GPS Derived Heights: A Height Modernization Primer

October 25, 2007
National Geodetic Survey

Indiana Height Modernization Forum

Renee Shields
National Geodetic Survey
National Oceanic and Atmospheric Administration
How to achieve accurate GPS heights

What types of heights are involved?
- Orthometric heights
- Ellipsoid heights
- Geoid heights

How are these heights defined and related?

How accurately can these heights be determined?
What is a GEODE蒂C DATUM?

• A set of constants specifying the coordinate system used for geodetic control, i.e., for calculating coordinates of points on the Earth*
• [above] together with the coordinate system and the set of all points and lines whose coordinates, lengths, and directions have been determined by measurement or calculation.*

*Definitions from the Geodetic Glossary, September 1986
Not To Be Confused With:

- **Ellipsoid**
  - A closed surface, whose planar sections are either ellipsoids or circles.*
  - Mathematical figure which helps define a Reference Frame
  - Clarke 1866, GRS80

- **Reference Frame**
  - A coordinate system associated with a physical system.*
  - NSRS, ITRF

*Definitions from the Geodetic Glossary, September 1986
A Geodetic Datum specifying the coordinate system in which horizontal control points are located.*

Defined by 8 Constants
- 3 define location of the origin of the coordinate system.
- 3 define orientation of the coordinate system.
- 2 define dimensions of the reference ellipsoid.

NAD 27, NAD 83

*Definition from the Geodetic Glossary, September 1986
Why is the Datum important?

The Datum is important because it provides a reference system for geographic coordinates. The map shows two circles: a 1000 m radius circle and a 500 m radius circle, which are important for surveying and geodetic purposes. The Flagpole, which is a key reference point, is located within the 1000 m radius circle, and the COMET marker is within the 500 m radius circle. These circles help to define the area that is surveyed and measured with high precision. The Datum used in this area is NAD83 and WGS84, which are coordinate systems used for geospatial data.
## Compare Horizontal Datum Elements

### NAD 27

<table>
<thead>
<tr>
<th>Ellipsoid</th>
<th>CLARKE 1866</th>
<th>GRS80</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>6,378,206.4 M</td>
<td>6,378,137.0 M</td>
</tr>
<tr>
<td>1/f</td>
<td>294.9786982</td>
<td>298.257222101</td>
</tr>
</tbody>
</table>

| Datum Point     | Triangulation Station, MEADES RANCH, Kansas | NONE, EARTH MASS CENTER |

| Adjustment       | 25k STATIONS, Several Hundred Base Lines, Several Hundred Astro Azimuths | 250k STATIONS, Approx. 30k EDMI Base Lines, 5k Astro Azimuths, Doppler Point Positions, VLBI Vectors |

| Best Fitting     | North America | World-Wide |
Vertical Control Datum?

• “A Geodetic Datum specifying the system in which vertical control points are located.” *
• A set of fundamental elevations to which other elevations are referred
• NGVD 29, NAVD 88 – Orthometric, “Sea Level”
• Others – IGLD, Cairo, Local Tidal

*Definitions from the Geodetic Glossary, September 1986
SUMMARY: This Notice announces a decision by the Federal Geodetic Control Subcommittee (FGCS) to affirm the North American Vertical Datum of 1988 (NAVD 88) as the official civilian vertical datum for surveying and mapping activities in the United States performed or financed by the Federal Government, and to the extent practicable, legally allowable, and feasible, require that all Federal agencies using or producing vertical height information undertake an orderly transition to NAVD 88.
## Vertical Datum Elements: NGVD29 vs NAVD88

### DATUM DEFINITION
- **NGVD 29**: 26 Tide Gauges in the U.S. & Canada
- **NAVD 88**: FATHER’S POINT/Rimouski, Quebec, Canada

### GEOID FITTING
- **NGVD 29**: Distorted to Fit MSL Gauges
- **NAVD 88**: Best Continental Model

### CORRECTIONS
- **NGVD 29**: Normal Gravity, Level, Rod, Temp.
- **NAVD 88**: Observed Gravity, Level, Rod, Temp. Magnetic, Refraction

### BENCH MARKS
- **NGVD 29**: 100,000
- **NAVD 88**: 450,000

### LEVELING (Km)
- **NGVD 29**: 106,724 (U.S. + Canada)
- **NAVD 88**: 1,001,500
Differential Leveling – NGVD29

Figure 1. First-order vertical control used in 1929 adjustment.
Figure 3. Vertical control used in 1988 adjustment.
Height Difference - NGVD29 to NAVD88

