CHAPTER 6

Procedures for Referencing Datums on Inland Flood Risk Management, Water Control, and Navigation Projects

6-1. Purpose. This chapter provides guidance for referencing project elevation grades on various inland flood risk management, water control, and navigation projects. Inland projects are defined as those with minimal or no tidal influence—their reference datums are defined relative to (1) modeled or measured hydraulic flows in rivers, (2) pool elevations in controlled reservoirs or between locks and/or dams, or (3) established reservoir and inland lake low water datums. This chapter outlines the field survey procedures needed to ensure these projects and their reference water level gages are adequately connected to the National Spatial Reference System (NSRS) orthometric datum established by the Department of Commerce.

6-2. Reference Grades on Inland Flood Risk Management and Water Control Projects. The relationship between geodetic and hydraulic datums on inland projects was outlined in Chapter 1 (Figures 1-2 and 1-3). In these figures, the relationships between the river stage, local gage, and terrestrial geodetic elevation(s) must be determined for each project. On river systems, these relationships are not constant, and vary spatially with the slope of the low water reference plane, design flood elevation, and geodetic datum readjustments. This relationship must be firmly established—either from direct river gage connections or from modeled hydraulic interpolations between gages.

a. Water surface elevation references. (See Chapter 2). The water surface elevation, or stage, is typically referred to a hydraulically based reference plane: e.g., Low Water Reference Plane (LWRP) in open flow rivers, or, in controlled areas, Project Pool, Low Water Pool, Normal Pool, Ordinary High Water Profile (OHWP), etc. The local river or pool gage may have its own reference datum from which flood stages are defined. The height of a levee or other water control structure is designed relative to predicted flood stage elevations on the river, along with other related design factors.

b. Flood protection or water control structure elevations. The reported elevation at the top of a floodwall, levee, or dam may have elevations based on more than one reference datum. The two minimum required reference elevations must include:

(1) Orthometric elevation directly referenced to current NSRS (NAVD88).

(2) Hydraulic elevation referenced to a defined reference plane (LWRP, pool, gage zero, etc.).

c. Other optional elevation references may include:

(1) Flood stage height reference.

(2) Ellipsoid height—based on local NSRS geoid model—useful for performing RTK topo surveys.

(3) Base Flood Elevation (BFE) reference—from local studies or models.

(4) NGVD29 elevation—usually based on older reference monuments or as-built drawings.

(5) Local USACE legacy datums—e.g., Cairo Datum, Sea Level Datum, MSL 1912.

d. Elevation uncertainties. Figure 1-2 in Chapter 1 illustrated the uncertainties in vertical datums on an inland flood risk management project. Each reference datum listed above has some statistical uncertainty level that must be considered in protection reliability, risk assessment models, and levee/floodwall certification. These datum uncertainties must be estimated for each project. NSRS (NAVD88) regional relative accuracy estimates may be obtained from NGS observation adjustment statistics. These NSRS uncertainties propagate down to local project control point (LPCP) elevations and then to topographic surveys of project grades. Methods for estimating the propagated uncertainties of elevation grades are described in Chapter 9. The accuracy of local hydraulic stage/flowlines may be more difficult to estimate—see Section 6-4. Pool or reservoir stage elevations (and local low water datums) are usually well defined based on long-term gage data. Legacy datum references (e.g., NGVD29) may have highly uncertain accuracies and origins.

e. River gage NSRS (NAVD88) elevation connection requirements. Figure 6-1 depicts a river gage connection to a floodwall cap elevation—shown here to a PBM set atop the wall. In this example, a river gage on LWRP or pool datum is connected with the regional NAVD88 network; thus providing an external (i.e., ellipsoidal and orthometric) reference for the gage, along with the LWRP or pool hydraulic profile reference for the floodwall cap. The relationship between the orthometric height, ellipsoidal height, geoid height, and the hydraulic elevation is shown.

(1) In the top part of Figure 6-1, a level run from the gage reference point (20.0 ft) established an elevation on the top of the I-wall at 40.35 ft (LWRP).

(2) In the lower part of Figure 6-1, differential GPS observations measured an ellipsoid height of 278.02 ft at the PBM atop floodwall. Given a published geoid height of (-) 94.03 ft for this area, the orthometric NAVD88 elevation of 372.05 ft is determined using the relationships outlined in Chapter 2.

(3) The NGVD29 elevation shown in Figure 6-1 (371.76 ft) is based on a modeled (VERTCON or CORPSCON) difference of 0.29 ft from NAVD88. This modeled relationship may be accurate to only ± 0.5 ft, depending on many factors. Legacy or local datums maintained on floodwalls, such as NGVD29, should always be caveated with appropriate metadata, to include estimated age, reliability, and accuracy.

