4 Survey Datums

Contents

4 Survey Datums

Today's multi organizational project development efforts require the use of common horizontal and vertical survey datums to ensure the accurate location of fixed works and rights of way throughout the life of the project. These requirements are compounded by the expanding use of geographic information systems (GIS) by this Department, local agencies, and private partners. Universally accepted common survey datums are essential for the efficient sharing of engineering and geospatial data for developing and operating a modern transportation system.

A geodetic datum is an abstract coordinate system with a reference surface (such as an ellipsoid) that serves to provide known locations to begin surveys and create maps. There are two main types of positional datums. Horizontal datums provide a reference for positions (latitude and longitude) on the surface of the Earth, while vertical datums are used to measure land elevations and water heights or depths.

The horizontal datum can be accessed and used through a collection of specific points on the Earth whose locations have been accurately determined. The vertical datum is similarly "realized" through a collection of specific points with known heights relative to a defined reference surface.

Tidal datums are a different kind of vertical datum than geodetic vertical datums, and are used, for example, as a reference level to which bathymetric soundings are referenced for nautical charts. Comparison between vertical geodetic datums and tidal datums can be done by geodetic surveys at tide gauges[1].

Since there are numerous datums in use for various geospatial applications, project managers, planners, surveyors, engineers, asset managers and stakeholders need to know to which datum their project data are referenced. Using the wrong datum can result in small to very large errors, which can cause project cost overruns and delays. Appropriate transformation tools are needed to integrate data from multiple sources referenced to different datums. Department Surveys needs to always be involved early in project planning, so that any issues involving datums can be identified and resolved.

At the beginning of each project, the project surveyor will approve the datums and control monuments to be used for all project development mapping.

[1] Definitions courtesy of National Ocean Service, http://oceanservice.noaa.gov/facts/datum.html

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4.1 Policy and Procedures

4.1-1 Policy

The official reference network within the United States is the National Spatial Reference System (NSRS), which is developed and maintained by the National Geodetic Survey (NGS). The official horizontal or geometric[2] datum of the United States is the North American Datum of 1983 (NAD 83), and the official vertical datum is the North American Vertical Datum of 1988 (NAVD 88).

The official geodetic reference network of the State of California is the California Spatial Reference Network (CSRN). The CSRN consists of all NSRS monuments in or near the State of California and any other monuments with data published by the California Spatial Reference Center (CSRC).

The California Public Resources Code[3] identifies the official geodetic datum to which horizontal positions and ellipsoid heights are referenced within the State of California as the North American Datum of 1983 (NAD 83). NAD 83 is the basis for the California Coordinate System of 1983 (CCS83), which will be used for all Department-involved transportation improvement projects.

The official geodetic datum to which orthometric heights (elevations) are referenced within the State of California is NAVD 88[4]. According to P.R.C. Sec. 8890, "Orthometric heights within the State of California that are based on the North America Vertical Datum of 1988 and conforming to the provisions of this chapter shall be known as "California Orthometric Heights of 1988" (COH88). This manual will use the term "NAVD 88", but this includes any elevations that conform to the provisions for COH88 elevations as described in P.R.C. Sections 8890-8902.

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[2] The terms "geodetic datum" and "geometric datums" are often used synonymously, but they have different meanings. According to NGS, a geodetic datum is "A set of constants specifying the coordinate system used for geodetic control…" A geometric datum, such as NAD 83, "has no direct dependence on the gravity field of the earth". Therefore, geometric datums are geodetic datums that have latitude, longitude, and ellipsoid heights, but are not constrained to any gravity data.

[3] P.R.C. Section 8852

[4] P.R.C. Section 8853

CCS83 and NAVD 88 values will be expressed in meters and decimals of a meter or feet and decimals of a foot. When values are expressed in feet, the “U.S. Survey Foot” (one foot equals 1200/3937 meters) shall be used as the standard foot.[5]

4.1-2 Procedures

All project development work (mapping, planning, design, right of way engineering and construction) for each specific Department-involved transportation improvement project shall be based on common horizontal and vertical datums (coordinates and elevations).

The project datums will be selected for each project by Surveys as early in the project development process as possible. This should be no later than the approval of the Project Initiation Document (PID) during project planning. See Sec. 4.6 for guidance on selecting project datums.

All surveys within the state highway system will be based on monuments that are part of the CSRN. Exceptions are permitted, with appropriate District Surveys functional approval (Surveys or Right of Way Engineering), for small, remote, or isolated surveys where ties to the official datums cannot be economically established. As resources are available, the Department will monitor and maintain the integrity of the CSRN in cooperation with NGS, CSRC and others.

When projects are located on the coast or near tidal estuaries, Surveys is responsible for determining the relationship between NAVD 88 elevations and local tidal datums, as referenced to the latest National Tidal Datum Epoch (NTDE) and published by the Center for Operational Oceanographic Products and Services (CO-OPS) of the National Oceanographic and Atmospheric Administration (NOAA).

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[5] P.R.C. Sections 8810 and 8893

4.2 Horizontal / Geometric Datums

4.2-1 Policy

All project delivery work (mapping, planning, design, right of way engineering and construction) for all Department-involved transportation improvement projects shall be based on the North American Datum of 1983 (NAD 83).

The official geodetic reference network of the State of California is the California Spatial Reference Network (CSRN)[6]. The CSRN consists of all horizontal geodetic control stations within the state that meet the following requirements[7]:

1. Be referenced to NAD 83.
2. Have been determined by Global Positioning System (GPS) survey methods.
3. Be published by the NGS or CSRC[8].
4. Have a NGS- or CSRC- published network accuracy of two centimeters or better, as defined by the Federal Geographic Data Committee (FGDC), or a NGS or CSRC published accuracy of first order or better *(see Chapter 5, Classification of Accuracy and Standards)*.
5. Have a NGS- or CSRC- published horizontal velocity or a horizontal velocity that can be determined using procedures and values published by NGS or CSRC.

4.2-2 Common Geodetic Ellipsoids

The surface of the earth is not round, or even very smooth. Over the centuries, geodesists and mathematicians have constantly measured the globe, trying to create mathematical models to fit the shape of the sea level surface of the earth. In the late 1800's, the U.S. Government began using an ellipsoid known as Clarke's Spheroid of 1866 as the basis for all geodetic surveys. The name of the final adjustment that used this reference ellipsoid was the North American Datum of 1927 (NAD 27).

Since 1986, NAD 83 has been the official horizontal and geometric datum in the United States. The mathematical reference surface used to represent NAD 83 is an ellipsoid called the Geodetic Reference System of 1980 (GRS 80). GRS 80 is a world-wide model which replaced Clarke's Spheroid of 1866, which was only accurate for North America.

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[6] P.R.C. Sec. 8855

[7] P.R.C. Sec. 8856

[8] CSRC data at http://csrc.ucsd.edu/
- NGS datasheets at http://www.ngs.noaa.gov/cgi-bin/datasheet.prl

The GRS 80 ellipsoid is the basis of three of the most common reference frames used today: NAD 83, the World Geodetic System of 1984 (WGS 84) and the International Terrestrial Reference Frame (ITRF). Initially, all three reference frames had the same ellipsoid shape, prime meridian, and center of mass. NAD 83 is a fixed, geometric ellipsoid that doesn't change its location as more accurate data becomes available. The WGS 84 ellipsoid[9] is periodically adjusted by the U.S. Department of Defense to reflect the latest calculations for the earth's center of mass, based on GPS satellite orbits.

The parameters of the earth's ellipsoid, as determined by the International Earth Rotation and Reference Systems Service (IERS), is the International Terrestrial Reference Frame (ITRF). ITRF 2008 (Epoch 2005.00) has an almost identical ellipsoid to NAD 83, but the center of mass is about 2.2 meters away. The ITRF started with the same prime meridian as NAD 83, but it has moved whenever IERS adjusts the prime meridian to achieve a "no net rotation", compensating for tectonic plate motion worldwide.

The WGS 84 reference frame started out equivalent to NAD 83, but WGS 84 has been adjusted to conform to the ITRF center of mass and prime meridian. The GPS satellites use the current version of WGS 84 (most recently G1674, published in February 2012) as the center of their orbits. The differences between ITRF 2008 and WGS 84 (G1674) are minimal.

Figure 4.1

Ellipsoid	Semi-Major Axis	Semi-Minor Axis	Center	Meridian
Clarke's 1866	6378206.4m	6356583.8m	N/A	Fixed
NAD 83	6378137.000m	6356752.314140m	Fixed	Fixed
WGS 84	6378137.000m	6356752.314245m	Adjusted	Adjusted

4.2-3 Description of NAD 83

The coordinate system for NAD 83 is based on latitude (defined as the angular distance North or South of the equator) and longitude (defined as angular distance East or West of the prime meridian). The NAD 83 prime meridian is about 102 meters east of the pre-navigation-satellite prime meridian at Greenwich, England.

[9] Department of Defense – World Geodetic System 1984
http://earth-info.nga.mil/GandG/publications/tr8350.2/wgs84fin.pdf

Positions referenced to NAD 83 data can be presented in two ways. The most common is Latitude, Longitude, and Ellipsoid Height. It can also be described in X-Y-Z coordinates, where 0,0,0 is the center of the ellipsoid. In order to use NAD 83 coordinates for plane surveying, the data must be projected to a two dimensional grid. In California, the California Coordinate System of 1983 (CCS83) is used. See Section 4.3 for more information.

