

McGEE SURVEYING CONSULTING

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Survey Report
for the
San Francisco Bay Area and Coastline LiDAR QA/QC Survey
in the
San Francisco Bay Area, California
for
Dewberry

OVERVIEW

Surveyed by: McGee Surveying Consulting (MSC) at 5290 Overpass Rd., Ste#107 Santa Barbara, CA 93111

Survey Method: GPS static

Client: Dewberry, LLC; **Project. Number:** ____; **Project Name:** San Francisco Bay Area LiDAR Mapping

Location: San Francisco Bays and the Pacific Coastline North and South of the Golden Gate

State: California

Attachments: Find the following Documents

- Spreadsheet Listing Control Points with Geodetic Coordinate, Ellipsoid Heights, UTM Grid Coordinates and NAVD88 Heights in meters
- NGS Data Sheets and CSRC Height Modernization Reports Control Points Referenced in this Survey
- CSRC NAD83, 2007.00 and 2009.00 Epoch Coordinate List and Velocities (NGS Sanctioned Positions)
- Photos of QAQC Points and Control Points

Appendix: Aerial photos of point locations

This document serves as a summary report on the above referenced QAQC survey. The purpose of this survey is to establish ground truthing points for validation of LiDAR measurements and DEM performed by others. Sixty points were surveyed for NOAA situated in 20 sites and 21 points were surveyed for the USGS situated in 7 sites as described in more detail under the NETWORK heading below. There existed sufficient CGPS (continuously operated GPS reference stations) to establish reliable horizontal positions and height modernization stations and benchmarks to establish vertical control for this project as addressed hereafter. See the map on Page 2 for the CGPS Network incorporated into this survey and the locations of the 27 sites identified by the first point number in each site.

This survey is based on the NAVD88 vertical datum utilizing the Geoid09 Model and the national re-adjustment of the NAD83 Datum published as the 2009.00 Epoch Adjustment. This Epoch supersedes the 1991.35 Epoch which is the first GPS network adjustment in California and differs by about 0.5 meters in position in this region due to the movement of the Pacific Plate relative to the North American Plate. In the following pages find an explanation of the datums and reference systems, survey accuracies, network survey process, adjustments and analysis.

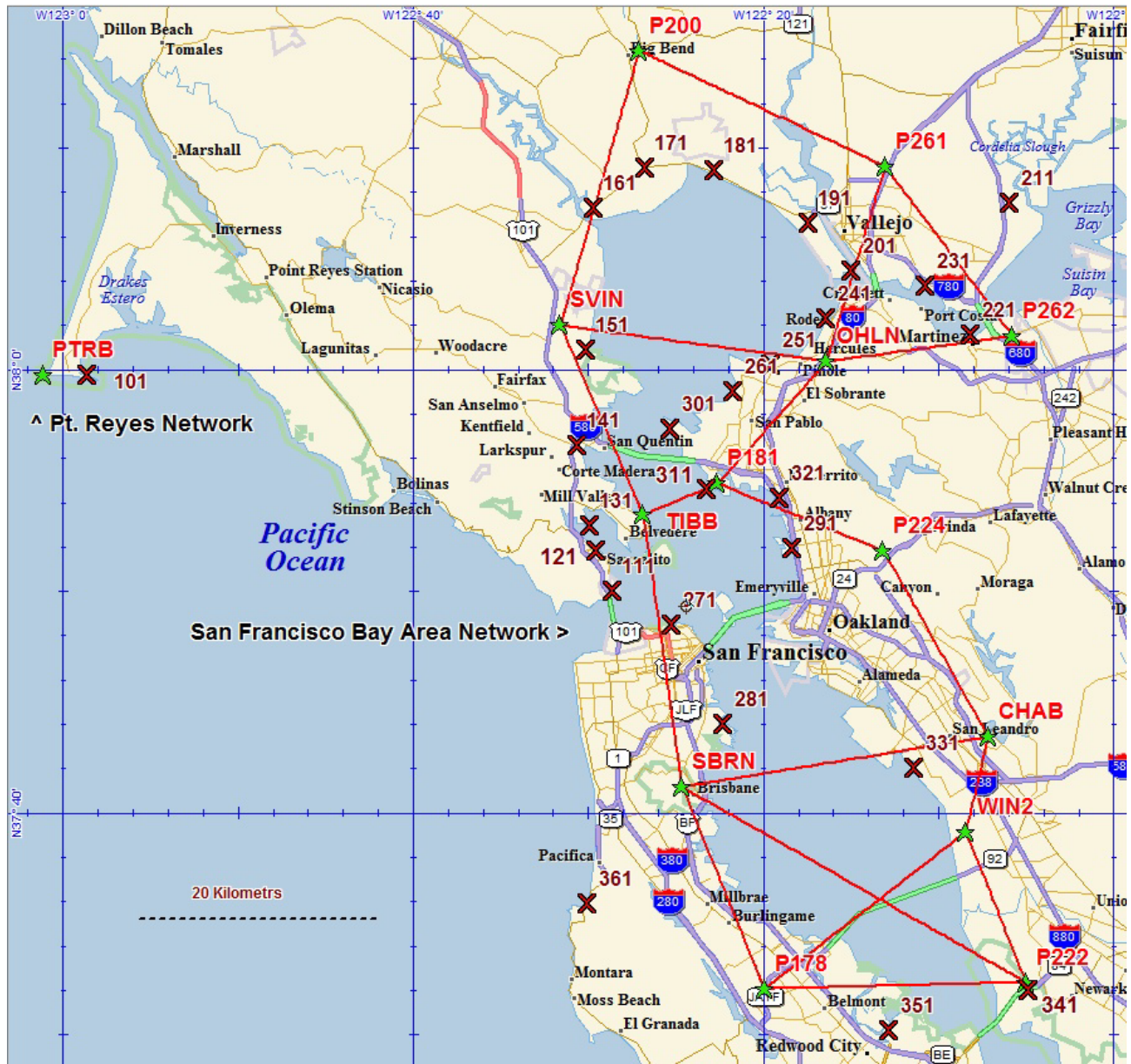
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Project Map of the CGPS Network & Site Survey Locations (north up)

(CGPS Stations indicated by a green star and Sites by a cross)



PROJECT DATUMS, REFERENCE SYSTEM

Horizontal Datum: North American Datum of 1983 (NAD83); **Epoch:** 2009.00

Reference Network: The survey is referenced to 14 California CGPS Stations (continuously operating GPS receivers mounted on a stabile platform similar to CORS). The California Spatial Reference Center (CSRC) provides NGS sanctioned positions on California CGPS Stations.