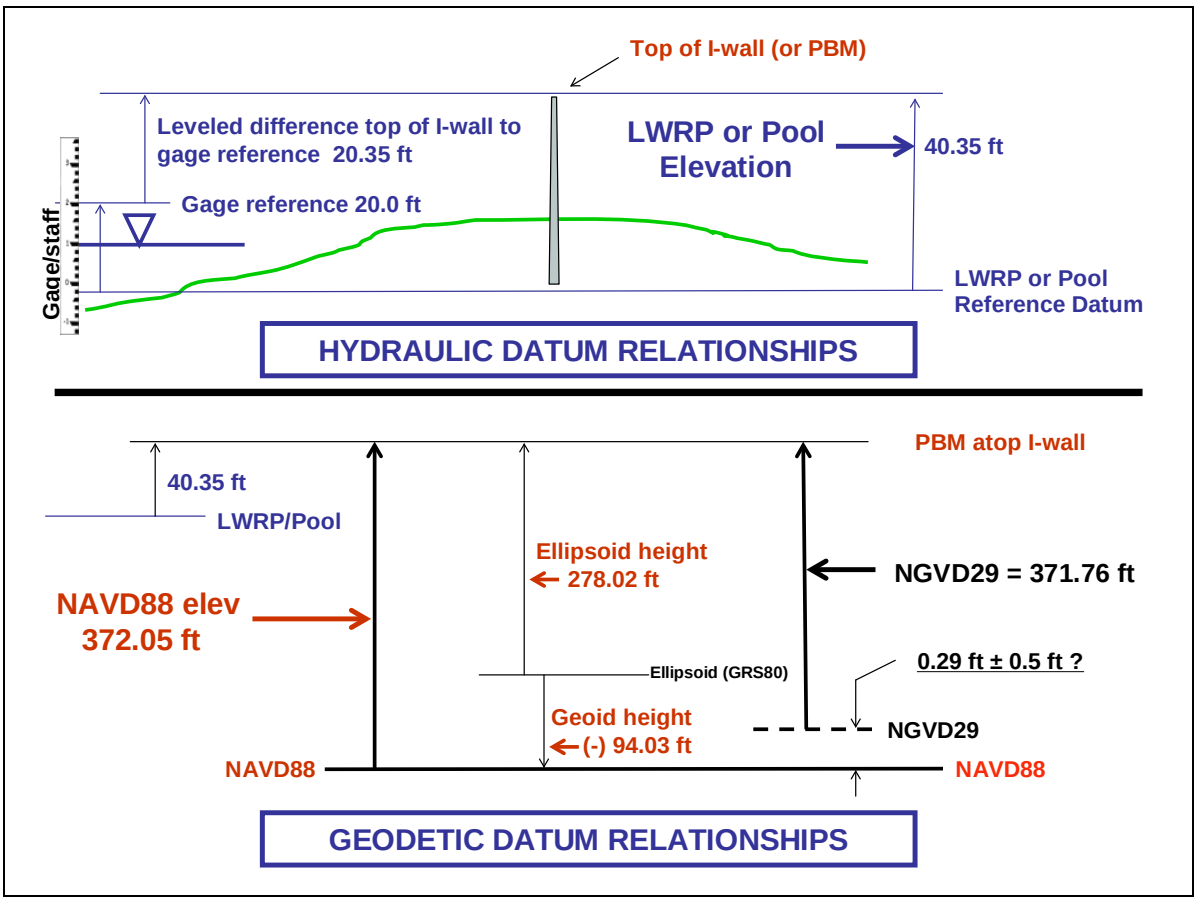

Figure 6-1. Orthometric height and hydraulic reference datum relationships on a floodwall.

6-3. Procedures for Connecting Inland River, Pool, or Reservoir Gages to the National Spatial Reference System. Inland river gages that are used to reference and model USACE floodwall design elevations should be firmly referenced to NAVD88, and be included within the NSRS. This is intended to insure these gages are on the same regional (nationwide) vertical datum used for hydrologic and hydraulic studies performed by USACE and other agencies. Gages referenced to unknown, legacy, or superseded datums (e.g., MSL 1912, NGVD29) must also be referenced to NAVD88.

a. Reference bench marks at river gages. A minimum of three bench marks shall be established around a river gage that is used to reference flood protection elevations on nearby levees or floodwall systems. Only one of these reference points needs to be connected to and published in the NSRS, using either CORS baseline observations, differential levels, or DGPS baseline observations (e.g., static or fast/rapid static methods). The remaining river gage bench marks and the gage zero reference can be surveyed using Third-Order differential leveling methods from the primary bench mark. Data for the gage's primary reference mark (PPCP) shall be incorporated into the NSRS database.

b. Reference bench mark descriptions—periodic inspections. The description for the gage's reference bench mark must contain, in addition to the standard location data, full metadata associated with that bench mark and its nearby river gage. For example:

