National Park Service
U.S. Department of the Interior

Resource Information Services Division

Accurate Elevations in Coastal National Parks

Preparing and planning for impacts of climate change

March 24, 2011

1. **Introduction**

The Department of Interior is developing a strategy to evaluate habitats, infrastructure, and resources at risk from the effects of global climate change (DOI Task Force on Climate Change 2008). In coastal ecosystems, locally expressed sea level rise (SLR) and an increase in storm frequency and intensity are two major impacts expected to result from climate change (Anthony et al. 2009, Zhang et al. 2004, McGranahan et al. 2007, Cazenave and Nerem 2004). In coastal areas, then, accurate elevation of habitats and other critical resources relative to the local tidal heights and the ability to monitor fine scale vertical change is vital information for climate change mitigation and park planning.

This manual outlines guidelines to help coastal National Parks access the best height or elevation data available. It focuses on the establishment of a high accuracy “backbone” of bench marks within individual parks, connected to the nation’s consistent coordinate system, with elevations extended from these marks to monitoring sites of interest. The manual includes basic workflows, a series of appendices, and a glossary. It also outlines and references procedures for measuring elevations in coastal parks relative to tidal datums, but actual measurements, observations, and calculations will likely require the services or consultation of trained surveyors and technical experts.

2. **Background**

2.1. Key Concepts

2.1.1. The ***elevation*** of onshore structures and resources with respect to local mean sea level is extremely important when planning for sea level rise, coastal inundation, or flooding.

2.1.2. ***Accuracy*** (lack of a bias error) is important because given the generally low slopes of coastal habitats, a small vertical elevation error may translate into a horizontal error on the order of meters.

2.1.3. ***Transformations*** between geodetic and tidal datums (see Key Definitions, below) are absolutely critical for climate change mitigation and park planning (e.g. for evaluating the risk of built infrastructure elevation to flooding; for restoring coastal habitats to appropriate tidal inundation regime).

2.1.4. The ***relative accuracy*** of elevations with respect to local water levels is most important because sea level rise and its impacts are locally expressed.

2.1.5. ***Relative Sea Level Trends*** reflect changes in local sea level with respect to local land elevations over time and are typically the most critical sea level trend for many coastal applications, including studying and managing for climate change.

2.2. Key Definitions

2.2.1. **Height** or **elevation** is distance perpendicular to the local gravity field, measured from a reference point, plane, or surface; for example, a height may be a number of feet above or below mean-low-water (MLW).

2.2.2.A **geoid** is a reference surface of the earth based on gravity. More specifically, it is the equipotential surface of the Earth's gravity field which best fits, in the least-squares sense, mean sea level. (see Appendix A for an illustration and further explanation).

2.2.3.A **Reference Ellipsoid** is an approximation of the geoid that is a mathematically "smooth" surface used in calculations (see Appendix B for an illustration and further explanation). Global Navigation Satellite Systems (GNSS) or Global Positioning Systems (GPS) provide elevations with respect to an ellipsoid.

2.2.4. A **Tidal Datum** is a locally determined surface defined by a particular phase of the tide from observed data in a particular location. The National Tidal Datum Epoch[1] defines the period of time over which the current tidal datum is defined (see Appendix C for an illustration and further explanation).

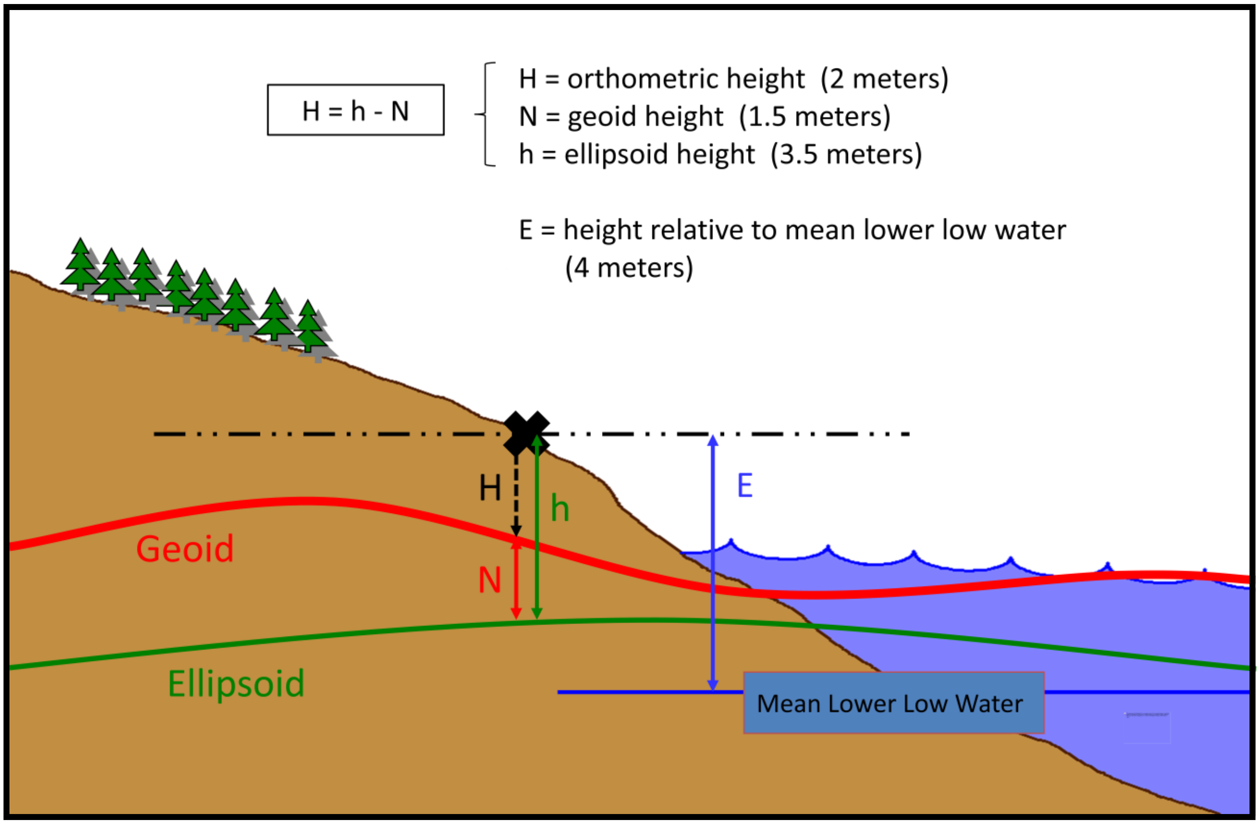
2.2.5. A **Vertical Datum** is a reference point, plane or surface from which elevations are measured. For example, the North American Vertical Datum of 1988 (NAVD 88) is the current national vertical datum which was defined with respect to mean sea level for a specific tidal epoch at a specific location (Father Point/Rimouski, Quebec, Canada).

2.2.6. **Orthometric Height** is the distance between the geoid and the Earth's surface. It is commonly referred to as elevation, and it can be calculated as the difference between the geoid and ellipsoid heights. Figure 1 below illustrates the relationship between orthometric, geoid, ellipsoid, and tidal heights**.**

[1] National Tidal Datum Epoch (NTDE) is a specific 19-year period of tidal observations used for primary datum calculations. The current NTDE is 1983-2001. (*See Appendix D to learn more about tidal datum epochs*).

The relationships between the terms defined in this section are illustrated in Figure 1 below. More illustrations for the terms defined in this section are included in the corresponding appendices.

Figure 1: Relationships between orthometric, geoid, ellipsoid, and tidal heights. While orthometric, geoid, and ellipsoid heights are related algebraically, local observations must be used when relating tidal datums to terrestrial heights.



The figure above illustrates the height of point "X" relative to the geoid[2] *(distance H), to the ellipsoid (distance h), and to Mean Lower Low Water (distance E).*

2.2.7. **Accuracy** refers to the agreement between a measurement and the true or correct value. In the context of geographic positioning, a*bsolute accuracy* refers to the agreement between a measured coordinate and the real-world position on the earth. *Relative accuracy* refers to the agreement between two measured coordinates and their positions on earth with respect to each other.

[2] The current geoid model used to calculate a NAVD88 orthometric height is Geoid09.

Overview

2.3. Goals and objectives

Coastal parks should efficiently manage resources, adapt to changing local sea levels, and mitigate impacts of inundation from more frequent and intense storms by maintaining a backbone network of geodetic monuments[3] and a series of strategically placed sentinel sites for referencing local tidal datums to park resources.

2.4. Recommendations

Three primary recommendations are listed below. The rest of the document helps describe how the recommendations can be implemented and what level of expertise may be required.

1. Establish and manage a network of backbone vertical control points in each park.

2. Establish and manage sentinel sites at or near locations of interest and/or importance in each park.

3. Ensure all backbone points and sentinel sites have highly accurate elevation data with ~~an~~ ellipsoid, orthometric, and tidal datum heights.

Before implementing the recommendations above, make sure to carefully review the following portions of this document:

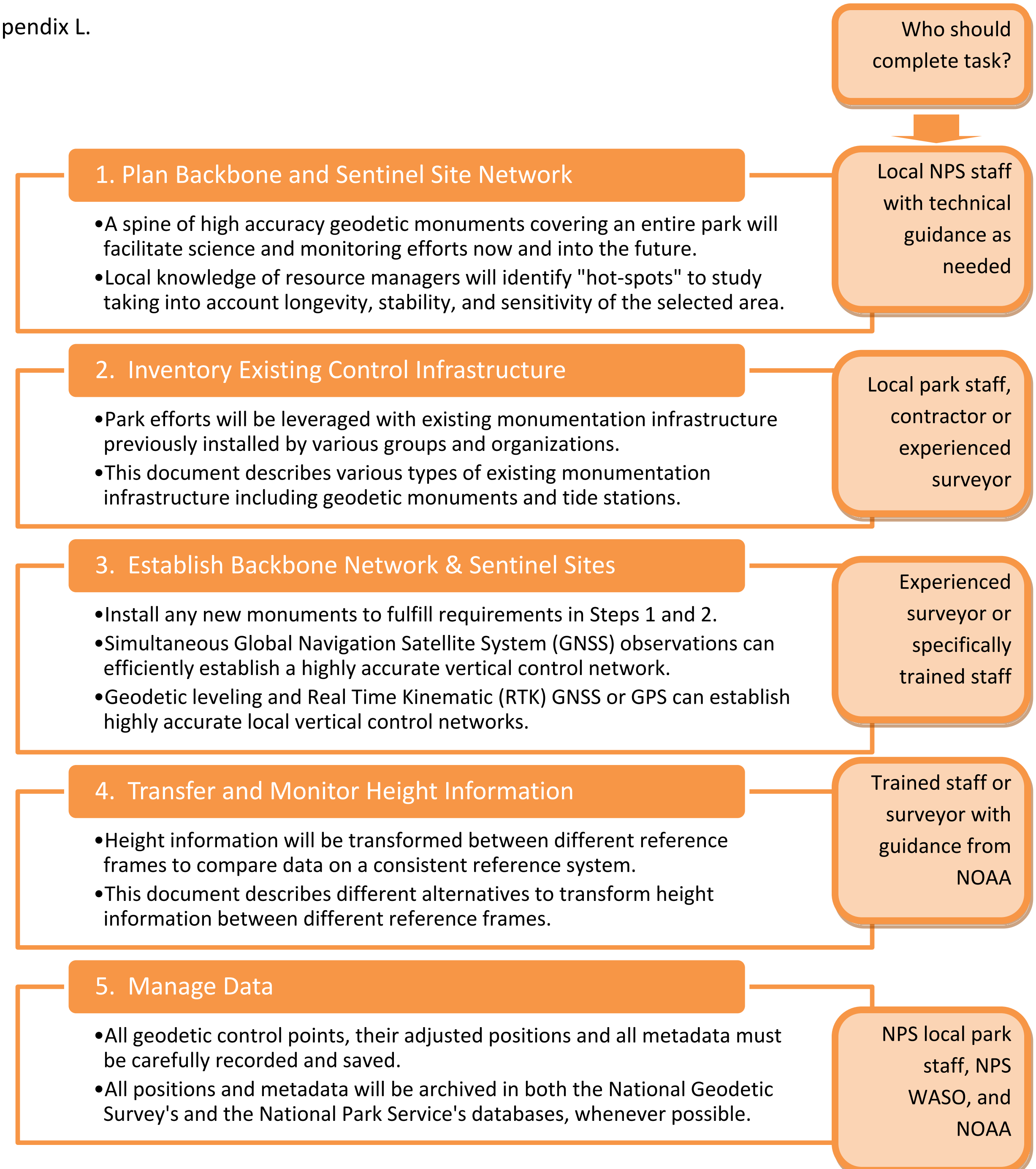
- *Section 3.3* which outlines a recommended process to follow,
- *Section 4.1* which defines the backbone network and sentinel sites in more detail, and
- *Section 4.3* which lists technical requirements for establishing the backbone network and sentinel sites.

