III. Geodetic Vertical and Water Level Datum

Summary of Scope and Purpose

The primary focus of this task is to establish a consistent, vertical reference framework model to support IPET performance evaluation activities. This geodetic framework--currently (NAVD88-2004.65)--will allow long-term monitoring of absolute flood/hurricane protection elevations relative to the local water surface reference datum, e.g., local mean sea level, river low water reference planes, etc. Controlling elevations on floodwalls, levees, pump stations, and bridges through the SE Louisiana region were surveyed relative to this framework. The framework additionally provides a consistent reference system for numerical and physical model studies performed in the region. This task assessed the impact of potential reduced flood/hurricane protection resulting from elevation changes (i.e., net land subsidence and sea level rise) throughout the region. The IPET additionally evaluated and compared flood/hurricane structure protection elevations (and older reference datums) at the time of original design/construction with the current elevations ("pre-Katrina"). Quality control field checks on recent aerial and LIDAR mapping will also be performed.

All of this work was accomplished in the field using water level gages (existing and historical), static GPS observations, and conventional topographic surveying methods. Archival data from the New Orleans District, and NOAA (National Geodetic Survey (NGS), and Center for Operational Oceanographic Products and Services (CO-OPS)) were used in these assessments.

The information contained in this Interim Geodetic Vertical and Water Level Datum section shall be considered provisional and subject to correction. Some of the geodetic and topographic survey data used in this assessment has not yet been fully quality assured. Due to time constraints, geodetic and water level datum concepts, assumptions, and estimates have not been adequately reviewed by the interagency team members, nor has an independent external review been conducted. Analysis of geodetic satellite observations and water level datum records obtained during the period November 2005 through mid February 2006 is still in progress. These actions will be completed prior to issuance of the IPET final report.

Background: (Education on Datums)

General Background on Southeastern Louisiana Elevation Datums

Geodetic Datums are vertical datums referenced to local mean sea level from a select set of tide gages, at different locations. In the United States, several vertical adjustments were made between 1900 and 1929. Since 1929, only two official datums exist, with several adjustments made in areas such as Southern Louisiana, where some original and releveling adjustments have been made. These datums make up the National Geodetic Vertical Datum of 1929 (NGVD 29). It was originally called the Sea Level Datum of 1929 (SLD 29) until Congress approved the name change on May 10, 1973. In 1929, the United States Coast and Geodetic Survey (USC&GS) created the SLD 29 (NGVD 29) as the datum with which to adjust all vertical control to, in North America. The 1929 datum is defined by 26 Tide Stations, held fixed to Local Mean Sea Level; 21 tide stations in the United States; and 5 tide stations in Canada. There were several adjustments to the datum, but no change in the definition of the datum until 1991, when the National Oceanic and Atmospheric Administration's (NOAA), National Geodetic Survey (NGS) established the North American Vertical Datum of 1988 (NAVD 88). Adjustments on the datums are noted by the year in parentheses after the datum name, i.e. NGVD29 (19xx) where 19xx is the year the NGVD29 datum was readjusted.

Before defining this datum and understanding the difference between NGVD 29 and NAVD 88, some key definitions of important factors must be explained. For example, the term **Equipotential** is defined as an irregular surface, perpendicular to the force of gravity at every location. This means that a potential gravitational force is the same at all locations along one surface, producing an infinite number of equipotential surfaces surrounding earth; and each of these locations along the surface has its own distinct shape and isn't parallel. A **Geoid** is an equipotential surface which most closely fits local mean sea level. It has problems in that it has variations in its local mean sea level. For example, the local mean sea level in New Orleans is not the same as in Florida. Variations in earth's gravitational field have an impact on the shape of a geoid. Therefore, local mean sea level at one location is not necessarily on the same equipotential surface as the local mean sea level for another location. Due to this difference in local mean sea level and the requirement to hold the 26 tide stations fixed, the network was warped to allow the local mean sea level at tide stations to remain fixed; hence, NGVD 29 is not equipotential.

On the other hand, NAVD 88 is defined by a tidal bench mark at Father Point/Rimouske, an International Great Lakes Datum of 1985 (IGLD 85) water level station at the mouth of the St. Lawrence River, in Quebec, Canada. Its elevation is held fixed in a minimally constrained, least square adjustment, which isn't distorted by constraints of local mean sea level in different areas, as in NGVD 29. Both datums produce orthometric heights or elevations. An orthometric height of a point on earth's surface is the distance from the reference surface (geoid) to the point, measured along the plumb line, normal to the geoid.

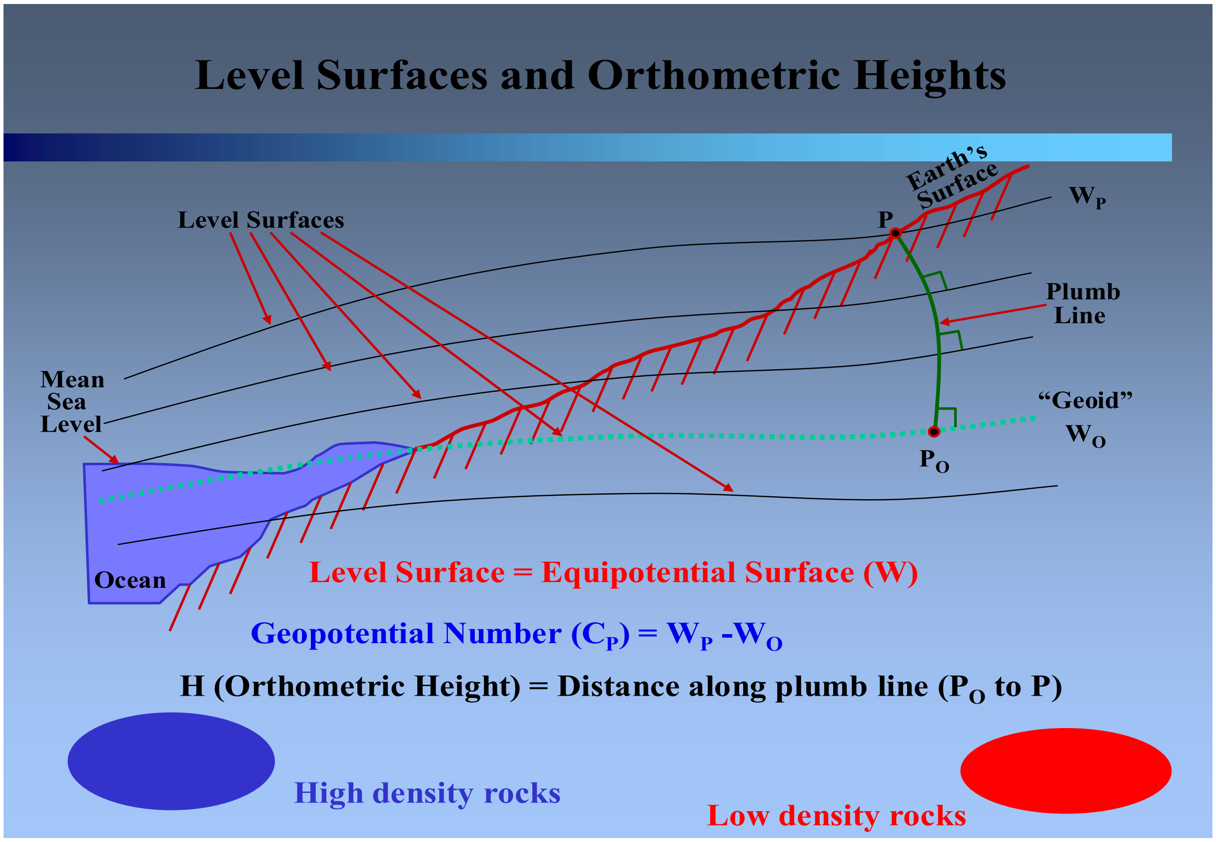


Figure III-1. Equipotential Surface and Orthometric Heights

Figure III-1 Key:

Level surfaces – in order to understand this term, imagine earth standing still; hence, the oceans standing still. There are no effects such as currents, tides, and winds, except for slight undulations created by gravity effects. Those slight undulations equal level surfaces.

Geoid – the level surface relating to today's mean sea level surface. This does not truly coincide with mean sea level because of the non-averaging effects of currents, tides, water temperatures, salinity, weather, solar/lunar cycle, etc. The geoid is a best-fit mean sea level surface.

Equipotential surfaces - add or subtract water and level surface changes, parallel to previous surface. This means creates an infinite number of possible level surfaces. Each equipotential surface has one distinct potential quantity along its surface.

Point on earth's surface - the level surface parallel to the geoid, achieved by adding or subtracting potential. Lines don't appear parallel; they are based on the gravity field and are affected by mass pluses and minuses.

Geopotential number - the numerical difference between two different equipotential surfaces. **W** = potential along a level surface. **CP** = geopotential number at a point.

Plumb line (over exaggerated in drawing) - a curved distance due to effects of direction of gravity, known as deflection of the vertical.

Orthometric height - exactly the distance along this curved plumb line between the geoid and point on the earth's surface. Close approximations can be made, but for accuracy, the gravity needs to be measured along this line, requiring a bored hole, which is impractical.

Illustration III-1. Excerpt from U.S. Army Corp of Engineers (Mean Gulf Level of 1899) Manual

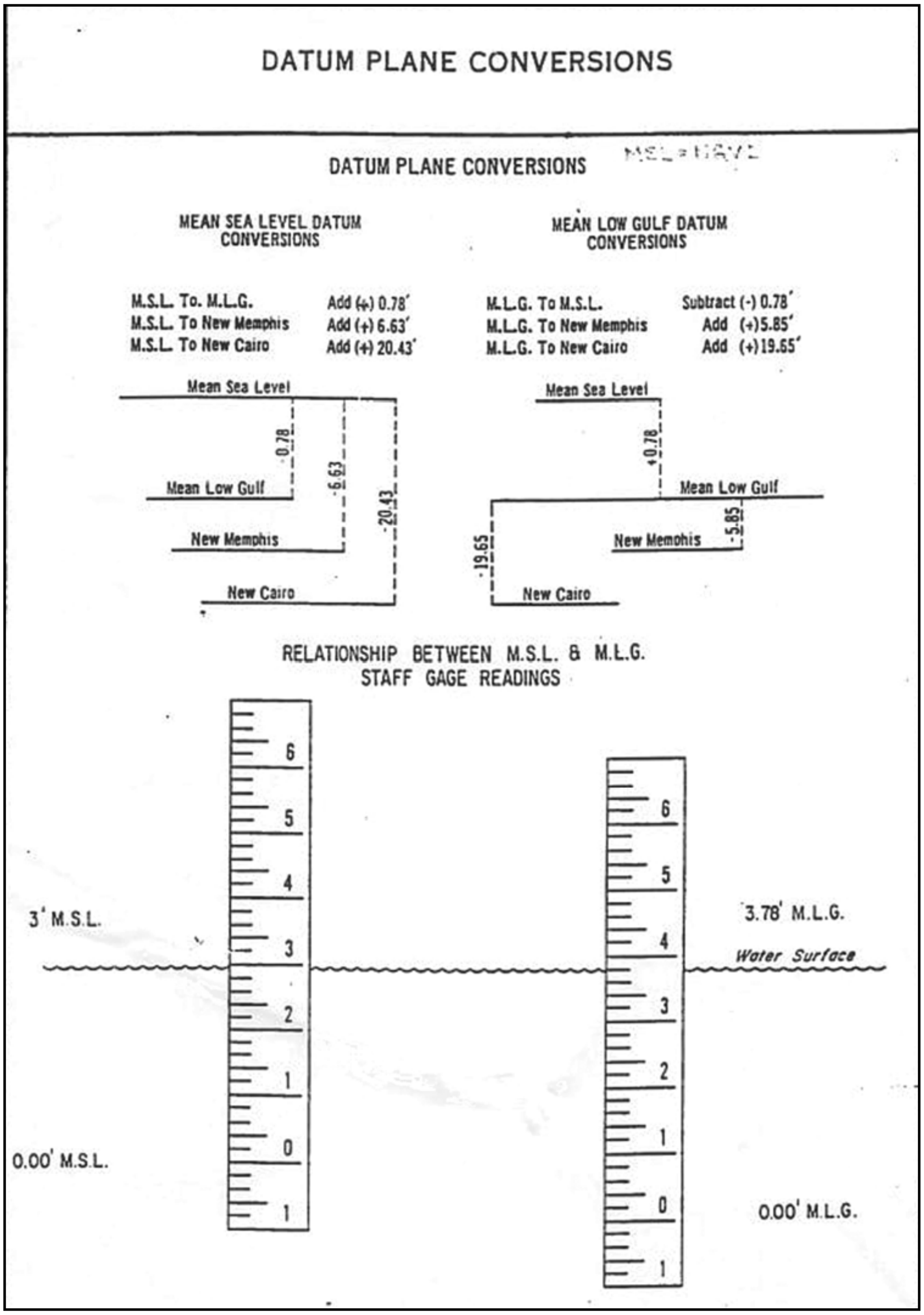
"In 1850, pursuant to an Act of Congress, the Secretary of War directed Mr. Charles Ellet Jr. to make a complete survey of the Ohio and Mississippi Rivers, with a view toward a master plan for flood prevention and navigation. In 1876, before the Mississippi River Commission was formed to coordinate all activities on the river, a survey of the Mississippi was begun in the vicinity of Cairo, Illinois, nicknamed Little Egypt. A temporary datum was adopted at 300 feet below a plane known as the Cairo City Datum of 1871. When the same survey was begun in the vicinity of Memphis in 1877, another temporary datum was adopted at 225 feet below the high water of June 23, 1858 at Memphis without any connection to the lower Delta Survey Datum of 1858. The first connection by precise levels between Memphis and Cairo was completed in 1880. The Mississippi River Commission established a tide gage at Biloxi, Mississippi. In 1882, a final value was adopted for Mean Gulf Level by the Mississippi River Commission based on the mean years of 1882, 1884, 1896, 1897 and 1898. In 1890, re-leveling was started at Fort Adams, Mississippi. The re-leveling ran south to Baton Rouge, Louisiana and north to Cairo, Illinois. In 1910 the level line from Memphis to Cairo was completed.

The U.S. Coast & Geodetic Survey (USC&GS) adopted the Mississippi River Commission value of Mean Gulf Level of 1899 and used it in the general adjustment of 1898, 1903 and 1907. The USC&GS later performed the General Adjustment of 1929, in reference to adjustments and datum relationships. The published elevations of the Mississippi River Commission for level lines between Biloxi and New Orleans and along the Mississippi River are mainly observed elevations based on one tide station, without orthometric corrections applied or corrected for closure. The relationship of Mississippi River Commission Vertical Datums with the Mean Sea Level Datum of 1929 will vary as a function of observational error and as the orthometric height varies. In 1944, the varying difference was noted between Mississippi River Commission Vertical Datum and USC&GS 1929 resulted in the tie-point method being established. However, the tie-point method seems to have faded from use. The Mississippi River Commission Vertical Datums have evolved into merely a number of indices that are transformed by algebraic addition. The true relations between the various Mississippi River Commission Vertical Datums and Mean Sea Level 1929 are now obscured by time and no longer used. The index relationships are as follows:"

Datum	Conversion to Mean Sea Level 1929
Ellet Datum of 1850	unknown
Delta Survey Datum of 1858	0.86
Old Memphis Datum of 1858	-8.13
Old Cairo Datum of 1871	-21.26
New Memphis Datum of 1880	-6.63
Mean Gulf Level Datum (preliminary) 1882	0.318
Mean Gulf Level Datum of 1899	0.00
New Cairo Datum of 1910	-20.434
Mean Low Gulf Level Datum of 1911	-0.78

Figure III-2. Datums and Conversions (all differences are in feet) Reference: Point of Beginning; Surveying Little Egypt by Milton Denny, PLS

Illustration III-2. Visual Chart of Datum Plane Conversions



Definitions:

The Cairo Datum (also referred to as New Cairo Datum) - based on a benchmark at a Corps of Engineers facility in Cairo, Illinois. Benchmark originally 20.434 feet above LMSL, so one had to always subtract 20.434 from each Cairo Datum number to equate it to LMSL.

Tidal Datums - used to establish local tidal phase averages as reference levels from which to reckon height or depth observations. To accurately compute, observations must be taken at a tide gage that has been collecting data for a period of over a 19 year National Tidal Datum Epoch. This time period allows inclusion of all variations in the path of the moon about the sun. Tidal datums are locally derived and should not be extended into areas which have differing hydrographic characteristics, without substantiating measurements. The most commonly used tidal datums are:

→ Mean Higher High Water (MHHW) - the average height of higher high waters at a tide gage, covering a 19-year period;

→ Mean High Water (MHW) - the average height of all high waters at a place, covering a 19-year period;

→ Mean Tide Level (MTL), 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. The difference is MTL does not include all the tide levels (i.e. MHHW and MLLW) unless the tide at a particular location is diurnal;

→ Local Mean Sea Level (LMSL), commonly referred to as Mean Sea Level (MSL) - the average height of the surface of the sea at a tide station for all stages of the tide, covering a 19-year period which is usually determined from hourly height readings measured from a fixed and predetermined reference level; and

→ Mean Lower Low Water (MLLW) - the average height of the lower low waters at a tide gage over a 19-year period.

Subsidence and Louisiana Surface Levels

Subsidence is the lowering or sinking of earth's surface. In Louisiana, subsidence is occurring at a rate of up to one inch, every three years, in some areas; especially in Southern Louisiana. Until the October 2005 release (by NOAA's National Geodetic Survey) of 85 benchmarks located in southern Louisiana, which showed heights (elevations) accurate to between 2 and 5 centimeters, surveyors, engineers, and the U.S. Army Corp of Engineers in New Orleans used vertical heights that had not been calibrated nor checked for several years; hence, inaccurate. Some of the 85 stations, which are part of the NAVD 88 (2004.65) epoch, showed as much as a one foot subsidence, or change, since the original published heights, covering a 10-year period. The average rate of subsidence across the area was about 0.6 feet subsidence/change, over a 10 year period.

This indicates that heights (elevations) published in the 60's, 70's, 80's, and early 90's may have changed even more. Southern Louisiana is currently undergoing the largest loss of land in the nation, due to subsidence and erosion; especially in the New Orleans area.

NOAA's objective is to improve upon the current vertical reference system, the NAVD 88 (2004.65) epoch, which consistently evaluates previously constructed, and proposed flood control and hurricane protection structures in New Orleans and Southeast Louisiana.

During a recent conference, Coastal Zone '05, officials from NOAA announced the new elevations for Louisiana [NAVD 88 (2004.65)], to improve the accuracy of the state's survey benchmarks and insure their accuracy for longer periods than in the past. "Using new technology available, such as the Global Positioning System and NOAA's Continuously Operating Reference Stations, will allow us (NOAA) to provide accurate elevation reference points in an efficient and timely manner," said Richard Spinrad, Ph.D., Assistant Administrator for NOAA's National Ocean Service.

"These new heights are more considerably accurate than what we have been able to measure previously," said Charlie Challstrom, former director of NOAA's National Geodetic Survey. "There is much work to be done, including providing tools and educating users on how to utilize the new information for future projects." It is critical that users of elevation data apply it in accordance with new approaches being developed, and work with NOAA and the Louisiana State University's, Spatial Reference Center (LSRC) to improve the geospatial reference system in Louisiana. While there will be fewer specific benchmarks maintained, the overall accuracy of the heights will be maintained for longer periods.

NOAA does not predict the rates of subsidence, nor attempt to determine its causes. We supply data used by the U.S. Geological Survey, U.S. Army Corps of Engineers, FEMA, state agencies, academia, emergency planners, engineers, surveyors, environmental restoration efforts, and others, to determine those rates. Furthermore, NOAA plans to maintain and update the NAVD 88 (2004.65) network of stations.

General background on the Low Water Reference Plane (LWRP)

The LWRP is the statistical elevation profile of the river, based on gage readings for times when the river discharge was exceeded 97% of the time or record during that twenty year period of observation. We have two known "epochs" of Miss. River LWRP the 1974 and the "1993" that are active. The 1974 LWRP Mile 313.7 to 242.0 is based on [the] 97% discharge duration of Tarbert Landing (1954 - 1973) and corresponding stages; mile 242.0 to Head of Passes is based on the Mean of 40 years (1891-1930) at Regular (MRC) gages and adjusted from low water information obtained Sept. 1931 and Nov. 1933.

New Orleans District updated the LWRP in the early 1990's and may have used a different statistical construct.

Background and Information on the Mean Low Gulf (MLG), as it interfaces with low water reference plane, will be provided in the final report.

Data Collection and Processing for Tidal/Datum Relationships

Development of Phase 1 Survey Data Collection Network Design

In order to develop a relationship between the local mean sea level and the current geodetic vertical network across the project area, measurements had to be made between tidal stations and the geodetic vertical network. This data collection effort was referred to as the Phase 1 survey. The Phase 1 survey involved GPS static survey measurements of existing and historical NOAA and USACE water level and tidal stations measured relative to NAVD 88_2004_65 benchmarks. Because of time constraints, the idea to use existing and historical gage information was chosen over installing gages over greater New Orleans for a period of one year. Conventional leveling, using precise digital leveling instruments, was used to measure differences between a minimum of three tidal benchmarks at each tidal station location to check for consistency as required by NOAA CO-OPS.

