resultant accuracy of an elevation measurement. It includes the precision which a tide or river stage is interpolated or extrapolated (i.e., modeled) relative to a reference gauge. In areas where modeling techniques are inadequate, where the project area is distant from the reference gauge, or with large tidal range and phase variations, carrier-phase DGPS techniques may be necessary to meet the required standard.

The above table was developed before RTK methods were readily available, and assumed that water surface elevations were directly extrapolated from the nearest gauge—i.e., no tidal model, no tidal zoning, etc. The maximum allowable bias standard is the governing criteria for survey accuracy (or actually repeatability). This bias is derived from repeated surveys over the same area (Performance QA Tests) as outlined in Chapter 11 of EM 1110-2-1003. Meeting this bias standard becomes difficult or impossible if tidal phase errors are not compensated. The "1/2 depth accuracy" standard in the table needs to be updated in accordance with the revised accuracy criteria in the next section of this guidance document. Depth accuracy standards in EM 1110-2-1003 Table 3-1 range from ± 0.25 ft to ± 2 ft, depending on depth and type of bottom; thus, the intended water surface model accuracy ranges from ± 0.1 ft to ± 1 ft. Accuracies well within these limits can be achieved by (1) using RTK elevation measurement (including geoid modeling), and (2) hydrodynamically modeling and calibrating the tidal MLLW datum relative to local NOAA gauges.

C-13. Accuracy of a Tidal-Geoid Model of a Navigation Project

Table C-1 below represents the desired accuracy of a navigation project model, considering both the MLLW datum and the geoid.

Table C-1. Recommended Accuracies for Reference Datums on Navigation Project Tidal Models

	Accuracy (95%)	Reference Datum
Absolute accuracy of tidal-geoid model	± 0.25 ft (± 8 cm)	MLLW
Relative accuracy of tidal-geoid model	± 0.1 ft (± 3 cm)	MLLW
Tidal-geoid model resolution	0.01 ft	
Linear density along navigation channel	100 to 500 ft (varies with magnitude of tidal range)	
Geoid model	use latest available at time of study (currently Geoid 03)	
Accuracy of predicted geoid model	< 5 cm	
Accuracy of predicted MLLW datums In offshore entrance channels	< 5 cm	
Tidal-geoid model format	1D or 2D (typically 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.

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 gauge 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 gauges. Regardless of the resultant absolute accuracy of a tidal model for a region, the relative accuracy is most critical. For navigation projects, dredging measurement and payment performed using RTK methods will typically employ a combined tidal-geoid model from which to correct observed ellipsoid heights measured at the water surface. Thus, the measured ellipsoidal elevation of the water surface at any point is corrected for (1) geoid undulation from the reference benchmark, and (2) tidal range (MLLW) variations from the reference benchmark based on hydrodynamic models of the tide in the region—see Figure C-12. The actual offshore water surface level above corrected MLLW is thereby measured at every observation (1 to 10 Hz) made by a survey vessel, dredge, or commercial vessel employing RTK methods; and an average surface level (or tide) computed using filters and/or an IMU. 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 typically fall around ±0.05 ft, regardless of the user. The tidal-geoid model developed for the project is considered as absolute.

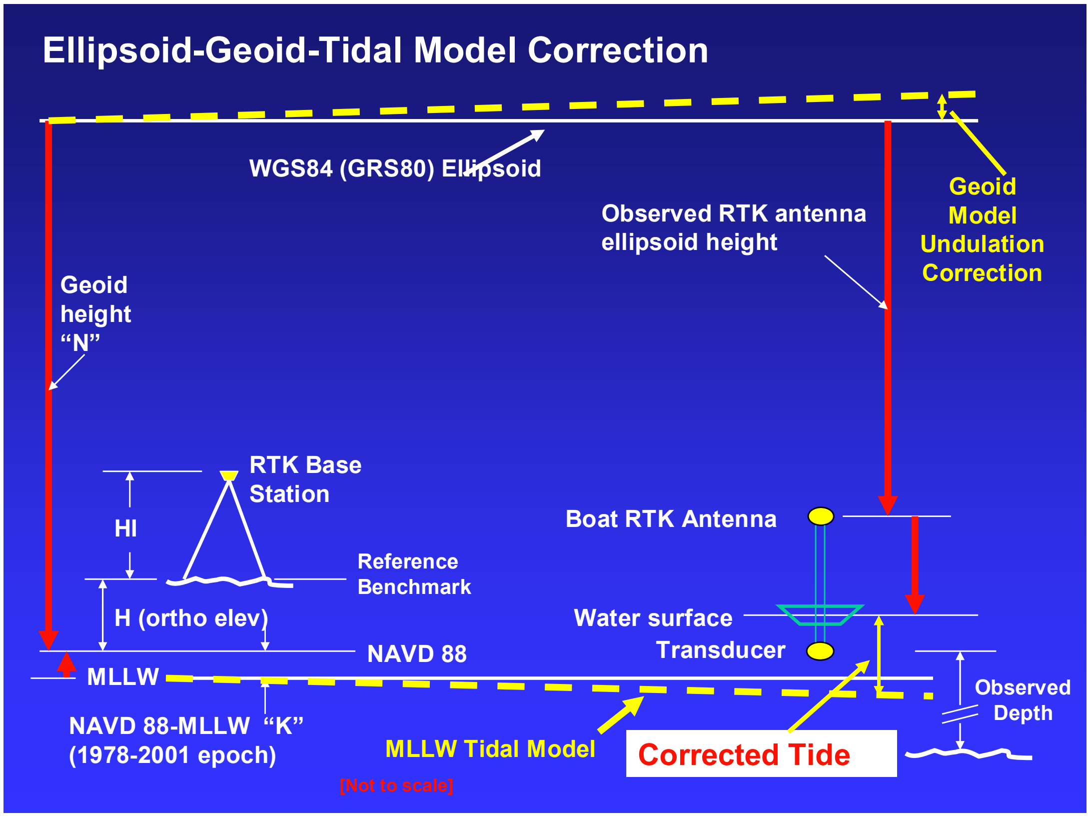


Figure C-12. RTK Tidal-Geoid model corrections for navigation projects

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 model will be used for offshore entrance channels, areas which obviously have no vertical control but have been estimated using other techniques (airborne gravity). Those modeling the project should check with NGS to confirm the accuracy of the predicted 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—reference Jacksonville District 2005.

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, or in the form of a "KTD" file used by commercial navigation dredging software (HYPACK, Inc.). Since most USACE navigation projects are linear, only a 1D model is 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 geoid model is significantly modified by NGS. 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 (K) or 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 gauge or staff gauge.

C-14. Corrective Options for Navigation Projects Requiring MLLW Datum Upgrades

A number of options exist to update a tidal model for coastal navigation projects that are found to be deficient and require upgrading. Updating the tidal model requires the following basic actions:

(1) Ensure tidal datum reference planes (MLLW) are defined relative to published NOAA gauges and tidal benchmarks.

(2) Ensure the latest tidal epoch adjusted by NOAA is used.

(3) Model the MLLW reference plane and geoid throughout the length of the project.

(4) Publish and disseminate the tidal-geoid model for users.

(5) Optionally develop the NAVD88-MLLW datum relationship at tidal benchmarks.

(6) Submit any hydrodynamic modeling data to NOAA for their use in expanding the nationwide VDatum.

Items (1) and (2) above are easily achieved as long as an existing or historical gauge 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 standard gauging program will have to be developed in order to establish a tidal datum at a project—see NOS 2003, "Computational Techniques for Tidal Datums Handbook." Any such effort must be coordinated with NOAA in order to ensure the project becomes included in NOAA's NWLON inventory. Time and cost estimates for performing the gauging can be obtained from NOAA.

Project modeling—Items (3) through (6) above—will require close coordination with District H&H elements, ERDC/CHL, and/or NOAA. In small tide ranges either between gauges or in the overall area, lineal interpolation of the MLLW model will often be sufficiently accurate and economically developed. These models may already have been developed for some projects, and may currently need only to be adjusted for tidal epoch updates and geoid models.

C-15. Modeling the MLLW Datum on Navigation Projects

As stated earlier, a number of techniques can be employed to model the MLLW datum on a navigation project. These range from extrapolating the MLLW datum from a single gauge to a full hydrodynamic model. Various options include:

- Small project and small tide range ... no model required, use gauge MLLW elevation extrapolated throughout project area
- VDatum model--check with NOAA CSDL if VDatum model exists or is planned
- Interpolated (simple linear or discrete tidal zoning) model between gauges
- TIN model ... MicroStation InRoads
- TCARI model ... TCARI Spatial Interpolation Tool
- Hydrodynamic model

Most often, linear or surface interpolations between gauges will be used.

On projects with larger tide ranges where the uncertainty of a linear model between gauges increases beyond the allowable tolerance, a more sophisticated hydrodynamic model may be required to best define the MLLW datum. This presumes adequate gauge records exist from which to calibrate the tidal model in an area. On some projects, a single gauge may be adequate. Others may require additional gauges to define the model. If these additional gauges do not exist, then a gauging program will have to be programmed. In addition, topographic and bathymetric models of the project may have to be generated if they do not exist. A firm connection to the orthometric datum (NAVD88) may also be required. Thus, a number of project-specific technical factors will govern the overall effort required to model the MLLW datum plane of a project. This will also include the experience of those assessing the tidal model relative to the required relative accuracy of the tidal model.

One must not lose sight of the overall error budget in evaluating the effort required to model the MLLW datum on a project. Relative to removing large phase and wind setup errors with RTK measurements, these MLLW datum modeling errors are often insignificant. Thus, before embarking on any extensive (and costly) gauging program, the significance or sensitivity of these added gauge observations on the overall tidal model must be substantiated. Likewise, the difference between a simple lineal interpolation and a hydrodynamically modeled interpolation must be evaluated for significance relative to the intended tolerance.

In addition, there is no point in performing elaborate MLLW datum tidal modeling unless RTK surface elevation measurements are mandated for the completed project. Having a MLLW tidal model accurate to ±0.1 ft with a ±1 ft phase error due to extrapolated gauge readings five miles offshore would obviously be an inconsistent use of resources.

Figure C-13 illustrates a typical modeling requirement for a coastal inlet navigation project. This project may currently be referenced to an unknown MLW or MLLW datum, is not referenced to local NOAA tide gauges, or has not been updated to the latest tidal epoch. As shown, the existing model is based on a straight-line interpolation between the gauges (assuming NOAA gauges were originally used). The MLLW variation is then interpolated, typically at 0.1 ft increments along the channel, as indicated by the stair-step in the figure. A recalibration of the MLLW tidal model for this project would result in the curved line shown in the figure. A hydrodynamic model would fit (calibrate) the induced astronomical tide to the MLLW datums at each gage. The upward shift in the curve from the original model might represent the sea level rise (epoch change) and/or MLW to MLLW conversion.

Of significance is whether this project can be just as effectively modeled using a simple straight-line interpolation between the gauges as opposed to running a full hydrodynamic model. In lower tide ranges, or with dense gauge 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 the figure.

Also shown on the figure is the relationship between other geodetic reference datums. The local geoid model (Geoid 03) would provide the undulation shown relative to NAVD88, and indirectly relative to MLLW. As stated previously, this relationship is not critical to maintaining the project on MLLW datum in that RTK observations will be "site-calibrated" to MLLW datum. The figure also illustrates the variation between NGVD29 and NAVD88.

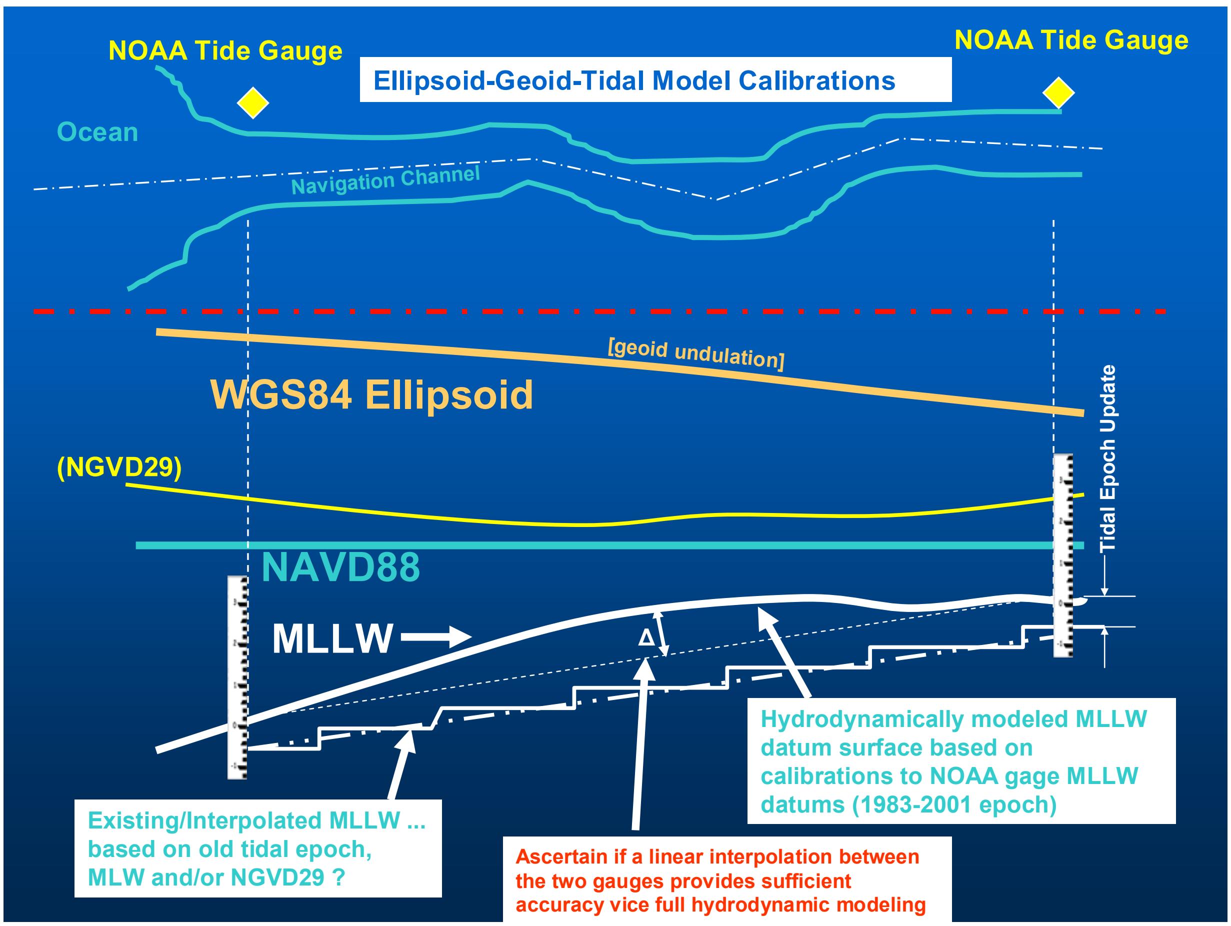


Figure C-13. Tidal Model Calibrations at a Navigation Project

The following figure depicts a navigation project where a simple straight-line interpolation of the tidal datum might be warranted in lieu of performing a full hydrodynamic model study. Initial estimates of changes in time and range of tide for any survey area can be obtained from a review of the NOAA tide prediction "Table 2" information found online. For instance, for the Miami harbor area, go to:

http://tidesandcurrents.noaa.gov/tides07/tab2ec3c.html#91

The tide table values should be used with caution as the data summaries are from observations of varying lengths and various time periods and may be out of date and no longer reflective of current conditions. NOAA will be providing USACE with tables and GIS layers of the latest published tidal and geodetic connection information for all locations which should be used for follow-up.

The tables list mean ranges of tide (MHW – MLW), Spring Ranges of Tide (Range of tide at New and Full moons) and the elevation of Mean Tide Level (MTL) above Chart Datum (MLLW). Data for the Miami area is shown below (in feet).

	Lat	Long	Mn Rge	Spg	Rge MTL
Miami Harbor Entrance	25° 46.1'	80° 07.9'	2.46	2.93	1.39
GOVERNMENT CUT,					
MIAMI HARBOR ENTRANCE	25° 45.8'	80° 07.8'	2.32	2.83	1.32
Biscayne Bay					
San Marino Island	25° 47.6'	80° 09.8'	2.14	2.57	1.21
Miami, Marina	25° 46.7'	80° 11.1'	2.18	2.59	1.22
Dodge Island,					
Fishermans Channel	25° 46.2'	80° 10.1'	2.10	2.52	1.19
Dinner Key Marina	25° 43.6'	80° 14.2'	1.94	2.33	1.10

This project has an adequate density of NOAA tide data and has a relatively small tidal range—around 2.5 ft at the ocean entrance. The mean range of tide varies decreases by 0.16 ft between the Miami Beach Government Cut and inside near the Port of Miami turning basin. Similarly, the 0.14 ft range decrease is small between outside on Miami Beach and Miami Beach Government Cut. The regionally modeled tidal range at a point 3 miles offshore in open ocean could be compared with the range at the Miami Beach pier to see if there is a significant difference. The slope of MLLW can be estimated by looking at the changes in the elevation of MTL relative to MLLW. On the outside, the MTL-MLLW difference is approximately 1.4 ft and decreases to approximate 1.2 ft. inside at the Miami Marina (see Figure C-14 below).

Given the small tide range, and the relatively small tidal range variations between outside and inside, the complexity of the variations is not sufficient to warrant a development of a new hydrodynamic model. Thus, a straight-line interpolation of the model between observation locations would be acceptable. The regional ocean tidal model would be considered in assigning a range value to the model for the outer offshore end of the entrance channel.