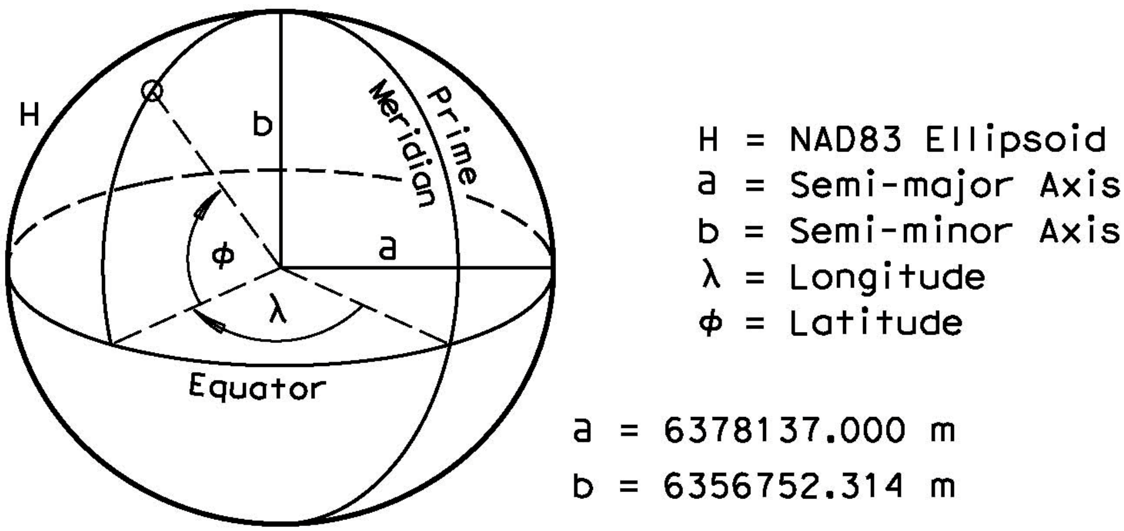

Figure 4.2 - NAD 83

4.2-4 Monuments and Datasheets

The NAD 83 datum is a mathematical model that must be projected onto the earth's surface for use by surveyors, in the form of geodetic control monuments. There are two basic types of geodetic control stations, passive and active.

A passive station is, in NGS terminology, a "conventional" ground station (e.g., a brass disk set in a substantial structure, a steel rod driven into the ground to refusal, or other such stable physical marks) that can be observed by surveyors using standard field equipment. All of the original High Precision Geodetic Network (HPGN) monuments, the subsequent densification stations (HPGN-D), and Height Modernization (Ht Mod)[10]

[10] Ht Mod Surveys are precision GNSS surveys performed per NOAA Technical Memorandums NOS NGS 58 and 59

monuments published by NGS are passive marks. Passive monuments can be used as either primary control stations or as calibration points for GNSS[11] rover units.

An active station is a GNSS antenna and receiver in a fixed location. They are called CORS (Continuously Operating Reference Station) when operated by NGS, and are generically known in California as CGPS (Continuous GPS) stations. Because of the continuous nature of their data, and their long observation history, the CGPS stations are the most accurate control monuments available (better than 1-2 cm horizontally, and 2-4 cm vertically).

NGS datasheets are ASCII text files that have data for survey control monuments in the NSRS. They can be for horizontal control, vertical control, or both. Datasheets and detailed descriptions of the data and metadata are available from NGS at http://www.ngs.noaa.gov/cgi-bin/datasheet.prl

4.2-5 Datum Tags, Epochs, and Velocities

The initial NAD 83 coordinates resulted from a nationwide least squares adjustment of the original terrestrial observations that had incrementally built up the NAD 27 network. The adjustment results were published in 1986, so that the first realization of the reference frame was called NAD 83 (1986). The term in parentheses, e.g. (1986) or (2007), is the *Datum Tag,* which denotes a specific realization, or adjustment, of the NAD 83 datum.

To fully specify the realization and timeframe, the datum tag must be followed by an epoch date, for example "NAD 83(2011) Epoch 2010.00." The published coordinates are valid for the epoch date displayed. The epoch date is in deciyear format, where the numbers to the right of the decimal point are derived from the Julian day of the year. For example, to determine the Julian day for 1991.35, multiply 0.35 times 365 (days, for a non-leap year) to ascertain that .35 year equates to the 128th day of the year, or May 8. The datum tag date (year) and the epoch date can be coincident or different.

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[11] All satellite navigation systems are collectively referred to as a Global Navigation Satellite System (GNSS). The first commercially available system was the United States' Global Positioning System (GPS). This chapter uses the terms "GNSS" to describe the field equipment and procedures for all satellite- based surveys, and "GPS" for the U.S. Government system and related technical terms.

For the HPGN survey, which extended over several months, the epoch date selected was the mean date of the field observations. For the HPGN-D surveys, the epoch date was not related to when the fieldwork was performed but rather was the epoch date of their constraining stations, which were –by definition—those that had been in the HPGN survey, which had an epoch date of 1991.35. For Height Modernization Program projects, the epoch date represents the mid-point of the three multi-hour observations of the Primary Base Network stations. For CORS datum tags, the NGS uses the data as of January 1st of the epoch year, so they usually have an epoch date ending in ".00".

P.R.C. Code Sections 8815.1 and 8877 require that when state plane or geodetic coordinates are shown on a record of survey, the epoch date shall be shown. To fully document the control used in a survey, the datum tag must also be shown; for example "NAD 83 (2007) Epoch 2002.00." The HPGN network is commonly called "Epoch 1991.35", but the full description is, "NAD 83 (1992), Epoch 1991.35".

Once an adjustment with its datum tag is established, there can be several epochs associated with the adjustment. For example, after the Landers earthquake in June, 1992, a re-observation of many of the affected HPGN and other geodetic monuments was performed, and monuments that were adjusted retained the datum tag of NAD 83 (1992), but were given a new epoch date of 1992.88.

Much of California is affected by relatively large crustal motions, both secular (constant slip) and episodic (earthquake). Over the years, portions of the CSRN have been resurveyed because of the Landers (1992), Northridge (1994), and Hector Mine (1999) earthquakes. In addition, secular crustal motions can exceed 0.16 foot (5 cm) per year, slowly shifting the locations of both passive and active stations. When data is collected for a long enough time, the horizontal and vertical velocities of the stations can be determined and published.

Documenting the datum tag, epoch date, and velocities of the monument coordinates is crucial because they are necessary to properly determine coordinates when using monuments from different adjustments and epochs.

Surveys with different datum tags and epochs can be translated to a common horizontal datum by using HTDP (Horizontal Time Dependent Positioning), a velocity computer model, which is available at http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml. First released in 1992, the program translates geodetic data from one epoch to another based on a geophysical model for horizontal velocities and episodic crustal motion in the western U.S. states. Using HTDP, a surveyor's adjustment could utilize control stations with coordinates from different published adjustments, although that is not preferred. The

HTDP model has an accuracy of about 1cm/year, and can account for much of the systematic error of geodetic coordinates resulting from crustal motion that occurs subsequent to the publication date.

4.2-6 NAD 27

Prior to the development of NAD 83, the standard geometric datum for the United States was the North American Datum of 1927 (NAD 27). NAD 27 was based on Clarke's Spheroid of 1866, which was a good fit for North America, but was not a good model of the Earth. NAD 27 was discontinued as a valid datum for new surveys in California as of January 01, 1995[12].

NAD 27 was created using data from terrestrial surveys, with a single triangulation monument at Meade's Ranch, Kansas held as the initial point. NAD 27 geodetic coordinates can be as much as 100 meters different from NAD 83 coordinates. NGS does not produce new coordinates referenced to NAD27. See Section 4.3-4 for guidance on converting coordinates between NAD 27 and NAD 83

4.2-7 NAD 83 Realizations

There have been multiple realizations of NAD 83. See Appendix 1 for a list of most NGS projects in California. Below are descriptions of the major adjustments (realizations).

4.2-7(a) NAD 83 (1986) Epoch 1984.00

The initial NGS station coordinates based on NAD83 were the result of a simultaneous nationwide adjustment of the original observation that incrementally built up the NAD27 network. The adjustment results were published in 1986, so the datum tag is formally known as NAD 83 (1986) Epoch 1984.00. Because the concept of datum tags and epochs was new, many of the early NAD 83 surveys did not identify the datum tag or epoch date, simply using the term "NAD 83". Whenever the term NAD 83 is used in documentation without any other identifiers, research must be done to identify the proper datum tag and epoch.

4.2-7(b) NAD 83 (1992) Epoch 1991.35

Due to the limitations of the NAD 27 observations, the 1986 adjustment had a network accuracy on the order of 1 meter. Surveyors using electronic distance meters and GPS equipment were soon reporting problems throughout the network. In 1991, the California High-Precision Geodetic Network (CA-HPGN) was established using GPS technology, based on 22 NGS Order "A" stations (1: 10,000,000 accuracy) as control.

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[12] P.R.C. Sec. 8817

The GPS survey was far more precise than the methods used to establish the NAD83 reference system in 1986. Coordinates for stations determined with reference to the CA-HPGN had an accuracy of Order B (1:1,000,000). The original spacing for the HPGN was 40 miles (64 km). To improve access to the HPGN, densification monuments were set at 10-15 mile (16-24 km.) spacing. The coordinates for these monuments were also given the 1991.35 epoch, as they were constrained to the original HPGN monuments.

When there were significant episodic events (earthquakes), the affected HPGN monuments were resurveyed, re-adjusted, and given new coordinates. In some cases (Landers Earthquake, 1992) the original datum tag (1992) was used, and the adjustment given a new epoch date. In others (Northridge, 1994), the re-adjustment was given both a new datum tag and epoch date.

4.2-7(c) NAD 83 (1998) Epoch 1998.5 and the Federal Base Network

The HPGN system was an adjustment of passive monuments within the State of California. Over the next few years, other states also created their own High Accuracy Reference Networks (The generic acronym HARN has been adopted to described both HPGN and HARN networks).

In 1995, NGS began the development of the Federal Base Network (FBN). This was to be a nationwide network of passive monuments with horizontal, vertical (orthometric), and gravity values. The maximum spacing was to be 100 km, with higher density in areas of high crustal motion. In California, many of the monuments chosen for the FBN were also HPGN monuments. Monuments were labeled “Federal Base Network” stations for those at the nominal 100-km spacing, and “Cooperative Base Network” for the higher density stations that were observed by partner agencies such as the Department.