Static Survey Phases

Three phases of GPS surveys were planned as the water receded and survey crews moved southeast and northeast along partially closed roads. Two phases were planned from a meeting in November 2005 and a third phase was added and then abandoned as the crews found tide gauge sites underwater and monuments destroyed. The Phases were called Phase 1A, Phase 1B, and Phase 1C.

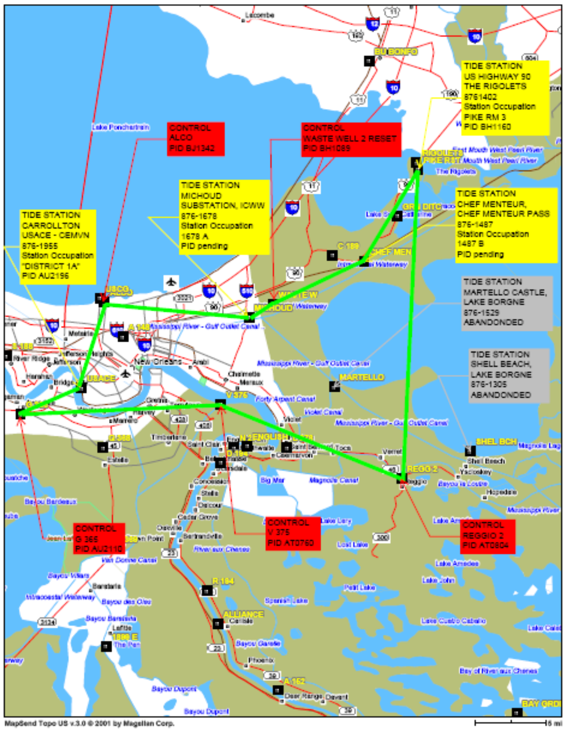


Figure III-3. Phase 1A Stations

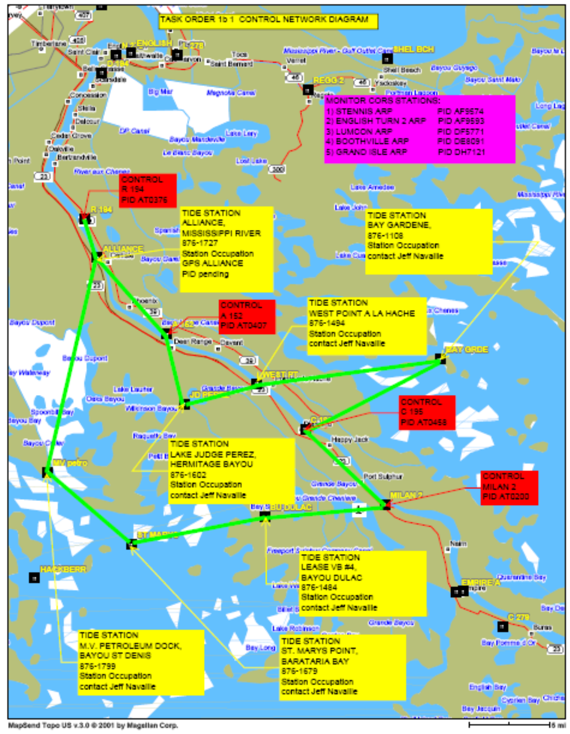


Figure III-4. Phase 1B Stations

The Phase 1A GPS static survey design unfolded as government personnel and contractors slowly reentered restricted areas just outside the City of New Orleans. Originally six tide stations were to be measured for the purpose of tying the tidal datums to the geodetic datum in Phase 1A. Three of the six tide stations were found to be totally destroyed during a reconnaissance survey to recover monuments and take photographs of these tide station sites. On 9 November 2005, team members visited the site of Tide Station 8761426 Greens Ditch, Lake St. Catherine to recover tidal bench marks. They reported the entire area had been graded with no sign of “All in the Family Camp” (a reference sited in the benchmark descriptions) or any of the tidal benchmarks. They reported no references existed to measure distances in order to recover the monuments. On 9 December 2005, personnel from 3001 visited Tide Station 8761529, Martello Castle, Lake Borgne. A photograph taken with a camera direction to the northeast shows the complete destruction of the castle. The three tidal benchmarks on this structure are considered destroyed. To the southeast of the castle on the marsh shoreline, four tidal benchmarks A, B, C and D were monumented in 1982; however, the personnel indicated that since 1982 those marks would now be 30 or 40 feet off the shoreline underwater. On 9 December 2005, personnel from 3001 visited Tide Station 8761305, Shell Beach, Lake Borgne. Three photographs taken showed the total destruction of the tide station that once recorded water level measurements from a large concrete quay built in World War II. One photograph to the west with the Fort Beauregard ruins in the background depicts the shoreline difference since 1982. The tidal benchmark in the foreground assumed to be 1305F or 1305G is bent and out in the water. This shoreline retreated at least 20 to 30 feet. One tide station at the New Orleans

District Office was added to the survey. NOAA named the station Carrollton. The USACE tide station was not measured to NOAA standards; however, useful information for this report will be tabulated including this tide station on the Mississippi River.

Phase 1B changed four or five times during the reconnaissance. Access to most of the tide stations in this area are by boat. The final GPS network for this static survey included NOAA Tide Stations: 8761602, Lake Judge Perez, Hermitage Bayou and 8761799, M.V. Petroleum Dock, Bayou St. Denis. Also included was a USACE tide station located at West Point, A La Hache on the Mississippi River. Seven benchmarks were recovered at 8761602, Lake Judge Perez, Hermitage Bayou (**Lake Judge Perez)**, one of which was damaged. This site was used in phase 1b1. The tide station USACE West Point, A La Hache, Mississippi River (**Pointe a la Hache)** was visited and incorporated into the Phase 1b1 network. At the tidal station 8761799, M.V. Petroleum Dock, Bayou St. Denis (**MV Petro**) 4 of the 5 monuments were recovered. Several tidal stations that were proposed to be included in the phase 1B survey were reported destroyed. Only two primary NOAA benchmarks at USACE Alliance, Mississippi River (Alliance) were not recovered. Three NGS vertical rod marks were recovered along the highway. Instead of using this site, the tidal station at **EMPIRE** was used since more monumentation called for on the description sheet were recovered at that site. It was also in close proximity to one of the 2004.65 marks, so only level work needed to be preformed here. The tidal station 8761679 St. Mary's, Barataria Bay (**St. Mary's Point**) was not used since no monuments were recovered at this site as it is now open water. The tidal station 8761108 Bay Gardene, Gulf of Mexico, was not used since insufficient monuments were recovered for it to be considered for use in the Phase 1b scheme. One of the monuments was found bent over, another was in about three feet of water, and another was believed to be under a pile of shell material. Not sure about the others. Pictures were taken to document the site.

The initial Phase 1C survey was removed due to time constraints, access to tidal benchmarks, and speculation, based on aerial photography, that the marks would not be found in useable condition. Another task order called Phase 1C was executed 28 February 2006 to identity, if possible with GPS, a 0.1-foot difference noticed in the Phase 1A measurements at Tide Station 8761927 U.S.C.G, New Canal relative to Tide stations 8761487, Chef Menteur and 8761402 , The Rigolets east of New Orleans. At a minimum, the task order will check the vertical control back to the primary tide gauge for Lake Pontchartrain and Lake Borgne, which is 8747437, Bay Waveland Yacht Club, Bay St. Louis, Mississippi.

The initial design of the GPS networks was based on the location and type of vehicle access to the tide stations. A National Geodetic Survey requirement for at least four NAVD 88_2004_65 geodetic marks surrounding the tide stations was carried out to ensure no recent benchmark settlements were placing unwanted bias into the GPS network measurements. A USACE civil engineer at the Engineer Research and Development Center, Alexandria, Virginia developed the preliminary GPS networks that could be field modified by a survey field coordinator from Jacksonville District on the ground in New Orleans. The network GPS diagrams were then sent to the National Geodetic Survey (NGS) for pre-approval into the National Spatial Reference System database of geodetic information. The networks were also checked to meet NGS GPS derived height specifications for data collection under the NGS two centimeter standard.

The Phase 1A GPS survey was exclusively land vehicle access after Martello Castle and Shell Beach tide stations were found destroyed. These two sites could only be accessed by water or air vehicles. The Phase 1B GPS survey network went through numerous changes as many sites were either destroyed or found under-water. A few USACE water level gauge sites on the Mississippi River were being added and removed as well as field conditions changed.

Contractor Data Collection and Processing Procedures

All of the data collection for this task was accomplished through a St. Louis District task order to 3001 Inc. who performed the data field data collection and processing.

The GPS data was collected using four Trimble 4000 SSE receivers, two Trimble 4000 SSI receivers, one Trimble 4700 receiver, six fixed-height tripods, six Trimble Compact L1/L2 antennas with ground plane and one Trimble microcentered L1/L2 antenna with ground plane. The differential leveling was performed with a Leica DNA 03 differential level.

GPS Data Collection and Processing. The static GPS network for this part of the project was designed to provide measurements from newly published NGS control points with NAVD88 2004.65 elevations to existing and historical tide stations. The GPS field procedures followed the NGS Bluebook specifications, as defined by NOAA 2005 - Guidelines for establishing GPS derived orthometric heights (standards: 2cm and 5cm) as well as the guidelines established in EM 1110-1-1003. The GPS network design was approved by the NGS Representative on the IPET project. The network was designed to include enough existing local control to establish elevations and positions on the temporary benchmarks which were surveyed as part of the network. The network was also tied into Continuously Operating Reference Stations (CORS). The datasheets for the CORS and the NGS monuments used can be found in the survey report supplied by 3001 Inc. (IPET-Survey Report.pdf) posted on the IPET Data Repository. The network was designed with multiple, simultaneous occupations of points in order to provide redundant vectors and loop closures.

The baselines were processed using Trimble Geomatic Office's baseline processing module, WAVE (*Weighted Ambiguity Vector Estimator*). Ionosphere-free fixed solutions were found to provide the best results. Preliminary blunder detections were undertaken using "Redundant Vectors" and Global Network Closures and any extremely large errors were eliminated.

The data are then processed using a minimally constrained geodetic control network to test the network internally, without external constraints, and produce a statistical summary. The statistics from this process are required to be within the tolerance outlined in the Geometric Geodetic Accuracy Standards and Specifications for using GPS Relative Positioning Techniques, published by the FGCC. These tolerances are represented as ellipsoids showing the margin of error value on a graph of the theoretical points, covariance values that indicate the degree of error of the vectors relative to the other vectors in the network, and a chi-squared test that compares the predicted variance determined through a least-squares analysis to the observed variance. The summary is evaluated to eliminate vectors that are outside of the error tolerances to be replaced with redundant vectors that are within the tolerances until all tolerances are met.

The quality of the existing horizontal controls is assessed before undertaking the constrained adjustment. Geodetic inverses between the control monuments were compared with the geodetic inverses derived from the minimally constrained least square adjustment results. This distance analysis is especially useful, since it provides a datum invariant means of comparison. Once the minimally constrained network satisfies the requirements of the above tests, control points in the network are selected with an optimum spatial relationship to fully constrain the network to known control points, and have their provided values entered as the position for those points and the network re-adjusted. The fully constrained positions are shown on the next two pages, and they are also in Appendix I and Appendix J. The same statistical tests are rerun on the adjusted network, as well as visually comparing adjusted values of control points to provided values of control points not used as constraints. Again, the summary is evaluated to identify vectors outside of the tolerances and constraining points reselected to obtain the best fit to the geoid where all vectors are within the prescribed tolerances.

The adjustment results show that the a posteriori variance factor of the network was close to 1.0, as should be desired, and passed the $\chi 2$ test. None of the residual components in the network were flagged for possible rejection under the τ-max test at the 0.05 level of significance. The relative confidence ellipses reveal that the horizontal positional accuracy between all directly connected pairs of stations in the network were better than (1:100,000) at the 95% level of confidence.

Leveling Procedures Used. Leveling to tidal marks in the marsh area were performed to second order, class II modified guidelines that were developed by USACE and NOAA NGS. These guidelines will be published in an appendix for the IPET final report. All leveling that was done on land, that could be driven to, followed the second order class I leveling procedures as described by the Specification and Standards of Accuracy established by the Federal Geodetic Control Subcommittee (FGCS).

USACE processing of GPS data and network adjustments

Preliminary processing of the GPS data collected for phase 1a and 1b was performed by ERDC-TEC and USACE SAJ using Trimble Geomatics Office and GRAFNAV software respectively. The preliminary results were used in the computation of the initial calculations for the local mean sea level values. Additional details to be provided in the final report.

NGS validating of Blue Booking/Publishing of phase 1 survey points

All of the GPS and leveling data will be processed and adjusted to NGS Blue Booking standards for publishing control to provide the final NAVD 88 2004.65 elevations for each tidal station observed in the phase 1 survey. This final processing is scheduled to be completed in late March 2006.

Processing of LMSL values & relationship between NAVD88 2004.65

Once the Phase 1 static surveys were performed, processed, and adjusted, the preliminary relationship between the current LMSL and the NAVD88 2004.65 datum adjustment at the various tide stations were computed by NOAA CO-OPS and USACE ERDC-TEC. The Blue Booking / Publishing of the GPS and level data in March 2006 will provide final values for publishing of the LMSL and NAVD88 2004.65 relationship. Methodology used by ERDC-TEC and NOAA CO-OPS will be explained in detail in the final report.

Data Analysis and Impacts

Evaluation of Designed and Constructed Elevations on Flood Control & Hurricane Protection Structures

Purpose. This Section reviews the various datums and elevations used in the design and construction of selected flood control and hurricane protection structures in the New Orleans area. An estimate is made of the originally constructed flood protection elevations relative to the local water surface and geodetic datums then used as construction references. Pre-Katrina flood protection elevations are estimated relative to the current local mean water surface and the latest geodetic reference scheme, based on topographic and geodetic surveys performed after the hurricane. Emphasis is placed on assessing elevations relative to the local mean water surface since hydraulic analyses and flood protection elevations were computed based on this surface. The focus is primarily on floodwall projects in Orleans Parish were surge elevations were near the design elevation of the structures.

Methodology. Originally constructed elevations were estimated based on a review of design memorandums and contract documents associated with a project. Archive geodetic control data was obtained from the US Coast & Geodetic Survey (USC&GS)—now the NOAA-National Geodetic Survey (NOAA NGS). Water level information was obtained from the NOAA/National Ocean Survey (NOS) Center for Operational Oceanographic Products and Services (CO-OPS). An evaluation of pre-Katrina (August 2005) elevations was based on post-Katrina geodetic and topographic surveys performed by New Orleans District, Task Force Guardian, and IPET survey crews.

Geodetic Datum and Tidal Epoch Elevations. As outlined in the Background, elevations throughout the IPET study area are referenced to a consistent geodetic datum—NAVD88 (2004.65). In order to relate this geodetic reference datum to the local water surface, long-term observations from water level gage data needs to be analyzed. The requirement to reference geodetic elevations to a water surface elevation is clearly outlined in Section II-5-4 (Water Surface Elevation Datums) of the Coastal Engineering Manual (EM 1110-2-1100):

> *Water level and its change with respect to time have to be measured relative to some specified elevation or datum in order to have a physical significance. In the fields of coastal engineering and oceanography this datum represents a critical design parameter because reported water levels provide an indication of minimum navigational depths or maximum surface elevations at which protective levees or berms are overtopped. It is therefore necessary that coastal datums represent some reference point which is universally understood and meaningful, both onshore and offshore. Ideally, two criteria should be expected of a datum: 1) that it provides local depth of water information, and 2) that it is fixed regardless of location such that elevations at different locations can be compared. These two criteria are not necessarily compatible.*

The two criteria expected of a datum are important concepts—especially the statement that they are "not necessarily compatible." This is exactly the case in the New Orleans area. The local depth of water information (e.g., MSL) cannot be simply correlated at different locations with a geodetic datum, such as NAVD88 (2004.65). Although geodetic reference datums are useful for providing consistent surveying, modeling, and subsidence analysis over a region, they do not provide a direct relationship to local water surface elevations that are the basis for flood protection elevations. Where this water surface is not constant (e.g., in tidal areas or rivers), a dense gage network is needed to model this water surface (MSL) relative to the geodetic reference datum (NAVD88 (2004.65)).

USACE EM 1110-2-1003 (Hydrographic Surveying) notes the importance of obtaining updated water level reference datums and tidal epochs for dredging navigation projects:

> *All USACE project reference datums, including those currently believed to be on MLLW, must be checked to ensure that they are properly referred to the latest tidal epoch, and that variations in secular sea level, local reference gage or benchmark subsidence/uplift, and other long-term physical phenomena are properly accounted for. In addition, projects should be reviewed to ensure that tidal phase and range characteristics are properly modeled and corrected during dredging, surveying, and other marine construction activity, and that specified project clearances above grade properly compensate for any tidal range variances. Depending on the age and technical adequacy of the existing MLLW reference (relative to NOS MLLW), significant differences could be encountered. Such differences may dictate changes in channels currently maintained. Future NOS tidal epoch revisions will also change*

the project reference planes. In many projects, existing NOS tidal records can be used ... tidal observations and/or comparisons will be necessary for projects in areas not monitored by NOS or in cases where no recent or reliable observations are available.

Other Corps of Engineers guidance documents emphasize the need to obtain accurate water surface profiles for use in design and construction. These include EM 1110-2-1416 (River Hydraulics), EM 1110-2-1607 (Tidal Hydraulics), EM 1110-2-1913 (Design & Construction of Levees), and EM 1110-2-1614 (Design of Coastal Revetments, Seawalls, and Bulkheads). The Hydraulic Engineering Center (HEC) Research Document No. 26 "Accuracy of Computed Water Surface Profiles" (1986) states in its Introduction that:

"Water surface profiles are computed for a variety of technical uses ... flood insurance studies, flood hazard mitigation investigations, drainage crossing analysis, and other similar design needs. The accuracy of the resulting computed profiles has profound implications. In the case of flood insurance studies, the computed profile is the determining factor in the acceptability of parcels of land for development. For flood control projects, the water surface elevation is important in planning and design of project features and in determining the economic feasibility of proposed solutions ... the relationship between mapping accuracy and resultant computed profile accuracy is therefore of major interest to engineers responsible for providing cost-effective technical analysis."

In analyzing pre- and post-Katrina levee/floodwall elevations, geodetic elevations on either NAVD29 or NAVD88 (2004.65) are adjusted to the local water level datum (e.g., sea level) published by the NOAA Center for Operational Oceanographic Products and Services (CO-OPS). The latest time period (National Tidal Datum Epoch) available is the 19-year period 1983-2001, which was released by CO-OPS in 2003. Nearly all of the floodwalls in the study area were designed and constructed during the previous tidal epoch (1960-1978); however there is no indication in design memorandums or contract documents of this, or previous, tidal epoch. The difference between the 1960-1978 and 1983-2001 epochs at the New Canal gage in Lake Pontchartrain is 0.15 ft, as shown in Figure III-5 below. In general, the MSL epoch change in the region averages about 0.2 ft.

In a high subsidence area such as New Orleans, the apparent sea level increase is significant. This means that an average mean sea level computed over a 19-year period may not represent the latest sea level condition, and related flood protection levels. In high-subsidence areas, NOAA has adopted alternate procedures for computing accepted tidal datums using the last several years of sea level data rather than the 19- year tidal epoch—typically the latest 5-year epoch. Reference NOAA Special Publication NOS CO-OPS 1 (Tidal Datums and Their Applications) and NOAA Special Publication NOS CO-OPS 2 (Computational Techniques for Tidal Datums Handbook).

A 5-year tidal epoch (e.g., 2001-2005) has not yet been developed for this Interim Report. Therefore, references to Mean Sea Level relate to an older 1960-1978 or 1983-2001 epochs. Given the historic subsidence occurring in this area, any conversion from the NAVD88 (2004.65) geodetic datum to an older MSL epoch could be underestimated by 0.1 to 0.3 ft or more.

Typical Geodetic and Water Level Datums used in New Orleans Area Floodwall Construction. The following graphic illustrates the various geodetic and water level datums existent over the years on a 1931 benchmark near the 17th Street Canal on Lake Pontchartrain. This graphic is typical of benchmarks throughout this high subsidence region. It shows that significant elevation differences relative to MSL can result depending on which NGVD29/NAVD88 datum or adjustment is selected. This is especially critical in a high subsidence area where using an outdated or superseded datum to construct a flood protection structure can result in a lower elevation than that intended in the design. Likewise, hydrologic or hydraulic models using terrain data based on disparate datums can have adverse computational impacts.

Water level data is based on direct vertical control connections between Benchmark ALCO and a NOAA National Water Level Observation Network (NWLON) gage (USCG New Canal) located in the same area. Published water level data (and reference datums) for this gage is based on data obtained between October 1983 and September 1992, and adjusted by NOAA for subsequent epoch changes. In November 2005, NOAA reinstalled a gage at this site and data collected from that time will be used to evaluate later epoch references.

