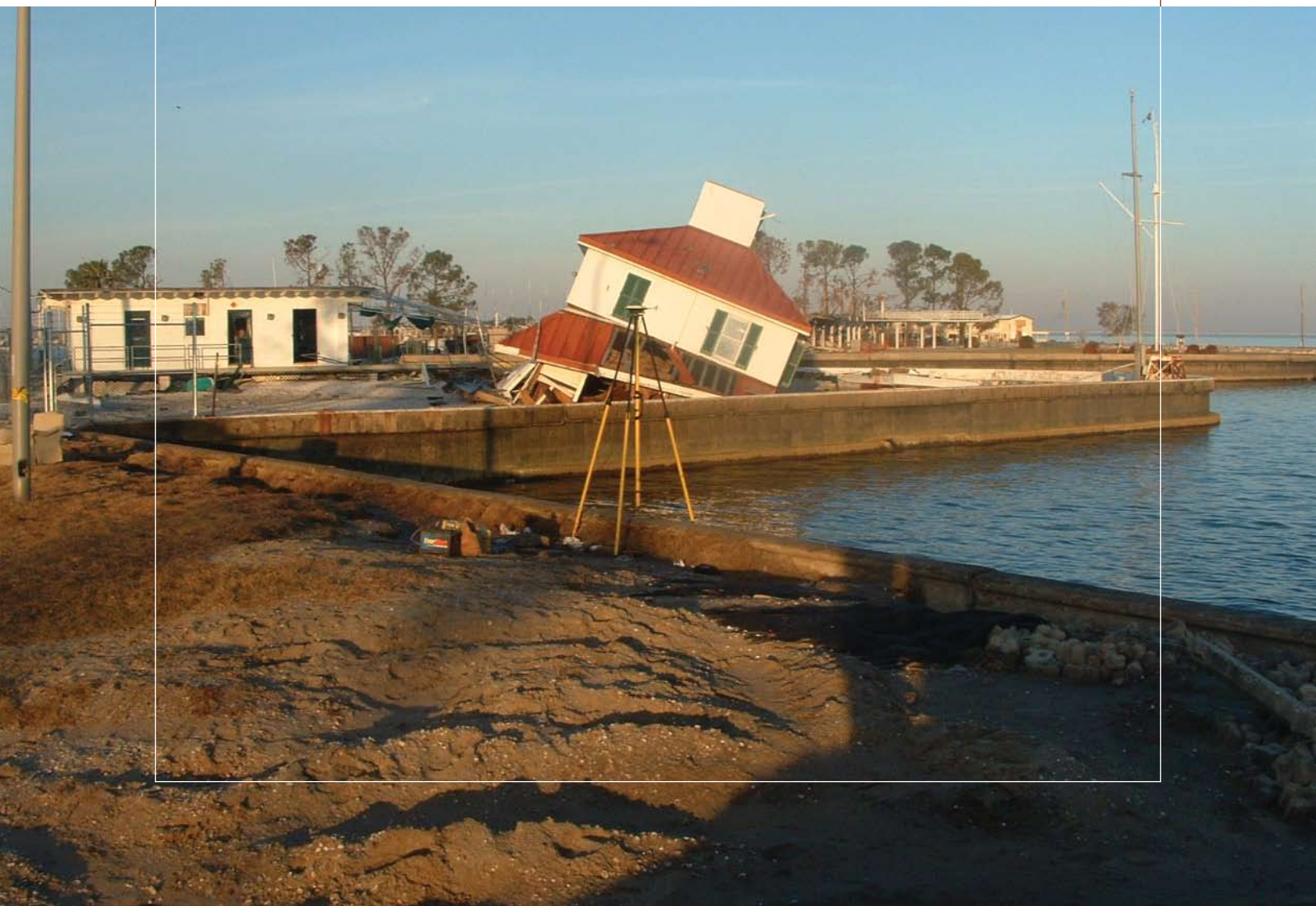
Analysis of Datums and Elevations in USACE Projects: FINAL REPORT

Prepared for
U.S. Army Corps of Engineers
Vertical Control Project Delivery Team

"Findings of errors [from the IPET Study] 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. We have a professional and ethical obligation…to ensure that they [our projects] 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."

-- Lt. Gen. Carl A. Strock
Memorandum for Major Subordinate Commands, December 2006



Analysis of Datums and Elevations in USACE Projects:

FINAL REPORT

--- December 2009 ---

Prepared for U.S. Army Corps of Engineers
Vertical Control Project Delivery Team

by the

Conrad Blucher Institute for Surveying and Science
Texas A&M University – Corpus Christi

Acknowledgements

The authors of the report wish to extend their sincere thanks to the following individuals for their cooperation and guidance throughout the research and publication process for the entire series of reports examining vertical accuracy requirements and estimation of uncertainty and datum variability:

James K. Garster
Survey Engineer, USACE AGC (Team Lead Vertical Control PDT)

Dave Doyle
Chief Geodetic Surveyor, NOAA NGS

William Bergen
PE, LS, Civil Engineer, HQUSACE

Mark Huber
Cartographic Technician, USACE AGC

Ed Myers
Physical Scientist, NOAA Office of Coast Survey

Dru Smith
Ph.D., Chief Geodesist, NOAA NGS

Andrew Garcia
Ph.D., Research Oceanographer, USACE ERDC-CHL

Manjo Samant
P.E., Program Manager, NOAA CO-OPS

Steve Gill
Chief Scientist, NOAA CO-OPS

David J. Robar
P.E., USACE Jacksonville District

Contents

Photo Courtesy:
Chad Purser/istock.com 1579370

About This Report

This report was prepared at the request of the Vertical Control Project Delivery Team, which is under the direction of James Garster, USACE. The mission statement of the Vertical Control Project Delivery Teams is:

> *To effect a fundamental change in the US Army Corps of Engineers (USACE) by implementing a nationwide reference system and subsidence standard methodology for updating geodetic and water level information within USACE projects and systems of projects. This will involve initiating and populating a database, providing and updating guidance manuals containing references to elevations and datums, developing certification process and providing training to reach certification, and developing standard methodologies.*

The USACE assembled this team as a direct result of the catastrophic losses endured after Hurricane Katrina struck the Gulf Coast in 2005. The emphasis on vertical accuracy came about as a result of an extensive investigation into the causes of levee failures in and around New Orleans. According to report written by USACE engineers entitled "Lessons Learned," published in the Point of Beginning website, "…elevation values used in construction were based on geodetic datums, not the local mean sea level as was the intent. Elevation values were often from older epochs of the existing NGVD 29 geodetic datum [National Geodetic Vertical Datum of 1929] instead of the most current published values" (http://www.pobonline.com/Articles/Article_Rotation/BNP_GUID_9-5 2006_A_10000000000000360086). Design engineers assumed that the NGVD 29 datum was equivalent to mean sea level and used NGVD 29 values as such, resulting in 1- to 3-foot differences between the intended design and constructed elevations." Moreover, the team learned that, "Construction projects were tied to/based on only one benchmark and often the datum epoch or date established was not included in construction documents." This is particularly troublesome given that "subsidence across the region has caused published benchmark elevations to change by more than 2 feet in the past 50 years."