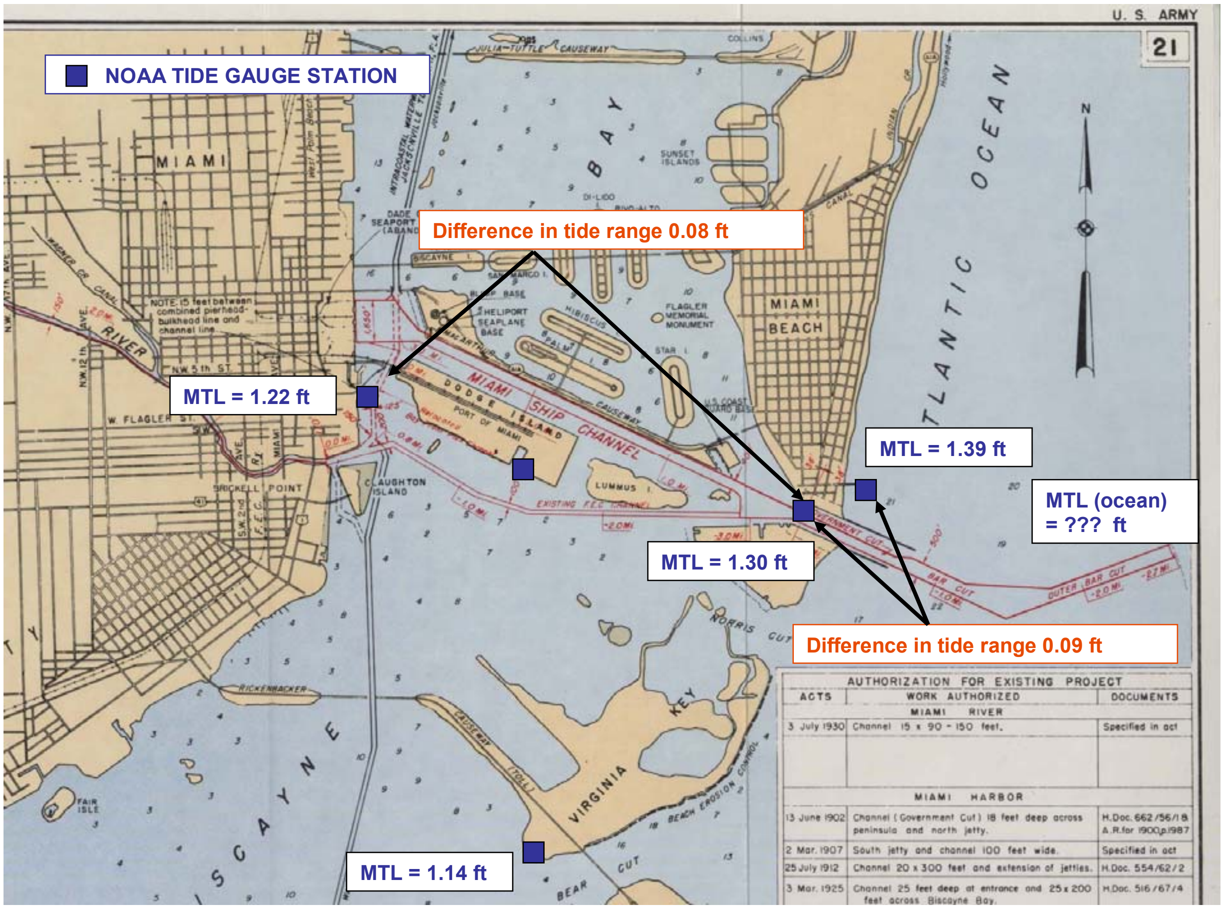


Figure C-14. Tidal Model Calibrations at Miami Harbor

A similar analysis can be made for a West Coast project with a larger tide range—Yaquina River, OR (Portland District). The authorized depth varies from 40-ft at the bar, to 18 ft at Yaquina, then 10-ft to Toledo. The estimate mean range of tide and the MTL-MLLW elevation differences from the tide tables are shown below (in feet).

Yaquina Bay and River	Lat	Long	Mn Rge	Spg Rge	MTL
Bar at entrance	44° 37'	124° 05'	5.9	7.9	4.2
Newport	44° 38'	124° 03'	6.0	8.0	4.3
Southbeach	44° 37.5'	124° 02.6'	6.37	8.34	4.51
Yaquina	44° 36'	124° 01'	6.2	8.2	4.4
Winant	44° 35'	124° 00'	6.3	8.2	4.3
Toledo	44° 37'	123° 56'	6.3	8.1	4.2

However, a check of the latest NOAA tide station published benchmark information shows that the tide table values are out-of-date and should not be used. In general, if the latitude/longitude files have values only to the nearest degree, as opposed to a tenth of a degree, then the data are from pre-1960 observations. Using the latest information collected in the 1980's by CO-OPS, the table becomes (in feet):

	Lat	Lon	Mn Rge	MTL
Bar at entrance	44 37	124 05	5.9	4.2
Newport	44 36.6	124 03.3	6.21	4.49
Southbeach	44 37.5	124 02.6	6.26	4.51
Weiser Point	44 35.6	124 00.5	6.46	4.57
Toledo	44 37.0	123 56.2	6.87	4.71

Thus the older results show much less variability in the tide range than the updated, more recent data. The table and Figure C-15 shows that the range of tide increases by almost 1.0 ft. from outside to upriver at Toledo, and there is a 0.50 ft. slope in MLLW relative to MTL. This may be an area where a hydrodynamic model may prove useful to account for the non-linear changes in the tide going upriver.

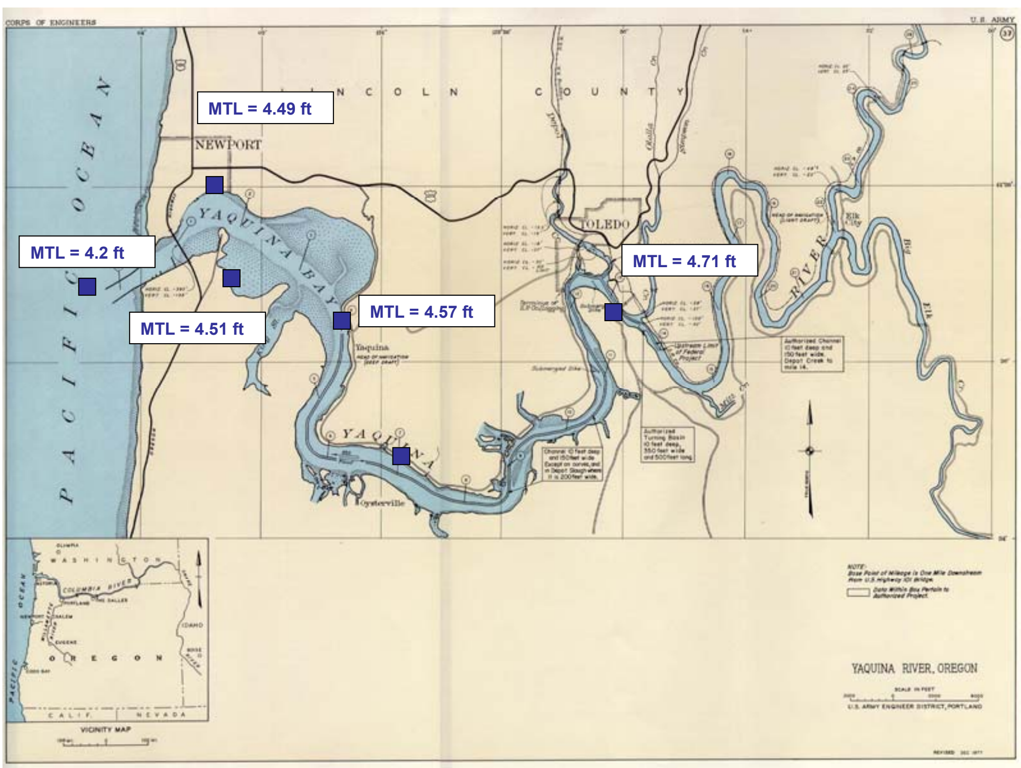


Figure C-15. Tidal Model Calibrations at Yaquina River, OR

The following New England District project (Portsmouth, NH) is typical of a large tidal range variance—approximately 8 ft. MTL variations at various points are shown in Figure C-16.

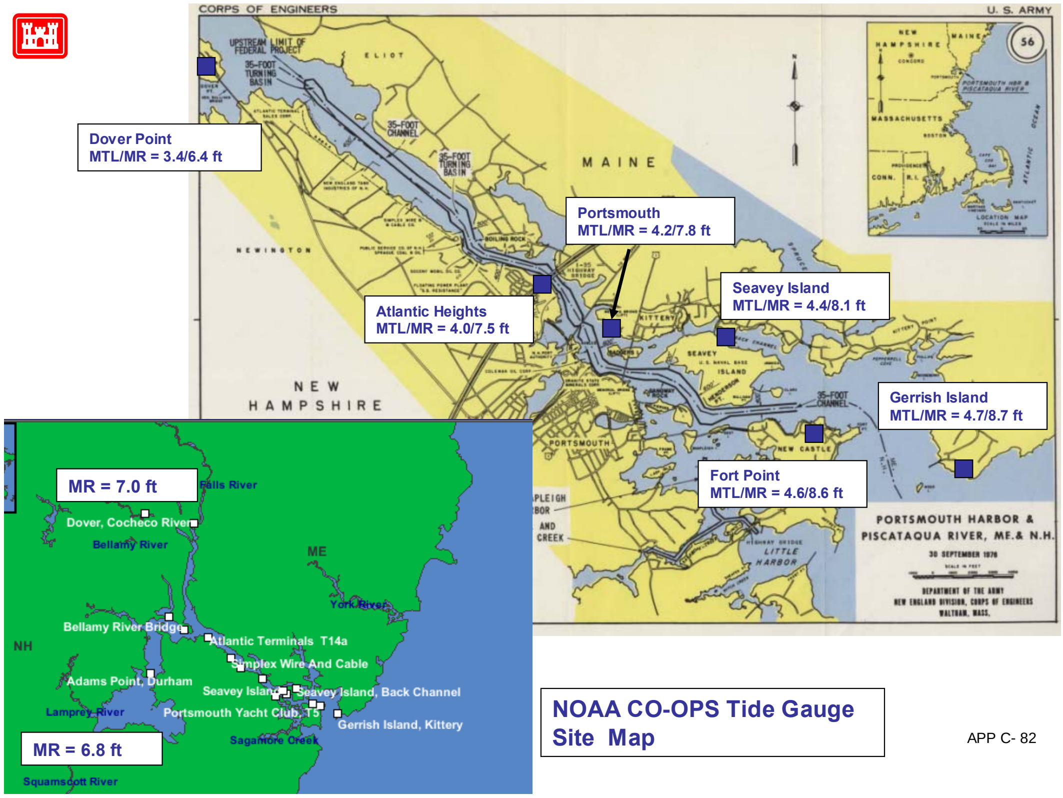


Figure C-16. Tidal Model calibrations at Portsmouth, NH

	Lat	Long	Mn Rge	Spg Rge	MTL
Portsmouth Harbour					
Jaffrey Point	43° 03.4'	70° 43.9'	8.7	10.0	4.7
Gerrish Island	43° 04.0'	70° 41.7'	8.7	10.0	4.7
Fort Point	43° 04.3'	70° 42.7'	8.6	9.9	4.6
Kittery Point	43° 04.9'	70° 42.2'	8.7	10.0	4.7
Seavey Island	43° 05'	70° 45'	8.1	9.4	4.4
Portsmouth	43° 04.7'	70° 45.1'	7.8	9.0	4.2

Even in these larger tidal ranges the gauge density appears sufficient to adequately model the MLLW datum variation by interpolation throughout the deep draft portion of the project. The following Figure C-17 is a graphic showing the CO-OPS discrete tidal zoning scheme for the project area. If RTK procedures were not employed at this project site, time and range correctors for each zone would be applied to an appropriate tide station installed in the harbor to account for time and range changes in the project area. The closest NOAA operating NWLON stations are Boston, MA and Portland, ME.

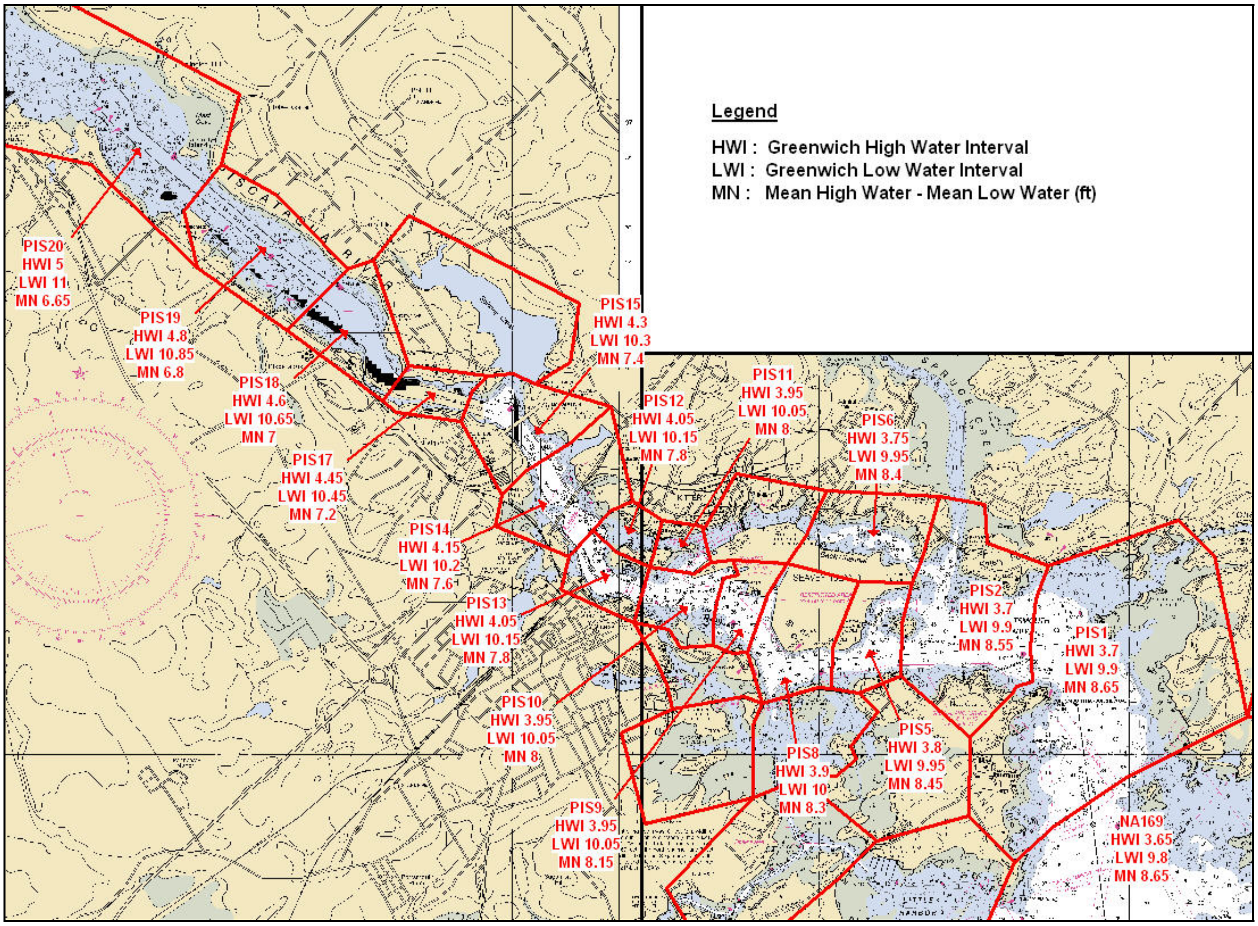


Figure C-17. NOAA Discrete Tidal Zoning Scheme for Portsmouth, New Hampshire

C-16. Hydrodynamic Tidal Modeling of Navigation Projects

From the above, it would appear that many deep-draft navigations will have a sufficient density of NOAA CO-OPS tidal data that interpolation models will be adequate. Interpolation models can be:

- a linear interpolation of elevation relationships over relatively short distances
- a discrete tidal zoning interpolation based on changes in cotidal lines over the survey area
- a continuous tidal zoning interpolation model such as TCARI

Where this is not the case, then a hydrodynamic tidal model may have to be generated to define the MLLW datum plane throughout a project.

The technical process of developing a hydrodynamic tidal model of a typical coastal inlet, and calibrating that model to one or more fixed gauges, is relatively straightforward and models for performing this are well documented in the USACE Coastal Engineering Manual (EM 1110-2-1100—Part II-5 and Part II-6) and other sources. Many USACE navigation projects have been extensively studied over the years and existing numerical models may be readily utilized to assess the tidal datum relationships—e.g., activities studied under the ERDC/CHL Diagnostic Modeling System.

Projects requiring hydrodynamic tidal modeling to define the MLLW datum can be accomplished by any number of organizations. Some of these include:

- District Hydrology & Hydraulics (H&H) section
- Coastal Engineering A-E firms
- NOAA (Office of Coast Survey—VDatum Group)
- ERDC/Coastal Hydraulics Laboratory (CHL)

Each of the above will have different approaches, costs, and turn-around response. CEPD cost estimates for this modeling effort can be obtained from any of these organizations. These costs may include gauging programs which will have to be obtained from NOAA. Actual installation can be accomplished via an A-E contract with a coastal engineering firm.

It is recommended that those performing the CEPD assessment closely coordinate with the H&H team in your District. Working with them will best develop the requirements, estimated costs, and implementation plan.

C-17. National VDatum

VDatum, coupled with the Tidal Constituent and Residual Interpolation (TCARI) continuous tidal zoning model, has considerable future application to many USACE projects—both inland and coastal. VDatum is a software tool developed by NOAA that allows users to transform geospatial data among a variety of geoidal, ellipsoidal, and tidal vertical datums. Currently the software is designed to convert between 28 vertical datums, including NAVD88 and MLLW. This 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. The VDatum software can be applied to a single point location or to a batch data file. Applying VDatum to an entire data set can be particularly useful when merging multiple data sources together, where they must first all be referenced to a common vertical datum. Emerging technologies, such as LIDAR and kinematic GPS data collection, can also benefit from VDatum in providing new approaches for efficiently processing shoreline and bathymetric data with accurate vertical referencing. Given the numerous applications that can benefit from having a vertical datum transformation tool, the NOAA goal is to develop a seamless nationwide VDatum utility that would facilitate more effective sharing of vertical data and also complement a vision of linking such data through national databases (Myers 2005). See also NRC 2004.

A VDatum model is generated using hydrodynamic modeling tools as shown in Figure C-18.

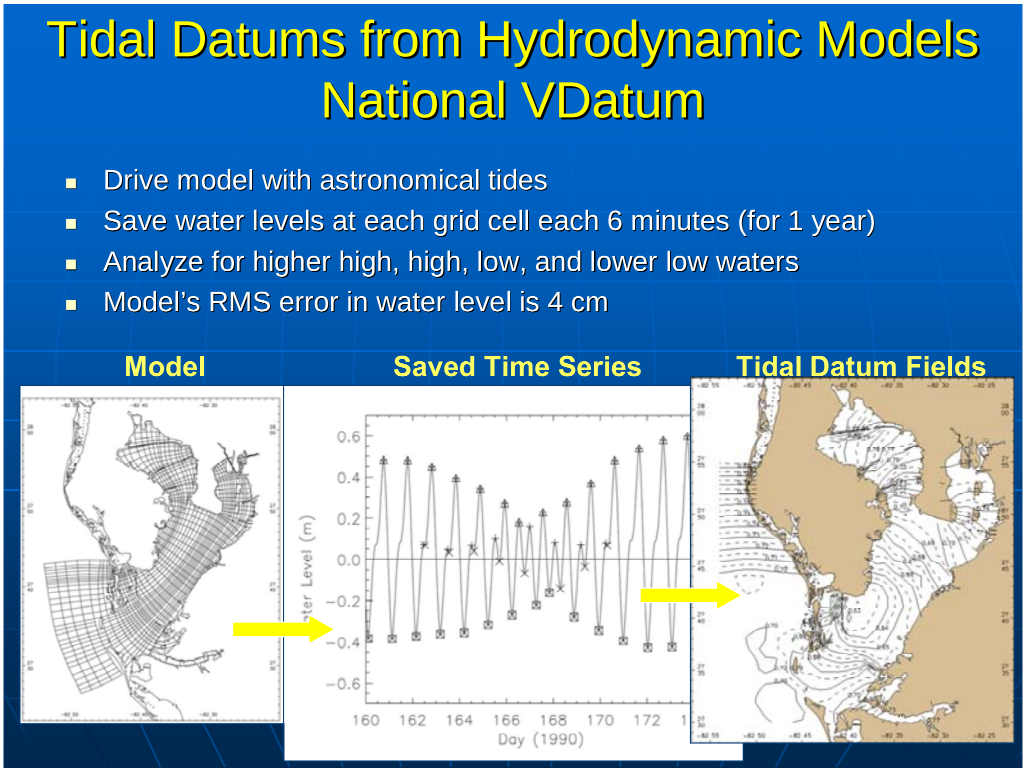


Figure C-18. NOAA National VDatum

The CEPD evaluation should check with NOAA to assess if VDatum coverage over a particular navigation project is adequate for direct generation of a MLLW tidal model of a navigation project passing through the NOAA model. This would entail evaluating the sensitivity, resolution, and density of the VDatum model.