A similar evaluation can be made at other NWLON gage sites in the New Orleans area—both at historic sites and at newly established sites.

(Note that Benchmark ALCO was not directly referenced in contract plans for any floodwall construction on the 17th Street Outfall Canal).

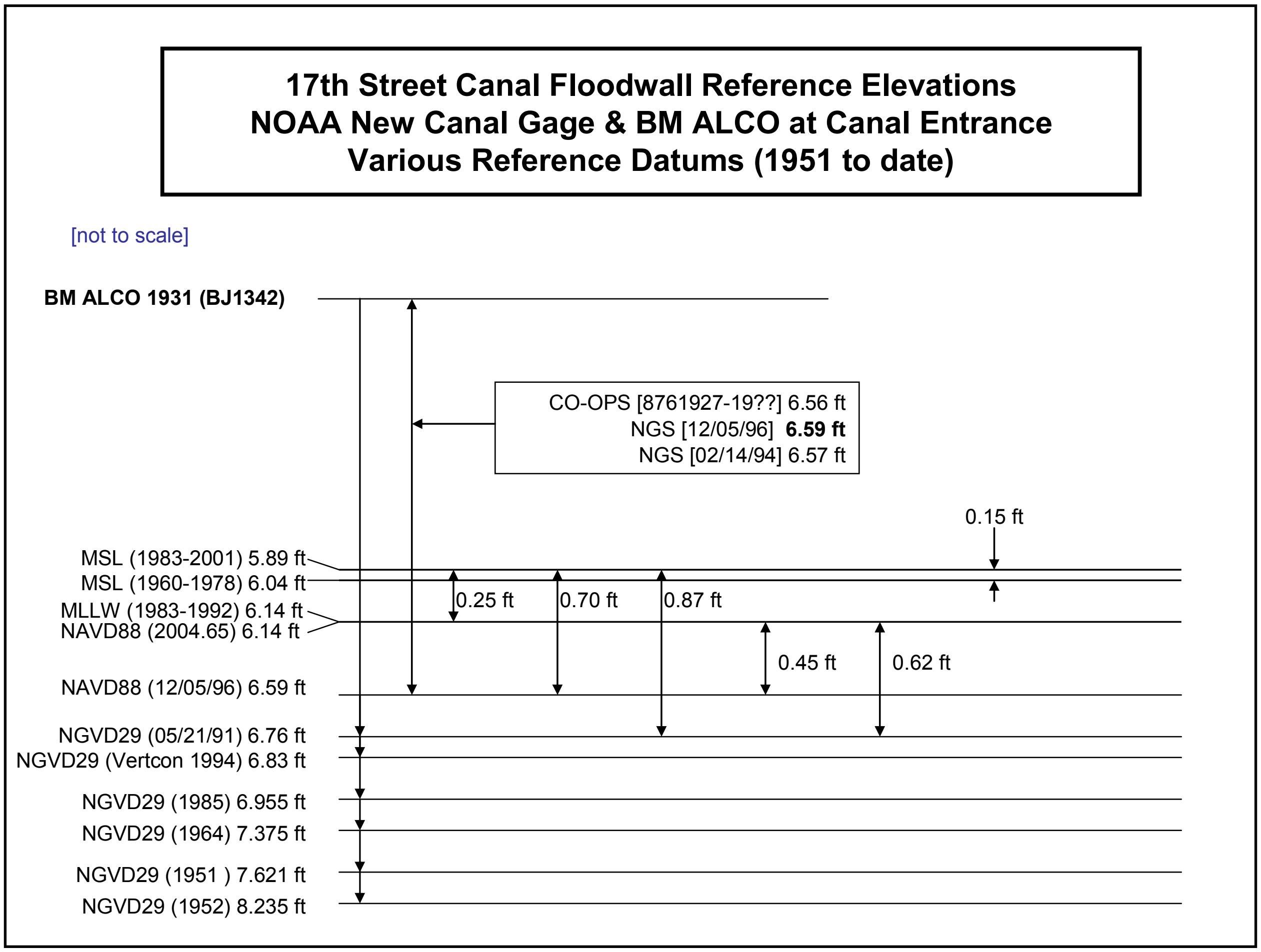


Figure III-5. Datum Relationships at Benchmark ALCO and NOAA New Canal Gage (1951 to date) (Source: NOAA CO-OPS and NOAA NGS (USC&GS))

The above figure does not show the original presumed convergence (or equivalency) of MSL and NGVD29, perhaps back in the early 1930s. Although NAVD29 (and previous adjustments) was originally based (or adjusted) to a "sea level" datum, it is not absolutely certain that NGVD29 and MSL converged at Lake Pontchartrain in the 1930s. (See Background discussion on sea level datums connected from Biloxi, MS).

Especially note that the 0.25 ft difference shown for the current NAVD88 (2004.65) datum to MSL is relative to an older, long-term tidal epoch (1983-2001). This 0.25 ft difference is used as a datum conversion for projects along this portion of Lake Pontchartrain. The datum conversion in the Inner Harbor Navigation Canal (IHNC) has not been fully determined by NOAA CO-OPS as of this Interim Report. It is estimated at 0.2 ft based on interpolations from the nearest NWLON gages. Updated conversions for the IHNC, GIWW, and MRGO will be contained in the Final Report. These updated conversion values will be based on a shorter-term, more recent epoch. At the New Canal gage, the conversion is likely to be larger than the current 0.25 ft value if there has been an "apparent sea level rise" since the 1983-2001 epoch.

1. Orleans Avenue Outfall Canal Construction Reference Datums. The following construction drawings and Design Memorandums were reviewed as part of this assessment:

- DACW29-93-C-0077: Orleans Avenue Canal—Flood Protection Improvement Project—Phase II-D (West Side: B/L Sta. 2+39.00 to Sta. 29+07.50)
- DACW29-97-C-0029: Orleans Avenue Outfall Canal—Parallel Protection-Phase II-A—East Side Floodwall (B/L Sta. 3+60.00 to Sta. 90+26.33)
- DACW29-95-B-0035: Orleans Avenue Outfall Canal—Parallel Protection-Phase II-C—West Side Floodwall (B/L Sta. 21+34.52 to Sta. 63+66.22)
- DACW29-99-C-0025: Filmore and Harrison Avenue Bridges—Phase I-C
- DACW29-00-B-0094: Robert E. Lee Boulevard Bridge—Phase I-B
- GDM No. 19—Orleans Avenue Outfall Canal (Volumes I, II, & III)—1988
- DM 01 Part III Hydrology and Hydraulic Analysis—Lake Pontchartrain & Vicinity-Lakeshore (Sep 1968)

Design Elevation Parameters. Parallel protection elevations are shown in GDM No. 19 and on various contract plans. GDM No. 19 (Vol I) notes that the SPH design stillwater surface elevation of Lake Pontchartrain at 11.5 ft NGVD. This base elevation was used in subsequent HEC-2 models to compute required floodwall elevation on each side of the canal and at the bridges. The design stillwater elevations in the canal at the Filmore Ave. Bridge is 12.10 ft NGVD, and 12.30 ft NGVD at the Harrison Avenue Bridge (DACW29-99-C-0025). The design canal stillwater elevation at the R.E. Lee Bridge was 11.90 ft NGVD (DACW29-00-B-0094). In these hydraulic analysis models, the stillwater elevation relative to NGVD (i.e., NGVD29) was generally assumed to be MSL. A standard freeboard (2 ft typical) and settlement (0.5 ft typical) was added to these stillwater heights to arrive at a design protection elevation referenced to NGVD. Typical flood protection elevations in the canal ranged from 14.0 to 14.9 ft. (DM 01 Part II noted a USACE recommendation for a 3-ft freeboard allowance vice 2 feet previously authorized—this recommendation was rejected).

Various contract plans indicate a “normal water surface” or “normal water level” elevation of 1.0 ft NGVD in the canal. The source of this apparent superelevation is not noted, nor is there any indication that this value was incorporated into the hydraulic analyses used in determining floodwall heights. (This is based on discussions with MVN personnel who ran these original hydraulic models). The 1.0 ft canal superelevation is believed to have been taken from pump station hydrograph records, or from gage records on Lake Pontchartrain or on the IHNC. Although a “NGVD” datum is noted, the year or adjustment epoch is not shown. The superelevation does roughly correlate with the approximate 0.9 ft amount that MSL elevation is above NGVD29 at

Benchmark ALCO—see Figure III-5. A typical section showing the normal canal water elevation is shown in the figure below, taken from DACW29-95-B-0035.

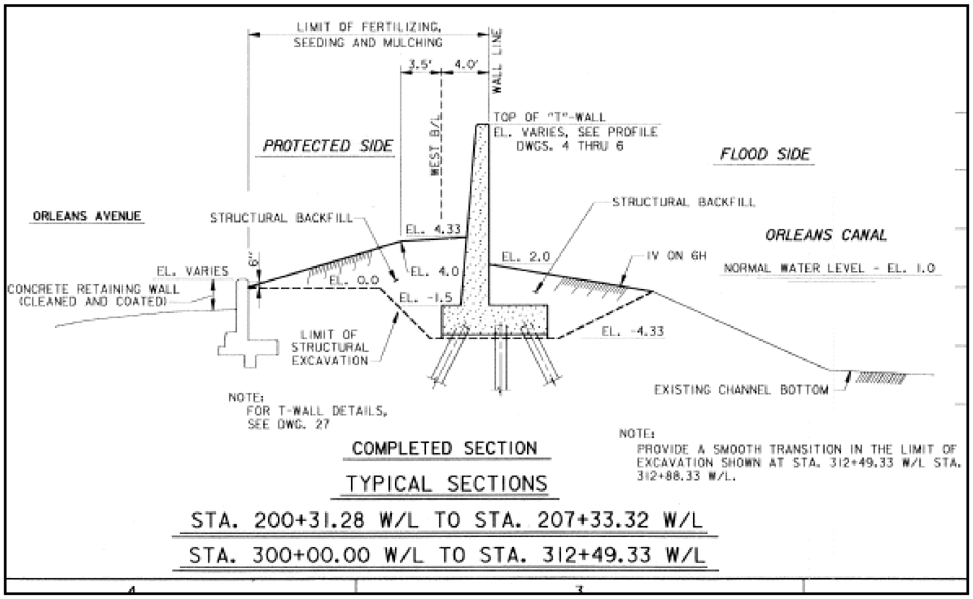


Figure III-6. "Normal Water Surface" Notation on Flood Side of Orleans Outfall Canal (Typical)

Reference Benchmark for Orleans Canal Floodwall Construction. Contract drawings indicate that Benchmark "CHRYSLER RM" was used as the vertical reference for design and construction associated with floodwalls constructed on the Orleans Avenue Outfall Canal. This mark was used for all the projects referenced above. This benchmark, originally set in 1931 by the USC&GS (now the National Geodetic Survey), is located in a concrete retaining wall at the intersection of Lakeshore Drive and the Orleans Outfall Canal.

No other benchmarks are noted in the construction plans. It is presumed all construction stake out during the period 1993 to 2000 was performed relative to this single benchmark.

Reference Datum of Benchmark "CHRYSLER RM." The Phase II-D Plans (DACW29-93-C-0077) note that PROJECT BM "CHRYSLER RM" is at elevation 7.11 ft "M.S.L." (Mean Sea Level) and on a "1983 Datum." The General Notes on the Phase II-D Plans indicate that "all elevations are expressed in feet and refer to National Geodetic Vertical Datum (N.G.V.D.). No datum date reference is indicated.

The Phase II-A Plans (DACW29-97-C-0029) and Phase I-C Plans (DACW29-99-C-0025) note in the "Tabulation of Bench Marks" that 'CHRYSLER RM" is at elevation "7.11 [ft] N.G.V.D. (1983 Epoch)." No reference to "NGVD29" or a subsequent adjustment is made.

The Phase I-B Plans (DACW29-00-B-0094) note CHRYSLER RM as 7.11 ft N.G.V.D. on the "1984 Epoch."

Thus, all construction documents are consistent in specifying a constant reference elevation and benchmark.

Historical Adjustments to CHRYSLER RM (1951 to date). The following table illustrates the various elevations associated with Benchmark CHRYSLER RM. Most of the changes are due to readjustments of level lines by the NOAA NGS (USC&GS), to account for subsidence in this area.

Table III-1
Successive Elevations on Benchmark CHRYSLER RM from 1951 to 2006

Elev, ft	Datum	Adjustment	Agency	Reference
8.533	NGVD29	19 Mar 52	USC&GS	
7.923	NGVD29	1951	USC&GS	L-13860
7.694	NGVD29	9 Apr 65	USC&GS	L-19622
7.108	NGVD29	1 Sep 82	USC&GS	L-19622/13860
7.231	NGVD29	30 Jan 86	USC&GS	L-24903
7.03	NGVD29	21 May 91	USC&GS	L-25283
6.83	NGVD88	14 Feb 94	USC&GS	BJ1349
6.85	NGVD88	Dec 96	USC&GS	BJ1349
6.42	NGVD88 (2004.65)	10 Feb 06	USC&GS	(unpublished/L-25517)
6.38	NGVD88 (2004.65)	11 Feb 06	USACE	IPET Survey Team
6.13 est	LMSL (1983-2001)	2005	NOAA CO-OPS	Provisional
TBD	LMSL (2001-2005)	(May 2006)	NOAA CO-OPS	

The “7.108” ft elevation from the 01 Sep 82 adjustment of CHRYSLER RM appears to be the source for the “7.11” ft elevation shown on the contract plans. Although more recent adjustments were available (1986 and 1991), the variance between these adjustments (± 0.1 ft) is not significant. It appears the “1983 Epoch” referenced in various contract documents may be referring to the horizontal adjustment datum, i.e., North American Datum of 1983 (NAD83). The above table clearly shows a subsidence trend in this area over a 50-year period, and the need to account for these relative elevation variations and trends. The 10 Feb 06 adjustment is based on unadjusted level data from 1994, as corrected to the epoch NAVD88 (2004.65). The 11 Feb 06 adjustment is based on a Third-Order differential level line run from Benchmark ALCO to Benchmark CHRYSLER RM, holding the NGS published NAVD88 (2004.65) elevation of ALCO fixed.

The Local Mean Sea Level difference based on the epoch (1983-2001) is provisional and is estimated based on provisional data from the NOAA New Canal gage (17th Street Canal). Local Mean Sea Level elevation differences for a later epoch (2001-2005) have not been computed as of this Interim Report date. They will be provided in the Final Report. It is estimated that the LMSL (2001-2005) difference from NAVD88 (2004.65) will be will be larger than that relative to the older LMSL epoch (1983-2001).

Local Mean Sea Level Relationships at the Orleans Avenue Outfall Canal. The elevation of Benchmark CHRYSLER RM can be related to the local mean sea level (LMSL) of Lake Pontchartrain using the relationships at the New Canal Gage (BM ALCO), which is slightly over a mile to the west of the Orleans Outfall Canal.

From Figure III-5 at the 17th Street Canal (New Canal Gage-Benchmark ALCO):

ALCO MSL (epoch 1983-2001)	5.89 ft (provisional)
ALCO NAVD88 (12/05/96)	6.59 ft
Difference:	(0.70 ft) [MSL — NAVD88]

CHRYSLER RM [NAVD88 (12/05/96)]	6.85 ft
Difference [MSL (epoch 1983-2001) — NAVD88]	-0.70 ft
LMSL at CHRYSLER RM (epoch 1983-2001)	6.15 ft

From the above, the estimated LMSL elevation of Benchmark CHRYSLER RM is 6.15 ft. This is based on the NOAA Tidal Epoch of 1983-2001.

For information, the LMSL elevation of CHRYSLER RM relative to the superseded 1960-1978 tidal epoch is estimated as:

CHRYSLER RM [NAVD88 (12/05/96)]	6.85 ft
Difference [MSL (epoch 1960-1978) — NAVD88]	-0.55 ft
LMSL at CHRYSLER RM (epoch 1960-1978)	6.30 ft

The elevation difference is attributable to the 0.15 ft change between the epochs. Since the 1983-2001 tidal epoch was not updated until ca 2003, mean sea level relationships during the time of construction would have had to been referenced to the 1960-1978 epoch. However, none of the contract documents makes mention of any particular tidal epoch.

Impact of Datum Variations on Constructed Floodwall Elevations. Given the nearly universal presumption that "NGVD" and "MSL" were equivalent "sea level" datums, and that floodwall design was computed relative to Lake Pontchartrain MSL, the actual constructed elevation on a typical floodwall in the London Avenue Outfall Canal is reduced by approximately:

Benchmark CHRYSLER RM	7.11 ft "NGVD" (Contract Plans-1982 adjustment)
Benchmark CHRYSLER RM	6.30 ft LMSL (1960-1978 epoch)
Difference:	0.81 ft

In effect, floodwalls designed relative to a MSL or LMSL datum would have been constructed about 0.8 ft lower when using the NGVD29 geodetic datum from a 1982 adjustment as a reference. Thus a floodwall designed to 14.0 ft

NGVD (i.e., MSL) would actually be constructed to 13.2 ft relative to LMSL (1960-1972 epoch), or 13.1 ft relative to the 1983-2001 LMSL epoch.

Assessment of Pre- and Post-Katrina Flood Protection Elevations (Orleans Avenue Outfall Canal). To evaluate pre-Katrina flood protection elevations, conventional topographic survey data taken just after the hurricane were obtained. Post-Katrina floodwall cap elevations were observed using conventional topographic surveying techniques—differential leveling and RTK methods. These elevations are also likely representative of pre-Katrina conditions in 2005. These surveys on the NAVD88 (2004.65) geodetic reference system can be adjusted to LMSL using the latest tidal datum epoch available (1983-2001)—e.g., topographic survey elevations observed on the NAVD88 (2004.65) geodetic datum were reduced by 0.25 ft to relate them to the estimated LMSL (1983-2001 epoch) elevation of Lake Pontchartrain. As noted above, this 0.25 ft conversion is provisional and does not necessarily reflect the current (2006) LMSL estimate in Lake Pontchartrain.

Designed and current floodwall elevations for selected sections of the Orleans Avenue Canal are listed in the following table. The average elevation was computed from representative shot points taken atop the floodwall along each reach. Variances in the floodwall cap elevation were as much as ± 0.5 ft along some reaches—probably due to uneven settlement.

Table III-2
Design and Current Floodwall Elevations in Selected Reaches (Orleans Avenue Outfall Canal)

Reach	No. of Shot Points	Design Elevation NGVD (MSL)	Average Elevation (2005-2006)	
			NAVD88 (2004.65)	LMSL (1983-2001)
WEST BANK RE Lee Blvd. to Filmore Ave.	15	N/A	13.2 ft	13.0 ft
WEST BANK Filmore Ave. to Harrison Ave.	20	14.0 ft (T-Wall)	13.4 ft	13.2 ft
WEST BANK Harrison Ave. to PS 7 / I-610	28	N/A	14.0 ft	13.8 ft
EAST BANK RE Lee Blvd. to Filmore Ave.	21	14.4 ft (I-Wall)	13.4 ft	13.2 ft
EAST BANK Filmore Ave. to Harrison Ave.	25	14.8 ft (I-Wall)	13.8 ft	13.6 ft
EAST BANK Harrison Ave. to PS 7 / I-610	19	14.9 ft (I-Wall)	13.9 ft	13.6 ft

Differences in floodwall cap elevations range between 0.8 ft and 1.3 ft.

2. London Avenue Outfall Canal Construction Reference Datums. The following construction drawings and Design Memorandums were reviewed as part of this assessment:

- DACW29-94-C-0079 (94-B-0047) As Built Mark Up—London Ave. Outfall Canal Parallel Protection— Mirabeau Ave.-to R.E. Lee Blvd (West Bank)—Mirabeau Ave. to Leon C. Simon Blvd. (East Bank)

- DACW29-02-C-0013 (01-B-0092) London Ave. Outfall Canal Parallel Protection—Floodproofing Mirabeau and Filmore Ave. Bridges
- DACW29-94-C-0003 (93-B-0080) As-Built London Ave. Outfall Canal Parallel Protection—Pump Station 3 to Mirabeau Ave. Floodwall
- DACW29-99-C-0005 (98-B-0060) As-Built London Ave. Outfall Canal Parallel Protection—Floodproofing Gentilly Blvd. Bridge
- DACW29-98-C-0082 (98-B-0065)As-Built London Ave. Outfall Canal Parallel Protection— Floodproofing Leon C. Simon Blvd. Bridge
- GDM 19A (Vol I and II) London Ave. Outfall Canal (1989)
- GDM 20 (Draft) London Ave. Canal Floodwalls and Levees—Orleans Levee District—Apr1986
- DM01 Part III Hydrology and Hydraulic Analysis—Lake Pontchartrain & Vicinity-Lakeshore (Sep 1968)

Design Elevation Parameters. Parallel protection elevations are shown in GDM No. 19A and on various contract plans. The design SPH stillwater surface elevation of Lake Pontchartrain is 11.5 ft NGVD. This base elevation was used in subsequent HEC-2 models to compute required floodwall elevation on each side of the canal and at the bridges. As in other Lake Pontchartrain projects, the "NGVD" elevation is assumed to be MSL or LMSL—e.g., "Lake Pontchartrain Normal Water Level = 0.0 ft MSL."