In light of these findings, the USACE set out to assess reference datum accuracy requirements that are currently in place, and to establish whether the USACE is able to perform reliable datum uncertainty analyses to ascertain the risks of project failure. To that end, the USACE contracted with the Conrad Blucher Institute for Surveying and Science at Texas A & M University-Corpus Christi to objectively answer these critical questions. Under the leadership of Dr. Gary Jeffress, Executive Director of the Blucher Institute, the Task 11 team, as it is referred to by the USACE, was assembled to collect, analyze, and ultimately present their findings regarding current datum accuracy requirements, and to determine to what extent the USACE is able

Flooding in New Orleans after Hurricane Katrina, 2005
Courtesy: NOAA

"Subsidence across the region has caused published benchmark elevations to change by more than 2 feet in the past 50 years."

Benchmark *Courtesy: USACE*

to perform reliable uncertainty analyses to ascertain the risks of project failure.

Over the course of a year, the Task 11 Team produced a series of reports. The first report, Phase 1, provided an assessment of the reference datum accuracy requirements that are currently in place in the USACE, and what challenges and obstacles district staff encounter as they carry out needed projects for their Districts. This phase included a thorough literature review of current USACE policy manuals, circulars, and other documents, and an analysis based on numerous interviews with USACE staff from districts around the country. The Phase 1 report concluded that engineers and surveyors from the USACE generally understand the issues related to datum uncertainty and that they welcome reducing this uncertainty as well as establishing a uniform approach to a datum uncertainty analysis.

The report revealed that each District has its own agenda and timeline to achieve implementation, which is largely dependent upon the resources and available personnel with the education and experience to undertake the work. Over the past decade, Districts have reduced personnel and funding for elevation analysis. Some Districts face significant funding, personnel, and resource shortages needed to implement datum uncertainty analyses.

Next, the Task 11 team produced a report entitled, "Uncertainty Model for Orthometric, Tidal, and Hydraulic Datums for Use in Risk Assessment Models." Phase 2 offered a technical discussion of risk assessment, specifically regarding relevant orthometric and water level datums and datum conversion for use in protection grade design, and discussion of a suggested approach to integrating vertical uncertainty into future USACE project risk assessments.

Findings in Phase 2 included an analysis of existing risk assessment guidelines within USACE, as well as a statistical discussion of perceived risk versus actual risk. This statistical discussion goes on to compare and quantify accuracy versus uncertainty. Each datum used by the USACE is analyzed for uncertainty and the accompanying risks, including terrestrial datum and water level datum, and datum conversions, such as converting legacy NGVD 29 measurements to NAVD 88 elevations.

The findings in Phase 2 also revealed that a very limited analysis of risks associated with converting legacy datums to modern datums has been conducted by the USACE, and that these initial studies reveal the complexities involved in the process, as well as a lack of historical data coverage of significant portions of the United States. **Both Phase 1 and Phase 2 technical reports can be read in their entirety at: http://www.agc.army.mil/ndsp/index.html.**

This report, the last in the series, is designed to clearly summarize the findings of this yearlong study, offer recommendations, and provide an overview of the findings suitable for non-technical readers.

Summary of Findings and Recommendations:

Update and Standardize Tidal Datums

Finding 1:

The USACE is moving towards standardizing tidal datums to the tidal datums computed by the National Oceanic and Atmospheric Administration (NOAA) for the latest official National Tidal Datum Epoch (presently the 1983-2001 NTDE). This will ensure that the USACE projects are designed to match current sea levels, which are constantly changing. For example, several Districts continue to use legacy datums that do not depict current sea level values. Using out of date tidal datums results in inaccuracies in project management, including inconsistent and uncertain dredging grades, over-dredging grades, costs, and environmental impacts.

Recommendation 1:

The USACE must continue its adoption of the latest datums as computed by NOAA. The USACE should redetermine the present authorized project channel depths along the nation's shorelines to the present NOAA Mean Lower Low Water datum for the 1983-2001 National Tidal Datum Epoch. These authorized project depths should be maintained to future adjustments of Mean Lower Low Water datum as determined and republished by NOAA.

Grand Isle, LA
Photo courtesy: USACE

Significantly Expand the Nation's Water Level Observation Stations

NOS Station in Chippewa County, MI
Photo courtesy: NOAA

Finding 2:

A recent study by the National Ocean Service (NOS) uncovered numerous gaps in coastal coverage of long-term water level observation stations required for nation-wide vertical control for determination of tidal datums. Many USACE navigation projects have inadequate water level data or datum references, which directly affects the constructed grade of these projects.

Recommendation 2:

To avoid duplication of services, the USACE and NOS should cooperate to jointly establish water level stations in areas where USACE projects need water level data, when feasible and when funding allows. The USACE should develop a template for a Memorandum of Agreement to aid Districts in achieving this cooperative effort. Cooperatively established water level stations should be integrated into the National Water Level Observation Network. This cooperation will also expand the coverage of V-Datum, which the USACE is now using for coastal projects.

Panama City, FL
Courtesy: NOAA

NOS Station in Panama City, FL
Photo Courtesy: NOAA

Educate the Public about Risks Associated with Changing Elevations

Finding 3:

There is the perception among the general public that measured elevations are unchanging. A common assumption is that once an elevation is accurately established, it remains constant over the lifespan of a project. In fact, elevations are changing across the nation from Alaska to Florida and beyond. In Alaska the USACE is increasing dredging depths to accommodate the impact of glacial rebound. In the Sacramento valley, land subsidence is causing the USACE to take additional flood mitigation measures.

An important finding from recent catastrophic events, such as Hurricane Katrina, is that critical project elevations often change over time due to land subsidence and rebound as well as sea level changes. In addition, out-of-date vertical datums can increase costs and environmental damage associated with uncertain or inconsistent dredging grades.

Recommendation 3:

By educating the public about the risks associated with inadequate and out-of-date vertical datums for projects constructed and maintained by USACE, the Corps would gain broader support for necessary improvements and modernization projects necessary for public safety. This could begin by maintaining an ongoing dialogue with policy makers regarding the risks associated with changing elevations.

Benchmark, or marker, that indicates severe subsidence (the marker should be flush to the ground). *Courtesy: NOAA*

Rigorously Update Vertical Datum Requirements

Finding 4:

The USACE has adopted a vertical accuracy standard of +/- 0.25 feet at the 95% confidence level for the connection of USACE projects to the National Spatial Reference System (NSRS) maintained by the National Oceanic and Atmospheric Administration. This standard is very acceptable on a national scale; however, the NSRS is subject to change over time. Such changes resulted in levees being built one to three feet too low in New Orleans, because they relied on the National Geodetic Datum of 1929, instead of modern sea level datums, as computed by the National Oceanic and Atmospheric Administration (NOAA) for the latest official National Tidal Datum Epoch (presently the 1983-2001 NTDE) by the National Ocean Service. Ultimately, some of these levees failed during Hurricane Katrina, and the use of outdated datums and/or misunderstanding of datums contributed to the failures.

Recommendation 4:

The USACE should establish an internal committee and mechanism for periodic review of its vertical accuracy requirements and associated datums to continuously maintain its connection to the NSRS throughout the project life cycle. Moreover, the USACE expertise in surveying should be emphasized, including ensuring that USACE surveyors, engineers, and planners receive ongoing professional development, specifically education about the NSRS.

