CHAPTER 2

Geodetic, Tidal, and Hydraulic Reference Datums Used to Define Project Grades on Civil Works Projects

2-1. Purpose. This chapter provides a technical overview of the interrelationship between geodetic (i.e., orthometric) and hydraulic datums that are used to reference various civil works projects. These datums are the baseline reference for designing protection elevations of levees and related water control structures, and the design depths of navigation projects. They are also used for setting grades during project construction and maintenance operations. The Corps uses a variety of orthometric and water level datums to reference coastal and inland navigation projects. Figure 2-1 provides a generalized illustration of the various references used on coastal and inland navigation projects in tidal, free flow, and controlled regimes. These same orthometric and hydraulic datums are also used to reference elevations of inland levees and dams.

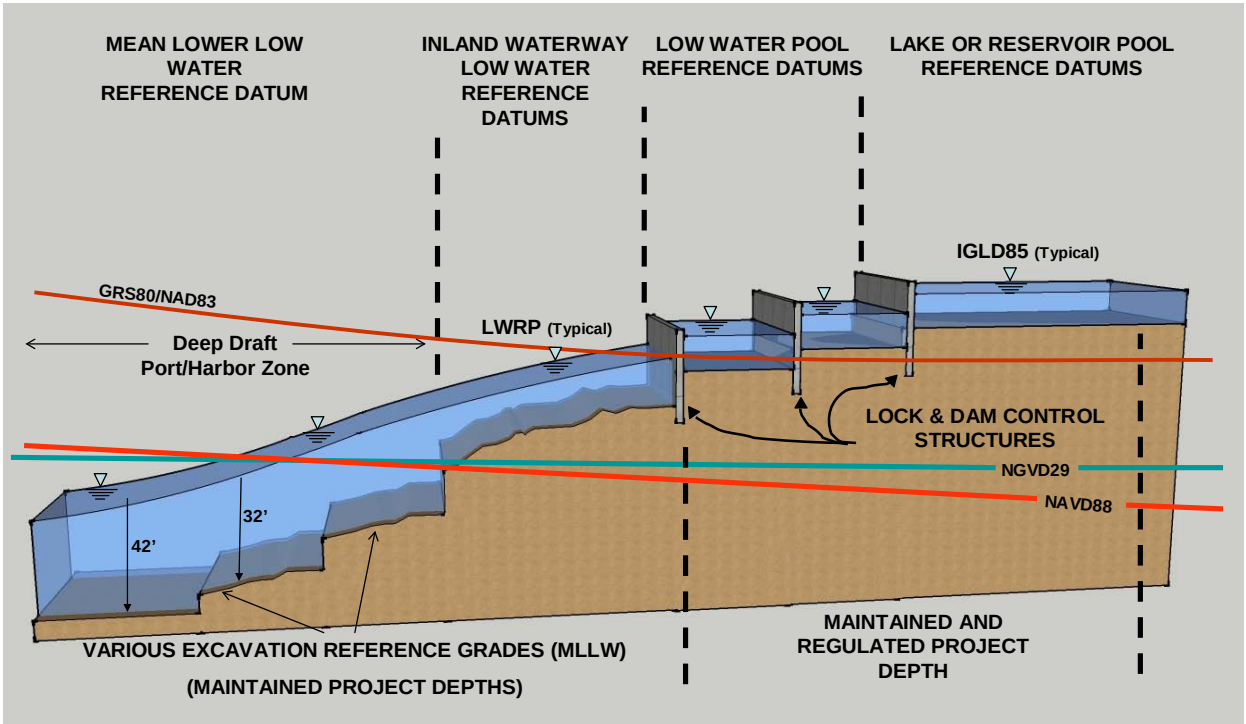

Figure 2-1. Tidal and inland vertical reference datums.

2-2. Geodetic and Hydraulic Vertical Reference Systems. The following paragraphs provide a general overview of the types of vertical datums used to define the elevations of USACE flood risk management, water control, HSPP, and navigation projects. Appendix B provides additional information on terrestrial and extraterrestrial geodetic datums and related 2D and 3D coordinate systems. For a more comprehensive discussion on geodesy, vertical datums, and GNSS height measurement, refer to the following publications: "*Physical Geodesy*" (Hofmann 2006) or "*What Does Height Really Mean*" (Meyer 2006).

a. Definition of geodetic datum. The "*Geodetic Glossary*" (NGS 1986) defines a geodetic datum as:

"*A set of constants specifying the coordinate system used for geodetic control, i.e., for calculating the coordinates of points on the Earth*."

(1) The above general definition applies to both horizontal and vertical datums. Vertical datums are normally defined relative to the fixed elevation of some point(s) on the Earth, or in the case of satellite-based ellipsoidal reference systems, a three-dimensional coordinate of a point near the mass center of the Earth.

(2) A more comprehensive definition of vertical datums that directly relates to studies of coastal and inland flooding, and USACE flood risk management project elevations, is outlined in the following excerpts from "*Mapping the Zone: Improving Flood Map Accuracy*" (NRC 2009):

"The data components of a flood study that involve a measurement of height or elevation can be grouped into four general categories:

(a) Elevation reference surface. Before elevation can be measured or the data used in engineering analysis, a measurement system must be established. The location of "zero" and a physical reference for elevation zero (in other words, a vertical datum) must be established on the Earth, where it can be used for all types of height measurements.

(b) Base surface elevation. Two types of base surfaces are important to flood studies: land surface elevation (topography) and its underwater equivalent (bathymetry). Topography is expressed as the height of a location above the geodetic datum and is in most cases a positive value. Bathymetry is expressed as the depth of the land surface below rivers, lakes, and oceans; positive depth is equivalent to negative elevation.

(c) Water surface elevation. The depth of water in rivers, lakes, and streams and the point at which water overtops their banks and spreads across the landscape are the subjects of riverine flood studies. The depth of water in the ocean and the impact of extreme events such as hurricane-induced storm surge or earthquake-induced tsunamis are the subjects of coastal flood studies. The height of water surfaces is measured with stream and tide gages. The location and elevation of the gages themselves must be determined accurately in order to correctly relate water surface measurements to other elevations.