The design stillwater elevation in the London Avenue Outfall Canal was 11.85 ft "NGVD." The 14.4 ft NGVD floodwall design was derived by adding 2.0 ft freeboard and 0.5 ft settlement allowances to the 11.85 ft stillwater elevation. Again, the NGVD floodwall elevation was generally assumed to be equivalent to MSL.

Reference Benchmark used in Orleans Outfall Canal Parallel Floodwall Construction. Benchmark "P 153" was used as the vertical reference for design and construction associated with most of the floodwalls constructed on both banks the Orleans Avenue Outfall Canal. This benchmark, originally set in 1951 by the US Coast & Geodetic Survey (USC&GS—now the National Geodetic Survey), is destroyed. It was located on the Lakeshore Drive Bridge over the London Avenue Canal. The mark was destroyed ca 2002 when a new bridge was constructed. (2005/2006 post-Katrina construction and topographic surveys in the London Avenue Canal have been referenced to Benchmarks GRAHAM and GRAHAM RM, both of which were on the original USC&GS level line with P 153).

Benchmark P 153 was used for most of the floodwall projects listed above. No other benchmarks are noted in the construction plans except on the 1998 Leon Simon Bridge Floodproofing project (DACW29-98-C-0082) where Benchmark "AA 190" was listed in addition to "P 153." On the 1999 Gentilly Blvd. Bridge floodproofing project (DACW29-99-C-0005), a Benchmark "U 153" is referenced in addition to "P 153"—as shown in the figure below. Other than on these two projects, it is presumed all other floodwall construction stakeout was performed relative to the single benchmark "P 153."

Reference Datum of Benchmark "P 153." Contract DACW29-94-C-0079 is typical in referencing the elevation of Benchmark "P 153" relative to "N.G.V.D. (EPOCH 1964)." The elevation noted for the "1964 Epoch" is 11.270 ft. This elevation is actually based on a 9 April 1965 USC&GS readjustment of the NGVD29 network in this area. Bridge floodproofing projects in the late 1990s show both the 11.270 ft NGVD 1964 Epoch and a 10.39 ft elevation based on the 1991 epoch. The figure below shows dual NGVD29 reference datums (epochs) for "P 153."

REFERENCE BENCH MARK		
DESIGNATION	DESCRIPTION	ELEVATION
P 153	AT NEW ORLEANS, ABOUT 0.8 MILES ALONG LAKESHORE DR. FROM THE WEST SIDE OF TRAFFIC CIRCLE AT THE JUNCTION OF ELYSIAN FIELDS AVE., ABOUT 0.55 MILES NE ALONG LAKE TERRACE DR. FROM THE EAST END OF THE LAKESHORE DR. BRIDGE OVER BAYOU SAINT JOHN, THENCE 0.1 MILES EAST ALONG LAKESHORE DR. TO THE BRIDGE ACROSS LONDON AVE. CANAL. SET IN THE TOP OF THE EAST END OF PEDESTRIAN WALK ALONG THE SOUTH SIDE OF THE BRIDGE OVER THE EAST ABUTMENT OF THE BRIDGE, 5 FT. SOUTH OF THE SOUTH CURB OF THE DRIVE, 6 IN. WEST OF THE EAST END OF THE BRIDGE AND ABOUT 1 FT. ABOVE THE DRIVE.	11.270 N.G.V.D. (1964 EPOCH) 10.390 N.G.V.D. (1991 EPOCH)
U 153	IN NEW ORLEANS, AT 2251 NORTH BROAD AVENUE, 33.7 M (110.6 FT.) SOUTHEAST OF THE SOUTHEAST CORNER OF PUMP STATION 3 AT 2251 NORTH BROAD STREET, 9.7 M (31.8 FT.) SOUTHWEST OF THE NORTHEAST CORNER OF A RETAINING WALL, 6.8 M (22.3 FT.) WEST OF THE NEAR RAIL OF THE SOUTHERN RAILROAD, 5.6 M (18.4 FT.) NORTHEAST OF THE NORHTWEST CORNER OF A FENCE, AND THE MONUMENT PROJECTS 0.2 M (0.7 FT.) ABOVE THE GROUND SURFACE.	4.81 N.G.V.D. (1991 EPOCH)

Figure III-7. Reference Benchmarks (Gentilly Blvd. Bridge Floodproofing—DACW29-99-C-0005)

Historical Adjustments to P 153 (1951 to date). The following table (Table III-3) illustrates the various elevations associated with Benchmark P 153. Most of the changes are due to readjustments of level lines by the NOAA NGS (USC&GS), to account for subsidence in this area.

Table III-3 Successive Elevations on Benchmark P 153 from 1951 to 2006				
Elevation, ft	**Datum**	**Adjustment**	**Agency**	**Reference**
12.087	NGVD29	19 Mar 52	USC&GS	
11.476	NGVD29	1951	USC&GS	L-13860
11.270	NGVD29	9 Apr 65	USC&GS	L-19622
10.708	NGVD29	1 Sep 82	USC&GS	L-19622/13860
10.623	NGVD29	30 Jan 86	USC&GS	L-24903
10.39	NGVD29	21 May 91	USC&GS	L-25283
10.20	NGVD88	14 Feb 94	USC&GS	BJ1361
10.21	NGVD88	5 Dec 96	USC&GS	BJ1361
9.79	NGVD88 (2004.65)	10 Feb 06	USC&GS	(unpublished/L-25517)
9.54 est	LMSL (1983-2001)	2005	NOAA CO-OPS	provisional
TBD	LMSL (2001-2005)	(May 2006)	NOAA CO-OPS	

The 10 Feb 06 NAVD88 (2004.65) elevation shown for P 153 is not based on recent observations since the mark no longer exists. This is the computed elevation assuming no subsidence has occurred since 1994. The 09 Apr 65 NGVD29 elevation of 11.27 ft corresponds to that used for most of the London Avenue Canal floodwall construction during the early 1990s. This elevation is listed as "Epoch 1964."

It is uncertain why the later readjustment elevations (i.e., 1982 and 1986) were not used for contracts issued after 1990. The 0.65 ft elevation change from 1965 to 1986 is significant. One of the As-Builts from a later contract that listed the 1991 elevation of P 153 (10.39 ft) appears to have held the 1965 elevation for construction stake out in setting the top of the floodwall, in lieu of the 1991 elevation—a 0.9 ft difference.

As in previous outfall canal projects in this area of Lake Pontchartrain, the above table clearly shows a subsidence trend in this area over a 50-year period, and the need to account for these relative elevation variations.

The Local Mean Sea Level difference based on the epoch (1983-2001) is provisional and is estimated based on provisional data from the NOAA New Canal gage (17th Street Canal). Local Mean Sea Level elevation differences for a later epoch (2001-2005) have not been computed as of this Interim Report date. They will be provided in the Final Report. It is estimated that the LMSL (2001-2005) difference from NAVD88 (2004.65) will be larger than that relative to the older LMSL epoch (1983-2001).

Local Mean Sea Level Relationships at the London Avenue Outfall Canal. The elevation of Benchmark P 153 can be related to the local mean sea level (LMSL) of Lake Pontchartrain using the relationships at the New Canal Gage (BM ALCO), which is about 2 ½ miles to the west of the London Outfall Canal.

From Figure III-5 at the 17th Street Canal (New Canal Gage-Benchmark ALCO):

ALCO MSL (epoch 1983-2001)	5.89 ft (provisional)
ALCO NAVD88 (12/05/96)	6.59 ft
Difference:	(0.70 ft) [MSL — NAVD88]

P 153 [NAVD88 (12/05/96)]	10.21 ft
Difference [MSL (epoch 1983-2001) — NAVD88]	-0.70 ft
LMSL at P 153 (epoch 1983-2001)	9.51 ft

From the above, the estimated LMSL elevation of Benchmark P 153 is 9.51 ft. This is based on the NOAA Tidal Epoch of 1983-2001 and is approximately representative of the MSL elevation at the time of construction.

The LMSL elevation of P 153 relative to the superseded 1960-1978 tidal epoch is computed as:

P 153 [NAVD88 (12/05/96)]	10.21 ft
Difference [MSL (epoch 1960-1978) — NAVD88]	-0.55 ft
LMSL at P 153 (epoch 1960-1978)	9.66 ft

The elevation difference is attributable to the 0.15 ft change between the epochs. Since the 1983-2001 tidal epoch was not updated until ca 2003, mean sea level relationships during the time of construction would have had to been referenced to the above 1960-1978 epoch.

Impact of Datum Variations on Constructed Floodwall Elevations. Given the nearly universal presumption that "NGVD" and "MSL" were equivalent datums, and that floodwall design was computed relative to MSL = 0.0 ft on Lake Pontchartrain, the actual constructed elevation on a typical floodwall in the London Avenue Outfall Canal is reduced by approximately:

Benchmark P 153	11.27 ft "NGVD" (Contract Plans)
Benchmark P 153	9.66 ft LMSL (1960-1978 epoch)
Difference:	1.61 ft

In effect, floodwall elevations designed relative to a LMSL datum would be constructed about 1.6 ft lower when using the 1965 adjustment of the NGVD29 geodetic datum as a reference. Thus a floodwall designed to 14.4 ft NGVD (i.e., MSL) would actually be constructed to 12.8 ft relative to LMSL (1960-1978 epoch), or 12.7 ft relative to the 1983-2001 tidal epoch.

Assessment of Pre- and Post-Katrina Flood Protection Elevations (London Avenue Outfall Canal). Designed and current floodwall elevations for selected sections of the London Avenue Canal are listed in the following table. Data were obtained and adjusted using identical procedures outlined for the

Orleans Avenue Outfall Canal evaluation. The average elevation was computed from representative shot points taken atop the floodwall along each reach. Variances in the floodwall cap elevation were typically ± 0.2 ft along some reaches.

Table III-4
Design and Current Floodwall Elevations in Selected Reaches (London Avenue Outfall Canal) New Orleans District/Task Force Guardian Post-Katrina Surveys Oct-Dec 2005

Reach	No. of Shot Points	Design Elevation NGVD (MSL)	Average Elevation (2005-2006)	
			NAVD88 (2004.65)	LMSL (1983-2001)
WEST BANK Leon Simon Ave. to RE Lee Blvd.	N/A	N/A	N/A	N/A
WEST BANK RE Lee Blvd. to Filmore Ave.	18	14.4 ft	13.0 ft	12.8 ft
WEST BANK Filmore Ave. to Mirabeau Ave.	23	14.4 ft	12.9 ft	12.7 ft
WEST BANK Mirabeau Ave. to Gentilly Ave.	27	14.4 ft	12.9 ft	12.7 ft
WEST BANK Gentilly Ave. to Pump Station 3	19	14.4 ft	12.9 ft	12.7 ft
EAST BANK Leon Simon Ave. to RE Lee Blvd.	8	14.4 ft	12.8 ft	12.6 ft
EAST BANK RE Lee Blvd. to Filmore Ave.	26	14.4 ft	12.9 ft	12.6 ft
EAST BANK Filmore Ave. to Mirabeau Ave.	17	14.4 ft	12.9 ft	12.6 ft
EAST BANK Mirabeau Ave. to Gentilly Ave.	24	14.4 ft	12.9 ft	12.7 ft
EAST BANK Gentilly Ave. to Pump Station 3	18	14.4 ft	13.1 ft	12.8 ft

NOTE: Topographic survey elevation data in this table derived from BM GRAHAM has not been verified.

During January 2006, Post-Katrina Overbank Surveys were taken north and south of the breach areas by 3001 Inc. These surveys were performed in support of IPET Team 5b physical modeling of the two breach sites on the canal. They also provide a quality assurance check on the above Task Force Guardian surveys performed shortly after Katrina. State plane coordinates are LA 1702 South and elevations are in feet NAVD88 (2004.65). The stationing is not the floodwall alignment.

Table III-5 Post-Katrina Floodwall Elevations Vicinity Breach Areas (London Avenue Outfall Canal) IPET Overbank Surveys January 2006 (3001, Inc.)				
X	**Y**	**Elev (ft)**	**Location**	**Datafile reference**
North Breach — West Bank — South of RE Lee Blvd				
Vicinity of Burbank Drive (South of RE Lee)				
Sta. 15+50				
3680399.87	554667.93	13.041	Top Edge Conc Fldwal	17thLondon.dc
3680399.17	554667.96	13.107	Top Edge Conc Fldwal	17thLondon.dc
Sta. 16+00				
3680403.85	554618.86	13.013	Top Edge Conc Fldwal	17thLondon.dc
3680403.4	554618.87	13.013	Top Edge Conc Fldwal	17thLondon.dc
South Breach — East Bank — North of Mirabeau Avenue				
Vicinity of Wildair Drive (North of Mirabeau)				
Sta. 51+00				
3680710.06	551132.49	12.86	TPF * (West Bank)	Book# 060856
3680709.06	551132.43	12.86	TPF (West Bank)	Book# 060856
Sta 51+50				
3680712.27	551082.53	12.86	TPF (West Bank)	Book# 060856
3680711.27	551082.47	12.87	TPF (West Bank)	Book# 060856
3680837.01	551090.56	12.87	TPF (East Bank)	Book# 060856
Sta. 52+00				
3680841.23	551040.73	12.87	TPF (East Bank)	Book# 060856
3680717.48	551032.76	12.88	TPF (West Bank)	Book# 060856
3680716.49	551032.7	12.89	TPF (West Bank)	Book# 060856
Vicinity of Mirabeau Avenue Bridge				
Sta. 58+00				
3680889.96	550392.53	12.72	TPF (East Bank)	Book# 060856
3580888.97	550392.46	12.72	TPF (East Bank)	Book# 060856
Sta. 59+00				
3680895.17	550342.76	12.77	TPF (East Bank)	Book# 060856
3680894.17	550342.69	12.77	TPF (East Bank)	Book# 060856
3680763.44	550334.28	12.87	TPF (West Bank)	Book# 060856
3680762.44	550334.21	12.87	TPF (West Bank)	Book# 060856
Sta. 59+50				
3680898.39	550292.86	12.77	TPF (East Bank)	Book# 060856
3680897.39	550292.79	12.77	TPF (East Bank)	Book# 060856
*TPF – top of concrete floodwall. Note: duplicate shots are at the flood side and protected side of the floodwall concrete cap.				

Comparison between the Oct-Dec 2005 MVN/Task Force Guardian surveys and the 2006 IPET surveys indicates a NAVD88 (2004.65) elevation agreement to within ± 0.1 ft. In general, current floodwall cap elevations are running about 1.7 ft below the original design elevation. This is consistent with the 1.6 ft estimated reduction computed in the preceding paragraph.

Floodwall elevations near the Mirabeau Avenue breach area were running between 12.5 and 12.6 ft LMSL (1983-2001). This assumes no abnormal undulation in the breach site—a reasonable assumption given the fairly uniform elevations in the existing (unbreached) floodwalls. Updated sea level epochs may reduce this relative elevation even further. A more detailed analysis of pre- and post-Katrina elevations on floodwalls adjacent to the North Breach (R.E. Lee Blvd) and South Breach (Mirabeau Ave) will be included in the Final Report.

3. 17th Street Outfall Canal Construction Reference Datums. The following construction drawings and Design Memorandums were reviewed as part of this assessment:

- Contract 92-1 Board of Levee Commissioners of East Jefferson Levee District -17th Street Canal West Side Levee Improvements
- Orleans levee District (OLD) Contract 02043-0489 As Built—17th Street Canal Phase IB—Hammond Hwy to Southern RR 1990
- DACW29-93-B-0025 Excavation and Flood Protection 17th St Canal—Capping of Floodwalls—East Side Levee Improvements
- DACW29-95-C-0093 (95-B-0095) As Built Markup—17th St Outfall Canal-Metairie Relief—Floodproofing Veterans Blvd Bridges
- GDM 20 Vol I & II-17th St Outfall Canal (Metairie Relief) Orleans Parish & Jefferson Parish 1990
- DM01 Part III Hydrology and Hydraulic Analysis—Lake Pontchartrain & Vicinity-Lakeshore (Sep 1968)

Design Elevation Parameters for 17th Street Canal
EAST SIDE LEVEE IMPROVEMENTS—FLOODWALL CAPPING (DACW29-93-B-0025)

Floodwall cap elevations:

Southern Railway Sta 126+02 to I-10 Bridge Sta 97+52	elev 15.0 ft NGVD
I-10 Bridge Sta 94+17 to Vet Hwy Sta 81+52	elev 14.5 ft
Vet Hwy Sta 80+00 to Hammond Hwy Sta 8+49	elev 14.0 ft
Hammond Hwy Sta 7+03 to Sta 0+00	elev 14.0 ft

Plans state normal water surface 1.5 to 2.0 ft NGVD (source of hydrograph not noted in plans)
Contract plan elevations are referenced to “USCE MONUMENT 14” elevation 8.77 ft NGVD

WEST SIDE LEVEE IMPROVEMENTS (Contract 92-1—1992) As-Builts

Top of Required Floodwall Elevations:

Lakefront Levee (Sta 549+78) to Vet Hwy (Sta 625+02)	elev 14.0 ft
Vet Hwy (Sta 626+25) to I-10 Bridge (Sta 638+84)	elev 14.5 ft
I-10 Bridge (Sta 642+23) to South. Railway Bridge (Sta 669+17)	elev 15.0 ft

Normal water surface elevation 1.5 ft to 2.0 ft
Reference construction benchmark: USCE Monument 14--elev: 8.77 NGVD (no epoch noted)

VETERANS BLVD BRIDGE FLOODPROOFING (DACW29-95-C-0093)

Still water level	12.5 NGVD
Wave action	14.5 NGVD
Design water level	12.5 ft @ 6,650 cfs @ 300 yr
Normal water level	1.5 to 2.0 ft NGVD @ 0 cfs (no hydrograph shown in plans—specifications not available)

Project Reference Benchmark: "**T-193**" elev 9.741 (NGVD 1972 epoch) on bridge abutment (last recovered 1994)

Phase I-B HAMMOND HWY TO SOUTHERN RAILWAY (OLD Contract 02043-0489 —1990):

Contract plans note that elevations are referred to MSL.
"Normal Water Surface" elevation ranges from 1.0 to 2.0 ft ... apparently either based on a pump station gage hydrograph or perhaps from a gage at Lake Pontchartrain (not indicated in the Plans). Section views indicate the normal water surface elevation is 1.0 ft (typical).
Floodwall sheet pile top elevations vary: 13.5, 14.0, & 14.5 ft

GDM 20 (1990)

Elevations referenced to NGVD (no epoch date noted).
Hydraulic & Structural design criteria:

- Lake Pontchartrain stillwater elevation 11.5 ft @ 300 year SPH
- Wind tide level (17th St Canal) 11.50 to 12.50 ft
- East Bank floodwall elevations: 14.00 to 15.00 ft
- West Bank floodwall elevations: 16.50 to 15.00 ft

Reference Benchmark used in 17th Street Canal Parallel Floodwall Protection. Benchmark "USACE MONUMENT 14" was apparently used as the vertical reference for nearly all the floodwall design and construction on the 17th Street Outfall Canal. The exception is the Veterans Blvd Bridge floodproofing project (DACW29-95-C-0093) in which a benchmark "T 193" in indicated on the contract plans. The origin of benchmark MONUMENT 14 could not be determined from New Orleans District records. The source survey data for the elevation shown on the contract drawings (8.77 ft NGVD) could not be found. The mark was never incorporated into the USC&GS (now the NOAA National Geodetic Survey) database.

No other benchmarks are noted in the construction plans reviewed above. It is presumed all construction stakeout for the East Bank (Orleans Parish) and West Bank (Jefferson Parish) floodwalls was performed relative to a single benchmark—MONUMENT 14.

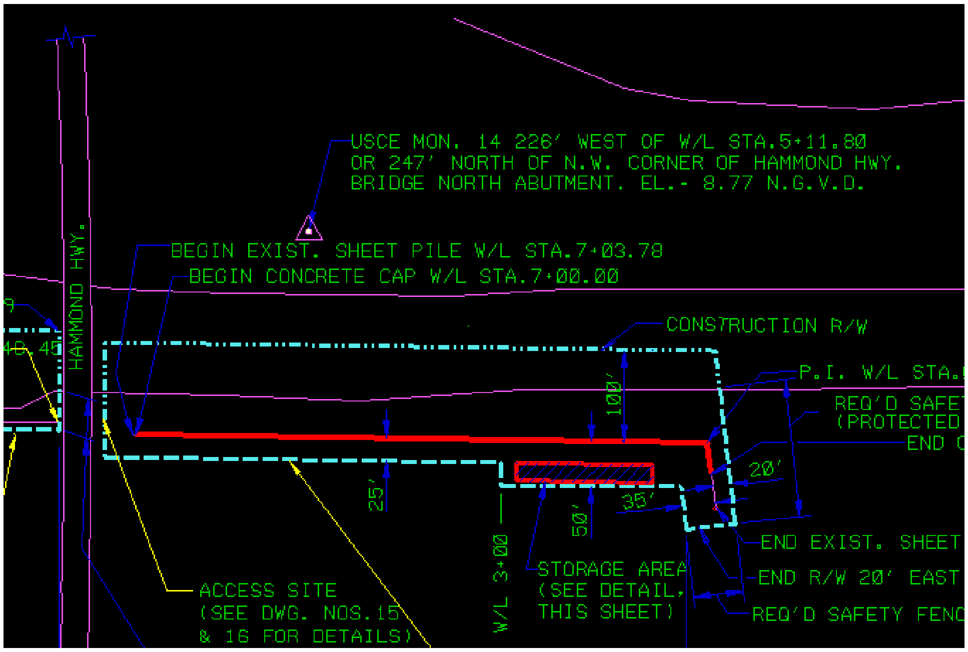


Figure III-8. 17th Street Canal Reference Benchmark USACE MONUMENT 14 near Hammond Hwy

Derived Elevations of Benchmark MONUMENT 14. Post-Katrina surveys to MONUMENT 14 indicated its elevation was suspect—not only currently but also most likely at the time of initial floodwall construction.