C-18. NOAA Requirements for Short-Term Tide Gauges Needed to Update Tidal Models at a Navigation Project

When historical NOAA tide gauge sites are occupied, or additional gauging data is 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 NWLP database.

- Types of recording gauge. At a new site, any temporary gauge that can measure record water levels at 6-minute intervals is suitable. The gauge must be firmly tied in and referenced to the local tidal benchmarks at the site.

- Location of temporary gauge. To be specified by modeler or NOAA CO-OPS.

- 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 calibrating hydrodynamic models)

- Tidal Benchmarks. Five (5) benchmarks are required around the gauge site. Follow mark construction requirements in Appendix B. (No deep driven rods are required).

- Data format and submittal. Follow NOAA CO-OPS submittal requirements.

- Datum transfer computations. Follow NOAA CO-OPS standards—NOS 2003. NOAA CO-OPS will check datum transfer computations if they are performed in-house or by an A-E.

- 3rd Order leveling between tidal benchmarks. Follow standard procedures in EM 1110-1-1005 for both new and existing gauge sites.

- Primary tidal benchmark elevation. Tidal benchmarks at both new and existing sites will be referenced to and input to the NSRS (NAVD88) using CORS-Only/OPUS & OPUS DB input methods outlined in Appendix B—i.e., ±0.25 ft accuracy.

C-19. Connecting Tide Gauge Reference Benchmarks to the NSRS (NAVD88)

It is desirable, but not absolutely essential, for USACE navigation project dredging and surveying applications, to reference MLLW datums at tidal benchmarks to NAVD88. Since navigation projects are referenced exclusively to MLLW, geodetic datums do not enter into the datum reduction equation other than initially referencing RTK ellipsoidal measurements. However, these ellipsoidal measurements are always recalibrated to local MLLW; therefore the geodetic relationship need only be estimated.

In order to support NOAA's program to update tidal benchmarks to NAVD88 (and the NSRS) for National VDatum densification, NOAA tidal benchmarks will be positioned using the CORS-Only/OPUS ±0.25 ft (±8 cm) methods described in Appendix B. These elevation observations will be input into the NSRS using the OPUS DB procedures also referenced in Appendix B. This support effort would occur only at new tidal benchmarks in USACE projects being updated to the latest MLLW model, and only at tidal stations used to calibrate a tidal model of the project.

NSRS benchmark descriptions for these tidal marks will follow the same guidance in Appendix B for river gauges; namely, record elevation differences between gauge reference marks and nearby benchmarks in NSRS station descriptions and periodic recovery notes.

Recovery notes on CO-OPS tidal benchmarks not published in the NSRS (but published in the NWLN database without a PID link) will be transmitted directly to CO-OPS.

C-20. Interim Options Pending RTK Implementation and Tidal Modeling

Districts with projects not on a NOAA certified MLLW datum should endeavor to minimize navigation project elevation errors by considering some of the following steps pending updates:

- Use NOAA tide gauge benchmarks for reference or run levels or static GPS to transfer NOAA MLLW (epoch 1983-2001) elevations to a more suitable benchmark

- Evaluate existing tidal models for reasonability

- Attempt to minimize the extrapolated distance between the gauge/staff and the project site

- Perform linear interpolation between gauges if multiple gauges are available

- Develop an interpolation model (tidal zoning or TCARI) for project (range and time corrections)—contact NOAA VDatum Group or CO-OPS as these may already exist

- Reevaluate any estimated tidal datums in offshore entrance channels based on newer ocean models

- Develop a preliminary (estimated) tidal-geoid model for project—KTD file

- Implement use of RTK survey methods as soon as possible

In some areas (large open bays), RTK observations may be beyond the range of this measurement method. Alternative methods (e.g., VRS networks) are available to extend the range of RTK systems, as is being done by Philadelphia District in Delaware Bay.

C-21. Coastal Hurricane and Shore Protection Projects (HSPP)

Coastal hurricane protection and shore protection structures include levees, breakwaters, floodwalls, revetments, jetties, groins, and dikes. Beach restoration projects are also included in this category. Hard structures are usually designed and constructed relative to a local tidal datum, such as MSL, MLW, MLLW, or MHW. For example, the San Pedro breakwater shown in Figure C-19 has elevations relative to MLLW datum.

The CEPD assessment of these projects is intended to verify (1) that the design/constructed sea level reference datum is current (i.e., latest tidal epoch and model) and (2) that the local project control has been connected with the NSRS (NAVD88).

Many shore protection projects have been designed to sea level datums based on interpolated or extrapolated references from gauges. Depending on the type of gauge, tidal range, and the distance from the gauge, this interpolation or extrapolation may be valid, or sufficiently accurate—say within ±0.25 ft of the reference water level datum. Obviously, with sea level rise, the crest elevation of structures may be below that originally designed. However, the original design documents should be checked to verify that allowance for sea level rise was considered in the design elevation.

Connection to the NSRS need only be at the ±0.25 ft accuracy level, as was the case with inland flood control projects. This connection is simply to provide other using agencies with an elevation on a federally recognized reference system—NAVD88.

Evaluated shore protection projects that are not on updated tidal and/or NSRS datums will require additional effort. In general, the updated sea level datum can be estimated (interpolated) given sufficient NOAA or Corps gauges exist in the region. The NSRS connection will normally be performed following the same accuracy standards and field survey specifications used for flood control structures in Appendix B—e.g., ±0.25 ft accuracy CORS-Only/OPUS and OPUS DB methods. At least one primary benchmark on each project shall have both a water level reference elevation and a NAVD88 elevation.

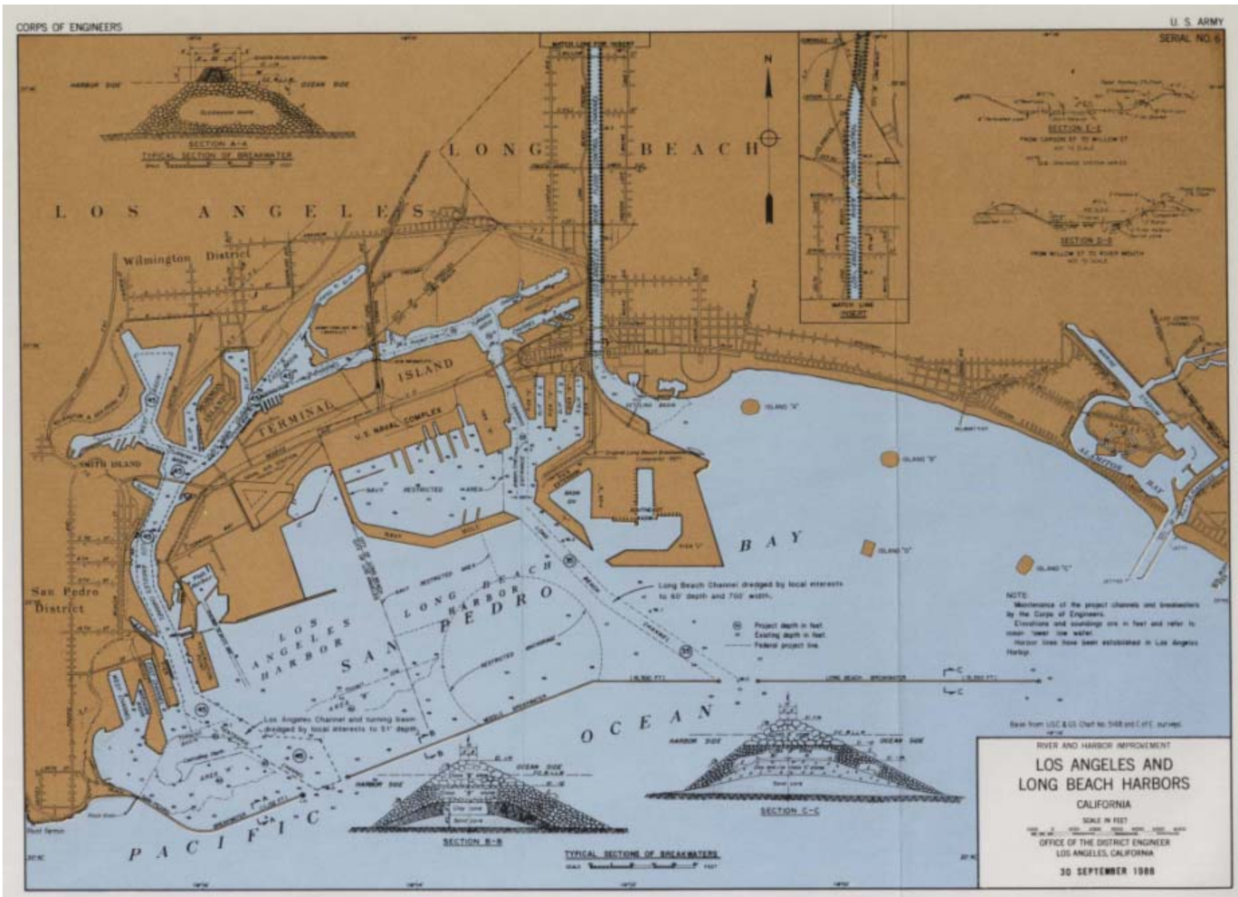


Figure C-19. Shore protection breakwaters—Los Angeles & Long Beach Harbors

C-22. Beach Renourishment/Restoration Projects

Beach restoration projects are usually designed relative to either tidal or geodetic datums, depending on local preferences. More often than not, this relationship between geodetic and tidal datums is not firmly established. As with the shore protection projects above, the reference benchmarks should be related to the latest tidal datum and have a firm reference to the NSRS (NAVD88).

The reference tidal datum may have been estimated from nearby gauges. In Figure C-20 below, gauges may or may not have been used to determine the reference datum at each of the projects on Staten Island. Interpolations between more distant gauges may have been used. Such an interpolated "model" is normally of sufficient accuracy—and normally would not exceed ±0.25 ft. The NAVD88 elevation on the primary benchmark at each project can be determined by CORS-Only/OPUS observations. As in flood control projects (Appendix B) this NAVD88 elevation would not supersede local project control relative elevation differences. However, the other marks may be adjusted to NAVD88 using the most recent leveling or RTK observations made between the marks.

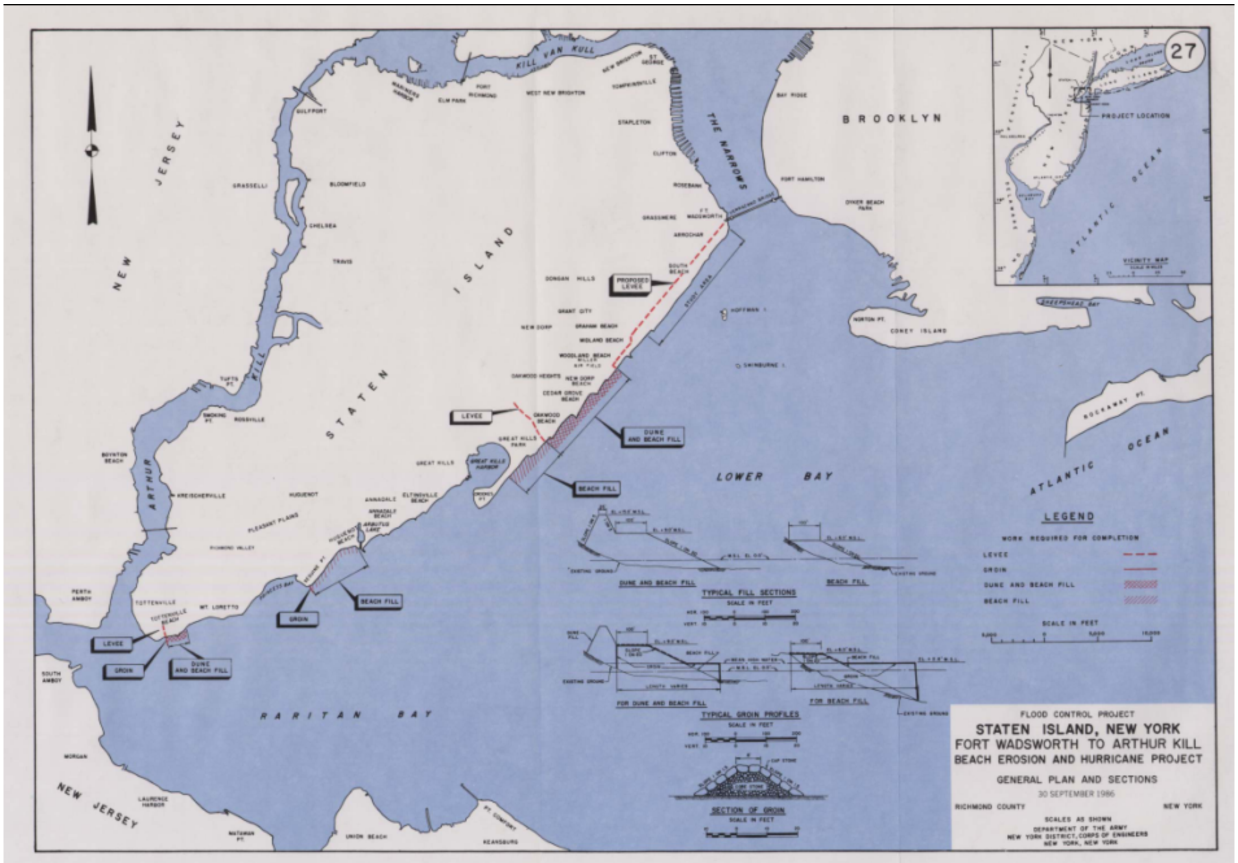


Figure C-20. Beach Erosion & Hurricane Protection Projects—Staten Island, NY

Beach renourishment/restoration projects are typically constructed relative to pre-set range monuments. On many projects, these fixed reference monuments are based on “NGVD,” NGVD29,” “MSL,” or perhaps “NAVD88.” In Figure C-21 below, taken from construction plans, the “NGVD” elevation of the range monument “PROFILE R-74.743” was likely determined in 1974 when the range monument was set. The original or current relationship with the NSRS is probably unknown. Its “NGVD” relationship to MLW (-1.0 ft) or MHW (+1.1 ft) is likely based on the relationship at the nearest NOAA tide gauge, which may be some 10 to 30 miles distant. The tidal epoch must be also indicated—in the above project, a quarter-foot tidal epoch difference may be indicated given the NGVD-MLW references. In this case, the entire beach project would be constructed 0.25 ft below the intended (design) elevation.

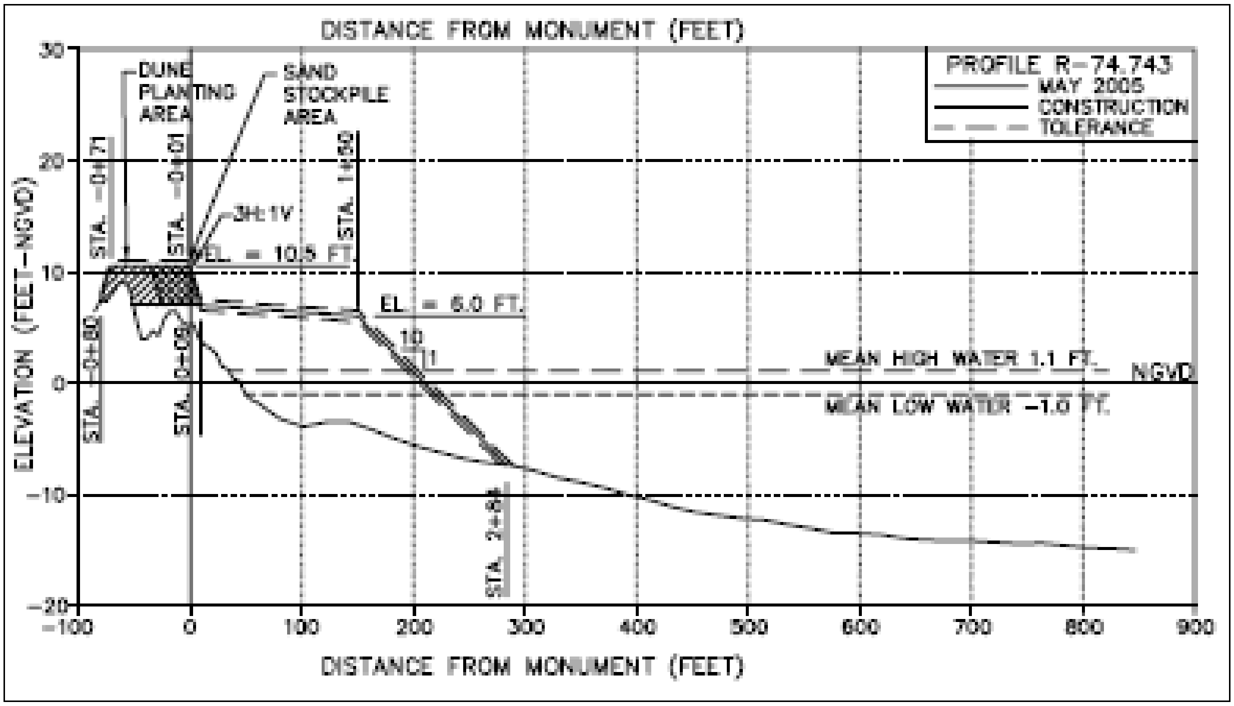


Figure C-21. Beach Renourishment Project—Typical Section

Evaluated beach erosion and hurricane protection projects that are not on updated tidal and/or NSRS datums may require additional effort. In general, the updated sea level datum can be estimated (interpolated) given sufficient NOAA or Corps gauges exist in the region (assuming no gauge data exists for the actual project location. An interpolated tidal range between two NOAA gauges would be reasonable if the tidal ranges at each gauge do not vary significantly—say < 0.3 ft. Once NOAA completes VDatum coverage for the entire US coastal areas, then a more refined (modeled) datum can be updated.

The NSRS connection will normally be performed following the same accuracy standards and field survey specifications used for flood control structures in Appendix B—e.g., ±0.25 ft accuracy CORS-Only/OPUS and OPUS DB methods. Only one primary benchmark on a beach renourishment project need be connected with the NSRS, assuming the relative elevations of other local project control benchmarks are firmly related to the primary mark.

Offshore borrow area elevations (or depths) may also be defined relative to different datums—MLLW, MSL, NGVD29, or NAVD88. Even beach profiles can have different datums and reference points on the same line—the shoreward section may be relative to a fixed range monument and the offshore portion may be relative to a sea level reference at a distant gauge. CEPD efforts must ensure that all measurements in a project stem from a common reference system and framework—i.e., benchmarks on the NSRS with consistent geodetic and sea level relationships.