Floodwall failure, post-Katrina.
Courtesy: USACE

Incorporate Elevation and Datum Risk Assessment into the USACE Project Protocols

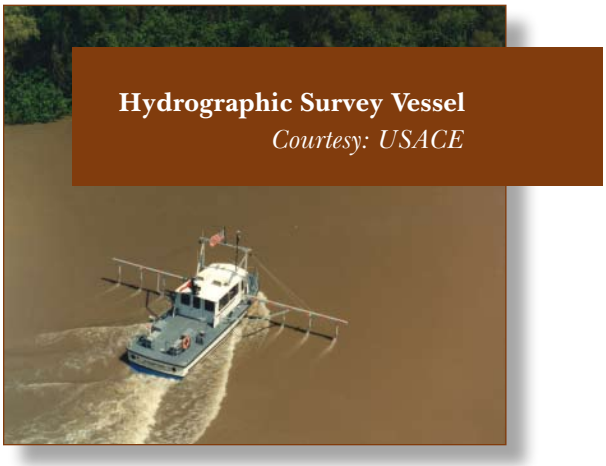
Finding 5:

As highlighted in Lt. General Strock's statement, currently there is no uniform USACE approach to incorporating vertical uncertainty estimates into USACE risk assessments. In the past engineers designing projects with known vertical uncertainty issues relied upon local knowledge and expert judgment to develop margins of safety.

Flooding in New Orleans, LA;
Courtesy: USACE

Recommendation 5:

The USACE should require every flood risk management project to formally analyze assumptions in vertical accuracy stemming from issues related to terrestrial datums, water level datums and datum conversions. The risks associated with land subsidence or rebound must be estimated over the project lifespan. Similarly changes in water level datums, both tidal and non-tidal, should be estimated for the duration of the project. Additionally, the inaccuracies associated with converting legacy datums to the project datums and to the NSRS must be incorporated into design elevations.



Hydrographic Survey Vessel
Courtesy: USACE

Update and Standardize Tidal Datums

Finding 1:

Sea levels are constantly changing, that's why it's so essential that the most current and accurate tidal datums available are utilized in USACE projects. However, several districts continue to use legacy datums that do not depict current sea level values. Using out of date tidal datums results in inaccuracies in project management, including inconsistent and uncertain dredging grades, over-dredging grades, costs, and environmental impacts.

The USACE is moving towards standardizing tidal datums to the tidal datums computed by the National Oceanic and Atmospheric Administration (NOAA) for the latest official National Tidal Datum Epoch (presently the 1983-2001 NTDE). This will ensure that the USACE projects are designed to match current sea levels.

Since the Army established the Corps of Engineers as a separate, permanent branch on March 16, 1802, the number of commercial, naval, and recreational vessel movements within dredged ship channels, rivers, and the intracoastal waterways has shown dramatic increases. According to the Department of Commerce, 95% of U.S. foreign trade by weight moves by sea, and two billion tons of cargo moves each year through U.S. ports. Since the 1930s the drafts of ships have deepened from 27 feet to today's largest and most efficient vessels with drafts of over 60 feet. Accurate ship channel depths relative to the latest sea levels are critical with many ships transiting our ports with two feet or fewer underkeel clearance.

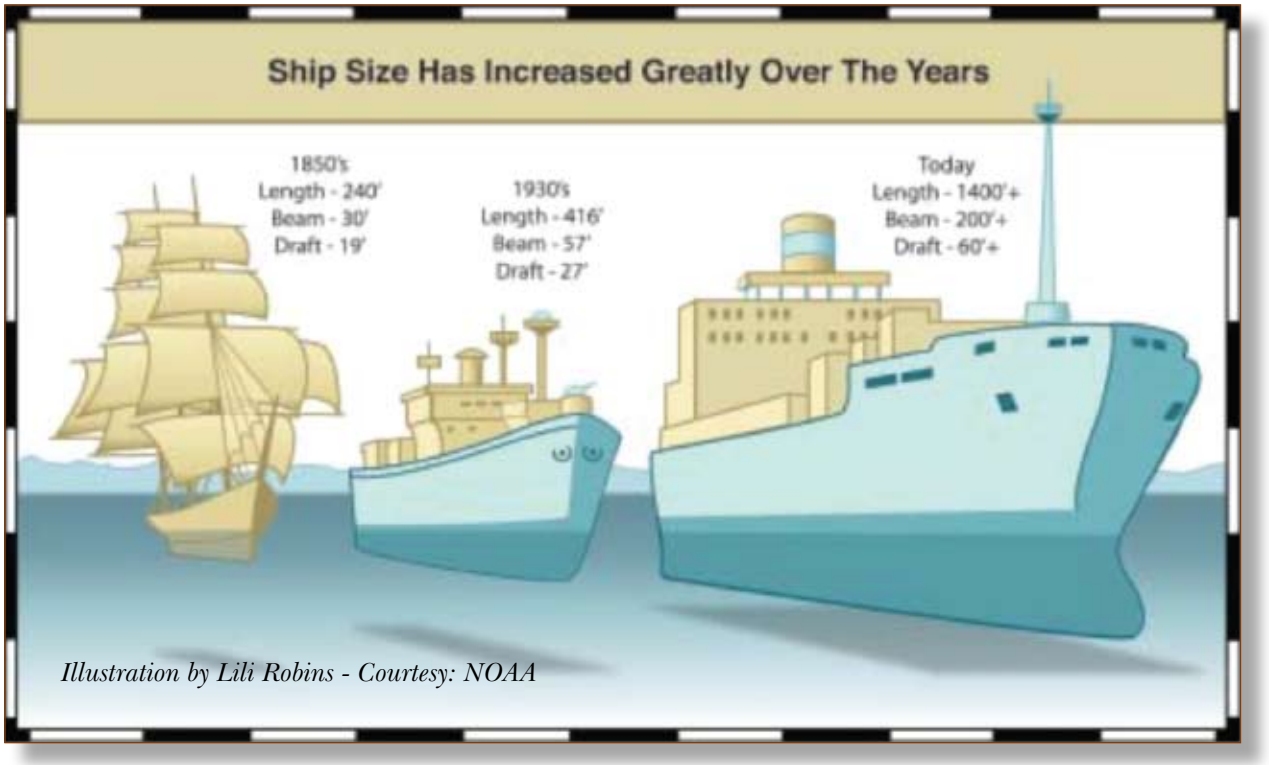


Illustration by Lili Robins - Courtesy: NOAA

Emma Maersk 3
Photo Courtesy: A.P. Moller Maersk

Most existing USACE projects were designed and referenced to older, superseded datums that are no longer supported by the U.S. Department of Commerce—e.g., National Geodetic Vertical Datum 1929, Mean Sea Level and Sea Level Datum of 1929, Mean Sea Level of 1912, Mississippi River Cairo Datum, Mean Low Gulf, etc. These older reference datums typically have unknown origins and may have significant elevation grade errors relative to updated National Spatial Reference System and National Water Level Observation Network datums used by other US federal and state agencies.

Recommendation 1:

The USACE must continue its adoption of the latest datums as computed by NOAA. The USACE should re-determine the present authorized project depths along the nation's shorelines to the present NOAA Mean Lower Low Water datum for the 1983-2001 National Tidal Datum Epoch. These authorized projects should be maintained to future adjustments of Mean Lower Low Water datum as determined and re-published by NOAA.