Additionally, it is recommended that technical installations, observations and computations be completed by experienced **land surveyors or others with equivalent knowledge, expertise or training**.

[3] Geodetic monuments are precise locations that are permanently marked with a brass disk, metal rod, cement or stone platform, or other permanent structure, and that have known positional information obtained through geodetic observations. Different types of monuments have varying stabilities. (*See Appendix F to learn more about the types, stability, and construction of geodetic monuments*).

2.5. Process

Establishing geodetic control monuments can be costly and time-intensive, but careful planning can help create an accessible and maintainable control network. Every park will have unique needs and resources, but processes outlined and described throughout this document can act as a guide. In all cases it is imperative to follow the planning steps, to choose among the appropriate alternatives, to consult with technical experts as necessary, and to capture all metadata. If any technical details are not explained adequately in this document, organizations to contact for more information are identified in Appendix L.



3. Best practices for high quality geospatial (vertical) data

3.1. Plan backbone and sentinel site network

This section explains backbone and sentinel site networks and will aid early planning efforts; *however, all plans will be revised after completing an inventory of existing monumentation infrastructure (see Section 4.2) and integrating technical requirements (see Section 4.3).*

Backbone site network is a series of physical survey monuments with highly accurate vertical control and a connection to the National Spatial Reference System[4] (NSRS). ***Sentinel sites*** are locations where park managers determine there are critical infrastructure, habitats, cultural sites, and populations of species of concern. The table below highlights some basic information about both networks.

Table 1: Backbone and Sentinel Site general information

	Backbone Site(s)	Sentinel Site(s)
Definition	Geodetic control stations connecting to the National Spatial Reference System	Locations near critical infrastructure, habitats, cultural sites or species of concern
Function	Permanent survey infrastructure providing local position reference for sentinel sites	Control points selected to monitor environmental, physical, or biological change over time
Accuracy	2-4 cm	4-10 cm
Positioning and Remote Sensing Technology	Stationary GNSS or GPS observations and OPUS processing	GNSS or GPS observations, typically Real Time, tied to base station (i.e. Backbone Monument)
Partnerships	Partner with state GIS coordinators, Department of Transportation survey groups, or NOAA's National Geodetic Survey to leverage resources	Partner with technical experts in geodetic control to ensure quality of data

[4] NOAA's National Geodetic Survey (NGS) defines and manages the National Spatial Reference System (NSRS), a consistent national coordinate system in the United States that specifies latitude, longitude, height, scale, gravity, and orientation, as well as how these values change with time.

3.2. Inventory and compile existing local control infrastructure.

The best method to conserve limited resources is to take advantage of all existing monumentation infrastructure. Different organizations have installed control networks throughout the country, and many high quality data-sets are available[5]. The recommended steps to complete a thorough inventory are listed below.

Who should complete task?

1. Identify monumentation infrastructure and data

- There are many types of existing monumentation infrastructure to identify.
- Use the descriptions below to learn what each type is, how to find it, and how to use it.

Who should complete task: NPS staff, GIS specialist, surveyor

2. Identify gaps, if present

- Monumentation infrastructure may not be present in the desired geographic location.
- Data may not be available for the desired time, accuracy or stability.

Who should complete task: NPS staff, guidance from surveyor/NOAA

3. Compile research in shapefile

- Local park knowledge can determine if scientific and management needs can be met.
- Technical experts can determine if accuracy and scientific requirements can be met.

Who should complete task: GIS specialist, guidance from surveyor/NOAA

The boxes below describe different types of monumentation infrastructure, how to locate existing monumentation infrastructure near your park, and how to use the data.

[5] Review NOAA's report "Technical Considerations for Use of Geospatial Data in Sea Level Change Mapping and Assessment" for a list of available datasets.

Active Geodetic Control (GNSS & CORS)

What is it?	Where do I find it?	How do I use it?
---> **Global Navigation Satellite System (GNSS)** receiver that continuously collects positional data ---> NOAA's National Geodetic Survey (NGS) manages a **Continuously Operating Reference Station (CORS)** network that supports three-dimensional positioning	---> **Visit http://www.ngs.noaa.gov/CORS/** ---> Use the interactive map to search for nearby stations in the CORS network ---> Locate three CORS stations within 100 km of desired location ---> Inquire with federal, state, and local surveyors on availability of non-CORS continuously operating GNSS. Verify data quality with NGS (e.g. USDA Forest Service Trimble network)	---> CORS will link survey monumentation on the ground to the **National Spatial Reference System (NSRS)** ---> CORS supports **Online Positioning User Service (OPUS)** that computes a position from GNSS data

Passive Geodetic Control (survey monuments)

What is it?	Where do I find it?	How do I use it?
---> Survey monuments are precise locations permanently marked with a brass disk, metal rod, cement or stone platform, or other permanent structure ---> Survey monuments are only useful if both the physical monument in the ground and the geographic coordinates on that monument are present and the monument has not been moved or altered since its installation ---> NOAA's National Geodetic Survey (NGS) manages a database with geospatial coordinates for many survey monuments ---> Many survey monuments exist that are not included in NOAA's National Geodetic Survey 's (NGS's) database.	---> **Visit http://www.agc.army.mil/ndsp/usmart.asp** to search for monuments and their datasheets with accurate heights. This Army Corps of Engineers (USACE) web tool's map and search function includes USACE control points as well as NGS and OPUS control points [NOTE: One should be searching for vertical control points] ---> **Search the NPS monumentation database** and any other public databases [e.g. Bureau of Land Management or (BLM), United States Department of Agriculture's Forest Service, United States Geologic Survey, and USACE]	--> A survey monument establishes a local elevation. Published coordinates (elevations) should be verified before use. [NOTE: Refer to Appendix E with respect to precision of NGS published NAVD88 elevations] ---> Areas of the country with substantial crustal motion (e.g. subsidence or isostatic rebound) must use caution when using old published elevation values [NOTE: Additional data collection may have been completed in areas with substantial crustal motion, so consult with technical experts to make sure you are using the most up-to-date data available]

Tide Stations (NWLON stations)

What is it?	*Where do I find it?*	*How do I use it?*
---> Tide stations continuously collect water level data ---> NOAA's Center for Operational Oceanographic Products and Services (COOPS) manages the **National Water Level Observation Network (NWLON)** ---> NWLON is a network of long-term and short-term water level stations.	---> **Visit http://www.agc.army.mil/ndsp/usmart.asp** to search for monuments and their datasheets with accurate heights. This Army Corps of Engineers (USACE) web tool's map and search function includes operational and historic stations as well as USGS and USACE gages	---> A tide station's datasheet lists the published tidal datums for that point and its immediate area ---> Exercise great caution if extending the datum to a larger geographic area and consult technical experts for guidance [NOTE: Read more about the NWLON network in Appendix G]

Tidal Benchmarks (survey monuments)

What is it?	*Where do I find it?*	*How do I use it?*
---> NOAA's Center for Operational Oceanographic Products and Services (COOPS) establishes survey monuments ---> The monuments often link the National Water Level Observation Network (NWLON) and the **National Spatial Reference System (NSRS)**. [NOTE: Survey monuments are fully defined in a preceding box]	---> **Visit http://www.tidesandcurrents.noaa.gov/** to select a tide station ---> Select "Benchmark Sheets" link for the tide station selected [NOTE: More information about locating tide stations is in a preceding box]	---> Tidal benchmarks often link tidal and terrestrial vertical datums ---> Each tidal benchmark has a description and a VM# ---> Many tidal benchmarks also have a PID# that references NOAA's National Geodetic Survey's (NGS's) database where complete geographic positioning information will be found

A thorough inventory of existing monumentation infrastructure will identify gaps in monumentation infrastructure or data that may not be sufficient in establishing the backbone network or sentinel sites. The table below summarizes minimum monumentation infrastructure and data requirements. A gap exists when the requirements are not met with existing monumentation infrastructure, so the table also recommends strategies to fill any gaps.

It is important to be aware that park size and terrain may dictate modification of the requirements listed in the table below. The spacing of the backbone network is most important along the coast when planning for sea level rise impacts, and the density of an inland network should be considered on a park by park basis. Depending on the terrain upon moving inland, assets and resources may quickly become less at risk (if the elevation increases rapidly) or remain at high risk (if the elevation remains low or the same). However, an important sentinel site must have a backbone network in close proximity for it to remain useful, regardless of whether the site is immediately adjacent to the coast or several kilometers inland.

Table 2: Monumentation Infrastructure technical requirements – The information summarized in the table below can help identify and fill in gaps. ***Alternatives are listed from the most desirable to least desirable, and technical experts (from NOAA and NPS) can be consulted when selecting an alternative or when modifying any requirements due to limitations with respect to time, financial resources or unique geography.***

Monumentation Infrastructure type	Monumentation Infrastructure requirements	Data requirements	Alternatives to fill gap
Active Geodetic Control (GNSS and CORS)	3 stations within 250 km radius	Currently active and operating at least a 30 second sampling rate	Install a CORS station, use stations outside 250 km radius, or use a station outside of CORS network
Passive Geodetic Control (survey monuments)	Setting should be Class A, B, or C, and Stability should be A[6]	Height should be accurate to cm level, and height should be updated within past 2 years	Install new monuments (Class A, Stability A), and resurvey existing monuments with old or less accurate data
Tide Stations (NWLON Stations)	1 station in immediate coastal area	Currently active and operating at least 8 months	Install new tide station, apply computation methods to use data from historic (not active) station, or use the closest available active tide station

3.3. Establish backbone network and sentinel network

Technical requirements must be met and procedures must be followed to ensure quality data can be collected from backbone and sentinel sites. Refer to Tables 3 and 4 below for a summary of technical requirements and procedures. Additionally, Appendix F includes more information about monument types, stability, and construction.

[6] See Appendix F to learn more about the types, stability, and construction of geodetic monuments.