C-23. Navigation Projects on the Great Lakes and Connecting Waterways

Navigation and shore protection projects on the Great Lakes and connecting waterways are normally referenced to the latest International Great Lakes Datum (IGLD). IGLD is specified by a year of the adjustment (IGLD 1955 superceded by IGLD 1985) Each lake has its own separate reference to IGLD 1985 defined by a NOAA nautical chart reference datum called Low Water Datum (LWD) as follows:

Heights of Low Water Datum (LWD) relative to IGLD 1985

Waterway	Feet	Meters
Lake Ontario	243.3	74.2
Lake Erie	569.2	173.5
Lake St. Clair	572.3	174.4
Lake Huron	577.5	176.0
Lake Michigan	577.5	176.0
Lake Superior	601.1	183.2

The datum reference in the connecting channels slopes between the fixed datums at each lake. The following Figure C-22 notes the reference elevations are based on the IGLD 1955, which has been superseded. References to current and superseded datums need to be assessed during the CEPD process.

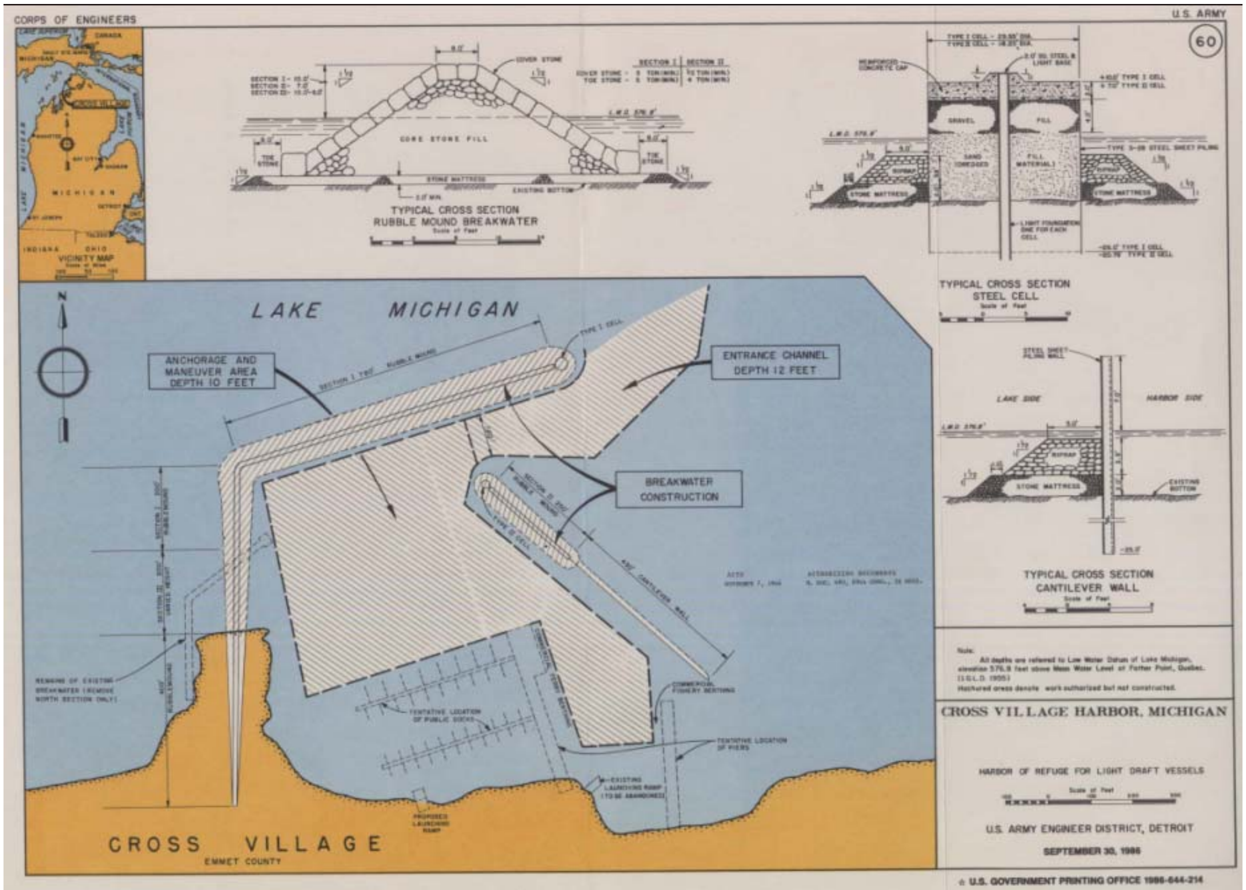


Figure C-22. Great Lakes IGLD55 reference

Primary project control benchmark connections to the NSRS would follow similar guidance outlined for flood control projects in Appendix B. In Figure C-23, elevations up the Fox River are referenced to a reference elevation at Green Bay, WI, which in turn is based on IGLD55. Low water pool elevations between the locks are not indicated on this drawing; however, they may be shown in the detailed design or as-built documents. Periodic connections to the NSRS at primary control benchmarks along this project would be beneficial. This reference would only need to be made to the ±0.25 ft accuracy level using CORS-Only/OPUS and OPUS DB methods.

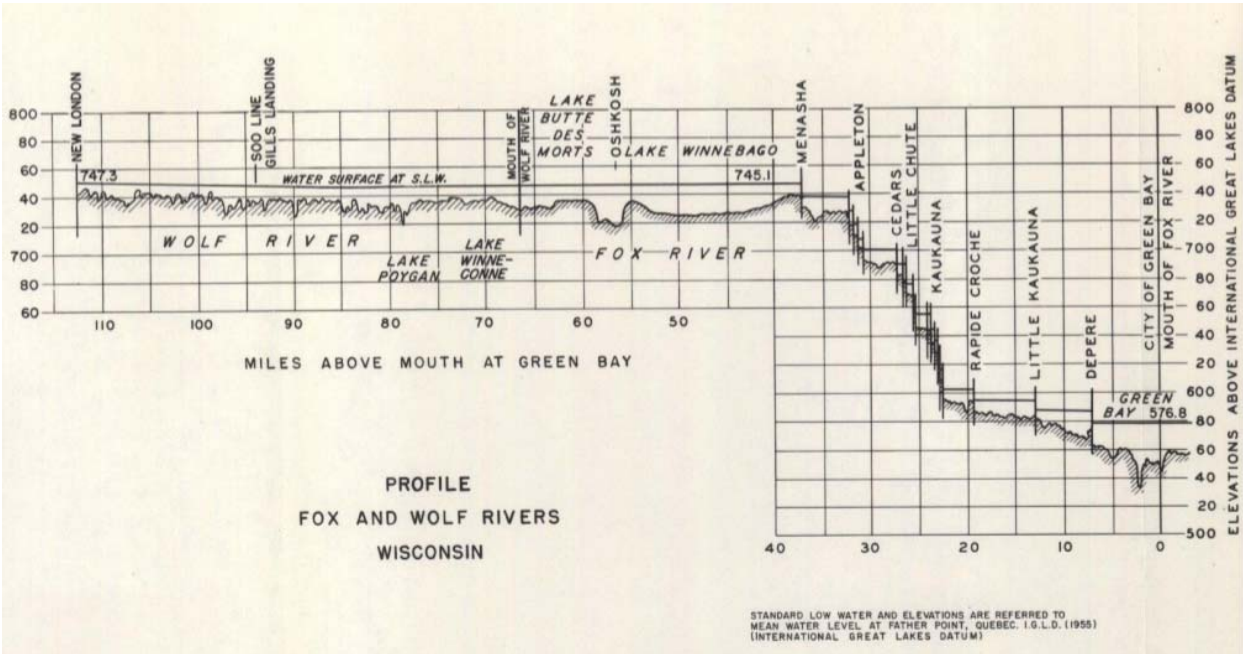


Figure C-23. IGLD55 reference on Fox River, WI

Note also that IGLD85 elevations are referenced to dynamic heights which differ from NAVD88 Helmert orthometric heights, as summarized below.

- NGVD29 -- "Normal" Orthometric Heights
- NAVD88 -- Helmert Orthometric Height
- IGLD85 -- Dynamic Height

Dynamic Heights are not equal to Orthometric Heights. Orthometric heights are distances from a reference surface normal to equipotential surfaces; however, they do not represent an equipotential surface. Dynamic heights define geopotential surfaces and represent distances based on hydraulic head differences (ie, work); thus, they may have significant application in Corps projects where head differences are critical—not only in the Great lakes but also on rivers or canal systems. The dynamic height of a benchmark is the height at a reference latitude of the geopotential surface through the benchmark. This value is of interest because two stations with different orthometric heights may have similar geopotential, due to undulations of the geopotential reference surface (geoid). The source of a dynamic height is always computed. The reference latitude for the US is North 45 degrees. The dynamic height is computed from a geopotential height. The geopotential height (a.k.a. geopotential number) is determined by:

$$\text{Geopotential Height } C = \text{Orthometric Height} \cdot (\text{Gravity} + (4.24E^{-5} \cdot \text{Orthometric Height}))$$

A dynamic height is then obtained by dividing the adjusted NAVD88 geopotential height (C) of a benchmark by the normal gravity value (G) computed on the GRS 80 ellipsoid at 45 degrees latitude (G = 980.6199 gal).

$$\text{Dynamic Height} = C/G = \text{Geopotential Height}_{\text{NAVD88}} / \text{Normal Gravity}_{\text{GRS80 } 45^{\circ}}$$

Measured elevation differences between benchmarks do not yield either orthometric height differences or dynamic height differences. Spirit level differences in elevation must be corrected (Orthometric Correction or Dynamic Correction) to obtain an orthometric heights or dynamic heights. See Meyer 2006 (Part III) and IJC 1995 for additional details on the differences between orthometric and dynamic datums.

Due to inaccuracies in NAVD88 leveling adjustments, a "hydraulic corrector" must be applied at subordinate points on the Great Lakes in order to obtain a reference engineering, construction or navigation datum. These hydraulic correctors are published by the IJC Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. An example of this correction is shown below:

Lakeport MI BM Burtch dynamic elev	178.796 m
LWD ref datum (Harbor Beach)	176.000
LWD water surface (Har Bch) below BM	2.796
Hydraulic Corrector	- (+ 0.202)
Local LWD reference water surface below BM Burtch (IGLD85)	2.594 m

- A staff gage would be set with "zero" set 2.594 m below BM Burtch
- This represents the construction reference datum for this project area
- Hydraulic corrector not available at all projects … must interpolate
- No hydraulic corrector is applied in connecting channels
- Accurate vertical datums are critical to channel condition reports used by commercial shippers loading iron ore 4 to 6 inches above rock-cut channels

C-24. Prioritizing Evaluation of Deep- and Shallow-Draft Navigation Projects

With over 900 navigation projects—approximately 299 deep draft and 627 shallow draft—the CEPD level of effort will have to be prioritized. The first step would be to separate out deep draft projects (>15 ft) from the lower priority shallow draft projects. The deep draft projects should be evaluated first, and in a prioritized order considering tonnage, bottom type, maintenance dredging frequency, average cost per CY, disposal costs, etc. These same criteria might be used in scheduling any corrective update actions needed

Many shallow draft projects will not economically warrant extensive CEPD evaluation or subsequent updating actions. This would be the case in projects with minimal maintenance that are primarily small recreational or fishing projects with little traffic—typically those projects in the 4 to 8 ft depth range. Some of these projects may be on an "assumed" tidal datum, or are referenced to a local benchmark on NGVD29 whose elevation is of uncertain origin and is not published in the NSRS database.

It is difficult to estimate the level of effort that should be expended in updating reference datums on these low-maintenance shallow draft projects. The main factor in prioritizing these projects would be long-term construction and maintenance costs on a project. Other factors like traffic and types of vessels might be used. Thus, a 4-ft draft project used primarily for shallow-draft recreation (e.g., Jet skies, canoes) will be at the bottom of the priority list, and only a cursory evaluation and update would be warranted.

Shallow draft project tidal ranges may also be estimated using either local gauge data or interpolated between nearby gauges. At minimum, the project reference should be updated to the latest NOAA tidal epoch even if the tidal range is estimated based on adjacent gauges. If the project has no gauge history, it is problematic whether an older "reference" benchmark on NGVD29 is a reliable datum reference. Likewise, a CORPSCON/VERTCON datum conversion to NAVD88 may also not be reliable if the two datums are not sufficiently modeled in this area. Connecting this benchmark with NAVD88 at another gauge site would be recommended. However, for many low priority shallow draft projects, there would be no urgency in performing this geodetic connection—it could be scheduled the next time a routine Project Condition Survey is performed.

In time, NOAA VDatum hydrodynamic coastal models may provide updated tidal and geodetic models for these isolated projects. Thus, deferring corrective actions (i.e., field surveys) on many low priority projects may be the recommended course of action. Deferring field surveys does not imply that the tidal epoch and model is not evaluated and updated.

C-25. CEPD Assessment of Navigation Project Models

Each navigation project being evaluated under the CEPD should be reviewed in the order below.

- Prioritize deep- and shallow-draft projects

- Obtain project documents from various District technical elements—control data, original design memorandums, recent maintenance plans & specs, current tidal datum and models, etc.

- Obtain VDatum coverage, gauge, and tidal benchmark records from NOAA CO-OPS.

- Estimate requirements. Project is on correct water level and geodetic datums, or will updated tidal modeling and field survey work be required.

- Recommended corrective action if additional work is required.

- Budget estimate. Prepare program budget time and cost estimate to update or correct project datum.

- Project Report. Draft project report and web-based report for each project, to include estimated program year and cost—see Appendix D.

- Implementation. Perform recommended corrective actions in programmed out year.

For deficient projects requiring additional gauging and/or hydrodynamic tidal modeling, the actual implementation action may require an assessment of the items in the following checklist. Not all of these steps will be applicable to every project.

Pre-Assessment Phase

- Obtain project limits
- USACE project requirements
  - Maintenance dredging frequency
  - Costs
  - Survey methods (RTK or direct gauge)
- Obtain next USACE maintenance dredging schedule
- Review original design memorandums and congressional authorizations
- NSRS Information
  - Distance from CORS stations
  - Geoid model accuracy
  - NSRS benchmark locations
- Tidal Information from CO-OPS
  - NWLON station locations
  - PORTS locations
  - Historical tide stations
  - NAVD88 connections at tidal benchmarks
  - GPS connections to tidal benchmarks
  - Local sea level trends
  - Cotidal charts
  - Tidal Zoning charts
  - VDatum availability—existing or planned
- Availability of existing models (in-house, A-E, ERDC, NOAA)

Assessment Phase

- Tides
  - Knowledge of tidal characteristics
  - Gaps in NWLON coverage
  - Gaps in published tidal datums
  - Gaps in stations with harmonic constants
  - Gaps in geodetic datum and GPS connections
- Geodesy
  - Gaps in NSRS coverage
  - CORS coverage (within 200 miles)
  - Lack of GPS surveys
  - Geoid accuracy assessment
- VDatum Assessment
  - Need to enhance existing VDatum, if one exists
  - Assess need for VDatum approach vice:
    - Project size & spatial changes in tidal characteristics
    - Changes in relationships of LMSL vs. geodetic datum

Operations Requirements Planning Phase

- Determine requirements for additional tidal datums and harmonic constants
- Determine requirements for new geodetic datum/GPS connections to tide stations
- Determine requirements for new CORS at a tide station
- Determine requirements for enhanced NSRS benchmarks

- Determine VDatum requirements
- Determine requirements for operation of tide stations during dredging and hydrographic survey operations
- Determine need for discrete tidal zoning, TCARI, VDatum, or use of RTK with VDatum for dredge or survey vessel elevation control.

C-26. Example of a CEPD Budget Estimate for Updating a Navigation Project

The following example is representative of a "worst case" project condition used to exemplify the various cost items that might be needed in updating the datum at a project. This hypothetical case assumes that a deep-draft project is on an uncertain pre 1960-1978 tidal epoch, that there has never been a NOAA tidal gauge or Corps gauge at the project, and there is no published NSRS vertical control around the project. The project has been maintained relative to a Corps benchmark of uncertain datum—both geodetic and tidal. A large tidal range variation is known to exist between the entrance and inland port facility—thus, a hydrodynamic model will be required. (Note that these "worst case" conditions will rarely occur on USACE deep draft projects. Most projects will have historical gauge data, NSRS vertical control, and/or an adequate density of tidal model data such that hydrodynamic modeling is not required)

To prepare a CEPD budget estimate for developing a MLLW reference datum at this navigation project, the following actions need to be considered.

- Set temporary gage for 30 days following NOAA CO-OPS requirements
- Set 5 tidal benchmarks at temporary gage site
- Connect one primary tidal benchmark to the NSRS (via CORS-Only/OPUS)
- Input NSRS connection and tidal benchmark descriptions to NSRS (OPUS DB)
- Run levels between tidal benchmarks and temporary gage (furnish direct to CO-OPS)
- Compute tidal datum transfer from NWLON gauge to temporary gauge (CO-OPS action)
- Develop and calibrate hydrodynamic tidal for project (In-house, CO-OPS, A-E)
- Develop tidal-geoid model for project
- Update project files

A cost estimate will follow the same format and simulated rates as the estimate in Appendix B.

Contract Administration

USACE hired-labor, technical S&A, coordination with NOAA, A-E, in-house (Project Manager)	30 MD @ $800/MD	$24000
USACE hired-labor, technical (H&H, Engineering, etc)	30 MD @ $800/MD	$24000
USACE hired-labor, CT admin charges		$7500
USACE hired labor & travel (site recon) (Proj Mgr)	5 MD @ $800/MD	$4000
	Travel	$1000
	TOTAL	$60500

A-E Contract Line Items

Set Temporary Tide Gauge

Mob/demob to project site [CD]	2 CD @ $2500	$5000
Construct/install temporary gauge	1 CD @ $2500	$2500
Gauge rental	30 d @ $100/d	$3000
Set/level/describe 5 tidal benchmarks	1 CD @ $2500	$2500
Record, process, transmit data to NOAA	5 MD @ $800	$4000
A-E Project Manager S&I	5 MD @ $1500	$7500
	TOTAL	$24500

Connect Primary Tidal Benchmark to NSRS/NAVD88

Recon for existing NSRS or USACE control	1 CD @ $2500	$2500
GPS, static baseline observations CORS	1 CD @ $2500	$2500
Process data (OPUS), transmit to NGS/CO-OPS	2 MD @ $800	$1600
	TOTAL	$6600

Data Processing and Reporting

NOAA CO-OPS: Process 30 day datum transfer, update database $5000 est

Develop/run hydrodynamic tidal model (In-House, A-E, NOAA, ERDC/CHL)
- Obtain topographic data for model
- Obtain/generate bathymetric data for model
- Obtain 30 d tidal data results from NOAA
- Run, calibrate & analyze model—develop tidal model
- Develop MLLW-geoid file for project

Total modeling costs: $10000 to $50000 est

USACE or A-E hired-labor to update documents & files 5 MD @ $800 $4000

TOTAL $19000 to $59000

Summary

Contract Administration	$60500
A-E Contract Line Items	$24500
	$ 6600

Data Processing and Reporting	$19000 to $59000
Subtotal	$110600 to 150600
Contingencies @ 10%	$ 11060 to $15060
TOTAL BUDGET ESTIMATE	**$121000 to $165000**

Obviously the largest (and most uncertain) line item is the tidal modeling. This cost will largely depend on the ready availability of topo/bathy models. If these models have to be created, the cost will significantly increase. The agency performing the model will also impact the cost. The high $50K estimate may represent only 40 hours labor.