The FBN network was published as NAD 83 (1998) Epoch 1998.5 in California. After the Hector Mine earthquake in 1999, a resurvey of the FBN was made for the affected area. The coordinates were published as NAD 83 (1998) Epoch 2000.35.

4.2-7(d) NAD 83 (CORS 1996) Epoch 2002.00

The FBN was only a partial realization of a national adjustment. The first adjustment to reach this goal was based only on CORS stations and designated NAD 83 (CORS1996) Epoch 2002.00. Even though NAD83 has the North American tectonic plate fixed geodetically, the NAD83 (CORS1996) realization incorporates 3-D velocities for the stations. This realization was not used directly in any adjustment of passive networks, but all later adjustments released by NGS are based on the CORS network.

4.2-7(e) NAD 83 (2007) Datum Tag

In 2007, NGS published a new nationwide realization, called NAD 83 (NSRS 2007). The "NSRS" is not displayed on the Datasheet because of formatting limitations. It was created by adjusting GPS data collected during various campaign-style geodetic surveys performed between the mid-1980's and 2005. The NAD 83 (NSRS 2007) adjustment used data from over 700 CORS, mostly on the stable North American tectonic plate. The adjustment used epoch 2002.00 (the standard epoch for CORS at the time) for the North American plate, and epoch 2007.00 for the western states and Alaska.

For California, NGS relied on the geodetic coordinates and velocities provided by the CSRC for 214 CGPS stations. The NAD 83 adjustment, transformed from the ITRF05 realization, included three dimensional velocities for CGPS monuments, but only two-dimensional velocities, using HTDP modeling, for passive monuments in the western U.S. states.

As part of the 2007 adjustment, several changes were made to the NGS datasheet format. This included adding the network and local accuracies, replacing orders of accuracies.

4.2-7(f) NAD 83 (2007) Epochs 2009.00 and 2011.00 (CSRC)

Because of ongoing crustal motion in much of California, CSRC published NAD83 (2007) 2009.00 coordinates for 766 CGPS in or near California. The CSRC published another adjustment, the NAD 83 (2007) 2011.00, for 830 CGPS because of the April (Easter) 2010 earthquake (El Major/Cucapah, M7.2) that impacted much of Imperial County.

4.2-7(g) NAD 83 (2011) Epoch 2010.00

Unlike the NAD83 (NSRS 2007) adjustment, HTDP velocity modeling was incorporated by NGS during the adjustment of the historical passive station GPS observations (vectors) for the entire country for the NAD 83 (2011) 2010.00 adjustment. This adjustment did not utilize data from CSRC because the CORS network in California had expanded to be sufficient as constraints.

4.2-8 Future Epochs

Geodetic organizations such as IERS, NGS and CSRC are constantly reviewing and refining the reference frames. They are also tracking and developing velocities of CGPS stations. All personnel who process GNSS data need to be aware of the latest information, and take it into account when processing data and planning future projects.

4.3 The California Coordinate System

4.3-1 Policy

Section 8817 of the *Public Resources Code* requires that all new surveys and new mapping projects, which use State Plane Coordinates, must use the California Coordinate System of 1983 (CCS83), which is based on NAD 83.

CCS83 is the coordinate system used for all mapping, planning, design, right of way engineering, and construction on Department-involved transportation improvement projects including special-funded State highway projects. The basis for the CCS83 system is the California Spatial Reference Network (CSRN).

When a map, set of plans, or other document uses State Plane Coordinates, a note shall be placed on the document to show the basis of the coordinates used including: the CCS zone, the physical reference network, datum tag, and epoch used to establish the coordinates (see Section 4.2-5). Specifically, any Project Control map, Record of Survey, or Appraisal map must include this information.

The CCS83 grids are fixed to the NAD83 datum. As tectonic shifts move the actual monuments, they don't move the grids. Think of dots slowly moving across a sheet of graph paper. Even though the points are moving, the graph paper grid is not. Even if the monuments still hold their relative positions, eventually they have moved too far to be accepted for their original location. They must then be updated to a current datum/epoch. See Section 4.6 for guidance.

All surveys using state plane coordinates must be referenced to at least two published NSRS or CSRN monuments to meet the "basis of bearing" requirements of Business and Professions Code Section 8771.5 and Public Resources Code Section 8813.1. There are CGPS networks (Real Time Networks- RTN's) that are not part of the NSRS or CSRN, but whose data are available through subscription. Any survey performed using these RTN's must be referenced to at least two published monuments in order to establish a basis of bearings for a project, and at least three monuments to verify the selected project datums.

4.3-2 Description of CCS83

Because of the complexity of performing the calculations for geodetic surveying and the limited extent of most surveying projects, most surveyors generally use plane surveying methods. For local projects, plane surveying yields accurate results, but for large systems, like the California transportation system, local plane surveying systems are not adequate. Not only are local plane coordinate systems inaccurate over large areas, but they cannot be easily related to other local systems.

In response to the needs of local surveyors for an accurate plane surveying datum useful over relatively large areas, the U. S. Coast and Geodetic Survey (the predecessor of NGS) developed the State Plane Coordinate Systems. The first California Coordinate System (CCS, later called CCS27) was based on NAD 27. CCS83 was later established to utilize the NAD 83 datum.

A plane-rectangular coordinate system is by definition a flat surface. Projecting the curved surface of the earth onto a plane requires some form of deformation. Imagine the stretching and tearing necessary to flatten a piece of orange peel. In California, the Lambert Conformal map projection is used to transform the geodetic positions of latitude and longitude into the y (Northing) and x (Easting) coordinates of the CCS83.

The Lambert Conformal projection can be illustrated by a cone that intersects the NAD 83 ellipsoid along two parallels of latitude as shown in Figure 4-3. These latitudes are known as the standard parallels for the projection. Distances lying along the standard parallels are the same on both the NAD 83 ellipsoid and the cone. Between the standard parallels, distances projected from the ellipsoid to the conic surface become smaller. Outside the standard parallels, distances projected from the ellipsoid to the conic surface become larger. Scale factors are used to reduce and increase distances when converting between the CCS surface and the ellipsoid surface. The scale factor is exactly one on the standard parallels, greater than one outside them and less than one between them.

The limits of each Lambert projection are generally chosen so that scale factors will be less than 1.00010 and greater than 0.99990 so that even if scale factors are disregarded discrepancies between ground measurements at sea level and distances on the CCS grid will be within 1:10,000. Maintaining the 1:10,000 constraint requires six zones in California. The zones have been created so that zone boundaries are coincident with county lines. See Figure 4-4.