(d) Structure elevation. The vulnerability of buildings and infrastructure to flood damage is directly related to their location with respect to the floodplain and the elevation and orientation of critical structural components with respect to the height of potential floodwaters. In addition, structures within the floodway (such as bridges, dams, levees, and culverts) influence the conveyance of water in a stream channel during a flood event, affecting flood heights."

b. Orthometric elevations and vertical datums. Floodwall and levee protection heights (and related inundation mapping elevations) are normally referenced to "orthometric" vertical

datums established by the National Geodetic Survey. Orthometric vertical datums provide a design and construction framework for referencing tidal gages and hydraulic models over a region. Orthometric datums are based on geopotential or equipotential surfaces referenced to some defined terrestrial origin—e.g., a tide gage PBM or the geoid. The two major orthometric datums used in CONUS include:

(1) National Geodetic Vertical Datum of 1929 (NGVD29)—superseded in the early 1990s.

(2) National Geodetic Vertical Datum of 1988 (NAVD88).

Older water control projects may be referenced to superseded vertical datums—e.g., MSL 1912. NAVD88 is the current federally recognized elevation reference system throughout CONUS. Neither NGVD29 nor NAVD88 are true "sea level datums." They are not equivalent to "Local Mean Sea Level" in CONUS. For example on the West Coast, NAVD88 is about 3 ft below LMSL. Failure to account for these orthometric datum anomalies in the design of a floodwall elevation can have significant adverse consequences since orthometric height differences in NAVD88 only approximate actual energy head differences. A redefinition of the NAVD88 is anticipated on or after 2018. This revision using gravity observations is expected to better approximate actual dynamic head elevation differences.

c. Hydraulic datums. These datums are found on inland river, lake, or reservoir systems, typically based on a low water pool or discharge reference point. Examples are the Mississippi River Low Water Reference Plane (e.g., LWRP74, LWRP93, or LWRP07) and the International Great Lakes Datum (IGLD55 or IGLD85). Low water reference planes may be defined relative to 97% discharge flows at river gages, from which river stage elevations are derived. River gage stage elevations are usually referenced to an orthometric datum such as NGVD29 or NAVD88. Hydraulic-based datums in inland waterways directly reference flood profiles and related elevations of flood protection levees or floodwalls and navigation clearances. A variety of inland reference planes are used in controlled pools and reservoirs, such as normal pool level, minimum regulated pool level, and flat pool level, low flow regulation pool, seasonal pool, and conservation pool. Dynamic height differences are often used in relating hydraulic datums. Dynamic heights, unlike orthometric heights, represent geopotential energy (hydraulic head) gradients in water surfaces (canals, rivers, lakes, reservoirs, hydropower plants, etc.) and thus may have application to Corps hydraulic models.

d. Tidal datums. Tidal datums are used throughout all USACE coastal areas and are based on long-term water level averages of a phase of the tide. Mean Sea Level (MSL) datum (or more precisely Local Mean Sea Level--LMSL) is commonly used as a base reference for hydrodynamic storm modeling, wind and wave surge modeling, high water mark observations, stillwater surge elevations, and design of coastal hurricane protection structure elevations. The relationship between these water elevations and the orthometric datum elevation varies spatially and must be computed or modeled. Depths of water in coastal navigation projects in the United States are usually defined relative to Mean Lower Low Water (MLLW) datum, but sometimes a local legacy datum is used. In isolated non-tidal coastal areas (e.g., Pamlico Sound, NC and Laguna Madre, TX) NOAA uses a Low Water Datum (LWD) as a chart datum. Tidal datums are essentially local datums (i.e., LMSL) and should not be extended more than a few hundred

feet from the defining gage without substantiating measurements or models. It is essential that the vertical datum plane used in these models use the geoid (or other equipotential surface) and not a geometric plane surface. Tidal datums are periodically updated by NOAA and thus are defined by their National Tidal Datum Epoch (NTDE)—currently 1983-2001.

e. Satellite or space-based datums. Satellite datums are three-dimensional, geocentric, ellipsoidal datums used by Global Navigation Satellite Systems (GNSS), such as the Global Positioning System (GPS)—e.g., ITRF and WGS84. The reference point for these systems is the estimated mass center of the earth. Ellipsoid heights of points in CONUS represent elevations relative to the NAD83/GRS80 mathematically defined ellipsoid. These ellipsoid heights can approximately be transformed to a NAVD88 orthometric elevation using a gravity (geoid) model developed by the National Geodetic Survey. This geoid model approximates the current NAVD88 orthometric reference surface in CONUS.

f. Local or legacy datums. Most USACE civil projects are, in effect, referenced to a local vertical datum. Nearly all construction, boundary, and real estate surveys are aligned to local horizontal datums, e.g., section corners, property corners, road intersections, chainage-offset construction layout, etc. Many local datums are based on arbitrary, unknown, or perhaps archaic origins. Vertical construction datums are often referenced to an arbitrary elevation at a PBM (e.g., elevation 100.00 ft). Some local datums with designated origins may be at distant points from a project—e.g., New Cairo Datum (Cairo, Illinois) projected south to the Gulf Coast in Louisiana. Most hydraulic-based river datums and MSL/MLLW tidal datums are actually local datums when they are not properly modeled or kept updated. Other local or legacy datums encountered in USACE may include Mean Low Gulf (MLG), Mean Gulf Level (MGL), Mean Low Tide (MLT), Old/New Memphis Datums, and Delta Survey Datum. USACE PBMs, TBMs, and floodwall elevations referenced to NGVD29 must be considered a local datum in that relationships to the national NSRS network are no longer maintained. Height differences between points determined from differential leveling are effectively local datums unless orthometric or dynamic height corrections are applied to the observed elevation differences. Geospatial coordinates for such points are primarily used for external reference, such as GIS mapping.