CONUS Range = 0.4 to 5.0 ft  (AK ~ 6.5 ft)

NOAA/NGS
Ellipsoid, Geoid, and Orthometric Heights

- **H** = Orthometric Height (leveling)
- **h** = Ellipsoidal Height (GPS)
- **N** = Geoid Height (model)

\[
H = h - N
\]
Sample Datasheet – Leveling

**NATIONAL GEODETIC SURVEY**

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>ALAMEDA</th>
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<tr>
<td>PID</td>
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<td>CO/JEFFERSON</td>
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<tr>
<td>USGS QUAD</td>
<td>FORT LOGAN (1994)</td>
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*CURRENT SURVEY CONTROL*

<table>
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<tr>
<th>NAD 83(1992)</th>
<th>39 42 39.39630(N)</th>
<th>105 03 57.01077(W)</th>
<th>ADJUSTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAVD 88</td>
<td>1663.505 (meters)</td>
<td>5457.68 (feet)</td>
<td>ADJUSTED</td>
</tr>
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<tr>
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<td>4,054,400.023 (meters)</td>
<td>COMP</td>
</tr>
<tr>
<td>LAPLACE CORR</td>
<td>-12.19 (seconds)</td>
<td>DEFLEC99</td>
</tr>
</tbody>
</table>

- **KK1393** The orthometric height was determined by differential leveling
- **KK1393** and adjusted by the National Geodetic Survey in June 1991.
Control network is becoming decimated
Costly, time consuming
Difficult to maintain
How to achieve accurate GPS heights

- Orthometric heights
- Ellipsoid heights
- Geoid heights
enter GPS... (GNSS)
Guidelines

NOAA Technical Memorandum NOS NGS-58

GUIDELINES FOR ESTABLISHING GPS-DERIVED ELLIPSOID HEIGHTS
(STANDARDS: 2 CM AND 5 CM)
VERSION 4.3

David B. Zilkoski
Joseph D. D’Onofrio
Stephen J. Frakes

Silver Spring, MD
November 1997

Available “On-Line” at the NGS Web Site:
www.ngs.noaa.gov/PUBS_LIB/pub_index.html

Guidelines for Establishing GPS-Derived Orthometric Heights
(Standards: 2 cm and 5 cm)
Version 1.4

David B. Zilkoski
Edward E. Carlson
Curtis L. Smith
National Geodetic Survey
1315 East-West Highway
Silver Spring, Maryland 20910
(301) 713-3391

October 2005
Components of NGS-58

- Equipment requirements
- Field Procedures/Data Collection
- Parameters
- Basic Control Requirements
- Processing/Analysis Procedures
Equipment Requirements

- Dual-frequency, full-wavelength GPS receiver
  - Required - observations > 10 km
  - Preferred - ALL observations regardless of length
- Geodetic quality antennas with ground planes
  - Choke ring antennas; highly recommended
  - Successfully modeled L1/L2 offsets and phase patterns
  - Use identical antenna types if possible
  - Corrections must be utilized by processing software when mixing antenna types
Equipment Requirements

“Fixed” Height Tripod
Antenna Height

The height is measured vertically (NOT the slant height) from the mark to the ARP of the antenna.

The height is measured in meters.

The ARP is almost always the center of the bottom-most, permanently attached, surface of the antenna.

See GPS Antenna Calibration for photo's and diagrams that show where the ARP is on most antennas.

If 0.0000 is entered for the height, OPUS will return the position of the ARP.
The antenna phase centers are located somewhere around here.

The Antenna Reference Point (ARP) is almost always located in the center of the bottom surface of the antenna.

The antenna offsets are the distance between the phase centers and the ARP.

If the user selects NONE as the antenna type, the offsets are set to 0.000 and the antenna phase center becomes the reference point.