Table 3: Technical Requirements for Backbone and Sentinel Sites

Technical Requirements	Backbone Sites	Sentinel Sites
Spacing	15-20 km between backbone sites[7]	within 1 km of a backbone site
Publish to OPUS-DB	required	not required; not recommended for sensitive sites
Publish to NPS database	required	required
Accuracy (local)	no minimum requirement	sub-cm accuracy relative to the local (backbone) network whenever practicable
Accuracy (network)	2-4 cm accuracy relative to the National Spatial Reference System (NSRS)	no minimum requirement
Observation method (preferred)	use Global Navigation Satellite Systems (GNSS) or Global Positioning System (GPS) with multiple observation sessions as long as practicable[8]	use geodetic leveling when practicable to achieve sub-cm accuracy relative to local network
Observation method (alternative)	complete simultaneous GNSS or GPS occupation of multiple sites when possible to improve network accuracy[9]	use Real Time Kinematic (RTK) GNSS or GPS in remote or hard-to-reach areas
Location	mark should be set away from areas of potential disturbance and have open skies for satellite observations	no minimum requirement
Stability (existing monument)	Class A, B, or C	no minimum requirement
Stability (newly installed mon.)	Class A	no minimum requirement
Setting (existing monument)	mark in massive structure or bridge with deep foundations, in rock outcrop, rod driven > 10 ft, or in concrete monument	no minimum requirement
Setting (newly installed mon.)	sleeved rod driven to refusal	no minimum requirement

Table 5 below details the process for installing **backbone sites**, and the same process can and can be used for establishing **sentinel sites**. However, make sure to **note differences in technical requirements** as described in Table 4 above.

[7] While preferred spacing of backbone sites is 15-20 km, the requirement can be modified in areas of where there is no foreseeable need for sentinel site observations.

[8] Recommended sessions are 5 – 48 hours including two 4 hour occupations with different satellite constellations (i.e. different time of day).

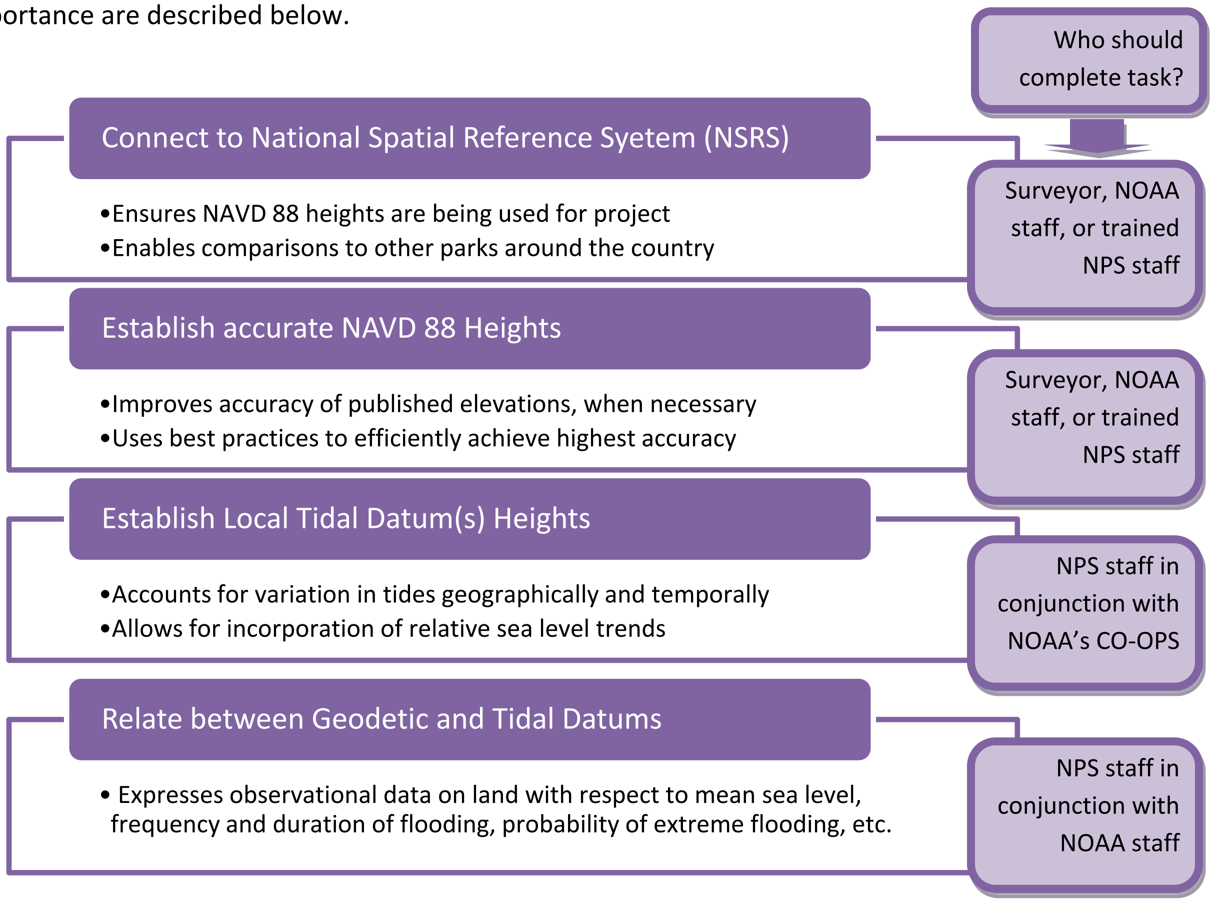
[9] Refer to "Guidelines for Establishing GPS-Derived Ellipsoid Heights" for detailed instructions (complete reference citation can be found in Appendix M, References).

Table 4: Establishing Backbone Sites – Following the five steps described below will allow for the efficient establishment of a backbone network. The same steps can establish sentinel sites, keeping in mind differences in technical requirements summarized in Table 3. **It is strongly recommended that a surveyor or individuals trained in survey techniques complete all surveying steps.**

1. Recover Marks	a. Locate benchmarks listed in the NGS database or other database in the field	b. If necessary, submit mark recovery form using http://www.ngs.noaa.gov/ngs-cgi-bin/recvy_entry_www.prl	NOTE: When a monument cannot be found in 30 min. search by two people, deem it a non-candidate site
REFERENCE: http://www.ngs.noaa.gov/ngs-cgi-bin/recvy_entry_www.prl			
2. Identify Obstructions	a. Note any obstructions that could impact GNSS observations at the benchmark	b. Complete an obstruction diagram for each verfied, candidate point using http://www.ngs.noaa.gov/RSD/forms/visibility.pdf	NOTE: Obstructions can include tree cover, power lines, hills, or any other large structures.
REFERENCE: http://www.ngs.noaa.gov/RSD/forms/visibility.pdf			
3. Identify new site(s)	a. Determine if a benchmark needs to be relocated or if a new monument is needed	b. Identify site in field for relocation or new benchmark	NOTE: Sites should have 50-100 year life expectancy and installed as "rod to refusal" (Class A), if possible
REFERENCE: http://www.ngs.noaa.gov/heightmod/Leveling/Manuals/Benchmark_9_13_07.pdf			
4. Receive permit(s)	a. Determine if permits are needed to install a relocated or new benchmark	b. If necessary, complete permitting process	NOTE: Any new or reset benchmarks must be established with the highest stability achievable
REFERENCE: http://www.ngs.noaa.gov/heightmod/Leveling/Manuals/Benchmark_9_13_07.pdf			
5. Survey Backbone	a. Survey all backbone sites using GNSS	b. Use Online Positioning User Service (OPUS) to process and publish data	NOTE: Make sure to select the option to publish the OPUS solution to store it in OPUS-DB
REFERENCE: http://www.ngs.noaa.gov/OPUS/			

3.4. Transfer and Monitor Height Information

In order to monitor change over time, compare information from different regions of the country, and manage the interface between aquatic and terrestrial resources, it is imperative to transform elevation data between different vertical datums. All transformations are heavily dependent on the quality of the original data and its corresponding metadata. The four general types of data transformations and their importance are described below.



3.4.1. *Establish connection to National Spatial Reference System (NSRS).*

Connecting to the NSRS ensures NAVD 88 heights are being used on a project and enables comparisons to other parks around the country. Simultaneous Static GNSS/GPS can establish a local geodetic network with sub-decimeter accuracy relative to the National CORS network[10], but specific technical procedures must be followed. The steps outlined below describe an efficient methodology and include references to numerous technical resources and guidelines.

[10] NOAA's National Geodetic Survey (NGS) manages a Continuously Operating Reference Station (CORS) network that supports three-dimensional positioning, and more information can be found at http://www.ngs.noaa.gov/CORS/.

Table 5: Establish Connection to NSRS. Following the four steps described below will efficiently support connection to the NSRS. **It is strongly recommended that a surveyor or individuals trained in survey techniques complete all surveying steps.**

1. Establish Passive Control	a. Select and field verify at least three geodetic control markers in or near the park	b. Submit mark recovery form using http://www.ngs.noaa.gov/ngs-cgi-bin/recvy_entry_www.prl	NOTE: Marks may have been recovered and obstructions identified while establishing backbone

REFERENCE: http://www.ngs.noaa.gov/ngs-cgi-bin/recvy_entry_www.prl

2. Complete GNSS/GPS Observations	a. Complete simultaneous GNSS observations of all 3 or more marks, ≥ 5 hrs	b. Repeat step '2a' during a second and separate GNSS constellation (by completing observations at a different time of day or on different day)	NOTE: Observe as long as practicable; 5-48 hour sessions recommended

REFERENCE: http://www.ngs.noaa.gov/OPUS/

3. Process Data	Use NGS's Online Positioning User Service (OPUS) to reduce or process GNSS/GPS data		NOTE: Use OPUS-Static rather than OPUS-RS to process the 5-48 hr observation sessions

REFERENCE: http://www.ngs.noaa.gov/OPUS/

4. Publish Data	Select "submit to database" option when using OPUS to pubish your solutions to OPUS-DB		NOTE: OPUS-DB effectively archives the calculated solution, but all metadata must still be recorded

REFERENCE: http://www.ngs.noaa.gov/OPUS/

3.4.2. *Establish accurate NAVD 88 heights*

NAVD 88 is the currently the official vertical geodetic datum in the United States as defined by NOAA's National Geodetic Survey (NGS). A number of remote sensing and positioning methods can establish accurate heights, but each has its own procedures, advantages, and levels of accuracy. Three recommended strategies are listed below, and more information about additional methods is summarized in Appendix H. **It is strongly recommended that a surveyor or individuals trained in survey techniques complete all surveying steps.**

Leveling	
The basics: -->Can achieve sub-cm accuracy relative to local network and NSRS -->Requires moderate to high technical expertise -->Recommended for high accuracy local network connections and monitoring of network and sensor stability -->Time required depends on distance of connection	*Definition:* Geodetic leveling is a survey technique used to measure elevation differences between benchmarks. *Procedure:* 1. Double run level loops through all backbone sites when practicable 2. Reduce data using LOCUS tool using averaged OPUS GPS Derived Heights held fixed at one control monument 3. Record all observations, metadata and positions 4. Publish results in NGS main database or NGS OPUS-Database when practicable *References:* http://www.ngs.noaa.gov/heightmod/Leveling/requirements.html http://beta.ngs.noaa.gov/locus/LOCUS2.html http://www.ngs.noaa.gov/OPUS/

Online Positioning User Service (OPUS) Static	
The basics: -->Can achieve 2-5 cm accuracy relative to the NSRS -->Requires relatively low expertise (training still required) -->Recommended for establishing networks and monitoring stability of networks over time -->Time required generally ≥ 5 hrs per point	*Definition:* OPUS processes your GNSS or GPS data files, computes coordinates, and emails your corrected* position with an option to publish your solution to OPUS-Database (OPUS-DB). *Procedure:* 1. Observe all backbone sites as long as practicable, 5-48 hour sessions recommended. 2. Use OPUS to reduce GNSS or GPS data 3. Publish results in OPUS-Database (OPUS-DB by selecting option to "submit to database" 4. Record all observations, metadata and positions *References:* http://www.ngs.noaa.gov/OPUS/

