RECLAMATION

Managing Water in the West

San Joaquin River Restoration Project – Geodetic Network

GPS Survey Report

U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region
Surveys and Mapping Branch, MP-220

December 2011

GPS SURVEY REPORT

San Joaquin River Restoration Project

Geodetic Network

December 2011

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SJRRP Geodetic Network –Survey Report

I. INTRODUCTION

This report details survey work completed by the Bureau of Reclamation, Mid–Pacific Region, Division of Design and Construction, Surveys and Mapping Branch (MP Surveys) for the San Joaquin River Restoration Project (SJRRP). This survey network was undertaken to provide consistent control on which to base the horizontal and vertical locations of SJRRP maintained staff gages. Recent surveys by RBF Consulting and the California Department of Water Resources (DWR) made us aware of subsidence issues in the project area. Due to these issues, the network was expanded to reach across the entire central valley to allow for the location of stable control stations. Certain control stations from these recent surveys were also selected as a part of our network to provide a direct link to any historic subsidence data. The expanded network also serves as a passive system for future monitoring of subsidence in the San Joaquin River valley. The survey work described in the following report was accomplished with the use of Global Positioning System (GPS), digital optical level and total station technology.

The survey conducted by MP Surveys included:

GPS observation of approximately 63 stations
Least Squares adjustment
Digital Level observation of approximately 195 stations
Digital Level data adjustment
Coordinate Listing
Control Point Data Sheets
Survey Report

The GPS observations incorporated in this survey report were accomplished in November and December 2011. The achieved horizontal accuracy for this network is +\- 1 centimeter based upon the Fully Constrained Network Adjustment – Adjusted Grid Coordinates – Northing Error and Easting Error, which exceeded the horizontal accuracy goal of +\- 2 centimeters. The achieved vertical accuracy for this network is +\- 2.5 centimeters based upon the Fully Constrained Network Adjustment – Adjusted Grid Coordinates – Elevation Error, which exceeded the vertical accuracy goal of +\- 3 centimeters. Ties to the existing control were made to determine the rotational biases. Elevations depicted in this report were determined by static GPS and digital level methods.

MP Surveys provided all GPS, digital level and total station equipment, associated hardware, and all software used during the field phase of the project. MP Surveys was responsible for preparing the final adjustment and this report.

This report details the personnel and equipment used on the project followed by a section detailing the chronology, the method of observing and computational procedures. All pertinent adjustments, coordinate listings and diagrams are included in the attached Appendices.

II. PERSONNEL AND EQUIPMENT

A. Personnel

MP Surveys supplied the following personnel during the field operation:

Gerald Davis, PLS	Project Manager (California PLS #8545)
Mark Morberg, PLS	GPS Supervisor (California PLS #8213)
Adrian VerHagen, LSIT	GPS Observer
John Harrison, LSIT	GPS Observer
Robert Keller	GPS Observer

As Project Manager, Mr. Gerald Davis, PLS was the responsible person in charge of the survey. Mr. Davis reviewed the daily work plans concerning GPS observations and was in direct charge of all the computations, adjustments and the preparation of the final GPS report.

Additional MP Surveys office personnel involved:

Matt Perigny	Graphic/Computer Support
Jillian Baber	Graphic/Computer Support

B. Field Equipment

MP Surveys supplied all computers, printers, software and office products. MP Surveys also supplied the following equipment:

3 – Trimble R8 GNSS GPS receivers

4 – Trimble TSC2 Data Collectors with Trimble Survey Controller software (Ver. 12.43, 12.44, and 12.45)

1 – Trimble 5601 Total Station (1")

1 – Leica DNA03 Digital Level (0.3mm)

1 – Leica Invar Level Rod (barcode read)

Klamath Basin Area Office supplied the following equipment:

2 – Trimble R8 GNSS GPS receivers

1 – Trimble TSC2 Data Collector with Trimble Survey Controller software (Ver. 12.43)

C. Adjustment Software:

Trimble Business Center: Database and Baseline processing program, (Ver. 2.40.3)

III. CHRONOLOGY

November 28, 2011 (332)
Mobilization and Project Management / Strategy meeting
Begin Static GPS Observation
Session 1 (station observed)
143, 120, 111, 112, 142
Session 2
134, 120, 113, 112, 145

November 29, 2011 (333)
Continue Static GPS Observation
Session 1
134, 142, 165, 141, 140
Session 2
154, 102, 163, 141, 140
Session 3
154, 139, 163, 114, 115
Session 4
104, 105, 114, 115
Session 5
125, 128, 105, 122, 153
Session 6
125, 128, 144, 147

November 30, 2011 (334)
Continue Static GPS Observations
Session 1
157, 146, 144, 147, 137
Session 2
108, 146, 167, 152, 137
Session 3
138, 146, 167, 110, 150
Session 4
138, 109, 119, 110, 166
Session 5
108, 109, 119, 148, 126

November 31, 2011 (335)
Continue Static GPS Observations
Session 1
109, 110, 167, 130
Session 2
108, 106, 107, 155, 126

December 1, 2011 (335), Con't.
Session 3
124, 106, 131, 135, 126
Session 4
157, 106, 162, 156, 133
Session 5
157, 124, 162, 161, 132
Session 6
121, 124, 135, 123, 132