The user does not need to know these offsets. They are passed to the processing software through the antenna type.
Data Collection Parameters

- VDOP < 6 for 90% or longer of 30 minute session
  - Shorter session lengths stay < 6 always
  - Schedule travel during periods of higher VDOP
- Session lengths > 30 minutes collect 15 second data
  - Session lengths < 30 minutes collect 5 second data
- Track satellites down to 10° elevation angle
- Repeat Baselines
  - Different days
  - Different times of day
  - Detect, remove, reduce effects due to multipath and having almost the same satellite geometry
Comparison of 30 Minute Solutions - Precise Orbit; Hopfield (0); IONOFREE
(30 Minute solutions computed on the hour and the half hour)

**MOLA to RV22** 10.8 Km

<table>
<thead>
<tr>
<th>Day 264</th>
<th>dh (m)</th>
<th>Hours Diff.</th>
<th>Day 265</th>
<th>dh (m)</th>
<th>Day 264 minus Day 265 (cm)</th>
<th>* diff &gt;2 cm</th>
<th>Mean dh minus &quot;Truth&quot; (cm)</th>
<th>* diff &gt;2 cm</th>
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<tbody>
<tr>
<td>14:00-14:30</td>
<td>-10.281</td>
<td>27hrs</td>
<td>17:00-17:30</td>
<td>-10.279</td>
<td>-0.2</td>
<td></td>
<td>-10.280</td>
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<td>14:30-15:00</td>
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<td>17:30-18:00</td>
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<tr>
<td>18:30-19:00</td>
<td>-10.271</td>
<td>21hrs</td>
<td>15:30-16:00</td>
<td>-10.276</td>
<td>0.5</td>
<td></td>
<td>-10.274</td>
<td>0.2</td>
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<tr>
<td>19:00-19:30</td>
<td>-10.277</td>
<td>21hrs</td>
<td>16:00-16:30</td>
<td>-10.278</td>
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<td>19:30-20:00</td>
<td>-10.271</td>
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<td>16:30-17:00</td>
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<td>14:00-14:30</td>
<td>-10.278</td>
<td>1.9</td>
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<td>-10.269</td>
<td>0.7</td>
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<td><strong>20:30-21:00</strong></td>
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<td><strong>18hrs</strong></td>
<td><strong>14:30-15:00</strong></td>
<td><strong>-10.295</strong></td>
<td><strong>4.1</strong></td>
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<td><strong>-10.275</strong></td>
<td><strong>0.1</strong></td>
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<td><strong>&quot;Truth&quot;</strong></td>
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<td></td>
<td></td>
<td></td>
<td><strong>-10.276</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Two Days/Same Time**

-10.254 > -10.251

Difference = 0.3 cm

"Truth" = -10.276

Difference = 2.3 cm

**Two Days/Different Times**

-10.254 > -10.275

Difference = 4.1 cm

"Truth" = -10.276

Difference = 0.1 cm
Station pairs with large residuals, i.e., greater than 2.5 cm, also have large repeat base line differences. NGS guidelines for estimating GPS-derived ellipsoid heights require user to re-observe these base lines. Following NGS guidelines provides enough redundancy for adjustment process to detect outliers and apply residual on appropriate observation, i.e., the bad vector.
Four Basic Control Requirements

- Occupy stations with known NAVD 88 orthometric heights
  - Stations should be evenly distributed throughout project
- Project areas < 20 km on a side, surround project with NAVD 88 bench marks
  - i.e., minimum number of stations is four; one in each corner of project
- Project areas > 20 km on a side, keep distances between GPS-occupied NAVD 88 bench marks to less than 20 km
- Projects located in mountainous regions, occupy bench marks at base and summit of mountains, even if distance is less than 20 km
Sample Project

Area: East San Francisco Bay Project
- Latitude 37° 50’’ N to 38° 10’’ N
- Longitude 121° 45’’ W to 122° 25’’ W

Receivers Available: 5

Standards: 2 cm GPS-Derived Heights
GPS-Usable Stations

- CORS
- HARN
- NAVD’88 BM
- New Station
- Spacing Station
- Primary Base Station
Processing: Five Basic Procedures

- Perform 3-D minimally constrained (free) adjustment
- Analyze adjustment results
- Compute differences between GPS-derived orthometric heights from free adjustment and published NAVD88 BMs
- Evaluate differences to determine which BMs have valid NAVD88 height values
- Perform constrained adjustment with results from previous step
Height Modernization Project

HARN - Average 50km, max 75km
Primary – 20-25km, max 40km
Secondary - Average 12-15km, max 15km
Local – Average 6-8 km, max 10km