Bench Mark:	*USED RIVER GAGE 12345 1955*
River Gage:	*[River gage name/file designation]*
Elevation:	*419.63 ft NAVD88 ± 0.22 ft [2008 03 21 adjustment]*
Elevation:	*40.35 ft above LWRP 20XX [2008 03 21]*
Elevation:	*20.35 above river gage zero reference [2008 03 21]*
Elevation:	*3.38 ft above 12345 RM 1 [2008 03 21]*
Elevation:	*0.97 ft below 12345 RM 2 [2008 03 21]*
Position:	*[SPCS X & Y location/accuracy/date]*
Source:	*[specify NGS "PID" and District file number]*

Subsequent bench mark "Recovery Notes" made at periodic (e.g., semi-annual, annual, biannual) gage inspections should also update the gage reference and adjacent reference bench mark connections. The NSRS datasheet in Figure 6-2 contains a simulated example of an inspection recovery note made for a reference bench mark at a river gage. The last gage inspection in 2009 noted that levels were run between the gage and reference bench marks. The results and differences from the 2008 elevations are included on the description. This example utilizes the NSRS for recording gage inspection recoveries in that the reference bench mark is published. Other documentation formats for gage inspections may also be used—e.g., U-SMART (see Chapter 3). An example U-SMART description for an inflow gage in Pittsburgh District is shown in Appendix H.

```
XX999  DESIGNATION -  CEMVS GAGE 12345 RM 1
XX999  PID         -  XX999
XX999  STATE/COUNTY-  MO/C OF ST LOUIS
XX999  USGS QUAD   -  GRANITE CITY (1998)
XX999                        *CURRENT SURVEY CONTROL
XX999  ____________________________________________________________________
XX999* NAD 83(1986)-  38 00 00.     (N)    090 00 00.     (W)     OPUS
XX999* NAVD 88     -       127.903  (meters)     419.63   (feet)  ADJUSTED
XX999  ____________________________________________________________________
XX999  GEOID HEIGHT-         -31.08  (meters)                     GEOID03
XX999  DYNAMIC HT  -         127.821 (meters)     419.36  (feet)  COMP
XX999  MODELED GRAV-     979,991.3   (mgal)                       NAVD 88
XX999  VERT ORDER  -  FIRST     CLASS II

XX999                          STATION DESCRIPTION  (2008)

XX999'DESCRIBED BY USAED ST LOUIS 2008 03 21 (R MESKO)
XX999'IN ST LOUIS, 1.35 KILOMETERS (0.85 MILE) SOUTH ALONG THE FLOOD WALL OF
XX999'THE MISSISSIPPI RIVER FROM THE GOLDEN ARCH BRIDGE OVER THE RIVER, SET
XX999'VERTICALLY IN THE EAST END OF THE ONLY LARGE SOLID PIER OF A RAILROAD
XX999'OVERPASS THAT LEADS WEST OVER THE TRACKS THAT PARALLEL THE FLOOD WALL,
XX999'AND 19.21 METERS (63.0 FEET) WEST OF THE WEST FACE OF THE FLOOD WALL.
XX999'THE MARK IS THE PRIMARY REFERENCE POINT FOR COE RIVER GAGE NO. 12345
XX999'WHICH IS APPROX 30 FT NORTH OF THE MARK.
XX999'THE MARK IS 1.04 METERS N FROM A WITNESS POST.
XX999'THE MARK IS 1.12 M ABOVE GROUND.
XX999'RIVER GAGE NO 12345 LEVELING REFERENCES RUN 2008 03 21
XX999'THE MARK IS 20.35 FT ABOVE THE ZERO GAGE REFERENCE POINT
XX999'THE MARK IS 40.35 FT ABOVE LWRPXX
XX999'THE MARK IS 3.38 FT ABOVE 12345 RM 2, A COE DISC LOCATED ON THE
XX999'FLOODWALL 45.6 FT NORTH.
XX999'THE MARK IS 0.97 FT BELOW 12345 RM 3, A COE DISC LOCATED ON THE
XX999'FLOODWALL 89.4 FT SOUTH.

XX999                          STATION RECOVERY (2009)

XX999'RECOVERY NOTE BY USAED ST LOUIS 2009 06 05 (R MESKO)
XX999'RECOVERED MARK AND RM1 AND RM2 IN GOOD CONDITION, AS DESCRIBED.