Vertical Datum: NAVD88

Reference Network: NGS and CSRC Height Mod Stations, NGS Benchmarks, and CSRC CGPS Stations

Geoid Model: Geoid 09; **Projection:** UTM Zone 10; **Units for Deliverables:** Meters

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PROJECT CONTROL: List of Published Positions on 2007.00 Epoch & 2009.00 Epoch

ID	Latitude(dms)	W.Longitude(dms)	EH(mtrs)	Ortho.Ht.	NGS PID
<u>CGPS 2009.00 Epoch</u>					
CHAB	37-43-26.80417	122-07-09.46527	214.495	246.841	DI9705
OHLN	38-00-22.49754	122-16-22.70841	-0.014	32.233	DH5958
P178	37-32-04.25440	122-19-56.45741	129.601	162.194	
P181	37-54-52.34891	122-22-36.26682	72.732	105.071	DI1087
P200	38-14-23.37857	122-27-06.07363	-24.577	7.162	
P222	37-32-21.24913	122-04-59.69752	54.016	86.648	DH9023
P224	37-51-50.01353	122-13-08.56290	407.880	440.080	DH3881
P261	38-09-10.64361	122-13-03.08973	118.690	150.586	DK9979
P262	38-01-30.52062	122-05-46.06508	-8.041	24.081	
PTRB	37-59-46.21894	123-01-07.33776	146.257		AJ1914
SBRN	37-41-10.37622	122-24-37.53810	-1.640	30.984	
SVIN	38-01-59.43258	122-31-34.69655	-27.031	5.080	
TIBB	37-53-27.13830	122-26-51.31663	-20.562	11.835	AI4507
WIN2	37-39-09.53160	122-08-26.20963	-27.107		
<u>Height Modernization Stations 2007.00 Epoch</u>					
283 (leveled from Ht Mod HT0613)				14.57	
27_CC_CO	38-03-08.79958	122-13-21.52520	-13.575	18.55	JT0530
F466	38-07-33.58414	122-29-21.70937	-31.612	0.37	JT0275
GPS_CP_4	37-54-11.57957	122-19-12.12612	-25.484	6.75	DE8481
GPS_CP_14	38-01-29.90661	122-08-21.15381	-29.419	2.62	AA3808
GPS_CP_54	37-56-01.46004	122-22-51.23850	-29.077	3.16	DE8503
HPGN_04HG	37-59-28.29799	122-21-21.50720	-23.981	8.23	AA3820
HPGN_04KJ	38-05-13.64269	122-06-42.21039	-4.971	27.07	AC9892
TIDAL_2	38-07-18.35870	122-06-03.36570	-29.366	2.71	JT0161
TIDAL_B	37-42-03.09518	122-11-22.16561	-29.855	2.69	HT2327
TIDAL_C	38-00-51.30956	122-30-07.40243	-30.031	2.11	AE7862
TIDAL_H	37-30-42.73142	122-06-34.23178	-29.599	2.95	DG6880
X552	38-06-25.98450	122-17-13.97812	-28.153	3.985	JT0321
X572	37-28-54.53999	122-08-59.10199	-29.754	2.82	DG6890
YACHT_RM_4	37-51-50.75444	122-18-56.24944	-29.071	3.26	AE5207
S97A	38-09-24.19052	122-06-49.53561	-29.613	2.40	DH6908
<u>Benchmarks & HARN Stations 2007.00 Epoch</u>					
134 (leveled from BM HT3532)				3.097	
304 (Remains of BM HT0945)				4.20	HT0945
J1393				18.659	JT9548
H480				66.911	HT1833
K5218				3.863	JT9537
M1393	38-09-04.86407	122-26-51.14960	-27.727	4.262	JT9545
N554				2.723	HT0002
TIDAL_Q	37-59-46.56279	122-58-44.57333	-13.297	19.812	HT3505
S1197	37-40-34.11578	122-06-37.18886	-15.284	17.168	HT0223
SF_56				3.800	HT0720
SF_58				3.563	HT0721
TIDAL_32	37-51-47.84052	122-29-35.97900	-28.880	3.569	HT1067
X124				19.213	HT2274
Y1240				5.043	HT1823

Reference Network Velocities & Stability: The NAD83, 2009.00 Epoch adjustment is referenced to the North American Plate. San Francisco straddles the Pacific Plate and North American Plates. The region is moving on average 1.9 cm. north and 1.9 cm. west per year, or northwesterly 2 ½ centimeters per year base on 12 CGPS Stations listed below (not including PTRB (not part of SF Network) or WIN2 (no velocity data)). The largest difference in the north and east velocities is 1.4 cm. and -0.9 cm. The maximum differential movement of the CGPS stations between 2009.0 and 2010.2 the date of this survey (1.2 years) is estimated at 1.7 cm. north and 1.1 cm. east. The deformation of two centimeter in the control network of CGPS Stations does not impact the accuracy requirements of this survey and the CGPS stations were constrained in the final adjustment to the 2009.00 Epoch (see Adjustments 1 below).

Annual Velocities (mtrs)

Station	N.Vel	E.Vel	Up_Vel	Station	N.Vel	E.Vel	Up_Vel
CHAB	0.018	-0.016	-0.001	P261	0.013	-0.014	-0.003
OHLN	0.018	-0.016	-0.001	P262	0.012	-0.016	0.008
P178	0.012	-0.021	-0.009	PTRB	0.036	-0.027	-0.002
P181	0.021	-0.020	0.023	SBRN	0.026	-0.023	-0.002
P200	0.017	-0.020	0.000	SVIN	0.024	-0.021	-0.003
P222	0.023	-0.023	0.003	TIBB	0.024	-0.019	-0.002
P224	0.016	-0.019	0.007	WIN2	?	?	?

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NETWORK

The survey established test points grouped in sites. Each site contains three test points in three land categories defined as marshlands, bare earth or short grass, and asphalt surfaces. Marshland is defined as bare earth surface below high water. A few marsh points could only be located in marsh grasses or about a meter above the high water line. The points were fundamental test points with a few exceptions of grasses in the marshes. Most of the test points on asphalt are located at a contrasting painted feature (see photos) to assist in assessing the horizontal accuracies of the lidar mapping. The sites were chosen to provide distribution, access to the shoreline, land categories, security for the survey activities, and in most cases control nearby for recovery of NAVD88.

The control surveys were conducted by creating two GPS networks. A small network (4 kilometers across) for a single site for the USGS at the western end of Point Reyes located 45 kilometers northwest of the San Francisco Bay entrance, and a large network (85 x 40 kilometers) that enclosed the north and south San Francisco Bays. The San Francisco Bay network consists of twenty sites for NOAA distributed around the north SF Bay, and six sites for the USGS distributed as follows: four sites around south SF Bay, one site on the Pacific coast about 22 kilometers south of the Golden Gate, and one site up the Sacramento River. The list below indicates the Agency for which each point was surveyed.