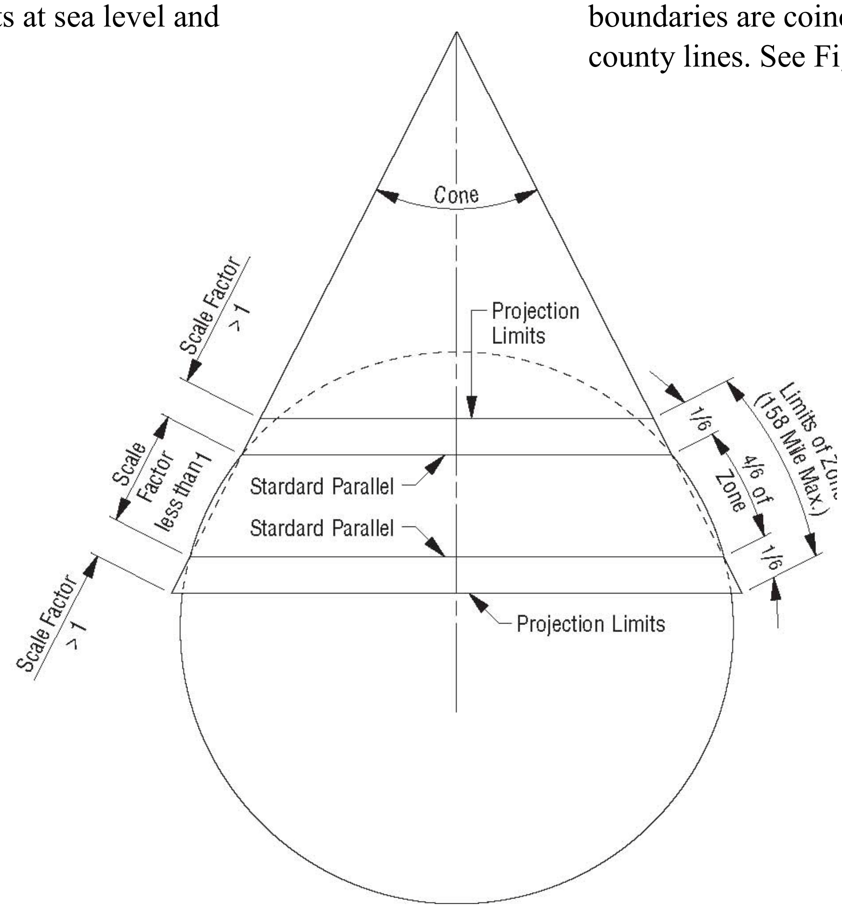


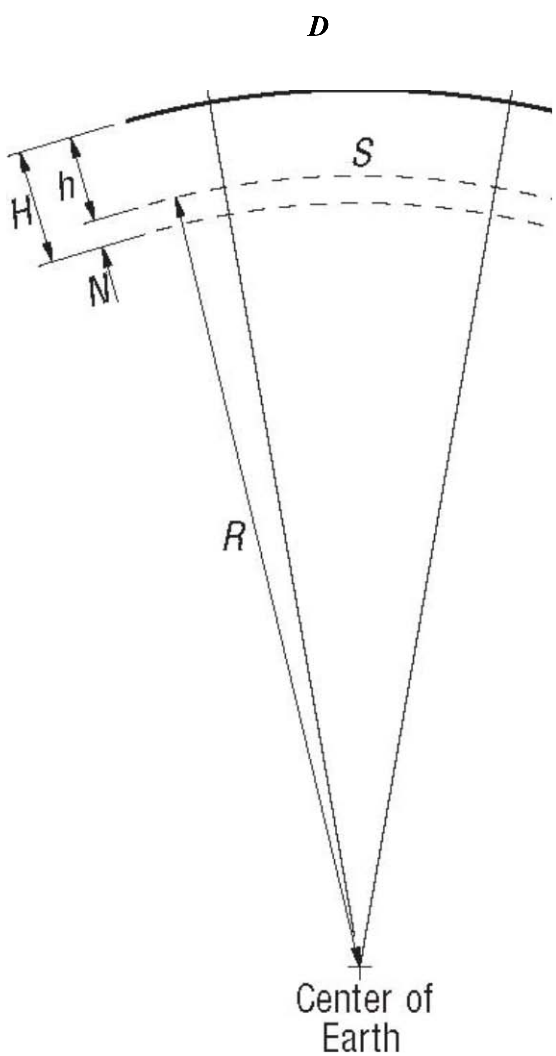
Figure 4-3


Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
DEL NORTE
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
GLENN
BUTTE
SIERRA
MENDOCINO
COLUSA
NEVADA
LAKE
SUTTER
YUBA
PLACER
YOLO
EL DORADO
SONOMA
NAPA
SACRAMENTO
ALPINE
SOLANO
AMADOR
MARIN
CALAVERAS
TUOLUMNE
MONO
CONTRA COSTA
SAN JOAQUIN
SAN FRANCISCO
ALAMEDA
MARIPOSA
SAN MATEO
SANTA CLARA
STANISLAUS
MERCED
MADERA
SANTA CRUZ
SAN BENITO
FRESNO
INYO
MONTEREY
TULARE
KINGS
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL

Figure 4-4

4.3-2(a) Grid Factors and Convergence Angles

Distances measured on the surface of the Earth must be scaled to corresponding lengths on the ellipsoid. This ellipsoidal or elevation factor varies with the elevation of the surface where the distance is measured. As the elevation of the measured line increases, the distance (radius) from the surface of the earth to its center increases, which correspondingly increases the length of the measured line. Thus, distances must be reduced in proportion to the change in radius between the ellipsoid and the radius of the Earth's surface where the measurement is made. See Figure 4-5.



$$S / D = (R / [R + h])$$

$$S = D * (R / [R + h])$$

or:

$$S / D = D * (R / [R + N + H])$$

Where:

S = Distance on ellipsoid

D = Distance on ground

R = Radius of ellipsoid for zone

N = Geoidal height

H = Elevation (orthometric height)

h = Ellipsoid height

Figure 4-5
(courtesy NGS)

Usually, the elevation factor (in CCS27 called the sea level factor) and the scale factor are not listed individually, but combined by multiplication into a grid factor or combined grid factor (CGF). Distances measured on the earth's surface are converted to CCS83 grid distances by multiplying by the CGF. Grid distances are converted to ground distances by multiplying the grid distance by the reciprocal of the CGF. The CGF will be expressed to a minimum of 7 places to the right of the decimal.

A central meridian is designated for each CCS83 zone. Lines running east-west on the CCS83 grid are constructed perpendicular to the central meridian. East-west CCS83 grid lines are tangent to parallels of latitude (latitudinal arcs) only at the central meridian. Lines running north-south on the CCS83 grid are constructed parallel to the central meridian. Therefore, the only true geodetic north-south line on a CCS83 grid is the central meridian. All other north-south lines vary from geodetic North by the plane convergence angle (γ). The plane convergence angle varies with longitude, increasing as the distance from the central meridian increases. See Figure 4-6.

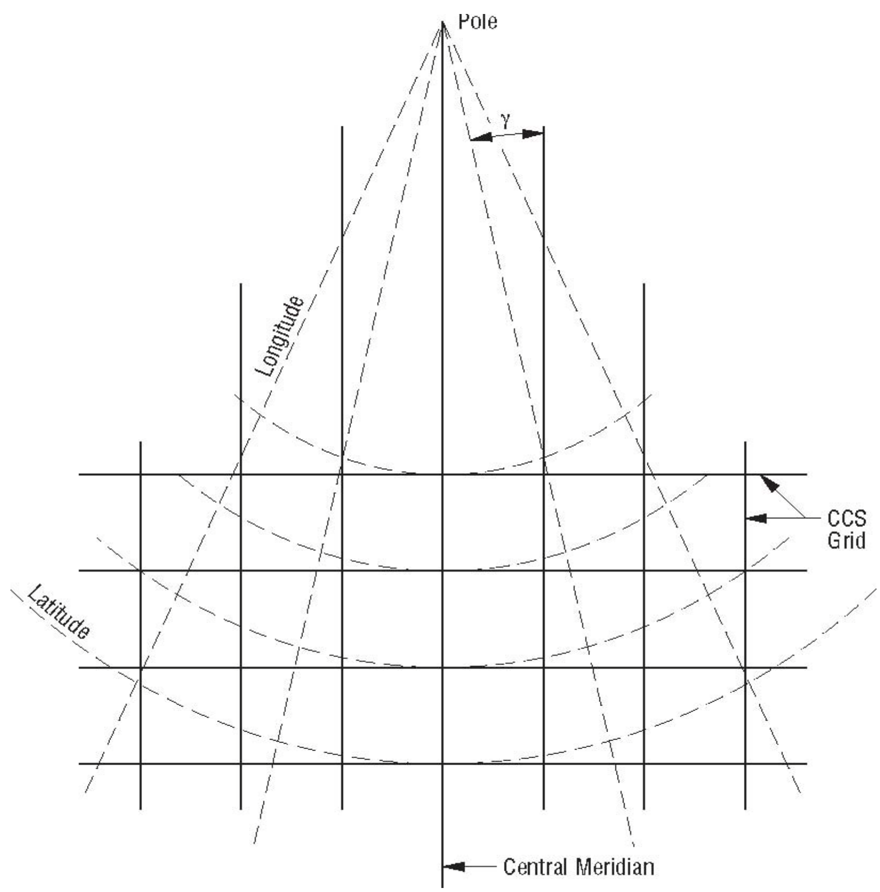


Figure 4-6

4.3-3 Universal Transverse Mercator (UTM) Coordinates and the U.S. National Grid

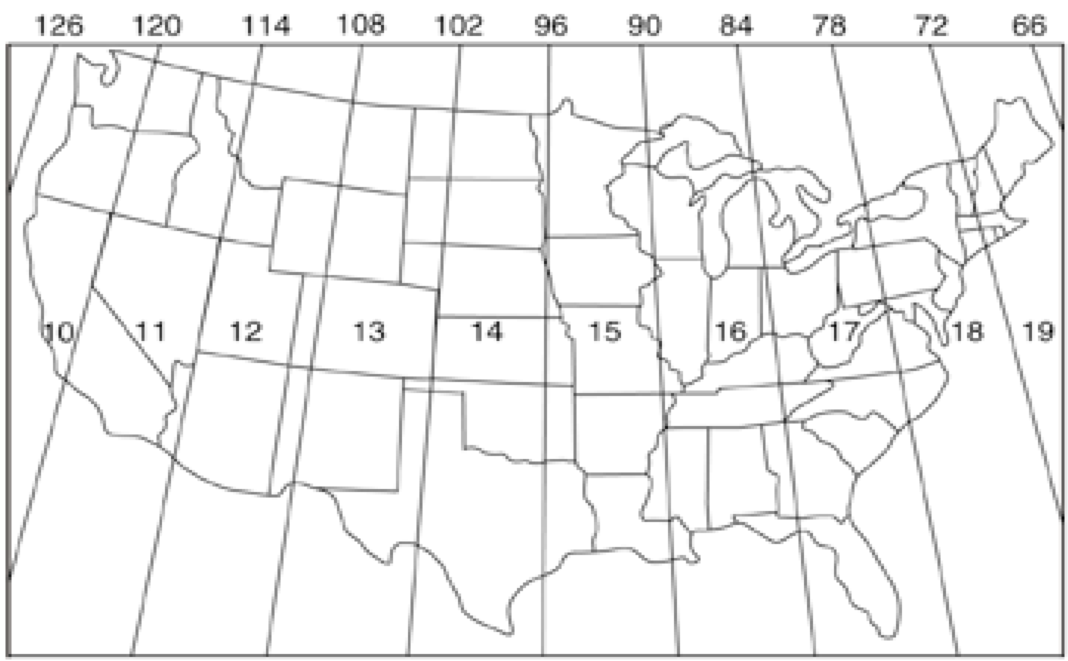
Another common coordinate system used by geographers and Geographic Information System (GIS) specialists is the Universal Transverse Mercator (UTM) coordinate system. The UTM system provides coordinates on a worldwide flat grid for easy computation.

The UTM coordinate system divides the world into 60 zones, each being 6 degrees longitude wide, and extending from 80 degrees south latitude to 84 degrees north latitude The polar regions are excluded. The first zone starts at the International Date Line (longitude 180 degrees) proceeding eastward. It uses WGS 84 as the reference ellipsoid.

The UTM is a conformal projection with a scale factor constraint of 1: 1,000. Positions are measured from the point of origin of each zone, which is the intersection of the central meridian with the equator. In the Northern Hemisphere, the "Northings" start at zero and the central meridian has an "Easting" of 500,000. Units are metric.

UTM coordinates are not commonly used by surveyors, but survey data is often converted from state plane or geodetic coordinates into UTM for large scale mapping.

Figure 4.7[13] UTM Grid



[13] Figure courtesy of NGS

Within the United States, the UTM system is further refined as the U.S. National Grid (USNG). This divides the 6 degree UTM grid further into zones of 8 degrees latitude, and then into grid zones beginning with a10 km square. Each 10 km square can then be reduced into smaller squares, down to one meter. These are not coordinates, but areas. The USNG is primarily used by emergency responders and GIS specialists.