Significantly Expand the Nation's Water Level Observation Stations

Finding 2:

A recent study by the National Ocean Service (NOS) uncovered numerous gaps in coastal coverage of long-term water level observation stations required for nation-wide vertical control for determination of tidal datums. Many USACE navigation projects have inadequate water level data or datum references, which directly affects the constructed grade of these projects.

Many of the USACE coastal projects need accurate water level observations that may not be located near a tide gauge that is included in the National Water Level Observation Network (NWLON) maintained by the National Ocean Service. Historically, whenever NWLON data were not available, the USACE has installed its own tide gauges, which may or may not have followed the national standards for water level observation set by the National Ocean Service. While these USACE tide gauges allowed a project to proceed, the continuation of maintenance and operation was expensive and time consuming for USACE staff.

For more than a decade the USACE Galveston District has supported the Texas Coastal Ocean Observation Network (see p. 16) and has enjoyed the benefit of a very dense network of tide gauges along the Texas coast at a fraction of the cost of establishing its own tide gage stations. The data from TCOON is overseen by the national Ocean Service and is provided to all users to National standards.

Similarly, the Engineer Research and Development Center (ERDC) needed continuous precise water levels at Dauphin Island, Alabama. The USACE funded the construction of the gauge platform to hardened specifications and handed over the maintenance to the National Ocean Service. NOS supports the continuous operation of the gauge white the USACE continues to use the water level data for hydrographic surveys and dredging operations.

NOS Partnership with USACE (see http://tidesandcurrents.noaa.gov/army.html)

USACE should further its efforts to foster its partnership with NOAA

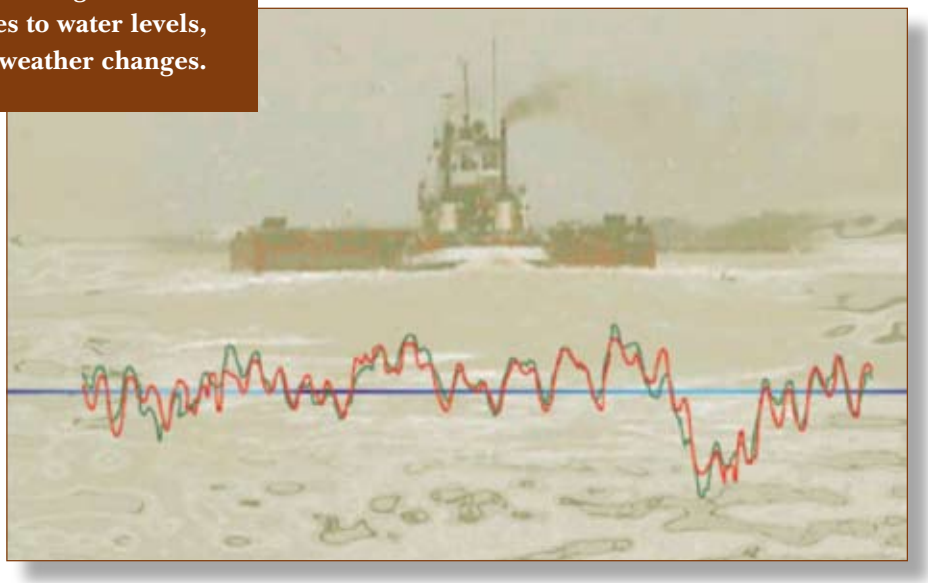
Tide Gauge at Dauphin Island, AL
Photo Courtesy: National Ocean Service, Center for Operational Oceanographic Products and Services

A cooperative approach to water level observation between USACE and NOS benefits both agencies. A cooperative approach for the establishment of required water level observations also allows state and local governments to participate, ensuring all levels of government can contribute and benefit from combining resources to collect high quality water level and meteorological data.

Recommendation 2:

The USACE should expand cooperation with the NOS and other state and local agencies to jointly establish water level stations in areas where USACE projects need water level data, when feasible and if funding allows. Cooperatively established water level stations should be integrated into the National Water Level Observation Network. This cooperation will also expand the coverage of V-Datum, which the USACE is now using for coastal projects (see p. 18).

Barge operators rely heavily on TCOON data. The data superimposed over this image indicate sudden changes to water levels, caused by weather changes.



Texas Coastal Ocean Observation Network (TCOON)

The Texas Coastal Ocean Observation Network was created by the Texas Legislature in 1991 to observe water levels along the Texas Gulf coast and is supported by a Memorandum of Agreement between Texas General Land Office (GLO) and NOAA's National Ocean Service (NOS). Soon after, the Texas Water Development Board (who used water level data to study bay and estuary circulation) and the Galveston District of the U.S. Army Corps of Engineers saw the benefits of TCOON and joined the agreement to assist in the sponsorship of the continuous operation and maintenance of TCOON.

Coincidentally, in 1989, the Conrad Blucher Institute for Surveying and Science (CBI) at Texas A&M University-Corpus Christi installed a state of the art water-level measurement system for the city of Corpus Christi as a source of real-time water level data for hurricane preparedness. Other state agencies, such as the GLO and the Texas Water Development Board, contracted with the CBI to provide coastal environmental observation data. Following the establishment of TCOON, the CBI was contracted to install and maintain TCOON and provide all observed data to all the TCOON sponsors. As a result, TCOON expanded to include more than 40 stations by 1998. NOS continues to provide oversight and technical assistance of the development of TCOON and participates in the annual sponsors' planning meeting.

"By far the biggest users of TCOON are the public…"

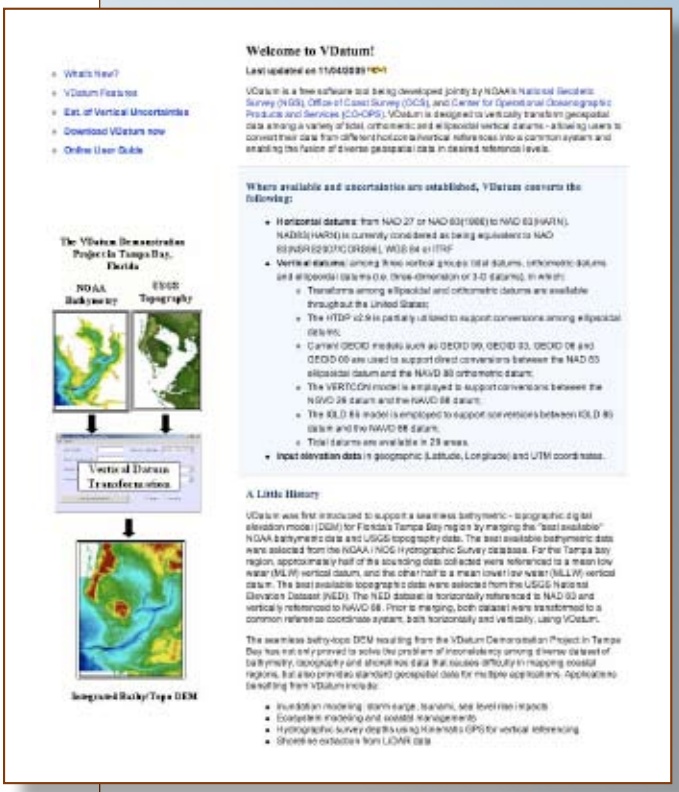
CBI's Division of Nearshore Research collects water level, wind speed, barometric pressure, salinity, water quality, and other environmental data from TCOON stations placed in the bays and estuaries along the Texas coast. Data are transmitted every three hours over the GOES satellite, which also allows NOS to acquire the data through the National Weather Service downlink at Wallops Island, VA. Data is now collected in near real time using Internet Protocol Modems using the cellular telephone network. Accessibility to the all observed data since 1991 is available through the TCOON website, which enables NOS personnel to validate a number of key attributes. This ensures that TCOON data is compatible with NOS standards and formats. TCOON is the first regional observation system in the country that allows this level of access and quality assurance by NOS. A password-protected section of the TCOON website allows designated NOS personnel access to the most critical quality-control attributes.