If an additional temporary gage is needed to better calibrate the tidal model, then the $30K field cost would roughly double.

In developing a program estimate, the Project Manager should closely coordinate the project requirements with H&H to insure that reasonable budget estimates are obtained—especially if any hydrodynamic modeling is required.

Using this same project with a more "typical" Corps scenario will yield a significantly reduced budget estimate. A more typical Corps deep-draft project condition being evaluated might include the following findings.

- Two or more historical NOAA gauges exist within the project, and these gauges have been updated to the latest epoch; thus, the tidal datum can be adequately modeled by linear interpolation.
- One of the NOAA gauge tidal benchmarks is published on the NSRS and includes an adjusted NAVD88 elevation.
- The Corps reference benchmark being used on the project is on NGVD29. However the benchmark is only a mile from the NOAA tidal benchmark on NSRS.
- The existing MLLW datum model for the project is of unknown origin or accuracy.

Basically, the CEPD assessment requirements for the project are straightforward.

- Utilize NOAA NSRS tidal benchmarks for future vertical reference—including RTK base.
- If needed, run levels from the NOAA NSRS benchmark to the Corps benchmark. Add Corps benchmark to NSRS.
- Model the project MLLW datum using existing NOAA gauge data.
- Develop/publish a tidal-geoid model for the project.

A cost estimate will follow the same format and simulated rates as the above estimate.

Contract Administration

USACE hired-labor, technical S&A, coordination with NOAA, A-E, in-house (Project Manager)	3 MD @ $800/MD	$2400
USACE hired-labor, technical (H&H, Engineering, etc)	3 MD @ $800/MD	$2400
USACE hired-labor, CT admin charges		$7500
USACE hired labor & travel (site recon) (Proj Mgr)	1 MD @ $800/MD	$ 800
	Travel	$ 500
	TOTAL	$13600

A-E Contract Line Items

Run levels from NSRS benchmark to USACE benchmark (RTK base)

Mob/demob to project site [CD]	2 CD @ $2500	$5000
Set/level/describe 5 tidal benchmarks	1 CD @ $2500	$2500
Process, Blue Book, transmit data to NOAA	3 MD @ $800	$2400
A-E Project Manager S&I	1 MD @ $1500	$1500
	TOTAL	$11400

Data Processing and Reporting

Develop new interpolated tidal model (In-House H&H or A-E)	1 MD @ $800	$ 800
Develop MLLW-geoid file for project	1 MD @ $800	$ 800
USACE or A-E hired-labor to update documents & files	1 MD @ $800	$ 800
	TOTAL	$2400

Summary

Contract Administration	$13600

A-E Contract Line Items	$11400
Data Processing and Reporting	$ 2400
Subtotal	$27400
Contingencies @ 15%	$ 4110
TOTAL BUDGET ESTIMATE	**$31500**

A major line item in the above estimate is the $11.4K to run a one-mile level line and input this data into the NSRS. If the NOAA tidal benchmark can be used as a RTK base station, then this line item could be eliminated, along with the associated A-E contract administration costs ($7.5K). This would reduce the budget estimate to the $10K level. Alternatively, this level line could be included in the next Project Condition Survey scope.

C-27. Estimating Cost Avoidance for Navigation Projects on Superseded Tidal Epochs

Navigation projects that have not been updated to the latest tidal epoch will have, for much of CONUS, deepened grades due to sea level rise. Correcting these projects to the current NOAA tidal epoch will reduce the amount of maintenance dredging on the next cycle—varying from 0.1 ft to more than 0.5 ft depending on the magnitude of sea level rise. This will be offset somewhat for projects never updated from MLW to MLLW datum. It is also possible that more refined CEPD tidal modeling of the MLLW reference will modify the project grade. In effect, this CEPD updating process may result in reduced dredging on some projects; thus, a cost savings (or avoidance) from this CEPD effort. These cost avoidances (positive or negative) should be estimated for navigation projects and included as a line item in the project reports—Appendix D. If the project is already on the latest tidal epoch and MLLW datum model, then no benefits would be reported.

Only a rough estimate of should be developed during the CEPD assessment. To simplify the estimate, assume the entire project area is maintained rather than the actual maintained shoaling areas; thus, there is no need to pull out contract drawings to assess the percentage of the project area routinely maintained. Obviously, the estimate is inflated if only small portion of project is maintained, or significant portions are naturally below grade. This can be offset by assuming a low unit price (cost/CY). However, if entire project were ever deepened, then a higher percentage of the project grade would be excavated. Note that this computation represents a one-time cost avoidance—once the project is adjusted to the correct epoch and MLLW datum model, no savings would result after the first maintenance dredging cycle. Reduced dredging will result each time epochs are updated by NOAA, assuming continuing sea level rise.

The cost avoidance can be simply estimated given a channel length, width, epoch change, and cost/CY:

Estimated volume = length (ft) x width (ft) x Δ_{epoch} (ft) ÷ 27 cy/ft3

Estimated cost reduction = Estimated volume x $/CY

As an example, we will use Mullet Key Cut in Jacksonville District's Tampa Bay, FL Project:

Dimensions: 22,000 ft long x 600 ft wide channel
Currently on 1960-1978 epoch ... $\Delta_{epoch} = 0.2$ ft
Assumed unit price of maintenance dredging: 10 $/CY

$$\text{Volume} = 22{,}000 \cdot 600 \cdot 0.2 \div 27 \text{ CY / ft}^3 \approx 100{,}000 \text{ CY}$$

Estimated Cost Reduction @ 10 $/CY ≈ $1 M

(Projected over the entire 60-mile project, this small 0.2 ft adjustment would equate to approximately $10M to $20M in reduced excavation cost if the project were ever deepened from 43/45 ft to 50 ft and the entire project area required deepening.)

C-28. Application of GPS in Measuring Surface Elevations on Navigation Projects

Once a definitive tidal model of a project's tidal MLLW datum, epoch, and local range variations has been established, and RTK elevation measurement is implemented to eliminate the tidal phase errors, then local ellipsoidal and geoidal variations in the RTK elevation measurement process need to be accounted for. These variations (or undulations) are shown in the following figures.

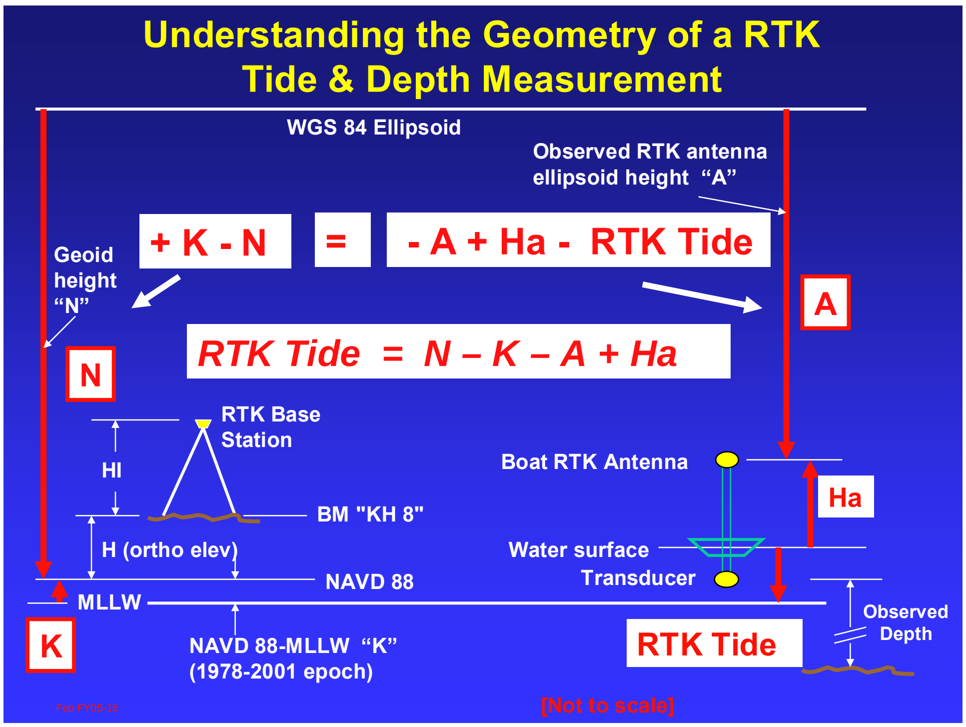


Figure C-24. RTK Tide Measurement--Basics

Figure C-24 describes the basic geometry of a RTK tide elevation measurement. The elevation of the water surface is measured using GPS measurements relative to the ellipsoid, which ranges some 50 to 100 feet above MLLW in CONUS.

The above figure "assumes" the MLLW datum elevation ("K") is constant over the region. It also "assumes" the height to the ellipsoid (geoid height "N") is constant. This is rarely the case in practice, as shown in Figure C-25 below.

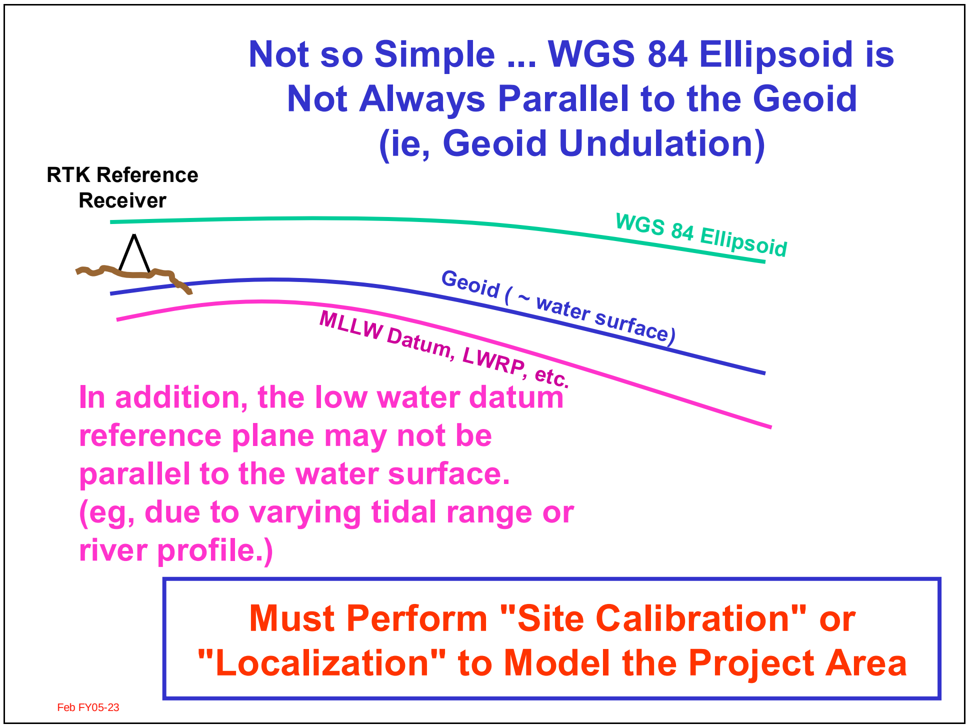


Figure C-25. Ellipsoid and MLLW datum undulations

As shown Figure C-26, a model of both the MLLW datum and ellipsoid/geoid is needed to effectively use RTK elevation measurement methods. Once developed, this model provides an absolute, defined correction surface for all users (dredging, surveying, etc.—a "KTD" file) in a navigation project, and eliminates the need for the inaccurate extrapolation of tidal gauge observations to remote project sites. Tidal phase errors and MLLW datum variations are effectively eliminated as long as the modeled MLLW-geoid variations are applied by all users—i.e., all use the same "site-calibration" "site localization" model. (MLLW datum variations are minimized by the tidal hydrodynamic model and are thus eliminated by rigidly fixing/calibrating the model to the tidal gauges). The only observational error is that of the RTK calibration process itself since the MLLW-geoid model used in the RTK elevation solution is assumed to be absolute.

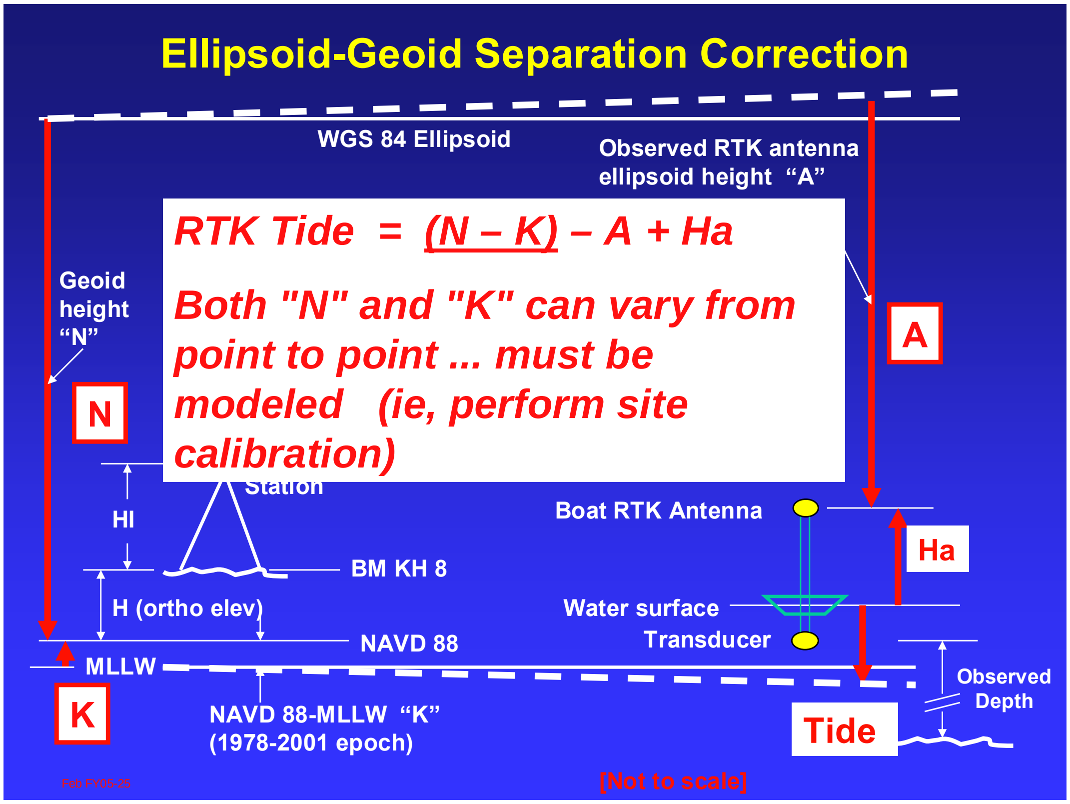


Figure C-26. Ellipsoid-Geoid-MLLW corrections

The tidal or combined tidal-geoid model ("KTD" file) is typically rectilinear rather than linear along a channel. A post spacing of every 100 or 500 ft is recommended. The resolution should be to the nearest 0.01 ft. An example of such a model is shown in Figure C-27 below.

RTK elevation observations cannot be relied on without performing periodic checks at the reference/base station (and hopefully at other points if available). As shown in Figure C-28, a tide staff is set near the RTK base station and RTK-derived tidal measurements are verified (and calibrated) against the gauge/staff reading.

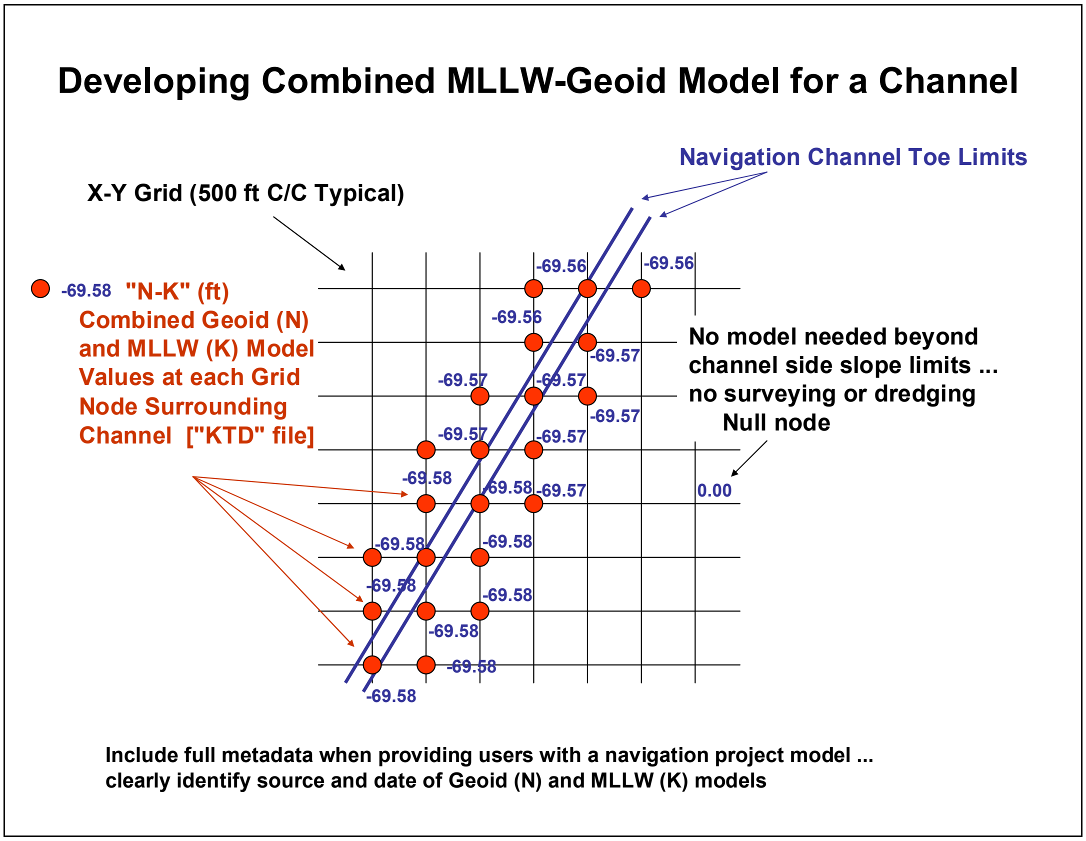


Figure C-27. MLLW-Geoid Model for RTK corrections

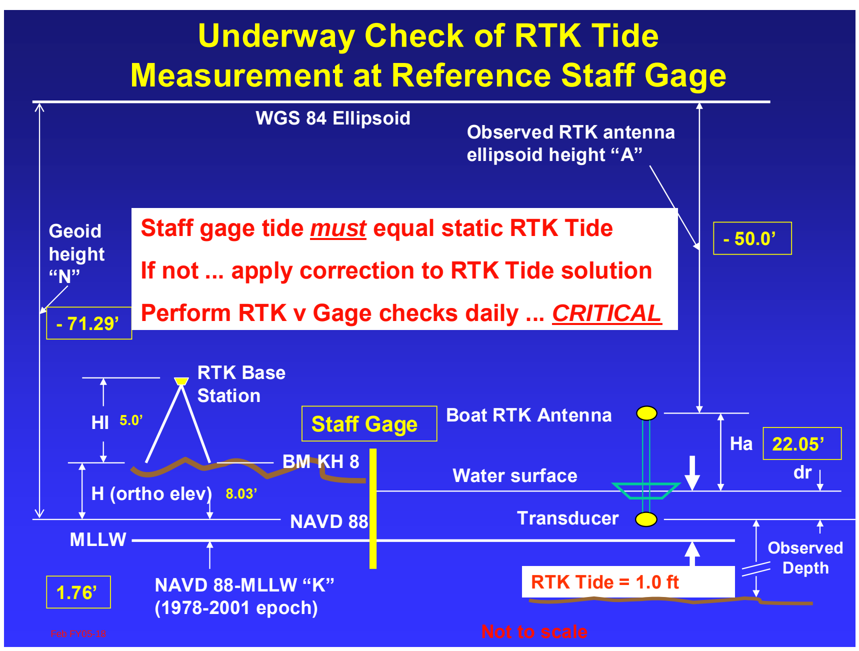


Figure C-28. RTK Quality Control (calibration) checks

APPENDIX D
Documentation and Reporting for Comprehensive Evaluation of Project Datums

D-1. Purpose

This Appendix provides guidance on documenting and reporting project-by-project evaluations of vertical datums used for flood protection, shore protection, hurricane protection, and navigation. It summarizes the basic steps taken to perform a project evaluation and what items to record in each project report. These reports will be retained by each District for their records and for implementation of corrective actions. The reports will be submitted to a database via a web-based reporting tool. The web-based reporting tool will generate a summary report to be signed and submitted to the Chief of Engineering and Construction by each District Command. Instructions for using the web-based reporting tool for upward reporting of District compliance are contained in this Appendix.