**OPUS provides positional information that is reduced from a large time series of instantaneous positions and that is corrected for atmospheric conditions present during the observation period, providing enhanced accuracy compared to non-adjusted positions.*

Real Time Kinematic Positioning (RTK)

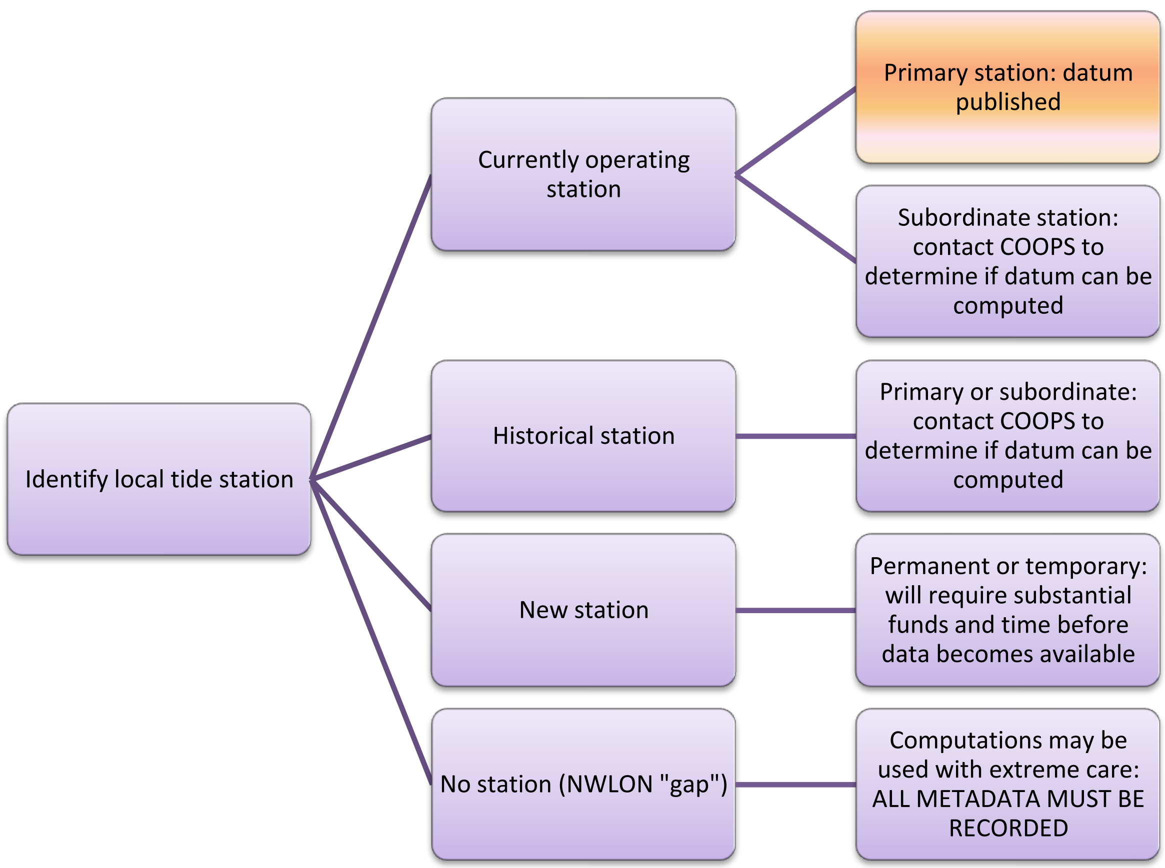
The basics:	*Definition:*
-->Can achieve 1-5 cm accuracy relative to the local network -->Requires high technical expertise -->Recommended for creating DEMs and positioning remote or hard to reach points -->Time required generally 1 sec to 6 min per point	RTK uses GNSS or GPS technology to produce and collect 3-D positions relative to a stationary base station. *Procedure:* 1. Select a base station from the park's "backbone" network of established geodetic survey monuments 2. Complete RTK observations and data processing following available guidelines 3. Record all observations, metadata and positions *References:* http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v1.0.pdf

3.4.3. *Establish local tidal datum(s) Heights*

Tidal datums are determined through local observations at tide stations within the CO-OPS National Water Level Observation Network (NWLON). Ideally, a currently operational, primary station with published tidal datums is near the park of interest. Depending on the distance between the NWLON station and a backbone or sentinel site, careful computations or extrapolations may need to be completed with the technical guidance of CO-OPS.

If an active, primary station is not nearby, subordinate or historical stations can sometimes be used to calculate a local tidal datum, with technical guidance. If stations or data does not exist, a new station could be installed; however, this option may be cost and time-prohibitive. In lieu of a new station, computations and assumptions may be used carefully and with technical guidance as long as all metadata is recorded. The diagram below outlines what options may be available.

Figure 2: Establish Local Tidal Datum Heights. Each branch below represents a different method to establish a local tidal datum. Options at the top of the diagram are generally preferred over those at the bottom of the diagram, but the ranking is not absolute. For example, “Historical station” is listed above “New station” because installing new stations can be cost-prohibitive, not because the data is necessarily of higher quality. Appendix G describes in more detail the characteristics of different kinds of stations.



3.4.4. *Relate Geodetic to Tidal Datums*

Relating geodetic and tidal datums facilitates monitoring, management and planning with respect to local sea level trends. It improves inundation models and allows park personnel to evaluate physical, biological, and ecological change with respect to sea level. Depending on the available information, it may be simple to look up the relationship between a NAVD 88 height and an elevation above Mean Lower Low Water (MLLW) at a published NWLON tide station. Even when the computation is simple, the result is localized to the station and should not be expanded to a greater geographic area without consulting technical experts.

In other instances, some calculations or interpolation may be necessary. NOAA is developing a tool called VDATUM to facilitate these transformations; however, VDATUM cannot be used in some regions of the country due to insufficient data. Additionally, even when VDATUM can be used, extreme caution must be exercised because more error will enter the result. The four processes available at this time to relate geodetic and tidal datums are listed and described in the table below. To better understand what each process entails, please thoroughly review the numerical example for each process that is included in Appendix H.

Table 6: Processes to relate Geodetic and Tidal Datums

Process	Overview	Technical expertise required
Published values	The relationship between geodetic and tidal datums is published on some tidal benchmark sheets	Low
Algebraic computation	If a benchmark has both a VM# and PID#, simple algebra can compute the relationship between geodetic and tidal datums	Low
Interpolation computation	If two nearby NWLON stations have defined relationships between geodetic and tidal datums, the relationship can be interpolated for a third NWLON station to act as primary control	High
VDATUM tool	NOAA continues to develop a tool that computes the difference between geodetic and tidal datums	High

If unsure what process to use, examine the decision tree below. The highlighted boxes illustrate preferred processes. **NOAA's CO-OPS office may be consulted for technical guidance when selecting the best method or computing the local tidal datum height.**

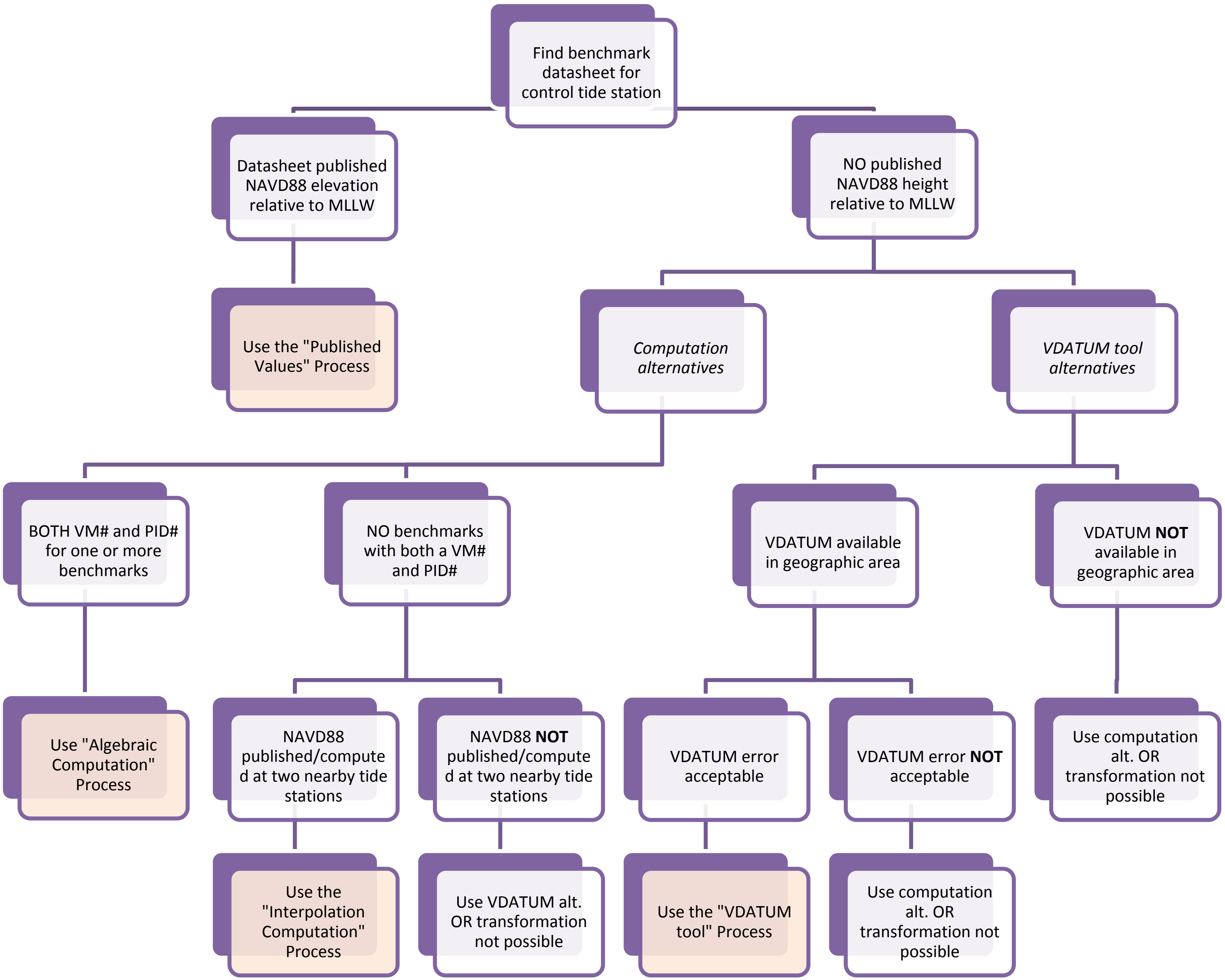


Figure 3: Relating Geodetic and Tidal Datums - Use the decision tree above to select the appropriate process

3.5. Manage data

3.5.1. Storing data

All recovered, re-observed, and newly installed survey monuments must be entered in the NPS survey monumentation database. If any new observations were completed, they should be published in an NGS database (either the integrated database[11] or OPUS-DB[12]) whenever possible.