By far the biggest users of TCOON are the public, who use the data for planning recreational sailing, fishing, windsurfing, and surfing activities. Additionally, the public and emergency planners rely heavily on the data during tropical storm events in Texas. The success of the TCOON program can be used as a template for many regional observing systems now being initiated across the nation in support of the Integrated Ocean Observation System (IOOS).

Map of TCOON Stations (TCOON Stations are in blue; NOS Stations are in red)

VDatum: Integrating the Nation's Elevation Data Efficiently and Accurately

The National Oceanic and Atmospheric Administration (NOAA) has developed a revolutionary vertical datum transformation tool (VDatum) to address the inconsistent datum problem. A datum is the reference level to which geospatial data are gathered. Geospatial data collected by NOAA and many other agencies and entities, particularly data collected in coastal regions, suffer from being tied to many different vertical reference datums. VDatum translates geospatial data between 36 different vertical reference systems and removes the most serious impediments to data sharing allowing for the easy transformation of elevation data from one vertical datum to another.

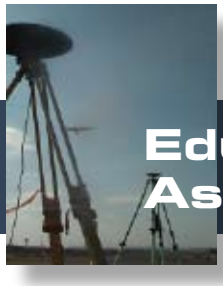


NOAA and the U.S. Geological Survey (USGS) first addressed the vertical datum transformation issue by collaborating on the pilot project of VDatum in the Tampa Bay region. The VDatum software was designed to accommodate 28 transformations spanning the three major classes of vertical datums: orthometric, ellipsoidal, and tidal. A geoid model was used to convert between orthometric and ellipsoidal datums, a topography of the sea surface was computed to relate orthometric and tidal datums, and tidal modeling was used to compute the tidal datums. The output from each of these models was integrated into the VDatum software and then applied to bathymetry and topography for Tampa Bay. Hydrographic survey data from NOAA, topographic data from the USGS, and other third-party elevation data were all converted to a common vertical datum using the VDatum software. These data were then integrated into a digital elevation model (DEM) to form a seamless data set across the land-water interface.

The successful development and implementation of VDatum in Tampa Bay showed how data could be made more useful to coastal managers and applications. Not only were all existing bathy/topo data integrated into a seamless DEM, but the tool can also be used to transform all future elevation data acquired in the area. Shorelines may be more accurately computed by applying VDatum to LiDAR data. Bathymetry may be more easily referenced to a vertical datum, without installation of temporary tide gauges concurrent to hydrographic survey operations. Furthermore, applications dependent on a seamless land-water DEM are now more accurate, including storm surge modeling, habitat restoration, sea level rise effects, and ecosystem studies. All of the benefits of having VDatum available in an area such as Tampa Bay demonstrated its potential utility in serving as a national backbone for linking and transforming elevation data from a multitude of sources.

Building a national VDatum has since proceeded with applications all around the country, from New York to California and along the Gulf Coast. Further development of VDatum continues, and as the regional VDatum applications begin to overlap, a seamless VDatum software will emerge to cover all of the U.S. coastal areas out to 25 nautical miles from land.

From NOAA's Vertical Datum Transformation website: http://vdatum.noaa.gov/welcome.html



Educate the Public about Risks Associated with Changing Elevations

Finding 3:

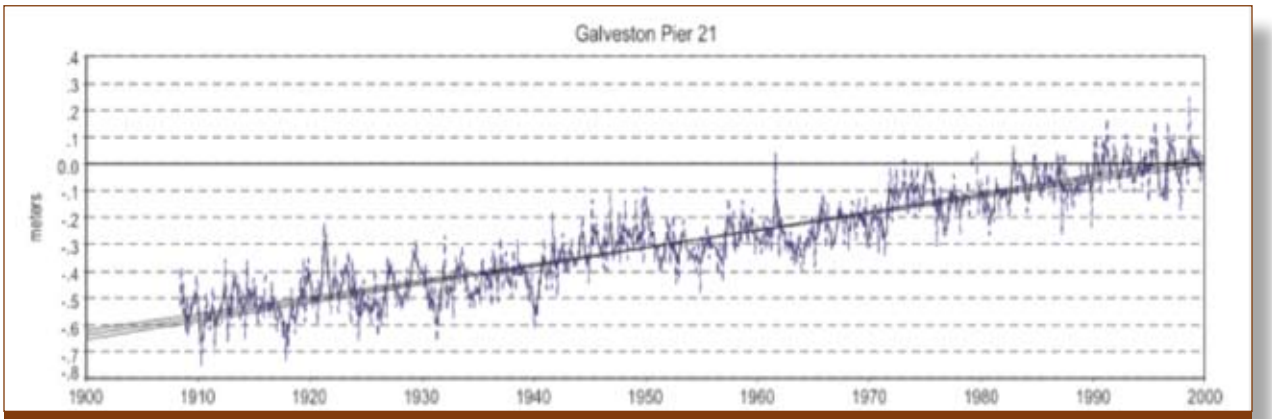
There is the perception among the general public that measured elevations are unchanging. A common assumption is that once an elevation is accurately established, it remains constant over the lifespan of a project. In fact, elevations are changing across the nation from Alaska to Florida and beyond. In Alaska the USACE is increasing dredging depths to accommodate the impact of glacial rebound. In the Sacramento valley, land subsidence is causing the USACE to take additional flood mitigation measures.

An important finding from recent catastrophic events, such as Hurricane Katrina, is that critical project elevations often change over time due to land subsidence and rebound as well as sea level changes. In addition, out-of-date vertical datums can increase costs and environmental damage associated with uncertain or inconsistent dredging grades.

Climate change and sea level rise are continuously brought to the public's attention. Unfortunately, as the discussion surrounding climate change has become more partisan, an atmosphere of confusion and disbelief has also emerged. Some associate the issues of subsidence with sea level rise and assume it is cause for debate and skepticism. However, there is now sufficient data to show that relative sea level change is occurring rapidly enough to require it be incorporated into engineering planning. Examples of this can be found in California, where subsidence along the Sacramento River has affected flood control levee elevations, and also along the entire Gulf Coast in Louisiana and Texas. The graph below from Galveston, Texas entitled, "Long Term Sea Level Data" shows the long-term relative sea-level rise at Galveston NOS tide gauge Pier 21. Note the substantial difference in sea level from 1929 to 2000.

Given the illustration below of the dramatic change is sea level over time, it is clearly evident that any USACE project along the coast must be continuously monitored for elevation changes.

Long Term Sea Level Data from NOAA Co-Ops



Galveston, TX rate of increase is equivalent to 2.13 ft/100 years at the Pier 21 tide gauge.