D-2. Applicability

This guidance applies to all federally authorized and constructed flood control, hurricane protection, shore protection, and navigation projects assessed under the CEPD project.

D-3. Scope

The guidance in this section provides minimum guidelines for recording the findings of project evaluations and upward reporting. Project evaluations are to be utilized for reporting project compliance, guiding corrective action, and for periodic project reassessments. Initial corrective action includes transitioning non-compliant projects to the correct datum(s) which may involve programming funds and executing the acquisition of geodetic or tidal surveys. Non-compliant projects transitioned to proper datums need to be reviewed and evaluated for operational deficiencies in design or construction uncovered during the execution of the CEPD.

D-4. District Evaluation Team

District Datum Coordinators have been appointed by their Districts as lead vertical datum coordinators with the responsibility to oversee the review of each project and approve/certify the evaluation report. District Datum Coordinators are encouraged to establish a team of knowledgeable individuals familiar with District projects to accomplish the mandated Comprehensive Evaluation of Project Datums. The District Datum Coordinator may want to consider an H&H engineer familiar with river and overland hydraulic modeling, a coastal engineer and/or surveyor familiar with tidal datums, and a project manager familiar with O&M, ICW, CEFMS, P2, and programming funds for future work. The size of the team will vary by District depending on the number and variety of projects to be reviewed and the amount of funding made available for the evaluations.

D-5. Funding Project Evaluation

Districts are instructed to fund the CEPD of flood control and hurricane protection projects operated and maintained by non-federal sponsors within the Inspection of Completed Works (ICW) account. The review of Corps-maintained projects, including navigation projects, is to be funded from existing O&M accounts associated with those projects. Depending on the phase of the project and activities currently underway during the evaluation period, other project funds (Construction General, General Investigations, etc.) may be applicable but need to be coordinated through Project Management. It is not the responsibility of the District Datum Coordinator to secure funding for project reviews or implementation of corrective actions. The executive office will be making periodic status reports to the Chief of Engineering and Construction and has the responsibility to fund these efforts.

The District Datum Coordinator is responsible to provide Project Management with timely evaluation reports including budget cost estimates such that funds can be programmed for corrective action. The District Datum Coordinator needs to work closely with Project Management to develop realistic implementation schedules and facilitate any additional PDT project reviews for possible new design/construction.

D-6. Example District Implementation Plan

Some District leaders may look to the District Datum Coordinator to provide an implementation plan as well as periodic status updates. The following example draft may provide assistance with communicating the CEPD effort to appropriate District elements.

CEPD Implementation Plan **DRAFT** **Jacksonville District**

1. BACKGROUND

This document addresses lessons learned from findings of the Interagency Performance Evaluation Task Force (IPET) on Hurricane Katrina (see IPET Volume II: Geodetic Vertical and Water Level Datums). Findings of errors of one to three feet in some of the elevations used in design, construction, maintenance, and evaluation of hurricane and flood control structures in New Orleans highlighted the need to ensure that flood control and navigation projects are referenced to the proper vertical datums to correctly compensate for subsidence/sea level rise. Furthermore USACE needs to be referenced to the same nationwide reference systems used by other Federal and local agencies responsible for flood forecasting, hurricane surge and inundation modeling, navigation, flood insurance rate maps, hurricane evacuation route planning, coastal boundary delineation, bathymetric mapping, and topographic mapping.

On 4 December 2006, Lieutenant General Strock issued a directive with interim guidance for Districts to perform a Comprehensive Evaluation of Project Datums (CEPD). This implementation plan is consistent with the permanent guidance being developed under direction of USACE-HQ.

2. AUTHORITY

A. Section 224 of WRDA 1992 (33 U.S.C. 562).

B. Interim Guidance For A Preliminary Evaluation Of Vertical Datums On Flood Control, Shore Protection, Hurricane Protection, And Navigation Projects, 31 October 2006

C. MSC Memorandum, Subject: Implementation of Findings from Interagency Performance Evaluation Task Force for Evaluating Vertical Datums and Subsidence/Sea Level Rise Impacts on Flood Control, Shore Protection, Hurricane Protection, and Navigation Projects, 4 December 2006.

D. Clinger-Cohen Act of 1996 as amended.

E. Florida Statutes, Chapter 62B-33 Division of Beaches and Shores – Rules for Coastal Construction and Excavation - Subsection 62B-33.0081 Survey Requirements - All vertical datum specified on the survey and referenced to the NAVD of 1988 in feet.

F. Engineering Regulation (ER) 1110-1-8156

G. Engineering Manual (EM) 1110-1-2909

H. CECW-CE Memorandum for Major Subordinate Commanders, 2 July 2004, Subject: Watershed Management and the Implementation of Enterprise Geographic Information Systems (eGIS) in the USACE 2012 Environment.

I. CECW-CE Comprehensive Evaluation of Project Datums, DRAFT 05 February 2007. Guidance for a Comprehensive Evaluation of Vertical Datums on Flood Control, Shore Protection, Hurricane Protection, and Navigation Projects.

3. RECOMMENDATIONS

A. Follow the lead of the Hurricane Katrina IPET Study (IPET 2006) in regards to the findings and lessons learned documented in Volume II: Geodetic Vertical and Water Level Datums.

B. For all future data collections, effective immediately, the following shall apply:

1. All new data (Hydrographic, Topographic, Cadastral, LIDAR, Remote Sensed Data, and other) collected in Florida and Georgia for civil works projects shall be in NAD 1983, NAVD 1988, and the applicable tidal datum as established by the Department of Commerce (MLLW 1983-2001 for navigation).

2. All new data (Hydrographic, Topographic, Cadastral, LIDAR, Remote Sensed Data, and other) collected in Puerto Rico and the USVI for civil works projects shall be in NAD 1983, PRVD 2002 where available, and/or the applicable tidal datum as established by the Department of Commerce (MLLW 1983-2001 for navigation).

3. Control sheets, channel limits, design templates, and other drawings shall be converted to the new datums. The official control drawings shall reside in the Project Wise System. For navigation projects the official datum is Mean Lower Low Water (MLLW 1983-2001) per WRDA 1992. As navigation projects and other project conditions surveys are conducted the control for the tide staffs must be surveyed to establish the NAVD 88 datum. The horizontal coordinates (NAD 83) can be derived from the NAD 1927 coordinates.

4. Notify all our sponsors by official letter from the District Engineer.

C. Transition to current vertical datums for collection, modeling, and reporting of inland surface and ground water stages.

1. All new regulation schedules issued with stage elevations labeled using NAVD88 as well as superseded datum values in Florida.

2. Gauges recalibrated to NAVD88 and stages reported in NAVD88 in Florida.

3. Convert gauge POR to NAVD88 or institute another convention to allow old data to be used for flood frequency studies.

4. In conjunction with SFWMD, convert water management operations to NAVD88 in Florida.

5. Convert hydraulic and hydrologic models to be “datum neutral”.

D. Enlist CCO in an outreach and public information campaign to educate stakeholders and the public on what we are doing, why we are doing it, and how it will affect them.

E. All technical elements at SAJ adhere to the published and required standards.

4. IMPLEMENTATION ACTIONS

An assessment is needed of the accuracy of flood/hurricane protection elevations on existing flood control, reservoir, impoundment, or like projects. Authorized coastal navigation projects need to be evaluated to ensure that maintained or constructed depths are based on the latest hydrodynamic tidal model. In addition, it is necessary to ensure all geospatial surveying and mapping is performed on datums that are consistent with national and Federal standards. During this review, special attention must be made to assess the following critical issues associated with a project's vertical reference:

- Controlling flood control structure elevations were designed relative to hydraulic or hydrodynamic models/studies that were based on reliable water-level gage data.
- Hurricane protection structure elevations have been designed and/or periodically corrected to the latest tidal epoch, and that these corrections additionally reflect any sea level, settlement, or subsidence/uplift changes.
- Permanent benchmarks for river, pool, reservoir, and tidal reference gages are placed at an adequate density and are accurately connected to the Department of Commerce National Spatial Reference Network (NSRS) used by Federal and local interests.
- Coastal navigation project depths are defined relative to Mean Lower Low Water (MLLW) datum and are being maintained to the latest tidal epoch (currently 1983-2001), as defined by the Department of Commerce and required by Section 224 of WRDA 1992 (33 U.S.C. 562), and that project depths are designed and maintained relative to hydrodynamic tidal models that are based on up-to-date water-level gage data.

5. IMPLEMENTATION SCHEDULE

SAJ will migrate to the new datums in an organized fashion based on a realistic schedule, in accordance with current guidance, and within funding constraints. In general, the following priorities will be adhered to for project evaluation and implementation of corrective action. However, projects with schedules and funding that lend themselves to immediate execution of CEPD guidance will be addressed as they become recognized.

1) Kings Bay and Herbert Hoover Dike
   1. Kings Bay is a critical naval facility with high tidal variances and known deficiencies in the project datum and project control.
   2. Herbert Hoover Dike is a vital structure protecting a significant population and economic region with known deficiencies in the project datum and project control. This evaluation effort will include HHD, the Okeechobee Waterway, and address the LORSS schedule.
2) Remaining Deep Draft Navigation Projects
   1. Corrective action for these projects can likely be provided by current O&M funds and are a high priority for USACE-HQ.
3) Remaining CERP Projects
   1. Prioritization of these projects will depend on available funds and some form of risk assessment (protected populations, known problems, subsidence, etc.).
4) Puerto Rico
   1. NGS is establishing a comprehensive vertical datum in Puerto Rico. Corrective action cannot be fully implemented until PRVD02 is completed. Implementation of Interim corrective action will depend on available funds and some form of risk assessment (protected populations, known problems, subsidence, etc.).
5) Beaches, Shallow Draft, USVI, etc.
   1. These projects are less critical (population, commercial risk, etc.) and will be addressed as scheduling and funding permits.

In some cases project datums will be corrected in an iterative process. Where practices are so outdated that even rudimentary corrections improve upon current conditions, short term corrections will be implemented immediately. These projects will still undergo evaluation with more permanent corrective action defined. For example, the following actions can be taken to improve compliance with some deep draft projects that are not dependent on a full project review:

- Use of NOAA tide stations (MLLW 1983-2001) in lieu of historic USACE benchmarks where available
- Use of RTK tide corrections and the latest geoid model (currently geoid03) where applicable

6. STATUS OF CEPD GUIDANCE IMPLEMENTATION

Interim guidance was issued 04 December 2006 directing each District to appoint a District Datum Coordinator for training to be held in the spring of 2007 where permanent guidance will be presented. SAJ has appointed a District Datum Coordinator and established an SAJ CEPD team to keep abreast of guidance development and begin implementing the directive for project evaluations and corrective action.

In general, our navigation projects are non-compliant. Most, if not all, are referenced to MLW with an outdated tidal epoch. Project Management has requested additional program funds for navigation projects in order to facilitate compliance. Special attention is being paid to Fernandina Harbor (Kings Bay Naval Submarine Base). With direct contact with NOAA NOS (CO-OPS, NGS, OCS), USACE-HQ, and ERDC-TEC, SAJ is already taking steps to improve this project and bring it fully into compliance with the USACE-HQ directive. Once corrective actions are explicitly defined, the District Datum Coordinator will work closely with CO-OH to make similar corrections at all SAJ navigation projects (deep draft followed by shallow draft).

The CERP Geodetic Control Network established in south Florida for the Everglades restoration program exceeds the minimum accuracy requirements for creating NSRS connections to our projects. However, the accuracy requirements for CERP were defined by the hydraulic nature and sensitivity of the Everglades and further field effort is needed to firmly establish the relationship between all gauges (including Lake Okeechobee) and the control network. Coordination with USGS and SFWMD will take place to document what has, and what has not, been accomplished with plans formulated to complete this task. Operations Branch is putting together a plan to begin making these ties at all structures related to Lake Okeechobee and Herbert Hoover Dike.

Efforts are underway between the state of Florida and NOAA NGS to extend the CERP network north of Orlando, from the east coast to the west coast of Florida. A similar effort to our initial CERP Geodetic Control Network is underway between the Commonwealth of Puerto Rico and NOAA NGS to establish a comprehensive vertical datum (PRVD02) in Puerto Rico. We are cooperating closely with NGS during this effort to ensure that as many of our historic control benchmarks, and projects, as practical are tied directly to the new datum. LIDAR and imagery acquisition in Puerto Rico, underway for a few years, is collected and archived in such a manner that once PRVD02 is firmly established, the data can readily be converted.

Intermittent projects, due to project engineers aware of the interim guidance, are being updated during design. These actions will be formally documented once permanent CEPD guidance is distributed and the official project evaluation effort is underway.

D-7. Documentation of Project Evaluation

A standardized report format should be used for all project assessments. A project report submitted in a consistent format provides essential background information to the project engineers. The following outline may be used for guidance in preparing an assessment report for project datums. This outline is not definitive; any additional information deemed pertinent by the District Datum Coordinator is to be included in the project evaluation report.

Section D-8 provides details for on-line reporting requirements. The questions listed therein should be taken into consideration when preparing each project report. However, the report format is purposely free-form to allow for unique and differing project circumstances.

Outline for Project Evaluation Report Submittals

Section 1: General Project Information
Overview of the project including P2 project ID, project name, Digital Project Notebook project ID, active status, primary purpose of the project (flood protection, hurricane protection, shore protection, deep or shallow draft navigation), and whether or not the project is tidally influenced.

Section 2: Identify Data Sources
List out all sources of data used in the development of this report including the Digital Project Notebook, a local CADD database, map files, Detailed Design Memorandum, General Design Memorandum, Feasibility Report, local control database, NSRS, NWLON, ADCIRC tidal database, Plans and Specifications, the Engineering Technical Lead, H&H Project Engineer, and the current Project Manager.

Section 3: Determine Hydrological and Hydraulic Accuracy Requirements
Coordinate with the H&H Project Engineer to understand the hydraulic engineering applications and define the governing accuracy for connecting primary project control monuments to the regional NSRS. This section should provide a brief synopsis of project requirements.

Section 4: Review Project documents
Verify that the original and/or periodic maintenance design documents (DDM, GDM, P&S, etc.) indicate that constructed project elevations (or excavated navigation depths) are based on direct hydraulic or tidal observations, or that the relationship between the hydraulic datum and the geodetic datum used for construction was firmly established. Confirm that current project documents (or equivalent CADD databases) used in design or construction plans accurately describe the source and datum of any elevations or depths. Verify master project drawings, contract plans, and specifications have sufficient feature codes or metadata that notes the reference datum, source, location, adjustment epoch, and dates of tidal or hydraulic observations, monument descriptions, etc.

Confirm that all USACE operated and maintained projects have, at minimum, three up-to-date vertical control benchmarks identified in the contract plans and specifications from which to stake out construction. Confirm these controlling benchmarks have dual elevations on the latest adjustments and/or epochs: (1) hydraulic/tidal and (2) NAVD88 (NSRS).

Verify that contract documents require RTK vertical control for dynamic tidal projects.

Section 5: Evaluate Water Level Gauge Network
List all gauges with corresponding project datums as identified in historic project documents and files. Where applicable, provide the VM for each gauge tied to NWLON and the PID for each gauge benchmark tied to NSRS.

Verify the existence of a permanent water level gauge network that adequately defines the spatially varying hydraulic or tidal datum in the project region. Existing or historic gauges should be established at a sufficient density such that the spatially varying hydraulic datum anomalies are (or were) modeled to an accuracy consistent with project requirements.

Confirm that one benchmark at each gauge site (or at a control structure site or levee segment) is geodetically (orthometrically) connected to the currently recognized national vertical datum (NAVD88) on the National Spatial Reference Network maintained by the National Geodetic Survey (NGS). Verify the measure down at the gauge is clearly established/defined/etc. to the water surface and noted on the appropriate datasheet in the NSRS.

Make sure that coastal navigation projects were converted from Mean Low Water (MLW), Mean Low Gulf (MLG), or other local tidal datums, to MLLW as a result of the requirements in WRDA 92 (33 U.S.C 562) that superseded older tidal datums and epochs; and that these revisions are based on the latest tidal model and not on approximated or estimated translations (e.g., VERTCON). Verify that water level datums for rivers and non-tidal channels are based on the mean depth for a continuous period of fifteen days of the lowest water in the navigation season of any year and the year of adjustment is reflected in the datum name.

Verify hydraulic-based inland river reference datums (and reference benchmarks therefore) are firmly connected to river gauges and the NSRS.

Section 6: Evaluate Project Control
List all project control and project datums as identified in historic project documents and files. Where applicable, provide the PID for each benchmark tied to NSRS. Confirm these controlling benchmarks have dual elevations on the latest adjustments and/or epochs: (1) hydraulic/tidal and (2) NAVD88 (NSRS) and the horizontal datum is NAD83.

In areas where subsidence or crustal uplift is known to exist, this connection must have been made periodically in order to monitor potential loss of flood protection or navigation grade. Verify that reported elevations of coastal protection structures and maintained depths of navigation projects fully account for geological and climatological factors that may impact their integrity.

Verify permanent benchmarks on navigation projects are at a sufficient density (i.e., spacing) needed to adequately model the water surface for project maintenance, including controlling dredging grades and related measurement and payment/clearance surveys. For tidal navigation projects, consider the need for RTK vertical control (especially for dynamic offshore or non-protected waters).

Section 7: Review Periodic Gauge Inspection Program
Make sure USACE operated gauge networks are periodically inspected at adequate intervals to verify the gauge reference setting and confirm that the measure down is clearly established/defined/etc. to the water surface. Verify USACE operated water level gauges are referenced to, at minimum, three (3) permanent benchmarks, as defined in EM 1110-2-1002 (*Survey Markers and Monumentation*). Verify that each scheduled inspection visit connects the gauge reference mark to stable benchmarks by 3rd Order differential levels—see EM 1110-1-1005 (*Control and Topographic Surveying)*.

Section 8: Define Corrective Action
For projects requiring corrective actions, identify specific steps required to implement the corrective actions. Include a brief narrative where necessary to provide clear guidance on future efforts.

