Chapter 5
Project Control, Coordinate Systems, and Datums

5-1. General Scope

This chapter provides guidance on the required geodetic reference datums and coordinate systems for USACE navigation and flood control projects. General guidance is also provided on setting survey control for dredging projects and positioning aids to navigation in these projects. The major emphasis in this chapter is on vertical reference datums for navigation projects--tidal, river, lake, pool, and flood control reservoirs. This chapter has minimal coverage of horizontal coordinate systems, horizontal datums, and control survey methods since this material is fully covered in other engineer manuals listed in Appendix A. In addition, nearly all hydrographic surveys and dredge positioning are now controlled by established, nationwide DGPS networks; thus reducing the need to establish supplemental horizontal control on dredging and navigation projects.

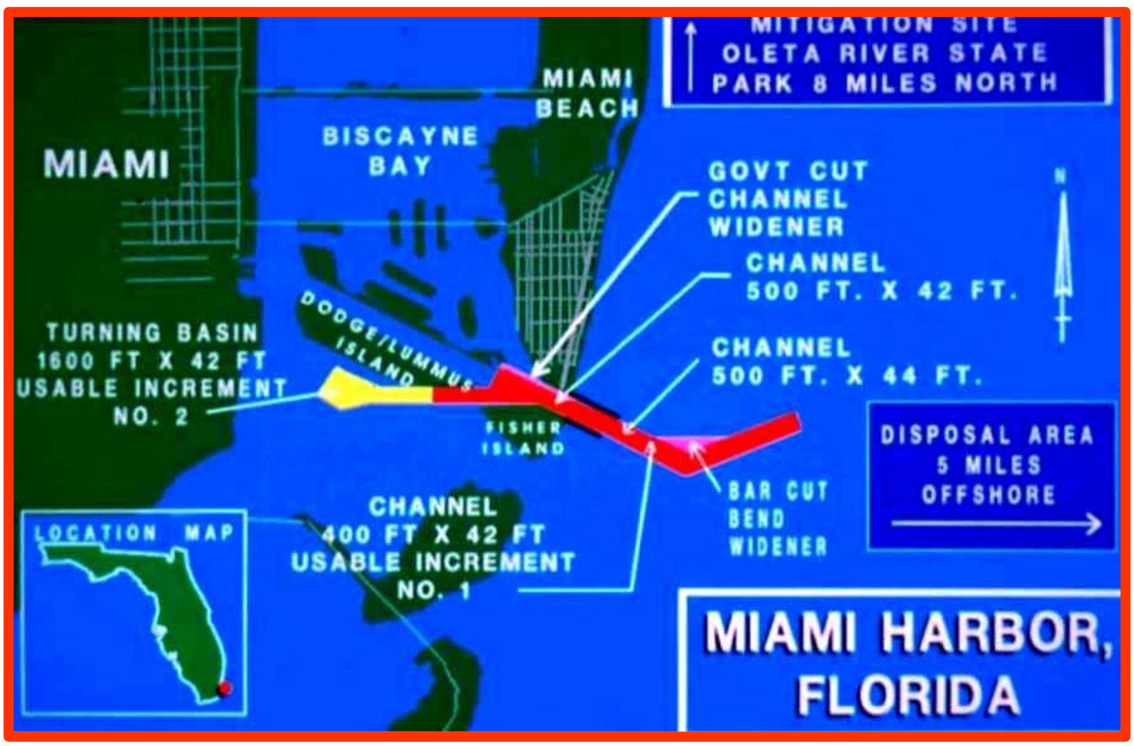


Figure 5-1. Channel and basin layouts for a typical deep-draft navigation project

5-2. Horizontal Control for Navigation and Flood Control Projects

Throughout the Corps, authorized engineering and construction projects are referenced to a variety of horizontal systems. Hydrographic surveys performed on dredging, navigation, and flood control projects must utilize the existing design dimensions for the project--Figure 5-1. In general, a horizontal reference system for a project is defined by the grid system covering the project and the origin (or reference datum) of that grid system. Grid systems used in the Corps include: Geographical (latitude-longitude), State Plane

Coordinate Systems (SPCS), Universal Transverse Mercator (UTM) grid system, and Chainage-Offset grid systems. These varied grid systems are usually (but not always) referenced to a local, regional, national, or international datum, such as the North American Datum (NAD) or the World Geodetic System (WGS).

a. Project control. All engineering projects should have permanent control monuments established along the project's perimeter. These marks are used to control offshore surveying and construction, and to define limits and scopes of work in contract plans and specifications. They may also serve as boundary monuments defining the project's limits. This control ideally has been connected to nearby National Geodetic Survey (NGS) control of higher-order accuracy, or connected to state or regional control surveys. Boundary monuments should have been connected to local property corners, rights-of-way, section corners, etc. The density of horizontal control was once determined by the need for visual dredging ranges and baseline requirements along each reach of a project. Typically, permanently monumented control points were required at 500 to 2,000 feet intervals along each side of a navigation project, and at denser intervals along jetties, beaches, and near structures. These points were generally accurately controlled within themselves. Ties to regional or national network systems were not always necessary. The recent use of GPS has largely eliminated the need for dense survey control around a project.

b. State plane coordinate systems. Navigation and flood control projects should be referenced to the local State Plane Coordinate System (SPCS) for that area. These X-Y grid systems are used to define project boundaries, construction limits, dredging limits, and channel dimensions. Hydrographic surveys are performed relative to these grid systems and data are collected in these coordinates. A limited number of Corps projects are referenced to the Universal Transverse Coordinate (UTM) grid system, a worldwide military grid system. Usually, UTM coordinates are determined by direct transform of local SPCS coordinates.

c. Reference systems for dredging control. Most engineering and construction work, including dredging, is aligned to a local project coordinate system. The datum for such local systems is typically a reference monument/baseline or, in the case of river and harbor construction, an artificial point such as the point of intersection (PI) between two channel alignment centerlines—see Figures 5-2 or 5-3. This PI may, in turn, be referenced by azimuth and distance to one or more monuments ashore. From such reference datum points, a local project grid is aligned to the project azimuth using standard station-offset coordinate convention. Most projects are additionally connected to the National Geodetic Reference System (NGRS) network using the local SPCS. The NGRS in itself may be defined by different datum references – the NAD 1927 or NAD 1983.

d. Global Positioning System (GPS). Differential GPS techniques are now used for setting most horizontal control on USACE projects--see EM 1110-1-1003 (NAVSTAR GPS Surveying) for procedures and standards. As detailed in EM 1110-1-1003, GPS satellite coordinates are referenced to the WGS 84 system, which has a direct relationship to the North American Datum of 1983 (NAD 83). GPS geocentric coordinates referenced to the WGS 84 ellipsoid must be converted to either the NAD 27 or NAD 83 datums, depending on which of these is used for a particular project. The NAD 27 or NAD 83 system is then converted to the local State Plane Coordinate System or Universal Transverse Mercator grid system. Most data acquisition software will perform these conversions automatically, using CORPSCON type conversion software. If not, it will be necessary to manually enter the WGS 84-NAD 27/83 conversions (in geocentric coordinate differences) for the local area. These conversions may be scaled to the nearest meter from contour maps depicting the differences in geocentric coordinates. The small difference between WGS 84 and NAD 83 (which uses the GRS 80 reference ellipsoid) is not significant for most Corps applications.

e. North American Datum. Most local project datums in USACE have been referenced to the NAD 27 coordinate system by direct survey connections with higher order monuments in the NGRS network. SPCS or UTM coordinates on common reference monuments or artificial alignment points define this relationship. Angular (or geodetic/geographic) latitude and longitude coordinates are sometimes used. Many USACE projects will eventually be converted to the redefined NAD 83. CORPSCON, a coordinate conversion program, should be used to convert to and from North American Datum of 1927 (NAD 27).

f. Supplemental project control. Supplemental project control may be needed in areas where GPS is inoperable (near bridges, power plants, etc.), or when fixed monuments are needed for beach renourishment projects or boundary control. Survey control for most hydrographic work should be established to 3rd Order, Class I accuracy standards (1 part in 10,000)—see Table 5-1. Control should be established from the National Spatial Reference System (NGRS) monuments where possible. Supplemental points within a project may be established by 3rd Order, Class II (1:5,000) procedures. Topographic mapping and surveying methods are described in EM 1110-1-1005 (Topographic Surveying). Standard engineering and construction surveying methods are acceptable for laying out baselines of limited range. Monumentation should conform to the requirements indicated in EM 1110-1-1002 (Survey Markers and Monumentation). Horizontal positions should normally be referred to (connected with) either NAD 27 or NAD 83. NAD 83 is the preferred datum. However, the continued use of NAD 27 will be acceptable until the surveys and project control systems can be converted to NAD 83. In either case, the horizontal datum actually used will be clearly noted on all plots, charts, maps, and coordinate files. All positions reported to other agencies should be in state plane coordinates, expressed in feet or meters within the proper zone. Exceptions to this will be allowed when UTM coordinates are used to eliminate the use of several state plane coordinate zones on a single project.

Table 5-1. USACE Point Closure Standards

Horizontal Control Surveys

USACE Classification	Point Closure Standard (Ratio)
Second Order Class I	1:50,000
Second Order Class II	1:20,000
Third Order Class I	1:10,000
Third Order Class II	1: 5,000
4th Order - Construction Layout	1: 2,500 - 1:20:000

Vertical Control Surveys

USACE Classification	Point Closure Standard (Feet)
Second Order Class I	0.025 sqrt (M)
Second Order Class II	0.035 sqrt (M)
Third Order	0.050 sqrt (M)
4th Order - Construction Layout	0.100 sqrt (M)

(M--distance in miles of level line)

g. Chainage-Offset coordinate systems. Navigation and flood control projects are locally referenced using an engineering chainage-offset system--Figure 5-2. Hydrographic surveys are performed relative to this system. Hydrographic data acquisition systems are also designed to operate on a chainage-offset system. Some systems allow use of geodetic latitude and longitude. Usually, SPCS coordinates are input to the system for reference, and the coordinates of the local chainage-offset grid are internally transformed to survey-specific cross sections or longitudinal range offsets.

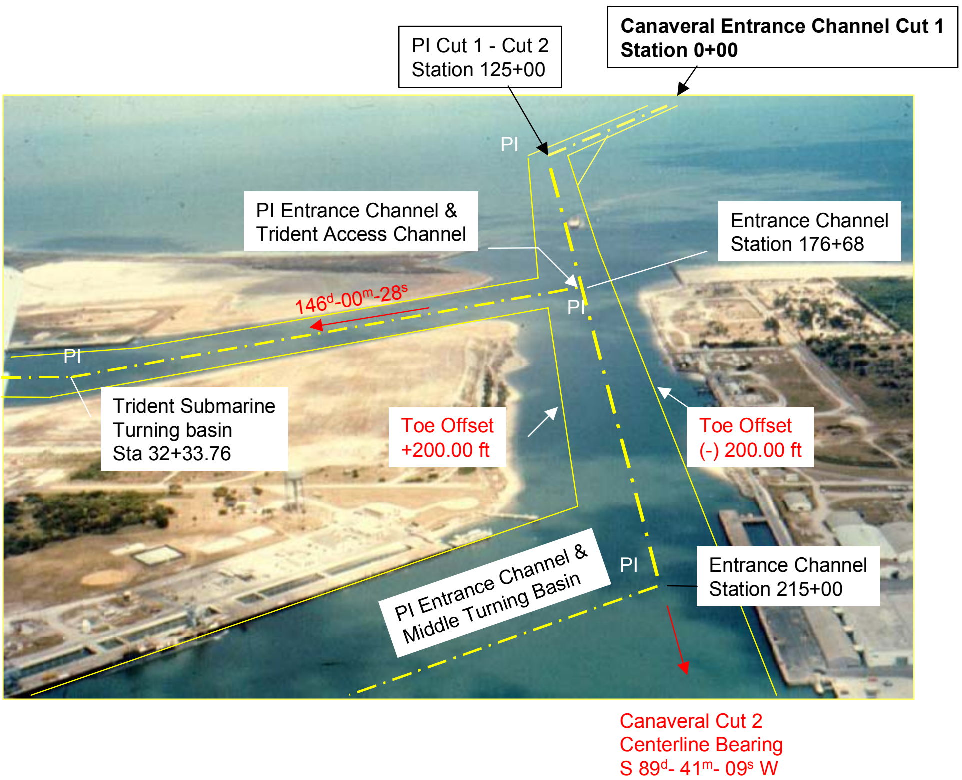


Figure 5-2. Chainage-offset project control scheme for a typical deep-draft navigation project--Cape Canaveral, FL (Jacksonville District)

(1) Station. Alignment stationing (or chainage) zero references are arbitrarily established for a given project or sectional area. Stationing on a navigation project usually commences offshore on coastal projects and runs inland or upstream. Stationing follows the channel centerline alignment. Stationing may be accumulated through each PI or zero out at each PI or new channel reach. Separate stationing is established for widener sections, turning basins, levees, floodwalls, etc. Each district may have its own convention. Stationing coordinates use "+" signs to separate the second- and third-place units (XXX + XX.XX). Metric chainage often separates the third and fourth places (XXX + XXX.XX) to distinguish the units from English feet; however, some districts use this convention for English stationing units.

(2) Offsets. Offset coordinates are distances from the centerline alignment of the channel or structure. Offsets carry plus/minus coordinate values. Normally, offsets are positive to the right (looking toward increasing stationing). Some districts designate cardinal compass points (east-west or north-south) in lieu of a coordinate sign. On some navigation projects, the offset coordinate is termed a "range," and is defined relative to the project centerline or, in some instances, the channel-slope intersection line (toe). Channel or canal offsets may be defined relative to a fixed baseline on the bank or levee.

(3) Azimuth. Channel azimuths are computed relative to the two defining PIs. Either 360-deg azimuth or bearing designations may be used. Azimuths of navigation projects should be shown to the nearest second.