= HARN
= Primary Base Network
= Secondary Base Network
= Local Base Network

= Existing NGS Level line
= New HMP Level line
GPS Ellipsoid Height Hierarchy

HARN/Control Stations
(25 km) 5.5 hr 3 days different times

Primary Base
(40 km) 5.5 hr
3 days different times

Secondary Base
(15 km) 0.5 hr
2 days different times

Local Network Stations
(7 to 10 km) 0.5 hr
2 days different times
Sample Datasheet - GPS

<table>
<thead>
<tr>
<th>KK1779</th>
<th>DESIGNATION - BARBARA</th>
</tr>
</thead>
<tbody>
<tr>
<td>KK1779</td>
<td>PID - KK1779</td>
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<tr>
<td>KK1779</td>
<td>STATE/COUNTY - CO/JEFFERSON</td>
</tr>
<tr>
<td>KK1779</td>
<td>USGS QUAD - GOLDEN (1994)</td>
</tr>
<tr>
<td>KK1779</td>
<td>*CURRENT SURVEY CONTROL</td>
</tr>
</tbody>
</table>

| KK1779* | NAD 83(1992) - | 39 51 05.58504(N) 105 10 43.39354(W) | ADJUSTED |
| KK1779* | NAVD 88 - | 1773.1 (meters) 5817. (feet) | GPS OBS |

| KK1779 | X -1,284,184.274 (meters) | COMP |
| KK1779 | Y -4,733,530.907 (meters) | COMP |
| KK1779 | Z 4,066,471.229 (meters) | COMP |

KK1779 The orthometric height was determined by GPS observations and a high-resolution geoid model.

KK1779
| OM1256 | CBN       | This is a Cooperative Base Network Control Station. |
| OM1256 | DESIGNATION | CAMBRIA GPS |
| OM1256 | PID       | OM1256 |
| OM1256 | STATE/COUNTY | WI/COLUMBIA |
| OM1256 | USGS QUAD | RANDOLPH (1980) |

*CURRENT SURVEY CONTROL*

| OM1256 | NAD 83(1997) | 43 34 10.47581(N) 089 06 09.35995(W) ADJUSTED |
| OM1256 | NAVD 88     | 303.84 (meters) 996.8 (feet) GPS OBS |

| OM1256 | X           | 72,495.418 (meters) COMP |
| OM1256 | Y           | -4,628,194.515 (meters) COMP |
| OM1256 | Z           | 4,373,750.772 (meters) COMP |

The orthometric height was determined by GPS observations and a high-resolution geoid model using precise GPS observation and processing techniques.
Ellipsoid, Geoid, and Orthometric Heights

\[ H = \text{Orthometric Height (leveling)} \]
\[ h = \text{Ellipsoidal Height (GPS)} \]
\[ N = \text{Geoid Height (model)} \]

\[ H = h - N \]
GEOIDS versus GEOID HEIGHTS

“The equipotential surface of the Earth’s gravity field which best fits, in the least squares sense, (global) mean sea level.”*

- Can’t see the surface or measure it directly.
- Can be modeled from gravity data as they are mathematically related.
- Note that the geoid is a vertical datum surface.
- A geoid height is the height from an ellipsoidal datum to a geoid.
- Hence, geoid height models are directly tied to the geoid and ellipsoid that define them (i.e., geoid height models are not interchangeable).

*Definition from the Geodetic Glossary, September 1986
In Search of the Geoid...

Dr. Dan Roman

Courtesy of Natural Resources Canada  www.geod.nrcan.gc.ca/index_e/geodesy_e/geoid03_e.html
High Resolution Geoid Models
USGG2003 (Scientific Model)

- Earth Gravity Model of 1996 (EGM96)
- 2.6 million terrestrial, ship-borne, and altimetric gravity measurements
  - offshore altimetry from GSFC.001 instead of KMS98
- 30 arc second Digital Elevation Data
- 3 arc second DEM for the Northwest USA
  - Decimated from 1 arc second NGSDEM99
- Computed on 1 x 1 arc minute grid spacing
- GRS-80 ellipsoid centered at ITRF00 origin

Long Wavelength - global
Medium Wavelength - regional
Short Wavelength - local
Gravity Coverage for GEOID03
High Resolution Geoid Models
GEOID03 (vs. Geoid99)