3.5.2. Metadata

All metadata must be recorded and included in database records. Specifically, the following information must be recorded or calculated:

Table 7: Required data and corresponding metadata

Data	Corresponding metadata	Restrictions
Height above Ellipsoid (HAE)	Ellipsoid model and epoch	NA
Orthometric height	Geoid model	Any point on land can have an orthometric height
Tidal datum height	Local tidal datum and tidal epoch	Tidal datum should not be applied > 3mi from tide station

The list in Table 7 is not exhaustive, so make sure to record any metadata suggested by other technical guidelines. Additionally, take care to record the equipment used (including software and version), the procedure followed, and the date/time of all field observations, and take digital photographs (both close-up and panorama/horizon) for archival and publishing purposes.

3.5.3. Monitoring data

All backbone and sentinel sites should be re-visited annually or biannually. This effort is especially important in areas of the country with substantial crustal motion (e.g. subsidence or isostatic rebound). Areas at high risk for inundation or sea level rise should be monitored more regularly. Areas with particularly sensitive resources or ecosystems (e.g. salt marshes) should also be monitored more regularly as well.

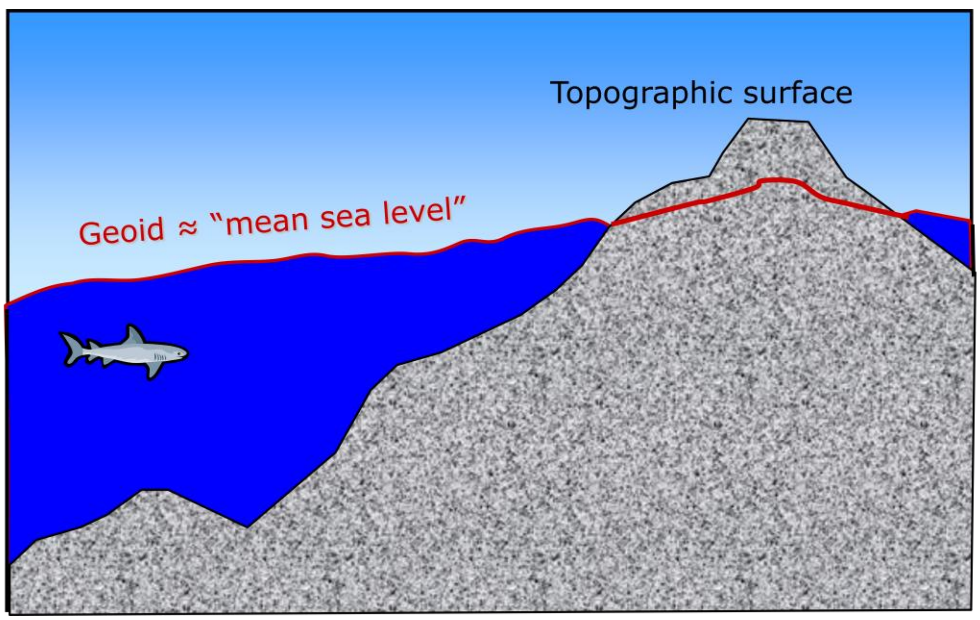
[11] Publishing in NGS Integrated database (IDB) requires "blue-book" process (http://www.ngs.noaa.gov/FGCS/BlueBook/).
[12] Publishing in OPUS-DB requires GNSS or GPS observations (http://www.ngs.noaa.gov/OPUS/).

4. **Appendices**

4.1. APPENDIX A: GEOID

- The geoid is the equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level . The geoid will have a greater height where more of the earth's mass is located (e.g. mountain ranges or western ocean boundaries), and will have lower height where the crust is thinner.
- NOAA's National Geodetic Survey (NGS) defines GEOID 09 as the current geoid model for the coterminous United States and Alaska
- Read more about the NGS geoid at http://www.ngs.noaa.gov/GEOID/

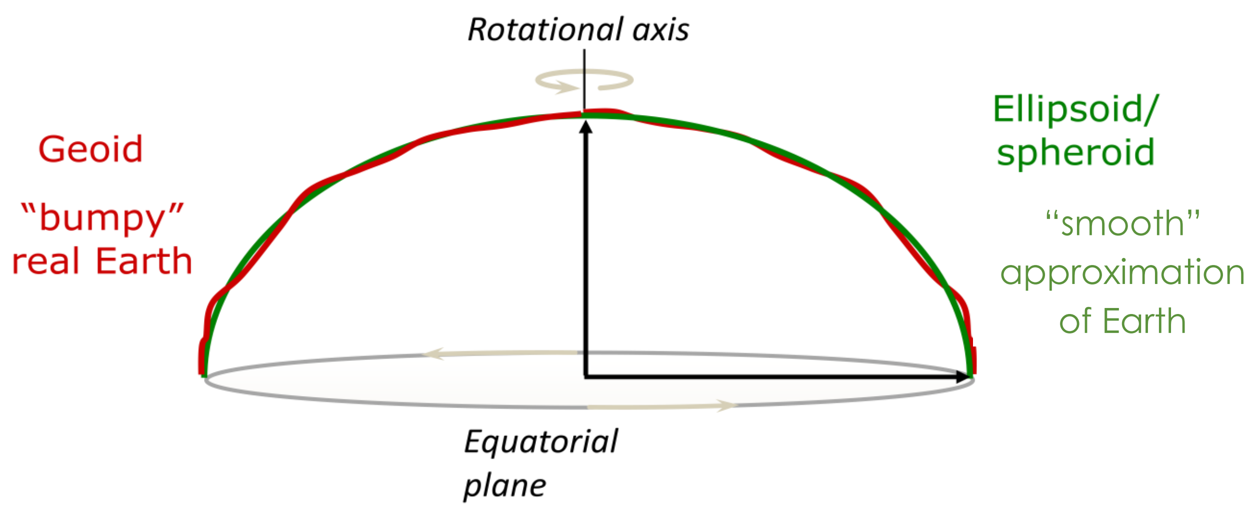
Figure: Illustration of the Geoid



4.2. APPENDIX B: Reference Ellipsoid

- A **Reference Ellipsoid** is an approximation of the geoid (see Appendix A) that is a mathematically “smooth” surface used in calculations
- Elevations computed using Global Navigation Satellite Systems (GNSS) or Global Positioning Systems (GPS) are heights above the reference ellipsoid
- WGS 84 is the most common reference ellipsoid used at this time

Figure: Illustration of the Reference Ellipsoid



4.3. APPENDIX C: Tidal Datums

- A **Tidal Datum** is the base reference elevation from which local water levels are measured, and some common tidal datums are illustrated and defined in the figure and table below.
- Tidal datums are derived from continuous observations over a specified interval of time (tidal epoch) at a specific location, and they are referenced to fixed and stable points on land (survey monuments or benchmarks).
- Tidal datums are local references and should not be extended into areas with different oceanographic characteristics.
- Tidal datums are also used as a basis for establishing legal boundaries and regulations.

Figure: Commonly used Tidal Datums - The datums in the figure below are all defined in Table on the next page.

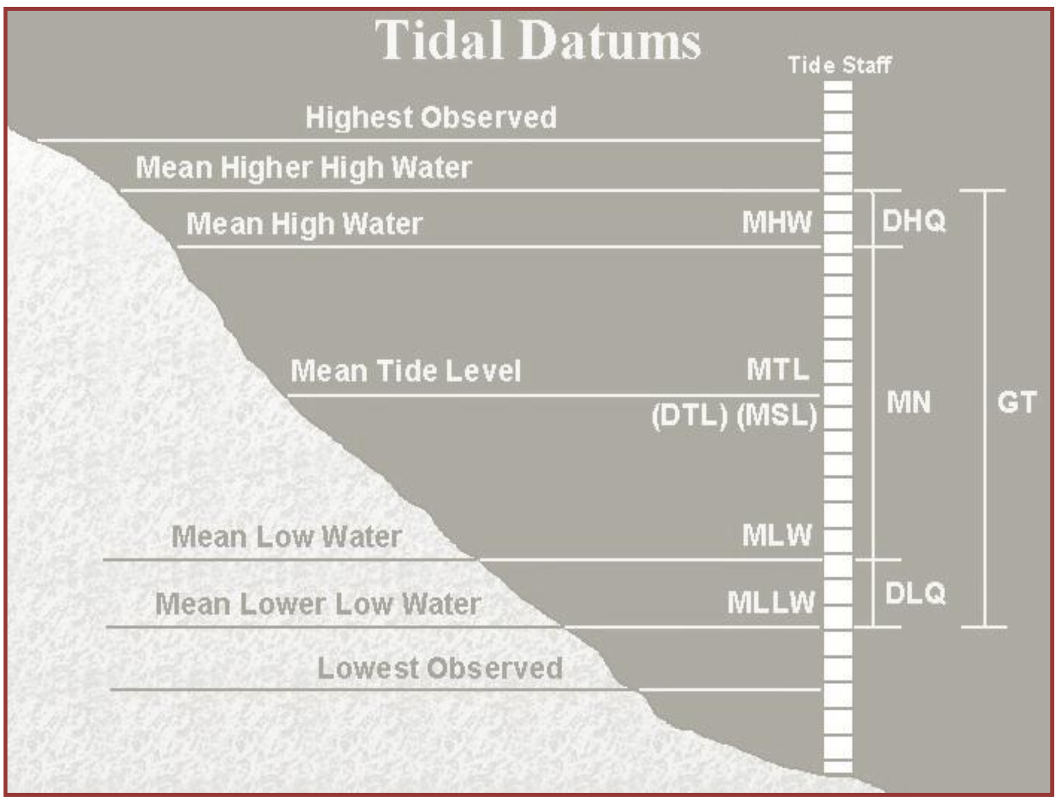


Table: Commonly Used Tidal Datums[13]

Tidal Datum	Definition
MHHW* Mean Higher High Water	The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
MHW Mean High Water	The average of all the high water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
DTL Diurnal Tide Level	The arithmetic mean of mean higher high water and mean lower low water.
MTL Mean Tide Level	The arithmetic mean of mean high water and mean low water.
MSL Mean Sea Level	The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. Shorter series are specified in the name; e.g. monthly mean sea level and yearly mean sea level.
MLW Mean Low Water	The average of all the low water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
MLLW* Mean Lower Low Water	The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
GT Great Diurnal Range	The difference in height between mean higher high water and mean lower low water.
MN Mean Range of Tide	The difference in height between mean high water and mean low water.
DHQ Mean Diurnal High Water Inequality	The difference in height of the two high waters of each tidal day for a mixed or semidiurnal tide.
DLQ Mean Diurnal Low Water Inequality	The difference in height of the two low waters of each tidal day for a mixed or semidiurnal tide.
HWI Greenwich High Water Interval	The average interval (in hours) between the moon's transit over the Greenwich meridian and the following high water at a location.
LWI Greenwich Low Water Interval	The average interval (in hours) between the moon's transit over the Greenwich meridian and the following low water at a location.
Station Datum	A fixed base elevation at a tide station to which all water level measurements are referred. The datum is unique to each station and is established at a lower elevation than the water is ever expected to reach. It is referenced to the primary bench mark at the station and is held constant regardless of changes to the water level gauge or tide staff. The datum of tabulation is most often at the zero of the first tide staff installed.

*Some locations have diurnal tides--one high tide and one low tide per day. At most locations, there are semidiurnal tides--the tide cycles through a high and low twice each day, with one of the two high tides being higher than the other and one of the two low tides being lower than the other.