2-3. Background on the Definition of the National Geodetic Vertical Datum of 1929 (NGVD29). Since 1929, only two official national vertical datums have been established—NGVD29 and NAVD88. Prior to 1929, the reference surface for a vertical datum has been some approximation of local mean sea level, but this was not a strict requirement. By 1900, the vertical control network for the United States had grown to 21,095 km of geodetic leveling. A reference surface was determined in 1900 by holding elevations referenced to local mean sea level (LMSL) fixed at five tide stations. Data from two other tide stations indirectly influenced the determination of the reference surface. Subsequent readjustments of the leveling network were performed by the US Coast and Geodetic Survey (USC&GS) in 1903, 1907, and 1912.

a. The first of these national datums was the Sea Level Datum of 1929 (SLD29). SLD29 was created by the US Coast and Geodetic Survey (USC&GS) as the datum to adjust all vertical control to in North America. The SLD29 is defined by 26 tide stations (held fixed to Local Mean Sea Level)—21 tide stations in the United States and five tide stations in Canada. When it

was established in 1929, SLD29 was believed to be a “mean sea level” datum although mean sea level was not the same at each gage. Mean sea level was not developed using the same epoch or period of record at each of the gages. Each gage was, in effect, a "local mean sea level" (LMSL) reference datum. However, over time, with sea level rise and other factors, it was no longer considered a “mean sea level” datum. In 1973, the name of SLD29 was changed to the National Geodetic Vertical Datum of 1929 (NGVD29).

b. In 1929, the international nature of geodetic networks was well understood, and Canada provided data from its first-order vertical network to combine with the US network. The two networks were connected at 24 locations through vertical control points (bench marks) from Maine/New Brunswick to Washington/British Columbia. Although Canada did not adopt the "Sea Level Datum of 1929" determined by the United States, Canadian-US cooperation in the general adjustment greatly strengthened the 1929 network. Table 2-1 lists the kilometers of leveling involved in the readjustments and the number of tide stations used to establish the datums.

Table 2-1. Legacy Vertical Datums in CONUS. (IPET 2007)

Year of Adjustment	Kilometers of Leveling	Number of Tide Stations
1900	21,095	5
1903	31,789	8
1907	38,359	8
1912	46,468	8
1929	75,159 (U.S.) 31,565 (Canada)	21 5

c. Holding Local Mean Sea Level (LMSL) heights fixed at these tide stations did not mean that the geodetic vertical datum and the LMSL were the same at any location outside of the 26 tide gages. Immediately after the 1929 adjustment, the relationship between NGVD29 and LMSL began to deviate due to apparent sea level change. NOAA updated LMSL and MLLW datums in the US with every change in National Tidal Datum Epoch (NTDE) starting with 1941-1959, 1960-1978, and 1983-2001. NGVD29 was not adjusted to account for sea level change during this time period. There were several later adjustments to the NGVD29 datum, but no change in the national geodetic datum until 1991, when NGS established the NAVD88. Adjustments to the datum are noted by the year (or epoch) in parentheses after the datum name, i.e., NGVD29 (19xx) where 19xx is the year the NGVD29 datum was readjusted in a region or local area based on either new data or releveling of an existing level line. It is noted that this is only an adjustment of the network and not a new datum.

Additionally, the local mean sea level at each of the 26 gages did not lie on the same equipotential surface due to local factors such as prevailing winds, ocean currents, etc. These differences were introduced into the national network as errors during the network adjustment.

2-4. Background on the Definition of the Current North American Vertical Datum of 1988 (NAVD88)**.** Unlike the multiple points which define the “zero level” of NGVD29, NAVD88 is defined by a single tidal bench mark at Father Point/Rimouski, an International Great Lakes Datum of 1985 (IGLD85) water level station at the mouth of the Lower St. Lawrence River, in Quebec, Canada. Its elevation was held fixed in a minimally constrained, least squares adjustment, which is not distorted by constraints of local mean sea level in different areas, as in NGVD29. The warping of NGVD29's reference surface means that the heights determined in that datum are not strictly "orthometric." Conversely, NAVD88's reference surface is equipotential, and therefore heights in that datum are nearly orthometric. The reason they are not truly orthometric is that the reference surface of NAVD88 was not specifically chosen as the geoid. In fact, most estimates of the difference between the NAVD88 reference surface and the geoid put the difference at the level of a few decimeters.

a. In support of NAVD88, the NGS converted the historic height difference links involved in the 1929 general adjustment to computer-readable form. The 1929 general adjustment was recreated by constraining the heights of the original 26 coastal stations. Free-adjustment results were then compared with the general adjustment constrained results. Several differences exceeded 50 cm. A large relative difference, 86 cm, exists between St. Augustine, Florida, and Fort Stevens, Oregon. This is indicative of the amount of distortion present in the 1929 general adjustment.

b. NAVD 88 combined 1,300,000 kilometers of leveling surveys held in the NGS data base, into a single least squares adjustment to provide users with improved heights for over 500,000 vertical control points distributed throughout the United States, on a common datum. There had been approximately 625,000 km of leveling added to the National Geodetic Reference System (NGRS) since NGVD29 was created. (The NGRS has been superseded by the NSRS). An extensive inventory of the vertical control network resulted in the identification of lost bench marks, several affected by crustal motion associated with earthquake activity, postglacial rebound (uplift), and subsidence. Other problems (distortions in the network) were caused by forcing the 625,000 km of leveling to fit previously determined NGVD29 height values. Some observed changes, amounting to as much as 9 m, were noted.

c. The NAVD88 datum adjustment formally began in October 1977 with releveling much of the first-order NGS vertical control network in the United States. The nature of such a network required a framework of newly observed height differences to obtain realistic, contemporary height values to form the readjustment. To accomplish this, NGS identified 81,500 km (50,600 miles) for releveling to be completed by NGS field crews. In addition to the NGS releveling, other federal agencies such as the USACE, many state agencies such as state Departments of Transportation, Departments of Natural Resources, etc. provided NGS with approximately another 20,000 km (32,400 miles) of new and releveled surveys. Replacement of disturbed and destroyed monuments preceded the actual leveling. This effort also included the establishment of "deep-rod" bench marks, which provided reference points for future