- Begin with USGG2003 model
- **14,185** NAD83 GPS heights on NAVD88 leveled benchmarks (vs. 6169)
- Determine national bias and trend relative to GPS/BMs
- Create grid to model local (state-wide) remaining differences
- **ITRF00**/NAD83 transformation (vs. ITRF97)
High Resolution Geoid Models
GEOID03 (vs. Geoid99)

- Compute and remove conversion surface from USGG2003
- Relative to non-geocentric GRS-80 ellipsoid
- **2.7 cm RMS** nationally when compared to BM data (vs. 4.6 cm)
- RMS ≈ **50%** improvement over GEOID99 (Geoid96 to 99 was 16%)
Composite Geoids

Gravity Geoid systematic misfit with benchmarks

Composite Geoid biased to fit local benchmarks

e = h – H - N

Earth’s Surface

Hybrid or Composite Geoid ≈ NAVD 88

0.015 M in Lakewood, CO – 2003 model

Gravity Geoid
2003 GPSBM Control Data Used to Create GEOID03

14308 total: 13554 NGS database (triangles) + 52 mod. S. Louisiana (diamonds) + 579 Canadian (plusses) + 123 rejected (X’s)
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<td>-12.19 (seconds)</td>
<td>DEFLEC99</td>
</tr>
<tr>
<td>KK1393</td>
<td>ELLIP HEIGHT-</td>
<td>1646.84 (meters)</td>
<td>GPS OBS</td>
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<tr>
<td>KK1393</td>
<td>GEOID HEIGHT-</td>
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<td>GEOID03</td>
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<td>DYNAMIC HT-</td>
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<table>
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<td>VERT ORDER</td>
<td>FIRST CLASS II</td>
</tr>
<tr>
<td>KK1393</td>
<td>ELLP ORDER</td>
<td>FOURTH CLASS II</td>
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</table>
The horizontal coordinates were established by GPS observations and adjusted by the National Geodetic Survey in January 1998.

The orthometric height was determined by differential leveling and adjusted by the National Geodetic Survey in June 1991.

The X, Y, and Z were computed from the position and the ellipsoidal ht.

The Laplace correction was computed from DEFLEC99 derived deflections.

The ellipsoidal height was determined by GPS observations and is referenced to NAD 83.

The geoid height was determined by GEOID03.

The dynamic height is computed by dividing the NAVD 88 geopotential number by the normal gravity value computed on the Geodetic Reference System of 1980 (GRS 80) ellipsoid at 45 degrees latitude (g = 980.6199 gals.).

The modeled gravity was interpolated from observed gravity values.
### Sample Datasheet

**NATIONAL GEODETIC SURVEY**

<table>
<thead>
<tr>
<th>Data Type</th>
<th>North</th>
<th>East</th>
<th>Units</th>
<th>Scale Factor</th>
<th>Convergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>KK1393;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KK1393; SPC CO C</td>
<td>- 513,324.546</td>
<td>951,632.174</td>
<td>MT</td>
<td>0.99999251</td>
<td>+0 16 25.8</td>
</tr>
<tr>
<td>KK1393; SPC CO C</td>
<td>- 1,684,132.28</td>
<td>3,122,146.56</td>
<td>sFT</td>
<td>0.99999251</td>
<td>+0 16 25.8</td>
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<tr>
<td>KK1393; UTM 13</td>
<td>- 4,395,677.639</td>
<td>494,356.607</td>
<td>MT</td>
<td>0.99960039</td>
<td>-0 02 31.4</td>
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</table>

**Elev Factor x Scale Factor = Combined Factor**

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Elev Factor</th>
<th>Scale Factor</th>
<th>Combined Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>KK1393! SPC CO C</td>
<td>0.99974170</td>
<td>0.99999251</td>
<td>0.99973422</td>
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<tr>
<td>KK1393! UTM 13</td>
<td>0.99974170</td>
<td>0.99960039</td>
<td>0.99934220</td>
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</tbody>
</table>

**Primary Azimuth Mark**

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Primary Azimuth Mark</th>
<th>Grid Az</th>
</tr>
</thead>
<tbody>
<tr>
<td>KK1393 SPC CO C</td>
<td>ALAMEDA AZ MK OFFSET</td>
<td>088 03 11.6</td>
</tr>
<tr>
<td>KK1393 UTM 13</td>
<td>ALAMEDA AZ MK OFFSET</td>
<td>088 22 08.8</td>
</tr>
</tbody>
</table>

