DEPARTMENT OF THE ARMY
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Engineering and Design

INTERIM GUIDANCE FOR A PRELIMINARY EVALUATION OF VERTICAL DATUMS ON FLOOD CONTROL, SHORE PROTECTION, HURRICANE PROTECTION, AND NAVIGATION PROJECTS

1. Purpose

This document provides interim guidance on the proper application of vertical datums used to reference protection elevations on flood control structures or excavated depths in navigation projects. It describes specific procedural actions immediately required to evaluate the accuracy and adequacy of existing flood protection elevations or controlling navigation depths. 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.

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 projects situated in coastal/tidal regions of the country, inland flood protection systems, and in areas with high rates of crustal subsidence or uplift.

3. 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 erroneously 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 Often vertical datums specified for construction stakeout were based on older, superseded adjustments.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 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. WRDA 92 specifically required that navigation projects on the Atlantic and Gulf Coasts be referenced to a vertical mean lower low water datum defined by the Department of Commerce. The intent of this Act was to supersede local 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.

4. References

See Appendix A.

5. 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:

- Controlling flood control structure elevations were designed relative to hydraulic or hydrodynamic models 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.

6. 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 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 equipotential surfaces based on some defined terrestrial origin—often a single point. Examples of orthometric datums include the National Geodetic Vertical Datum of 1929 (NGVD 29) and National Geodetic Vertical Datum of 1988 (NAVD 88).
- 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.
- 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 gage without substantiating measurements or models.

- Space-Based (Ellipsoidal) Datums: These are three-dimensional, geocentric, ellipsoidal datums used by the Global Positioning System (GPS)—i.e., WGS 84. Ellipsoid heights of points on the earth represent elevations relative to the WGS 84 reference system. The geoid height represents the elevation of the WGS 84 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. This is 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 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 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—see Appendix B, paragraph 4.

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.

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

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

EM 1110-2-1005, "Control and Topographic Surveying," Chapter 5, "Geodetic Reference Datums and Local Coordinate Systems," Section III (Vertical Reference Systems).

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."

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)

7. 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 criteria described below. Projects that do not conform to these minimum standards are considered deficient and require remedial action. The assessment items below should be addressed in the evaluation report for each project, as applicable.

(1) Verify the existence of a permanent water level gage network that adequately defines the spatially varying hydraulic or tidal datum in the project region. Existing or historical gages 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 gages 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 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.

(3) Verify that coastal navigation projects were converted from MLW, 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)—see Appendix B, paragraph 1.

(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 gage networks are periodically inspected at adequate intervals to verify the gage reference setting and other criteria. Gage inspection and referencing procedures should be documented in a standards manual, or, at minimum, conform to gage inspection criteria used by the Department of Commerce (NOAA)—see Appendix B, paragraph 2.

(6) Verify USACE operated water level gages 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 gage reference mark to stable benchmarks by 3rd Order differential levels—see EM 1110-1-1005 (*Control and Topographic Surveying)*.

(7) Verify that one benchmark at each gage site (or at a control structure site or levee segment) is geodetically (orthometrically) connected to the NAVD 88 datum on the National Spatial Reference Network maintained by the National Geodetic Survey (NGS)—see paragraph B-3 below. 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. Projects still defined relative to undefined or superseded datums—e.g., "Mean Sea Level," "NGVD," or "NGVD 29"—are considered deficient and in need of updating. There may be limited exceptions to this.

(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 from which to stake out construction. Confirm these controlling benchmarks have dual elevations on the latest adjustments and epochs: (1) hydraulic/tidal and (2) NAVD 88 (NSRS).

(10) 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 & payment/clearance surveys. Permanent benchmarks should ideally be spaced at least every 2,500 ft along a project. A larger spacing may be warranted on navigation projects where dredging grade is being controlled using GPS real-time kinematic methods.

(11) Verify permanent benchmarks shown on 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 gages 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.

8. Corrective Actions Required for Projects Not Meeting Minimum Standards

Projects deemed to be deficient in any of the criteria outlined in paragraph 7 above will require corrective action. The amount of time and expense will vary considerably, depending on the geographical size of the project, the density and reliability of existing water level gages, NOAA modeling support and capability, and various other factors. Coastal projects requiring updated tidal models will require by far the most effort. Updating river, pool, or reservoir gage elevations will require minimal time and expense. This preliminary assessment report 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 in 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, or are on superseded epochs, will require initiating a coordinated effort with NOAA CO-OPS to reliably update a model for the project. This may require setting one or more short-term tidal gages to perform simultaneous comparison datum translations between an existing National Water Level Observation Network (NWLON) station—see NOS 2003 (*Computational Techniques for Tidal Datums Handbook*)—and/or developing a tidal model utilizing the hydrodynamic modeling tools developed in VDatum—e.g., "*Tidal Constituent and Residual Interpolation*" (TCARI) which can be applied to develop the MLLW datum relationship over a project reach. See Myers 2005 and Brennan 2005 for details on VDatum and TCARI respectively. See Appendix B, paragraph 4.

b. Water Level Gage Upgrades. USACE gages with insufficient reference benchmarks must be upgraded. This can be accomplished with either hired-labor or contract forces.

c. Geodetic Control Survey Connections to the NSRS. River/tidal gage benchmarks or reference benchmarks on dams, pools, lakes, reservoirs, or like projects requiring ties to the

NSRS (i.e., NAVD 88) can often be economically accomplished using GPS height transfer methods—see NOAA 2005 (*Guidelines for Establishing GPS Derived Orthometric Heights (Standards: 2cm and 5cm*)). These guidelines describe detailed procedures for transferring orthometric elevations between points. Conventional differential leveling may be a more economical option, especially over short distances. Permanent benchmarks or control points established or reestablished are to follow the latest NOAA 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". Compliance with this policy requires approval by NGS prior to the data collection for the control survey. See Appendix B, paragraph 3.