XX999'RELEVELING RESULTS FROM 2009 06 05 GAGE INSPECTION:
XX999'THE MARK IS 20.34 FT ABOVE THE ZERO GAGE REFERENCE POINT
XX999'THE MARK IS 40.34 FT ABOVE LWRPXX
XX999'THE MARK IS 3.39 FT ABOVE 12345 RM 2, A COE DISC LOCATED ON THE
XX999'FLOODWALL 45.6 FT NORTH.
XX999'THE MARK IS 0.97 FT BELOW 12345 RM 3, A COE DISC LOCATED ON THE
XX999'FLOODWALL 89.4 FT SOUTH.
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Figure 6-2. Simulated NSRS datasheet with gage inspection recovery notes.

6-4. Elevation Accuracy Requirements at Reference Gages.

a. Hydrological and hydraulic accuracy requirements. In order to best define the governing accuracy standard required for connecting primary project control monuments to the regional NSRS, it is necessary to understand the hydraulic engineering requirements and applications for such connections. River, pool, or reservoir gages normally have highly accurate local datums—i.e., at the gage itself. However, the absolute vertical relationship between adjacent gages is often uncertain, as was illustrated in Figure 1-2. For example, two river gages separated by 20 miles may have been referenced to orthometric datums 50 years ago—e.g., SLD29 or NGVD29. Surveys were never performed directly connecting the reference bench marks at these gages. The uncertainty between the connections could exceed 0.5 ft or more—see "*Mapping the Zone: Improving Flood Map Accuracy*" (NRC 2009). Calculated water surface profiles could also vary by as much as foot or more, depending on numerous factors. These uncertainties and variations need to be considered in defining relative NSRS accuracy requirements for reference bench marks at a gage. The following excerpt from NRC 2009 illustrates the considerations needed in determining the NSRS accuracy requirements for adjacent river gages:

> "*... frequency analysis of stage height is not the same thing as frequency analysis of base flood elevation because the BFE is defined relative to an orthometric datum [NAVD88] ... and the stage height is defined relative to an arbitrary gage elevation datum. However, it is not necessary to reconcile these datums because what we are seeking is not the elevation itself, but rather the uncertainty of the elevation. The difference between the stage height and the flood elevation is the fixed datum height that is the same for all measurements and thus does not affect their variations from year to year*."

The nominal ± 0.25 ft relative accuracy standard in Table 3-1 is believed to be adequate for most USACE projects; fully considering hydraulic design models, design criteria, construction tolerances, and other federal and state agency accuracy requirements.

b. Accuracy estimates. Region-wide hydraulic accuracy requirements can also be estimated using the guidance in "*Accuracy of Computed Water Surface Profiles*" (HEC 1986). This study assessed the survey accuracy required to achieve desired profile accuracies, as illustrated in Table 6-1.

Table 6-1. Survey Accuracy Requirements[1] for Specified Profile Accuracies. (HEC 1986)

		Manning's n-value reliability $N_r = 0$		Manning's n-value reliability $N_r = 1$	
Stream Slope (ft/mile)	Profile Accuracy Emean [2] (ft)	Aerial Survey Contour Interval	Topo Map Contour Interval	Aerial Survey Contour Interval	Topo Map Contour Interval