As mentioned earlier, the coastal shore protection and hurricane protection systems within the New Orleans District were the original source of datum uncertainty risk that led to this study when the New Orleans hurricane protection system failed during the storm surge event associated with Hurricane Katrina in 2005. The post-Hurricane Katrina Interagency Performance Evaluation Task Force (IPET) study identified that the failed hurricane protection system for New Orleans was caused by hurricane protection system construction elevations established on the National Geodetic Vertical Datum (presumably NGVD 1929) instead of the most recent tidal datums as computed by the Department of Commerce (NOAA, National Ocean Service). While the NGVD 1929 datum was accurate and very useful at its inception, developments in the science of geodesy have shown that by using mean sea level at 26 tide gauges as control for NGVD 29 actually introduced distortions into the 1929 adjustment. It is now known that the 26 tide gauges were subject to local hydrologic and meteorological effects. Also, the long-term effects of sea level rise and land subsidence should dictate that an up-to-date water level datum be used as the basis of elevations needed to reduce the risk of a water level event in order to compensate for changes in water level over time. The New Orleans District has moved to the NOAA NOS latest tidal epoch datum for the reconstruction of hurricane protection levees.

9th Ward, New Orleans
Photo Courtesy: USACE

Floodwall, post-Katrina
Courtesy: USACE

17th Street, New Orleans, post-Katrina
Photo courtesy: USACE

Downtown New Orleans
Photo Courtesy:
Joseph Nickischer/istock.com 2118963

While engineers and surveyors from the USACE generally understand the issues related to datum uncertainty and wish to reduce this uncertainty and establish a uniform approach to a datum uncertainty analysis, the general public is unaware of the need for continuous improvement of the National Spatial Reference System and the need for up-to-date accurate vertical datum in USACE projects.

By emphasizing the connection between disastrous events, such as Hurricane Katrina, and the importance of accurate elevations in construction of all protection systems the public can and should be educated sufficiently to understand the need for these changes.

By educating the public about the risks associated with inadequate and out-of-date vertical datums for projects constructed and maintained by USACE, the Corps would gain broader support for necessary improvements and modernization projects necessary for public safety. This could begin by maintaining an ongoing dialogue with policy makers regarding the risks associated with changing elevations.

Recommendation 3:

Hurricane Katrina
Courtesy: NOAA

Consequences of Elevation Inaccuracy

Photo Courtesy: Caroline Miller

Homeowners in a rural community near Beaumont, Texas are now very familiar with the consequences of out of date survey elevations, and taxpayers are paying for the mistake in the form of a government buyout of hundreds of now worthless houses. This is after the storm surge of Hurricane Ike flooded the homes with three feet of water, despite elevation certificates that indicated they were built several feet above the mean sea level. The approximate inaccuracy of the measurement? About three feet; that's a lot when you live along the Gulf. The discrepancy not only destroyed homes, but priceless memories, and for some residents, the hope of ever owning a home again.

When their homes were constructed in the Country Road Estates subdivision in the mid 1990's, surveyors relied on a monument, a brass disc, placed by the National Geodetic Survey in 1954. Back then, the monument's elevation was 6.32 feet above sea level. However, a lot changed over the decades, most likely due to both subsidence and corruption of the marker during construction projects. In 1980, federal surveyors for FEMA estimated the benchmark's elevation to actually be 3.1 feet lower than the 1954 measurement. At the time of construction, this was unbeknownst to the homeowners, who paid surveyors in order to receive Elevation Certificates (required by FEMA for flood insurance purposes) showing elevations above the flood stage. The surveyors assumed the data from the original 1954 survey was accurate and didn't cross check the elevations. The surveyors have since been fined by the Texas Board of Professional Land Surveying.

But what's even more troublesome is that inaccurate home elevations that are calculated using unreliable monuments could be widespread. A Texas Water Commission study of the area in the 1970's revealed that the area where the National Spatial Reference System benchmark was located was subject to approximately three feet of subsidence. Recent surveys of adjoining benchmarks show up to four feet in subsidence in the same area, indicating that the area has experienced another foot of subsidence since the Texas Water Commission report. According to Garey Gilley, a surveyor and director of the Texas Spatial Reference Center at Texas A&M University Corpus Christi, the same discrepancies can occur anywhere in Texas, to anyone who lives near a river, a stream, a creek, or a drainage ditch.

Possible solutions to the problem include updating the National Geodetic Survey that would replace monuments placed in the ground with a new network of station outfitted with GPS transmitters. The data produced by the transmitters would be continually updated, unlike the current system which relied on data derived from a brass disc placed in the ground 50 years prior. NOAA's National Geodetic Survey, in cooperation with other state and local agencies, has requested this modernization be funded and enacted. Unfortuntately, the funding for Height Modernization Program was severely cut in fiscal year 2009 by the U.S. Congress.

TEXAS BOARD OF PROFESSIONAL LAND SURVEYING
12100 Park 35 Circle, Bldg. A, Suite 156 MC-230 Austin TX 78753
(512) 239 5263 Fax (512) 239 5253
www.txls.state.tx.us

Unfortunately, the Board's concerns are not limited to this one monument. Due to the prevalence of subsidence, the unconsolidated soils, and other geologic factors in this area, the Board has concerns about the accuracy and reliability of other benchmarks in this area. This is not a new problem. The effects of subsidence in this area have been noted in a FEMA Flood Insurance

July 11, 2009

Study prepared in 1983 for the City of Port Arthur (Community No. 485499) and in 1982 report from the Texas Department of Water Resources on Land-Surface Subsidence in the Texas Coastal Region (Report 272), among other reports. The network of benchmarks in this area needs to be re-leveled in order to verify its accuracy.

It is the responsibility of governmental entities to establish reliable benchmarks for the security and benefit of the public. Land surveyors, and those that rely upon the services of land surveyors, depend upon the accuracy and reliability of benchmarks. Land surveyors are expected to connect all boundaries to identifiable physical monuments and must be able to rely upon the accuracy of public monuments in order to practice their profession. The network of public benchmarks in portions of Jefferson County needs to be modernized and verified for accuracy in order to provide that reliability.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SERVICE
National Geodetic Survey
Silver Spring, Maryland 20910-3282

AUG 6 2009

Re: Elevation Benchmarks in Jefferson County, Texas

Dear Ms. Foster:

Thank you for your letter of July 11, 2009, concerning elevation benchmarks in Jefferson County, Texas. Together with our partners at the Harris-Galveston Subsidence District and the Texas Spatial Reference Center at Texas A&M University at Corpus Christi, NOAA's National Geodetic Survey (NGS) is actively seeking a solution to constituent concerns about the accuracy and reliability of benchmarks in Jefferson County and the adjacent areas of the Texas coast. This cooperation has included technical assistance and funding through our National Height Modernization Program for the past several years. Unfortunately, in Fiscal Year (FY) 2009 the funding available for such work was greatly reduced by the U.S. Congress because of other national priorities.