[13] The chart can also be found at http://tidesandcurrents.noaa.gov/datum_options.html

4.4. APPENDIX D: Tidal Datum Epochs (NTDE)

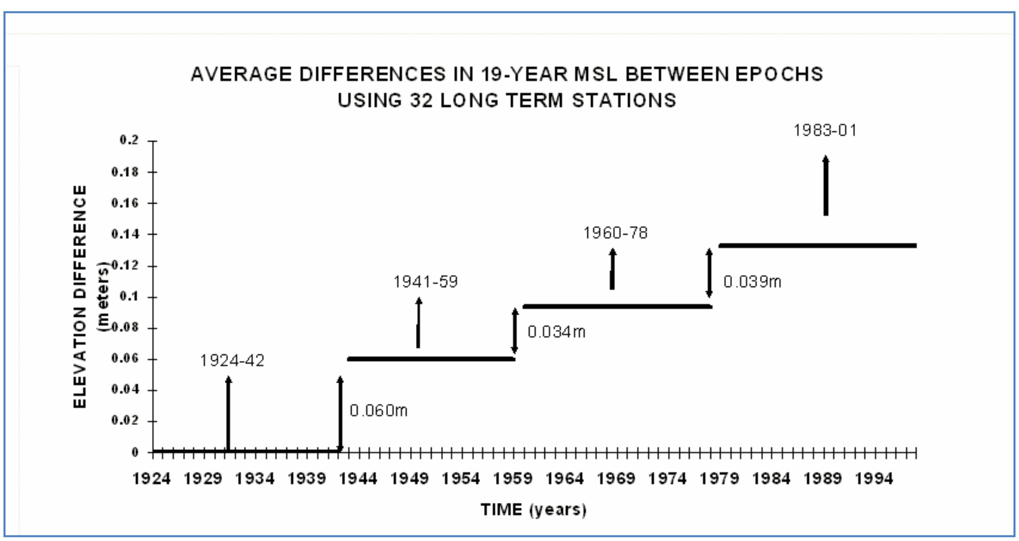
1. What is the National Tidal Datum Epoch (NTDE)?

- National Tidal Datum Epoch (NTDE) is a common time period to which tidal datums are referenced.
- A Tidal Datum Epoch is a specific 19 year period that includes the longest periodic tidal variations caused by the astronomic tide-producing forces.
- The present NTDE is 1983 through 2001 and is actively considered for revision every 20-25 years.
- Tidal Datum Epochs help average out long term seasonal meteorological, hydrologic, and oceanographic fluctuations.
- Tidal Datum Epochs provide a nationally consistent tidal datum network by accounting for seasonal and apparent environmental trends in sea level that affects the accuracy of tidal datums.

2. Why does the National Tidal Datum Epoch (NTDE) change?

- Each NTDE takes into account sea level rise.
- A modified 5 year epoch for Mean Sea Level (MSL) can be used **ONLY** in some areas along the Gulf Coast as well as southeast and southwest Alaska where anomalous sea level trends of a much greater magnitude occur than in the rest of the country.

Figure: History of updates to the National Tidal Datum Epoch due to sea level change from "Technical Considerations for Use of Geospatial Data in Sea Level Change Mapping and Assessment."



4.5. APPENDIX E: North American Vertical Datum of 1988 (NAVD 88) Heights

- NAVD 88 orthometric heights for survey monuments are displayed on NOAA's National Geodetic Survey's (NGS'S) datasheets where available
- If there was a height for the station on the National Geodetic Vertical Datum of 1929 (NGVD 29), then that height will be displayed under SUPERSEDED SURVEY CONTROL

Figure: Example of NAVD 88 and NGVD 29 Heights on NGS datasheet

The NGS Data Sheet

See file dsdata.txt for more information about the datasheet.

```
DATABASE =  ,PROGRAM = datasheet, VERSION = 7.85
1        National Geodetic Survey,   Retrieval Date = AUGUST 11, 2010
 KK1538 ***********************************************************************
 KK1538  DESIGNATION -  1 SIA
 KK1538  PID         -  KK1538
 KK1538  STATE/COUNTY-  CO/DENVER
 KK1538  USGS QUAD   -  COMMERCE CITY (1994)
 KK1538
 KK1538                         *CURRENT SURVEY CONTROL
 KK1538
 KK1538  NAD 83(1986)-  39 46 37.     (N)     104 52 59.      (W)     SCALED
 KK1538  NAVD 88     -      1607.650  (meters)     5274.43    (feet)  ADJUSTED
 KK1538
 KK1538  GEOID HEIGHT-         -17.51  (meters)                       GEOID09
 KK1538  DYNAMIC HT  -        1606.129 (meters)     5269.44   (feet)  COMP
 KK1538  MODELED GRAV-    979,624.3    (mgal)                         NAVD 88
 KK1538
 KK1538  VERT ORDER  -  FIRST     CLASS II
 KK1538
 KK1538.The horizontal coordinates were scaled from a topographic map and have
 KK1538.an estimated accuracy of +/- 6 seconds.
 KK1538
 KK1538.The orthometric height was determined by differential leveling and
 KK1538.adjusted in June 1991.
 KK1538
 KK1538.The geoid height was determined by GEOID09.
 KK1538
 KK1538                          SUPERSEDED SURVEY CONTROL
 KK1538
 KK1538 NGVD 29 (??/??/??) 1606.757  (m)         5271.50   (f) ADJUSTED    1 2
 KK1538
 KK1538.Superseded values are not recommended for survey control.
 KK1538.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
 KK1538.See file dsdata.txt to determine how the superseded data were derived.
```

- There are various Vertical Control sources, as listed on the datasheet and defined in the table below. The list is organized with the most accurate control sources at the top and less accurate control sources at the bottom. **Note that the Vertical Control source will change how many decimal places are displayed, and the more common Vertical Control sources are highlighted in red.**

Table: Vertical Control Sources used to establish NAVD 88 heights

	Vertrical Control Source NAME	Vertical Control Source DESCRIPTION	Number of Decimal Places Rounded to
1	ADJUSTED	Direct Digital Output from Least Squares Adjustment of Precise Leveling	3
2	ADJ UNCH	Manually Entered (and NOT verified) Output of Least Squares Adjustment of Precise Leveling	3
3	POSTED	Pre-1991 Precise Leveling Adjusted to the NAVD 88 Network After Completion of the NAVD 88 General Adjustment of 1991	3
4	READJUST	Precise Leveling Readjusted as Required by Crustal Motion or Other Cause	2
5	N HEIGHT	Computed from Precise Leveling Connected at Only One Published Bench Mark	2
6	RESET	Reset Computation of Precise Leveling	2
7	COMPUTED	Computed from Precise Leveling Using Non-rigorous Adjustment Technique	2
8	GPSCONLV	Leveled Orthometric Height tied to GPS HT_MOD Orthometric Height	2
9	LEVELING	Precise Leveling Performed by Horizontal Field Party	2
10	H LEVEL	Level between control points not connected to bench mark	1
11	GPS OBS	Computed from GPS Observations	1
12	VERT ANG	Computed from Vertical Angle Observations	1; if no check, then 0
13	SCALED	Scaled from a Topographic Map	0
14	U HEIGHT	Unvalidated height from precise leveling connected at only one NSRS point	2
15	VERTCON	The NAVD 88 height was computed by applying the VERTCON shift value to the NGVD 29 height	0

4.6. APPENDIX F: Types, stability, and construction of geodetic monuments

Geodetic monuments or marks are precise, stable locations that are permanently marked with a brass disk, metal rod, cement or stone platform, or other permanent structure, and different types of monuments have varying stability.

Mark Accuracy: geodetic control marks report accuracy bounds for each position value. These accuracies are estimated from the survey technique used and the coherence of the survey within the existing network (See FGDC accuracy standards at http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part2/chapter2).

Mark Type: geodetic control marks can include many types of surveyed objects. The type of mark can also help explain stability problems. Some types of marks are listed in the table below, but the list is not exhaustive. Visit the NGS website at http://www.ngs.noaa.gov/marks/descriptors.shtml#type to view a more complete list.

Table: Types of geodetic monuments or marks (list not exhaustive)

Rod types	Disk types	Misc. types	Landmarks
Metal rod	Benchmark disk	Pipe cap	Lone tree
Flange-encased rod	Triangulation station disk	Concrete post	Water tower
	Tidal station disk	Stone monument	Flagstaff

Mark Setting: the structure to which the mark is affixed. Survey marks should be stable, permanent, unique, recoverable, and safe-to-use. Marks can be set in rocks, boulders, or structures. They can also be characterized as shallow, un-sleeved deep, or sleeved deep settings. Guidelines for setting marks can be found in the Benchmark Reset Guidelines at http://www.ngs.noaa.gov/marks/reset/ or NOAA Manual NOS NGS 1 at http://www.ngs.noaa.gov/PUBS_LIB/GeodeticBMs.

Mark Stability: the best estimate of the mark's ability to maintain a long-term, constant position relative to other local features. Different stability classes and examples are summarized in the table below, and more information can be found on the NGS website at http://www.ngs.noaa.gov/marks/descriptors.shtml#stability.

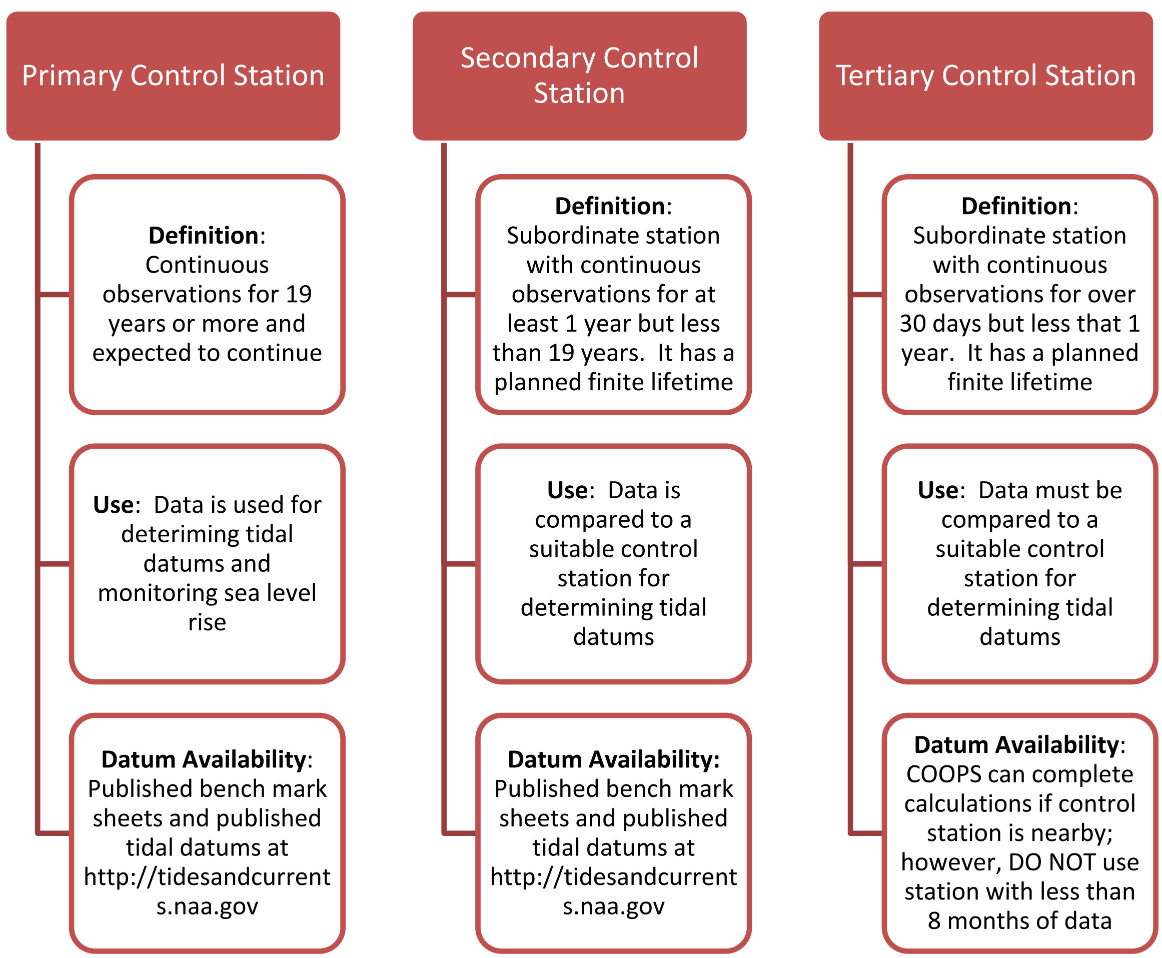
Table: Stability of geodetic monuments with examples