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 the US Department of Commerce (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.

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, stable benchmarks should be added as necessary to control the project for conventional surveying methods or preferably at a larger density needed to accommodate GPS real-time kinematic construction control methods. These permanent benchmarks must be firmly connected to applicable hydraulic gages and regional NSRS datums as described above and are to follow the latest NOAA NGS guidelines and submitted to NGS for review using the NGS Policy on Submitting Data for Inclusion into the National Spatial Reference System or "Blue Booking". See Appendix B, paragraph 3.

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 gage. 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 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 gages, 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 and the NOAA National Geodetic Survey.

9. Periodic Reassessments of Controlling Reference Elevations

Subsequent periodic reevaluations of project reference elevations and related datums covered in this document will be included as an integral component in the various civil works inspection programs of completed projects. 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 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.

10. 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 a knowledge of the latest GPS technology used for extending vertical control and real-time construction layout. These 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 actions that may be required for each project—including a budget cost and time estimate to rectify any identified deficiencies. More information is to be provided at the required training classes.

11. Technical Assistance and Training

This interim 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 two and one-half day training course on vertical reference datums that is intended to supplement evaluation actions in this guidance. This training will cover all the technical references listed in

Appendix A of this guidance document. Designated coordinators for this assessment action should contact TEC for technical assistance and interpretations regarding this guidance, and for information on the required training course tentatively scheduled to be held in the Washington, DC area during March 2007. Prior to attending this training course, coordinators shall have thoroughly familiarized themselves with all the technical documents listed in Appendix A. This would especially include IPET 2006. The point of contact at TEC is Mr. James Garster (CEERD-TR-A), e-mail James.K.Garster@usace.army.mil.

12. 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).

Appendix A
Referenced Documents

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

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

EM 1110-1-1005
Control and Topographic Surveying (01 Jan 06 Draft at http://crunch.tec.army.mil/).

EM 1110-2-1003
Hydrographic 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 1110-2-1619
Risk Based Analysis for Flood Damage Reduction Studies.

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

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 .

NGS 2004
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.

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 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.

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
Additional Technical Guidance

B-1. 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 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 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.*

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 gage 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.

B-2. Water Level Gage Operation and Maintenance Standards

USACE-operated water level gages that are used to reference elevations of flood control projects or tidal parameters on navigation projects must be rigorously maintained and documented. District procedures should meet or exceed the standards set forth by the Department of Commerce (Center for Operational Oceanographic Products and Services—CO-OPS). An assessment should evaluate existing District gage 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/

B-3. 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 system is being adopted by most Federal agencies, including FEMA, USGS, 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. An NGS "Height Modernization" program has been underway for the last few years that supports the vertical component of the NSRS. Accordingly, USACE will ensure flood control projects and navigation projects are referenced to this NSRS system. Permanent benchmarks or control points established or reestablished for USACE projects are to follow the NGS Policy on Submitting Data for Inclusion into the NSRS or "Blue Booking", requiring GPS observation schema to be submitted to NGS prior to any data collection. See http://www.ngs.noaa.gov/FGCS/BlueBook/ for more info on this process. The NSRS is 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. Reference should be made to Appendix C (Development and Implementation of NAVD 88) of EM 1110-1-1005 (*Control & Topographic Surveying*). Procedures and standards for performing survey connections to the NSRS are outlined in EM 1110-1-1003 (*NAVSTAR GPS Surveying*) for 2-cm accuracy GPS height differencing, and EM 1110-1-1005 for traditional differential leveling.

B-4. National VDatum

VDatum, coupled with the Tidal Constituent and Residual Interpolation (TCARI) continuous tidal zoning model, has considerable future application to all 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, as shown in the figure below. 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 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.

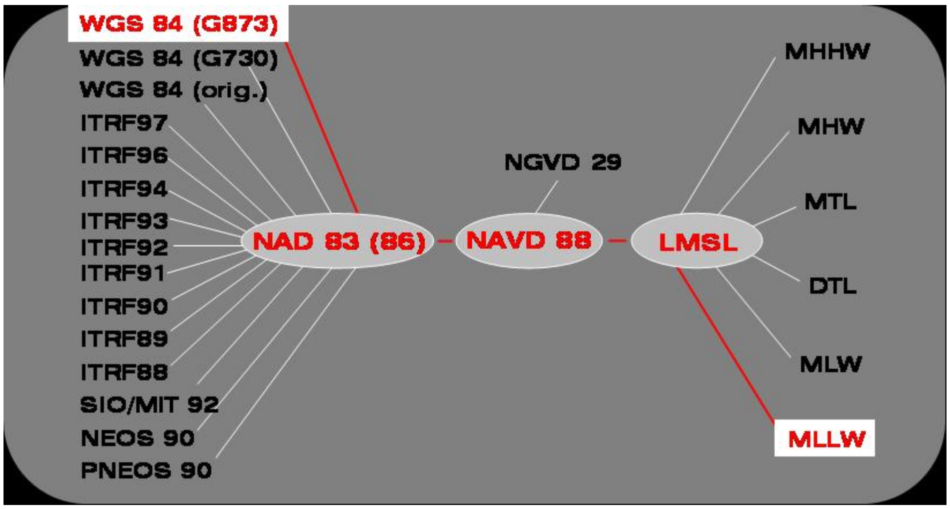

Figure 1. VDatum Transformation Options