4.3-4 Coordinate Conversions

Conversions between geodetic coordinates and CCS83 coordinates are normally made using computer programs. The programs also calculate plane convergence angles and grid factors for each position. Though grid factors will differ from point to point because of change in elevation and latitude, a mean grid factor will be selected for each project. This policy will usually cause no appreciable loss in accuracy and will eliminate confusion caused by multiple grid factors.

For higher-order control surveys - where the elevations of control points vary significantly, or for projects that extend for large north/south distances - assigning more than one grid factor may be appropriate. CCS83 coordinates are specific for each zone because each CCS83 zone is a unique Lambert projection. Department projects that extend from one zone into another should use CCS83 coordinates based only on one zone. CCS Coordinates for one zone can be easily converted to coordinates of a second zone by first converting to geodetic coordinates and then converting to CCS83 for the second zone.

There is no direct conversion for coordinates between CCS27 and CCS83. Conversion programs like the National Geodetic Survey's NADCON (North American Datum Conversion Utility) are only approximate conversions that are generally not accurate enough for engineering and boundary surveys. These programs should not be used to convert coordinates on survey control points between CCS27 and CCS83. They are only acceptable for planning (resource grade) purposes.

The two recommended methods for obtaining CCS83 coordinates for old CCS27 surveys are:

- Conducting a resurvey of the CCS27 survey using CCS83 station coordinates as the reference control. This requires original notes from the CCS27 survey, but is the best way to retrace control or land net surveys.
- Use a 2D conformal transformation (i.e., rotation and scale) based on common points. This is the simplest method for transforming existing alignment files, but can only be considered an approximation of the land net.

4.4 Vertical Datums

4.4-1 Policy

All project delivery work (mapping, planning, design, right of way engineering and construction) for each Department-involved transportation improvement project shall be based on a common vertical datum. PRC Section 8853 identifies the official geodetic datum to which orthometric heights are referenced within the State of California as the North American Vertical Datum of 1988 (NAVD 88).

The official vertical datum to which orthometric heights are referenced for all mapping, planning, design, right of way engineering, and construction on Department-involved transportation improvement projects, including special-funded State highway projects shall be NAVD 88. Exceptions to this policy, as determined by the District Survey Manager in consultation with the Project Manager are permitted for:

- Projects which are small, remote and isolated.
- Maintenance, traffic safety and rehabilitation projects that are controlled by existing fixed works.
- Minor projects for which it is not cost effective to establish NAVD 88 vertical control.
- Expedited projects for which it is not feasible to establish NAVD 88 vertical control.
- Projects that are contiguous to earlier projects with elevations referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) and uniformity (common vertical datum) is desirable.

Generally, the only acceptable alternate vertical datum is NGVD 29. For project locations where published NAVD 88 data is not locally available, establishing NAVD 88 control using GPS Height Modernization survey methods should be considered before adopting NGVD 29 elevations.

4.4-2 North American Vertical Datum of 1988 (NAVD 88)

NAVD 88 consists of a leveling network on the North American Continent, ranging from Alaska, through Canada, across the United States, affixed to a single origin point on the Eastern shore (Father's Point/Rimouski, at the mouth of the St. Lawrence River, New Brunswick, Canada). In 1993, NAVD 88 was affirmed, in the Federal Register Notice Volume 58, No. 120 [http://www.ngs.noaa.gov/PUBS_LIB/FedRegister/FRdoc93-14922.pdf], as the official vertical datum of the National Spatial Reference System (NSRS) for the Conterminous United States and Alaska. General information about geodetic vertical datums can be found online here: http://www.ngs.noaa.gov/datums/vertical/VerticalDatums.shtml.

4.4-3 National Geodetic Vertical Datum of 1929 (NGVD 29)

NGVD 29 was an adjustment of first-order leveling surveys during which the elevations of 26 tidal stations in North America were held as fixed. When NGS created the NAVD 88 Datum, 75% of all benchmarks in California were not included as part of the NAVD 88 adjustment. NGVD 29 benchmarks that have not been upgraded to NAVD 88 should be considered local monuments, and should only be used for minor projects when it is not cost effective to establish NAVD 88 control, *and* it is unlikely that the NGVD 29 benchmarks have experienced subsidence or uplift in the (4) decades since they were last leveled. If in doubt, consult with the Geotechnical Services branch.

4.4-4 Geoids

The geoid can be defined as "The equipotential surface of the Earth's gravity field which best fits, in a least squares sense, a global mean sea level"[14]. As a practical matter, an accurate geoid model is needed to convert ellipsoid heights determined by GPS/GNSS to land-based vertical datums, such as NAVD 88.

By measuring the earth's gravity around the globe, geodesists can create a "gravimetric geoid", which reflects the various densities within the earth. The hybrid geoid published by NGS is a gravimetric geoid which is constrained to NAVD 88 bench marks that also have NAD 83 ellipsoid heights. Such a geoid model is constrained to the realization of NAD 83 ellipsoid heights in effect at the time of the model's development. When ellipsoid heights change because of a new realization, the new ellipsoid height and the published orthometric height are fixed and the geoid modeling effort produces a new geoid height.

GEOID03 was based on the NAD 83 (1992) adjustment, GEOID09 was constrained to NAD 83 (NSRS 2007), and the current geoid model, GEOID12A, is constrained to NAD 83 (2011). When determining orthometric heights using GNSS equipment, an understanding of the relationship between geoid models and the datum tag of ellipsoid heights is critical.

4.4-5 Local Datums

Some cities have adopted specific vertical datums by ordinance, and require their use for projects within their jurisdiction. Under some circumstances, the use of these local datums may be considered. See Section 4.6.

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[14] Geodetic Glossary (NGS, NOS, NOAA, Rockville MD, September 1986) http://www.ngs.noaa.gov/CORS-Proxy/Glossary/xml/NGS_Glossary.xml

4.5 Tidal Datums

4.5-1 Policy

Whenever a project is near the ocean or a tidally influenced waterway, the project surveyor must compare elevations referenced to tidal datums, such as local mean sea level (LMSL), MLLW, and MHHW, with NAVD 88 elevations. If it is possible that high tides may potentially impact the project, the project surveyor will notify project management.

The elevation of "0.00 NAVD 88" is very close to Mean Sea Level elevations at tide gauges on the East Coast, but can differ by about three feet in California. This is why Project Engineers must be given accurate tidal elevations, or they may assume a drainage that doesn't exist, or believe that a facility is adequately protected from tidal or storm surge activity when it is not. The *Highway Design Manual* (Sec. 873.2) uses a formula based on tidal datums to determine the "Design High Tide" (DHT) for structures subject to tidal influence. Surveys should provide the Project Engineer with the datums needed to calculate DHT for all projects along tidal waters.

4.5-2 Tidal Cycles

There are two high tides and two low tides each day on the west coast. This is called a "mixed semi-diurnal tide" because each high and low tide differs measurably in their heights. The more extreme tides are called the Higher High Water and the Lower Low Water.

The National Ocean Service (NOS) is part of the National Oceanic and Atmospheric Administration (NOAA), and is tasked with determining tidal datums for the United States and territories. This work is performed by the Center for Operational Oceanographic Products and Services (CO-OPS). CO-OPS operates and maintains the system of tidal and water level (Great Lakes) stations for the United States.

The oscillating tides follow the cycle of the moon rotating around the earth as the earth rotates around the sun. The entire cycle takes about 18.6 years. CO-OPS publishes data for tidal datums based on a 19-year observation time block, known as the National Tidal Datum Epoch (NTDE). The current NTDE is the period 1983-2001.