Stability	Definition	Examples
A	Setting expected to hold well	Large structure with deep foundation Large structure with foundation on bedrock In outcrop or ledge
B	Setting will probably hold well	Massive structures or retaining walls Abutment or pier of large bridges; tunnels Metal rods driven > 10 ft into ground
C	Setting may hold well, but commonly subject to movement	Set in top of concrete monument Retaining wall or concrete ledge Footings of small/medium structure
D	Setting of questionable or unknown reliability	Object driven in ground Object surrounded by mass of concrete Metal rod with base plate buried into ground

4.7. APPENDIX G: National Water Level Observation Network (NWLON) Stations

- NOAA's **Center for Operational Oceanographic Products and Services** (CO-OPS) manages the National Water Level Program (NWLP)
- The National Water Level Observation Network (NWLON) is a part of the NWLP and includes **210 long-term, continuously operating water-level stations** throughout the United States and around the world
- Control stations have a primary water level sensor, data collection platform with Geostationary Operational Environmental Satellite (GOES) transmitter, a power source, and a shelter from the elements.
- Different types of control stations, based on **definition, use, and availability** are described in the figure below.

Figure: Types of NWLON stations and their characteristics



4.8. APPENDIX H: Positioning and remote sensing technologies

There are many different positioning methodologies; some have existed for centuries while others are much newer, developing with the expansion of remote sensing technologies. The table below summarizes some methods with brief descriptions of their strengths and limitations regarding applications, accuracy, time, and expertise.

Table: Summary of positioning and remote sensing technologies

Method	Recommended Application	Accuracy	Time required	Expertise required	Procedures or guidelines
Leveling	High accuracy local network connections and monitoring of network and sensor stability	Sub-cm relative to local network and possibly NSRS	Depends on distance of connections (hours to days)	Moderate to high technical expertise	NGS webpage at http://www.ngs.noaa.gov/heightmod/Leveling/requirements.html
Static Global Navigation Satellite Systems (GNSS)	Establishing networks and monitoring stability of networks over time	2-5 cm relative to NSRS	Long occupation times (3-4 hours per point)	Relatively low technical expertise	NOAA Technical Memoranda NOS NGS-58 and NOS NGS-59
Real Time Kinematic (RTK) GNSS	Creating DEMs and position remote or hard to reach points	1-5 cm relative to local network	Short occupation times (1 sec-6 min)	High technical expertise	NGS User Guidelines for Single Base Real Time GNSS Positioning
Light Detection and Ranging (LIDAR)	Develop terrain models	15 – 100 cm	Flight time and air-craft required	Moderate to high technical expertise	http://lidar.cr.usgs.gov/LIDAR_Viewer/
Digital Elevation Model (DEM)	Model inundation, sea level rise, and storm surge scenarios	Dependent on data used to generate model	Data collected with other technologies	Relatively low technical expertise	http://eros.usgs.gov/#/Guides/dem
Flood plain mapping	Establish flood plains and flood insurance rate maps	Dependent on data used to generate map	Data collected with other technologies	Moderate to high technical expertise	http://msc.fema.gov/webapp/wcs/stores/servlet/FemaWelcomeView?storeId=10001&catalogId=10001&langId=-1

4.9. APPENDIX I: Numerical examples relating Geodetic and Tidal Datums

Published Values Process

Unknown: Tidal datum elevation for benchmark with Permanent Identifier (PID) AI8357

Known: NAVD 88 height of benchmark AI8357 from NGS datasheet[14]

NAVD 88 height at nearby tide station Eastport (Station ID: 8410140) [15]

Where is this information? See excerpt from tidal benchmark sheet below.

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

HIGHEST OBSERVED WATER LEVEL (01/10/1997)	=	7.383
MEAN HIGHER HIGH WATER (MHHW)	=	5.874
MEAN HIGH WATER (MHW)	=	5.729
NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)	=	3.029
MEAN SEA LEVEL (MSL)	=	[illegible]
MEAN TIDE LEVEL (MTL)	=	2.932
MEAN LOW WATER (MLW)	=	0.136
MEAN LOWER LOW WATER (MLLW)	=	0.000
LOWEST OBSERVED WATER LEVEL (08/09/1972)	=	-1.426

Equation:

$$BM\ Height\ (MLLW) + NAVD88\ (MLLW) = BM\ Height\ (NAVD88)$$

Computation:

$$AI8357\ (MLLW) + 3.029\ m = 4.943\ m$$

$$AI8357\ (MLLW) = 1.914\ m$$

[14] To find this value, go to http://www.ngs.noaa.gov/cgi-bin/datasheet.prl, select retrieve "datasheets," search by PID, and the datasheet for AI8357 will list NAVD88 = 4.943 m. It also lists that the orthometric height was determined by differential leveling and adjusted in July 2002.

[15] To find this value (as illustrated in excerpt above), go to http://www.tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Bench+Mark+Data+Sheets, enter Station ID 8410140 directly, and near the bottom of the benchmark sheet page find NAVD88 = 3.029 m

Algebraic Computation Process

NOTE: In this example there is enough information to complete the "Published Values Process"; however, in order to learn how to complete the "Algebra Computation Process," ignore the published NAVD88 (MLLW) for station 8410140.

Unknown: Tidal datum elevation for benchmark with Permanent Identifier (PID) AI8357

Known: NAVD 88 height of benchmark AI8357 from NGS datasheet[16]

PID#'s for tidal benchmark(s) at nearby tide station Eastport (Station ID: 8410140) from tidal benchmark sheet[17]

NAVD 88 heights for tidal BM(s) at Eastport (Station ID: 8410140) from NGS datasheets[18]

Tidal datum elevations for tidal BM(s) at Eastport (Station ID: 8410140)[19]

Where is this information? See excerpt from tidal benchmark sheet below.

Bench Mark Elevation Information — In METERS above:

Stamping or Designation	MLLW	MHW
NO 3 1918	14.223	8.494
MAINE 40 1907	15.199	9.470
NO 2 1918	10.779	5.050
NO 4 [illegible]	[illegible]	[illegible]
NO 8 1975	11.791	6.062
NO 9 1975	7.974	2.245
NO 10 1975	9.732	4.003
0140 K 1976	12.114	6.385

[16] To find this value, go to http://www.ngs.noaa.gov/cgi-bin/datasheet.prl, select retrieve "datasheets," search by PID, and the datasheet for AI8357 will list NAVD88 = 4.943 m.

[17] To find these values, go to http://www.tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Bench+Mark+Data+Sheets, enter Station ID 8410140 directly. The first three benchmarks listed are (1) 'NO 3 1918' = 'PID# PD0006,' (2) 'MAINE 40 1907' = 'PID# PD0003,' and (3) 'NO 2 1918' = 'PID# PD0005'

[18] To find these values, go to http://www.ngs.noaa.gov/cgi-bin/datasheet.prl, select retrieve "datasheets," search by PID. The datasheet for PD0006 will list NAVD88 = 11.198 m, the datasheet for PD0003 will list NAVD88 = 12.170 m, and the datasheet for PD0005 will list NAVD88 = 7.753 m.

[19] To find these values (as illustrated in excerpt above), go to http://www.tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Bench+Mark+Data+Sheets, enter Station ID 8410140 directly, and near the bottom of the benchmark sheet page find for 'NO 3 1918,' MLLW= 14.223 m, (2) for 'MAINE 40 1907,' MLLW = 15.199 m, and (3) for 'NO 2 1918,' MLLW = 10.779 m.

Equation:

$$BM\ Height\ (MLLW) +\ NAVD88\ (MLLW) = BM\ Height\ (NAVD88)$$

Where:

$$NAVD88\ (MLLW) = AVERAGE[BM\ Height\ (MLLW) -\ BM\ Height\ (NAVD88)]$$

Computation:

$$\left.\begin{array}{l} 14.223\ m - 11.198\ m = 3.025 \\ 15.199\ m - 12.170\ m = 3.029 \\ 10.779\ m - 7.753\ m = 3.026 \end{array}\right\} \quad \frac{(3.025+3.029+3.026)}{3} = 3.027$$

$$AI8357\ (MLLW) +\ 3.027\ m = 4.943\ m$$

$AI8357\ (MLLW) = 1.916\ m$

Interpolation Process[20]

Unknown: NAVD 88 height at tide station Wells (Station ID: 8419317)

Known: Mean Tide Level (MTL) at Wells (8419317) from tidal benchmark datasheet[21]

Mean Tide Level MTL at two nearby tide stations (Seavey and Pine Point) from tidal benchmark sheets[22]

NAVD 88 heights at same nearby tide stations (Seavey and Pine Point)[23]

Where is this information? NAVD 88 heights must be published on datasheets or computable through another method described in this section.

Equation:

$$Station\ Height\ (MTL) + NAVD88\ (MTL) = Station\ Height\ (NAVD88)$$

Where:

$$NAVD88\ (MTL) = AVERAGE[SH\ (NAVD88) - SH\ (MTL)]$$

Computation:

$$1.409\ m - 1.333\ m = 0.076\ m$$

$$1.499\ m - 1.437\ m = 0.062\ m$$

$$\frac{(0.076+0.062)}{2} = 0.069\ m$$

$$1.440\ m + 0.069\ m = SH\ (NAVD88)$$

$$SH\ (NAVD88) = 1.509\ m$$

[20] This process only provides an estimate until more data can be gathered. Additionally, the example estimates the NAVD 88 height at a tide station where there are known NAVD 88 heights one station to the north and one station to the south). If the location of the tides stations, relative to one another, is different (e.g. both reference stations are to the south), then the interpolation must be modified and should not be treated like an average.

[21] To find this value (as illustrated in excerpt), go to http://www.tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Bench+Mark+Data+Sheets, enter Station ID 8419317 directly, and near the bottom of the benchmark sheet page find MTL = 1.440 m

[22] Follow process in note 20 for Stations 8419870 and 8418445 to find MTL = 1.333 m and 1.437 m, respectively

[23] Follow process in note 14 for Stations 8419870 and 8418445 to find NAVD88 = 1.409 m and 1.499 m, respectively

VDATUM Tool Process

Read the "Estimations of Vertical Uncertainties in VDatum" at http://vdatum.noaa.gov/docs/est_uncertainties.html and check if VDatum is available in your region of the country at http://vdatum.noaa.gov/about/availability.html.

There are step-by-step instructions on how to download the VDatum software and use the program at http://vdatum.noaa.gov/welcome.html. The program is still under development, and it should continue to improve in the future.