<u>Pt#</u>	<u>Agency</u>	<u>Pt#</u>	<u>Agency</u>	<u>Pt#</u>	<u>Agency</u>	<u>Pt#</u>	<u>Agency</u>	<u>Pt#</u>	<u>Agency</u>
101	USGS	151	NOAA	203*	NOAA	261	NOAA	312*	NOAA
102*	USGS	152*	NOAA	211	USGS	262*	NOAA	313	NOAA
103	USGS	153	NOAA	212*	USGS	263	NOAA	321	NOAA
104	USGS	161	NOAA	213	USGS	271*	NOAA	322*	NOAA
111	NOAA	162	NOAA	221	NOAA	272	NOAA	323	NOAA
112*	NOAA	163*	NOAA	222*	NOAA	273	NOAA	331	USGS
113	NOAA	171	NOAA	223	NOAA	281	USGS	332	USGS
121	NOAA	172	NOAA	224	NOAA	282	USGS	333*	USGS
122*	NOAA	173	NOAA	231	NOAA	283*	USGS	341	USGS
123	NOAA	181*	NOAA	232*	NOAA	291	NOAA	342*	USGS
131	NOAA	182	NOAA	233	NOAA	292*	NOAA	343	USGS
132*	NOAA	183	NOAA	241	NOAA	293	NOAA	351	USGS
133	NOAA	191	NOAA	242*	NOAA	301	NOAA	352	USGS
134	NOAA	192	NOAA	243	NOAA	302*	NOAA	353*	USGS
141	NOAA	193	NOAA	251	NOAA	303	NOAA	361	USGS
142	NOAA	201	NOAA	252	NOAA	304	NOAA	362*	USGS
143*	NOAA	202	NOAA	253*	NOAA	311	NOAA	363	USGS

* The asterisk indicates points used for Base Stations during the survey. In addition the Height Mod Stations M1393 and X552 were used for Base Stations.

The networks derive their horizontal positions and ellipsoid heights from a backbone of 14 CGPS stations and their NAVD88 heights (elevations) from 14 leveled NGS benchmarks and 15 Height Modernization Stations some of which are also CGPS stations. The survey was conducted as a static radial network from Base Stations set for local site control indicated by an asterisk in the above table. The Base Stations were positioned from the nearest CGPS Stations. The vectors for the CGPS Network (Page 2) are based on 24 hour observations downloaded from SOPAC or the NGS.

For redundancy, a roving receiver occupied points twice at different times of day. In some cases a single vectors was measured to a control point which was validated by checking the published positions. See below under the "ACCURACY" heading for a summary of the vector statistics representing the measurement accuracies of this survey. The GPS Networks are shown below and aerial photos showing the locations of the QAQC Test Points are included in the Appendix.

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The CGPS Stations take their assigned four letter ID, and the NGS benchmarks and Height Modernization Stations are identified by their Station Name and cross referenced below to their NGS PID (six character point identification). New QAQC Points are numbered in the 101-363 range non-inclusive. The QAQC Points are assigned a 3 digit number with the right hand digit indicating the land category as follows: 1 = marsh point taken below high water with a few exceptions on sandy, muddy, grassy, or concrete sloping surface (i.e. 101); 2 = bare earth, gravel or short grass on a level surface (i.e. 102); 3 = level asphalt surfaces at contrasting painted features (i.e. 103, see photos); 4 = horizontal check point (i.e. 104, see points 104, 134, 224, and 304). The last four points were in addition to the required points to ensure adequate horizontal testing.

ACCURACY

Observations of the GPS Constellation were processed into vectors and evaluated in a minimally constrained adjustment with the following results.

Loop Closures: Loop closures were run for the CGPS network as shown on Page 2. Closures were generally ½ centimeter on average with a 2 centimeter closure between WIN2 and P222.

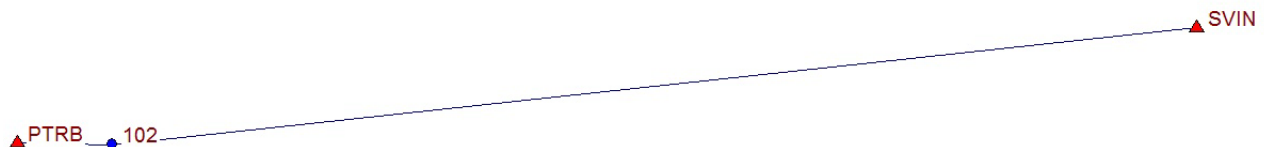
CGPS Network Vectors: 25 vectors average 19.4 kilometers in length with a maximum of 33.2 kilometers. The two dimensional residuals average 0.2 centimeters with a standard deviation of 0.1 centimeters and a maximum of 0.6 centimeters. Excepting one vector between WIN2 and P222 with a vertical residual of 1.8 centimeters, the absolute value of the vertical residuals average 0.2 centimeters with a standard deviation of 0.2 centimeters and a range of -0.5 to +0.6 centimeters.

QAQC Vectors: 170 vectors with residuals average 2.3 kilometers in length with a maximum of 14.7 kilometers. The two dimensional residuals average 0.4 centimeters with a standard deviation of 0.3 centimeters and a maximum of 1.7 centimeters. The absolute value of the vertical residuals average 0.5 centimeters with a standard deviation of 0.6 centimeters and a range of -3.8 to +2.6 centimeters.

Accuracy: In assessing the adjustment results, the expectation is the relative and absolute accuracies will be better than 2 centimeters horizontal and 3 centimeters vertical.

ADJUSTMENTS & ANALYSIS of Point Reyes Network follows

Point Reyes GPS Network: Site for Points 101-104 (north up)

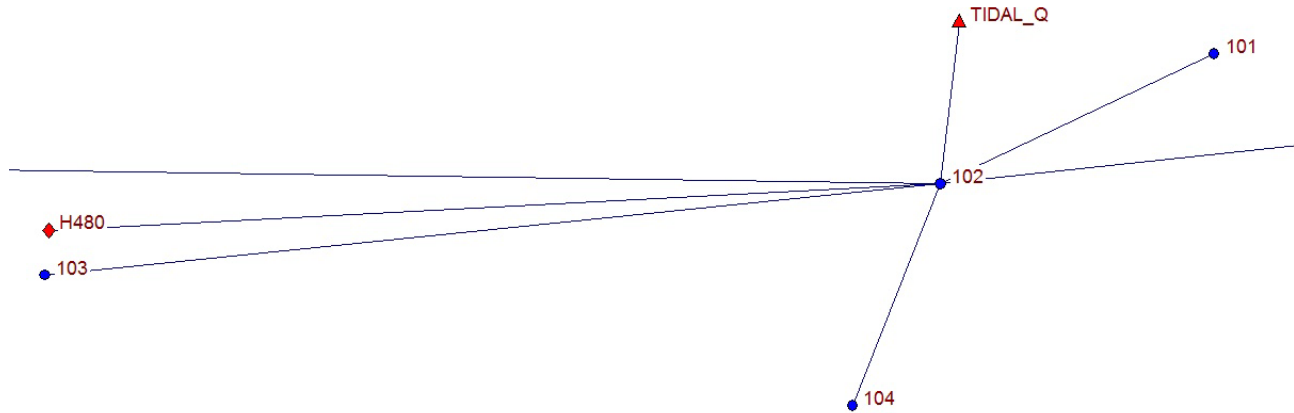


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Enlargement of Point Reyes Site (north up)



Adjustment 1 for Point Reyes: 3D/Ellipsoid Heights - Minimally Constrained Adjustment

The CGPS Station PTRB was fixed in a 3D Minimally Constrained Adjustment at its published 2009.00 Epoch position to determine latitude, longitude, and ellipsoid heights of other points. The results follow with coordinate changes from published to computed positions listed below in meters.