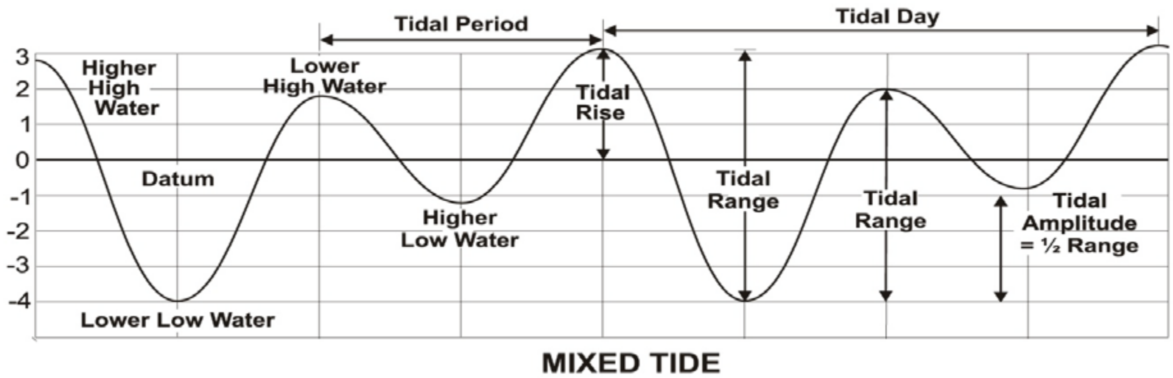

Figure 4.8

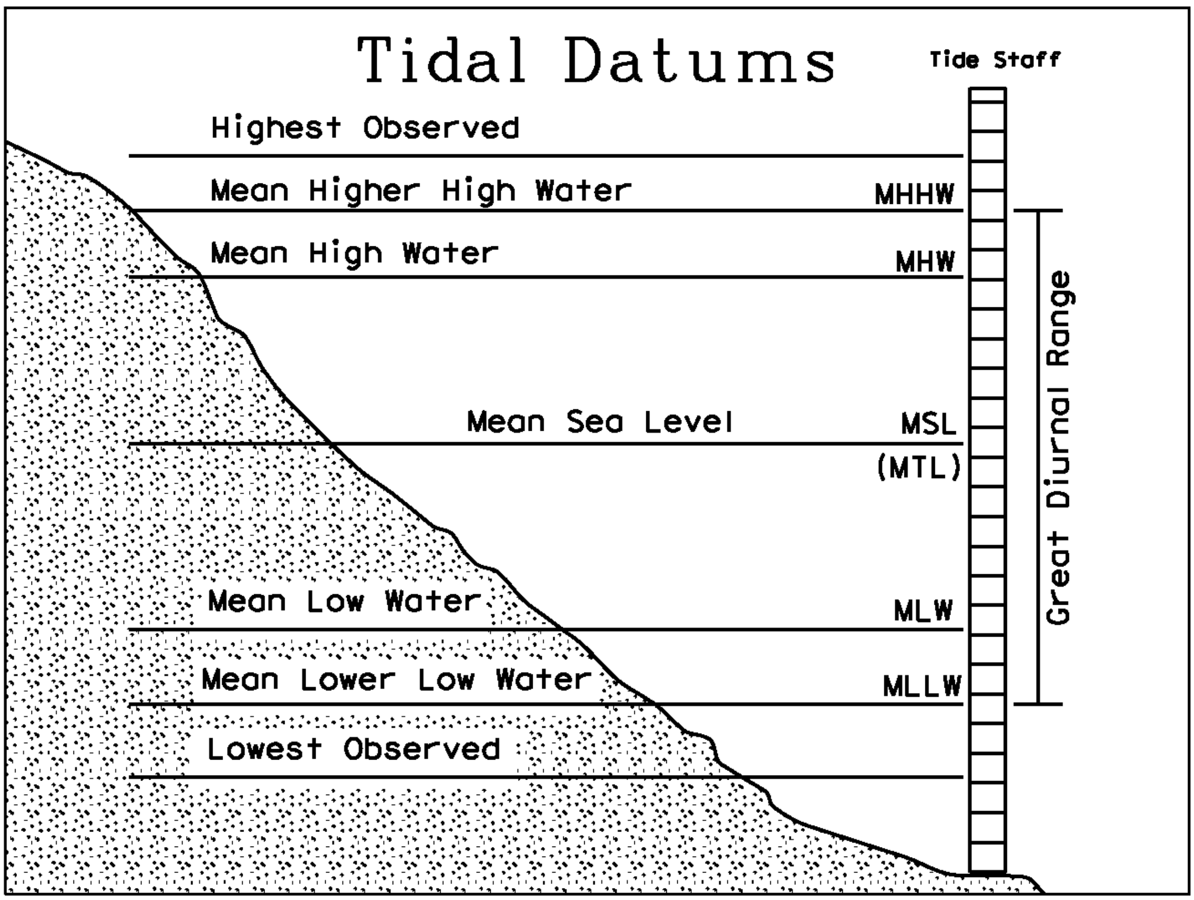

Figure 4.9

4.5-3 Tidal Datum Descriptions[15]

Highest Observed Water = This is the highest water level recorded at the tide station *The Lowest and Highest Observed Water Levels are not datums (which are averages of many measurements), but single observations representing the greatest range recorded at that tide station.*

Highest Astronomical Tide (HAT) = The elevation of the highest predicted astronomical tide expected to occur at a specific tide station over the NTDE (not shown on Fig. 4.9).

Mean Higher High Water (MHHW) = The average of the higher high water height of each tidal day observed over the NTDE.

Mean High Water (MHW) = The average of all the high water heights observed over the NTDE. *This is the datum used to compute bridge clearances on nautical charts. In California, it is the upper limit of state-owned tidelands.*

Mean Sea Level (MSL) = The arithmetic mean of hourly heights observed over the NTDE.

The Mean Tide Level (MTL) = The arithmetic mean of the MHW and Mean Low Water.

Mean Low Water (MLW) = The average of all the low water heights observed over the NTDE. *In the State of California, this is the lower limit of state-owned tidelands.*

Mean Lower Low Water (MLLW) = Average of the lowest of the two low tides each day. *This is the height of 0.000 (datums are published in metric) at each tidal station. This is also the nautical chart "0.00" datum for depth soundings.*

Great Diurnal Range (GT) = Difference in height between MHHW and MLLW
Shown as "Diurnal Range = R" in the Highway Design Manual, Figure 873.2A.

4.5-4 Tidal Station Data

There are a dozen primary tide stations in California. These stations have continuous data collected throughout the entire current NTDE. There are also secondary stations (more than one year of data, but less than one NTDE) and tertiary stations (less than one year of data). The secondary and tertiary stations are generally temporary, used to establish the differences (in water level and time) between a nearby primary station and the lesser station. They are removed when no longer needed. Sometimes a secondary station is intended to become a primary station after achieving the longevity requirements and the publication of a new NTDE that encompasses that period.

CO-OPS references the tidal stations to several tidal benchmarks, which usually have NAVD 88 elevations. While the tidal benchmarks are referenced to the tide station by differential leveling, the benchmarks themselves may have been elevated using many

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[15] Figures 4.8, 4.9 and the Tidal Datum descriptions courtesy of NOAA.

different techniques, including conversion from NGVD 29 to NAVD 88 using VERTCON.

The data for any tide station operated by CO-OPS can be found on their website at http://tidesandcurrents.noaa.gov/. The site includes a GOOGLE™ map of the United States, and by zooming in on a location or selecting an area in the drop-down menu in the upper right, you can find the nearest tidal station and retrieve the tidal datums and bench mark data by bringing up the station home page and using the "Benchmark Sheets" link (NOT the Datums link).

Example of Tidal Station Data

```
Tidal datums at PORT CHICAGO, SUISUN BAY based on:

     LENGTH OF SERIES:       19 YEARS
     TIME PERIOD:            January 1983 - December 2001
     TIDAL EPOCH:            1983-2001
     CONTROL TIDE STATION:

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

     HIGHEST OBSERVED WATER LEVEL (12/03/1983)    =  2.415
     MEAN HIGHER HIGH WATER (MHHW)                =  1.498
     MEAN HIGH WATER (MHW)                        =  1.343
     MEAN TIDE LEVEL (MTL)                        =  0.785
     MEAN SEA LEVEL (MSL)                         =  0.781
     MEAN LOW WATER (MLW)                         =  0.226
     MEAN LOWER LOW WATER (MLLW)                  =  0.000
     NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)    = -0.335
     LOWEST OBSERVED WATER LEVEL (01/08/1989)     = -0.447
```

Note that the information is in published in Meters. All data should be converted to the U.S. Survey foot before being used for projects.

The blank after the words "Controlling Tide Station" indicates that this is a primary station. Secondary and tertiary stations will list the control tide station, and tide predictions on the CO-OPS web page will show the expected differences in height and time between the control station and the station being reviewed. For instance, the tide predictions for Point Pinole (ID 9415056) indicate that the high tide is 1.04 feet higher, and occurs 72 minutes after, high tide at its control station, San Francisco (Golden Gate).

4.5-5 Converting Station Tidal Datums to NAVD 88

The inclusion of the NAVD 88 datum of "-0.335" in the example above means that this station is referenced to three or more bench marks with NAVD 88 elevations.

The NAVD 88 datum should be read as "The NAVD 88 elevation of "0.000" is equivalent to 0.335 meters **below** the MLLW datum at this station." Or "Adding 0.335 meters to each tidal datum will give you the tidal datum information elevation in NAVD 88 elevations."

Here, the HOWL is 2.415 meters above MLLW datum, or 2.750 meters (2.415 + 0.335) above NAVD 88 datum. Converting to feet, HOWL = 9.02 feet NAVD88.

You can perform similar conversions for any of the tidal datums.

Conversion of Port Chicago Tidal Datums to NAVD 88 Feet.

Datum	MLLW Metric	NAVD 88 Metric	NAVD 88 Feet
HOWL*	2.415	2.750	9.02
MHHW	1.498	1.833	6.01
MHW	1.343	1.678	5.51
MTL	0.785	1.120	3.67
MSL	0.781	1.116	3.66
MLW	0.226	0.561	1.84
MLLW	0.000	0.335	1.10
NAVD 88	-.335	0.000	0.00
LOWL	-.447	-.112	-.37