**SUPERSEDED SURVEY CONTROL**

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Ellipsoid H (01/12/98)</th>
<th>NAVD 88 (01/12/98)</th>
<th>NGVD 29 (??/??/??)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KK1393</td>
<td>1646.88 (m)</td>
<td>1663.51 (m)</td>
<td>1662.577 (m)</td>
</tr>
<tr>
<td>KK1393 ELLIP H (01/12/98)</td>
<td>GP( ) 4 1</td>
<td>GP( ) 4 1</td>
<td>GP( ) 4 1</td>
</tr>
<tr>
<td>KK1393 NAD 83(1992)</td>
<td>39 42 39.39665(N)</td>
<td>105 03 57.01291(W)</td>
<td>AD( ) 1</td>
</tr>
<tr>
<td>KK1393 NAD 83(1986)</td>
<td>39 42 39.39304(N)</td>
<td>105 03 57.01147(W)</td>
<td>AD( ) 1</td>
</tr>
<tr>
<td>KK1393 NAD 27</td>
<td>39 42 39.43921(N)</td>
<td>105 03 55.06755(W)</td>
<td>AD( ) 1</td>
</tr>
<tr>
<td>KK1393 NAVD 88 (01/12/98)</td>
<td>1663.51 (m)</td>
<td>5457.7 (f)</td>
<td>LEVELING 3</td>
</tr>
<tr>
<td>KK1393 NGVD 29 (??/??/??)</td>
<td>1662.577 (m)</td>
<td>5454.64 (f)</td>
<td>ADJUSTED 1 2</td>
</tr>
</tbody>
</table>

**Superseded values are not recommended for survey control.**

**NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.**

**See file dsdata.txt to determine how the superseded data were derived.**
<table>
<thead>
<tr>
<th>KK1393</th>
<th>DESIGNATION - ALAMEDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>KK1393</td>
<td>PID - KK1393</td>
</tr>
<tr>
<td>KK1393</td>
<td>STATE/COUNTY - CO/JEFFERSON</td>
</tr>
<tr>
<td>KK1393</td>
<td>USGS QUAD - FORT LOGAN (1994)</td>
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</tbody>
</table>

*CURRENT SURVEY CONTROL*

<table>
<thead>
<tr>
<th>KK1393*</th>
<th>NAD 83(1992) - 39 42 39.39630(N) 105 03 57.01077(W)</th>
<th>ADJUSTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>KK1393*</td>
<td>NAVD 88 - 1663.505 (meters) 5457.68 (feet)</td>
<td>ADJUSTED</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KK1393</th>
<th>X - -1,277,430.994 (meters)</th>
<th>COMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>KK1393</td>
<td>Y - -4,745,618.632 (meters)</td>
<td>COMP</td>
</tr>
<tr>
<td>KK1393</td>
<td>Z - 4,054,400.023 (meters)</td>
<td>COMP</td>
</tr>
<tr>
<td>KK1393</td>
<td>LAPLACE CORR - -12.19 (seconds)</td>
<td>DEFLEC99</td>
</tr>
<tr>
<td>KK1393</td>
<td>ELLIP HEIGHT - 1646.84 (meters)</td>
<td>(12/03/02) GPS OBS</td>
</tr>
<tr>
<td>KK1393</td>
<td>GEOID HEIGHT - -16.65 (meters)</td>
<td>GEOID03</td>
</tr>
<tr>
<td>KK1393</td>
<td>DYNAMIC HT - 1661.883 (meters)</td>
<td>5452.36 (feet)</td>
</tr>
<tr>
<td>KK1393</td>
<td>MODELED GRAV - 979,592.8 (mgal)</td>
<td>NAVD 88</td>
</tr>
</tbody>
</table>

**HORZ ORDER - FIRST**

**VERT ORDER - FIRST \** CLASS II

**ELLP ORDER - FOURTH \** CLASS II

**NAV88** – **Ellipsoid Ht + Geoid Ht = ...**

1663.505 – 1646.84 – 16.93 = -0.265 \** USGG2003

1663.505 – 1646.84 – 16.65 = +0.015 \** GEOID03
National Gravity Survey Plan

Dr. Dru Smith
Chief Geodesist, NOAA/NGS
Retold by Renee Shields

Indiana Height Modernization Forum
October 25, 2007
Indianapolis, IN
NGS 10 year plan (2007-2017)

Mission of NGS

- To define, maintain and provide access to the National Spatial Reference System to meet our nation’s economic, social, and environmental needs

And

- To be a world leader in geospatial activities, including the development and promotion of standards, specifications, and guidelines.
NGS 10 year plan (2007-2017)  
Vision (to achieve the Mission) of NGS

- The NSRS must be more accurate than all activities which build upon it, while still being practically achievable.