A differential level line run in November 2005 from primary Benchmark ALCO to MONUMENT 14 yielded an elevation of 7.06 ft NAVD88 (2004.65) on MONUMENT 14. Comparing equivalent reference datums and adjustment epochs:

MONUMENT 14	7.06 ft NAVD88 (2004.65)
Difference (NGVD29-NAVD88 (2004-65))	+0.62 ft [from Figure III-5]
MONUMENT 14 (most probable elevation)	7.68 ft NGVD29 (05/21/91)

Thus, the most probable elevation in 1991 is 7.68 ft (assuming no significant subsidence to date). The difference in elevation due to datum uncertainty is estimated as:

MONUMENT 14 (Construction Plans)	8.77 ft NGVD (unknown adjustment epoch)
MONUMENT 14 (most probable elevation)	7.68 ft (05/21/91)
Difference	1.09 ft (due to datum readjustment)

It is not likely a datum readjustment accounted for the large 1.09 ft difference.

Given "NGVD" was generally assumed to equal "MSL" on design and construction documents, the LMSL (1983-2001) elevation of MONUMENT 14 is estimated as:

MONUMENT 14	7.06 ft NAVD88 (2004.65)
Difference (MSL-NAVD88 (2004-65))	-0.25 ft [from Figure III-5]
MONUMENT 14	6.81 ft LMSL (1983-2001)

Then,

MONUMENT 14 (Construction Plans)	8.77 ft NGVD ≈ MSL
MONUMENT 14	6.81 ft LMSL (1983-2001)
Difference	1.96 ft

This 1.96 ft elevation disparity at Benchmark MONUMENT 14 may be due to a number of factors:

- The origin of the 8.77 ft elevation shown on the plans is unknown. There are no records available indicating how this elevation was set.
- It is uncertain what date the elevation was established, or on what vertical datum/adjustment it was referred to.
- Assumption that NGVD = MSL.
- Subsidence may have occurred since the elevation was established.
- Mark had incorrect elevation in 1990 (this is believed to be the likely problem based on recollections by MVN personnel).

The above assumptions can be roughly confirmed using pre-Katrina LIDAR topography (2000) and/or post-Katrina conventional topographic surveys in 2006 and 2006—see assessment following.

Assessment of Pre- and Post-Katrina Flood Protection Elevations (17th Street Outfall Canal). Design and current floodwall elevations for selected sections of the 17th Street Canal are listed in the following table, based on post-Katrina topographic surveys performed by MVN/Task Force Guardian and IPET Team 6. Data were obtained and adjusted using identical procedures outlined for the previous Orleans and London Canal evaluations. The average elevation was computed from representative shot points taken atop the floodwall along each reach. Variances in the floodwall cap elevation were typically less than ± 0.2 ft along some reaches.

Table III-6
Design and Current Floodwall Elevations in Selected Reaches (17th Street Outfall Canal) New Orleans District/Task Force Guardian Post-Katrina Surveys Oct-Dec 2005

Reach	No. of Shot Points	Design Elevation NGVD (MSL)	Average Elevation (2005-2006)	
			NAVD88 (2004.65)	LMSL (1983-2001)
WEST BANK Lakefront Levee to Veterans Hwy	58	14.0 ft	12.7 ft	12.4 ft
WEST BANK Veterans Hwy to I-10 Bridge	23	14.5 ft	13.4 ft	13.1 ft
WEST BANK I-10 Bridge to Southern RR	16	15.0 ft	13.4 ft	13.1 ft
EAST BANK Hammond Hwy to Veterans Hwy	26	14.0 ft	12.4 ft	12.1 ft
EAST BANK Veterans Hwy to I-10 Bridge	37	14.5 ft	13.5 ft	13.2 ft
EAST BANK I-10 Bridge to Southern RR	18	15.0 ft	13.6 ft	13.3 ft

During January 2006, Post-Katrina Overbank Surveys were taken north and south of the breach areas by 3001 Inc. These surveys were performed in support of IPET physical models of the breach sites. They also provide a quality assurance check on Task Force Guardian surveys performed after Katrina. State plane coordinates are LA 1702 South and elevations are in feet NAVD88 (2004.65). The stationing is not the floodwall alignment.

Table III-7 Post-Katrina Floodwall Elevations Vicinity East Bank Breach Area (17th Street Outfall Canal) IPET Overbank Surveys January 2006 (3001, Inc.)				
X	**Y**	**Elev (ft)**	**Location**	**Datafile reference**
South of Hammond Hwy (Vicinity Hay Place)				
Sta. 4+50				
3664412.64	554305.82	12.373	Top Conc Fldwall	17thLondon.dc
3664413.38	554305.78	12.376	Top Conc Fldwall	17thLondon.dc
Sta. 5+00				
3664409.22	554256.33	12.418	Top Conc Fldwall	17thLondon.dc
3664409.99	554256.3	12.425	Top Conc Fldwall	17thLondon.dc
Sta. 5+50				
3664406.5	554205.41	12.329	Top Conc Fldwall	17thLondon.dc
3664405.82	554205.56	12.318	Top Conc Fldwall	17thLondon.dc
South of Hammond Hwy (Vicinity 40th Street)				
Sta. 14+00				
3664348.77	553357.14	12.409	Top Conc Fldwall	17thLondon.dc
3664348.05	553357.13	12.36	Top Conc Fldwall	17thLondon.dc
Sta. 14+50				
3664345.33	553307.32	12.389	Top Conc Fldwall	17thLondon.dc
3664344.67	553307.28	12.414	Top Conc Fldwall	17thLondon.dc
Sta. 15+00				
3664341.03	553257.2	12.461	Top Conc Fldwall	17thLondon.dc
3664341.86	553257.23	12.475	Top Conc Fldwall	17thLondon.dc
Note: duplicate shots are at the flood side and protected side of the floodwall concrete cap.				

Based on provisional observations, current floodwall cap elevations appear to be running about 1.5 to 2 ft below the original design elevation. This is somewhat consistent with the 1.96 ft estimated reduction computed in the preceding paragraph.

Floodwall elevations near the Hammond Highway breach area were running between 12.1 and 12.2 ft LMSL (1983-2001) based on the IPET surveys and slightly lower (11.9 ft to 12.1 ft) using MVN survey data closer to the breach site. (Shots on floodwalls on each side of the breach were actually down to about elevation 11.7 ft; however it is not clear if the walls were deformed/deflected at these points). Updated sea level epochs may reduce these relative elevations even further.

The approximately 2-ft difference indicated in the above table correlates with the elevation projections made in the previous paragraphs. The above can be illustrated in the following graphic.

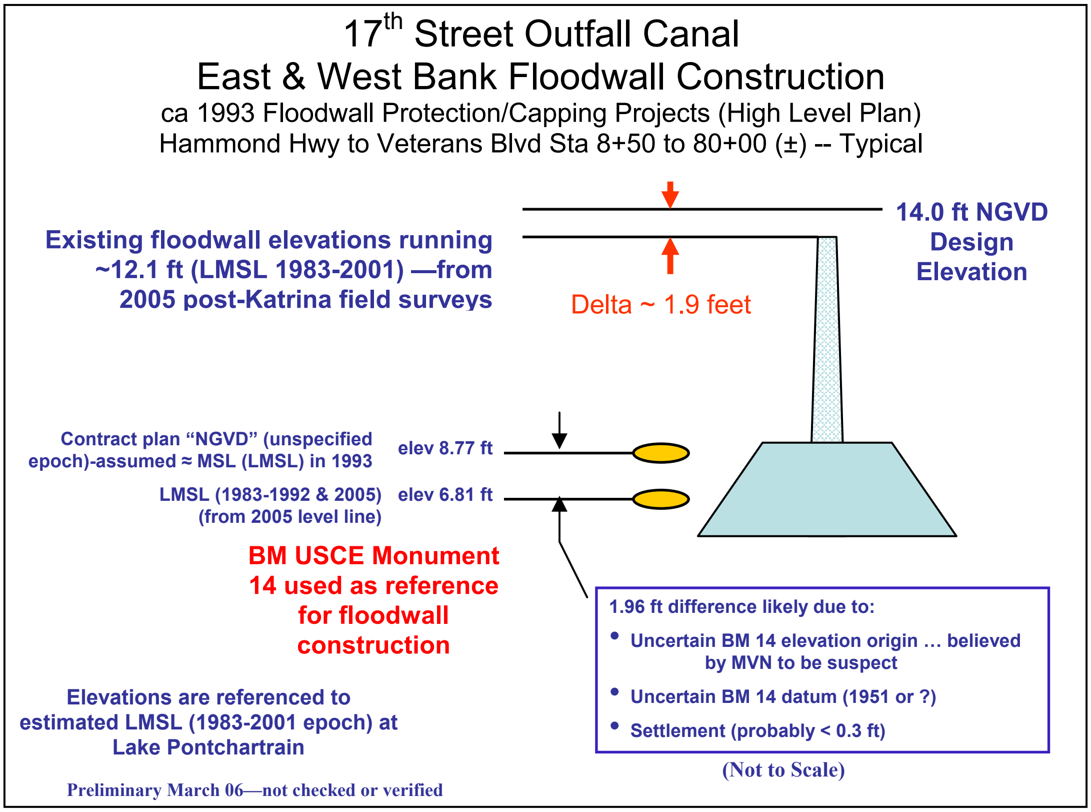


Figure III-9. Design vs. Current Floodwall Elevation—East Bank 17th St Outfall Canal

Pre-Katrina LIDAR Elevations on the 17th Street Floodwall Caps (East Side Breach Site). (This information has not yet been obtained for this Interim Report since it has not yet been adjusted to NAVD88 (2004.65). This LIDAR data will be compared with post-Katrina topographic survey data taken adjacent to the breach site. This analysis will be included in the Final Report.)

4. Inner Harbor Navigation Canal (IHNC) Construction Reference Datums. The following as built construction drawing was reviewed as part of this assessment:

- DACW29-70-B-0088 As Built Mark Up-IHNC Inner Harbor Navigation Canal East Levee—IHNC Lock to Florida Ave Levee & Floodwall Capping

Other floodwalls along the IHNC east or west bank were not evaluated in this assessment since the above area covers the critical breach site at the Lower 9th Ward.

Design Elevation Parameters for East Levee Floodwall Capping (1969). IHNC Lock to Florida Ave Sta. 0+00 to 56+20. Reference benchmark used for construction: "BM 1" or same mark as USC&GS "M-152"

- Elevation 21.811 ft MSL (1969 contract plans)

- (Located on IHNC East Lockwall—intact 2006)

- 2005 Post-Katrina GPS connection (MVN 10 Nov 05): Elev 20.34 ft NAVD88 (2004.65)

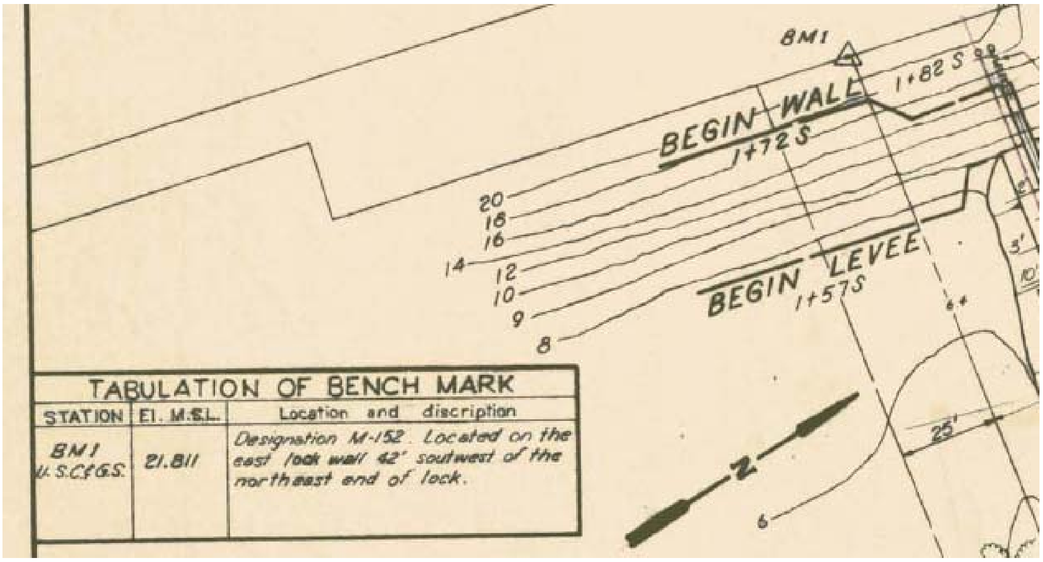


Figure III-10. Location and Description for “BM 1” (M 152 USC&GS) at IHNC Lock

- I-Walls constructed to 15.0 ft MSL—per As-Built Plans

- (No DM/GDM could be found noting design & freeboard parameters)

Historical Adjustments to Reference Benchmark M 152 (1951 to date). The following table (Table III-8) illustrates the various elevations associated with Benchmark M 152. Most of the changes are due to readjustments of level lines by the NOAA NGS (USC&GS), to account for subsidence in this area.

Table III-8
Successive Elevations on Benchmark M 152 from 1951 to 2005

Elev, ft	Datum	Adjustment	Agency	Reference
22.090	NGVD29	1951	USC&GS	L-13860
22.697	NGVD29	19 Mar 52	USC&GS	
21.070	NGVD29	1951/1 Sep 82	USC&GS	L-13860
21.811	NGVD29	1963/9 Apr 65	USC&GS	L-19622
21.811	MSL	1969 Contract Plans	MVN	DACW29-70-B-0088
21.071	NGVD29	1963/1 Sep 82	USC&GS	L-19622
21.070	NGVD29	1982	USC&GS	L-19622
21.148	NGVD29	1985/30 Jan 86	USC&GS	L-24903
20.96	NGVD29	21 Jun 91	USC&GS	L-25283/AU0668
20.963	NGVD29	1995	USC&GS	L-25517
20.76	NAVD88	14 Feb 94	USC&GS	AU0668
20.81	NAVD88	Dec 1996	USC&GS	AU0668
20.34	NAVD88 (2004.65)	10 Nov 05	USACE	MVN
TBD	LMSL (1983-2001)	(May 2006)	NOAA CO-OPS	
TBD	LMSL (2001-2005)	(May 2006)	NOAA CO-OPS	

From the above table it is apparent that the then (1969) most current elevation (21.811 ft) of M 152 was used in the contract plans, irrespective of the fact that the NGVD29 elevation was given as MSL.

The difference between MSL and NGVD29 at this location on the IHNC during the 1963-1969 period has not been determined. It is uncertain that older gage data would be able to quantify this difference to any level of confidence.

Local Mean Sea Level elevation differences in the IHNC have not been computed as of this Interim Report date. They will be provided in the Final Report. It is estimated that the LMSL (1983-2001) difference from NAVD88 (2004.65) will be around 0.2 ft ± 0.1 ft. The difference may be slightly larger for a later LMSL epoch (2001-2005).

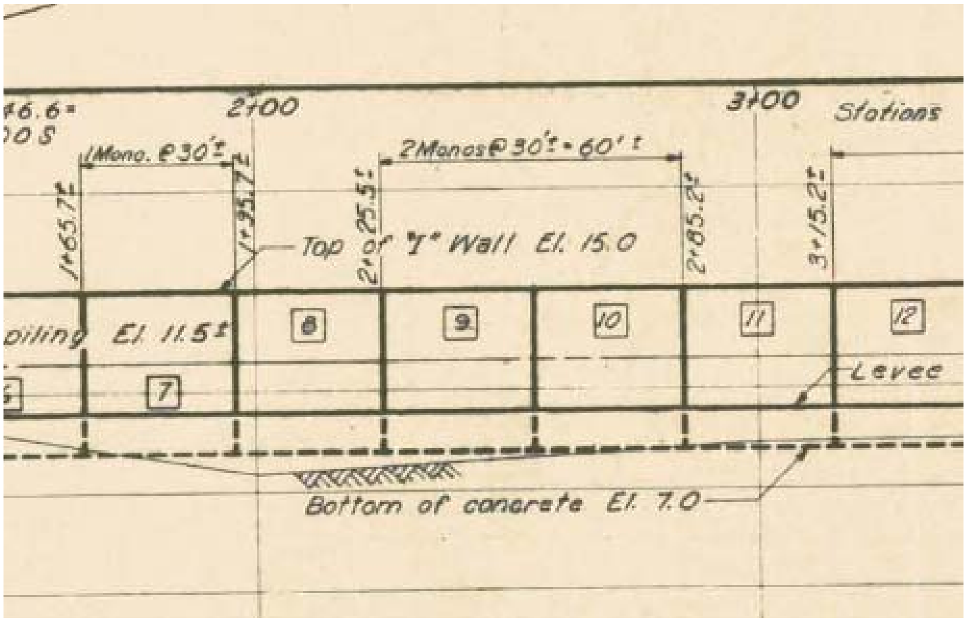


Figure III-11. East Side I-Wall Design Elevation 15.0 ft (Sta. 2+00 Typical)

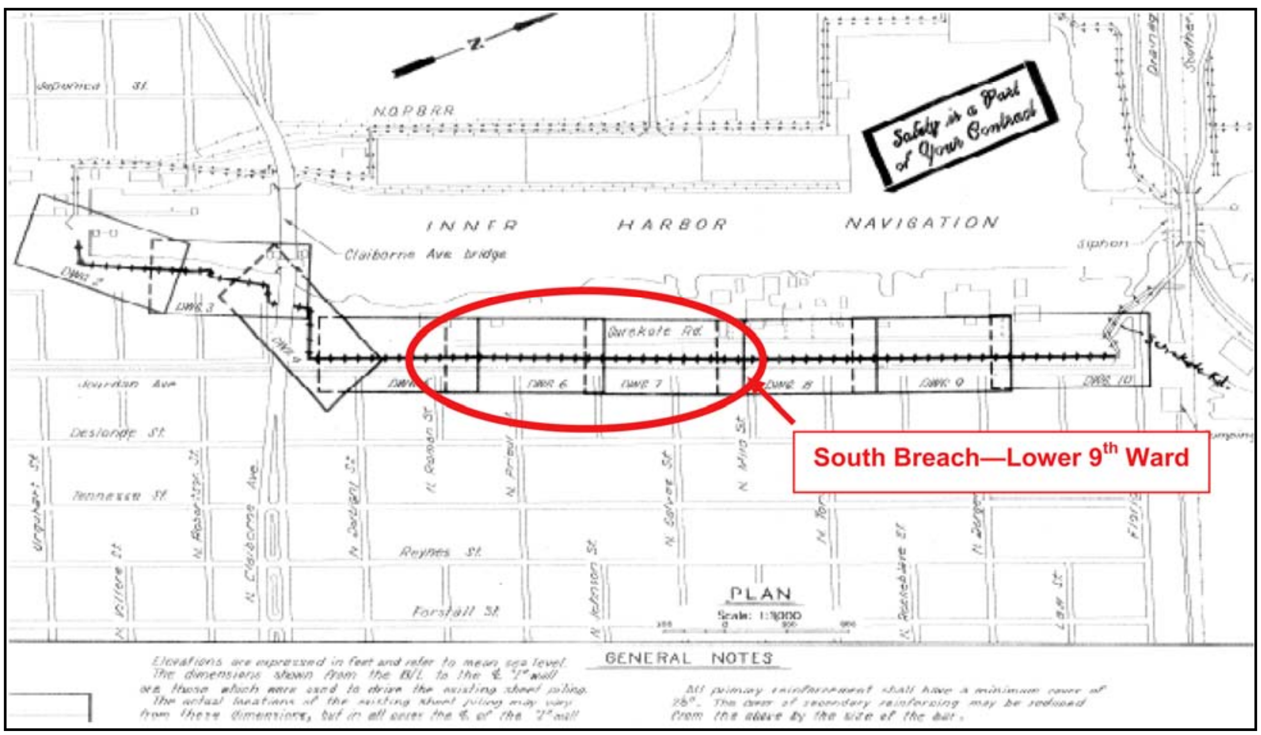


Figure III-12. IHNC East Side Floodwall Capping—IHNC Lock North to Florida Avenue (Lower 9th Ward Breach at approximately Sta. 2+00)

Assessment of Pre- and Post-Katrina Flood Protection Elevations (IHNC East Bank Floodwall between Claiborne and Florida Avenues). New Orleans District survey crews ran levels/RTK surveys to various points along the IHNC, as shown in the drawing below.