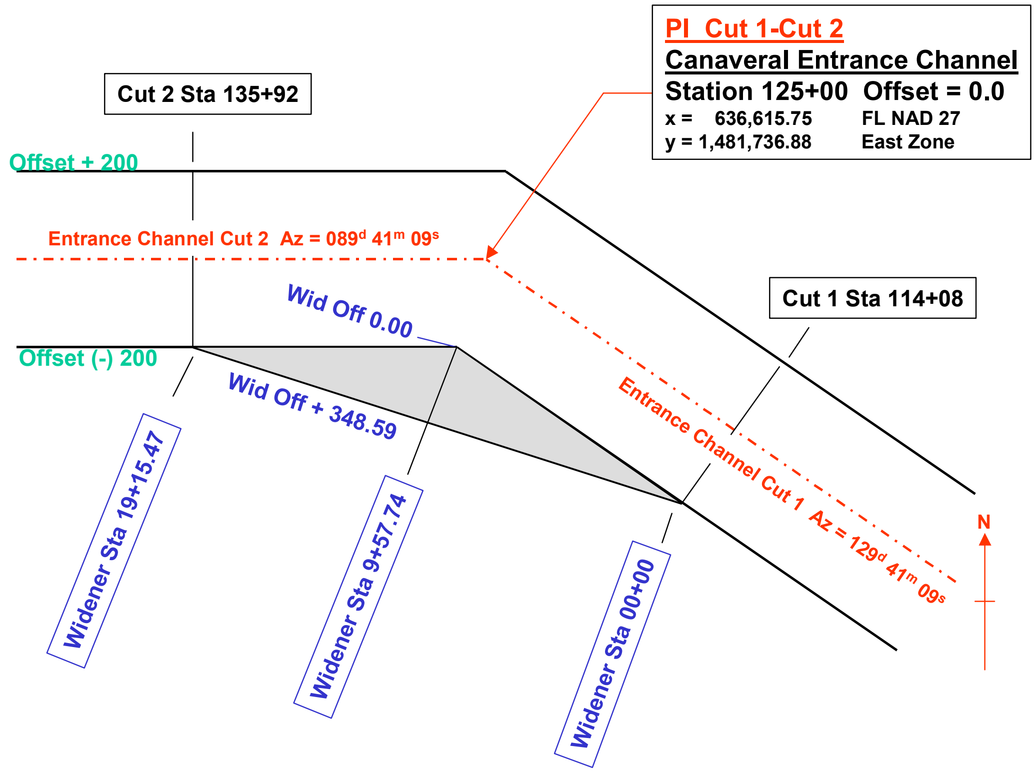


Figure 5-3. Chainage-offset control for a 400-ft coastal navigation project. Widener section has separate chainage-offset system from main channel. Note project stationing accumulates between channel reaches

h. Other local alignments. Different project reference grids may be established for widener sections (Figure 5-3), turning basins, and disposal areas. River sections and coastal beach sections are often aligned perpendicular to the project/coast. Each of these sections is basically a separate local datum with a different reference point and azimuth alignment. Beach sections may also be referenced to an established coastal construction setback line. Circular and transition (spiral) curve alignments are also found in some rivers, canals, and flood control projects such as spillways and levees. Hydrographic surveys will generally be aligned to the chainage and offsets along such curves.

i. River systems. Surveys along inland waterways, such as the Mississippi River, are often referenced to either arbitrary or monumented baselines along the bank. In many instances, a reference baseline for a levee is used, and surveys for revetment construction are performed from offsets to this line. Separate baselines may exist over the same section of river, often from levees on opposite banks or as the result of revised river flow alignments. Baseline stationing may increase either upstream or downstream. Most often, the mouth of a river is considered the starting point (Station 0 + 00), or the river reaches are summed to assign a station number at the channel confluence. Stationing may increase consecutively through PIs or reinitialize at channel turns. In addition, supplemental horizontal reference is made to a river mile designation system, in particular when interpolating stage gradients between two points (sections). River mile systems established years ago may no longer be exact if the river course has subsequently realigned itself. River mile designations are used to specify geographical features and provide navigation reference for users.

j. Automated survey coordinate systems. To perform a translation from SPCS to the project chainage-offset coordinate system (or vice versa), only two points common to both grid systems are required--or, one common point and an azimuth relationship. When a series of cross-sections is run on a given project, the common coordinates of the end points of one of these sections is input in the automated positioning system. These points are commonly termed the "start point" and "stop point," and basically define an artificial reference baseline--refer to Figure 5-4. Actually, a new reference grid/datum is established for the automated positioning system. These end points are selected such that the full project is covered. In dredging work, the end points are placed a sufficient distance outside the channel toes to ensure adequate side slope coverage. The length of this artificial baseline is used to measure the distance along the offset track, and is displayed to the helmsman for reference. The "left-right" indicator displays the lateral deviation from the track. On a uniform channel, section "offsets" are run parallel to this reference baseline. Most automated systems allow input of a constant offset increment--e.g., 100-ft-spaced cross sections. Hydrographic systems vary in the way lines are computed by the system. For some nonuniform sections (river sections, beach profiles, etc.), a separate reference line may have to be input for each desired line. Some systems allow a series of these reference lines to be saved in a database. Due to the possibility of accumulated round-off errors in the internal software, care should be taken not to project this reference line beyond 10 to 20 times its length. Vessel guidance and "distance along track" measurements are performed relative to this reference baseline and its offsets. Automated system input reference computations are performed in the field. A record of these computations should be made in a field book or on a worksheet.

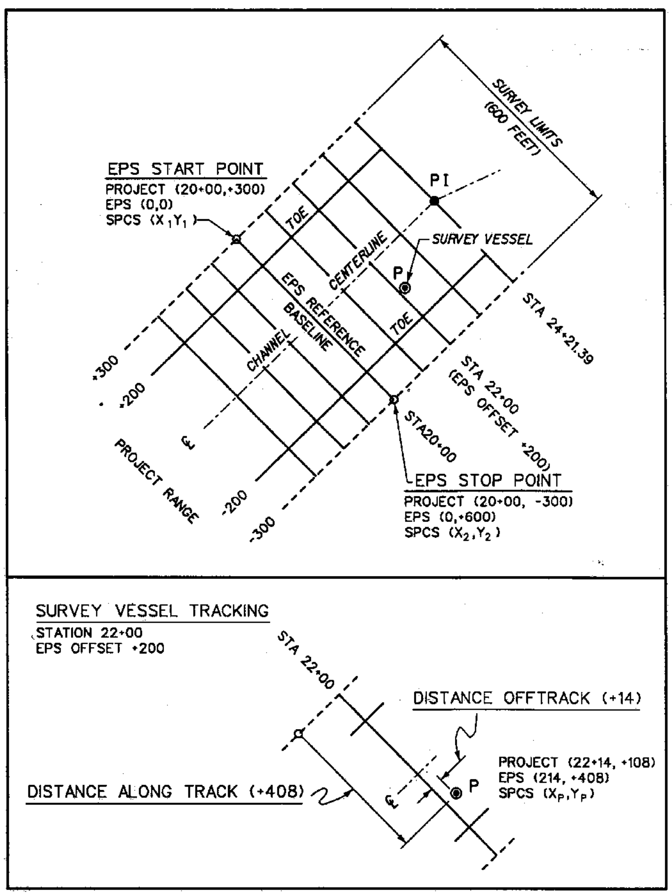


Figure 5-4. Reference baselines and coordinate systems used in automated data acquisition systems

k. Direct surveying on project coordinates. Many construction surveys are performed directly on the project coordinate system, and are not referenced to any SPCS or NGRS grid systems. Tag line baselines are normally laid out on the local project datum, and all subsequent coordinates are referenced to that station-offset system. Any type of automated positioning system can be operated using project coordinates. One advantage is that displayed coordinates are in the station-offset system. A disadvantage is that resultant positions may not be referenced to the local SPCS datum.

5-3. Positioning of Aids to Navigation in Authorized Projects

Surveys to determine the positions of navigation aids (NAVAIDs) in estuaries, inland rivers, harbors, or lakes may be required as part of some hydrographic surveys. Specific NAVAID positioning requirements will be contained in project instructions or scopes of work. Navigation aid positions will be transmitted to other mapping agencies for inclusion on charts, notices to mariners, etc. Failure to identify/locate critical NAVAIDs on surveys for contract plans and specifications could lead to subsequent contract disputes, especially if temporary NAVAID relocation is required during the contract period. Since these aids are critical in controlling navigation, special care shall be used to obtain accurate positions consistent with the standards specified in Table 3-1. Since it is not always practical (or necessary for design/construction purposes) to locate every NAVAID on a project, only major, permanent NAVAID structures require topographic survey methods and precision. Such structures include lighthouses and fixed sailing ranges on major navigation channels. These types of NAVAIDs are distinguished from the more numerous smaller fixed beacons, daymarks, piles, dolphins, and the like, which hereafter will be termed semi-permanent fixed NAVAIDs. Buoys, lighted or otherwise, are called floating NAVAIDs. Permanent fixed NAVAID structures should be positioned to USACE 3rd Order, Class II standards per Table 5-1. Semi-permanent fixed NAVAIDs and floating NAVAIDs may be positioned within the accuracy levels of the hydrographic survey system being used--e.g., 2-meter code-phase DGPS. Positions of navigational aids should be reported in the form of State plane coordinates on NAD 27 or NAD 83, and expressed in feet along with the accuracy to which they were positioned. Values reported to USCG and other maritime interests should be provided with their geographic latitude and longitude coordinates and the accuracy to which they were positioned. USCG criteria for NAVAID positioning may call for USACE Third Order, Class I accuracy. When NAVAID locationing is performed in support of, and funded by the USCG, that agency's accuracy requirements should be adhered to. Otherwise, Third Order, Class II, or DGPS-level accuracies described above will suffice.

5-4. Vertical Control for Navigation and Flood Control Projects

Providing an accurate vertical reference is perhaps the most important aspect in hydrographic surveying. This is especially critical on river and harbor navigation projects that are subject to varying tidal phase and range, sloping river stage, and uncertain vertical network benchmark accuracies. Figure 5-5 depicts the various vertical reference planes used on Corps projects—ranging from coastal ocean navigation to headwater flood control reservoirs. The various hydraulic reference planes are shown relative to the NGVD 29 national reference. The newer NAVD 88 vertical reference system is different from and not parallel with the NGVD 29, as will be explained in later sections. The NGVD 29 approximates a mean sea level datum. NAVD 88 does not; in fact it is 3 feet below mean sea level on the US West Coast--refer to Figure 5-8.

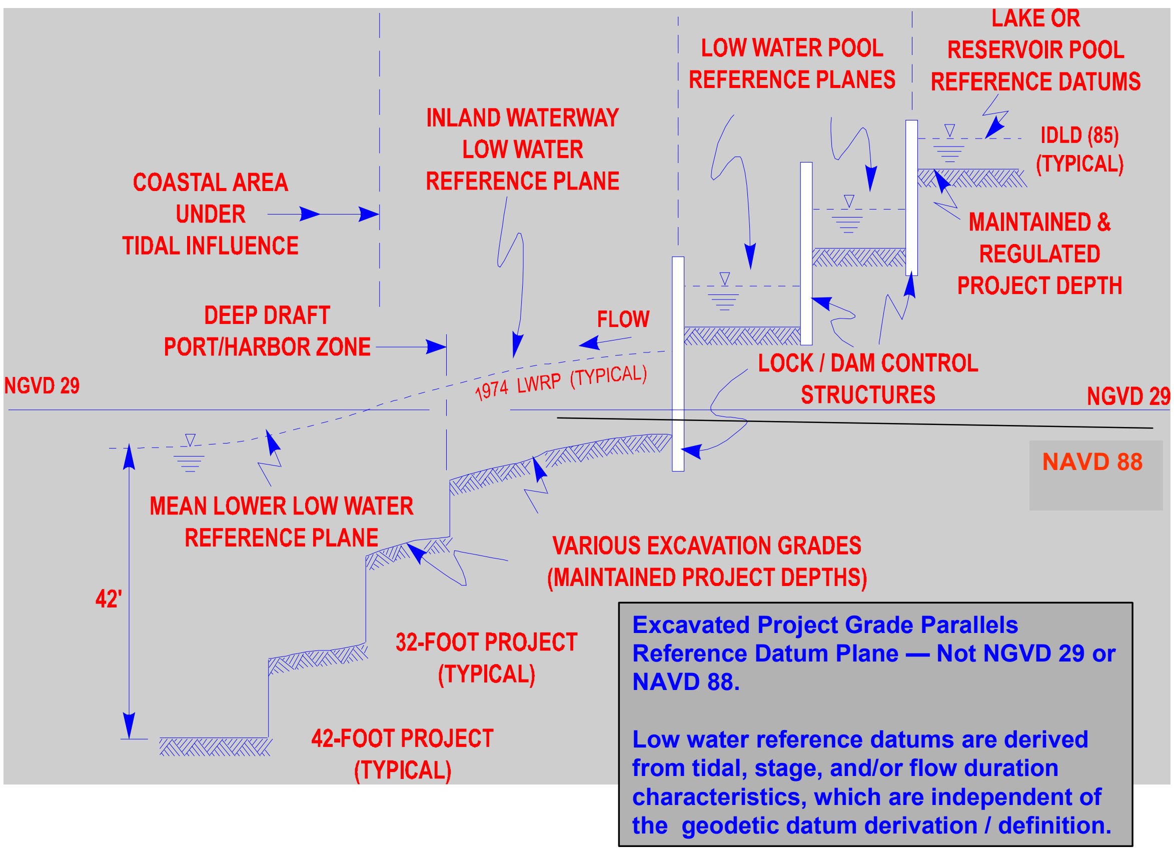


Figure 5-5. Vertical reference planes for navigation and flood control projects

a. Tidal areas. In offshore coastal areas, navigation projects are referenced to a tidal datum—Mean Lower Low Water (MLLW) throughout CONUS. This MLLW reference plane is not a flat surface but slopes as a function of the tidal range in the area. Tidal range can increase or decrease near coastal entrances; thus the MLLW must be accurately modeled throughout the navigation project. The required project depth also slopes as a function of the tidal range in an offshore area. The project depth is parallel to the MLLW curve as shown in Figure 5-5, an indication of decreasing tidal range towards shore. If the tidal range were increasing in Figure 5-5, then the slope of the grade and MLLW curve would be downward. At some point near or upstream of an entrance, the MLLW curve crosses the NGVD 29 plane, being influenced by river slope but still subject to tidal range superimposed on this slope. The required grade at all points on the navigation project is dependent on tidal modeling--i.e., determining the elevation of the MLLW datum plane from a series of gage observations at each point. A number of tide gages may need to be established along a navigation project to adequately model the MLLW curve. Depending on the magnitude of the tidal range and linearity of the slope, recording gages may need to be placed at 0.5- to 5-mile increments along the project. Gages should be spaced such that the accuracy of the MLLW elevation at any point in the project is +/- 0.1 ft. This may be achieved by 3 to 30 days of observations. The MLLW reference elevation between the gages is estimated by linear interpolation.

b. River areas. Proceeding up river in Figure 5-5, a constant maintained navigation depth will slope with the average river surface. River datums are referenced to a low water reference plane (LWRP), such as the LWRP 1974 reference used in the unregulated portion of the Mississippi River. Like tidal MLLW, the low water river datum must be determined from gage/staff observations at sufficient points along the river to adequately define the surface. The spacing of these observations must be sufficient to allow linear interpolation between staff gage points. For a river that drops 0.5 ft/mile (e.g., Mississippi) gages or benchmarks may be required at least every quarter- to half-mile in order to reference hydrographic surveys.

c. Controlled river pools. Between river control structures, low water pools are used to reference maintained navigation depths, as shown in Figure 5-5. Since these pools themselves may exhibit some slope, sufficient gages/benchmarks within the pools should be established to account for any minor slope.

d. Reservoir pools. Depths in controlled reservoirs are usually referenced to a national vertical datum (e.g., NGVD 29 or NAVD 88).

e. Great Lakes. Depths in the Great Lakes and connecting channels are referenced to the International Great Lakes Datum (IGLD) of 1985. IGLD 85 represents a low water datum from which navigation is maintained. The datum must be adjusted for slope in the connecting channels between the Great Lakes.