- The *acceleration of gravity* at points used in defining the NSRS should have an absolute accuracy of **10 microGals** at any time.

- The *gravimetric geoid* used in defining the NSRS should have an absolute accuracy less than **1 centimeter** anyplace at any time.
NGS 10 year plan (2007-2017)

Vision (to achieve the Mission) of NGS

- NGS must track *all of the temporal changes* to the defining points of the NSRS in such a way as to maintain the accuracy of the NSRS definition continually.

- NGS must develop and maintain guidelines for users to *access* the NSRS *at a variety of accuracies*.

- NGS will publish all coordinates of *defining points* of the NSRS with an *epoch tag* and will furthermore publish *velocities* relative to that epoch-tagged set of coordinates.
Gravity Survey Plan – Why?

- Delivering the vertical datum to customers through height coordinates on passive marks can not be perpetuated
  - Questionable values in the mountains
  - Impossibility of monitoring
  - Ease of mark destruction

- By comparison, a well known and monitored gravity field, combined with CORS yields the ability to more accurately and efficiently continue to deliver the vertical datum
Gravity Survey Plan

- To be developed before the end of FY08
- Comprehensive
- Ten year (plus) look at needs
Gravity Survey Plan

• National Scale has 2 parts:
  – High Resolution Snapshot
  – Low Resolution Movie

• Local/Regional Scale has 1 part:
  – High Resolution Movie
Gravity Survey Plan

- National High Resolution Snapshot
  - Predominantly through airborne gravity
  - With Absolute Gravity for ties and checks
  - Relative Gravity for expanding local regions where airborne shows significant mismatch with existing terrestrial
Gravity Survey Plan – Phase I(a) - Testing

- Test varieties of flight heights / speeds / spacings for optimal ratio of

\[ \text{\$\$ : g-accuracy} \]
Gravity Survey Plan – Phase I(b) - Testing

- Test area for proof of concept to define vertical datum from GPS + gravimetric geoid
- PR/VI cost would run ~$300k
Gravity Survey Plan – Phase II - Operations

- In a carefully chosen order...
Gravity Survey Plan

- National Low Resolution Movie
  - Epochal (annual?) absolute gravity re-measurements at key areas
  - GOCE for more global signatures
Gravity Survey Plan

- Regional High Resolution Movie
  - Certain regions may require repetitive surveys to model the diversity of mass changes occurring locally
  - Can not be done with NGS personnel as is
- Survey Types:
  - Gravity (absolute + relative)
  - Co-located GPS+Leveling in space/time
    - Minimally constrained
Gravity Survey Plan

- **Airborne**
  - Critically needed as a one-time high resolution “snapshot” of gravity in the USA
  - As opposed to the thousands of surveys, with hundreds of instruments and operators over dozens of years
  - One time survey

- **Absolute**
  - Cyclical for episodic checks in fixed locales
  - Co-incident with foundation CORS?
  - Two field meters plus one fixed SG

- **Relative**
  - More frequently attached to “Height Mod” surveys
Gravity Survey Plan (Geoid slopes)

- More Δh GPS surveys co-located with ΔH leveling surveys
  - Minimally constrained (e.g. no “contamination” from published benchmarks)
  - Direct check on (and input to) the gravimetric geoid slopes
  - Can be culled from existing Height Mod surveys or attached to new ones
Questions?

Contact information

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Height Modernization Manager
N/NGS1, SSMC3, Room 9357
1315 East-West Highway
Silver Spring, MD 20910
301-713-3231, x116
Renee.Shields@noaa.gov
Network / Local Accuracy

Local Accuracy of 2 cm

Network Accuracy of 5 cm
Goal Achieved?

With the means to get more accurate ellipsoid heights, we can now use these ellipsoid heights on benchmarks to further improve the geoid model.

With the improved geoid model we can use GPS to compute accurate orthometric heights.