Station	dN	dE	dZ	
PTRB	-0.000	-0.000	-0.000	Fixed CGPS Station on the 2009 Epoch
SVIN	-0.015	0.005	-0.074	CGPS Station 2009.00 Epoch
TIDAL_Q	0.086	-0.029	-0.015	HARN Station on the 2007.00 Epoch

Comment: The difference at TIDAL_Q located about 3.5 kilometers easterly of PTRB is due mostly to the difference in the 2007.00 and the 2009.00 Epochs (PTRB velocities :North 0.036, East -0.027, Up -0.001). The small difference at SVIN located 43 kilometers easterly negates any need for a constrained adjustment. The results of this adjustment are listed in the attached Coordinate Listing

Adjustment 2 for Point Reyes: Orthometric Heights - Minimally Constrained

In a Minimally Constrained horizontal and vertical adjustment TIDAL_Q was fixed at its published NAVD88 orthometric height. The measured ellipsoid height differences were combined with Geoid 09 separations to determine heights at other points. The differences from published to computed are listed below in meters.

Station	dZ	
H480	0.000	Benchmark
SVIN	-0.058	CGPS
TIDAL_Q	-0.000	Fixed Benchmark

Comment: The difference or closure on benchmark H480 located 0.8 kilometers west-southwest of TIDAL_Q is 0.000 meters and no further adjustments are necessary. The results of this adjustment are listed in the attached Coordinate Listing

ADJUSTMENTS & ANALYSIS of San Francisco Bay Area Network follows

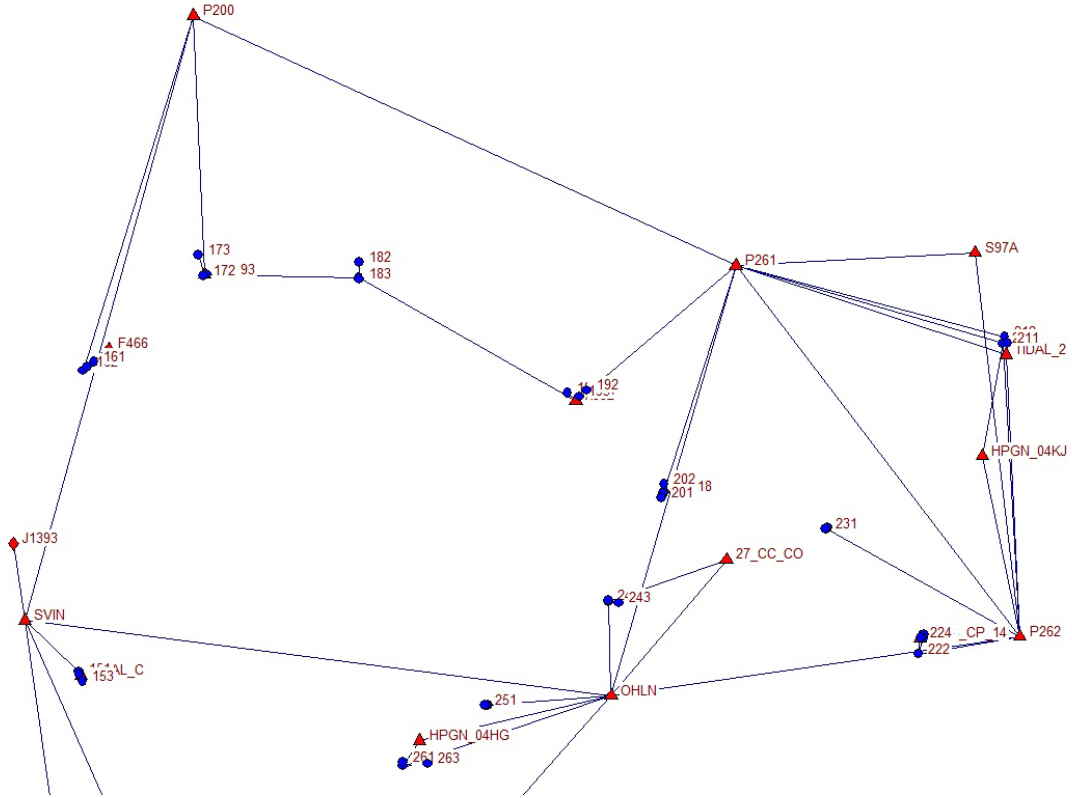
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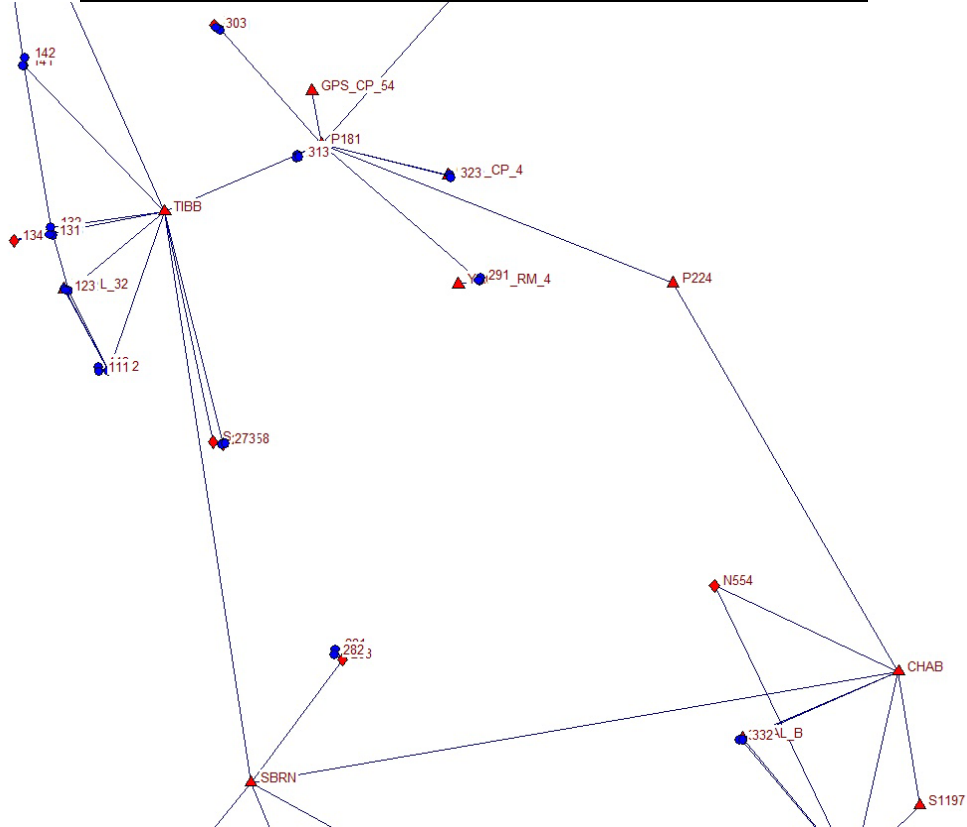
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North Portion of San Francisco Bay GPS Network (north up)