4.5-5 VDatum Software

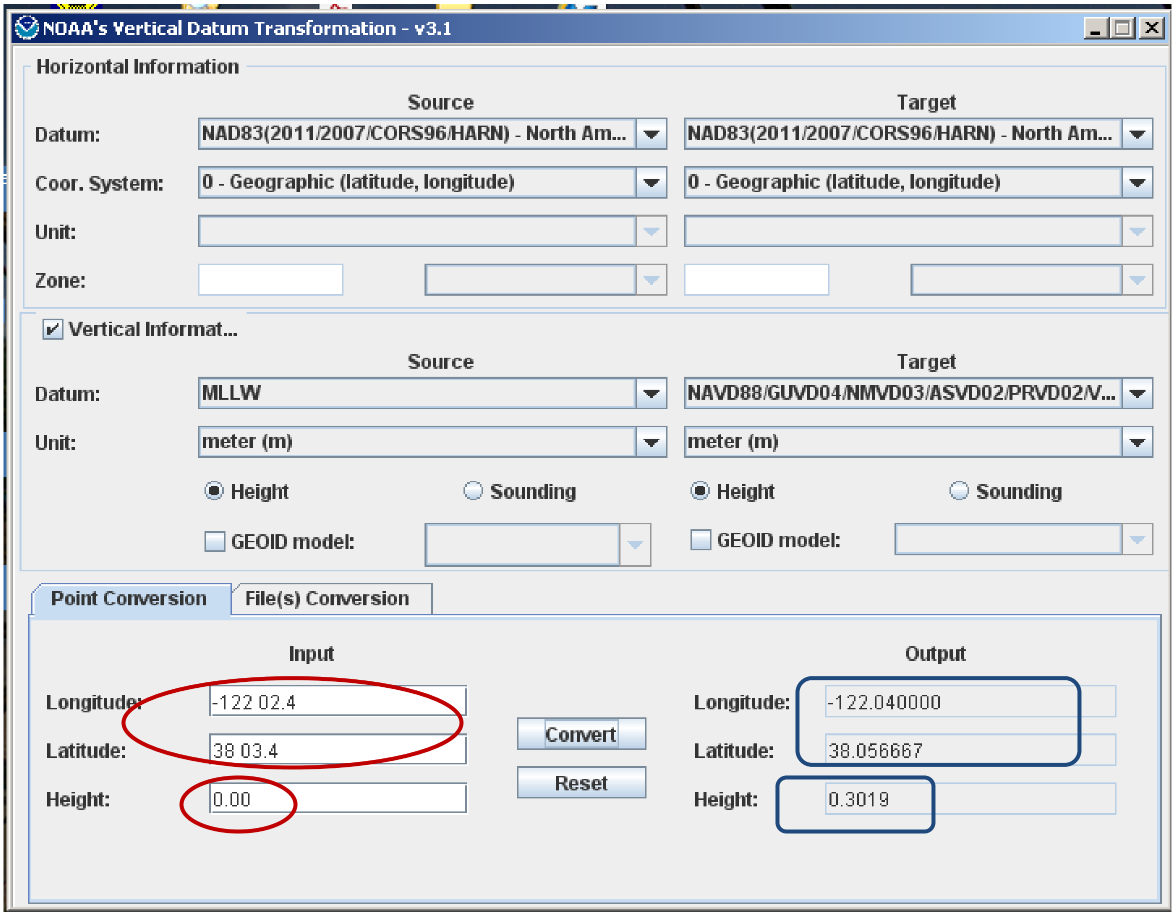
Unfortunately, there are tide gauge stations that are not referenced to NAVD 88, so in many stretches of the coastline and inland areas the tidal datums cannot be directly determined. For areas where there are no nearby tide stations, NOAA has developed a software program (VDatum) which can convert between ellipsoid heights, NGVD29, NAVD 88, and tidal datums. The height conversions are based on VERTCON and a geoid model that the user selects, where pertinent.

The operator can input geodetic coordinates[16] or UTM coordinates, and the VDatum program will return heights referenced to MLLW, MSL, MHHW, or other major tidal datums, in NAVD 88 or NGVD 29. It does not give elevations referenced to HOWL, as that is one observation, not a datum.

The accuracy of the data and the conversions has been tabulated for each geographic coverage used in the model. The error is cumulative and dependent on which and how many conversions are needed to go from input vertical reference system to the output datum. The largest maximum cumulative error (MCE) for one of the four datasets in California is nearly +/- 10cm. Users of VDatum should review the table provided in the documentation and calculate the error associated with their conversion.

[16] One of the usual methods for determining geodetic coordinates for a site is to use an on-line mapping program, such as Google Earth™. These programs do not publish information on the accuracy of their data, so the information can only be used for planning purposes.

Here is an example of using VDatum to convert from MLLW at the Port Chicago Tide Station to NAVD 88 elevations. In this case, the VDatum solution of 0.302 meters is only 0.033 meters (0.11 ft) different than the published datum difference of 0.335 meters.



Input Datum and Elevation

Output Datum and Elevation

Figure 4.10

In order for the Project Engineer to determine the Design High Tide for a project, they must be given the NAVD 88 elevations for MLLW, MSL, and MHHW. The HOWL will be provided when available.

A NOAA webinar can be reviewed to learn more about Tidal Datums. The recorded webinar and powerpoint file are available for download or viewing at: http://www.ngs.noaa.gov/corbin/class_description/Geodetic_Tidal_Datums_0811.shtml.

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4.6 Selecting Project Datums

4.6-1 Policy

Project datums must be selected early in the project delivery process. Ideally, Cost Estimate Maps and other PID phase mapping would be on the final project datum. If early maps aren't on the final project datums, that must be documented. When new control will be used for a project, datum tags based on the NGS CORS are preferred over any based on passive monumentation, as the CORS are more likely to be included in future realizations. The project datums and the horizontal and vertical CSRN monuments used to establish project control will documented in a "Project Datums and Control" sheet.

Any NAD 83 datum tag and epoch published on or after the establishment of the HPGN is acceptable, if it meets the requirements described below.

Control monuments used in determining the datum tag and epoch for a project must meet the required specifications for accuracy. All horizontal project control survey monuments must be included in a constrained adjustment that meets first order standards or better, as defined by Figure 5.1A of Chapter 5 "Standards", of the *Surveys Manual,* or within the horizontal standards set for the CSRN. The procedures for a GNSS control survey are described in Chapter 6 "Global Positioning System (GPS) Survey Specifications", and Chapter 9 "Control Surveys".

In order to meet the specifications above, a minimum of three CSRN monuments, located in at least three quadrants surrounding the project, must be observed. All monuments should have the same datum tag and epoch as the proposed datum(s). As good practice, four monuments should be occupied, so if one monument fails to meet specifications, the minimum standards can still be met.

Where local governments have adopted horizontal or vertical datums by ordinance, these datums may be considered when planning project datums. Horizontal datums must be based on a NAD 83 horizontal datum.

Vertical elevations will be based on a minimum of two monuments with NAVD 88 orthometric heights. See Section 4.6-3 for exceptions to this policy. Tidal datums will be provided for projects adjoining coastal waters and tidal estuaries.

4.6-2 Methods for Selecting Horizontal Control Datums

The determination of which datum to use for a project is not always clear. Issues include:

- Existing control datums at the site
- The datums used in adjoining projects
- Expected lifespan of the project
- Plans for future projects in the same area
- Age of the current control monuments
- Cost of establishing new control

4.6-2(a) Use of CORS / CGPS Monuments for Control

When project control will be based on the latest datum tag and epoch, using only CORS/ CGPS control stations is the preferred method. These stations will be the most likely to fit a constrained adjustment, as older data may have been used to establish the coordinates of passive stations..

When the intent is to use CORS / CGPS stations that are a part of the CSRN, but an older datum is preferred, a constrained adjustment must be performed to prove that the network accuracy of the older datum still meets the published accuracies.

4.6-2(b) Use of Passive Monuments for Control

If the GNSS control survey will be based on any passive monuments, or a Real Time Network that is not a part of the CSRN, a GNSS field survey of passive CSRN monuments will be performed to determine the proper datum tag and epoch for each project. Field procedures must match the requirements for the published accuracy of the network as described in Chapter 6. All NGS CORS monuments within 10 km (6.2 mi.) of the project must be included in the adjustment. The final constrained adjustment must fall within the relative accuracy published for the monuments and the network (usually 2 cm.).

For example, if four monuments have an average published network accuracy of less than 2 cm, and a constrained adjustment for three of them meets the 2cm standard; the chosen datum tag is acceptable. If the constrained adjustment cannot meet the published accuracies, then coordinates based on another datum tag must be used.

For projects using only conventional traverses for control, a traverse must be run between at least two pairs of GPS monuments that will be used as control. If the traverse meets the requirements for a Second-order survey as described in Figure 5-1A and Chapter 7.3 of this manual, the datum for the GPS pairs is acceptable as the project control datum.

4.6-3 Vertical Datums

NAVD 88 elevations based on two benchmarks will be used whenever feasible. Current NGS vertical survey standards[17] call for benchmarks to be set at 7-10 km (4-7 mi.) intervals. Projects located between two benchmarks less than 10 km apart will use NAVD 88 elevations. Projects located more than 7-10 km from the nearest NAVD 88 benchmark should establish new vertical control for the project.

There are existing projects that were built using NAD 83/ CCS83 coordinates and NGVD 29 elevations. It is acceptable to accept the horizontal control for adjoining projects, but the vertical will be updated to NAVD 88.

Exceptions to use NGVD 29 are only allowed on minor projects in a city that has adopted the NGVD 29 datum by ordinance, or where establishing new control would be not be cost effective.

4.6-4 Superseded Horizontal Datums

Highway projects built before the early 1960's used local coordinates only, not CCS coordinates. Any project in an area without CCS coordinates will establish NAD 83 control using a recent datum tag.

Projects built between the 1960's and early 1990's primarily used CCS27 coordinates. Existing CCS27 control monuments can be used to retrace cadastral surveys established using CCS27, and for re-establishing existing highway alignments on projects that do not involve any new rights of way. CCS27 will not be used for any new highway alignments or rights of way.

Any NAD 83 survey performed before the creation of the HPGN network and the datum tag of NAD 83 (1992) Epoch 1991.35 is not acceptable control for new projects.

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[17] NOAA Technical Memorandum NOS NGS 59
http://www.ngs.noaa.gov/PUBS_LIB/NGS592008069FINAL2.pdf

4.6-5 Project Datums and Control Form Procedures

Each project will have a “Project Datums and Control” form. The purpose of the form is to define the primary control for the lifespan of the project. The datums listed will be used during all surveys performed for the project.

The horizontal control monuments listed on the form will be used as the “Basis of Bearings” for all mapping. The mean convergence angle and combined factor of the primary monuments will be used for all project surveys. All elevations will be based on at least two monuments with NAVD 88 orthometric heights of third order or better. If GNSS surveys will be used for determining elevations, the appropriate geoid will be listed.

Tidal datum will be provided as needed.

The Project Control and Datum Forms may be completed as part of the project control survey, but must be completed before any engineering or right of way surveys. All supporting documentation, such as NGS datasheets and a constrained adjustment report, must be attached.

See FORM 4.1 on the following pages. Individual forms may show more information, but all information shown on the example is required.

The form must be prepared under the direction of a licensed land surveyor. Any datums that require approval must be signed by the Department project surveyor.