1	0.1	10 ft	n/a	n/a	n/a
1	0.5	10 ft	5 ft	n/a	n/a
1	1.0	> 10 ft	10 ft	10 ft	2 ft
1	1.5	> 10 ft	10 ft	10 ft	5 ft
1	2.0	> 10 ft	10 ft	>10 ft	10 ft
10	0.1	2 ft	n/a	n/a	n/a
10	0.5	10 ft	5 ft	n/a	n/a
10	1.0	10 ft	5 ft	10 ft	n/a
10	1.5	> 10 ft	10 ft	10 ft	2 ft
10	2.0	> 10 ft	10 ft	10 ft	5 ft
30	0.1	2 ft	n/a	n/a	n/a
30	0.5	10 ft	2 ft	n/a	n/a
30	1.0	10 ft	5 ft	10 ft	n/a
30	1.5	> 10 ft	10 ft	10 ft	2 ft
30	2.0	> 10 ft	10 ft	10 ft	5 ft

[1] Denotes maximum survey contour interval to produce desired survey accuracy
[2] Emean is "mean absolute reach error"

c. From Table 6-1, given the allowable error in a water surface profile, and considering other hydraulic factors, the required accuracy of topographic data (e.g., stream cross-sections) can be estimated. Topographic survey accuracies in this older publication are defined relative to a National Map Accuracy Standard (NMAS) contour interval parameter. These can be converted to NSSDA 95% confidence standards. HEC 1986 should be reviewed in order to appreciate the impact (or often lack thereof) of survey accuracy on computed water surface profiles. For example, if a hydrological or hydraulic water surface profile model is sensitive to cross-sectional accuracy at the ± 2 ft (NSRS) level, there would then be no point in requiring control points for these sections to be accurate to the ± 0.1 ft (NSRS) level.

d. Regional gage accuracy for levees and related flood protection projects. The Bois Brule Levee and Drainage District in St. Louis District represents a typical main-stem Mississippi

River levee system (see Appendix I). On this levee segment the river slope drops approximately 13 ft over a 12-mile reach. Given the magnitude of the elevation change over this 12-mile distance, the design levee grades between each end of the system would not need a high level of accuracy relative to the NSRS. A ± 0.25 ft to ± 0.5 ft relative accuracy between the northerly and southerly limits would be adequate for most engineering purposes. These levels of accuracy can be easily achieved with static DGPS, CORS/OPUS, or conventional differential leveling methods.

e. Gage accuracy requirements in low gradient areas. Many floodplain areas with minimal water surface gradients will require more accurate elevation connections with the NSRS in order to measure flow or inundation conditions. An example is the Jacksonville District's Central and Southern Florida (C&SF) project that contains a vast network of levees, canals, control gates, pump stations, and other control structures throughout southern Florida; including portions of the Everglades. In some cases, elevation differences over a few miles may be only 0.2 ft. To provide a consistent geodetic reference framework for this project, the USACE and NGS performed high accuracy "height modernization" control surveys at hundreds of PBMs throughout the region. These geodetic surveys included a network of static GPS baselines and high-order differential leveling. Geodetic survey standards followed NGS specifications and resultant "PPCP" data were adjusted and published by the NGS—see "*Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)*" (NOAA 1997) and "*Guidelines for Establishing GPS Derived Orthometric Heights (Standards: 2 cm and 5 cm) version 1.4* " (NOAA 2005). These NSRS PPCPs were subsequently used to establish LPCP elevations near gages and pump stations.