(Red Symbol = Control Points, Blue Symbol = QAQC Points)



Central Portion of San Francisco Bay GPS Network (north up)

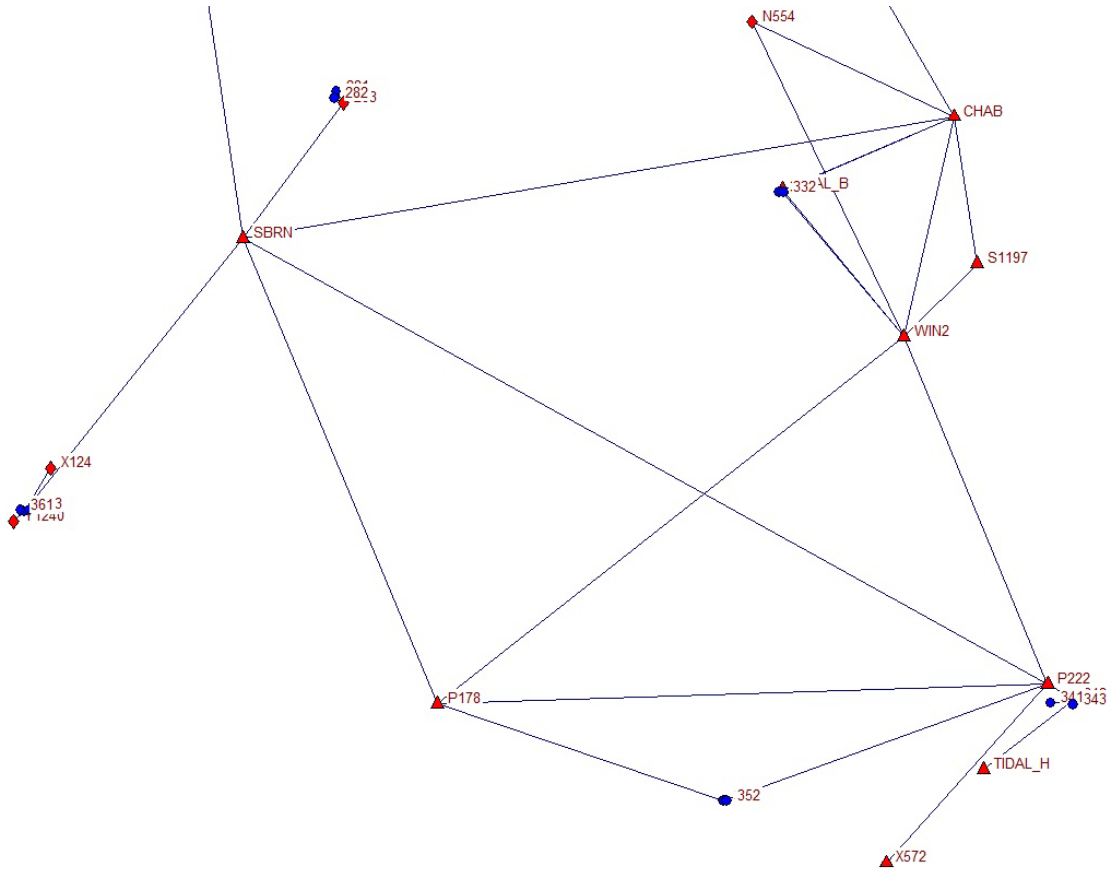


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South Portion of San Francisco Bay GPS Network (north up)



Adjustment 1A: 3D/Ellipsoid Heights - Minimally Constrained Adjustment

The CGPS Station P181 was fixed at its 2009.00 Epoch published position in a 3D Minimally Constrained Adjustment to determine latitude, longitude, and ellipsoid heights at other points. All other points listed below were set free resulting in residual differences between the published and the computed positions. These residuals, in meters, provide an indication of how well the new measurements fit existing control to identify outliers.

Station	dN	dE	dZ	Station	dN	dE	dZ
<u>CGPS Stations 2009.00 Epoch</u>				<u>Ht Mod Stations 2007.00 Epoch</u>			
CHAB	0.002	0.000	0.016	27_CC_CO	0.060	-0.025	-0.014
OHLN	-0.006	0.008	-0.011	F466	0.029	-0.024	-0.039
P178	0.009	-0.003	0.005	GPS_CP_14	0.033	-0.006	-0.089
P181	-0.000	-0.000	-0.000	GPS_CP_4	0.058	-0.020	-0.075
P200	-0.009	0.006	-0.001	GPS_CP_54	0.048	-0.032	-0.060
P222	0.004	-0.002	0.035	HPGN_04HG	-0.004	-0.018	-0.050
P224	-0.006	0.003	0.045	HPGN_04KJ	0.028	-0.031	0.004
P261	-0.020	0.017	0.023	M1393	0.020	-0.008	0.003
P262	-0.015	0.006	-0.006	S1197	0.051	-0.020	0.000
SBRN	0.013	-0.005	-0.012	S97A	0.039	-0.002	-0.047
SVIN	-0.000	0.001	-0.012	TIDAL_2	0.008	0.017	-0.037
TIBB	0.001	-0.001	-0.018	TIDAL_32	0.062	-0.012	-0.040
WIN2	-0.001	-0.000	-0.011	TIDAL_B	0.043	-0.025	-0.037
				TIDAL_C	0.020	-0.018	-0.027
				TIDAL_H	0.059	-0.013	-0.113
				X552	0.053	-0.033	-0.015
				X572	0.053	-0.024	-0.111
				YACHT_RM_4	0.086	0.012	0.000

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Comment: The CGPS Stations, published on the 2009.00 Epoch, result in average residuals of north -0.2, east +0.2, up +0.4 centimeter with a maximum of north 1.3, east 1.7, up 4.5 centimeters. Given the reported accuracies of this survey discussed above (Page 5), the up residuals of 4 centimeters at P222 and P224 are larger than expected and may be outliers. Outliers can be identified by solving an unconstrained 3D transformation (7-parameter conformal) that best fits the measured vectors based on the present constellation to the published positions of the reference network. See Adjustment 1-B below for results.