"traditional" and GPS leveling techniques. Field leveling of the 81,500 km network, and the 20,000 km submitted by state agencies, was accomplished to Federal Geodetic Control Committee (FGCC) First-Order, Class II specifications, using the "double-simultaneous" method. NGS worked closely with both Canada and Mexico to ensure sufficient connections were made along both borders of the United States. NGS field crews also worked closely with both countries to carry the vertical control into both countries and make connections to their vertical network and both countries ran into the United States making connections. Both Canada and Mexico provided NGS with their leveling data so that the NAVD88 would be more extensively “North American” than NGVD29 had been. The general adjustment of NAVD88 was completed in June 1991.

d. The leveling observations used in NAVD88 were corrected for rod scale and temperature, level collimation, and astronomic, refraction, and magnetic effects. All geopotential differences were generated and validated, using interpolated gravity values based on actual surface gravity data. Geopotential differences were used as observations in the least-squares adjustment, geopotential numbers were solved for as unknowns, and after the adjustment was complete, orthometric heights were computed using the well-known Helmert height reduction. The weight of an observation was calculated as the inverse of the variance of the observation, where the variance of the observation is the square of the a priori standard error multiplied by the kilometers of leveling divided by the number of level sections.

2-5. Satellite-Based Vertical Reference Systems . The current and rapidly expanding use of satellite-based ellipsoidal reference systems provides a mechanism for establishing an external reference framework from which orthometric, tidal, hydraulic, and local vertical datums can be related spatially and temporally. GPS along with other expanding global navigation and positioning systems (i.e., GNSS or Global Navigation Satellite Systems) such as GLONASS (Russian Federation), Galileo (European Community), Compass (China), etc. will further the use of satellite-based systems as the primary measurement reference for project elevations, dredging grades, machine control, and related mapping applications. Various initiatives are underway by NOAA, FEMA, and other agencies to refine the models of some of the various vertical datums listed above—resulting in a consistent National Spatial Reference System that models and/or provides transformations between the orthometric, tidal, and ellipsoidal datums. Paramount in these efforts is the NOAA "National VDatum" project that is designed to provide accurately modeled transformations between ellipsoid-based reference systems, orthometric datums, and tidal datums.

a. NAD83/GRS80 ellipsoid. In the near future, most engineering and construction site control (including GPS/GNSS-based machine control systems) will be referenced using various DGPS/RTN techniques; therefore, it is essential that all USACE project elevations be referenced to the NAD83/GRS80 ellipsoid so that the relationship between this ellipsoidal datum and local hydraulic/tidal datums is firmly established. Most federal agencies, including USACE in EM 1110-1-1003 (*NAVSTAR GPS Surveying*), have specifications for measuring and defining vertical elevations derived from satellite-based measurements.

b Ellipsoid and orthometric heights. In recent years much emphasis has been put on the determination of orthometric heights from GPS ellipsoid height measurements, as shown in

Figure 2-2. In this figure the "plumb line" is the curved line between a point on the earth's surface and a point on the geoid, everywhere tangent to the direction of gravity (or, in other words, everywhere perpendicular to all equipotential surfaces through which the line passes). The "orthometric height" is 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 absolute accuracy, gravity needs to be measured along this line, requiring a bored hole, which is impractical. For general geodetic control survey applications in USACE, GPS height difference observational accuracy can equal or exceed traditional (leveling) observations. As illustrated in Figure 2-2, with a highly accurate model of the geoid (geoid height—"*N*"), the purely geometric ellipsoidal height "*h*" determined by GPS can be transformed into an orthometric height "*H*"—e.g., NAVD88.

$$h \approx H + N \quad or \quad H \approx h - N \qquad \text{Eq. 2-1}$$

where,

h = Ellipsoid Height (NAD83/NSRSxx)
H = Orthometric Height (NAVD88)
N = Geoid Height (GEOIDxx)

c. Ellipsoid and geoid heights. The ellipsoid surface has nothing to do with the level surfaces and it cuts through all level surfaces because it is not a function of the Earth's gravity field. Therefore GPS-derived ellipsoid heights are not related to the geoid or the gravity field; thus requiring a model to obtain differences between the geoid and ellipsoid to determine orthometric height. Geoid height (also termed geoid separation or geoid undulation) is the difference between the geoid and ellipsoid at any given point on the earth's surface. The geoid height is always negative in CONUS (as shown in Figure 2-2). The term "equipotential surface" is defined as an irregular surface, whose gravity potential energy is constant at every point. By extension, therefore the force of gravity is perpendicular to an equipotential surface at every location on that surface. Because the value of gravity potential energy can be any number (corresponding to one equipotential surface), there are therefore an infinite number of equipotential surfaces surrounding the Earth with each equipotential surface lying either completely within or completely without another surface; they do not intersect one another. Due to the non-homogenous distribution of Earth's masses, each of these surfaces has its own distinct shape.

d. Geoid and local mean sea level. The "geoid" is the one equipotential surface which most closely fits global mean sea level in a least squares sense. However variations between local mean sea level and the geoid at one location may be radically different from such variations at another location. As an example the LMSL-geoid difference in New Orleans is not the same as LMSL-geoid difference in Miami, Florida since the geoid is fit to global mean sea level and its definition is therefore not strongly influenced by the local hydrodynamic phenomena which affect local mean sea level. In the absence of all forces besides gravity, the ocean surface would lie on the geoid. However tides, currents, river runoff, wind, circulation, and other forces all impact sea level. The effects of these forces do not average to zero over time, and since these

forces vary from site to site, any given tide gage may determine local mean seal level but not directly determine the geoid. Due to this difference in variations between the geoid and local mean sea level, and the fact that 26 tide stations were held fixed in establishing NGVD29, the NGVD29 reference surface was warped to allow the local mean sea level at tide stations to define the "zero elevation" of heights in the NGVD29 datum; hence, NGVD29's reference surface is not equipotential.