6-5. Levee System Connections to the NSRS. The following guidelines are recommended procedures to establish PPCPs suitable for defining project elevations relative to the NSRS. They are based on the nominal target accuracy standard of ± 0.25 ft relative to the published NSRS. Field survey methods for performing the connections were covered in Chapter 3. These guidelines are also applicable to other water control and inland navigation projects covered in this chapter.

a. General PPCP requirements. Each levee project or segment should have at least one PPCP that has been connected to the NSRS. On large levee projects, PPCPs should be spaced between 15 to 20 mile intervals. This recommended spacing is dependent on local RTK or RTN capabilities, district survey standards, and the distance from the PPCP to the levee. In general, the PPCP should be located relatively close to the project in order to establish supplemental LPCP connections using GPS static or rapid static baseline methods—see Figure 6-3. If the project is covered by an RTN, then a less dense network of PPCPs will be required for RTN site calibration. When multiple PPCPs are established on a levee segment, it is recommended that these PPCPs be interconnected with static GPS baseline observations, along with observed baselines to nearby CORS points.

b. Supplemental LPCPs. LPCPs on a levee segment are connected with the PPCPs using the various survey methods described in Chapter 3. The density of LPCPs is site dependent. In general, static or RTK techniques are most efficient to perform this connection. Descriptions for these points should be included in a district project control database (e.g., U-SMART) for

permanent retention. The NSRS elevations determined for these LPCPs should not supersede local construction or legacy elevations—see Chapter 3.

c. Water level gage connections. Reference PPCP bench marks need to be set near each water level gage associated with a levee system or water control project. These gage reference marks will be designated as “Primary Project Control Points" and will be connected to the NSRS using any of the methods covered in Chapter 3. Level ties between the gage reference PBMs are also required and elevation differences and associated metadata should be included in the NSRS bench mark description or the U-SMART database system.

d. Bench mark construction. Bench mark construction for new PPCPs and LPCPs points will follow the guidance in EM 1110-1-1002 (*Survey Markers and Monumentation*). Type C (USACE disk set in existing concrete structure) marks are recommended. Type F and Type G marks (disk attached to shallow rod or rebar), or other suitable type marks/monuments, are also acceptable as bench marks. Geodetic survey quality deep-driven mark stability is not required. At least three reference bench marks are required at each gage.

e. Summary of PPCP and LPCP connections. Figure 6-3 summarizes the general NSRS connection requirements for PPCP control on a levee segment. PPCP elevations were established by GPS or leveling observations to surrounding NSRS bench marks. LPCP connections with the PPCPs are also indicated. Topographic site plan surveys would be performed relative to the nearest LPCPs on the levee.