5-5. Tides and Tidal Datums

A datum is defined as the base elevation used as a reference from which to reckon heights or depths. Example datums which most surveyors are familiar with are mean sea level, mean lower low water (MLLW) and mean high water. Tidal datums are defined in terms of the rise and fall or phase of the tide. High Water is the maximum height reached by a rising tide while Low Water is the minimum height reached by a falling tide. Vertical datums are used as a reference on NOS nautical charts. Depths are referred to MLLW--also called chart datum. Heights, such as towers and bridge clearances, are referred to Mean High Water (MHW). A tidal benchmark is a fixed vertical monument used to reference a local tidal datum. A minimum of three benchmarks is required unless the station datum is connected to NAVD 88.

a. Hydrographic surveys in tidal areas should be referenced to a base elevation on NAVD 88. In areas where this is not possible, hydrographic surveys in tidal areas should be referenced to a base elevation on NGVD 29, which has been determined by meaning the tide heights over the National Tidal Datum Epoch. The National Tidal Datum Epoch is the specific 19-year period (Metonic cycle) adopted by the NOS as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., MLLW) for tidal datums. The present National Tidal Datum Epoch is 1960 through 1978. Due to the long-term rise in global sea level and land subsidence, tidal datums are constantly changing and require continuous monitoring and updating. It is the mission of the NOS to collect tidal data and to reduce it to a mean value relative to the National Tidal Datum Epoch; therefore, NOS tidal datums should be used as a basis for hydrographic surveying in tidal areas. The National Tidal Datum Epoch is reviewed annually by NOS for possible revision and must be actively considered for revision every 25 years.

b. NOAA's *User's Guide for the Installation of Bench Marks and Leveling Requirements for Water Level Stations* prescribes the requirements for connecting USACE tidal bench marks to the national vertical network maintained by U.S. Coast & Geodetic Survey (USC&GS). The relationship between MLLW to both NAVD 88 *and* NGVD 29 will be made clear where NAVD 88 data is available. Hydrographic surveys in tidal areas should be referenced to NAVD 88 instead of the older NGVD 29. There are several reasons that NGVD 29 is not supported for these surveys. The old data was adjusted by different manual methods--the new data is collected and adjusted by least squares using digital computers. Many of the 107,000 kilometers measured for the NGVD 29 adjustment have been destroyed by:

• the Interstate Highway System construction,
• subsidence in Texas and Louisiana,
• earthquakes in California,
• flooding in the Midwest
• mass wasting on hillsides
• vegetation

In addition, 730,000 kilometers of levels were measured for the North American Vertical Datum of 1988 (NAVD 88) of which 625,000 kilometers were measured with better equipment.

c. Listed below are some definitions of types of vertical datums and their sources used in USACE.

National Geodetic Vertical Datum of 1929 (NGVD 1929)
• Geodetic datum derived from an adjustment of the first order level network of the United States and Canada.
• In the adjustment, local mean sea level (MSL) was held fixed at 26 tide stations, 21 in the U.S. and 5 in Canada.

North American Vertical Datum of 1988 (NAVD 1988)
• Geodetic datum derived from an adjustment of the first order level network of the U.S., Canada, and Mexico.
• In the adjustment, local MSL was held fixed at Rimouski, Quebec, Canada.
• Releveling First-Order Network
• Least Squares Adjustment
• Decided on Minimum Constrained System
• Primary BM at Father Point, Rimouski, Quebec
• Satisfied IGLD Requirements
• NAVD 88 not tied to MSL for U.S. coastline

International Great Lakes Datum of 1955 (IGLD 1955)
• Geodetic datum derived from first order level network along connecting channels of the lakes and water level transfers across the various lakes.
• In the adjustment, local MSL at Fathers Point, Quebec was held fixed.

International Great Lakes Datum of 1985 (IGLD 1985)
• Geodetic datum derived from first order level network throughout the Great Lakes in the U.S. and Canada.
• In the adjustment, local MSL at Rimouski, Quebec was held fixed.

5-6. Tide Stations

To facilitate the process of establishing tidal datums, tide stations are operated at various locations for long- (primary), medium- (secondary), and short-term (tertiary) durations--refer to Figure 5-6.

a. Primary control tide station. Long-term tide stations are referred to as primary control tide stations. These are tide stations at which continuous observations have been made over a minimum 19-year Metonic cycle. Their purpose is to provide data for computing accepted values of the harmonic constants essential to tide predictions and to the determination of tidal datums. The data series from these stations serves as a primary control for the reduction of relatively short series of observations from subordinate tide stations through comparison of simultaneous observations, and for monitoring long-period sea level trends and variations.

b. Secondary control tide station. Medium-term tide stations are referred to as secondary tide stations. These are stations at which continuous observations have been made over a minimum period of one year but for less than a 19-year Metonic cycle. The series is reduced by comparison with simultaneous observations from a primary control tide station. These stations provide for a 365-day harmonic analysis, which includes the seasonal fluctuation of sea level.

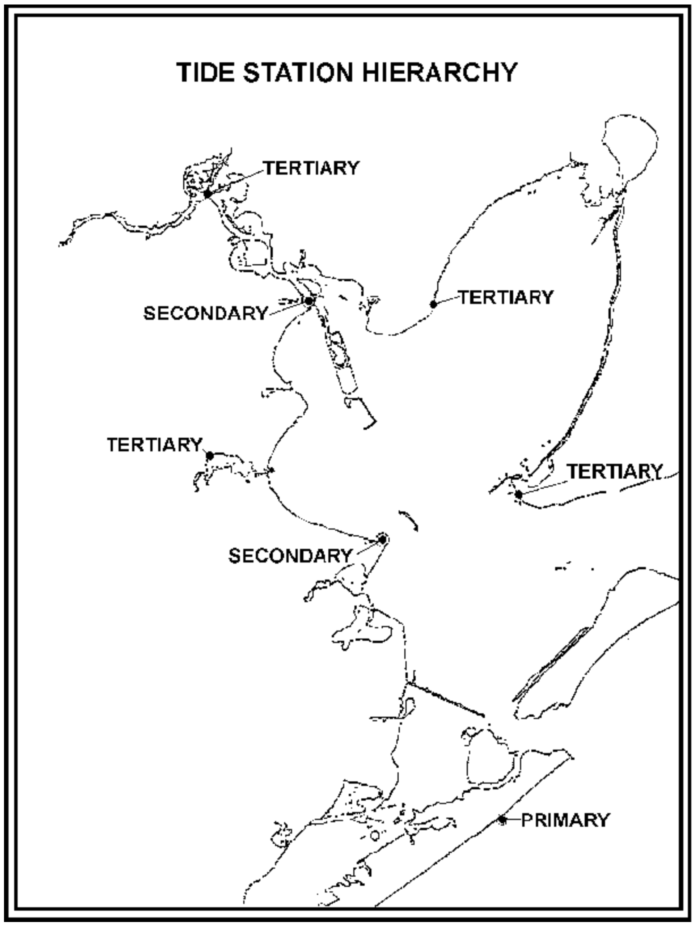


Figure 5-6. Schematic map showing relationship of tide stations

c. Tertiary tide station. Short-term tide stations are referred to as tertiary tide stations. These are tide stations at which continuous observations have been made over a minimum period of 30 days but for less than one year. The series is reduced by comparison with simultaneous observations from a secondary control tide station. These stations provide for a 29-day harmonic analysis.

d. Comparison of simultaneous observations. This is a reduction process in which a short series of tidal observations at any place is compared with simultaneous observations at a control station where tidal constants have previously been determined from a long series of observations. It is usually used to adjust constants from a subordinate station to the equivalent of those that would be obtained from a 19-year series. The National Tidal Benchmark System (NTBMS) provides datum information for previously occupied tidal measurement locations. Listed below are the general statistics for this system.

- Number of stations: approx. 6000
- East Coast: 3000
- Gulf Coast: 500
- West Coast: 1000
- Alaska: 1200
- Pacific Islands: 150
- Great Lakes: 177

5-7. Need for Updated Tidal Datums

Since tidal datums used for hydrographic surveying are referenced to benchmarks that are subsiding with the land relative to sea level, they should be monitored and updated constantly to remain valid. For example, in the Hampton Roads area of Virginia, failure to update tidal datums could result in errors of as much as 1.41 ft per century. Even larger errors can result if tidal datums are based on less than a 19-year mean, or, as in some Pacific coast projects, if earthquake activity has occurred.

a. An old and inaccurate rule of thumb often used in dredging is that datum planes be kept level in reference to sea level datums for any given reach of river or throughout any given stretch of dredging, even in areas where the local MLLW was not level. This creates a special problem near inlets and can result in a benchmark having two different dredging datum elevations, one for upstream, another for downstream, and neither corresponding to local MLLW. Level dredging datums will be discussed later in more detail.

b. It should also be noted that if dredging datums do not agree with true local MLLW, one of two problems will result. If dredging datums are below MLLW, charts will show depths shallower than reality, creating more dredging and giving local mariners and pilots a false impression of shoaling. If dredging datums are above MLLW, charts will show depths greater than reality, decreasing the amount of dredging and causing local mariners and pilots to run aground. In the first situation (normally found in areas where tidal datums are not kept current because of rising sea level and land subsidence), the error gives shipping an unrecognized safety factor at the expense of extra dredging. In the second situation, the error could cause a ship grounding.

5-8. Accurate Tidal Datums

Considering the ongoing rise in sea level relative to the landmass (Figure 5-7), accurate and up-to-date tidal datums are required to ensure that channels are dredged to the proper depths. Inaccurate datums result in unknown over- or under-dredging. Over-dredging provides an unknown and expensive safety factor that is not required. Under dredging can cause disastrous groundings. The optimum design depth cannot be obtained unless the proper tidal datum is correctly utilized. In areas charted by NOS, hydrographic surveying datums for dredging should be the same as NOS chart datums (MLLW).

5-9. NOS Tidal Datums

NOS has modified and updated its methods of determining and labeling the various tidal and chart datums for all coasts of the United States. The National Tidal Datum Convention of 1980 became effective November 28, 1980. This convention:

- Established one uniform, continuous tidal datum system for all marine waters of the U.S., its territories, the Commonwealth of Puerto Rico, and the Trust Territory of the Pacific Islands, for the first time in history.

- Provided a tidal datum system independent of computations based on type of tide.

- Lowered chart datum from MLW to MLLW along the Atlantic coast of the U.S.
- Updated the National Tidal Datum Epoch from 1941 through 1959, to 1960 through 1978.
- Changed the name Gulf Coast Lower Water Datum to MLLW.
- Introduced the tidal datum of Mean Higher High Water (MHHW) in areas of predominantly diurnal tides.
- Lowered Mean High Water (MHW) in areas of predominantly diurnal tides.

a. USACE navigation projects that are referenced to older datums (e.g., MLW along the Atlantic coast or various Gulf coast low water reference planes) must be converted to and correlated with the local MLLW tidal reference established by the NOS. Changes in project grades due to redefining the datum from MLW to NOS MLLW will normally be small, and in many cases will be compensated for by offsetting secular sea level or epochal increases occurring over the years. Thus, impacts on dredging due to the redefinition of the datum reference are expected to be small and offsetting in most cases.

b. 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.

c. Conversion of project datum reference to NOS MLLW may or may not involve field tidal observations. In many projects, existing NOS tidal records can be used to perform the conversion, and short-term simultaneous tidal comparisons will not be required. 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.

(1) Since the shoreline, as depicted on NOS nautical charts and bathymetric maps, is the MHW line, the computational method adopted by this convention provides one uniform and continuous shoreline along all coasts of the coterminous U.S., Hawaii and Alaska, U.S. possessions, Puerto Rico, the Virgin Islands, the Trust Territories of the Pacific Islands, and UN Trust Territories under U.S. jurisdiction.

(2) Use of this computational method also allows states that have designated the MHW line as the boundary between private and state land and have one, two, three, four and/or six tides per tidal day along part (or all) of their coast, and two tides along the rest, to implement the tidal datum of MHW so that they will possess one uniform and continuous boundary between private and state lands.

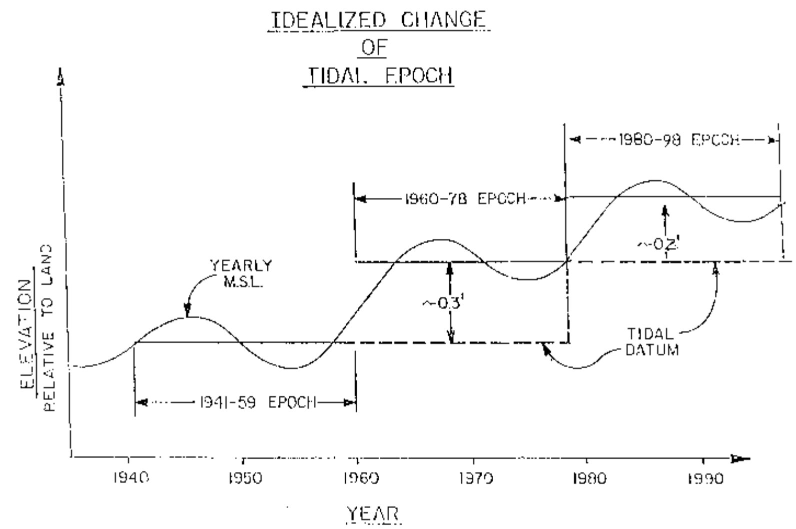


Figure 5-7. Schematic diagram of tidal epochs

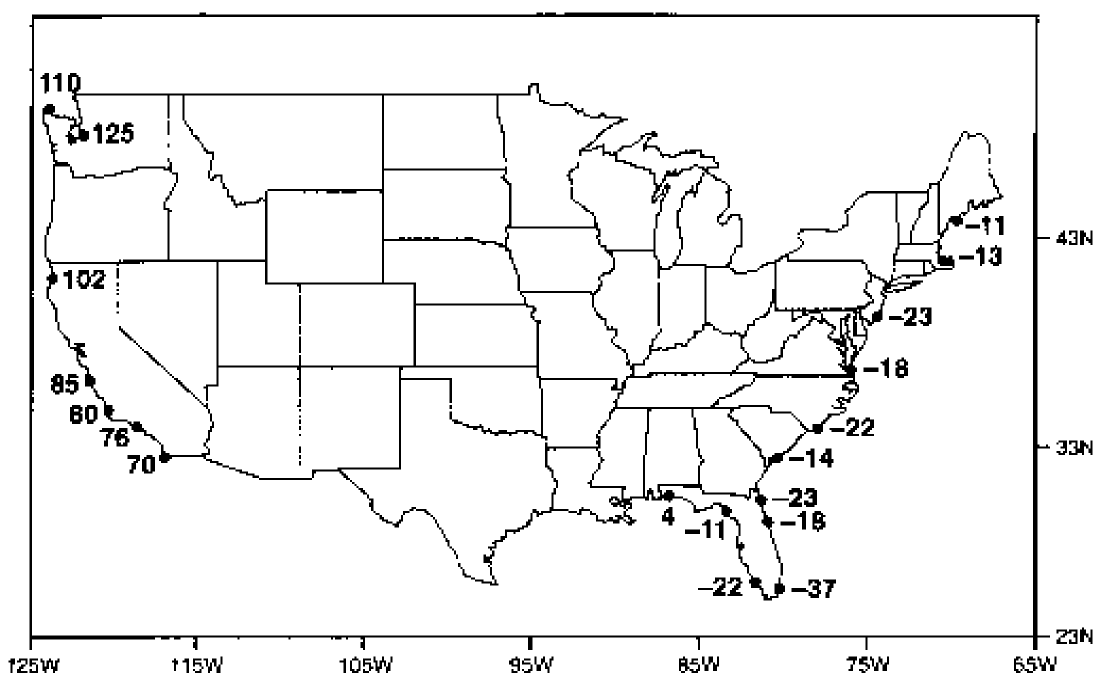


Figure 5-8. MSL datum relative to NAVD 88-- units in centimeters

Of particular importance for USACE--refer also to Figures 5-9 and 5-10:

Atlantic coast. Along the east coast of the U.S., the tide is semidiurnal with two high waters (on average) each tidal day. The chart datum has been changed from MLW to MLLW. This will be given lowest priority when publishing new values. However, MLW on the 1941-1959 epoch will closely approximate MLLW on the 1960-1978 epoch. Thus, MLW on the 1941-1959 epoch will continue to be acceptable until the MLLW data on the 1960-1978 epoch are available.