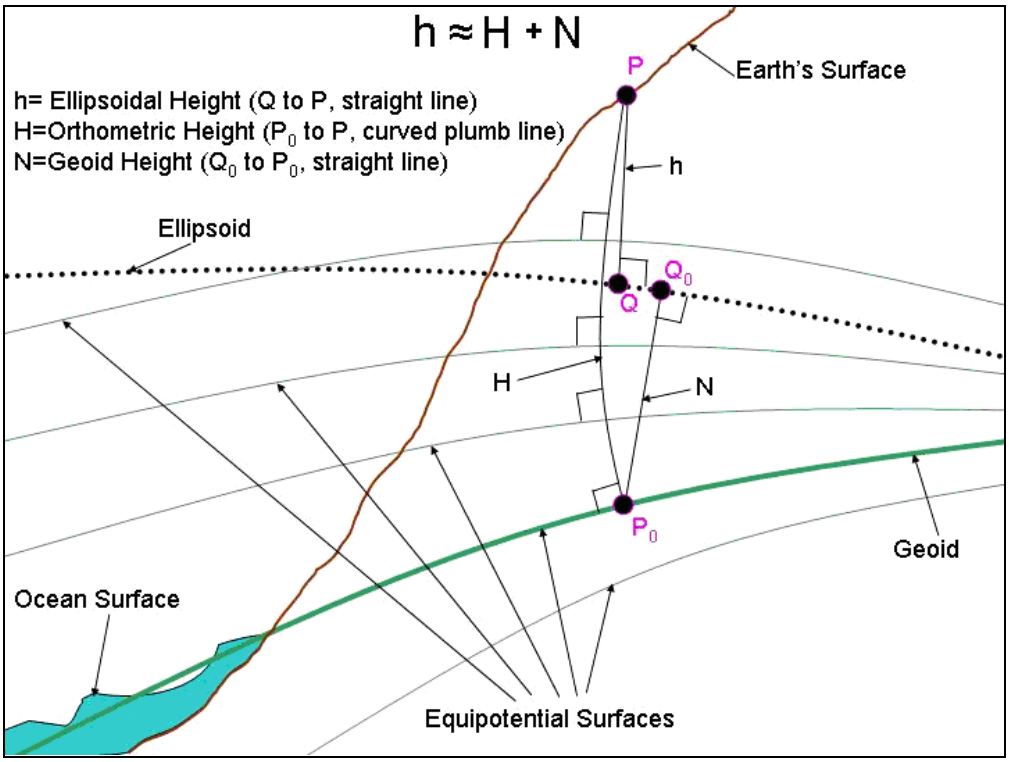

Figure 2-2. Relationship between the ellipsoid, geoid and orthometric heights. (IPET 2007)

e. Satellite height and leveled height differences. Over short distances, satellite derived elevation differences are not as accurate as those that are determined from traditional spirit or digital leveling observations. Therefore, traditional spirit leveling will normally be used for local construction stakeout. Satellite (RTN) observations are acceptable for detailed site plan design.

f. Orthometric height and dynamic height differences. Leveled elevation differences between bench marks do not yield either orthometric height differences or dynamic height differences. Spirit or digital leveling differences in elevation must be corrected to obtain orthometric heights or dynamic heights—i.e., orthometric corrections or dynamic corrections—see Hofmann 2006. Orthometric corrections, being a function of a level line length and direction, are usually negligible for engineering purposes. Dynamic height corrections are usually negligible except in high elevation (energy head) differences, such as those occurring between a hydroelectric power plant's reservoir intake structure and the lower spillway. Due to inaccuracies in NAVD88 leveling adjustments, a "hydraulic corrector" must be applied at

subordinate points on the Great Lakes in order to obtain a reference engineering, construction, or navigation datum. These hydraulic correctors are published by the IJC Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (IJC 1995).

g. GPS/GNSS reference frames. Navigation satellite orbits are computed from data collected by a global network of receivers coordinated by the International GNSS Service for Geodynamics (IGS). The accuracy of the GPS orbits depends on many factors, including the accuracy of the coordinates of the data collection sites. The earth's surface is not fixed and rigid like an eggshell. It consists of many sections, or plates, which move slowly over time in various directions and rates in a process called crustal motion. Scientists have been studying this movement for several reasons. This includes trying to determine where land masses are with respect to one another and where they will be in the future. IGS monitoring sites are located on these crustal plates. The International Earth Rotation Service (IERS) periodically computes the positions of the sites for a given date. The sites define the IERS, the International Terrestrial Reference Frame (ITRF), and the date defines the epoch. The IERS also computes the movement velocities of the sites to estimate where the sites will be in the "near" future with some degree of accuracy. The ITRF is an internationally accepted standard, and is the most accurate geocentric reference system currently available. The longer the sites operate, the better the positions and velocities can be determined and the more accurate the satellite orbits will be.

2-6. Tidal Datums Used to Reference Coastal HSPP and Navigation Projects. Tidal datums are used to establish local tidal phase averages as reference levels from which to reckon flood/hurricane protection structure heights or depth measurements in a navigation project. One of these tidal averages is the mean level of the water surrounding the gage. Observations are taken from a tide gage that has been collecting data for a period covering a 19-year National Tidal Datum Epoch period—NTDE. This time period allows inclusion of all practical variations in the path of the moon about the earth and the earth about the sun. Tidal datums are locally derived and must not be extended into areas that have differing hydrographic characteristics, without substantiating measurements. The most commonly used tidal datums are:

a. Mean Sea Level (MSL) or Local Mean Sea Level (LMSL). The average height of the surface of the sea at a tide station for all stages of the tide, typically covering a 19-year period which is usually determined from hourly height readings measured from a fixed and predetermined reference level. Most USACE coastal hydrodynamic modeling and design is referenced to MSL.

b. Mean Lower Low Water (MLLW). The average height of the lower of the two low waters occurring in a day, at a tide gage over a 19-year period. Most CONUS, and some OCONUS, coastal navigation projects are referred to this datum. This datum superseded Mean Low Water (MLW) that was previously used as the navigation reference datum for the East Coast CONUS. Some HSPP and navigation projects may still be referenced to a legacy MLW datum.

c. Mean High Water (MHW). The average height of all high waters at a tide station, covering a 19-year period. Heights of bridges over navigable waterways and legal coastal shoreline boundaries are referred to this datum. Likewise are legal shoreline boundaries in many

jurisdictions (variations of MHW are outlined in Chapter 7). Coastal shorelines shown on navigation charts depict MHW whereas depths on the same chart are referred to Mean Lower Low Water. Exceptions to this are found on USACE inland navigation charts.

d. Mean Tide Level (MTL). Sometimes termed half-tide level, 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. MTL does not include all the tide levels (i.e., MHHW and MLLW). Hydraulic design manuals sometimes erroneously refer to MTL as being synonymous with Mean Sea Level.