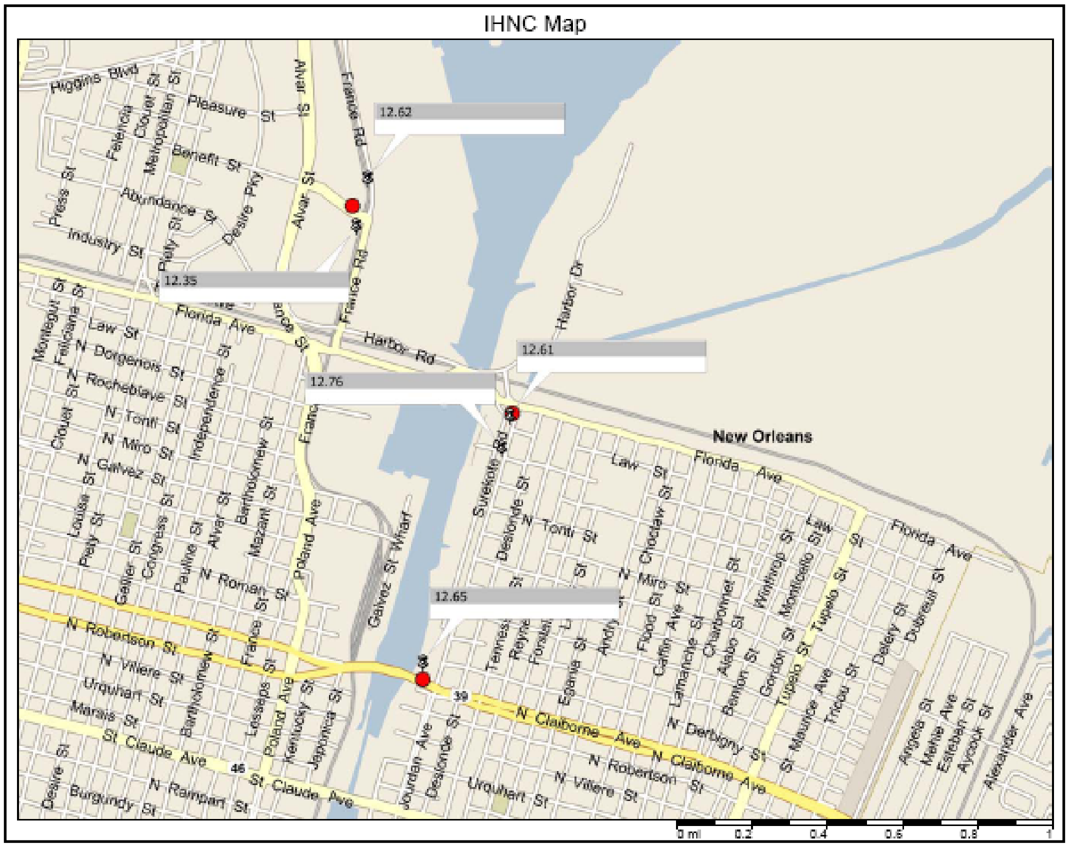


Figure III-13. Selected Post-Katrina Elevations on IHNC Floodwalls

12.35 ft - 50' south of floodgate w-27/w-28 off France road.
12.62 ft - 150' north of same floodgate off France road.
12.61 ft - near pumping station on Florida Ave
12.76 ft - 300' south of pump station Florida Ave.

During January 2006, Post-Katrina Overbank Surveys were taken north and south of the breach area by 3001 Inc. These surveys were performed in support of IPET physical modeling. They also provide a quality assurance check on MVN Task Force Guardian surveys performed after Katrina. State plane coordinates are LA 1702 South and elevations are in feet NAVD88 (2004.65). The stationing is not the floodwall alignment.

Table III-9 Post-Katrina Floodwall Elevations in Selected Reaches (East Bank IHNC) IPET Surveys Overbank Surveys January 2006 (3001, Inc.)				
X	**Y**	**Elev, ft**	**Location**	**Datafile reference**
RTK shots atop East Bank floodwall vicinity Florida Avenue Bridge:				
Sta. 0+00				
3696362.82	540601.98	12.616	Top Edge Conc Fldwal	IHNCEAST.dc
3696363.6	540602.19	12.638	Top Edge Conc Fldwal	IHNCEAST.dc
Sta. 0+50				
3696375.81	540546.84	12.561	Top Edge Conc Fldwal	IHNCEAST.dc
3696374.68	540547.01	12.589	Top Edge Conc Fldwal	IHNCEAST.dc
RTK shots atop floodwall vicinity Claiborne Avenue Bridge:				
Sta. 41+65				
3695275.99	536566.87	13.402	Top Edge Conc Fldwal	IHNCEAST.dc
3695275.76	536566.93	13.399	Top Edge Conc Fldwal	IHNCEAST.dc
Sta. 44+00				
3695089.7	536384.8	13.271	Top Edge Conc Fldwal	IHNCEAST.dc
3695089.47	536384.94	13.333	Top Edge Conc Fldwal	IHNCEAST.dc
Sta. 44+50				
3695069.01	536338.05	13.323	Top Edge Conc Fldwal	IHNCEAST.dc
3695069.34	536337.93	13.296	Top Edge Conc Fldwal	IHNCEAST.dc
Note: Duplicate shots are at the flood side and protected side of the floodwall concrete cap.				

From the above tables, elevations along the East Bank floodwall north of the breach area were running around 12.6 ft to 12.7 ft NAVD88 (2004.65). South of the breach area the elevations range from 12.7 ft to 13.4 ft near the Claiborne Avenue Bridge.

Assuming a 0.2 ft difference between LMSL and NAVD88 (2004.65)—[this value has not been quantified at the time of this Interim Report]—then the post-Katrina floodwall elevation relative to LMSL is approximately 12.5 ft. This 12.5 ft LMSL elevation would also be representative of the 2005 pre-Katrina floodwall elevation in this reach.

5. Stillwater and Normal Water Surface Elevations in Design Documents. Various design memorandums (DM) were reviewed to assess the reference datums used in determining hurricane design elevations. These included:

- DM 01 Part 1 Hydrology and Hydraulic Analysis--Lake Pontchartrain & Vicinity--Chalmette (Aug 1966)
- DM 01 Part 2 Hydrology and Hydraulic Analysis--Lake Pontchartrain & Vicinity--Barrier (Aug 1967)
- DM 01 Part 3 Hydrology and Hydraulic Analysis--Lakeshore (Sep 1968)
- DM 13 Vol I GDM Orleans Parish Lakefront Levee West of IHNC (Nov 1984)

Lake Pontchartrain and Vicinity Projects. DM 01 Part 2 (1967) states the average high tide of Lake Pontchartrain at 1.4 ft. This level is used as a base (or initial) elevation for subsequent storm surge modeling. The design memorandum notes all elevations are referred to "Mean Sea level."

DM 01 Part 3 (1968) and DM 13 Vol 1 (1984) later noted the average high tide in Lake Pontchartrain at 0.7 ft. This was adjusted down 0.7 ft from the 1.4 ft average high tide cited in the 1967 Barrier Plan (DM 01 Part 2). This was based on a USC&GS releveling and gage adjustment.

TABLE 1
CRITICAL AVERAGE LAKE ELEVATIONS
DESIGN HURRICANE

Track	Starting lake stage feet	Contributions: Rainfall feet	Contributions: Runoff feet	Contributions: Overflow feet	Final lake stage feet
A	0.7	0.6	0.1	0.2	1.6
C	0.7	0.7	0.1	0.7	2.2
F	0.7	0.7	0.1	0.6	2.1

Figure III-14. Average Lake Pontchartrain stages (DM 01 Part 3—1968)

Other design memorandums note the "normal water level" of Lake Pontchartrain at 0.0 ft MSL (Appendix B of GDM 20 (Draft) London Ave. Canal Floodwalls and Levees—Orleans Levee District—(Apri1986).

(Note that the Design or Hurricane Tide is the maximum stillwater surface elevation experienced at the location during the passage of a hurricane. This Design Tide uses the initial normal (predicted) tide as a base reference, or alternately the high tide. EM 1110-2-1913 notes freeboard was, in the past, used to account for hydraulic, geotechnical, construction, operation, and maintenance uncertainties. Currently a risk-based analysis is used to set the final levee grade to account for settlement, shrinkage, cracking, geologic subsidence, and construction tolerances.)

DM 01 Part 1—Chalmette (1966) indicates a "normal predicted tide" of 1.60 ft (MLW) and a (-) 0.60 ft correction from MLW to MSL. This implies a normal predicted tide of 1.0 ft MSL at the Chalmette area. Resultant observed and computed hurricane surge heights are relative to MSL. A plate depicting typical tidal cycles in Lake Borgne and Lake Pontchartrain indicates MSL elevations average +1.0 ft above 0.0 MSL in both areas. DM 01 states the average tidal ranges in Lake Borgne and Lake Pontchartrain are +1.0 ft and 0.5 ft respectively, and the average elevation of the lakes "differs very little." The elevation of Lake Borgne is given at 0.9 ft and Lake Pontchartrain 1.0 ft. The source of these elevations (i.e., gage and/or leveling datum) is not readily apparent in the design memorandum. Given all elevations in the design memorandum refer to MSL it is presumed that these 0.9 and 1.0 ft "normal water surface" superelevations also refer to MSL. If these elevations are based on gages referenced to a "NGVD" datum, this is not apparent from the limited records viewed.

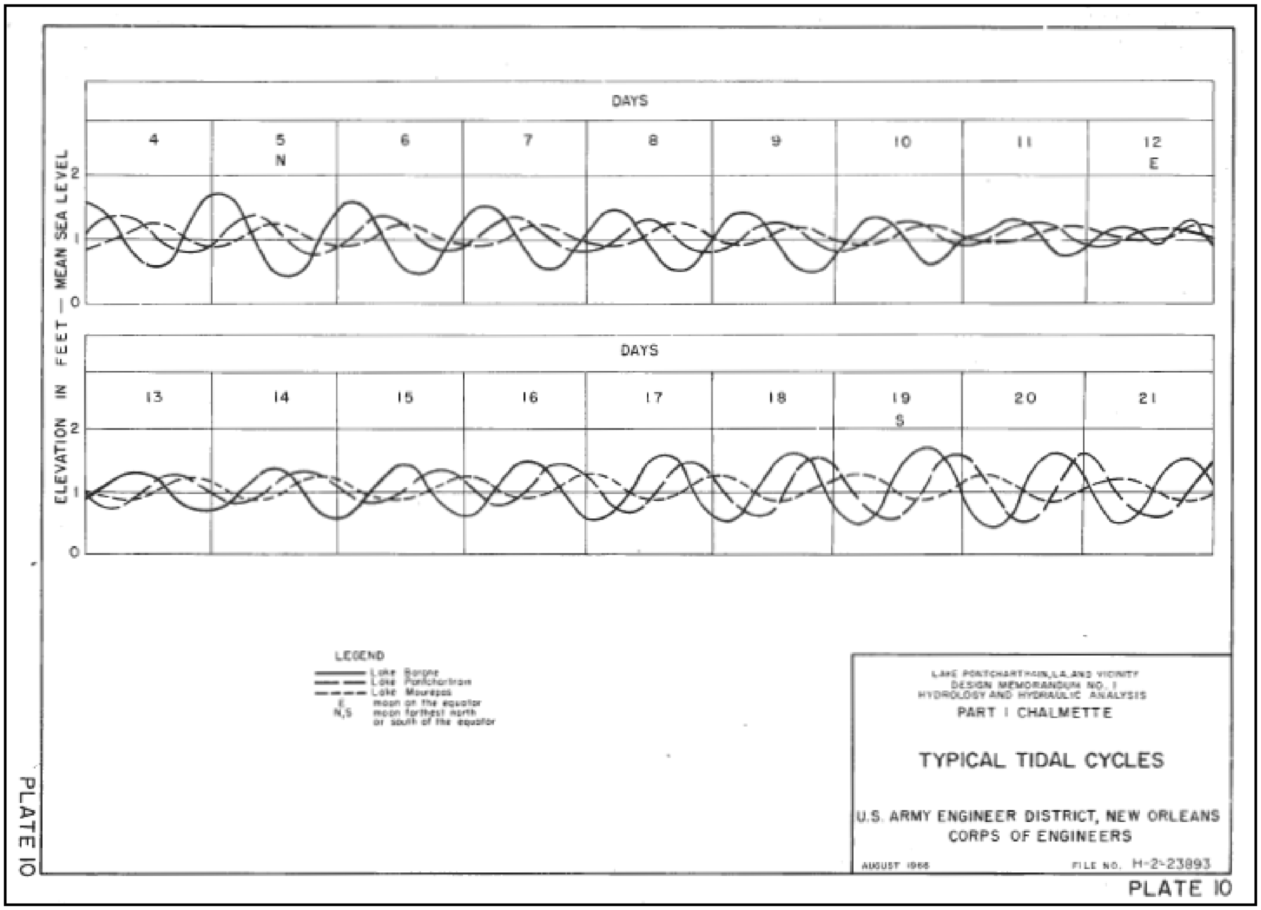


Figure III-15. +1.0 ft superelevation on Lake Borgne and Lake Pontchartrain (DM 01 Part 1)

The following plate from DM 01 Part 3 depicting wind tide profiles indicates the Mean Lake Level of Lake Pontchartrain as +1.0 ft.

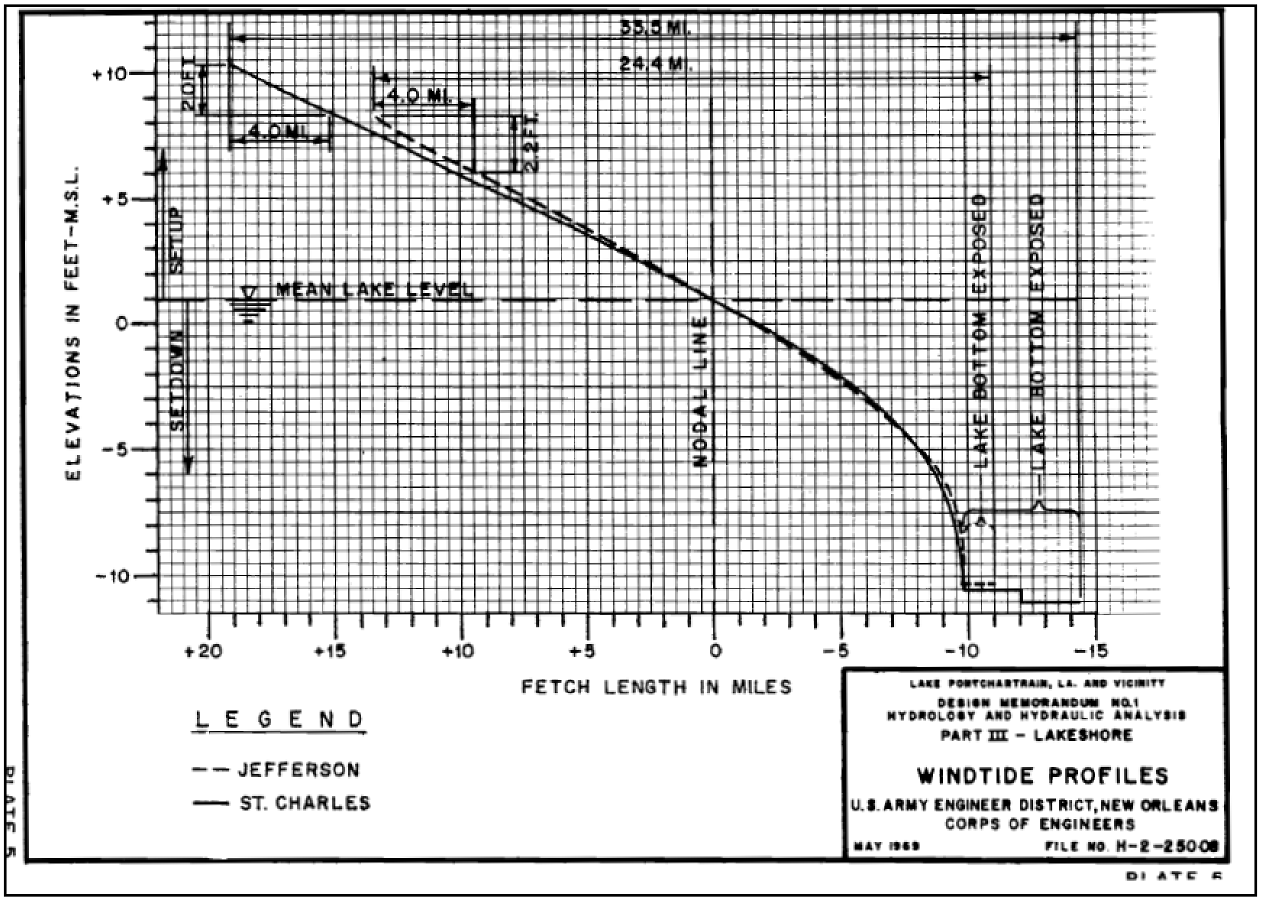


Figure III-16. +1.0 ft "Mean Lake Level" relative to MSL for Lake Pontchartrain (DM 01 Part 3)

Design and construction document depict Normal Water Levels in the outfall canals ranging between +1.0 ft to +2.0 ft. The source and reference datum for these estimates is not clear from the documents.

New Orleans to Venice Projects. Referenced design memorandums:

- DM 01 GDM Supp 04—New Orleans to Venice--Reach B2--Fort Jackson to Venice (Aug 1972)

- DM 01 GDM Supp 06--West Bank Mississippi River Levee--City Price to Venice (Mar 1987)

Stillwater elevations and hurricane design elevations on the New Orleans to Venice projects generally refer to the MSL datum (DM 01 GDM Supp 04--1972). Tides along the coast are noted having a mean range of 1 foot. Both headwater flooding and tidal effects are compensated for in computing surge elevations in the Mississippi River north of Venice. Page A-16 of DM 01 GDM Supp 04 states the Predicted "Mean Normal Tide" in the project area varies from 0.4 ft to 1.0 ft MSL. It is unclear if this Mean Tide is equivalent to Mean Tide Level or how it relates to Mean Sea Level. The design hurricane surge height for the project area is given as 11.5 ft MSL.

DM 01 GDM Supp 06 (1987) noted that surge studies performed after Hurricane Betsy in 1965 were in error by as much as 1 foot due to readjustments to the NGVD level network in this area. This resulted in hurricane stages being 1 foot too high.

> (4) Subsequent to completion of the NESCO study, it became apparent based on a new level network that bench mark elevations in the study area were actually as much as 1 foot lower with respect to national geodetic vertical datum than their recorded elevations. Therefore, all stages experienced during Betsy and used in the NESCO study were recorded too high with respect to national geodetic vertical datum. The undisturbed river profile and the Betsy surge crest profile used and computed in the NESCO study are shown on figure 6, plate B-10. However, the maximum stage shown at West Pointe-a-la-Hache, mile 49 AHP, was 14.4 feet rather than 15.2 feet, and the mean stage at the Carrollton gage, mile 103 AHP, prior to Betsy, was 2.0 feet rather than 2.7 feet. The 2.0-foot stage at Carrollton is the mean tide level on the day before Betsy struck the Louisiana coast. Corrected profiles are shown on plate B-7.

Figure III-17. NGVD29 network adjustment impact (Appendix B--DM 01 GDM Supp 06 (1987))

Mississippi River Gulf Outlet Projects. Referenced design memorandums:

- DM 01 A--MRGO Channels Mile 63.77 to 68.85 (Jul 1957)
- DM 01 B--MRGO Channels Mile 39.01 to 63.77 (May 1959)
- DM 01 C--MRGO Channels Mile 0 to 36.43 (Bayou La Loutre) Mile 0.0 to (-) 9.75 (38 ft Contour) (Nov 1959)
- DM 02 GDM Supp 03-Bayou La Loutre Reservation (Feb 1968)
- DM 01 GDM--Michoud Canal (Jul 1973)

All documents refer MRGO channel elevations to Mean Low Gulf (MLG), which is 0.78 feet below MSL. This reference is standard for dredging and navigation projects in this region—see the Background to this Report.

Records from a water level recording gage on the GIWW at Paris Road indicated average yearly high and low water stages significantly above that expected for an area subject to direct tidal flow, as shown in the figure below. The reason for this anomaly in unclear.