f. Application projects. The following appendices contain examples of USACE inland projects that have been connected to the NSRS.

(1) Appendix H. East Branch Clarion River Dam and Spillway Control Surveys (Pittsburgh District),

(2) Appendix J. Establishing NSRS Elevations on 15 Dam and Reservoir Projects in Pittsburgh District.

(3) Appendix I. St. Louis District: Control Surveys--Bois Brule Levee and Drainage District.

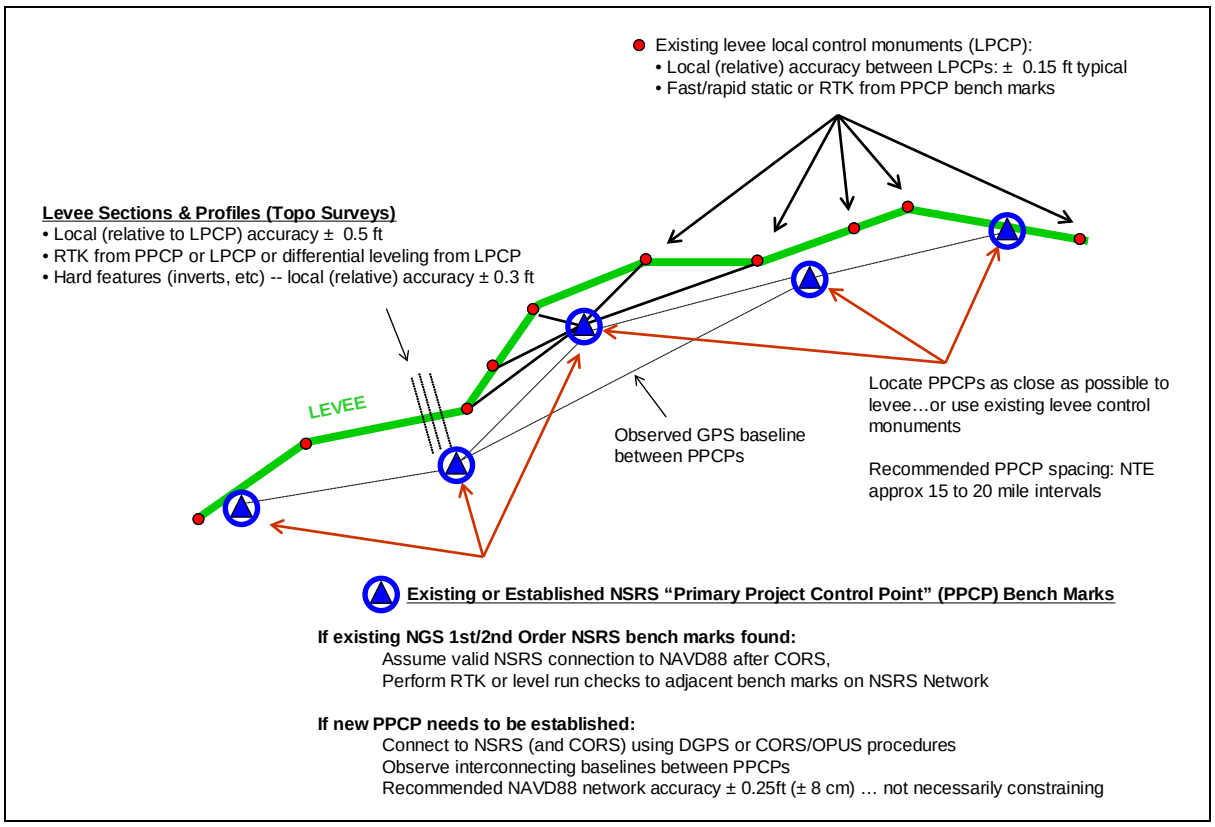

Figure 6-3. NSRS and local reference bench marks on a levee system.

6-6. Dam and Reservoir Connections to the NSRS. For most dam projects, multipurpose hydropower projects, and related impoundment reservoirs, only one PPCP needs to be tied in to the NSRS, as illustrated in Figure 6-4. This point will usually be one of the deformation and settlement monitoring bench marks used on periodic inspection surveys. NSRS referenced elevations for all the other monitoring points can be computed from the elevation differences in the most recent periodic inspection report—these differences are generally accurate to 0.005 ft tolerances when precise geodetic leveling techniques are employed. The PPCP at a dam and reservoir project can be referenced to the NSRS using the survey techniques covered in Chapter 3. In general, CORS/OPUS observations will be adequate to provide a reliable reference to the NSRS. In some instances, networked baseline connections may be selected.

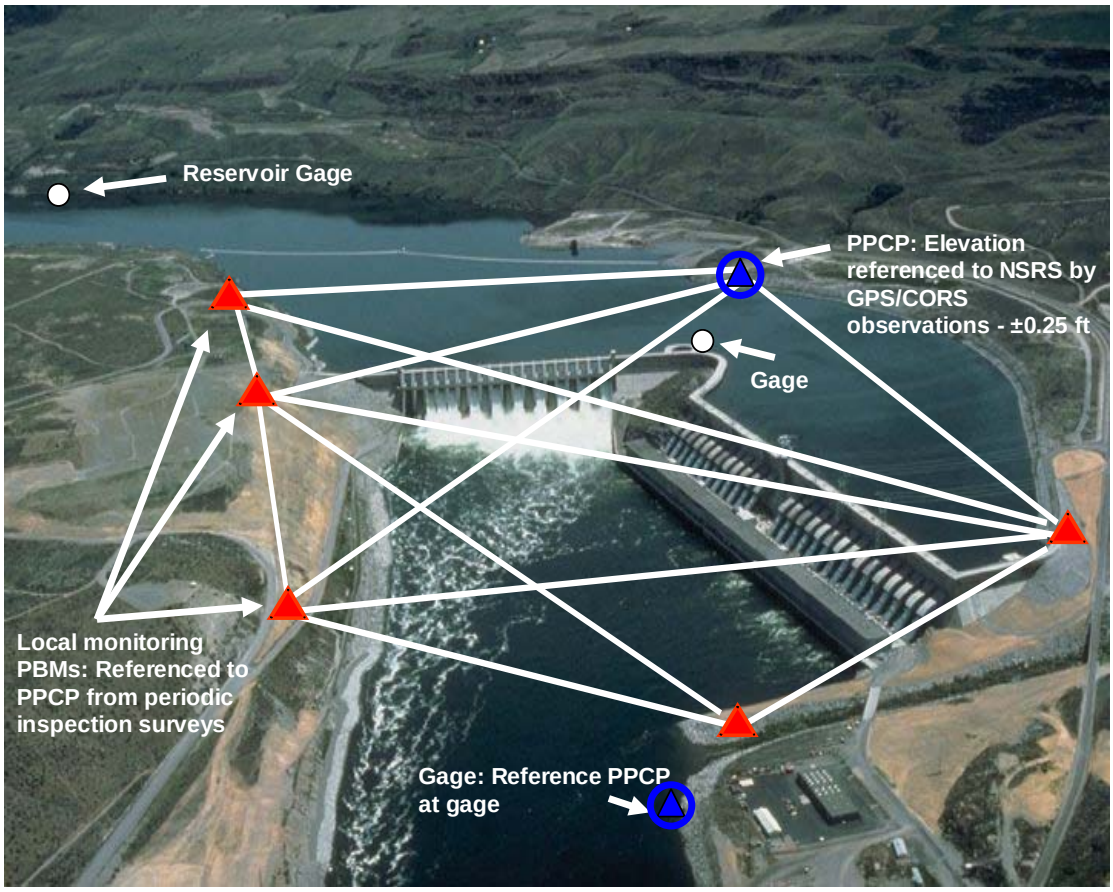

Figure 6-4. NSRS connections at a multipurpose hydropower project.

a. The guidance in this section is not intended to modify local datums used on periodic deformation monitoring inspections or for water control purposes. The intent is to add a reliable NSRS reference to these structure points and any gages near the dam and reservoir. This allows pool, intake, spillway, and crest elevations to be externally referenced to the current NSRS reference datum. The nominal ± 0.25 ft relative NSRS accuracy will normally be suitable for most projects. Exceptions may exist for large impoundment reservoirs. Detailed guidance for monitoring relative elevations around dams is covered in EM 1110-2-1009 (*Structural Deformation Surveying).*

b. Vertical settlement monitoring networks are often referenced to an arbitrary datum—i.e., 100.00 ft or 1,000.00 ft at the primary reference point held fixed in the network. Relative elevation accuracies (not NAVD88 accuracies) are most critical. For example, a monitoring plug on a concrete monolith may have a local vertical precision of ± 0.001 ft relative to an adjacent monolith plug, and perhaps ± 0.005 ft relative to the external monitoring network some 500 ft to 1,000 ft distant. In many cases, the monolith point is also referenced to a superseded legacy vertical datum, such as NGVD29. Thus, a monolith plug could have two defining elevations—e.g., 104.678 ft on the deformation monitoring network datum and 786.3 ft (± ? ft) on the legacy NGVD29 datum. Once the network is updated to the NSRS, the NAVD88 elevation for this

same monolith point might be 784.82 ft ± 0.2 ft. This NSRS elevation may have been obtained from static GPS baseline observations to NSRS points 5 to 10 miles distant, and/or CORS points 50 to 150 miles distant.