FORM 4.1 Project Datums and Control

Project Information

Project ID / EA: Co-Rte- PM:
Description:
Project Manager: ________________

Datums

- ☐ Horizontal
  - o NAD 83
    - ▪ Datum Tag (YYYY): ____________
    - ▪ Epoch Date (YYYY.YY): ___________
    - ▪ CCS Zone: _________ C.F.: ______________ θ = __________
  - o NAD 27 (Requires Approval)
    - ▪ CCS Zone: _________ C.F.: ______________ θ = __________
  - o Other (Requires Approval): _______________
- ☐ Vertical
  - o NAVD 88 Geoid___________
  - o NGVD 29 (Requires Approval)
  - o Other (Requires Approval): ________________
- ☐ Units
  - o U.S. Survey Feet
  - o Metric

Control Monuments

STATION ID	NAME	NORTHING	EASTING	95% HORIZ. CONFIDENCE	ELEV.

☐ Monument datasheets attached (Required)

☐ Constrained Adjustment Attached (Required)

Prepared by ____________________

Approved by ___________________

FORM 4.1 - Project Datums and Control (Continued)

Tidal Datums

Tidal Datums based on:

- o Tidal Benchmarks at Tide Station ________________
- o VDatum Software

Datum	MLLW Metric	NAVD 88 Metric	NAVD 88 Feet
HOWL*			
MHHW			
MHW			
MTL			
MSL			
MLW			
MLLW	0.000		
NAVD 88		0.000	0.00
LOWL*			

* HOWL and LOWL only determined for Primary Tide Stations with Tidal Benchmarks

APPENDIX 1 – Geodetic Control Projects in California

Datum Tag	EPOCH	GPS Proj.#	NETWORK
92	**1991.35**	**412**	Statewide HPGN Network and statewide adjustment
92	**1992.88**	495	Post-Landers EQ (6/28/92)
94	**1995.0**	752 & 909	Post-Northridge EQ (1/17/94)
92	1995.42	1134	SF Bay Ht Mod (superseded by 1997.30)
92	1995.50	994 & 1006	CGPS Project (CSRC)
92	1997.30	1283 & 1308	Bay-Delta Ht Mod (includes the 1996 North Bay network)
92	1997.30	1491	Hamilton Field Ht Mod
98	**1998.50**	**1288**	Statewide FBN Re-observation (see 4.2-7c)
98	1999.51	1478	Yolo County (Subsidence/) Ht Mod, 1st observations
98	**2000.35**	**1460**	Post-Hector Mine EQ (10/16/99)
98	2000.86	1659	Contra Costa County Ht Mod
CORS96	**2002.00**	**N/A**	**CORS epoch**
98	2002.53	1790	Yolo County (Subsidence/) Ht Mod, 2nd observations
98	2002.86	1821	Delta Subsidence Net 2002
98	2002.75	1881	South SF Bay Ht Mod
98	2002.82	1809	Tuolumne County Ht Mod
	2004.00		CGPS epoch (CSRC)
98	2004.30	2103	Glenn County (Subsidence/)Ht Mod, 1st observations
98	2004.50	2091	Clovis
98	2004.50	2017	San Joaquin Ht Mod (incl Los Banos, Visalia, and San Luis Obispo (post-Cambria EQ [12/22/03] nets) Post-Parkfield EQ (9/28/04)
98	2004.69	1988/B	North Region Ht Mod
07	**2007.00**	**N/A**	**NATIONAL READJUSTMENT, 2007**
07	2007.00	2421	Folsom Lake
07	2007.00	2422	Yolo County (Subsidence/) Ht Mod, 3rd observations
07	2007.00	2516	Sac Valley (DWR)
07	2007.00	2548	Shasta Lake (USBR)
07	2007.00	2650	Primary Base Stations for DWR CVFED (RBF) Project, San Joaquin
07	2007.00	2835	Delta Network 2011
07	2007.00		Central Coast Ht. Mod. 2007 (CSRC)
11	**2010.00**	N/A	**NATIONAL ADJUSTMENT of 2011**

	Date	Project No.	NAVD 88 LEVELING PROJECTS
	2003	L26615	SoCA Leveling to CGPS (CSRC contractor JFA)
--	2004	L26517	Caltrans D-06 (Hwy 152)
	2004	L26517/1	Caltrans D-06 (Panoche)
	2004	L26518	Caltrans D-06 (Hwy 198)

Note: **bold** is a national, 'statewide', or large regional (post-earthquakes) adjustment

APPENDIX 2, Glossary

Term	Description
Adjustment	The process of changing the values of a given set of quantities so that the results calculated using the changed set will be better than those calculated using the original set. Also call a realization.
CBN	Cooperative Base Network. That portion of the FBN whose values were not provided by NGS personnel, but by outside agencies.
CCS27	California Coordinate System of 1927. A state plane coordinate system based on a Lambert Conformal projection of the NAD 27 ellipsoid. Superseded by CCS83.
CCS83	California Coordinate System of 1983. A state plane coordinate system based on a Lambert Conformal projection of the NAD 83 ellipsoid.
CGF	Combined Grid Factor. Scale factor applied to distances to convert between grid distances and ground distances when using state plane coordinates
CGPS	Continuous GPS. A permanent GNSS antenna and receiver station.
CO-OPS	Center for Operational Oceanographic Products and Services Unit of the NOS resonsible for tidal data.
CORS	Continuously Operating Reference Station. A system of Continuous GPS stations operated by the NGS. See CGPS.
CSRC	California Spatial Reference Center, part of Scripps Institute of Oceanography, University of California, San Diego
CSRN	California Spatial Reference Network, maintained by the CSRC. See NSRS.
Datum	A geodetic datum is an abstract coordinate system with a reference surface (such as sea level) that serves to provide known locations to begin surveys and create maps.

Datum Tag	A specific realization of a datum, expressed by the year.
Department	The California Department of Transportation
Epoch	The effective date for positional data.
FBN	Federal Base Network. A nationwide NGS network of permanently monumented stations with horizontal, vertical, and gravity values. See CBN.
Geoid	The equipotential surface of the Earth's gravity field which best fits, in the least-squares sense, mean sea level.
GLONASS	Global Navigation Satellite System (Russian)
GNSS	Global Navigation Satellite System. Any satellite-based navigation system that uses precise timing of radio signals. Currently, GPS and GLONASS are operational, with COMPASS (China) and Galileo (Europe) planned.
GPS	Global Positioning System. Satellite based navigation and positioning system operated by the U.S. Air Force.
GRS 80	Ellpsoid used as the basis for NAD 83 and WGS-84
HARN	High Accuracy Reference Network. A passive monument reference network with Order "B" accuracy (8mm +/- 1: 1,000,000) See HPGN.
Height, Orthometric	The distance between the geoid and a point measured along the plumb line and taken positive upward from the geoid.
HT. MOD.	Height Modrnization is an NGS initiative to establish orthometric heights using GNSS technology in conjunction with traditional leveling, gravity, and remote sensing information.
HPGN	High Precision Geodetic Network. Early name for HARN. The term is still used in California to avoid confusion.
HTDP	Horizontal Time Dependent Positioning. Program for predicting the horizontal and vertical movement of geodetic monuments.

IERS	International Earth Rotation and Reference Systems Service, the international agency responsible for maintaining the ITRF.
ITRF	International Terrestrial Reference Frame. International datum for earth's ellipsoid, similar to WGS-84.
NAD 27	North American Datum of 1927 - Ellipsoid formerly used for mapping in the U.S. Based on Clarke's Spheroid of 1866. Superseded by NAD 83.
NAD 83	North American Datum of 1983 - The official ellipsoid used for mapping purposed in the United States and territories.
NADCON	The North American Datum Conversion Utility program is the Federal standard for converting coordinates between NAD 27 and NAD 83 datums. Accurate to 1 meter.
NAVD 88	North American Vertical Datum of 1988. The official datum for orthometric heights in the United States.
NGS	National Geodetic Survey. Formerly known as The U.S. Coast and Geodetic Survey
NGVD 29	National Geodetic Vertical Datum of 1929. NGVD 29 was the official datum for orthometric heights in the U.S. until superseded by NAVD 88. It is no longer supported by NGS.
NOAA	National Oceanographic and Atmospheric Administration NOAA is the parent organization for the NOS
NOS	National Ocean Service. Agency responsible for tidal datums and nautical charts for the U.S. Government. Parent agency of NGS and CO-OPS
NSRS	National Spatial Reference System, maintained by NGS, is a consistent national coordinate system that specifies latitude, longitude, height, scale, gravity, and orientation throughout the U.S.
NTDE	The National Tidal Datum Epoch is a particular 19-year series of tidal measurements over which the tidal phases (such as mean lower low water) are determined.

P.R.C.	California Public Resources Code
PID	Project Initiation Document. The final product of the initial phase of project development (i.e., "K" phase)
Realization	See Adjustment
Reference Frame	A collection of points on the earth's surface whose coordinates have been accurately determined, and by which a datum can be realized.
RTN	Real Time Network. A network of CGPS stations that provide real-time kinematic (RTK) correctors to field GNSS users over the internet via cellular phone networks or digital radio link.
Spheroid	See Ellipsoid
Tidal Datums	See Section 4.5-3 for the definitions of tidal datums (MLLW, MSL, MHHW, etc.)
USNG	United States National Grid. A rectangular grid system used in the United States, based on the UTM.
UTM	Universal Transverse Mercator. Worldwide coordinate system with 60 zones , each with a width of 6 degrees longitude. Based on WGS 84 ellipsoid.
VDatum	The Vertical Datums software is a tool developed by NOAA to convert orthometric heights (NAVD 88 or NGVD29) to tidal datums.
VERTCON	The Vertical Conversion software computes the modeled difference in orthometric height between the North American Vertical Datum of 1988 (NAVD 88) and the National Geodetic Vertical Datum of 1929 (NGVD 29) for a given location specified by latitude and longitude. Not accurate for third order leveling or better.
WGS 84	World Geodetic System of 1984. Ellipsoid used by GPS satellites

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