Gulf coast. Along the Gulf coast of the U.S., the tide is mixed in some areas and diurnal in others. There are other tides associated with islands, distances up bays and estuaries, and within lagoons. The presence of diurnal tides in the Gulf, and the fact that they do not stay purely diurnal at any one place, caused the tidal datum of MHW, as previously defined, to be non-uniform and discontinuous. In order to provide a uniform and continuous MHW Line, this convention intended that all (except in very special cases) high waters appearing with adjacent ranges equal to or greater than 0.1 foot be used in the mean for the datum of MHW regardless of the type of tide. For the MHHW line, the one high water of a diurnal tidal day and the highest high water of a multiple high water tidal day will be used in the mean for the datum. The MLW and MLLW lines are determined by similar computations of their respective datums. The name of the chart datum has been changed from Gulf Coast Low Water Datum (GCLWD) to MLLW, only to be consistent with those of other coasts of the United States. The GCLWD is a tidal datum that was used as an NOS chart datum from November 14, 1977, to November 27, 1980, for the coastal waters of the U.S. Gulf Coast. GCLWD is defined as MLLW when the type of tide is mixed and was MLW (now MLLW) when the type of tide was diurnal.

Pacific coast. Along the west coast, the tide is almost always mixed, with two high waters (often unequal in height) each day. The chart datum will continue to be MLLW.

d. These modifications have provided one uniform and continuous chart datum, MLLW, for all coasts of the U.S. With few exceptions in these coastal tidal areas, MLLW should be the dredging datum. This datum should be based on local tidal observations and computations referred to the National Tidal Datum Epoch. To ensure this, hydrographic surveys should be based on MLLW and should also be related to the NGVD 29 *and* NAVD 88, as specified previously. This allows continuity and identification of the slopes of local MLLW datums for long channels or when various reaches are dredged.

e. Depths of USACE navigation projects in coastal areas subject to tidal influences are currently referred to a variety of vertical reference planes, or datums. Most project depths are referenced to a local or regional datum based on tidal phase criteria, such as MLW, MLLW, Mean Low Gulf, or GCLWD. Some of these tidal reference planes were originally derived from U.S. Department of Commerce, NOS observations and definitions used for the various coasts. Others were specifically developed for a local project and may be without reference to an established vertical network (e.g., NAVD 88 or NGVD 29) or a tidal reference. Depending on the year of project authorization, tidal epoch, procedures, and the agency responsible for or connected to the reference datum, the current adequacy of the vertical reference may be uncertain or, in some cases, unknown. In some instances, project tidal reference grades may not have been updated since original construction. In addition, long-term physical effects may have significantly impacted presumed relationships to the NOS MLLW datum.

f. Since 1989, nautical charts published by USC&GS, U.S. Department of Commerce, reference depths (or soundings) to the local MLLW reference datum, also termed a "chart datum." USCG Notices to Mariners also refer depths or clearances over obstructions to MLLW. Depths and clearances reported on USACE project/channel condition surveys provided to USC&GS, for incorporation into its published charts in plan or tabular format, must be on the same NOS MLLW reference as the local chart of the project site.

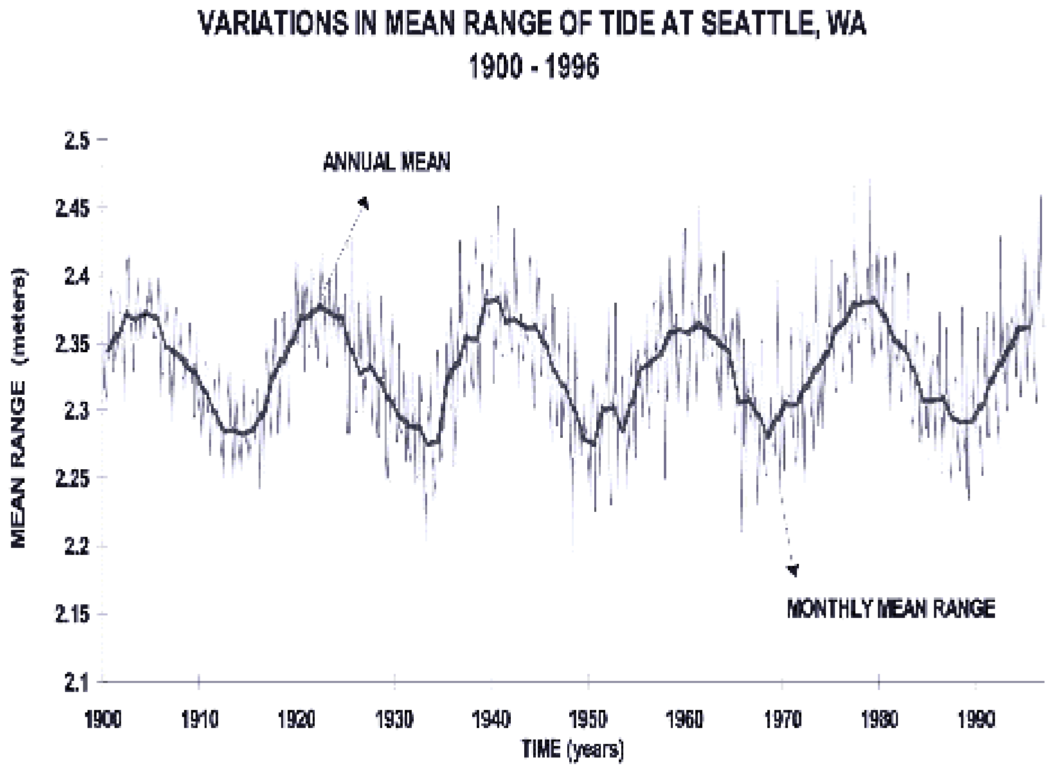


Figure 5-9. Example of mean range of tide on Pacific coast

g. The Water Resources Development Act of 1992 (WRDA 92), Section 224, requires consistency between USACE project datums and USC&GS marine charting datums. This act amended Section 5 of the Rivers and Harbors Appropriation Act of 1915 to define project depths of operational projects as being measured relative to a MLLW reference datum for all coastal regions; only the Pacific coast was previously referenced to MLLW. The amendment states that this reference datum shall be as defined by the Department of Commerce for nautical charts and tidal prediction tables (NOS) for a given area. This provision requires USACE project reference grades to be consistent with NOS MLLW.

h. Implementation actions. A number of options are available to USACE commands in assessing individual projects for consistency and accuracy of reference datums, and performing the necessary tidal observations and/or computations required to adequately define NOS MLLW project reference grade. Datum establishment or verification may be done using USACE technical personnel, through an outside Architect-Engineer (A-E) contract, by another USACE district or laboratory having special expertise in tidal work, or through reimbursable agreement with NOS. Regardless of who performs the tidal study, all work should be closely coordinated with both the USC&GS and NOS in the Department of Commerce.

i. Technical specifications. The general techniques for evaluating, establishing, and/or transferring a tidal reference plane are fully described in the USACE and Department of Commerce publications.

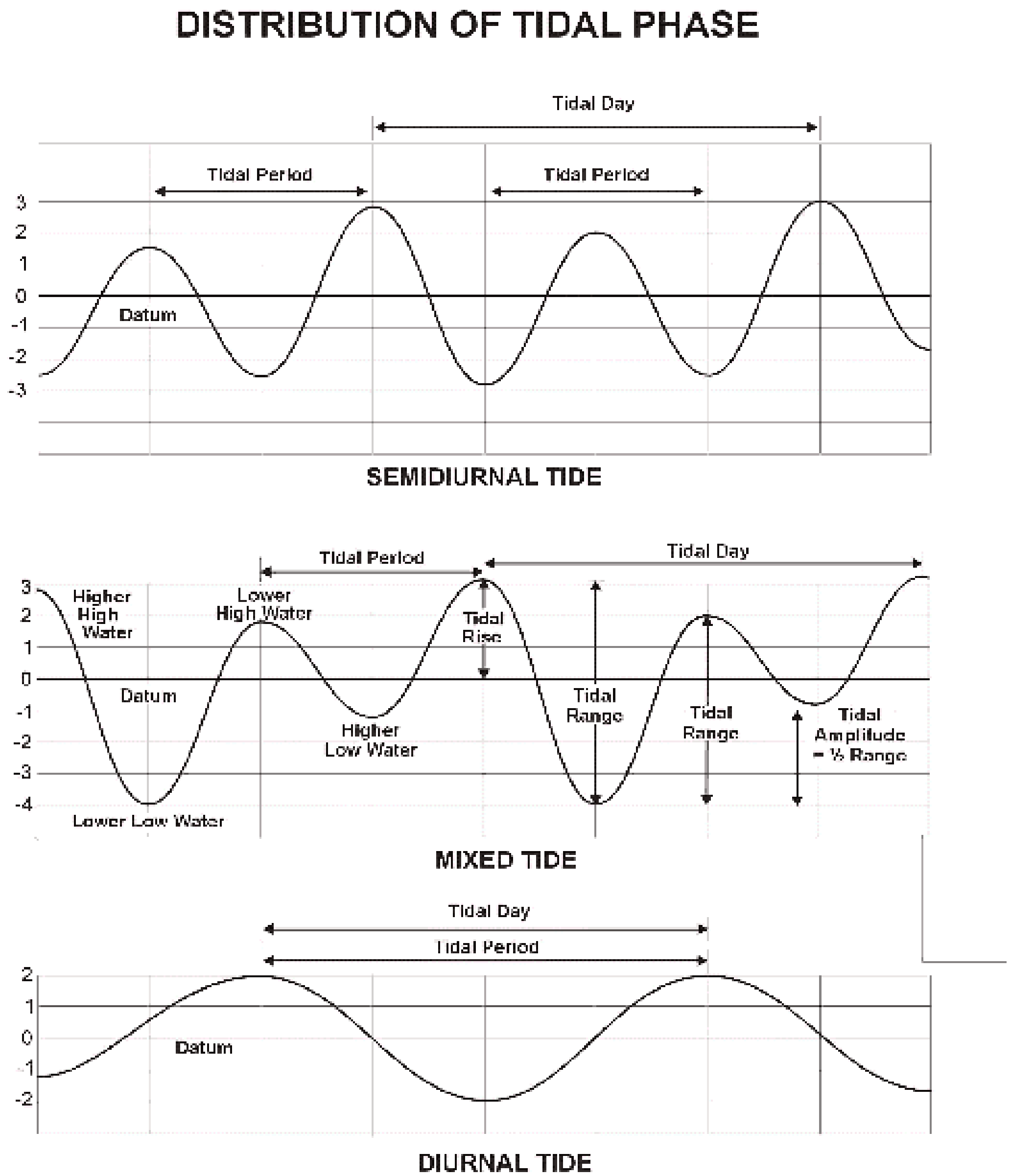


Figure 5-10. Types of tidal phases

5-10. Establishing Tidal Datums

Establishing tidal datums for the United States and its territories is the primary responsibility of NOS. Depending on the location, NOS may already have all the necessary information to ensure that proper tidal datums are utilized for hydrographic surveys. This would include NOS tidal benchmarks in the immediate vicinity of the project site (the tidal characteristics at the project site should be the same as those at the site of the tidal benchmarks) and 1960-1978 epoch and NGVD values (NAVD 88) and descriptions for these marks.

a. Department of Commerce contacts. Before and during the course of any tidal study, close coordination is required with NOS.

b. Sources. If in-house forces are not used, the following outside sources may be utilized to perform a tidal study of a project, including any field tidal observations.

(1) *Architect-Engineer (A-E) contract.* A number of private firms possess capabilities to perform this work. Either a fixed-scope contract or indefinite delivery type (IDT) contract form may be utilized. In some instances, this type of work may be within the scope of existing IDT contracts. Contact NOS to obtain a typical technical specification which may be used in developing a scope of work.

(2) *Reimbursable support agreement.* Tidal studies and datum determinations may be obtained directly from the NOS, Department of Commerce, via a reimbursable support agreement. A cooperative agreement can be configured to include any number of projects within a district. Funds are provided to NOS by standard inter-agency transfer methods and may be broken down to individual projects. Contact the Chief of the Ocean and Lake Levels Division to coordinate and schedule a study agreement.

c. Scheduling of conversions. Section 224 of WRDA 92 did not specify an implementation schedule for converting existing projects to NOS MLLW (or verifying the adequacy of an existing MLLW datum). It is recommended that a tidal datum study be initiated during a project's next major maintenance cycle.

d. If all necessary tidal datum information is not available, one of the following methods may be utilized.

(1) *NGVD/MLLW differential method.* This involves NOS tidal benchmarks in the immediate vicinity (tidal characteristics the same as those at the project site) with 1960-1978 and NGVD elevations and project benchmarks with NGVD elevations. Direct comparison of the existing project datum to the actual NOS tidal datum can be made by computing the NGVD/MLLW differential for the tidal benchmarks and comparing it with the NGVD-project datum differential at the project site. In effect, this is the same as leveling between them. The error in the existing project datum can then be computed and corrected by applying the NGVD/MLLW differential to the project benchmarks.

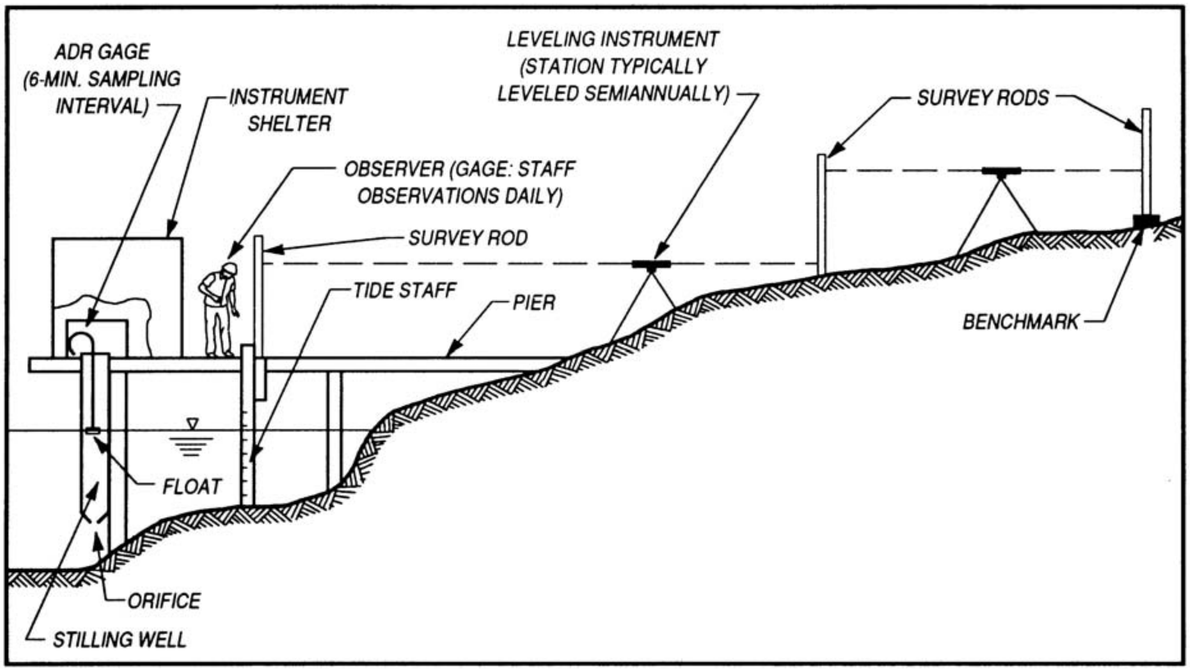


Figure 5-11. Schematic of method of differential leveling

(2) *Leveling and NGVD/MLLW differential method.* This involves the same situation outlined in the first method, except that neither the project datum nor the NOS tidal datum has been related to NGVD. Field leveling (Figure 5-11) is needed to develop the required relationships, after which the differentials, errors, and necessary corrections are computed as discussed above.