The Height Mod Stations are published on the 2007.00 Epoch. If the estimated average movement since 2007 (north and west 4 centimeters) is taken into account, based on the average velocities listed on Page 3, then the average residuals are reduced to about 1 centimeter in the north and 2 centimeters in the east. The ellipsoid height residuals in the up component are more than expected given that Height Mod Stations are usually held to 2 centimeters at the 95 % confidence level. The primary purpose of including Height Mod Stations in this survey is to recover and model NAVD88 Heights as shown below in Adjustments 3A, 3B, 3C, and 4 (refer to “Comments” under Adjustment 3-C for analysis).

Adjustment 1B: 3D/Ellipsoid Heights – Unconstrained Adjustment – Solved Transformation

All CGPS were included in an equally weighted best fit 3D Transformation Solution to determine 2009.00 Epoch latitude, longitude, and ellipsoid heights. The Height Mod Stations (published on the 2007.00 Epoch) were set free in the adjustment. The adjustment results follow with the solved transformation parameters and differences from the published to the computed positions listed below in meters.

GPS Datum Transformation Parameters Based on CGPS Stations

Scale Factor 0.999999790234: 0.209766 PPM (Solved)

Rotation Around North Axis : -0.161042 Sec (Solved)

Rotation Around East Axis : 0.000255 Sec (Solved)

Rotation Around Vert Axis : -0.038100 Sec (Solved)

Station	dN	dE	dZ	Station	dN	dE	dZ
<u>CGPS Stations 2009.00 Epoch</u>				<u>Ht Mod Stations 2007.00 Epoch</u>			
CHAB	0.003	0.004	0.001	27_CC_CO	0.068	-0.031	-0.022
OHLN	-0.000	0.003	-0.016	F466	0.034	-0.036	-0.029
P178	0.003	0.000	0.005	GPS_CP_14	0.041	-0.009	-0.102
P181	0.001	-0.005	0.002	GPS_CP_4	0.061	-0.024	-0.076
P200	-0.001	-0.007	0.006	GPS_CP_54	0.050	-0.038	-0.057
P222	0.002	0.005	0.017	HPGN_04HG	-0.000	-0.024	-0.049
P224	-0.003	0.002	0.037	HPGN_04KJ	0.039	-0.035	-0.011
P261	-0.010	0.010	0.015	M1393	0.027	-0.019	0.010
P262	-0.006	0.004	-0.023	S1197	0.052	-0.015	-0.015
SBRN	0.009	-0.006	-0.007	S97A	0.050	-0.007	-0.063
SVIN	0.001	-0.008	-0.000	TIDAL_2	0.019	0.013	-0.054
TIBB	0.002	-0.007	-0.011	TIDAL_32	0.061	-0.018	-0.030
WIN2	-0.002	0.004	-0.025	TIDAL_B	0.043	-0.022	-0.048
				TIDAL_C	0.022	-0.028	-0.016
				TIDAL_H	0.056	-0.005	-0.130
				X552	0.061	-0.040	-0.019
				X572	0.049	-0.016	-0.125
				YACHT_RM_4	0.088	0.009	-0.001

Comment: The transformation parameters are minimal, as expected, and indicate that the WGS84 measured vectors fit very well to the NAD83, 2009.00 Epoch reference frame represented by the 13 CGPS Stations. The CGPS Station’s average residuals are zero in north, east and up as expected from a best fit solution. The residuals range in centimeters is north -1.0 to +0.9, east -0.9 to +1.0, up -2.5 to +3.7. In a follow up adjustment (not shown) , the height component of P224 was set free resulting in vertical residuals at the other CGPS Stations that range +/- 2.0 centimeters. See Adjustment 2 below for final results.

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Adjustment 2: 3D/Ellipsoid Heights - Constrained Adjustment

Because of the minimal size of the transformation parameters in Adjustment 1-B above, a 3D transformation has no advantage and a standard constrained adjustment was applied. All CGPS stations were fixed in a 3D Constrained Adjustment except the height of P224, to determine final latitude, longitude, ellipsoid heights, and UTM plane coordinates for points established by this survey and the Height Mod Stations. The results follow with the differences from published to computed positions listed below in meters. The results of this adjustment are listed in the attached Coordinate Listing.

Station	dN	dE	dZ	Station	dN	dE	dZ
CGPS Stations 2009.00 Epoch				Ht Mod Stations 2007.00 Epoch			
CHAB	-0.000	-0.000	-0.000	27_CC_CO	0.066	-0.034	-0.002
OHLN	-0.000	-0.000	-0.000	F466	0.039	-0.030	-0.038
P178	-0.000	-0.000	-0.000	GPS_CP_14	0.048	-0.012	-0.082
P181	-0.000	-0.000	-0.000	GPS_CP_4	0.058	-0.020	-0.075
P200	-0.000	-0.000	-0.000	GPS_CP_54	0.048	-0.032	-0.060
P222	-0.000	-0.000	-0.000	HPGN_04HG	0.002	-0.026	-0.039
P224	-0.000	-0.000	0.038	HPGN_04KJ	0.047	-0.043	-0.004
P261	-0.000	-0.000	-0.000	M1393	0.033	-0.016	0.001
P262	-0.000	-0.000	-0.000	S1197	0.053	-0.020	0.011
SBRN	-0.000	-0.000	-0.000	S97A	0.057	-0.014	-0.056
SVIN	-0.000	-0.000	-0.000	TIDAL_2	0.026	0.006	-0.043
TIBB	-0.000	-0.000	-0.000	TIDAL_32	0.061	-0.010	-0.022
WIN2	-0.000	-0.000	-0.000	TIDAL_B	0.043	-0.024	-0.034
				TIDAL_C	0.020	-0.020	-0.014
				TIDAL_H	0.055	-0.011	-0.149
				X552	0.072	-0.049	-0.037
				X572	0.049	-0.021	-0.146
				YACHT_RM_4	0.086	0.012	0.000

Comment: The Height Mod Station's latitude, longitude, and ellipsoid heights are updated to the 2009.00 Epoch and the differences shown above are from the 2007.00 Epoch positions to this survey. (see Coordinate Listing).

Adjustment 3A: Orthometric Heights - Minimally Constrained

In a Minimally Constrained horizontal and vertical adjustment Tidal_32 was fixed at its published NAVD88 orthometric height. The measured ellipsoid height differences were combined with Geoid 09 separations to determine heights at other points. The differences from published to computed heights are listed below in meters.