***

4.10. APPENDIX J: Glossary

accuracy - agreement between a measurement and the true or correct value

adjustment - process of changing the values of a given set of quantities so that results calculated using the changed set will be better than those calculated using the original set

backbone site - physical survey monuments with highly accurate vertical control consistently spaced throughout a park supporting accurate elevation computation at priority sites within the park

benchmark - see definition for geodetic monument

Continuously Operating Reference Station (CORS) network - provides Global Navigation Satellite System (GNSS) data consisting of carrier phase and code range measurements in support of three dimensional positioning, meteorology, space weather, and geophysical applications throughout the United States, its territories, and a few foreign countries

control station - point on the ground whose horizontal or vertical location is the basis for obtaining locations of other points

control, vertical - control points whose elevations are accurately known; can be identified with physical points on the Earth and can be used to provide elevations for other surveys

datum - reference point, plane or surface

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

datum, tidal- base reference elevation from which local water levels are measured

datum, vertical- reference point, plane or surface from which elevations are measured

Digital Elevation Model (DEM)- digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals

elevation- see definition for height

epoch - a specific period of time

error - disagreement between a measurement and the true or accepted value

floodplain map - shows the location of the normal channel of a water course, surrounding features or developments, ground elevation contours, flood levels and floodplain limits for particular storm event recurrence interval (e.g. the elevation and horizontal extent of the high water marks of a 200-year flood)

geodesy - science concerned with determining the size and shape of the Earth and how it changes with time

geodetic control - a control station and its coordinates established by geodetic methods

geodetic control, active - control station designated by an operating GNSS or GPS receiver

geodetic control, passive - control station designated by a geodetic monument

geodetic leveling - process of finding vertical distances, or elevations, from a selected equipotential surface to the Earth's surface or finding differences of elevations

geodetic monumentslocations permanently marked with a brass disk, metal rod, cement or stone platform, or other permanent structure

geoid - the equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level

Global Navigation Satellite System (GNSS) - navigational and positioning system by which the location of a position on or above the Earth can be determined by a special receiver at that point interpreting signals received simultaneously from several of a constellation of satellites

Global Positioning System (GPS) - navigational and positioning system by which the location of a position on or above the Earth can be determined by a special receiver at that point interpreting signals received simultaneously from several of a constellation of satellites developed by the U.S. Department of Defense

height - distance perpendicular to the local gravity field, measured from a reference point, plane, or surface

height above ellipsoid- distance between the reference ellipsoid and the Earth's surface

height, geoid - distance between the geoid and reference ellipsoid

height, orthometric- distance between the geoid and the Earth's surface

height, tidal datum- distance between an established tidal datum and the Earth's surface

interpolation- method of constructing new data points within the range of a discrete set of known data points

Light Detection and Ranging (LIDAR)- remote sensing system used to collect topographic data using laser technology

metadata- information that captures the basic characteristics of a data or information resource, representing the "who," "what," "when," "where," "why," and "how" of the resource

National Spatial Reference System (NSRS) - consistent national coordinate system in the United States that specifies latitude, longitude, height, scale, gravity, and orientation, as well as how these values change with time

National Tidal Datum Epoch (NTDE)- specific 19 year period that includes the longest periodic tidal variations caused by the astronomic tide-producing forces

National Water Level Observation Network (NWLON)- network of 175 long-term, continuously operating water-level stations throughout the U.S., including its island possessions and territories and the Great Lakes

NOAA's Center of Operational Oceanographic Production (CO-OPS) - office in NOAA's National Ocean Service that provides the national infrastructure, science, and technical expertise to monitor, assess, and distribute tide, current, water level, and other coastal oceanographic products and services

NOAA's National Geodetic Survey (NGS) - office of NOAA's National Ocean Service that defines and manages a national coordinate system, the National Spatial Reference System (NSRS)

North American Datum of 1983 (NAD 83) - horizontal control datum for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the Geodetic Reference System 1980

North American Vertical Datum of 1988 (NAVD 88) - vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-U.S. leveling observations. It held fixed the height of the primary tidal bench mark at Father Point/Rimouski, Quebec, Canada

Online Positioning User Service (OPUS)- internet-based program that processes GNSS or GPS data file, sends a user a highly accurate computed (reduced, adjusted) position, and provides option to publish the position in an online database (OPUS-DB)

precision - repeatability of a measurement, but it does not require one to know the correct or true value

Real Time Kinematic (RTK) positioning - employs GNSS or GPS technology to produce and collect three-dimensional positions relative to a stationary base station

reference ellipsoid- approximation of the geoid that is a mathematically "smooth" surface used in calculations

remote sensing - instrument-based techniques used to acquire and measure spatially organized data or information and employed at a finite distance from the observed target

sea level, global - average height of all Earth's oceans with respect to the geoid, and in equilibrium with the gravitational field of the earth.

sea level, local - height of the water as measured along the coast relative to a specific point on land

sea level rise (SLR), global - the increase currently observed in the average Global Sea Level Trend primarily attributed to thermal expansion and ice melt

sea level trend, global- reflect changes in Global Sea Level

sea level trend, relative - reflect changes in local sea level over time and are typically the most critical sea level trend for many coastal applications

sentinel site - locations where Park managers determine there are critical infrastructure, habitats, cultural sites, and populations of species of concern

shapefile- spatial data format that stores nontopological geometry and attribute information for the spatial features in a data set

superseded survey control- coordinates established on a control station that have been replaced by newer, more accurate coordinates

survey monument- see definition for geodetic monuments

tide stations- water level measurement system with an acoustic water level sensor, data collection platform, and backup measurement system

historical station - tide station with a water level data record that is not currently collecting water level data

primary control station- tide station with continuous observations for 19 years or more and expected to continue

secondary control station- subordinate tide station with continuous observations for at least 1 year but less than 19 years with a planned finite lifetime

tertiary control station- subordinate station with continuous observations for over 30 days but less that 1 year with a planned finite lifetime

VDATUM- software tool being developed by NOAA, designed to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums

VERTCON- software tool developed by NOAA's National Geodetic Survey to transform data between the National Geodetic Vertical Datum of 1929 (NGVD 29) and the North American Datum of 1988 (NAVD 88)

WGS 84 - the World Geodetic System of 1984, the reference frame used by the U.S. Department of Defense (DoD) and defined by the National Geospatial-Intelligence Agency (NGA)

4.11. APPENDIX K: Acronyms

Acronym	Definition
BM	Benchmark
CO-OPS	Center for Operational Oceaniographic Products and Services
CORS	Continuously Operating Reference Stations
DEM	Digital Elevation Model
DHQ	Mean Diurnal High Water Inequality
DLQ	Mean Diurnal Low Water Inequality
DOI	Department of Interior
DOT	Department of Transportation
DTL	Diurnal Tide Level
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GT	Great Diurnal Range
HAE	Height Above Ellipsoid
HWI	Greenwich High Water Interval
LIDAR	Light Detection and Ranging
LWI	Greenwich Low Water Interval
MHHW	Mean Higher High Water
MHW	Mean High Water
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MN	Mean Range of Tide

Acronym	Definition
MSL	Mean Sea Level
MTL	Mean Tide Level
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NGS	National Geodetic Survey
NGVD 29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NSRS	National Spatial Reference System
NTDE	National Tidal Datum Epoch
NWLON	National Water Level Observation Network
NWLP	National Water Level Program
OPUS	Online Positioning User Service
OPUS-DB	Online Positioning User Service-Database
PID	Permanent Identifier
RTK	Real Time Kinematic
SET	Surface Elevation Table
SLR	Sea Level Rise

4.12. APPENDIX L: Additional Resources

***PLEASE NOTE**: ALL WEB ADDRESSES WERE UP TO DATE WHEN THIS DOCUMENT WAS CREATED. IF A LINK NO LONGER WORKS, PLEASE CONTACT THE AGENCY OR ORGANIZATION THAT MAINTAINS THE SITE. THIS APPLIES TO ALL WEB ADDRESSES WITHIN THE DOCUMENT AND LISTED IN THIS APPENDIX.*

Table: Summary of web addresses included in this document and their managing agency or organization.

Managing Agency/Organ.	Web Page	Web address
Federal Geographic Data Committee	**FGDC BLUE-BOOK GUIDELINES**	http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part2/chapter2
FEMA's Map Service Center	**FEMA'S BLUE BOOK**	http://msc.fema.gov/webapp/wcs/stores/servlet/FemaWelcomeView?storeId=10001&catalogId=10001&langId=-1
NOAA's Center for Operational and Oceanographic Products and Services	**CO-OPS HOMEPAGE**	http://tidesandcurrents.noaa.gov/
	HISTORIC TIDE DATA	http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Historic%20Tide%20Data&state=All%20Stations&id1
	TIDE STATION MAP INTERFACE	http://www.tidesandcurrents.noaa.gov/gmap3/
NOAA's National Geodetic Survey	**LOCUS WEBPAGE**	http://beta.ngs.noaa.gov/locus/LOCUS2.html
	NGS HOMEPAGE	http://www.ngs.noaa.gov/
	DATASHEET SEARCH PAGE	http://www.ngs.noaa.gov/cgi-bin/datasheet.prl
	CORS HOMEPAGE	http://www.ngs.noaa.gov/CORS/
	BLUEBOOK PROCEDURES	http://www.ngs.noaa.gov/FGCS/BlueBook/
	GEOID HOMEPAGE	http://www.ngs.noaa.gov/GEOID/
	BENCHMARK RESET PROCEDURE	http://www.ngs.noaa.gov/heightmod/Leveling/Manuals/Benchmark_9_13_07.pdf
	GEODETIC LEVEING REQUIREMENTS	http://www.ngs.noaa.gov/heightmod/Leveling/requirements.html
	MARK STABILITY	http://www.ngs.noaa.gov/marks/descriptors.shtml#stability
	MARK TYPE	http://www.ngs.noaa.gov/marks/descriptors.shtml#type
	MARK RESET FORM	http://www.ngs.noaa.gov/marks/reset/
	MARK RECOVER FORM	http://www.ngs.noaa.gov/ngs-cgi-bin/recvy_entry_www.prl
	OPUS HOMEPAGE	http://www.ngs.noaa.gov/OPUS/
	USER-CONTRIBUTED SOFTWARE	http://www.ngs.noaa.gov/PC_PROD/PARTNERS/index.shtml
	NOAA MANUAL NOS NGS 1	http://www.ngs.noaa.gov/PUBS_LIB/GeodeticBMs
	REAL TIME USER GUIDELINES	http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v1.0.pdf

	VISIBILITY OBSTRUCTION DIAGRAM	http://www.ngs.noaa.gov/RSD/forms/visibility.pdf
NOAA's National Ocean Service	**VDATUM AVAILABILITY**	http://vdatum.noaa.gov/about/availability.html
	VDATUM UNCERTAINTY	http://vdatum.noaa.gov/docs/est_uncertainties.html
	VDATUM HOMEPAGE	http://vdatum.noaa.gov/welcome.html
NPS's Geographic Information Systems	**NPS GIS HOMEPAGE**	http://www.nps.gov/gis/
NPS's Lands Resources Division	**NPS LANDS RESOURCES DATABASE**	http://landsnet.nps.gov/monuments
USGS Earth Resources Observation and Science Center	**DIGITAL ELEVATION MODEL GUIDELINES**	http://eros.usgs.gov/#/Guides/dem
	LIDAR VIEWER	http://lidar.cr.usgs.gov/LIDAR_Viewer/

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Authors

Timothy G. Smith, National Park Service National GPS Program Coordinator
Tim_Smith@nps.gov, (303)969-2086

Christine Gallagher, National Geodetic Survey, NOAA
Christine.Gallagher@noaa.gov

National Park Service
U.S. Department of the Interior

Resource Information Services Division
12795 W. Alameda Pkwy.
Lakewood, CO 80228

www.nps.gov/gis

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