(3) *Leveling to a known tidal datum method.* This involves leveling from the project site to a known tidal datum due to the nonavailability of NGVD at either site. Tidal characteristics are assumed to be the same at both sites. If the leveling is too costly, operating tide stations at both sites and performing simultaneous comparison computations to determine the datum at the project site may be more efficient.

(4) *Interpolation method.* This involves interpolation between two existing sites where tidal datums were previously determined. The estuary's tidal characteristics are assumed to be changing at a fairly constant and linear rate, with one previously established tidal datum upstream and another one downstream of the project site. The upstream project site and downstream sites will have to be related to each other by one of the above methods or by transfer through simultaneous staff reading at all three sites. The differentials can then be computed as outlined in the NGVD/MLLW differential method. A linear interpolation can then be performed. Finally, errors in the existing project datum and necessary corrections are computed as outlined in the NGVD/MLLW differential method.

(5) *Operating tide stations method.* This involves situations in which existing tidal datums are not reliable, are too far from the project site, or do not exist. Operation of a tide station is required to establish the datum. Since 19 years of records are required to establish an accurate tidal datum, the principles of comparison of simultaneous observations should be employed to adjust short-term readings to the 19-year equivalent, with several tide stations operated simultaneously. One station should be at the project site (tertiary) and another one at a primary station site. Depending on the geographical relationships and tidal characteristics, a secondary station may also be required. Primary stations operated

throughout the United States by NOS provide the 19 years of continuous readings required. NOS also operates some secondary stations possibly providing the seasonal comparisons required. The operation of tertiary stations on project sites and possible reinstallation and operation of gages at previous secondary sites for simultaneous comparisons will be required. Due to the potential use of the tidal data for marine boundaries and other non-dredging purposes, collection of adequate data for court verification should be considered. This generally requires three months of data at the tertiary station along with data for the same three months at the associated secondary and primary stations. Arrangements should be made for NOS to process the data and determine the tidal datum. A cooperative agreement with NOS may be initiated by contacting the Chief, Ocean and Lake Levels Division.

e. Tidal reference boundaries. Figure 5-12 depicts various jurisdiction zones on the Atlantic Coast. Determination and demarcation of the MHW line is often required for some Corps regulatory permitting activities. Procedures and accuracy standards may vary widely between jurisdictions and/or projects. The processes for performing MHW demarcation surveys are beyond the scope of this manual.

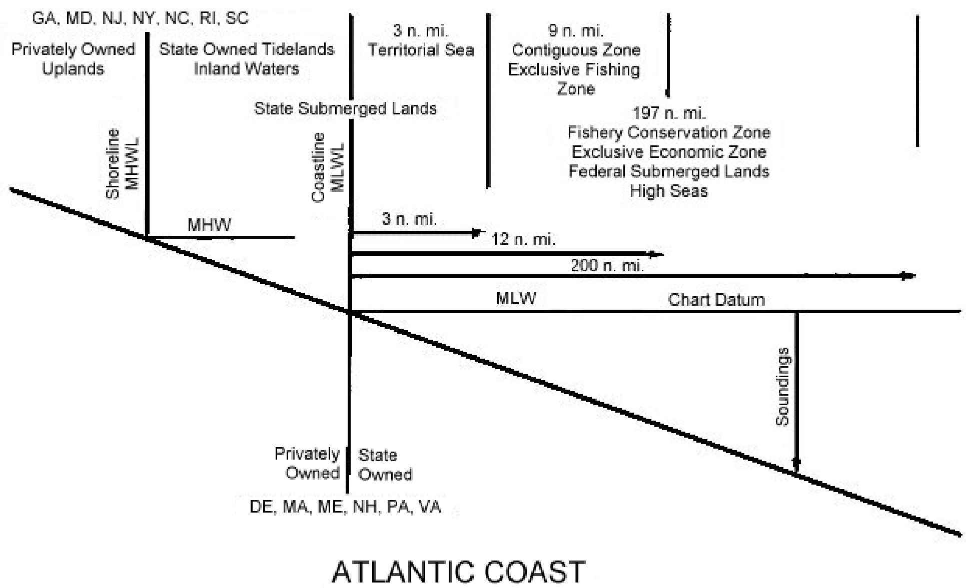


Figure 5-12. Diagram of terminology of tidal datums on Atlantic Coast

5-11. Equipment and Field Work Associated with Operating Tide Stations

To determine a tidal datum at a given site, a true and accurate record of the tide levels and times should be obtained. The length of this record depends upon the local characteristics and other factors previously discussed. The three types of tide stations (primary, secondary, and tertiary) usually require different amounts and types of facilities and services.

a. Structures. The purpose of the structure is to protect the installation. A variety of structures may be used, including buildings, piers, wharves, and pilings in open water. Primary stations usually require buildings; secondary stations may require a small house depending on the location and environment; and tertiary stations can usually be installed on any supporting structure.

Figure 5-13. Primary automatic gage to record tides

b. Gages. The purpose of the gage is to record continuous times and water level heights at the site--Figure 5-13. This is usually an automatic electromechanical type recorder. The only variation in gages from primary to tertiary stations would be that primary stations may have more than one gage and may have additional equipment for telemetering the data to other locations.

c. Float wells. A float well is a stilling well in which the float of a float-actuated gage operates. A stilling well is a vertical pipe with a relatively small opening (intake) in the bottom. It is used in a gage installation to dampen short-period surface waves while freely admitting the tide, other long-period waves, and sea level variations, which can then be measured by a tide gage sensor inside. The well provides a protected place for a float, which is connected to the gage by a wire or cable, to maintain itself at the water's surface for accurate recordings. In general, larger wells of 12 inch diameter with small intakes are used with primary and secondary stations to provide more damping effect for accurate readings. Smaller wells of 4 in. diameter with small intakes are generally used with tertiary stations for ease of installation for shorter periods.

d. Staffs. A tide staff is a tide gage consisting of a vertical graduated staff from which the height of the tide can be read directly. It is called a fixed staff when secured in place so that it cannot be easily removed. A portable staff is one designed for removal from the water when not in use. For such a staff a fixed support is provided. The support has a metal stop secured to it so that the staff will always have the same elevation when installed for use. The staff provides a means for manual observations to verify recordings and serves as a fixed reference for recording water levels and a direct connection to tidal benchmarks. Staff types can vary from an electric tape device to a vitrified or fiberglass staff.

e. Observers. A local tide observer is required to provide a daily manual check to verify recorded data. NOS requires five observations per week in most situations.

f. Reports. Weekly reports are submitted to the district by observers for monitoring purposes. Records can be obtained that document any changes or modifications to the gage or staff for proper data processing and reduction.

g. Leveling. Leveling from the staff or the electric tape to tidal benchmarks is the means of transferring the tidal datums to permanent marks for future use and ensuring staff stability. 3rd order leveling is usually required.

h. Benchmarks. Benchmarks are used as a fixed reference and permanent record of the tidal datums. Benchmarks are established in accordance with the standards set forth in EM 1110-1-1002. In low-lying marshes and beach areas, deep-driven rod-type marks driven to refusal are required.

5-12. Off-Site Tide Observations

These observations usually occur in inlets, offshore entrance channels, and open waters of bays where on-site tide observations are not easily obtained.

a. Errors associated with off-site tide observations are as follows:

(1) Figure 5-14 shows two tide curves of equal range with a 1-hr time offset. The solid line represents the tide at the project site, and the dashed line represents the tide at the observer's site. The tide height at the two sites will coincide only once every 6.2 hr. At all other times, errors will occur at a maximum of 0.6 ft (for the case shown) at the middle of each ebb and flood tide. If the first survey were done on an ebbing tide and the second survey were done on a flooding tide, or vice versa, the error would be doubled, resulting in a total maximum error between surveys of 1.2 ft.

(2) Figure 5-15 shows two tide curves with a 0.5-ft range difference and a 1-hr time offset. The solid line again represents the tide at the project site, and the dashed line represents the tide at the observer's site. It is again shown that the tide heights at the two sites will coincide only once about every 6 hr. At all other times, errors will occur at a maximum of 1.0 ft near the end of a flood tide and at 0.5 ft near the end of an ebb tide. If two surveys were made with the first near the end of an ebb tide and the second near the end of the flood tide, the error would be compounded to a total of 1.5 ft. Note that larger tide ranges or increased time offsets will create even larger errors than those shown here.

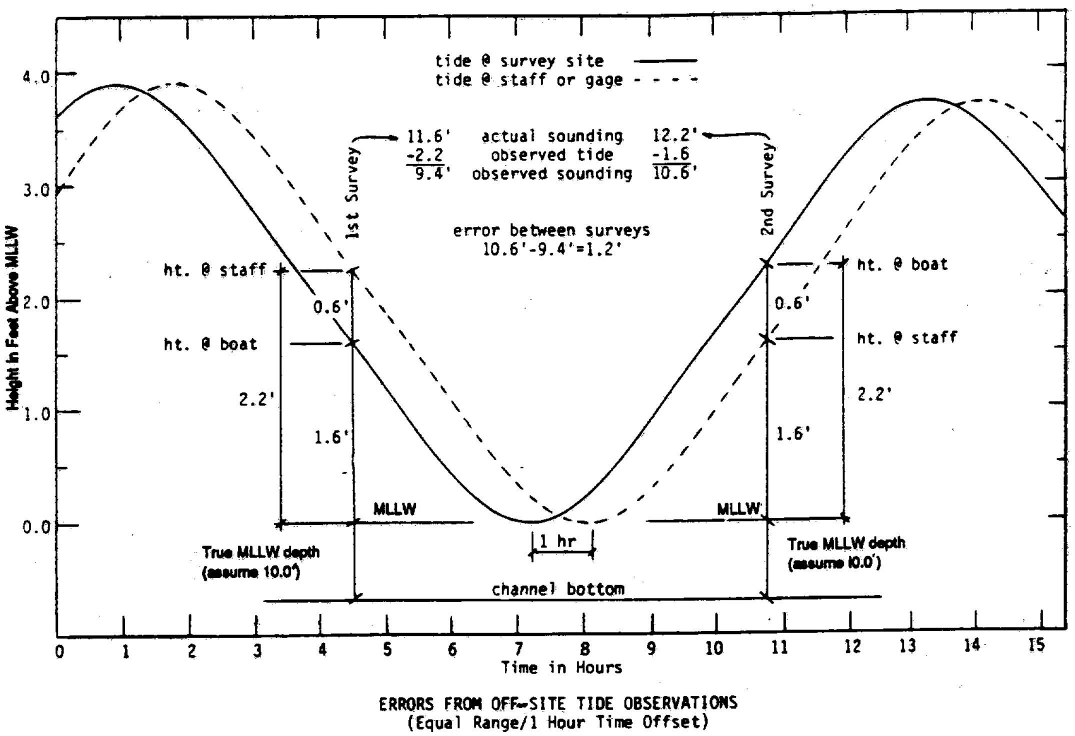


Figure 5-14. Errors from off-site tide observations. (Equal range of tide with 1 hour time offset)

b. Depending on the geographical location and local tidal characteristics, several alternative solutions should be considered to eliminate these errors:

(1) The first would occur where it is possible to surround the site with several tide stations operating simultaneously. Appropriate interpolations could provide accurate on-site tidal data. If all tide stations and the survey and dredge vessels were equipped with telemetering devices, this could be done in real time onboard. Note that the tidal datums should have been determined in advance of the surveying or dredging. Without telemetering devices, the recorded tides could be analyzed and the appropriate interpolations performed with tide correctors computed for use in postprocessing and plotting the hydrographic surveys. The dredge would require real-time information to ensure proper operation.

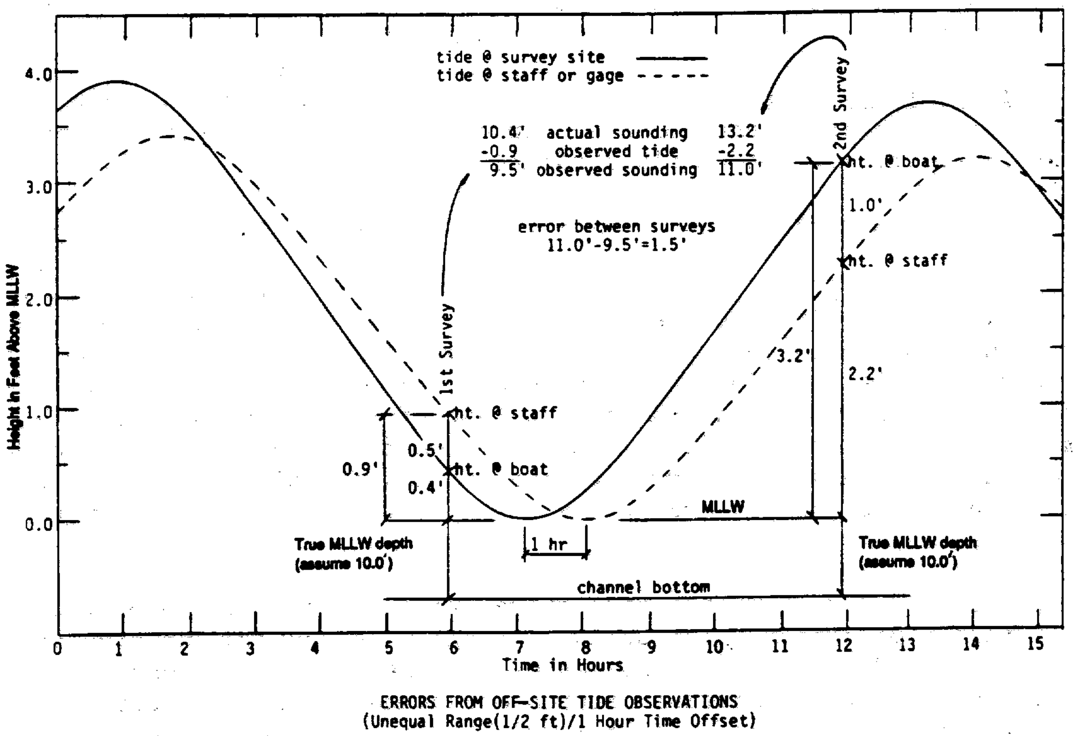


Figure 5-15. Errors from off-site tide observations. (Unequal range of tide with 0.5 range and 1 hour time offset)

(2) Another approach would be required if the site could not be surrounded by tide stations. In this case, an on-site tide station could be installed on an offshore platform and actual tides recorded. This would require collecting enough reliable data to determine a tidal datum as previously discussed through short-term simultaneous readings and comparisons with secondary and primary control tide stations. Once the datum was established, real-time tides could be telemetered to the survey and dredge vessels or the recorded tides could be used later to postprocess and plot the surveys.

(3) In areas where it is not feasible to maintain an offshore tide station indefinitely, a zoning approach may prove adequate. This would involve operating onshore tide stations simultaneously with the offshore station as outlined above. However, by mathematical modeling or zoning of the tidal regime in the offshore area, the offshore station could be removed and the tides at the offshore site accurately projected from the onshore tide stations, which would continue to operate. Some districts have had limited success with offshore tide gages using either acoustic or pressure sensing devices to determine offshore water elevations. Historical information for zoning models and predicted information from tide tables may be provided by NOS.

c. The key to utilizing offshore tide stations effectively is to collect enough data for a datum determination through the method of comparison of simultaneous observations with secondary and primary control tide stations before the channel design is complete.

5-13. Water Level Reference Planes

The following sections describe some of the low water reference planes used in the Great Lakes and on inland waterway systems.