Station	dZ	Desc.	Station	dZ	Desc.
134	0.011	BM	P224	0.055	CGPS
283	-0.002	BM	P261	0.042	CGPS
304	0.008	BM	P262	-0.014	CGPS
27_CC_CO	0.003	HM	S1197	-0.021	HM
CHAB	0.008	CGPS	S97A	-0.056	HM
F466	-0.014	HM	SBRN	-0.003	CGPS
GPS_CP_14	-0.029	HM	SF_56	-0.008	BM
GPS_CP_4	0.001	HM	SF_58	-0.033	BM
GPS_CP_54	0.018	HM	SVIN	0.005	CGPS
HPGN_04HG	0.019	HM	TIBB	-0.008	CGPS
HPGN_04KJ	0.042	HM	TIDAL_2	-0.036	HM
J1393	0.000	BM	TIDAL_32	-0.000	HM Fixed
K5218	0.008	BM	TIDAL_B	-0.076	HM
M1393	0.034	HM	TIDAL_C	0.006	HM
N554	0.006	BM	TIDAL_H	-0.083	HM
OHLN	-0.004	CGPS	X124	-0.027	BM
P178	0.008	CGPS	X552	0.009	HM
P181	-0.000	CGPS	X572	-0.065	HM
P200	0.046	CGPS	Y1240	-0.031	BM
P222	-0.059	CGPS	YACHT_RM_4	0.028	HM

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Comment: The vertical residuals average -0.5 centimeters with a range of -8.4 to +5.6 centimeters. Trends in the geoid and outliers may be identified by solving an unconstrained 3D transformation (6-parameter conformal, no scale change) that best fits the measured vectors to the published NAVD88 heights of the reference network. See Adjustment 3-B below for results.

Adjustment 3B: Orthometric Heights - Unconstrained Adjustment – Solved Transformation

In a Minimally Constrained adjustment, all points with known NAVD88 heights were equally weighted in a best fit 3D transformation solution. The measured ellipsoid height differences were combining with Geoid 09 separations to determine NAVD88 orthometric heights. The differences from the published to the computed heights are listed below in meters.

GPS Datum Transformation Parameters

Scale Factor 1.000000000000: 0.000000 PPM (None)
Rotation Around North Axis : 0.132977 Sec (Solved)
Rotation Around East Axis : 0.138592 Sec (Solved)
Rotation Around Vert Axis : -0.027340 Sec (Solved)

Station	dZ	Desc.	Station	dZ	Desc.
134	0.006	BM	P224	0.068	CGPS
283	0.011	BM	P261	0.033	CGPS
304	0.002	BM	P262	-0.006	CGPS
27_CC_CO	0.001	HM	S1197	0.011	HM
CHAB	0.037	CGPS	S97A	-0.060	HM
F466	-0.036	HM	SBRN	0.011	CGPS
GPS_CP_14	-0.024	HM	SF_56	-0.003	BM
GPS_CP_4	0.005	HM	SF_58	-0.027	BM
GPS_CP_54	0.017	HM	SVIN	-0.011	CGPS
HPGN_04HG	0.014	HM	TIBB	-0.010	CGPS
HPGN_04KJ	0.044	HM	TIDAL_2	-0.036	HM
J1393	-0.018	BM	TIDAL_32	-0.002	HM
K5218	0.003	BM	TIDAL_B	-0.050	HM
M1393	0.012	HM	TIDAL_C	-0.008	HM
N554	0.028	BM	TIDAL_H	-0.038	HM
OHLN	-0.005	CGPS	X124	-0.010	BM
P178	0.039	CGPS	X552	-0.000	HM
P181	-0.000	CGPS	X572	-0.019	HM
P200	0.018	CGPS	Y1240	-0.014	BM
P222	-0.014	CGPS	YACHT_RM_4	0.035	HM

Comments: The average height residuals are zero as expected from a best fit solution. The range is -6.0 to +6.8 centimeters. The rotations around the north and east axis indicate a rotation refinement to the Geoid 09 Model and are equivalent to about 1 millimeter per kilometer. Further analysis identified points with excessive residuals or residual differences inconsistent with its neighbors and were set free as listed below

Adjustment 3C: Orthometric Heights - Unconstrained Adjustment – Solved Transformation

In a Minimally Constrained adjustment, all points with known NAVD88 heights except those listed below as set free were equally weighted in a best fit 3D transformation solution. The measured ellipsoid height differences were combining with Geoid 09 separations to determine NAVD88 orthometric heights. The differences from the published to the computed heights are listed below in meters.

GPS Datum Transformation Parameters

Scale Factor 1.000000000000: 0.000000 PPM (None)
Rotation Around North Axis: 0.053087 Sec (Solved)
Rotation Around East Axis : 0.160741 Sec (Solved)
Rotation Around Vert Axis : -0.026693 Sec (Solved)

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Station	dZ		Station	dZ	
134*	0.011		P224	0.063	Free
283	0.013		P261	0.025	
304*	0.003		P262	-0.017	
27_CC_CO	-0.005		S1197*	0.005	
CHAB	0.030		S97A	-0.072	Free
F466	-0.035		SBRN	0.015	
GPS_CP_14	-0.034		SF_56*	-0.001	
GPS_CP_4	0.003		SF_58*	-0.025	
GPS_CP_54	0.017		SVIN	-0.008	
HPGN_04HG	0.013		TIBB	-0.008	
HPGN_04KJ	0.033	Free	TIDAL_2	-0.048	Free
J1393*	-0.015		TIDAL_32*	0.002	
K5218*	-0.003		TIDAL_B	-0.054	Free
M1393*	0.012		TIDAL_C	-0.005	
N554*	0.024		TIDAL_H	-0.043	Free
OHLN	-0.010		X124*	-0.003	
P178	0.042	Free	X552	-0.006	
P181	-0.000		X572	-0.022	
P200	0.017		Y1240*	-0.007	
P222	-0.020		YACHT_RM_4	0.034	

Comment: It is recognized that the ellipsoid heights of the Height Mod Stations do not fit well as shown by the differences listed in Adjustments 1-A, 1-B and 2. However, the NAVD88 heights fit within a range of -3.5 to +3.4 centimeters as shown above. Twelve of these points (indicated by an asterisk) are leveled NGS First Order Benchmarks (134 was leveled from an NGS Benchmark). The absolute value of the vertical differences of these points average 0.9 centimeters with a standard deviation of 0.8 centimeters, and a range of -2.5 to +2.4 centimeters. This is a validation of the accuracy range of -3.5 to +3.4 centimeters for the NAVD88 heights of the Height Mod Stations which are based on benchmarks.