Caroline Miller's House after flooding resulting from Hurricane Ike. The house has since been demolished.
Photo Courtesy: Caroline Miller

Rigorously Update Vertical Datum Requirements

Finding 4:

The USACE has adopted a vertical accuracy standard of +/- 0.25 feet at the 95% confidence level for the connection of USACE projects to the National Spatial Reference System (NSRS) maintained by the National Oceanic and Atmospheric Administration. This standard is very acceptable on a national scale; however, the NSRS is subject to change over time. Such changes resulted in levees being built one to three feet too low in New Orleans, because the USACE relied on the National Geodetic Datum of 1929, instead of modern sea level datums, as computed by the National Oceanic and Atmospheric Administration (NOAA) for the latest official National Tidal Datum Epoch (presently the 1983-2001 NTDE) by the National Ocean Service. Ultimately, some of these levees failed during Hurricane Katrina, and the use of outdated datums and/or misunderstanding of datums contributed to this failure.

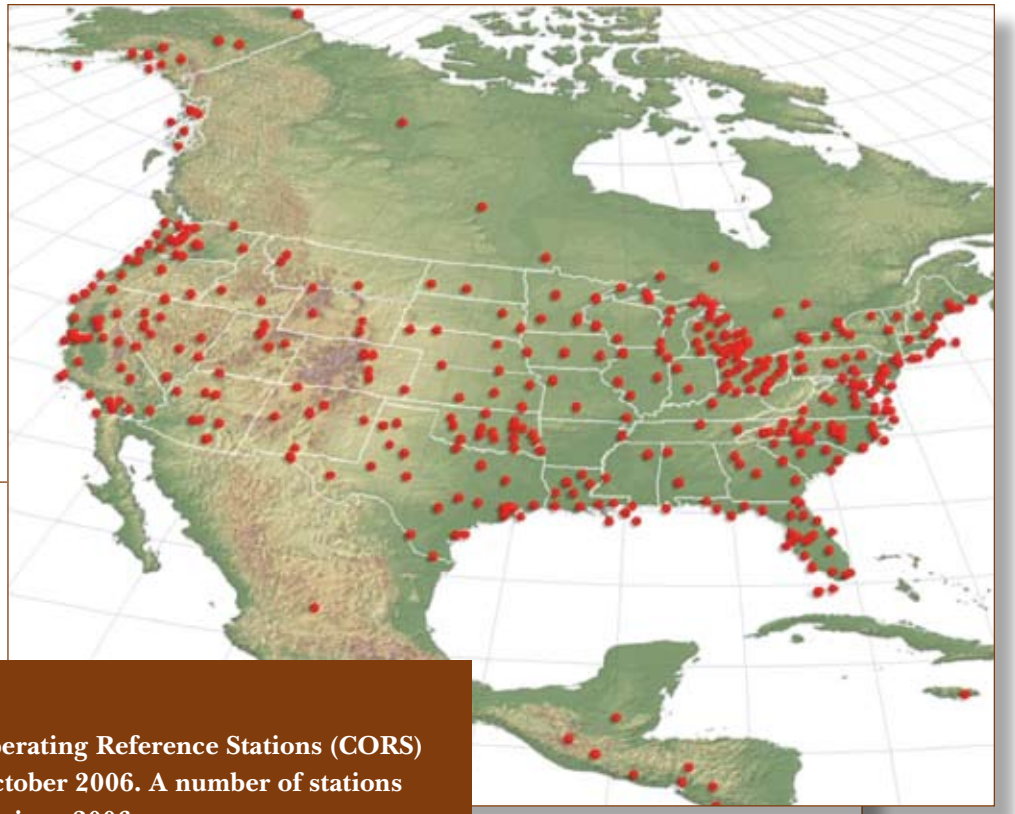
A continuously operating GPS reference station, part of CORS

The NSRS, including the Continuously Operating Reference Stations (CORS) GPS network, is maintained by several government agencies including NOAA-NGS, state government agencies, and contributing members of the private sector. NGS routinely conducts network analysis in areas to support the NSRS. Such analysis includes CORS coordinates and new GPS survey data, and might indicate the need for area readjustments. If it is ascertained that the published CORS coordinates have a negative influence on an area readjustment, then the CORS coordinates expressed in the International Terrestrial Reference Frame and/or the North American Datum of 1983 frame may be revised irrespective of any coordinate change tolerances.

Given this, the USACE's commitment to tying datum elevations to the NSRS is critical. In so doing, the USACE will ensure the most up to date datum elevations, and thus avoid inaccuracies that could have dire consequences, as was the case in New Orleans.

Recommendation 4:

The USACE should establish an internal committee and mechanism for periodic review of its vertical accuracy requirements and associated datums to continuously maintain its connection to the NSRS throughout the project life cycle. Moreover, the USACE expertise in surveying should be emphasized, including ensuring that USACE surveyors, engineers, and planners receive ongoing professional development, specifically education about the NSRS.



Continuously Operating Reference Stations (CORS) coverage as of October 2006. A number of stations have been added since 2006.

Incorporate Elevation and Datum Risk Assessment into the USACE Project Protocols

Finding 5:

As highlighted in Lt. General Strock's statement, currently there is no uniform USACE approach to incorporating vertical uncertainty estimates into USACE risk assessments. In the past engineers designing projects with known vertical uncertainty issues relied upon local knowledge and expert judgment to develop margins of safety.

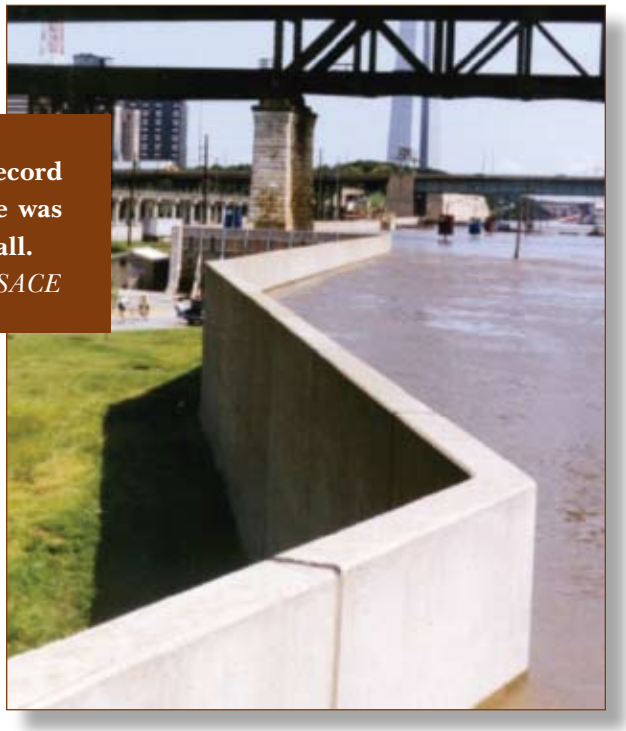
Land subsidence is common along the Gulf coast of the United States, whereas land rebound is common along the coast of Alaska. The combined effects of land subsidence, or isostatic rebound, coupled with sea level changes are referred to as relative sea level rise or fall. This can be a large source of elevation errors. Worse still, relative sea level changes results in elevation bias, bias in which most assumed project elevations are too high or too low.

In some cases it is possible to separate land subsidence or rebound from changing sea levels. However, in many cases there are insufficient data to separate the two effects. In engineering risk assessments, subsidence and rebound cause elevations to change relative to the intended datum over the project lifespan. This can be a critical consideration.