5-14. International Great Lakes Datums

a. The Great Lakes-St. Lawrence River system area (Figure 5-16). The official datum is now IGLD 85. IGLD 85 was officially established in January 1992, replacing IGLD 55. Districts working with the previous official datum, IGLD 55, were to have moved over from IGLD 55 to IGLD 85 by January 1993. This changeover cannot be accomplished in a practical sense until NOAA publishes the IGLD 85 benchmark data for the area. IGLD 85 data is available for the gages, but the spacing of the gages is not dense enough to support project control. As soon as NOAA data is available for a project area, IGLD 85 should be used for any hydrographic surveys on the Great Lakes.

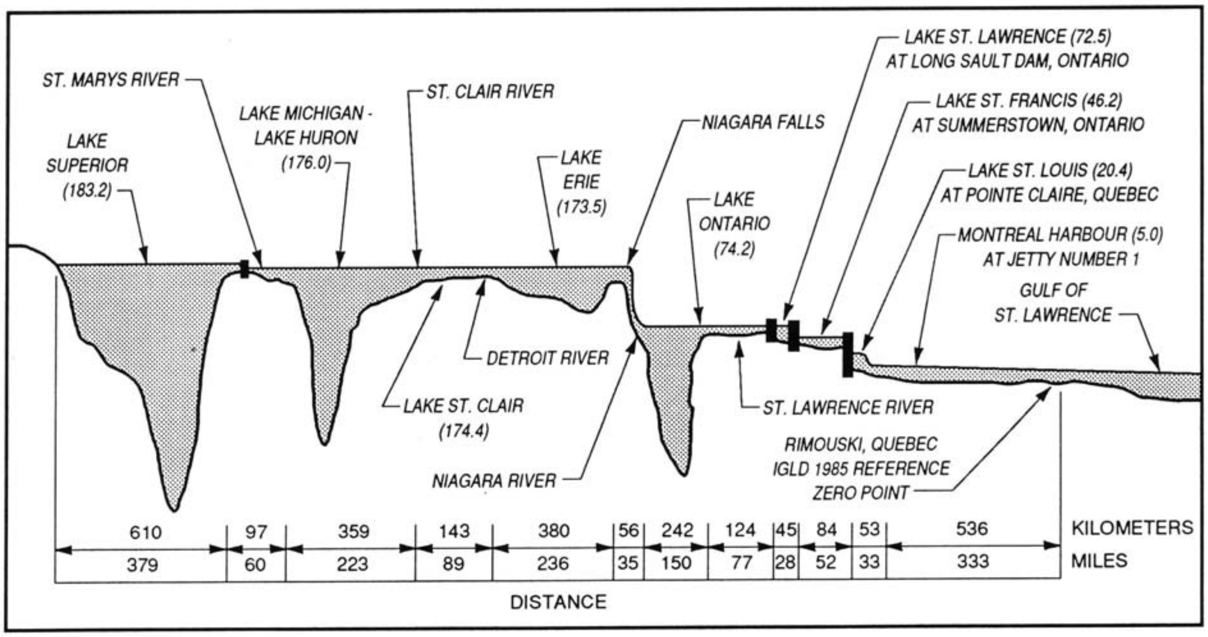


Figure 5-16. IGLD 85 datums for the Great Lakes-St. Lawrence River systems

(1) The earth's crust experiences movements around the entire Great Lakes-St. Lawrence River system area and therefore must be vertically readjusted every 25 to 30 years. This crustal movement is called isostatic rebound, which is the gradual rising of the earth rebounding from the weight of the glaciers during the last glacial age. The reference point for IGLD 55 was Pointe-au-Pere (Father's Point), Québec. When IGLD 55 was created, it was known that readjustment would be necessary due to the effects of isostatic rebound. Crustal movement is not uniform across the Great Lakes basin and causes bench marks to shift not only with respect to each other, but also with respect to the initial reference point. Subsidence and other local effects can cause bench marks to shift as well. In addition to these reasons, new surveying technology and adjustment techniques made the time ripe to revise the datum.

(2) The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data revised the IGLD 55 datum and established IGLD 85. This committee has input to the international management of the Great Lakes-St. Lawrence River system. Representatives from the U.S. and Canada are members on this committee. The efforts of the Coordinating Committee to revise IGLD 55 and establish IGLD 85 were coordinated with the efforts to establish the new common international vertical datum for the U.S., Canada, and Mexico, NAVD 88. 1985 is the central year of the period during which water level information was collected for the datum revision (1982-1988). The reference zero point for IGLD 85 is located at benchmark #1250G, at Rimouski, Québec--see Figure 5-16. This benchmark has an IGLD 85 elevation of 6.723 m and IGLD 55 elevation of 6.263 m. IGLD 85 increases the number and accuracy of

benchmarks in the Great Lakes area. Agencies within both the U.S. and Canada will use IGLD 85. NOS and the Canadian Hydrographic Service (CHS) began reporting water levels referenced to IGLD 85 upon its implementation in January 1992. For a period of time, conversion factors for both IGLD 55 and IGLD 85 water level data will be provided by NOAA/NOS Great Lakes Section and CHS. The monthly water level bulletins published by USACE and CHS will reflect this information.

(3) IGLD 85 will not change water levels established for federal flood insurance programs in the U.S. These levels are referred to NAVD 88. Elevations common to both NAVD 88 and IGLD 85 are available from NOAA/NOS Great Lakes Section and NGS Vertical Network Branch. Lake-level outflows will not be affected by the datum change to IGLD 85. As benchmark information becomes available, navigation, construction, and other improvement work on the Great Lakes should be referred to IGLD 85. Either datum is acceptable until the benchmark data is available for the respective USACE district. Drawings should include a note for the vertical IGLD datum in use to avoid blunders.

(4) USACE permit applications will still be referenced to the Ordinary High Water Mark (OHWM) as defined under Section 10 of the Rivers and Harbors Act. As benchmark information becomes available, new applications should reference IGLD 85.

b. Each of the Great Lakes has an independent low water reference plane, or chart datum. The elevations of these planes of reference on IGLD 85 are shown in Figures 5-16 and 5-17.

c. Low water datums are also established at points along the connecting channels where surface gradients occur. Improvements to navigation projects (including surveys) within these areas are performed relative to the low water datum for a particular reach of a river. Surveys performed within any section of a connecting waterway must be appropriately corrected for these datum gradients (Figure 5-17).

GREAT LAKES, CONNECTING CHANNELS AND ST. LAWRENCE RIVER WATER LEVELS AND DEPTHS

Department of the Army, Detroit District Corps of Engineers

The present and expected water levels on the Great Lakes, Connecting Channels and the St. Lawrence River, as well as the period-of-record average levels for the Great Lakes, are given in **Inches** above (+) or below (−) Low Water Datum (LWD). Low Water Datum is a plane of reference used on a navigation chart. It is also known as Chart Datum. The Low Water Datums for each location below, are given in feet on International Great Lakes Datum, 1955.

Indicator Points		Period-of-record* Average Levels 20 JAN	Present Levels 20 JAN 90	Period-of-record* Average Levels 5 FEB	Expected Levels 5 FEB 90	Low Water Datum
	GREAT LAKES					
	Lake Ontario	+ 15"	+ 14"	+ 16"	+ 13"	242.80
	Lake Erie	+ 16	+ 18	+ 16	+ 18	568.60
	Lake St. Clair	+ 13	+ 12	+ 10	+ 10	571.70
	Lakes Michigan-Huron	+ 13	+ 4	+ 13	+ 3	576.80
	Lake Superior	+ 4	− 3	+ 3	− 4	600.00
	ST. LAWRENCE RIVER					
0	Above Long Sault Dam		+ 1		− 4	237.50
1	Above Iroquois Dam		+ 19		+ 16	239.90
2	Ogdensburg		+ 11		+ 10	242.20
2J	Alexandria Bay		+ 12		+ 12	242.60
3	Head of River at Cape Vincent		+ 14		+ 13	242.80
	DETROIT RIVER					
4	Lake Erie at Pelee Passage		+ 18		+ 18	568.60
5	Mouth of River at Gibraltar		+ 16		+ 16	568.77
6	Head of River above Belle Isle		+ 12		+ 11	571.47
	ST. CLAIR RIVER					
7	Mouth of River at St. Clair Flats		+ 12		+ 10	571.70
8	Algonac		+ 9		+ 8	572.50
9	St. Clair		+ 7		+ 6	574.04
10	Blue Water Bridge		+ 5		+ 4	576.25
11	Head of River at Fort Gratiot		+ 4		+ 3	576.50
12	Lake Huron Approach Channel		+ 4		+ 3	576.50
	ST. MARYS RIVER					
13	Mouth of River at Detour		+ 4		+ 3	576.80
14	West and Middle Neebish		+ 7		+ 7	577.00
15	Head of Little Rapids		+ 12		+ 11	577.60
16	Below Locks		+ 14		+ 14	577.80
17	Above Locks		0		0	599.50
18	Head of River at Point Iroquois		− 3		− 4	600.00

Available water depth is determined for a location by adding (if+) or subtracting (if−) the amount from the above table to the appropriate channel depth shown in the profile on the backside of this table or to the water depths shown on National Oceanic and Atmospheric Administration (NOAA) navigational charts.

CAUTION: Depths so determined are representative of a still water surface elevation, disturbed by neither wind nor other causes. Depths, however, may be reduced or increased as much as several feet for short periods of time due to these disturbances, or when sections of channels develop shoals. Vessel masters should refer to "Local Notice to Mariners" for extent of shoaling and scattered bedrock projections in all channels.

Figure 5-17. Reference datums for connecting channel in the Great Lakes

d. Geopotential numbers for individual benchmarks are the same in both the NAVD 88 and the IGLD 85. A difference between IGLD 85 and NAVD 88 is that the IGLD 85 benchmark values are given as dynamic heights and the NAVD 88 values are given in Helmert orthometric heights. Dynamic heights show potential energy of a system, whereas orthometric heights are the result of geopotential number (energy surface) divided by local gravity. The dynamic height for the same point on IGLD 85 and IGLD 55 can vary between 1 cm and 40 cm. Orthometric elevations from differential leveling will not yield dynamic elevations. The differences between the two datums (e.g., IGLD 55 and NGVD 29) have been determined from differential leveling and long-term stage observations. These differences are published where stage observations have been made. For example, on Lake Erie (IGLD 55 = 563.6 ft), differences between NGVD 29 and IGLD 55 are (-) 1.57 ft at Cleveland, OH, (-) 1.45 ft at Toledo, OH, and (-) 1.29 ft at Buffalo, NY. To establish a reference datum at any point from a NGVD 29 benchmark elevation requires application of the NGVD 29-IGLD 55 conversion for that area, including any required interpolations between reference points.

e. Other local reference planes have been established by local jurisdictions (Table 5-2). These local reference planes can be related to either IGLD 85 or NAVD 88. If the data is not available to refer to IGLD 85, then IGLD 55 may be referred to; if the data is not available to refer to NAVD 88 then NGVD 29 may be referred to. The relationship between the various datums should be clearly indicated on all drawings or plots of surveys performed in such areas.

Table 5-2.
Local Datum Reference Elevations

Area	IGLD (1955) Elevation (feet)
Chicago city datum plane	578.18
Cleveland city datum plane	573.27
Buffalo city datum plane	574.28
Milwaukee city datum plane	579.30

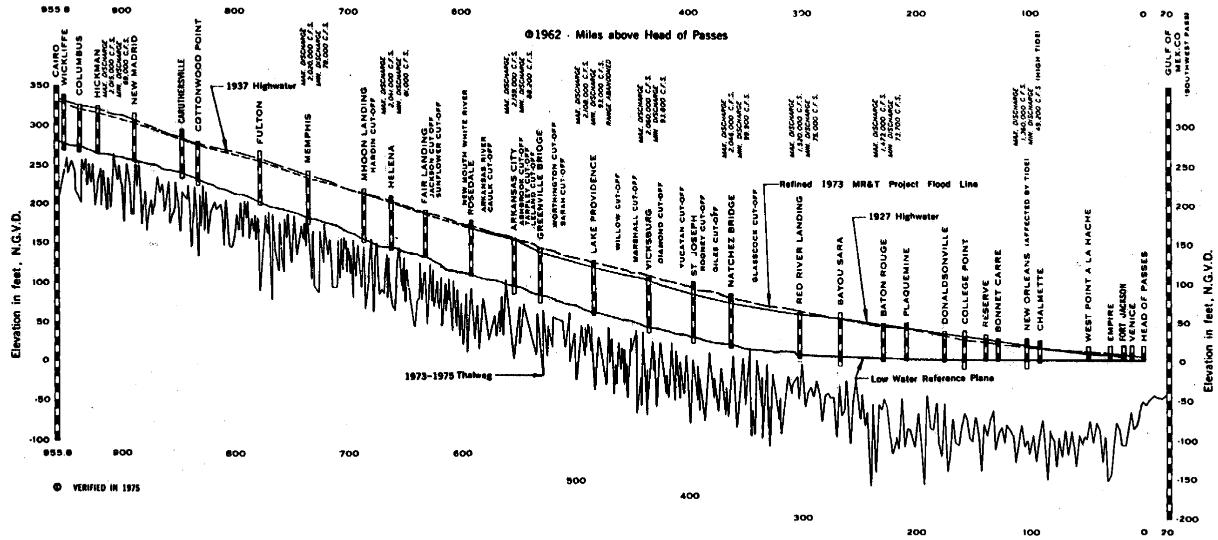
For example, at Chicago, the difference between IGLD 55 on Lake Michigan and the Chicago City Datum Plane is:

IGLD 55 Lake Michigan:		576.80 feet
Chicago city datum	-	<u>578.18</u> feet
Difference	(-)	1.38 feet

In other words, an IGLD 55 Lake Michigan elevation adjusted relative to the Chicago city datum would decrease 1.38 ft. Differences between all points in an area may not be constant. Velocity head, pressure head, and vertical adjustment residuals are factors.

5-15. Low Water Reference Planes (LWRP) -- Middle and Lower Mississippi River

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 the 1974 LWRP--see Figure 5-18--and most recently, the 1993 LWRP. These hydraulic-based reference planes were established from long-term observations of the river's stage, discharge rates, and flow duration periods 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 (particularly in areas containing a rock bottom). The gradient is approximately 0.5 ft per river mile. The ever-changing river bottom will influence the LWRP. Changes in the stage-discharge relationship will influence the theoretical flow line for the LWRP.