Section 9: Cost Estimate
Develop a budget cost estimate, showing effort and rates, to implement the corrective action(s). Provide enough information to facilitate a future, more thorough, independent government estimate if necessary.

Section 10: Implementation Plan
At a minimum, identify the funding source and estimated date for completion for corrective actions. Where applicable, include milestones addressing contract administration and/or begin and end dates for individual steps identified above.

Section 11: Potential One-Time Cost-Avoidance Savings (Navigation Projects)
Coastal navigation projects should include an estimate of potential one-time savings for dredge construction or maintenance as a result of bringing the project datum into compliance with WRDA 92.

Districts should maintain a file (digital or hard copy) for each project that contains the project evaluation report and copies of important information used in developing the report including data from on-line resources (NGS datasheets, CO-OPS benchmark sheets, etc.), copies of control sheets from construction documents, and copies of relevant pages from Design Memorandums and General Design Memorandums. The reports should be detailed but do not need to be exhaustive. These reports can function as an executive summary for a more comprehensive file maintained by the District. All file information should be organized and clearly dated to facilitate periodic project reassessments, reducing the cost of future reviews.

D-8. Reporting Findings from Project Evaluations

Completed project evaluation reports are to be converted to Adobe Acrobat PDF file format for submission and distribution. All reports will be submitted via a web-based reporting tool for compliance tracking in addition to being submitted to the current Project Manager. The Project

Manager has the responsibility to distribute the report to the Project Delivery Team (PDT), including the Engineering Technical Lead and H&H Technical Lead.

The primary focus of this document is to evaluate and report compliance with appropriate use of vertical datums in design and construction. Additional guidance may be developed to instruct Districts with regard to evaluating the findings of the CEPD as they impact design, construction, and operation of federally authorized flood protection, shore protection, hurricane protection, and navigation projects and tracking corrective actions to implement appropriate project changes through new design and construction including public notices where project changes are significant. The District Datum Coordinator is responsible for the evaluation of project datums, defining corrective action for non-compliant projects in order to transition the project to the proper datum(s), reporting of all findings to the District Commander and appropriate PDT members, and submitting required information via the web-based reporting tool. Project PDT members will be responsible for implementing corrective action to bring a project into compliance and defining any necessary actions with regard to new design and construction work.

Upon completing the evaluation of each project, the District Datum Coordinator is to access the web-based reporting tool, provide basic information regarding the project, and submit the project evaluation report. When all project evaluations have been completed for the District, it will be possible to generate a summary report for the District Commander's signature and subsequent submission to the Chief of Engineering and Construction. District Datum Coordinator's should be prepared to brief their District Commander and Project Managers with regard to the status of implementing corrective action. The Chief of Engineering and Construction may require periodic updates to the web-based reporting tool and subsequent updated summary reports with the District Commander's signature.

The following questions are to be answered utilizing the web-based reporting tool:

1. General Project Information

a. P2 project ID?

b. Project name?

c. Digital Project Notebook project ID?

d. Is the project, or a portion thereof, currently authorized? (*yes/no*)

e. What is the primary purpose of the project (*pick one*)?

i. Flood protection

ii. Hurricane protection

iii. Shore protection

iv. Navigation

1. Tidal v. Non-Tidal (*pick one*)

2. Deep Draft v. Shallow Draft (*pick one*)

2. Identify Data Sources

a. Digital Project Notebook? (*yes/no*)

b. Local CADD/GIS database? (*yes/no*)

c. Historic map files? (*yes/no*)

d. Detailed Design Memorandum? (*yes/no*)

e. General Design Memorandum? (*yes/no*)

f. Plans and Specifications? (*yes/no*)

g. Current Engineering Technical Lead for the project? (*yes/no*)

i. Does attached evaluation report list the name of the current ETL? (*yes/no*)

h. Current H&H Project Engineer for the project? (*yes/no*)

i. Does attached evaluation report list the name of the current H&H Project Engineer? (*yes/no*)

i. Current Project Manager? (*yes/no*)

i. Does attached evaluation report list the name of the current Project Manager? (*yes/no*)

3. Determine Hydrological and Hydraulic Accuracy Requirements

a. Did the H&H Project Engineer define the governing accuracy for connecting primary project control monuments to the regional NSRS? (*yes/no*)

1. If yes, provide value

2. If no, provide value to be used based on professional judgment

a. Does the attached evaluation report include a brief explanation detailing the basis for this value? (*yes/no*)

4. Review Project Documents

a. Does project have a minimum of three up-to-date vertical control benchmarks identified in the latest version of the contract plans and specifications from which to stake out construction? (*yes/no*)

b. Do the original and/or periodic maintenance design documents (DM, GDM, P&S, etc.) indicate that constructed project elevations (or excavated navigation depths) are based on direct hydraulic or tidal observations, or that the relationship between the hydraulic datum and the geodetic datum used for construction (e.g., NGVD 29 or NAVD 88) was firmly established? (*yes/no*)

i. If yes, provide supporting documentation (*pdf copy of construction plans*)

c. (*tidal*) Do project conditions (large variance in tidal mean range across project; dynamic offshore or non-protected waters) require the use of RTK for vertical control? (*yes/no*)

i. If yes:

1. Do the contract documents require RTK vertical control? (*yes/no*)

2. Does the attached evaluation report include a brief explanation detailing the basis for the tidal-geoid correction? (*yes/no*)

5. Evaluate Water Level Gauge Network

a. Does a permanent water level gauge network (existing or historic gauges) adequately define the spatially varying hydraulic or tidal datum in the project region to an accuracy consistent with project requirements? (*yes/no*)

b. Is the measure down at the gauge clearly established/defined/etc. to the water? (*yes/no*)

i. If yes, is this information clearly stated in the recovery notes of the controlling NSRS benchmark? (*yes/no*)

1. If yes, provide PIDs of primary benchmarks

c. (*tidal*) Project referenced to MLLW in the current tidal epoch? (*yes/no*)

i. If yes, provide NOAA CO-OPS Tide Station IDs

d. (*non-tidal*) Is the project's hydraulic-based inland river, non-tidal channel, or pool reference datum (and reference benchmarks) firmly connected to water level gauges and the NSRS? (*yes/no*)

i. If yes:

1. provide PIDs of primary benchmarks

2. Does the attached evaluation report include a brief explanation detailing the basis for the hydraulic datum (how was it established)? (*yes/no*)

6. Evaluate Project Control

a. Do the controlling benchmarks have dual elevations on the latest adjustments and/or epochs: (1) hydraulic/tidal and (2) NAVD88 (NSRS)? (*yes/no*)

i. If yes, provide PIDs of primary benchmarks

b. Are the controlling benchmarks referenced to NAD83? (*yes/no*)

c. Does the project footprint reside in an area where subsidence or crustal uplift is known to exist? (*yes/no*)

i. If yes, is the NSRS connection periodically updated in order to monitor potential loss of flood protection or navigation grade? (*yes/no*)

d. (*navigation - tidal/non-tidal*) Are permanent benchmarks at a sufficient density (i.e., spacing) needed to adequately model the water surface for project maintenance, including control of dredging grades and related measurement and payment/clearance surveys? (*yes/no*)

7. Review Periodic Gauge Inspection Program

a. Is the project gauge network operated by USACE? (*yes/no*)

i. If yes:

1. Are the gauges periodically inspected at adequate intervals to verify the gauge reference setting and confirm that the measure down is clearly established/defined/etc. to the water surface? (*yes/no*)

2. Are the water level gauges referenced to a minimum of three (3) permanent benchmarks, as defined in EM 1110-2-1002 (*Survey Markers and Monumentation*)? (*yes/no*)

a. If yes, provide PIDs of primary benchmarks

3. Are 3rd Order differential level connections performed from the gauge to the reference marks during scheduled inspection visits (see EM 1110-1-1005 Control and Topographic Surveying)? (*yes/no*)

8. Define Corrective Action

a. Project Compliant (*yes/no*)

i. If no,

1. What is the estimated cost for compliance?
2. What is the estimated completion date?
3. (*tidal*) What is the estimated cost-avoidance?
4. What is the estimated cost of assessment?

9. Submit report (Adobe PDF file)

D-9. Example Project Evaluation Report: Non-compliant Deep Draft Navigation

The following example report is provided in order to illustrate the level of effort and detail needed for reporting a project assessment. This example report is a simulation and contains some fabricated data.

****simulated report for illustrative purposes only- this project has not been evaluated****

CEPD Evaluation Report: **Kings Bay** **P2 Project ID 945804753904**

Section 1: General Project Information

DPN:3064
Status: Authorized
Type: Navigation, deep draft (tidal)

Section 2: Data Sources

DPN
ProjectWise CADD files
Contract W912EP-06-C-0124 (P&S)
ETL: Jane Smith
H&H:Jane Smith
PM: John Smith
District BENCH control database
NSRS/NWLON on-line databases
Memorandum Report: Tidal Relations along the Saint Mary's Entrance Channel to Kings Bay, Fernandina, Florida (Brian Shannon, 1998)

Section 3: Hydrological and Hydraulic Accuracy Requirements

This is a deep draft navigation project for the U.S. Navy. NSRS publication of control is not pivotal but is useful. In accordance with CEPD guidance, use of NWLON control to establish a consistent MLLW 1983-2001 reference datum throughout the project area to an accuracy of +/- 0.25 ft. is an essential requirement.

Section 4: Project Documents

Current project documents will need to be updated to accurately describe the source and datum of all elevations and depths relative to MLLW 1983-2001. Tide stations, benchmarks, and PIDs of all project control needs to be tabulated on contract documents with NAVD88 to MLLW 1983-2001 clearly defined. The location of all control should be clearly shown in the contract plans. Contract documents currently require RTK vertical control for a portion of the project but not all.

Section 5: Water Level Gauge Network

A sufficiently dense network of current and historic NOAA tide gauges and benchmarks exists throughout the project area to facilitate an accurate model of MLLW 1983-2001. Use of RTK with an accurately defined MLLW 1983-2001 tidal datum for vertical control is required for all P&S and measurement and payment surveys conducted for this project.

<u>Tide Stations with available data on-line</u>
Tide Station 8679511 Kings Bay, GA
Tide Station 8679758 Dungeness, Seacamp Dock, GA
Tide Station 8679945 Beach Creek, GA
Tide Station 8720030 Fernandina Beach, Amelia River, FL – Only station with an established tie to the NSRS (PIDs: BC0160, BC0166, BC0167, BC0171, BC0174, BC0175, BC1542, BC1543, BC1815, BC2522)

<u>Historic Tide Stations shown on-line but data must be requested (CO-OPS)</u>
Tide Station 8679909 Range “A” Light Tower
Tide Station 8720011 Cut 1n Front Range, St. Marys River Entr
Tide Station 8720008 Platform Off Tiger Island
Tide Station 8720012 Cut 2n Front Range, St. Marys River Entr

<u>Historic Tide Stations shown only in CO-OPS Station Index – data must be requested (CO-OPS)</u>
Tide Station 8679411 South Cumberland Is. Outside
Tide Station 8679598 Cumberland Snd. Daymarker 22
Tide Station 8679964 St. Marys, St. Marys River
Tide Station 8679997 St Marys Jetty
Tide Station 8679998 St. Mary's Ent. Chl., Offshore Platform
Tide Station 8720001 St. Marys River Headwaters
Tide Station 8720002 St. Marys River, Seaboard Coast Rr
Tide Station 8720003 Crandall, St. Marys River
Tide Station 8720004 Crandall, St. Marys River
Tide Station 8720005 Fort Clinch, Amelia Island
Tide Station 8720006 Little St. Marys River
Tide Station 8720007 Roses Bluff
Tide Station 8720009 Amelia River Ent.
Tide Station 8720023 Chester, Bells River
Tide Station 8720028 Bells River Ent.
Tide Station 8720031 Fernandina Beach, (Backup)
Tide Station 8720036 Fernandina, Terminal Corp Dock

Project datum has not been updated in accordance with WRDA 92. The entire project needs to be updated to MLLW 1983-2001.

- Project datum for southern portion is MLLW 1960-1978
- Project datum for northern portion is undocumented but believed to be MLW (epoch unknown)

Section 6: Project Control

GPS reference station at Fort Clinch (MLLW 1960-1978; reportedly established from NOAA tide station 8720030 Fernandina Beach, Amelia River). Project referenced to NAD83 (PIDs above).

Surveys for PCS, P&S, and measurement & payment are conducted utilizing RTK tide corrections based on MLLW 1960-1978 established for GPS reference station at Fort Clinch for the southern portion of the project (Cut A through Cut G).

Surveys for the northern portion of the project, Dungeness Seacamp Dock to Kings Bay, are controlled by tide staffs of unknown origin. It is assumed that these staffs were established from NOAA benchmarks and set to MLW but are one or two epochs out of date.

Only one tide station for the project has published NSRS connections. However, all the tide stations have published NWLON connections. The project currently does not account for sea level rise and is being maintained to a depth beyond current authorization. Defining and using a MLLW 1983-2001 datum based on the NWLON tide stations in the area will bring this project into compliance. Connecting more of the tide stations (benchmarks) to the NSRS via OPUS-DB is recommended in order to facilitate V-Datum development and establish a clear relation between NAVD88 and MLLW 1983-2001 for the area but isn’t absolutely necessary since all project work is authorized relative to MLLW 1983-2001.

Once MLLW 1983-2001 is properly established for the project area, a sufficient number of vertical control benchmarks should exist to satisfy this requirement. Recommend field verification of bench marks still in existence with recovery notes submitted to NGS/CO-OPS.

Section 7: Periodic Gauge Inspection Program

NA – gauges owned and operated by NOAA. Third order levels should be run between benchmarks during each survey and tide staff established/checked. Tide correction results should be compared to on-line NOAA results.

Section 8: Corrective Action

SUMMARY OF CORRECTIVE ACTIONS

1. establish MLLW 1983-2001 for project area
   a. request unavailable tidal data from CO-OPS
   b. model MLLW 1983-2001 using a spatial interpolation tool
2. field work
   a. establish NSRS ties to tide stations 8679511, 8679758, 8679945, and 8720030 using GPS and OPUS-DB (Optional: facilitates V-Datum development and establishes MLLW 1983-2001 to NAVD88 separation for KTD file)
   b. run third order levels to secondary tidal BMs and submit via OPUS-Levels
   c. set tide staffs to facilitate field verification of tidal corrections during surveys
   d. set any required RTK base benchmarks at secure or permanent sites
3. establish HYPACK KTD file for surveys
4. update current design and contract documents with new project control including all benchmark metadata

Section 9: Cost Estimate

Contract Administration

USACE hired-labor, technical S&A	5 MD @ $800/MD	$4000
USACE hired-labor, CT admin charges	5 MD @ $800/MD	$4000
USACE hired-labor, travel (recon)	$1000	$1000
		$9,000

A-E Contract Line Items

Mob/demob to project site	2 CD @ $2500/CD	$5000
Static GPS & 3rd order levels	2 CD @ $2500/CD	$5000
Set tide staffs (on-shore)	2 CD @ $2500/CD	$5000
Set tide staff at front range	1 CD @ $2500/CD	$2500
Set secure RTK base benchmark	1 CD @ $2500/CD	$2500
Field verify tidal datum model/KTD (performed at later date)	1 CD @ $2500/CD	$2500
		$22,500

Data Processing and Reporting

Model MLLW 1983-2001	10 MD @ $800/MD	$8000
Develop HYPACK KTD file	1 MD @ $800/MD	$800
QA A-E field work/OPUS submissions	5 MD @ $800/MD	$4000
Update design/contract documents	2 MD @ $800/MD	$1600
		$14,400

Summary of Budget Cost Estimate

Contract Administration		$9,000
A-E Contract Line Items		$22,500
Data Processing and Reporting		$14,400
	Subtotal	$45,900
Contingencies @ 20%		$9,180
	Total Budget Estimate	$55,080

Section 10: Implementation Plan

PM: John Smith
FWI: L0BB0 A-E SVCS $22,500 available 01 June 2007
Labor: 072D14 $23,400 available 01 June 2007

01-30 June 2007
- request historic tidal data from NOAA/CO-OPS
- task order contract administration including SOW, government estimate, RFP, pre-negotiation memorandum, negotiation memorandum, and NTP
- begin modeling tidal datum

01-31 July 2007
- execute task order

01-31 August 2007
- finish tidal model
- QA A-E field work
- process and submit data to OPUS-DB and OPUS-Levels
- update design and construction documents
- develop and field verify KTD file

Section 11: Potential One-Time Savings

Estimated volume = 18 miles (95040 ft.) long x 500 ft. wide x 0.25 ft. sea level rise ÷ 27 cf/cy = 440,000 cy
Estimated cost reduction = 440,000 cy x $10/cy = $4,400,000

D-10. Example Project Evaluation Report: Compliant Deep Draft Navigation

The following example report is provided in order to illustrate the level of effort and detail needed for reporting a project assessment. This example report is a simulation and contains some fabricated data.

*****simulated report for illustrative purposes only – this project has not been evaluated*****

CEPD Evaluation Report:	Key West Harbor	P2 Project ID 386262040802

Section 1: General Project Information

DPN:4867
Status: Authorized
Type: Navigation, deep draft (tidal)

Section 2: Data Sources

DPN
ProjectWise CADD files
Contract W912EP-05-C-0254 (P&S)
ETL: Jayne Sumner
H&H:Jayne Sumner
PM: Jon Smyth
District BENCH control database
NSRS/NWLON on-line databases
ADCIRC Tidal Database
Complexities of Tidal Zoning for Key West, FL (Kristen A. Tronvig and Stephen K. Gill, THSOA 2001)

Section 3: Hydrological and Hydraulic Accuracy Requirements

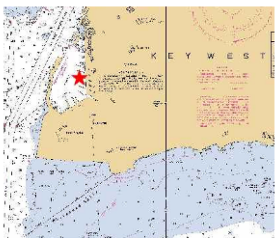
This is a deep draft navigation project for the U.S. Navy. NSRS/NWLON control meets project requirements and CEPD guidance.

Section 4: Project Documents

See Contract W912EP-05-C-0254, P&S. Contract documents clearly define Tide Station 8724580 and all benchmarks as project control. Survey notes indicate control marks and datum used to generate all data. Tidal observations are maintained by NOAA and available on-line, no additional metadata necessary. Project documents clearly require use of RTK and latest geoid model (currently Geoid03).

Seven benchmarks listed in the contract plans have NAVD88 and MLLW 1983-2001 elevations. Project documents plainly indicate MLLW 1983-2001 (see Contract W912EP-05-C-0254, P&S). The relationship between NAVD88 and MLLW 1983-2001 is clearly defined both graphically and in text.