In many areas, the effects of relative sea level change can be estimated over the life expectancy of the project. In Galveston, Texas, for example, historical data at the Galveston Pier 21 tide gauge indicated an average relative sea level rise of approximately 0.21 feet every decade. For a project with a life expectancy of 50 years, this results in a relative sea level rise of approximately one foot. As the above examples illustrate, today, more than ever, it is important to carefully consider the impacts of vertical inaccuracy issues, relative sea level

Engineering designs need to account for vertical control over the project lifespan.
Photo courtesy: USACE

"…problems of vertical inaccuracy as well as land subsidence and rebound must be incorporated into risk assessments."



St. Louis Flood Wall. The 1993 flood's record stage of 49.58 feet at the St. Louis gage was just two feet shy of the top of the floodwall.
Photo Courtesy: USACE

change, as well as land subsidence and rebound. These conditions are ever changing, requiring periodic review and updates. Engineering designs need to consider the impact of these issues on their projects over its design lifespan.

Current USACE engineering guidelines for flood risk assessment are described in detail in EM 1110-2-1619, "Engineering and Design: Risk-Based Analysis for Flood Damage Reduction Studies." After Hurricane Katrina it was recognized that the problems of vertical inaccuracy as well as land subsidence and rebound must be incorporated into risk assessments. An approach to making adjustments to vertical elevations based upon these considerations should be standardized within the USACE and other agencies involved in conducting risk and damage estimates using assumed elevations.

A lone benchmark at Shell Beach, Louisiana - once on dry land - is now a visible reminder of the combined effects of relative sea level rise and shoreline retreat.
Photo Courtesy: USACE

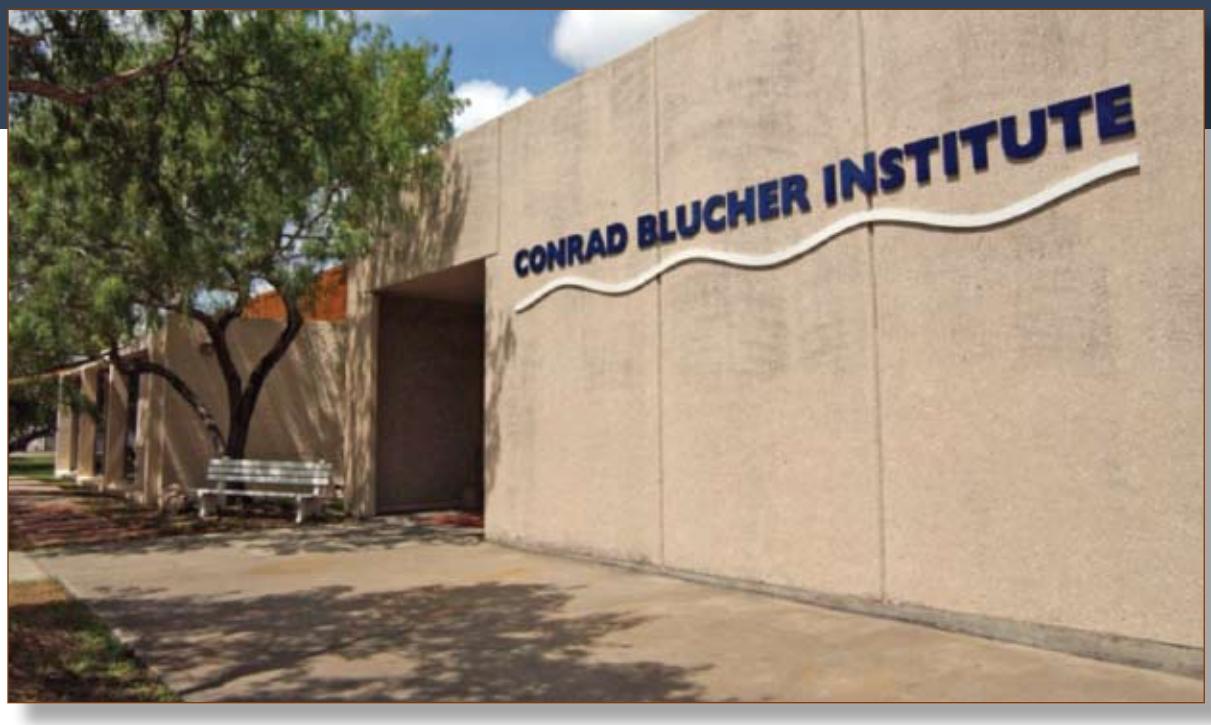
Recommendation 5:

The USACE should require every flood risk management project to formally analyze assumptions in vertical accuracy stemming from issues related to terrestrial datums, water level datums and datum conversions. The risks associated with land subsidence or rebound must be estimated over the project lifespan. Similarly changes in water level datums, both tidal and non-tidal, should be estimated for the duration of the project. Additionally, the inaccuracies associated with converting legacy datums to the project datums and to the NSRS must be incorporated into design elevations.

Multi-Purpose Reservoir in St. Louis District
Photo Courtesy: USACE

Areas where subsidence has been attributed to groundwater pumpage (Land Subsidence in the United States, USGS Circular 1182)

The Conrad Blucher Institute for Surveying and Science Texas A&M University - Corpus Christi



The Conrad Blucher Institute conducts innovative research and encourages scientists and professional engineers to develop and apply technology solutions relevant to surveying, scientific measurements, and to the issues in the Gulf of Mexico region and the nation. The Institute has achieved and maintains a national reputation for developing innovative geospatial science research and serves as a focused resource area for geospatial datasets relevant to the coastal environment. The Institute regularly participates in cooperative ventures with other academic entities and federal and state agencies.

About the Authors:

Gary Jeffress, Ph.D., RPLS: Dr. Gary Jeffress is a Professor of Geographic Information Science and Director of the Conrad Blucher Institute for Surveying and Science at Texas A&M University-Corpus Christi. Dr. Jeffress is Principal Investigator for the Texas Coastal Ocean Observation Network and the Texas Height Modernization program. He holds a Ph.D. in Surveying Engineering from the University of Maine (National Center for Geographic Information and Analysis), and a Master of Surveying Science and Bachelor of Surveying degrees from the University of New South Wales. Dr. Jeffress is a Registered Professional Land Surveyor in the State of Texas and past-president of the Texas Society of Professional Surveyors and past-president of the Geographic and Land Information Society. Dr. Jeffress currently sits on the Hydrographic Services Review Panel, and the Data Archiving and Access Requirements Working Group for the Scientific Advisory Board of the National Oceanic and Atmospheric Administration. Dr. Jeffress was born in Australia and has been citizen of the United States since 2003. He has lived in Corpus Christi since 1990.

Edward R. Jones, Ph.D. Statistics, B.S. Computer Science: Dr. Jones has more than 30 years of experience in teaching and applying statistical methods in research and manufacturing. This includes risk assessments and analysis for several corporations and government agencies. Since retiring from Texas A&M University-Corpus Christi, he has worked in the design, implementation and testing of scientific software.

Jennifer J. Bray, M.A. English: Ms. Bray is an instructor of writing at Texas A&M University Corpus Christi, and has been a technical writer and consultant since 2003. She is a former award-winning broadcast journalist.

Prepared for the U.S. Army Corps of Engineers

Vertical Control Project Delivery Team

by the

Conrad Blucher Institute for Surveying and Science

Texas A&M University-Corpus Christi