Additional details on these tidal reference planes are covered in Chapters 4 and 7, and in NOAA technical publications listed at Appendix A.

2-7. Geodetic and Hydraulic Datum References on USACE Projects. A variety of vertical reference systems are used on Corps flood protection and navigation projects. Of significance is the local relationship between the terrestrial or orthometric datums (NAVD88) and the hydraulic datums (MSL, LMSL, MLLW, LWRP, Normal Pool, etc.) from which flood protection heights and navigation grades are modeled and designed. During the detailed design or evaluation of flood protection or HSPP projects, outdated or superseded geodetic datums (e.g., NGVD29, MSL 1912) should be referenced to the federal NSRS datum—e.g., NAVD88. Likewise, outdated riverine, pool, reservoir, lake, or tidal reference planes should be referenced to the current NSRS datum.

a. CONUS and OCONUS reference datums. References throughout this guidance to the NSRS (NAVD88) are applicable only to the current vertical adjustment in the CONUS. NOAA has established independent vertical datums (orthometric or tidal) for some OCONUS locations—e.g., Puerto Rico (PRVD02), Guam (GUVD04), US Virgin Islands (St. Thomas--VIVD09). Other OCONUS locations may have local tidal datum references—see Table 2-3. CONUS projects can be referenced to the NAD83/GRS80 ellipsoid and NAVD88. All OCONUS locales can be globally referenced to the WGS84 ellipsoid and local NWLON tidal gage, as applicable. Geodetic reference datums for most CONUS and OCONUS project areas are outlined in Tables 2-2 and 2-3.

Table 2-2. Geodetic and Hydraulic Datum References for USACE Flood Risk Management, Navigation, and HSPP Projects (CONUS).

Project Location	Geodetic Reference		Hydraulic/Tidal Reference
	Horizontal	Vertical	
Inland rivers, pools, reservoirs, etc.	NSRS (NAD83)	NSRS (NAVD88)	USACE modeled LWRP LWRP or pool
Coastal (tidal waters) Navigation projects HSPP projects	NSRS (NAD83)	NSRS (NAVD88)	NOAA NWLON (NTDE) hydrodynamically modeled Local Mean Sea Level (LMSL) or MLLW (navigation projects) between NWLON stations
Great Lakes	NSRS (NAD83)	NSRS (IGLD85) [1]	NOAA NWLON hydrodynamically modeled local IGLD85

[1] A separate IGLD85 datum is specified for Lakes Ontario, Erie, Huron, Michigan, and Superior.

Great Lake	IGLD85 Chart Datum	Ordinary High Water Mark (Section 10)
Superior	601.1 ft	603.1 ft
Michigan-Huron	577.5	581.5
St. Clair	572.3	576.3
Erie	569.2	573.4
Ontario	243.3	247.3

Hydraulic slopes are specified for connecting channels (e.g., Detroit River, St. Clair River, and St. Marys River, Niagara River, St Lawrence River). Additional details on IGLD are in Chapter 6.

Table 2-3. Geodetic and Hydraulic Datum References for USACE Flood Risk Management, Navigation, and HSPP Projects (OCONUS).

Project Location	Geodetic Reference Horizontal	Geodetic Reference Vertical	Hydraulic/Tidal Reference
Alaska	NSRS (NAD83)	NSRS (NAD83/GRS80) local datums or NAVD88	NWLON tide gages (LMSL/MLLW)
Puerto Rico	NSRS (NAD83)	PRVD02 [1]	Gage PBM 975 5371A (San Juan)
U.S. Virgin Islands:			
St. Thomas	NSRS (NAD83)	VIVD09 [1]	Gage 975 1639 F (Charlotte Amalie)
St. Croix	NSRS (NAD83)	VIVD09	Gage 975 1401 M (Lime Tree Bay)
St. Johns	NSRS (NAD83)	VIVD09	Gage 975 1381 Tidal 2 (Lameshur Bay)
Hawai'i			
Kaua'i	NSRS [2] (NAD83)	Local Tidal MLLW	Gage 161 1400 (Nawiliwili) Tidal 5
O'ahu	NSRS (NAD83)	Local Tidal MLLW	Gage 161 2340 BM 8
Moloka'i	NSRS (NAD83)	Local Tidal MLLW	Gage 161 3198 Tidal 10
Lana'i	NSRS (NAD83)	Local Tidal MLLW	(Univ of Hawaii gage-Kaumalapau)

Table 2-3 (Continued). Geodetic and Hydraulic Datum References for USACE Risk Management, Navigation, and HSPP Projects (OCONUS).

Project Location	Geodetic Reference Horizontal	Geodetic Reference Vertical	Hydraulic/Tidal Reference
Hawai'i (Contd):			
Maui	NSRS (NAD83)	Local Tidal MLLW	Gage 161 5680 BM A
Hawai'i	NSRS (NAD83)	Local Tidal MLLW	Gage 161 7760 Tidal 4
Kaho'olawe	NSRS (NAD83)	Local Tidal "MLL"	n/a ["Mean Lower Low" datum]
Ni'hau	NSRS (NAD83)	Local Tidal MLLW	n/a [3]
American Samoa:			
Tutuila (Pago Pago)	NSRS (83) HARN 2002	American Samoa Vertical Datum of 02	Gage PBM 177 0000 PBM S
Tau	NSRS (83) HARN 2002	American Samoa Vertical Datum of 02	n/a
Aunuu	NSRS (83) HARN 2002	American Samoa Vertical Datum of 02	n/a
Ofu	NSRS/ HARN 02	USGS 1963	n/a
Rose	NSRS/ HARN 02	USGS 1963	n/a
Olosega	NSRS/ HARN 02	USGS 1963	n/a

Table 2-3 (Continued). Geodetic and Hydraulic Datum References for USACE Risk Management, Navigation, and HSPP Projects (OCONUS).