c. Gages near the dam or in the reservoir must also be referenced to the NSRS elevation datum. Procedures and documentation are similar to that required for levee projects in the above paragraphs. The relationships with legacy orthometric datums and reservoir pool datums must be documented at each gage.

d. Appendix H contains an example of geodetic surveys that were performed to establish primary project control on Pittsburgh District's Clarion River (East Branch) Dam and Spillway. See also Appendix J.

6-7. Inland Navigation Lock and Dam Connections to the NSRS. Inland lock structure elevations (and related gate structures, sills, guide walls, dams, etc.) are connected to the NSRS similarly to dam and reservoir projects described above. Figure 6-5 depicts a control scheme for a typical lock structure. Upstream and downstream gages should be referenced to the NSRS at this lock. As with dam and reservoir projects described above, NSRS (NAVD88) elevations will not supersede local construction, water control, or deformation monitoring elevations on LPCPs used at the site. The relationships between NAVD88 and legacy orthometric datums and controlled pool datums upstream and downstream of the lock must be documented at each gage.

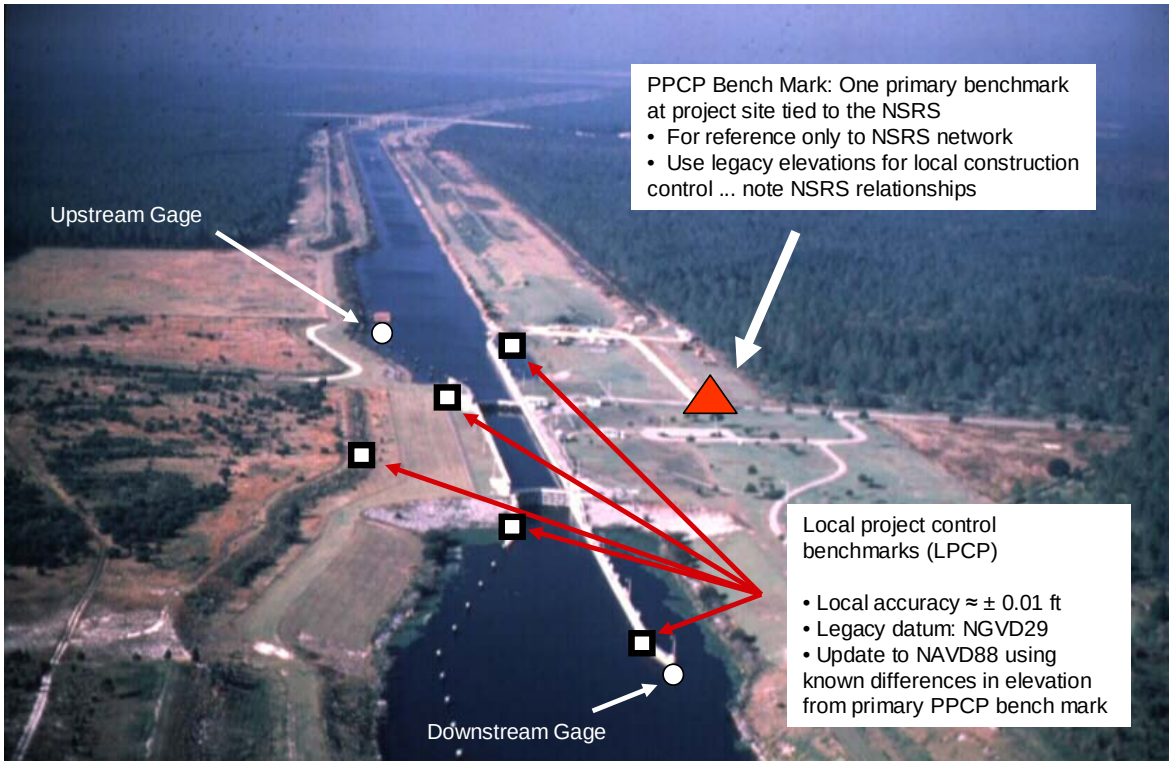

Figure 6-5. NSRS connections at an inland lock project.

6-8. Referencing Projects on the Great Lakes and Connecting Waterways. Navigation and shore protection projects on the Great Lakes and connecting waterways are referenced to the International Great Lakes Datum (IGLD). IGLD is specified by the year of the adjustment (currently 1985). Each of the five Great Lakes has its own independent IGLD low water reference datum, as listed in Chapter 2 (Table 2-2). The IGLD85 and its relationship to NAVD88 is determined and defined by the International Joint Commission—see "*Establishment of International Great Lakes Datum--1985*" (IJC 1995). IGLD elevations of bench marks are published in the NSRS.

a. The datum references in the connecting channels (i.e., Niagara, Detroit, St. Clair, and St.Marys Rivers) between the fixed datums at each lake are developed by the local USACE districts. See a complete listing in Appendix K.

b. Primary project control point connections to the NSRS (i.e., IGLD85 or NAVD88) would follow similar guidance outlined for navigation, shoreline protection, and flood risk management projects in this manual.

c. Both NAVD88 and IGLD85 are referenced to the same primary bench mark at Pointe-au-Père/Rimouski, Quebec. The only difference is that the IGLD85 elevations are published as dynamic heights and the NAVD88 elevations are published as Helmert orthometric heights.

d. Due to inaccuracies in NAVD88 leveling adjustments in the Great Lakes region, a “hydraulic corrector” must be applied at subordinate points on the Great Lakes in order to obtain a reference datum for engineering, construction, or navigation projects. These hydraulic correctors at gage sites are published by the IJC Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

e. Appendix K contains additional technical information on IGLD85 dynamic heights and hydraulic correctors. It also includes an example of a Detroit District navigation project in Lake Superior that is referenced to IGLD85.