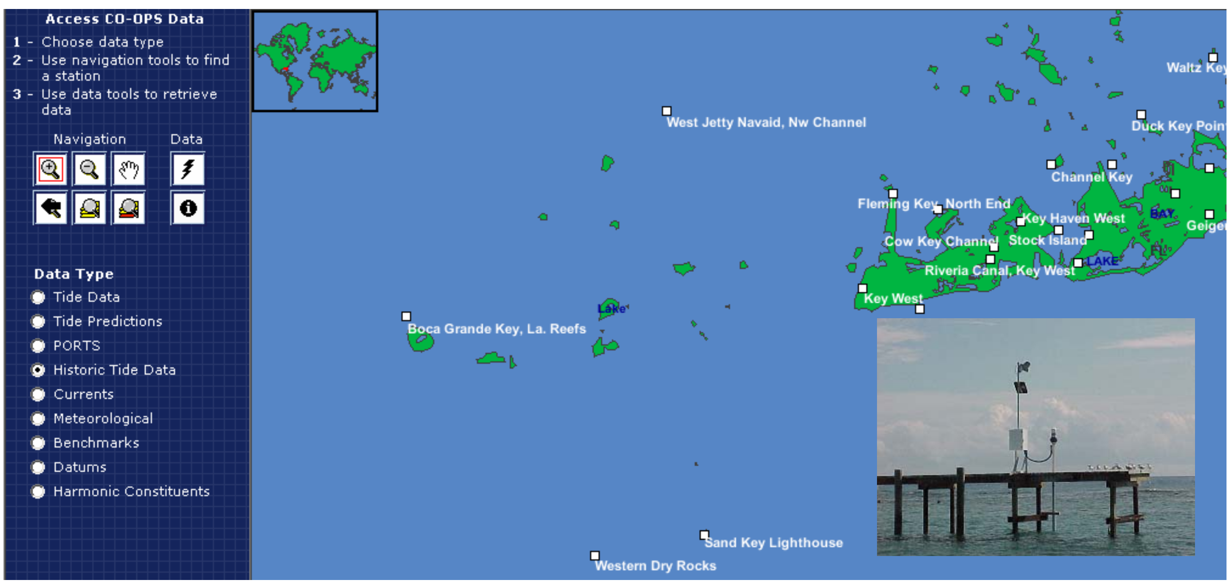
Section 5: Water level gauge network



Project control was established from NOAA Tide Station 8724580 in Truman Basin, Key West Florida.

NWLON VM#: 13915, 706, 710, 712, 714, 716, 1781, 12415, 13696, 15837

NSRS PID: AA0009, AA0003, AA0005, AA0007, AA0008, AA1753, AA1645



Further investigations reveal that mean tide range of Sand Key Lighthouse (Tide Station 8724635) is within 0.05-ft. of tide station in Truman Basin. ADCIRC Tidal Database also confirms uniform offshore tide range in project area.

Project datum has been updated to MLLW 1983-2001 in accordance with WRDA 92. Tide Station 8724580 benchmarks are published in the NSRS. Project is on the current tidal datum epoch and therefore maintained depths fully account for sea level rise.

Section 6: Project Control

Hydrographic surveys performed with RTK (Geoid03) base station set on one of the control marks listed above. Third order levels are performed between marks prior to surveying. RTK tide corrections are calibrated to NOAA tide staff on site. Station recovery notes are submitted to NSRS and levels are submitted to OPUS-Levels. Project referenced to NAD83.

Project is controlled from one NOAA Tide Station in combination with RTK GPS and Geoid03 for tidal corrections. Conversations with Dr. Dan Roman [NOAA NGS] confirm that Geoid03 is applicable for this “near shore” (7 miles) project given the lack of tide station data available.

Section 7: Periodic Gauge Inspection

NA – gauges owned and operated by NOAA. Third order levels run between benchmarks during each survey and tide staff established/checked. Tide correction results compared to on-line NOAA results.

Section 8: Corrective Action

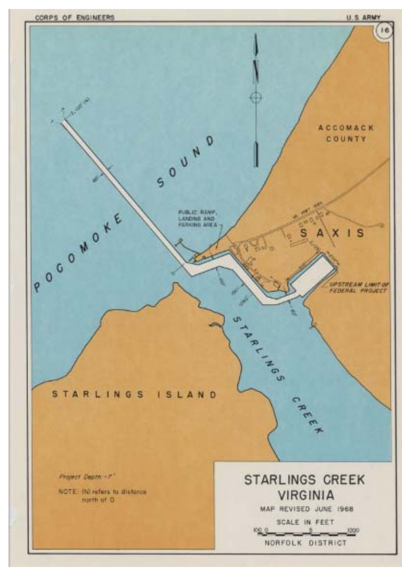
Project is compliant with CEPD guidance. No corrective action required at this time.

D-11. Example Project Evaluation Report: Non-compliant Shallow Draft Navigation

The following example report is provided in order to illustrate the level of effort and detail needed for reporting a project assessment. This example report is a simulation and contains some fabricated data.

******simulated report for illustrative purposes only – this project has not been evaluated******

CEPD Evaluation Report:	Starlings Creek, Saxis Harbor, VA	P2 Project ID 386262040802



Section 1: General Project Information

DPN:9865
Status: Active
Type: Navigation, shallow draft (tidal)

Section 2: Data Sources

DPN
ProjectWise CADD files
Map files
Feasibility Report
General Design Memorandum
Detailed Design Memorandum
ETL: Jackie Welp
H&H:Ted Hack
PM: Don Sneed
NWLON on-line database

Section 3: Hydrological and Hydraulic Accuracy Requirements

Aside from being on the wrong tidal epoch, this shallow draft navigation project is suitably controlled to meet project accuracy requirements and CEPD guidance.

Section 4: Project documents

Project documents need to be updated to latest tidal epoch.

Section 5: Water Level Gauge Network

Tidal datums at SAXIS, STARLING CREEK based on:

TIDE STATION:	8633777 SAXIS, STARLING CREEK, VIRGINIA
CONTROL TIDE STATION:	8632200 KIPTOPEKE, CHESAPEAKE BAY
LENGTH OF SERIES:	4 MONTHS
TIME PERIOD:	August 1988 - November 1988
TIDAL EPOCH:	1983-2001

VM#: 4869, 4867, 4868, 4870, 4871, 4872, 4873

PID: XX1234, ZZ1234

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

MEAN HIGHER HIGH WATER (MHHW)	= 0.774
MEAN HIGH WATER (MHW)	= 0.724
MEAN TIDE LEVEL (MTL)	= 0.383 (1.26 ft)
MEAN SEA LEVEL (MSL)	= 0.381 (1.25 FT)
MEAN LOW WATER (MLW)	= 0.042
MEAN LOWER LOW WATER (MLLW)	= 0.000

There is no need (or justification) to perform a tidal model for this small project. Sufficient information exists to interpolate and verify a suitable MLLW datum for the project footprint.

Section 6: Project Control

Current project control is based on a superseded tidal epoch and NAD83. Bench marks are published in the NWLON and the NSRS database. There are a sufficient number of tidal benchmarks to control measurement and payment surveys for maintenance dredging.

Section 7: Periodic Gauge Inspection Program

NA – gauges owned and operated by NOAA. Third order levels run between benchmarks during each survey and tide staff established/checked.

Section 8: Corrective Action

SUMMARY OF CORRECTIVE ACTIONS

1. update current design and contract documents with new project control including all benchmark metadata
2. update KTD file

Section 9: Cost Estimate

Update design/contract documents	2 MD @ $800/MD	$1600
Contingency	25%	$400
	Total Budget Estimate	$2000

Section 10: Implementation Plan

PM: Don Sneed
FWI: L0BB0 A-E SVCS $2,000 available 01 June 2007
Labor: 072D14 $2,000 available 01 June 2007

15-30 June 2007

- update design and construction documents
- develop KTD file (field verify during next project survey)

Section 11: Potential One-Time Cost-Avoidance Savings

Estimated volume = [(100 ft. x 1100 ft.) turning basin + (200 ft. x 500 ft.) harbor + (60 ft. x 2100 ft.) channel] x 0.33 ft. sea level rise ÷ 27 cf/cy = 12,500 cy

Estimated cost avoidance = 12,500 cy x $10/cy = $125,000

D-12. Example Project Evaluation Report: Flood Protection

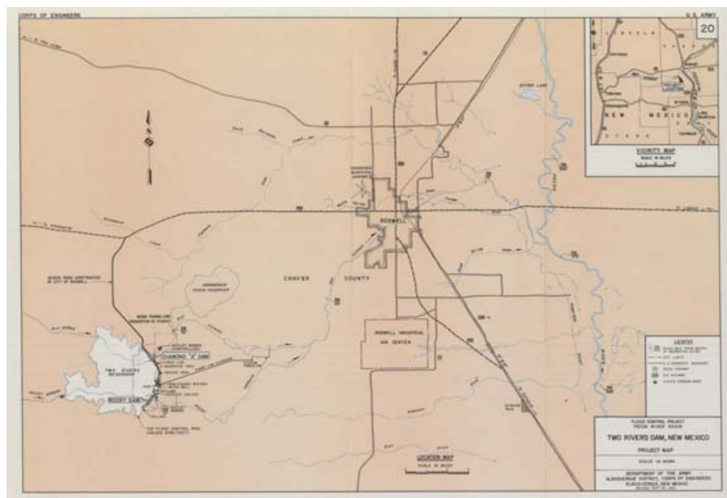
The following example report is provided in order to illustrate the level of effort and detail needed for reporting a project assessment. This example report is a simulation and contains some fabricated data.

*******simulated report for illustrative purposes only – this project has not been evaluated******

CEPD Evaluation Report: Two Rivers Dam, NM P2 Project ID 895092040802

Section 1: General Project Information

DPN:8375
Status: Active
Type: Flood Protection



Section 2: Data Sources

DPN
ProjectWise CADD files
Map files
Feasibility Report
General Design Memorandum
Detailed Design Memorandum
ETL: John Rooster
H&H:Danielle Crassburn
PM: Theodore Muck

Section 3: Hydrological and Hydraulic Accuracy Requirements

H&H project requirements are met utilizing CEPD guidance for NSRS connections at accuracy of 0.25 ft. with internal project control accuracy at 0.1 ft.

Section 4: Project documents

Project documents adequately describe project control based on current status. However, these documents will have to be updated once the project is brought into compliance.

Section 5: Water Level Gauge Network

Rocky gauge (Corps bench marks “Clyde”, “A-76”, “AJF476”)
Diamond “A” gauge (Corps bench marks “97654”, “RM-1”, “RM-2”)
Rio Arroyo gauge (USGS bench marks “B789”, “A123”, “B867”)
Rio Hondo (USGS bench marks “Mill”, “Hondo”, “982”)

Water level gauges on site are not tied to national database. Two Rivers Reservoir datum is defined as a ”fixed offset of 3500 ft. from mean sea level” and needs to be tied/defined to NSRS (NAVD88). Spacing of gauges is sufficient to establish water level surface over project area.

Section 6: Project Control

Deformation monitoring marks are not currently tied into the NSRS ("Clyde", "A-76", "AJF476", "97654", "RM-1", "RM-2").

Project not currently tied to NSRS. A 10 mile radial search of the NGS database yields no vertical control within 5 miles of project site. Most marks set in the 1930s on Hwy 70 ROW. Marks out to BM E 203 have not been recovered since the 1930s and are probably no longer there. Given that the marks are greater than 60 years old, there is a high probability that an extensive static GPS vertical network will be required at this site.

A radial search of the NSRS for 1st Order vertical control out to 25 miles yielded a few potential points. These are typically 12 to 20+ miles scattered around Roswell, NM but have not been recently recovered. It is best to assume NSRS ties to be made via CORS/OPUS. Horizontal ties to NAD83 will be incidental to vertical ties.

Section 7: Periodic Gauge Inspection Program

Gauges are inspected annually within the ICWs program. Third order levels are run between bench marks and gauges. Gauges are visually inspected to verify they are functioning properly. Measure-down values are checked annually.

Section 8: Corrective Action

Tie in one primary benchmark at project site to NAVD88 / NAD83 using CORS-Only/OPUS solution. Add this primary mark to NSRS. Level to other project control (Corps and USGS) on project site including gauges and measure-down values. Update project documents accordingly.

Section 9: Cost Estimate

Contract Administration

USACE hired-labor, technical S&A	10 MD @ $800/MD	$8000
USACE hired-labor, CT admin charges		$7500
USACE hired-labor, travel (recon)	2 MD @ $800/MD	$1600
	Travel	$600
		$17,700

A-E Contract Line Items

Mob/demob to project site	2 CD @ $2500/CD	$5000
Recon for existing NSRS or Corps control	2 CD @ $2500/CD	$5000
Static GPS	1 CD @ $2500/CD	$2500
3rd order leveling	2 CD @ $2500/CD	$2500
		$15,000

Data Processing and Reporting

Reduce field notes and organize data for submission	2 MD @ $800/MD	$1600
Input data to NSRS & coordinate with NGS	1 MD @ $800/MD	$800
Update design/contract documents	2 MD @ $800/MD	$1600
		$4,000

Summary of Budget Cost Estimate

Contract Administration		$17,700
A-E Contract Line Items		$15,000
Data Processing and Reporting		$4,000
	Subtotal	$36,700
Contingencies @ 25%		$9,175
	Total Budget Estimate	$45,875

Section 10: Implementation Plan

PM: Theodore Muck
FWI: L0BC0 A-E SVCS $15,000 available 01 June 2007
Labor: 072D14 $21,700 available 01 June 2007

01-30 June 2007
- task order contract administration including SOW, government estimate, RFP, pre-negotiation memorandum, negotiation memorandum, and NTP

01-31 July 2007
- execute task order

01-31 August 2007
- QA A-E field work
- process and submit data to OPUS-DB
- update design and construction documents

Section 11: Potential One-Time Cost-Avoidance Savings

NA

APPENDIX E
List of Supplemental Training Material to Accompany this Guidance Document

The following list of presentation documents is intended to supplement the guidance in this document. They include examples of CEPD assessments and proposed solutions. Sessions in blue are presented by NOAA, in black by the Corps. Digital copies of PowerPoint slides for these sessions are available from ERDC/TEC.

Introduction

1	Greetings and Introductions
2	CEPD Background & Summary of IPET Vol. II
3	General Overview of Corps Reference Datums
4	Overview of CEPD Assessment Criteria

Levee Systems and Related Flood Control Projects

5	Geodesy Overview (NOAA/NGS)
6	CORS/OPUS (presentation & demo/hands-on) (NOAA/NGS)
7	NGS 58/59 (NOAA/NGS)
8	Data Submission to NSRS (NOAA/NGS)
9	Inland Flood Control Projects: CEPD App B-1 to B-16
10	Inland Flood Control Projects: CEPD App B-17 to B-30
11-1	Sample Flood Control Projects--CEPD App B
11-2	Sample Flood Control Projects--CEPD App B (Contd)
12	Flood Control Project Practical Exercise (groups)

Coastal Navigation Projects, Hurricane Protection Projects, and Shore Protection Systems

13	Tidal Datum Overview (NOAA CO-OPS)
14	Tidal Modeling MLLW (V-Datum, TCARI SIT) (NOAA CO-OPS)
15	Coastal HSPP & Navigation Projects: App C-1 to C-14
16	Coastal HSPP & Navigation Projects: App C-15 to C-25
17	Appendix C-26 and RTK Tides (Key West) ***
18-1	Sample HSPP & Nav Projects--CEPD App C
18-2	Sample HSPP & Nav Projects--CEPD App C (Contd)
19	HSPP & Nav Project Practical Exercises (groups)

Project Documentation and Reporting

20	CEPD Final Documentation & Reporting: App D

APPENDIX F
CEPD Directive Memorandum

CECW-CE (1110)

MEMORANDUM FOR MAJOR SUBORDINATE COMMANDS

SUBJECT: Implementation of Findings from the Interagency Performance Evaluation Task Force for Evaluating Vertical Datums and Subsidence/Sea Level Rise Impacts on Flood Control, Shore Protection, Hurricane Protection, and Navigation Projects

1. The purpose of this memorandum is to issue the second of a series of directives to implement lessons learned from the recent findings of the Interagency Performance Evaluation Task Force (IPET) on Hurricane Katrina. Findings of errors of one to three feet in some of the elevations used in design, construction, maintenance, and evaluation of hurricane and flood control structures in New Orleans highlighted the need to ensure that our flood control and navigation projects across the country are referenced to the proper vertical datums to correctly compensate for subsidence/sea level rise. Furthermore we need to confirm that these vertical datums are adequately referenced to nationwide spatial reference systems used by other Federal and local agencies responsible for flood forecasting, hurricane surge and inundation modeling, navigation, flood insurance rate maps, hurricane evacuation route planning, coastal boundary delineation, bathymetric mapping, and topographic mapping. We have a professional and ethical obligation to periodically reassess our projects to ensure that they are correctly designed, constructed, and maintained on the proper vertical datums to compensate for subsidence/sea level rise in order to provide appropriate flood and hurricane protection and navigation depths.

2. My direction to you is as follows:

a. Every District shall conduct a vertical datum review of all their federally authorized and constructed hurricane protection, shore protection, flood control, and navigation projects, and evaluate them against the technical criteria provided in the attached document. The purpose of this review is to (1) inventory the vertical datums used on all flood control, hurricane protection and navigation projects, (2) identify deficiencies in those datums that require corrections, (3) transition to the correct datums, and (4) implement appropriate project changes, e.g, increase levee heights or reduce dredging. Where project changes are significant, public notices shall be given. Where additional funds are required to implement project changes, programming actions should be initiated as soon as possible.

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SUBJECT: Implementation of Findings from the Interagency Performance Evaluation Task Force for Evaluating Vertical Datums and Subsidence/Sea Level Rise Impacts on Flood Control, Shore Protection, Hurricane Protection, and Navigation Projects

b. Districts shall appoint a lead vertical datum coordinator to oversee the review of each project and approve/certify the evaluation report. This individual shall have a solid technical background in surveying and geodesy, and shall have completed a mandatory training course developed by ERDC, Topographic Engineering Center, specifically for this purpose. The three day training course will be held in Alexandria, VA, in March 2007. Please send name of District vertical datum coordinator to Jim Garster, ERDC TEC, by 15 December 2006.

c. Once training has been completed, District Datum Coordinators will report the status of vertical datums for all Flood Control, Shore Protection, Hurricane Protection and Navigation projects through a web based survey tool. The survey tool will capture information outlined in Section seven of the Interim Guidance Document (Attached). Once all District projects status has been assessed and reported, the District Commander will send a final report to the Chief of Engineering and Construction. Detailed information on filling out the survey and report generation will be explained at the training course.

d. Districts will fund the vertical datum review of flood control and hurricane protection projects operated and maintained by non-federal sponsors within the Inspection of Completed Works (ICW) account. Review of Corps-maintained projects, including navigation projects, will be funded from existing O&M accounts associated with those projects.

3. The attached guidance is intended to cover the requirements for an initial assessment and reporting. More permanent guidance will include a periodic review of vertical datums in various inspection programs of completed civil works projects. Permanent guidance, to be provided at the training course, will also call for permanent benchmarks or control points to be established or reestablished for all Flood Control, Shore Protection, Hurricane Protection, or Navigation Projects following the latest National Geodetic Survey (NGS) guidelines and submitted to NGS for review using the NGS Policy on Submitting Data for Inclusion into the National Spatial Reference System (NSRS) or “Blue Booking.”

4. The overall point of contact for this effort in Headquarters is M.K. Miles, CECW-CE, 202-761-5532, and the technical point of contact in ERDC, is James Garster, ERDC-TEC, 703-428-9026.

/s/ 04 December 2006
CARL A. STROCK
Lieutenant General, USA
Commanding

Encl

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SUBJECT: Implementation of Findings from the Interagency Performance Evaluation Task Force for Evaluating Vertical Datums and Subsidence/Sea Level Rise Impacts on Flood Control, Shore Protection, Hurricane Protection, and Navigation Projects

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