Project Location	Geodetic Reference Horizontal	Geodetic Reference Vertical	Hydraulic/Tidal Reference
American Somoa (Cont)			
Swains	NSRS/ HARN 02	USGS 1963	n/a
Guam	NSRS (83) HARN 1993	Guam Vertical Datum of 2004 GUVD04	Gage 163 0000 PBM TIDAL 4
Northern Marianas Islands:			
Saipan	NSRS (83) 2002 HARN	No. Marianas Vert Datum of 2003 (NMVD03)	Gage 163 3227 PBM UH-2C
Rota	NSRS (83) 2002 HARN	No. Marianas Vert Datum of 2003 (NMVD03)	n/a [Tidal 3]
Tinian	NSRS (83) 2002 HARN	No. Marianas Vert Datum of 2003 (NMVD03)	n/a [Tidal 1]
Aguijan	NSR (83) 2002 HARN	No. Marianas Vert Datum of 2003 (NMVD03)	n/a

Table 2-3 (Concluded). Geodetic and Hydraulic Datum References for USACE Risk Management, Navigation, and HSPP Projects (OCONUS).

Project Location	Geodetic Reference Horizontal	Geodetic Reference Vertical	Hydraulic/Tidal Reference
Marshall Islands:			
Kwajalien	WGS84	Local Tidal	Gage 182 0000 Tidal 8
Palau/Babeldaup	WGS84	Local Tidal	n/a
Micronesia (Federated States):			
Chuuk	WGS84	Local Tidal	184 0000 (Chuuk)
Kosrae	WGS84	Local Tidal	n/a
Pohnpei	WGS84	Local Tidal	n/a
Yap	WGS84	Local Tidal	n/a
Wake Island	NSRS (83)	Local Tidal	Gage 189 0000
Midway (Sand Island)	NSRS (83)	Local Tidal	Gage 169 9910 Tidal 21
Johnson Atoll	NSRS (83)	Local Tidal	Gage 161 9000 PBM MON JON

NOTE: Data in this table were obtained from Jacksonville District, Honolulu District, NGS, and CO-OPS. It is considered current as of 2009. NGS and CO-OPS are periodically updating horizontal and vertical references in these OCONUS areas; thus, users should contact the local District, NGS, and/or CO-OPS to ensure the latest reference datums are being used.

[1] PRVD02 and VIVD09 are currently (2010) being updated based on new leveling and gravity data
[2] All horizontal datums in Hawaiian Islands based on HARN 1993 adjustment
[3] n/a – indicates reference datum or gage is "not available" or is uncertain

b. Inland waterway reference datums. Various datums are used in controlled and free flow portions of inland river systems. Gages on the main stream Mississippi, Ohio, and Missouri Rivers, and their tributaries, are referenced to various datums. Gage zeros may be referenced to a geodetic datum, a low water reference plane, an arbitrary stage elevation, or a purely arbitrary elevation. Gage records maintained and published by USACE, USGS, or other agencies will should clearly define the gage zero reference datum. Some gages have been updated to

NAVD88; however, in many cases this was accomplished using VERTCON/CORPSCON approximations.

(1) Low water reference planes. On the Mississippi River, between the mouths of the Missouri and the Ohio Rivers (the Middle Mississippi River), depths and improvements are referenced to a LWRP. No specific LWRP year is used for the Middle Mississippi north of Cairo, IL. Below Cairo, IL, depths and improvements along the Mississippi River are referenced to a dated LWRP (e.g., LWRP74, LWRP93, LWRP07). These hydraulic-based reference planes are established from long-term observations of the river's stage, discharge rates, and flow duration periods—often developed about the 97-percent flow duration line. The elevation of the LWRP drops gradually throughout the course of the Mississippi; however, some anomalies in the profile are present in places. The gradient is approximately 0.5 ft per river mile in some reaches. The ever-changing river bottom will influence the LWRP. Changes in the stage-discharge relationship will influence the theoretical flow line for the LWRP. The LWRP is periodically updated by District H&H branches in the Mississippi Valley Division (MVD)—see Figure 2-3.