TABLE A-7
Average Annual High & Low Water Stages
Gulf Intracoastal Waterway at Paris Road Bridge

Year	Mean High Water (m.s.l.)	Mean Low Water (m.s.l.)
1959	Insufficient records	
1960	Insufficient records	
1961	2.58	1.66
1962	2.37	1.30
1963	2.27	1.27
1964	2.51	1.34
1965	2.77	1.37
1966	2.83	1.46
1967	Insufficient records	
1968	2.86	1.54
1969	3.30	1.87
1970	3.30	1.91

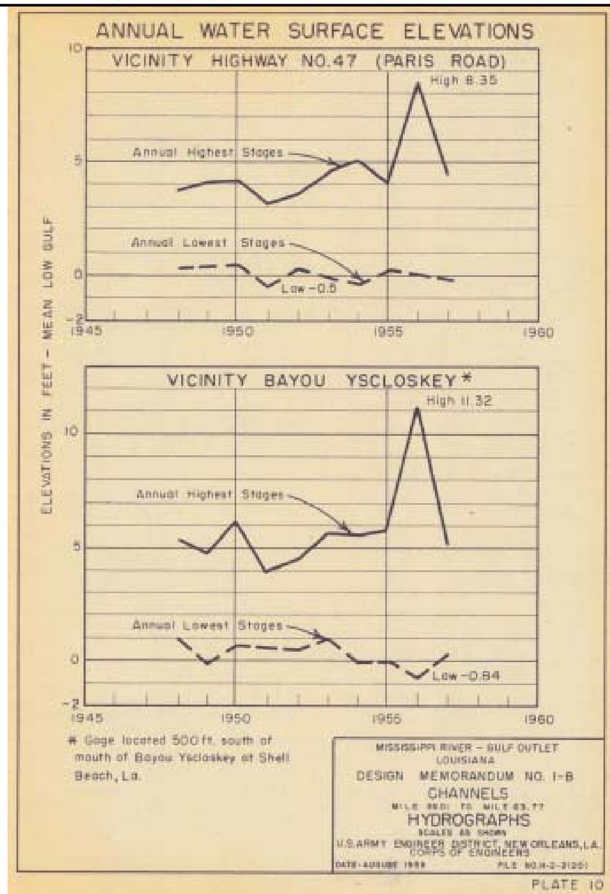


Figure III-18. GIWW water level stages at Paris Road (DM 01 GDM)

DM 02 GDM Supp 03-Bayou La Loutre Reservation (Feb 1968) notes the Average Water Surface for this section of the MRGO at 0.75 ft MSL. The maximum expected hurricane surge (SPH) is 15.0 ft MSL.

Preliminary Findings

Maps of datum/adjustment differences (project area with values)

The following figures show the relationship between NGVD 29(1991) and NAVD88 2004.65 elevations differences, the NGVD 29(1991) and NAVD 88(1994/1996) elevation differences, and the NAVD88(1994/1996) and NAVD88 2004.65 elevation differences at selected control monuments.

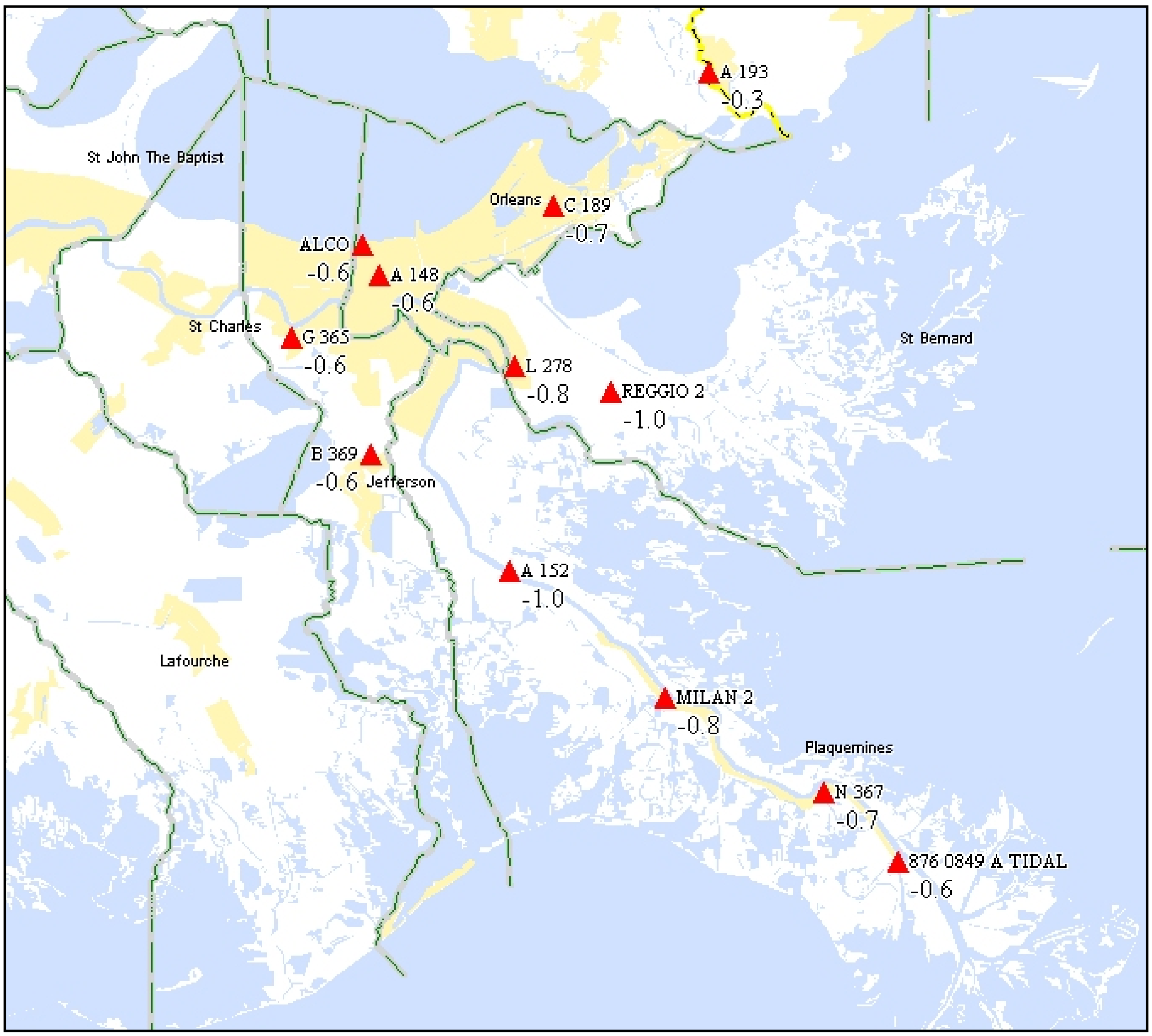


Figure III-19. Elevation Difference between NGVD29(1991) and NAVD88(2004.65) at select control monuments (values in feet)

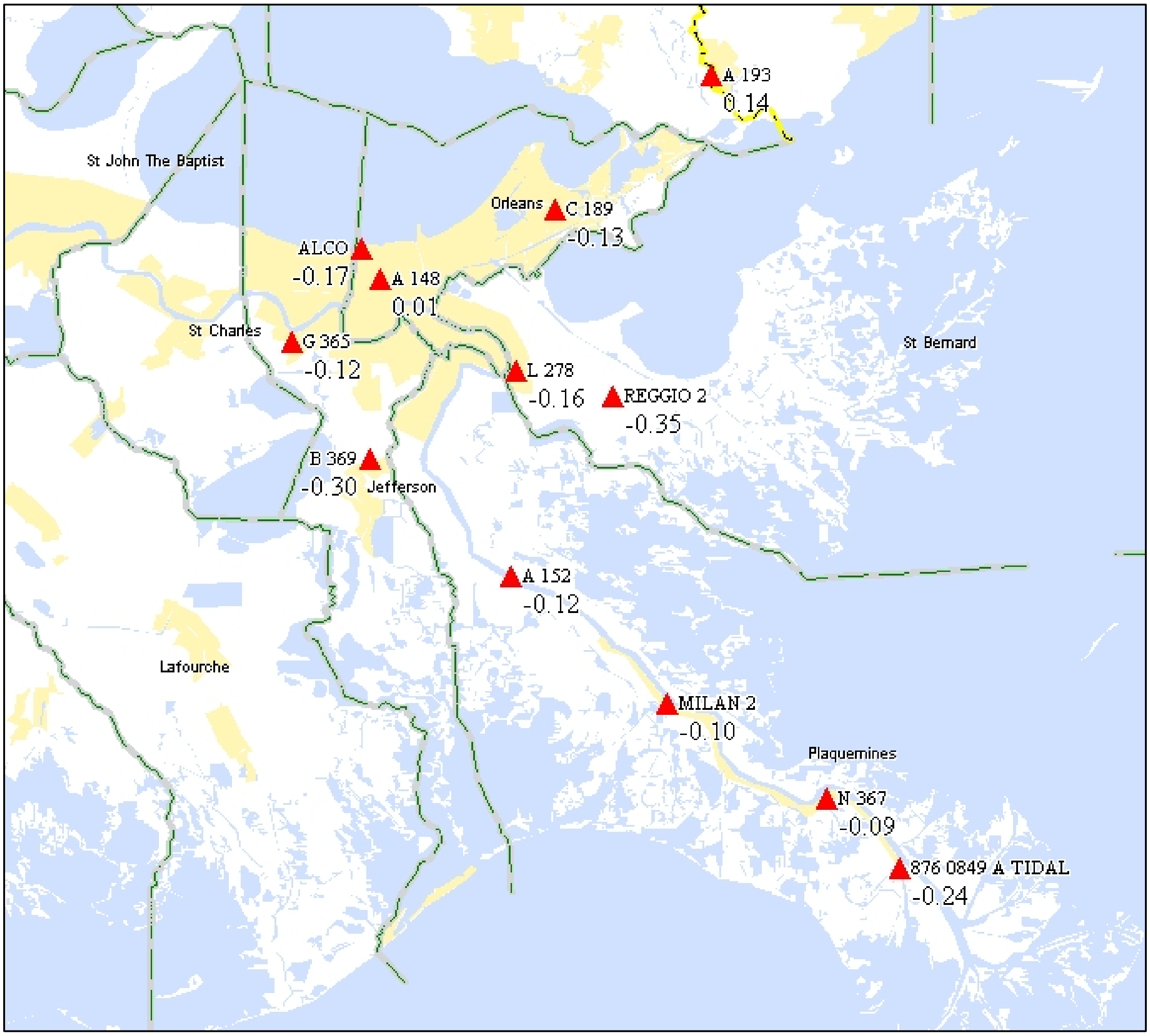


Figure III-20. Elevation Difference between NGVD29 (1991) and NAVD88(1994/1996) at select control monuments (values in feet)

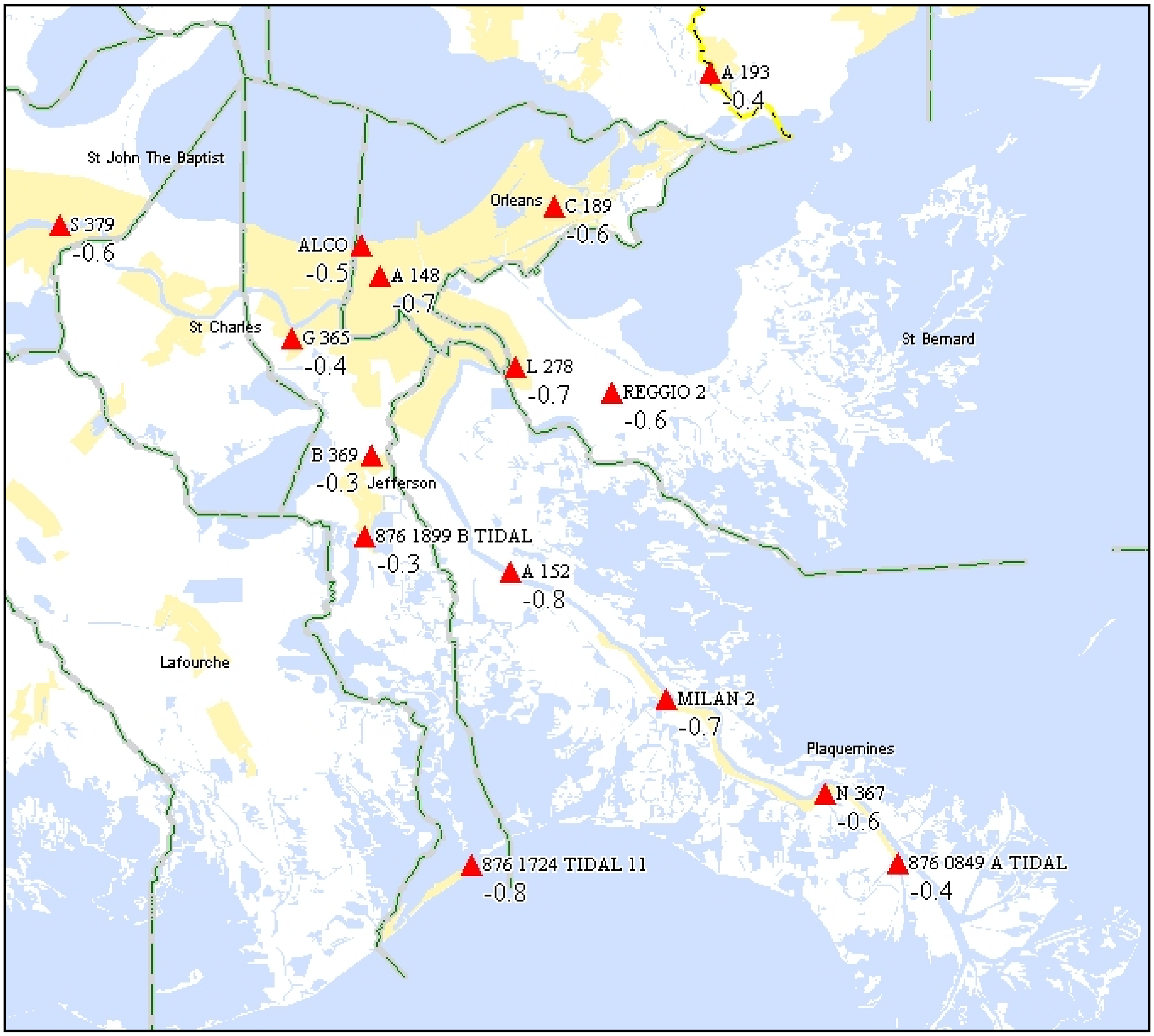


Figure III-21. Elevation Difference between NAVD88(1994/1996) and NAVD88(2004.65) at select control monuments (values in feet)

Preliminary relationships between the LMSL and NAVD88 2004.65

The preliminary results show the LMSL is almost a constant level surface above NAVD 88_2004.65 (the current geodetic datum). Two anomalies were noticed in the preliminary results. The LMSL above the current geodetic datum 8761602 Lake Judge Perez, Hermitage Bayou was 0.1 feet higher than the other stations. This is because the station is located far into the bayou above Barataria Bay. The range of tide will decrease significantly here (0.42 feet) and the presence of the land will force the water to slightly rise. This raises the LMSL. The LMSL at 8761678 Michoud Substation, Intercoastal Waterway is a half-foot lower than the other water level stations. The contractor went back into the field 21 and 22 February 2006 to measure from a different monument (WES 19 1978) here. The results were almost identical; the LMSL is 0.4 feet below the current geodetic datum and 0.5 feet lower than the LMSL at the other water level stations. This maybe either a hydraulic event from the canals and locks, or this is due to a large intake of water at the Michoud Substation.

The following figures show the preliminary relationship between the LMSL and the NAVD88 2004.65 datum.

Figure III-22. Map of Tide Stations and Values from NOAA CO-OPS Showing the height of the LMSL above NAVD88 2004.65 values (all values in feet)

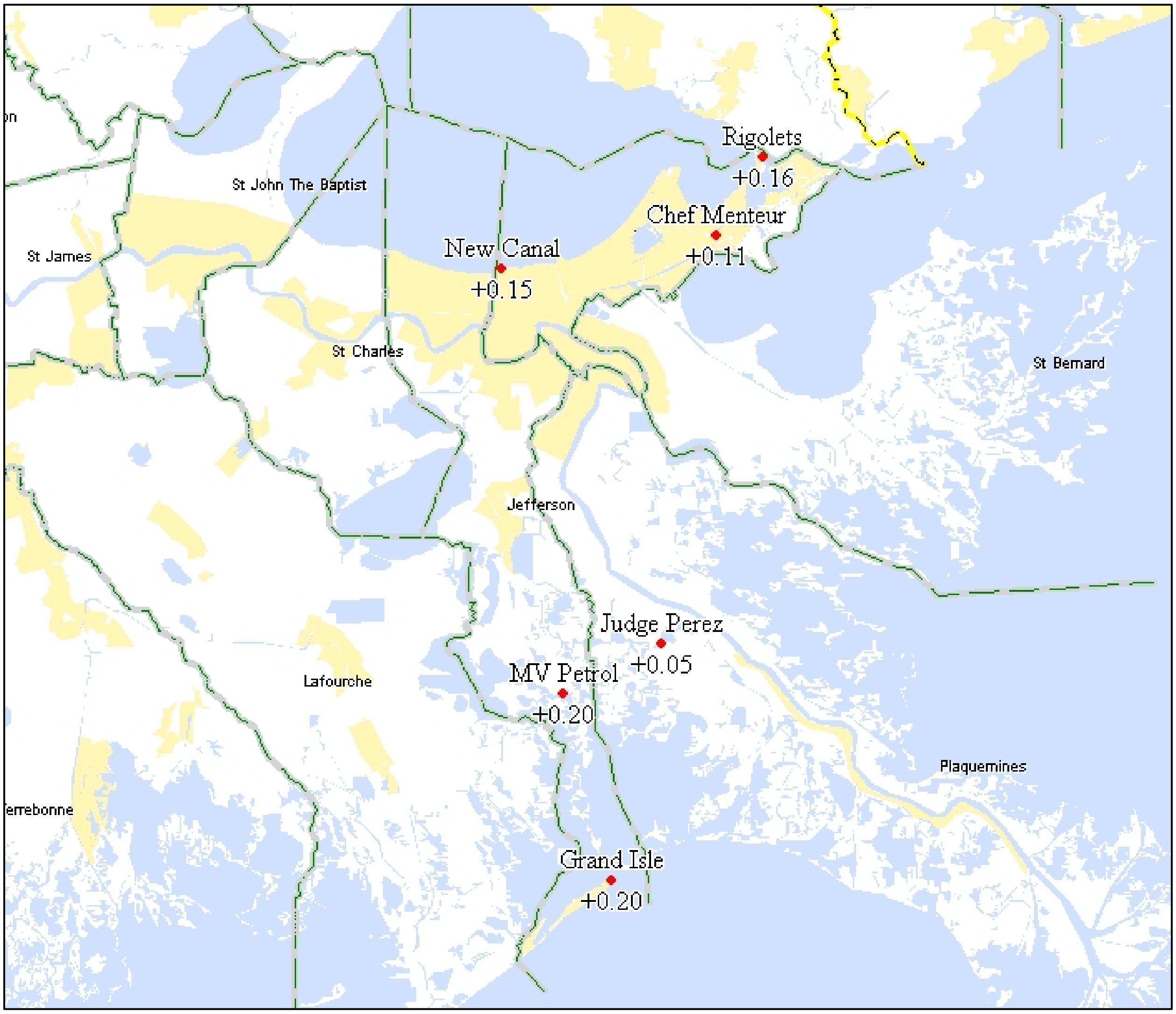


Figure III-23. Map of Tide Stations and Values from ERDC-TEC Showing the height of the LMSL above NAVD88 2004.65 values (all values in feet)

Example Datum shifts & Local Mean Sea Level relationship to the datum over time

The following figure shows the changes in the elevation values at Benchmark ALCO 1931 from 1952 until present including an elevation of LMSL in 2005. The changes in elevation are due to various adjustments on the datums and a datum shift (between NGVD29 and NAVD88).