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

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

GAGE	①1962 MILES A.H.P.	GAGE ZERO FT. NGVD	GAGE READING - FT. HIGHEST	LOWEST	BANKFULL	* LWRP
CAIRO, ILL. (OHIO RIVER)	953.8	270.47	59.51	−1.0	44	9.6
WICKLIFFE, KY. (A)	951.5	269.12	58.18	4.95	42	10.2
COLUMBUS, KY.	937.2	266.38	54.54	0.05	43	7.8
HICKMAN, KY. (B)	922.0	264.73	51.5	−0.4	37	3.4
NEW MADRID, MO.	889.0	255.48	47.97	−0.60	40	2.7
CARUTHERSVILLE, MO.	846.4	235.49	46.0	−0.72	35	4.0
COTTONWOOD POINT, MO.	832.7	230.18	44.4	−3.9	36	3.1
FULTON, TENN.	778.2	208.61	47.25	−7.7	34	−3.1
MEMPHIS, TENN.	734.7	183.91	48.7	−5.35	34	−2.6
MHOON LANDING, MISS.	687.5	161.22	53.2	−8.85	35	−3.9
HELENA, ARK.	663.0	141.70	60.21	−3.0	41	4.1
FAIR LANDING, ARK. (C)	632.5	132.20	55.6	−4.8	40	−0.9
ROSEDALE, MISS.	592.2	108.73	50.4	−2.05	44	3.0
ARKANSAS CITY, ARK.	554.1	96.66	59.2	−5.3	44	0.2
GREENVILLE (BRIDGE), MISS. (D)	531.5	74.92	58.2	6.7	48	11.3
LAKE PROVIDENCE, LA.	487.2	80.71	50.7	−7.7	37	
VICKSBURG (CANAL), MISS.	437.6	46.25	58.4	−6.8	42	—
VICKSBURG, MISS.	435.7	46.23	53.24	−7.0	43	0.1
ST. JOSEPH, LA.	396.4	33.12	55.3	−10.7	40	0.0
NATCHEZ, MISS.	363.3	17.28	58.04	−2.7	48	6.1
RED RIVER LANDING, LA.	302.4	0.00	60.94	2.89	46	10.6
BAYOU SARA, LA.	265.4	0.00	55.46	0.96	36	5.25
BATON ROUGE, LA.	228.4	0.00	47.28	−0.07	29	2.57
PLAQUEMINE, LA.	208.8	0.00	43.04	−0.9	25	1.7
DONALDSONVILLE, LA.	175.4	0.00	36.01	−0.39	23	1.33
COLLEGE POINT, LA.	157.4	0.00	32.32	−0.6	17	1.06
RESERVE, LA. (B)	138.7	0.00	26.0	−0.1	15	0.70
BONNET CARRE, LA. (C)	128.0	0.00	23.79	−0.62	14	0.68
NEW ORLEANS, LA.	102.8	0.00	21.27	−1.6	11	0.48
CHALMETTE, LA.	91.0	0.00	17.58	−0.52	8	0.08
WEST POINTE A LA HACHE, LA.	48.7	0.00	15.25	−1.06	3	0.06
EMPIRE, LA. (G)	29.5	0.00	10.92	−0.74	1	−0.21
FORT JACKSON, LA.	18.6	0.00	14.3	−2.67	2	−0.40
VENICE, LA. (F)	10.7	0.00	9.11	−0.73	1	−0.36
HEAD OF PASSES LA. (E)	−0.6	0.00	12.03	−0.85	1	−0.36

Figure 5-18. Profile of Lower Mississippi River 1974 low water reference plane

a. Construction and improvements along the river are performed relative to the LWRP at a particular point. Differences in LWRP elevations between successive points along the river are determined from simultaneous staff readings and are referenced to benchmarks along the bank. The LWRP slope gradients between any two points must be corrected by linear interpolation of the profile. Thus, over a typical 1-mile-long section of river with a 0.5-ft gradient, each 1,000-ft O/C river cross section will have a different LWRP correction, each dropping successively at 0.1-ft increments.

b. From 1993 on, NAVD 88 should be used as the common reference plane from which LWRP elevations are measured, if possible. The relationship of all project datums to both NGVD 29 and NAVD 88 will be clearly noted on all drawings, charts, maps, and elevation data files. All initial surveys should be referenced to both NAVD 88 and NGVD 29. If this is not possible then NGVD 29 should be used as the common reference plane from which LWRP elevations are measured until the move to NAVD 88 can be made. Differences between the LWRP and NGVD 29 are published for the reference benchmarks used to control surveys and construction activities. In some FOAs, surveys are performed directly on NGVD 29 without regard to the LWRP profile (elevations above NGVD 29 are plotted rather than depths). The LWRP depths are then contoured from the plotted NGVD 29 elevations, with the LWRP profile gradients applied during the contouring process.

c. If a survey is conducted over a given reach of the river, the LWRP-NAVD 88 and/or the LWRP-NGVD 29 conversion must be interpolated based on the slope profile over that reach. For example:

@ River Mile 736.0: LWRP = 181.5 NGVD 29

@ River Mile 736.4: LWRP = 182.2 NGVD 29

The 0.7-ft drop in 0.4 mile is linearly interpolated for any river cross section run within this 0.4-mile stretch, i.e., a river cross section at mile 736.2 would use a 181.85-ft conversion from NGVD 29 to LWRP.

5-16. Other Inland Water Reference Systems

Controlled portions of the Mississippi are referred to pool levels between the controlling structures. Although a variety of reference datums are used on other controlled river systems or impoundment reservoirs, most are hydraulically based and relate to some statistical pool level (e.g., "normal pool level," "flat pool level," "minimum regulated pool level," etc.).

a. On the Mississippi River above Melvin Price Locks and Dam at Alton, IL, to Lock and Dam No. 22 at Saverton, MO, (Figure 5-19) the reference used is related to the minimum regulated pool elevation. These pools are regulated referenced to a "hinge point." The pools are drawn down when the river's flow will provide adequate navigation depths naturally. When the flows are reduced to low volumes, the pools are reestablished and are essentially level. The depths and improvements along this reach of the Mississippi River are referenced to the "minimum regulated pool" elevations.

b. On the Mississippi River above Lock and Dam No. 22 at Saverton, MO, to St. Paul, MN, a "flat pool level" reference is used, and soundings are shown as "depth below flat pool." The flat pool is the authorized elevation of the navigation project and can be referenced to any number of local datums. Most commonly, this level is referenced to the mean sea level (MSL) datum of 1912, the general adjustment which preceded 1929. Conversions between MSL 1912 and NGVD 29 are available. The Illinois Waterway pool elevations (Figure 5-20) are referred to NGVD 29; however, relationships to numerous other datums are also made.

c. Vertical clearances (bridges, transmission lines, etc.) are usually measured relative to high and low waters of record, or relative to full pool elevations. Shore lines shown on river drawings and navigation maps may be referenced to a low water datum (i.e., LWRP). On the Mississippi River above Lock and Dam No. 22 at Saverton, MO, the plotted shore line is referenced to full pool stage at dams with discharges equaled or exceeded 90 percent of the time. Given the variety of reference levels, special care must be taken to properly identify the nature and source of all vertical reference datums used on a project.

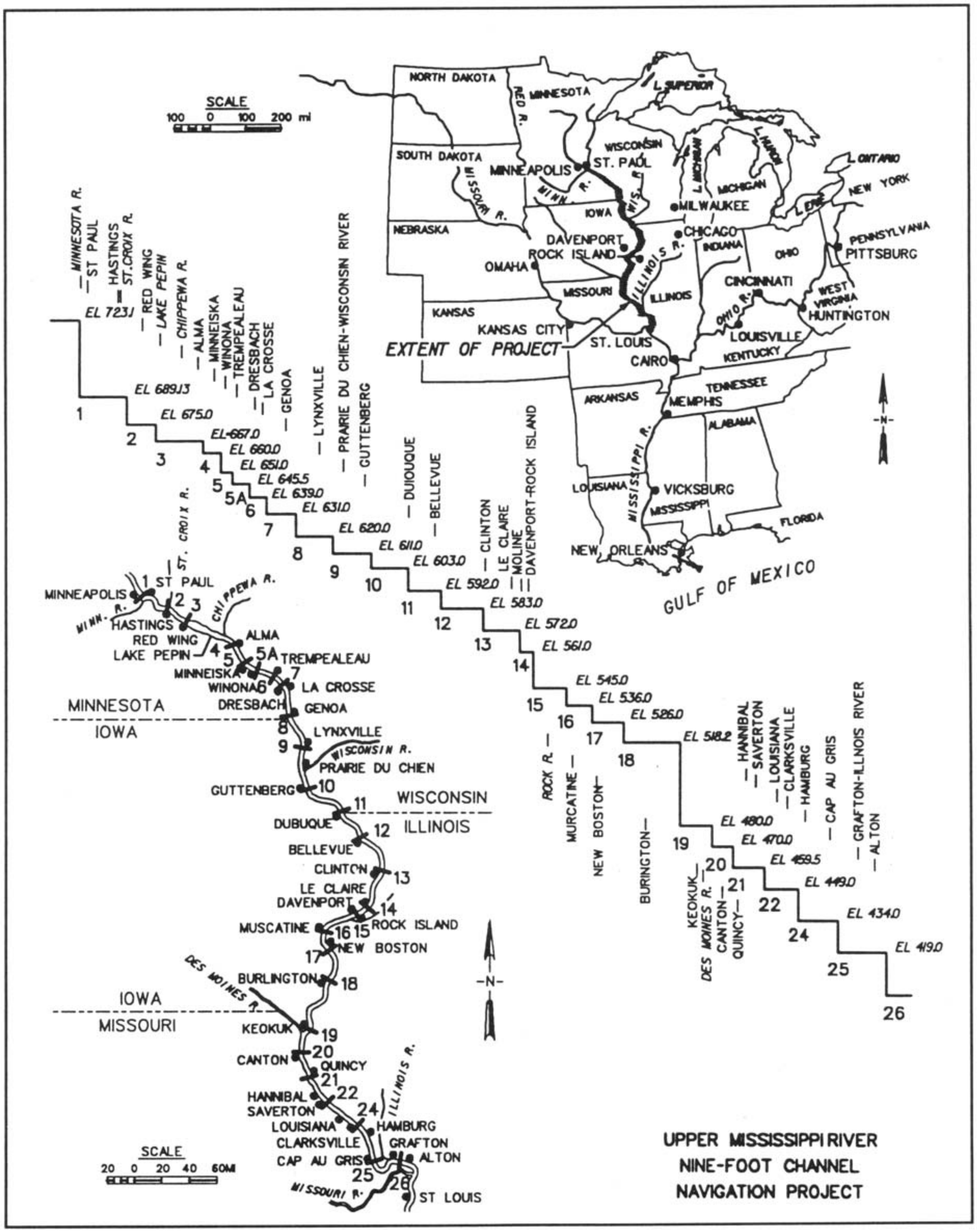


Figure 5-19. Upper Mississippi River reference systems

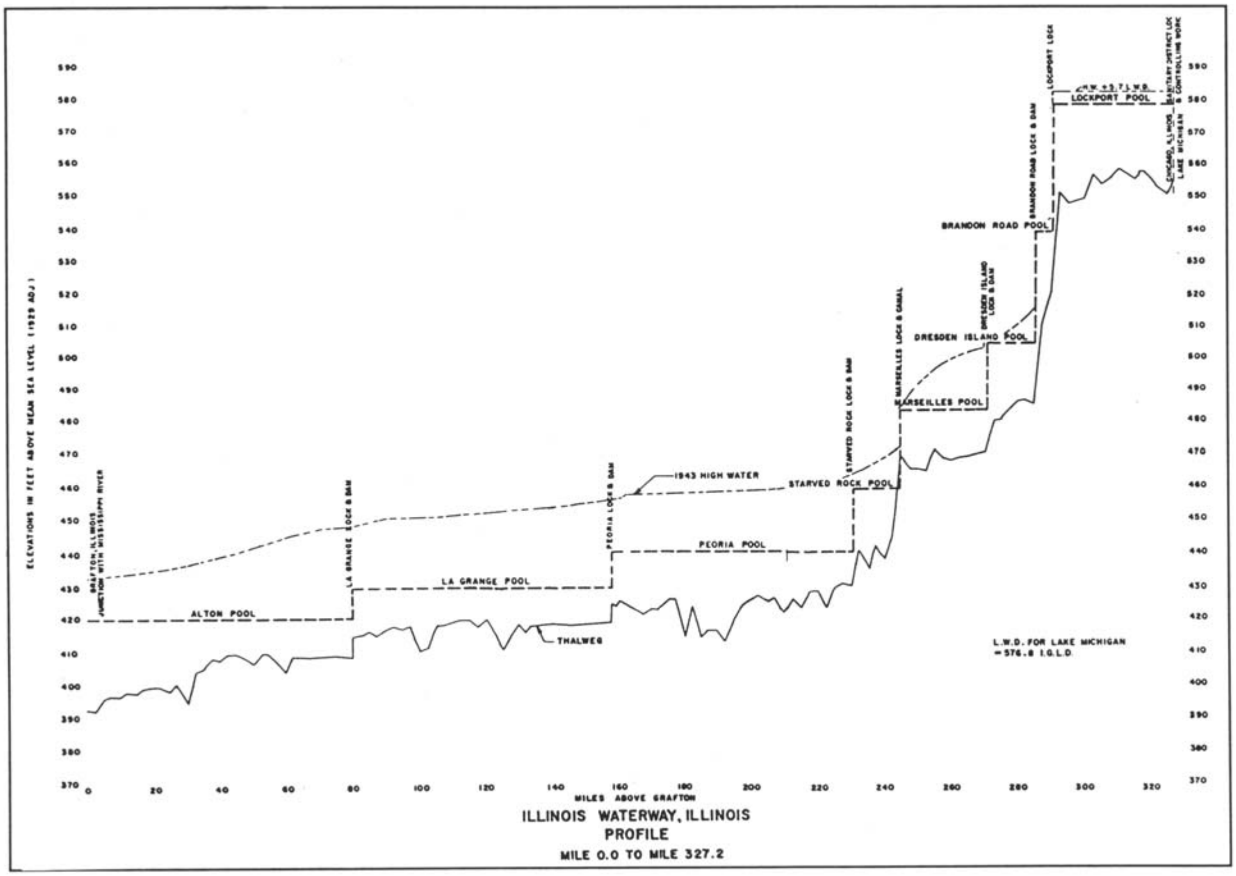


Figure 5-20. Illinois Waterway Profiles -- Mile 0.0 to Mile 327.2

5-17. Tides and Water Level Stage Measurement Systems--Reference Gage Location

Criteria for each survey class are given in Table 5-4. The vertical reference benchmark and/or staff should be located as close to the work area as possible to minimize the effects of tidal phase lags and range differences (or river slopes) which may exist between the staff site and the project area. The possibility of a wind setup may be minimized by working during low wind velocity conditions (less than 15 knots). The staff should be located on the same body of water as the project area (e.g., do not observe tides on intracoastal waterways for work offshore). The same benchmark/staff should be used for all surveys associated with a project. Vicinity sketches should be maintained in project records indicating the precise gage location in relation to surrounding features. To assist in reestablishment of the datums used, a minimum of three tidal benchmarks should be set or chosen within 500 ft of the gage and, by leveling, their elevation above the tide datum determined. Descriptions of each benchmark are to be written in accordance with EM 1110-1-1002.

5-18. Tidal Zoning

Tidal zoning is the practice of dividing a hydrographic survey area into discrete zones or sections, each one possessing similar tidal characteristics. One set of tide reducers is assigned to each zone. Tide reducers are used to adjust the soundings in that zone to chart datum (MLLW). Tidal zoning is necessary to correct for differing water level heights occurring throughout the survey area at any given time. Each zone of the survey is geographically delineated such that the differences in time and range do not exceed certain limits, generally 0.2 hr and 0.2 ft respectively; however, these limits could change depending upon the type of survey, location, and tidal characteristics. The tide reducers are derived from the water levels recorded at an appropriate tide station, usually nearby. Tide reducers are used to correct the soundings throughout the hydrographic survey area to a common, uniform, uninterrupted chart datum. On large bays, tide gage zoning should be used to find the correct water elevation at the vessel. Tidal zonings, as developed by the NOS, are used where there is a difference in water level slope and/or time of tidal phase between the tide gage and survey sites. For many surveying requirements in these areas, it is impractical and cost-prohibitive to actively maintain tide gages close to the survey site, making the use of tidal zonings advantageous. Figure 5-21 shows a tidal zoning model for Chesapeake Bay. Table 5-3 lists corrections for the model at the Cape Henry Channel location relative to the southern-most tide gage on the southerly end of the Chesapeake Bay Bridge Tunnel. Note that all the time corrections are negative. This is because the entire Cape Henry Channel is east of the gage toward the Atlantic Ocean.