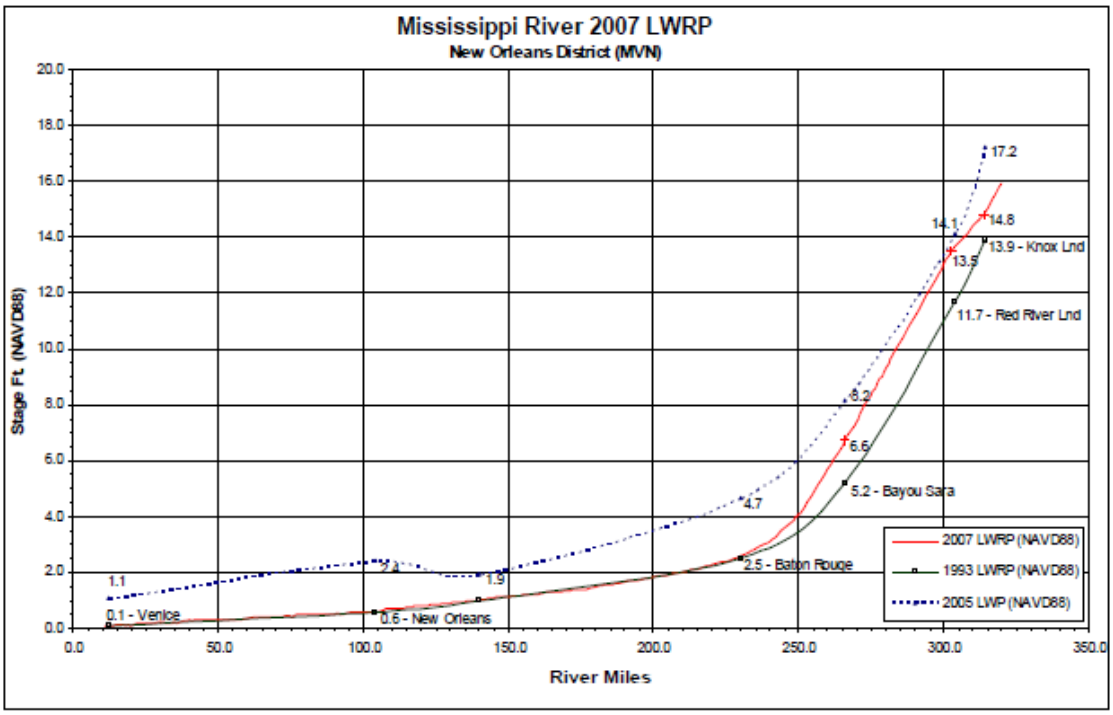

Figure 2-3. Lower Mississippi River LWRP [1993/2005/2007] relationships—New Orleans District. (CEMVN)

(2) Controlled pools. Between river control structures, low water pools are used to reference maintained navigation depths. Since these pools themselves may exhibit some slope, sufficient gages/benchmarks within the pools may need to be established to account for any slope. In the Upper Mississippi River pools, flow profiles between the upper and lower dams establish "project pool" elevations and "ordinary high water profiles." Elevations/stages of

"primary control points" or "hinge/pivot points" between locks and dams are also defined for each pool.

(3) Reservoirs. Most upland reservoir elevations are referenced to an orthometric datum—i.e., a legacy NGVD29 or NAVD88.

c. Sample inland river gage datums and stages. The following examples in Table 2-4 are taken from selected gages covering some 1,700 miles of the Mississippi River from Minneapolis, MN to the Gulf. These sample gages (from over 200) illustrate the varied datums and gage zero/stage references used on inland river systems.

Table 2-4. Reference Elevations on Selected Gages—Upper, Middle, and Lower Mississippi River.

Gage	River Mile	Gage Datum Elevation (ft)	Flat Pool Elevation (ft)	Stage at Flat Pool (ft)
[St. Paul District: most gage datum elevations are set to 700.0 ft or 600.0 ft ... referenced to NGVD29]				
St. Anthony L/D (U)	654.1	700.0	796.5	96.5
L&D 5 (L)	738.1	600.0	651.0	51.0
Winona, MN	725.7	640.0	643.8	5.8
L/D 7 (L)	702.5	600.0	631.0	31.0
L/D 10 (L)	615.1	600.0	603.0	3.0
[Rock Island District: gage datum elevations are referenced to MSL 1912]				
L/D 11 (L)	583.0	588.2	592.0	3.8
Ft Madison Br., IA	383.9	6.8	518.2	518.2
L/D 22 (U)	301.2	446.1	459.5	13.4
[St. Louis District: gage datum elevations are referenced to NGVD29]				
L/D 22 (L)	301.2	446.1	449.1	3.0
L/D 24 (U)	273.5	421.81	445.5	445.5
L/D 27 (L)	185.1	350.0	380.5	380.5

Table 2-4 (Concluded). Reference Elevations on Selected Gages—Upper, Middle, and Lower Mississippi River.

Gage	River Mile	Gage Datum Elevation (ft)	Flat Pool Elevation (ft)	Stage at Flat Pool (ft)
			Low Water Reference Plane [open flow]	
St. Louis, MO	179.6	379.94	376.4	
Cape Girardeau, MO	52.1	304.65	309.9	
Cairo, IL (Ohio Riv.)	2.0	270.47	277.9	
	Above Head of Passes			
New Madrid, MO	889.0	255.48	303.48	
Vicksburg, MS	435.7	46.23	99.47	
Red River Landing	302.4	0.0	60.94	
New Orleans	102.8	0.0	21.27	
Head of Passes	-0.6	0.0	12.03	

d. Datums on other river systems. Gages in portions of the Ohio River are referenced to the "Ohio River Datum (ORD)." Flood stages are relative to the gage zero—e.g., at Cincinnati, the 52.0 ft flood stage is relative to the 429.613 ft gage zero (ORD). The Green River is referenced to the "1929 General Adjustment" which may be equivalent to NGVD29. Gages on the Missouri River and tributaries are referenced to "MSL." Other USACE projects have similar local river datum references that are hydraulically modeled—e.g., Atchafalaya River, Columbia River, Snake River, etc.

e. Variety of inland reference datums. The following excerpt from the University of Illinois "Natural Resources Geospatial Data Clearinghouse" illustrates the need to have reliable conversions between legacy datums and to standardize datums for civil works applications.

"Each benchmark is tied to a specific known elevation marker, called a datum. Agencies working in Illinois rely on several vertical datums which are not easily related to each other. Some of these include:

NAVD88, the North American Vertical Datum of 1988.
NGVD29, the National Geodetic Vertical Datum of 1929.
The City of Chicago Datum, one of numerous legacy municipal datums.
NGVD12 [i.e., 1912 Adjustment], used by the USACE Rock Island District for management of the Mississippi River.
The Ohio River Datum, used by the USACE Louisville District for management of the Ohio River.

Approximate conversions between these legacy data exist, but their use degrades the precision of the measurements. During emergencies, these inconsistencies can cause confusion and waste valuable time. Multiple datums also make it virtually impossible to create useful, accurate, seamless maps and supporting flood data for the state. An example of the problems that multiple vertical datums can cause can be found in the Mississippi Valley in Northern Illinois, where levee top surveys are in NAVD88 and water level measurements are in NGVD12.

Because of the large number of different datums, numerical conversions between networks are approximate. This fact lowers the accuracy of existing elevation data sets."