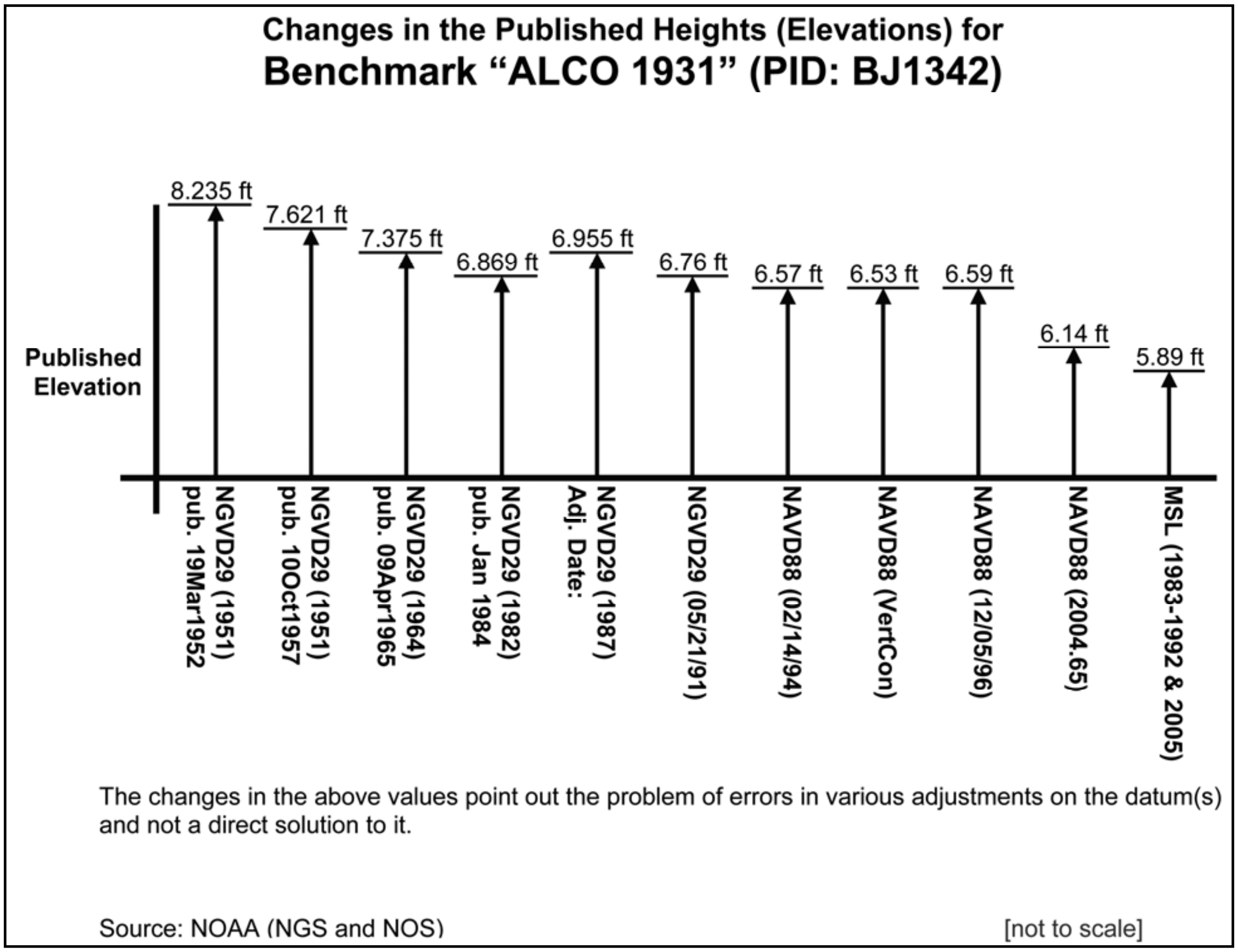


Figure III-24. Elevation changes at Benchmark "ALCO 1931" since 1951

Preliminary Methodology (Procedures) for conversion of previous vertical datum/adjustments to NAVD88 2004.65

The methodology used to shift historical survey data to NAVD88 (2004.65) will vary dependent upon many factors such as time, funds, accuracy requirements, etc. Generally there are four methods to determine the datum/epoch shift.

1. Field Measurements w/ Known Historical Elevation: This method will yield the most accurate values based on the historical reference marks. The reference marks will need to be recovered and occupied/surveyed using the guidelines in NGS 58. The difference between the elevation used for the original survey and the elevation established from the new network will directly tie in the old work to the latest control. This will not account for any differential subsidence that occurred between the reference mark and the survey positions.

2. Field Measurements w/o Known Historical Elevation: When the reference benchmark is not recorded and unknown, some assumptions will be required such as what mark was used and what its elevation was. Again follow the procedures in NGS 58 to establish new elevations on the reference mark. The historical elevation will have to be assumed based on what was available at the time of design. The difference between the assumed historical elevation and the newly established elevation will be used to shift the survey to the new datum/epoch.

3. Common Published Marks in Survey Area: When time and money are constraints, the closest marks with published elevations in both datum/epochs can be used to determine an average shift for the area. This method contains many assumptions and therefore is the least accurate but may be of some use for projects that don't require accuracy.

4. CORPSCON: This method does not account for subsidence or the change in elevation from epoch to epoch. CORPSCON model was also tied to the published elevations at the time the model was created which contained errors associated with the already deteriorating elevation accuracies. This method should not be used for anything other that a pure datum shift keeping in mind that subsidence is not accounted for.

Summary of Findings and Recommendations

This section summarizes tentative recommendations based on findings and lessons learned from this portion of the study. These draft recommendations are subject to additional review and consideration by IPET Geodetic Vertical and Water Level Datum Team interagency members and other external reviewers.

Dual Elevations on Flood Control and Hurricane Protection Structures

Finding: Design and construction documents referenced both geodetic datums (e.g., NGVD29) and water level datums (e.g., MSL) without defining the geographical relationships, numerical differences, observation epochs, or other significant metadata associated with these datums. In most cases, NGVD29 was incorrectly assumed as an equal elevation to MSL.

Recommendation: Planning, design, construction, and operation & maintenance inspection documents containing elevation data on flood control structures should show both geodetic and water surface referenced elevations. The relative water surface reference datum (i.e., LMSL) should be used as the baseline for hydraulic modeling and related levee height design computations. The terrestrial geodetic datum should be used for construction stake out and subsequent periodic subsidence modeling. The base gage defining a water level datum must be clearly defined, along with applicable tidal or river stage epochs, and conversion parameters to relate water level datums to the local geodetic datum.

Geospatial Data Source Feature or Metadata Records

Finding: Design and construction documents seldom identified the source of hydrographic, topographic, or construction survey records, including water level gage records.

Recommendation: Planning, design, and construction documents containing survey information should contain detailed source (i.e., metadata) information on geospatial coordinates or terrain models included in those documents. This would include the location and repository for the original source data, field book numbers, monument descriptions, etc. Geospatial metadata incorporated in documents shall have sufficient detail such that there is no uncertainty (currently or in the future) as to the location of the original data, its origin, and other temporal relationships.

Epoch Designations of Published Topographic Elevations

Finding: Design and construction documents seldom identified the epoch associated with a particular datum. This is especially critical in a high subsidence area where apparent sea level rise (i.e., combined sea level rise with subsidence) can have significant changes over a relatively short period.

Recommendation: Reported elevations of surface topography, subsurface bathymetry, and/or constructed structures in high subsidence areas should contain feature (metadata) information on the source datum and applicable adjustment epoch date. This applies to both geodetic elevations (e.g., 12.345 ft NAVD88 (2004.65)) and water level based elevations (e.g., (-) 5.25 ft LMSL (2001-2005) or 35.0 ft MLLW (1983-2001) or 12.3 LWRP (1974)). Hard copy or CADD data files should place this metadata information in the General Notes on the first sheet of a series, with appropriate references on subsequent sheets that depict topographic information.

Future Updates to NAVD88 in New Orleans Region

Finding: Geodetic elevations are extremely time-dependent in this region and must be periodically adjusted to account for apparent sea level changes.

Recommendation: The current (2004.65) adjustment to the “time-dependent” (VTDP) NAVD88 network for the Southeast Louisiana area should be periodically reviewed for subsidence relative to the nationwide spatial reference system. This review should be performed annually by the NOAA National Geodetic Survey (NGS) using CORS observations and other applicable geodetic sources. When periodic reviews by NGS indicates average elevation changes in the VTDP network exceed 0.05 ft, then actions should be taken to revise and update the time-stamped NAVD88 VTDP network for this region. This update should be performed at least every 5 years regardless of elevation changes. NGS must closely coordinate subsequent updates with the Corps of Engineers and other federal, state, parish, levee board, and other local agencies to ensure that engineers and others responsible for the planning, design, and construction of flood control structures are made aware of the revised adjustments. These subsequent adjustments must also be closely coordinated within NOAA to ensure CO-OPS water level datum references are appropriately revised to reflect any geodetic datum revisions.

Additional Co-located CORS and NWLON Sites for Subsidence Monitoring

Finding: There is an insufficient density of subsidence and water level monitoring points to adequately evaluate current flood protection elevation elevations of control structures.

Recommendation: NOAA should establish subsidence and water level monitoring instrumentation at the following sites in Southeast Louisiana by NOAA. These sites will be used to monitor future land subsidence and reference water level datums, as required to assess and update protection elevations of flood control structures throughout the region. Each site should contain complete NOAA quality CORS GPS and NWLON gage instrumentation.

1. Lake Pontchartrain (USCG Station--17th Street Canal—NOAA New Canal gage site)

2. Lake Pontchartrain (East end—The Rigolets or Chef Menteur area—NOAA gage sites)

3. IHNC (Corps of Engineers Lock—existing gage site)

4. GIWW-MRGO (Michoud Substation area—NOAA gage site)

5. Lake Borgne (New Shell Beach area)

6. Venice, LA (New Orleans District Project Office)

7. Mississippi River (Carrollton gage site-New Orleans District Office)

New Orleans District Water Level Gages

Finding: There is an insufficient density of subsidence and water level monitoring points to adequately evaluate current flood protection elevation elevations of control structures.

Recommendation: To provide additional surface modeling coverage, New Orleans District gages (and those maintained by the USGS, NWS, levee boards, and others) should be connected and referenced to NAVD88 (2004.65), or the latest geodetic datum published by NGS. New Orleans District should make modifications to District-owned gages to meet NOAA NWLON specifications and include these gages in the NWLON.

Local Mean Sea Level Epoch Updates and Relationships

Finding: 19 year updates to LMSL computations is too long an interval in this high subsidence area.

Recommendation: LMSL epochs should be periodically updated by NOAA CO-OPS in order to monitor subsidence and/or apparent sea level rise at NWLON gage sites. Five-year tidal epochs should be computed and reevaluated yearly, and apparent sea level rise estimated for NWLON gages in the area. CO-OPS should perform these periodic evaluations in close coordination with New Orleans District hydraulic engineers (CEMVN-EH). The New Orleans District should reassess gage datums on non-NWLON gages on an annual basis, in close coordination with CO-OPS reevaluations and updates. NOAA CO-OPS should develop and publish an operating manual specific to the process of maintaining water level datums in this Southeast Louisiana region.

Mean Sea Level and Local Mean Sea Level

Finding: These two terms should not be used interchangeably.

Recommendation: When referring to the mean water surface at or near a specific flood control project, LMSL should be used. A LMSL derived elevation should clearly identify the water level reference gage location and the time series (epoch) over which the mean surface elevation was computed.

Coordination of Topographic Survey Data Collection, Processing, and Management

Finding: A variety of topographic survey data is produced by various elements within and outside the New Orleans District, primarily by contracted surveying and mapping firms. Given this dispersion, locating datasets is a difficult process.

Recommendation: The New Orleans District should develop a comprehensive GIS system to maintain hydrographic, topographic, and geodetic data collected by various engineering, construction, and operations entities within and/or external to the District. Data formats should be standardized based on existing Corps guidance—e.g., CADD/GIS Technology Center, EM 1110-1-1005 (Topographic Surveying), etc.

Vertical Control Monumentation Requirements and Stakeout Procedures on Flood Control Construction Projects

Finding: Most construction contract documents reference only one benchmark for controlling construction.

Recommendation: A minimum of three (3) permanent benchmarks should be identified on design and construction drawings for all flood control projects. These marks should be established during the planning and design phase. The marks shall be situated at each end of the project. They shall be established relative to existing NAVD88 (20XX.XX) control established by the NGS, using either conventional differential leveling and/or the latest NGS-approved differential GPS network observations. Prior to and during actual construction stake out, these primary reference marks should be verified externally and internally. Field records of these survey verifications shall be permanently archived.

LIDAR and Photogrammetric Mapping Calibration and Testing

Finding: Various LIDAR mapping projects covering the region were not independently ground truthed for absolute accuracy.

Recommendation: Contracts for aerial mapping services shall contain quality assurance provisions for calibrating, ground truthing, and testing delivered mapping products. These methods should follow long-established testing methods outlined in standards such as USACE EM 1110-1-1000 (Photogrammetric Mapping), FGDC, ASPRS, and FEMA.

USACE Policy and Manual on Maintaining Geodetic and Water Level Datums in High Subsidence Areas

Recommendation: USACE ERDC should develop an Engineering Manual (or an addendum/update to the Coastal Engineering Manual) providing theory, guidance, & procedures on maintaining reliable reference datums in high-subsidence areas, including distinguishing engineering applications between water level and geodetic datums. Alternatively, this guidance may be implemented by a policy document (Engineering Regulation).

Differential GPS Survey Standards for Establishing Construction Control

Recommendation: NGS procedures shall be used for establishing supplemental orthometric elevations using GPS. NGS shall develop and promulgate specific operating procedures applicable to this high-subsidence area. These procedures should include methods of determining orthometric elevations relative to local VTDP benchmarks as well as methods for direct establishment of orthometric elevations from CORS stations. Both geodetic accuracy and construction accuracy methods should be covered. Required accuracies are outlined in EM 1110-1-1005.

Supplemental Field Survey Support to Other IPET Teams

This section summarizes topographic survey support performed by the IPET Survey Team in support of modeling requirements needed by other IPET study teams. Approximately 75% of Team 6's field survey work involved support to other IPET Teams. These surveys were performed concurrent with the primary geodetic control surveys connecting NOAA NWLON gages. Field survey operations began in early December 2005 and are still in progress as of the end of February 2006. Surveys were performed throughout the entire study area: Orleans, St. Bernard, Plaquemines, St. Charles, and Jefferson Parishes.

Field survey operations were performed by 3001 Inc., a Louisiana based surveying company. This firm was under an Indefinite Delivery Contract to St. Louis District. St. Louis District awarded a labor-hour type task order to 3001 Inc. on 5 December 2005. IPET Team members Bill Bergen (HQUSACE) and Jeff Navaille (Jacksonville District) arrived in New Orleans on 4 December 2005 and began working out of the New Orleans District Office. Initial efforts involved controlling pump stations, high water mark (HWM) locations, and NOAA NWLON tidal gage sites, which included setting benchmarks for subsequent GPS connections to the NGS NAVD88 (2004.65) reference network. The first 3001 Inc. survey crew arrived in New Orleans on 11 December 2005 and began static GPS surveys for benchmarks at pump stations and priority HWM sites. Three 3001 Inc. survey crews were fully operating by 14 December 2005 and continued working on the various tasks outlined below through 23 December 2005. Survey operations resumed on 3 January 2006 and are continuing at this date.

The following list summarizes various field survey projects performed from 5 December 2005 through February 2006. The supported IPET model is shown in parenthesis.

- High Water Mark Surveys: Leveling to approximately 50 HWM points plus 2,000 ft of levee profile surveys along a five (5) mile levee in St. Bernard Parish (IPET Numerical Storm Surge Models)

- High Water Mark Surveys: Interior Orleans Parish—levels to various residential locations (IPET Numerical Storm Surge Models)

- High Water Mark Surveys: Plaquemines Parish—levels to various locations (IPET Numerical Storm Surge Models)

- Surge Elevation Surveys: Orleans Marina & Lakefront Airport—levels to time-stamped Katrina storm surge points (IPET Numerical Storm Surge Models)

- Bridge Surveys: Low-chord elevation and obstruction surveys (IPET Numerical Storm Surge Models)

  Orleans Outfall Canal: 4 auto bridges
  London Ave Canal: 1 RR bridge and 6 auto bridges

IHNC: 3 RR bridges
17th St Canal: 5 auto bridges

- Pump Station Control Surveys: Approximately 69 pump station first floor elevations throughout Orleans, Jefferson, St. Bernard, and Plaquemines parishes (IPET Pump Station Performance Assessment)

- Pump Station Control Surveys: 5 pump station first floor elevations in St. Charles Parish (IPET Pump Station Performance Assessment)

- Lake Pontchartrain Water Level Gage GPS Surveys: Tie in reference marks on eight (8) USGS, NWS, and levee board gages in the vicinity of Lake Pontchartrain and the IHNC(IPET Numerical Storm Surge Models)

- IHNC West Bank Levee Profile Surveys: SeaLand/Maersk Private Levee (IPET Numerical Storm Surge Models)

- IHNC West Bank Breach Area Topographic Surveys: Florida Ave to I-10 Bridge (IPET Interior Drainage Modeling)

- Ground Truthing/Calibration Surveys of Low-Altitude 2000/2005 LIDAR DEMs: (IPET Data Management)

- Ground Truthing/Calibration of High-Altitude JALBTCX 2005 LIDAR: North shore of Lake Pontchartrain (JALBTCX & IPET Data Management)

- Ground Truthing/Calibration of High-Altitude FEMA/LSU LIDAR: Selected side shot calibration points throughout region (IPET Data Mamagement)

- Hydrographic and Topographic Canal Cross-Sections: Selected sites in Jefferson & Orleans Parishes (IPET Interior Drainage Model)

- Levee/Floodwall Overbank Cross-Sections: London Avenue, 17th Street, & IHNC Breach Sites: (IPET Physical Model of Breaches & IPET Floodwall Performance Analysis)

- Interior Drainage Topographic Sections: Approximately 85 cross-sections at selected locations throughout St. Bernard Parish (IPET Interior Drainage Support)

- Invert Elevations: London & Orleans Outfall Canal pump stations (IPET Numerical Storm Surge Models)

- TBM Descriptions: Stable and recoverable marks to be documented and described in accordance with New Orleans District procedures (MVN/Task Force Guardian)

- Orleans Outfall Canal BM ALCO to CHRYSLER Level Run (IPET Survey Team)

- IHNC Hydrographic Multibeam Survey: Seabrook Bridge to GIWW and GIWW to Mississippi River (IPET Storm Surge/Wave Hydrodynamics)

- High Water Mark Surveys: Orleans Parish vicinity Ninth Ward—levels to various locations (IPET Numerical Storm Surge Models)

Field Survey Procedures and Specifications

All field surveys for supplemental topographic work were performed following established Corps of Engineers and NOAA standards and specifications.

Static GPS surveys were performed to set permanent or temporary benchmarks throughout the five-Parish area. Supplemental topographic surveys were performed from these benchmarks to HWMs, pump stations, floodwalls, etc. Over 100 benchmarks have been established to date.

These static GPS surveys were rigorously connected to the NGS approved NAVD88 (2004.65) network. Procedural GPS survey methods followed (and actually exceeded) the guidelines in the following NOAA publications:

- **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: 2 cm and 5 cm)" version 1.4, National Geodetic Survey (2005 DRAFT)

Procedural specifications applicable to topographic engineering and construction surveys included:

- **EM 1110-1-1003** NAVSTAR Global Positioning System Surveying

- **EM 1110-1-1005** Control and Topographic Surveying (1 January 2006 Draft)

The above guidance documents also contain the accuracy standards required for hydraulic modeling type surveys involved on these projects. In general, required vertical accuracy tolerances were ± 0.1 foot. Horizontal accuracy varied depending on the nature of the survey—e.g., HWM horizontal locations are not as critical as floodwall cap locations.

Topographic surveys were performed using all of the following methods and equipment:

- Conventional differential leveling (spirit/compensator/digital levels)
- Electronic total stations

- Static Differential GPS surveys
- GPS real time kinematic (RTK) methods

Field survey data was collected in a standard bound survey book and/or on an electronic data collector attached to or part of a total station or RTK survey system. Digital images were taken for HWM and pump station first floor elevation shots.

Figure III-25. (Left) Static GPS survey to establish elevation on a benchmark outside a St. Bernard Parish pump station. (Right) Leveling first floor elevation inside Jefferson Parish Pump Station No. 3.

All of the above manuals were cited in the St. Louis District task order specifications.

Hydrographic surveys, including multibeam surveys, were performed following the guidance for Special Surveys (i.e., non-navigation/dredging surveys) in: **EM 1110-2-1003** Hydrographic Surveying

Figure III-26. (Left) IHNC Almonaster Bridge—low chord elevation 3.51 ft NAVD88 (2004.65). (Right) Leveling to USGS recording gage and Orleans Levee District staff gage on I-10 bridge over IHNC

Data Processing and Submittal

The contractor processed and reduced all survey data to a submittal format consistent with EM 1110-1-1005 and the New Orleans District. GPS baselines were reduced and networks adjusted using standard COTS software packages — e.g., Trimble Geomatics Office. Data submittals were posted on an ERDC ftp site for transfer to the requesting IPET Team.

All data submittals contain supplemental metadata records that are compliant with the Federal Geographic Data Committee Standard "Content Standard for Digital Geospatial Metadata", FGDC-STD-001-1998.

Quality Control and Quality Assurance Procedures

The survey contractor (3001 Inc.) was responsible for performing quality control over all work performed, in accordance with the Quality Control Plan submitted on award of the basic Indefinite Delivery Contract. Many of the specifications listed above provide forms of quality control by requiring specific observing schemes, redundant observations, connection checks between control points, closed loop level lines, periodic RTK calibration checks, level peg tests, etc. The contractor was expected to perform additional quality control checks during data processing and prior to submittal.

Quality assurance checks were performed by both the contractor and government (IPET Survey Team). GPS observations establishing supplemental vertical control points were checked by running independent solutions from NOAA CORS stations distant from the NAVD88 (2004.65) project network. This afforded a blunder check on all points. The government performed spot checks on data submittals, including reality checks by modelers receiving the data.

A few isolated survey data errors or blunders were found by both the contractor and government, indicating a quality control/assurance process was in place.

Quality assurance is still in progress as of this Interim Report.