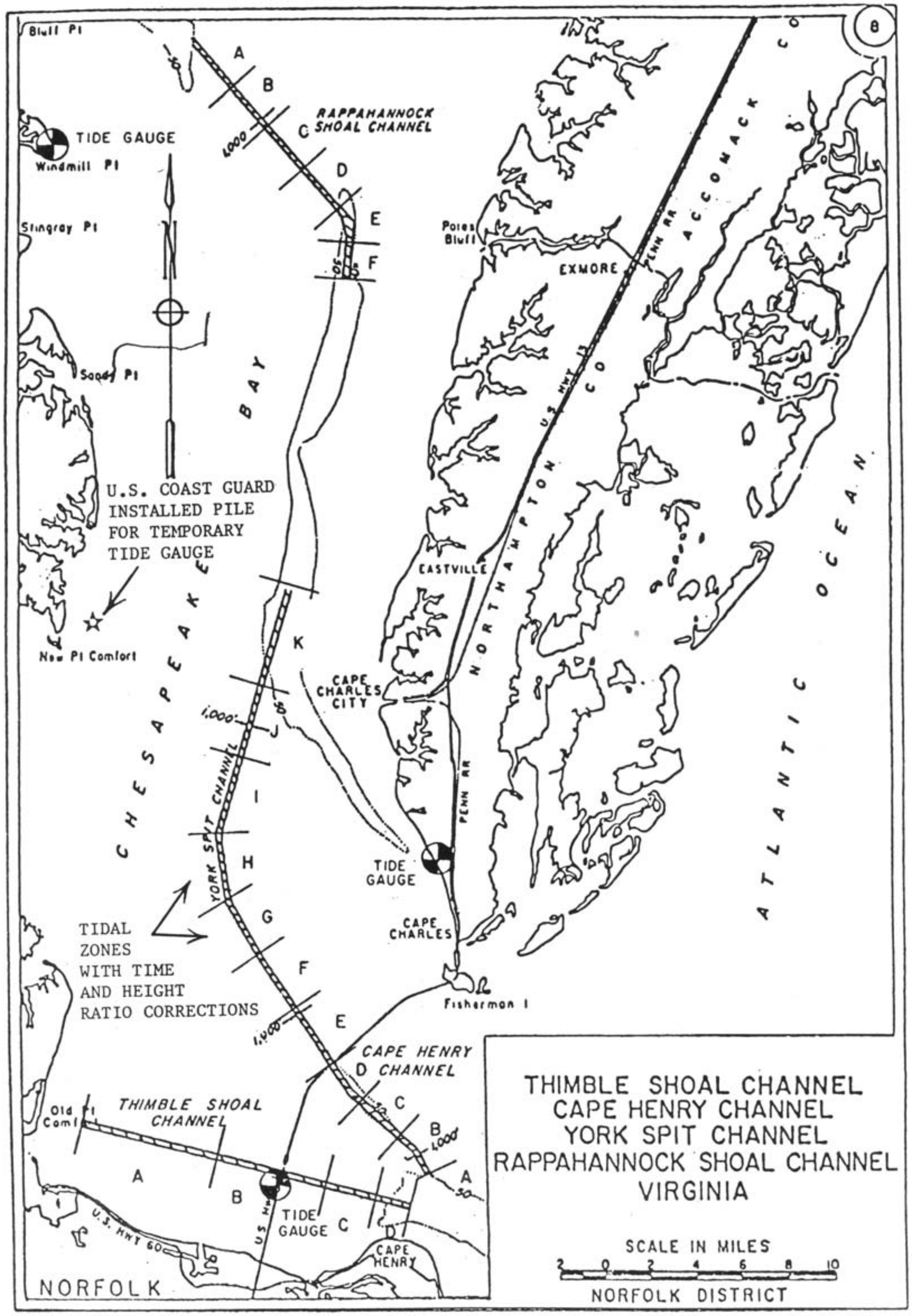


Figure 5-21. Chesapeake Bay tidal zones

Table 5-3. Cape Henry Channel Tidal Zoning
Tide Correction Factors Based on Chesapeake Bay Bridge Tunnel Gage
10 July 1991

Zones	Station to Station	Time of Occurrence	Height Ratio
A	-20+00 to +20+00	-23 min high water -17 min mean -11 min low water	x 1.21
B	+21+01 to +133+00	-17 min high water -13 min mean -09 min low water	x 1.15
C	+133+01 to +239+73	-11 min high water -9.5 min mean -08 min low water	x 1.08
D	+239+74 to +332+86	Direct on CBBT gage " "	N/A

Example of tidal zoning correction for tidal zone B:

Channel Station 100+00 **Time 1000 EST**

Tide stage occurs 13 minutes (on average) later at CBBT tide gage … i.e., 1013 EST

Gage reading at 1013 EST:	+2.00 ft above MLLW
height ratio:	x1.15
Gage reading corrected for time and height to be applies to the 1000 EST sounding	+ 2.30 ft above MLLW

Table 5-4.
Tides and Water Levels Measurement Criteria

Criteria	Minimum Standard per Survey Class		
	Hard Material	Soft Material	Other Surveys
Gage/Staff Location (1)	On-Site	On-Site	Near-Site
Tidal Zoning Requirements	Determine on Case-by-Case Basis		Not Required
Gage Reading Frequency	As needed for 0.1-ft surface change		
Leveling Frequency -- Gage to Benchmarks (3rd Order Levels -- 2 BM's Required) per Project	Start & Finish of Project		Project Start Only
Start/Finish Difference in Gage Reference Elevation	0.05 ft	0.1 ft	n/a
Staff Marking Intervals	0.1 ft		
Least Count of Readings	0.1 ft		
Stilling Wells Required if Sea States Exceed	0.5 ft	1.0 ft	2.0 ft

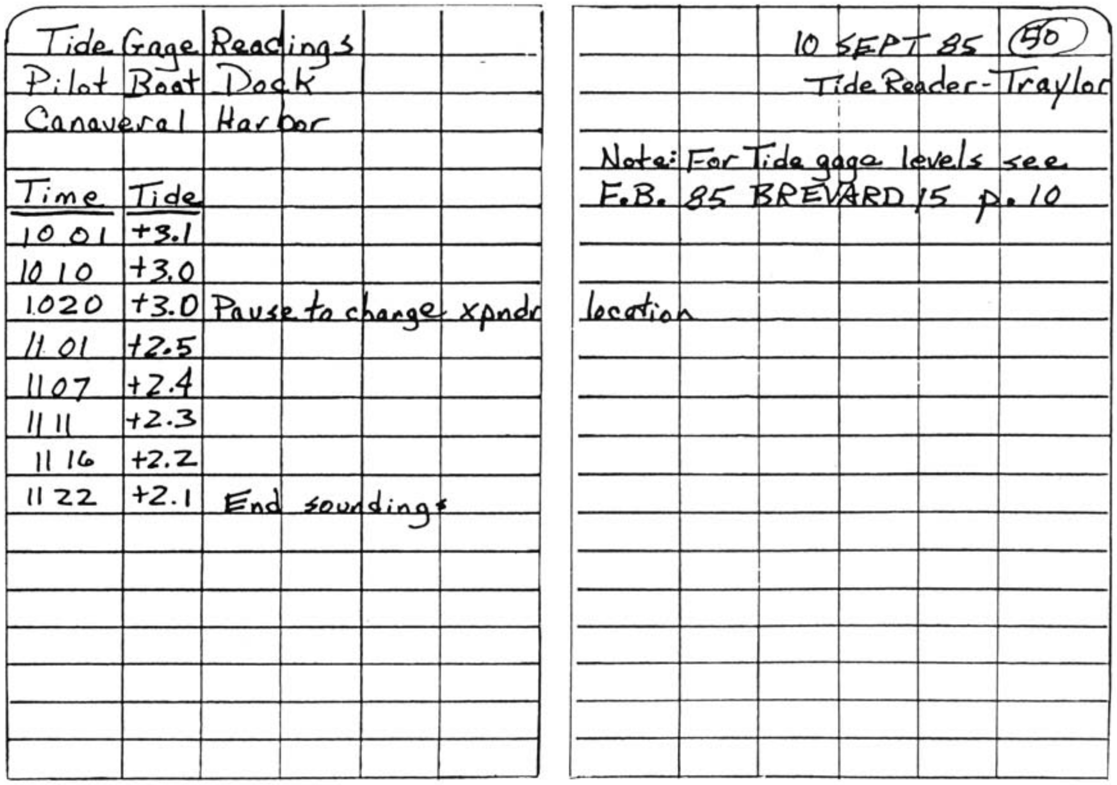
(1) An on-site gage for "Hard Material" is defined as a location relative to the project area such that not more than a 0.1-ft surface gradient exists between the two sites. Slopes of 0.3 and 0.8 ft are allowable for "Soft Material" and "Other Survey" gages, respectively. Tidal or surface gradient zoning is required if these criteria cannot be met.

5-19. Gage Reading Intervals

During the course of a survey, gage readings shall be recorded in either standard field books, forms, or automated printouts--see Figure 5-22.

a. Tidal. For each survey class, gage readings will be taken at intervals equal to or shorter than those indicated. Readings at proper intervals will ensure a correct determination of the actual tidal curve. Because certain reduction computations use only high and low readings, care should be taken near the time of high or low water to take accurate readings.

b. Inland. The slope or gradient of the water surface along inland streams and rivers is constantly varying. Water surface determinations should be made daily at 1-mile intervals or less. For more critical navigation and dredging surveys, determinations shall be made a minimum of twice daily at intervals not exceeding 0.5 mile, except near major stabilization or improvement structures where water surface determination should be made immediately upstream and downstream of the structure. The water surface should be computed for each section by a method similar to that previously described.



Tide Gage Readings
Pilot Boat Dock
Canaveral Harbor

10 SEPT 85 (50)
Tide Reader-Traylor

Note: For Tide gage levels see F.B. 85 BREVARD 15 p. 10

Time	Tide	
10 01	+3.1	
10 10	+3.0	
1020	+3.0	Pause to change xpndr location
11 01	+2.5	
1107	+2.4	
1111	+2.3	
11 16	+2.2	
11 22	+2.1	End soundings

Figure 5-22. Tide gage/staff readings recorded in a surveyor's field book

5-20. Leveling Frequency

On major coastal projects, leveling from at least two tidal benchmarks to the gage (or staff) should be performed at the beginning and end of a project. USACE 3rd order standards should be followed for all differential leveling work. The tidal benchmarks which reference the tide staff should be connected with at least two firmly established benchmarks, preferably USC&GS/NOS marks, on NAVD 88 where possible and NGVD 29 where the appropriate data for NAVD 88 is not available. This is critical since the entire project will be referenced to the established datum at that point. Any oddities or anomalies in the vertical datum should be investigated. All subsequent surveys should utilize the same benchmark. When temporary staffs are set for short duration surveys, they should be periodically checked for movement, especially if the staff is situated in an unstable location. A temporary benchmark (TBM) should be set adjacent to the gage/staff to facilitate this checking process. On stable river surfaces, lakes, or reservoirs, the surface elevation may be obtained from a level rod shot to the surface each day. In such stable mediums, a staff or gage would not be necessary. Staffs or water level/tide gages may be set to directly read on the local low water reference datum, project datum, or at any arbitrary level (Figure 5-23). Setting staffs/gages to read directly on the local datum helps to preclude conversion blunders.

5-21. Start/Finish Difference in Gage Elevation

Gage leveling should be performed before and after a payment survey project, and the measured gage elevation should be within prescribed limits to ensure that the gage has not been disturbed or settled.

5-22. Staff Markings/Least Count of Readings

All gages/staffs are to be marked to 0.1 ft, and readings are to be expressed to the nearest 0.1 ft. This precision will ensure the required accuracy in reduction computations. However, if prevailing conditions permit reading to 0.01 ft, this should be done to improve accuracy. Unit markings will be dependent on whether the gage is set to an absolute or reference datum.

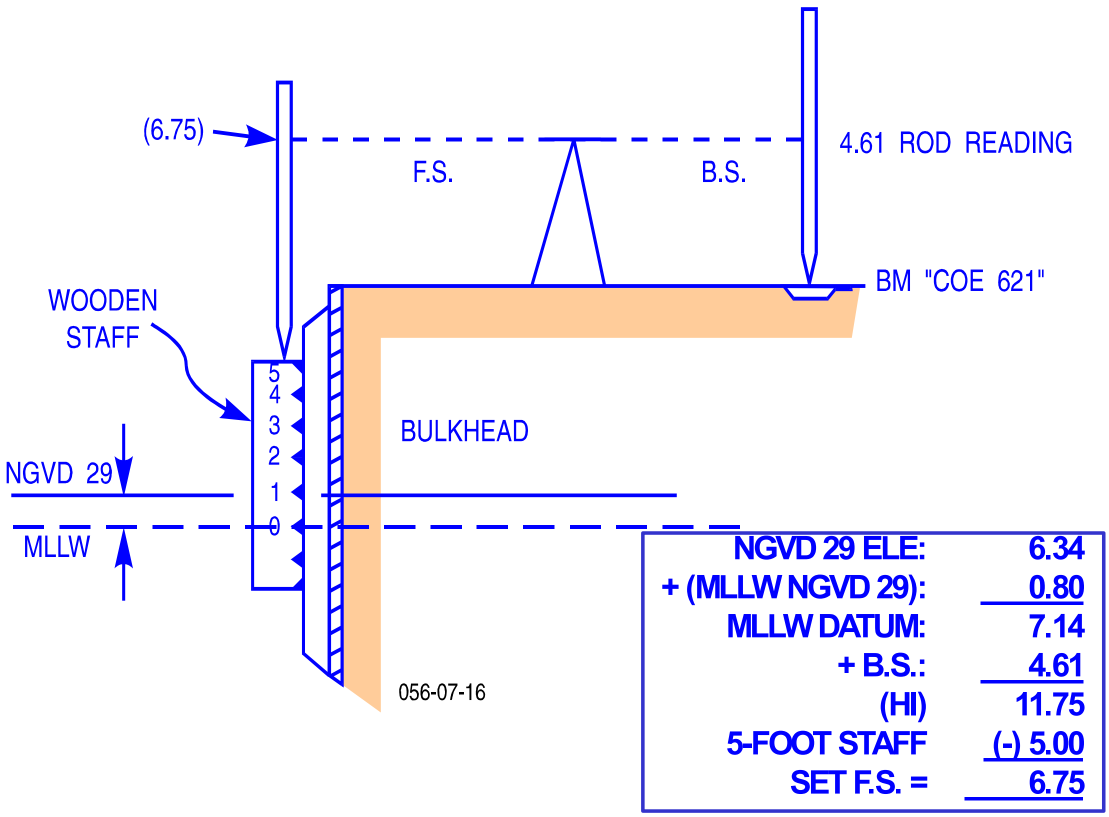


Figure 5-23. Procedure for setting a staff gage relative to a construction datum plane

5-23. Stilling Procedures

Water surface fluctuations at a gage should be stilled so that the maximum range of water rise and fall with one wave passage is negligible. Stilling well construction ranges from the very simple Plexiglas tube to a more complex float system in a PVC tube. Electronic filters are also used to still the surface fluctuations. The orifice for water entry should be located near the well's bottom and at least three multiples of wave height below the surface . The opening's size should be regulated to permit adequate movement of water into or out of the well for long-term tide changes but to prohibit a significant water exchange during passage of a wave crest or trough. On some offshore gages, the stilling well itself is used to support the gage platform.

5-24. Mandatory Requirements

The criteria in Table 5-1 and Table 5-4, including supplemental explanatory paragraphs, are considered mandatory.