Adjustment 4: Orthometric Heights - Constrained Adjustment– Solved Transformation

In a Constrained Adjustment (minimally constrained horizontally), all points with NAVD88 heights with the exception of those listed below were fixed vertically in a best fit 3D transformation solution. The measured ellipsoid height differences were combining with Geoid 09 to determine NAVD88 orthometric heights. Seven points listed below were set free. The differences from the published to the computed heights are listed below in meters.

```

GPS Datum Transformation Parameters
Scale Factor 1.000000000000:  0.000000 PPM (None)
Rotation Around North Axis :  0.043830 Sec (Solved)
Rotation Around East Axis  :  0.332053 Sec (Solved)
Rotation Around Vert Axis  : -0.021145 Sec (Solved)

Station      dZ
HPGN_04KJ    0.030
P178         0.048
P224         0.049
S97A        -0.083
TIDAL_2     -0.053
TIDAL_B     -0.0781
TIDAL_H     -0.020
    
```

Comment: The results of this adjustment are listed in the attached Coordinate Listing under "Ortho. Ht."

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DATA COLLECTION & PROCESSING

Date of Field Surveys: April 7-20 and May 7, 2010

GPS Survey Parameters:

Epoch Rate (seconds): 15" for 8-20 minute static occupations, 1 to 3 hours for Base Stations, and 24 hours between CGPS Stations.

Minimum Satellites: 5 ; **GDOP**=< 6; **Elevation Mask for Data Collection & Processing (degrees):** 10

GPS Observables: L1 & L2 Carrier wave, C/A Code and P-Code; **Boulder K Index:** 0-2

Equipment:

GPS Base Receiver Unit No.: M3, **Operator:** McGee; **Station Identification:** varies

Receiver Make & Model: Leica 530 ; **Antenna Make & Model:** Leica AT502

Antenna Mount: Fixed Pole and Tribrach/Tripod; **Antenna Height:** varies

GPS Rover Receiver Unit No.: M4, **Operator:** McGee, **Station Identification:** varies

Receiver Make & Model: Leica 530 ; **Antenna Make & Model:** Leica AT502

Antenna Mount: Fixed Pole; **Antenna Height:** varies

CGPS & Ephemeris: The rapid ephemeris and rinex files for the CGPS were imported from the NGS and SOPAC.

QAQC ANALYSIS- Not included here, see Dewberry & Davis for analysis

NGS STATIONS and CGPS DESCRIPTIONS (see attached file)

SURVEYOR'S STATEMENT

This Report on the criteria and procedures used on this QAQC Survey was prepared by me on June 3, 2010 for the purpose of validating LiDAR data and the digital elevation model (DEM) at the request of Dave Maune and Tim Blak of Dewberry.

Michael R. McGee, PLS 3945 (CA)

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APPENDIX:

Point Reyes Point Locations

(Red Symbol = CGPS Stations, Cyan = NAVD88 Control, White = QAQC Points)

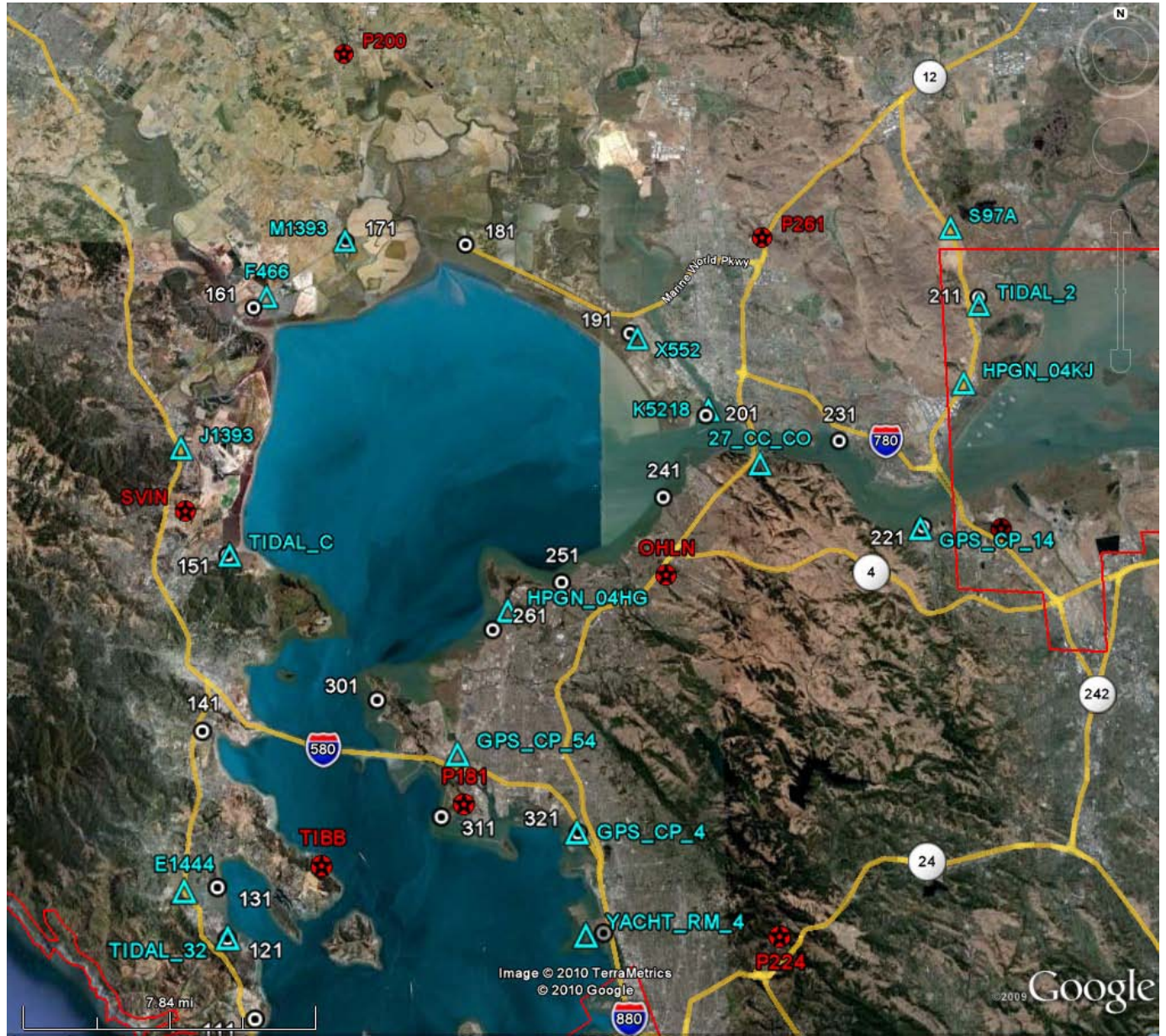


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San Francisco North Bay Point Locations (north up)

(Red Symbol = CGPS Stations, Cyan = NAVD88 Control, White = QAQC Points)



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San Francisco South Bay Point Locations (north up)

(Red Symbol = CGPS Stations, Cyan = NAVD88 Control, White = QAQC Points)