December 2, 2011 (336)
Continue Static GPS Observations
Session 1
121, 147, 101, 123, 129
Session 2
158, 153, 159, 123, 129
Session 3
105, 153, 127, 116, 159
Session 4
114, 163, 127, 160, 103
Session 5
127, 143, 131, 135, 141

December 3, 2011 (337)
Complete Static GPS observations of Primary Control Network
Session 1
128, 139
Session 2
140, 145
Session 3
123, 168
Session 4
137, 155

December 5 – 9, 2011
Begin total station and digital level observations
Gage stations observed
CTK, MIL, LDC, H41, SJF, DNB, SKAGGS, GRF, JBP

December 19 – 23, 2011
Continue total station and digital level observations
Gage stations observed
CBP, SJB, SJN, MEN, SDP, SWA, ELN, EBM, SSH, SJS, MSG, FFB, NEW

January 10 – 11, 2012
Complete total station and digital level observations
Gage stations observed
SMN, NEW

February 2012
Final adjustment of static GPS network, total station, and digital level data completed.

March 2012
GPS report and appendices completed.

April 2012
GPS report and appendices QA/QC'd and peer review completed.

May 2012
Peer review comments incorporated into report. Final report issued.

IV. METHODS

All primary control survey work on the San Joaquin River Restoration Project Geodetic Network was accomplished by static GPS methods. Approximately 61 control points were surveyed as a part of the primary control network. The horizontal datum for this project is the California Coordinate System of 1983, Zone 4, based upon NAD 1983 (epoch 2007), and the vertical datum is NAVD 1988. All coordinates and elevations are reported in U.S. Survey Feet.

Static Survey

GPS observations were made during the daytime hours, with sessions typically averaging 30 minutes in duration. There was an acceptable satellite visibility window from approximately 7 AM to 5 PM. Communication between observers was maintained through the use of cellular phones, which allowed for adjustment of the pre-planned observation schedule due to unforeseen circumstances. Observation start and stop times, antenna height measurements, station descriptions and other pertinent details were recorded on session log sheets. Transportation between control points was achieved through the use of 4 wheel drive government vehicles.

Data processing was performed on a daily basis by the Project Manager and GPS Supervisor. Each evening following the observation sessions, the collected data was downloaded from the internal memory of each data collector and processed using Trimble Business Center (TBC). This processing resulted in a fixed and / or float solution for each baseline. Float solutions were not used in the final constrained adjustment, as fixed solutions represent the most accurate solution. The statistical output generated from the data processing provided the first quality control indicators. These indicators showed acceptable results.

After the baselines were processed and reviewed for statistical integrity, a minimally constrained least squares adjustment was run on a daily basis using TBC. This software adjusts GPS vectors in three dimensions and was designed for network densification using GPS observations. The maximum post processed GPS vector residuals resulting from the least squares adjustment are +\- 1.8 centimeters in the horizontal plane and +\- 6.4 centimeters in the vertical plane. All free adjustments computed in the field were in NAD 83.

RTK GPS and Total Station Surveys

Secondary project control and site features were located in the horizontal dimension using RTK GPS through either the use of a conventional base station setup or Virtual Reference Stations, as dictated by cell coverage, and / or a conventional total station. These features include gage houses, local benchmarks and project monitored staff gages.

Redundant control checks were performed from each base station, virtual or actual, each day to prevent blunders and enable the localization of virtual base collected data. At least two control stations being part of the geodetic network were surveyed at the beginning and completion of each RTK session. This enabled the RTK data to be adjusted to the static control station values, which were held “fixed” for all RTK surveys. This allowed all GPS data to be put on the same datum / epoch and provided “sanity checks” for the data gathered using virtual base stations.

Staff gages and features which were not able to be surveyed using RTK, due to vegetation or proximity to standing water, were surveyed using the Trimble 5601 total station's reflectorless capabilities. All measurements were made in "standard" mode, which averages seven EDM returns for each measured point. Staff gages lying within the waterway of the San Joaquin River were also surveyed for elevations using this same method. A minimum of two individual measurements in both the Direct and Reverse faces were made for each "elevated point" to help prevent blunders, systematic and random errors. The splits of all measured angle sets were verified to be within project tolerances of 5" Horizontal and 10" Vertical maximum.

Digital Level Surveys

NAVD 88 elevations for project monitored staff gages, local benchmarks and secondary control points were established through digital leveling techniques utilizing a Leica DNA03 digital level, rated to .3mm/Km, reading barcodes on Leica Invar Level Rods.

Physical field notes were kept alongside electronic field notes as an independent verification of each digital level observation. All observations were made as a part of closed level loops, with a maximum closure of 0.006' per √Mile.

V. ADJUSTMENTS

Minimally Constrained Adjustment

A primary network was surveyed as part of this project. This network was comprised of existing and new stations and ties into existing National Geodetic Survey (NGS) control stations.

The minimally constrained adjustment computes the network independent of multiple fixed controls and is an indicator of the quality of the GPS measurements. The minimally constrained adjustment held one point (NGS control station K 361) fixed horizontally and vertically, which produced the following results:

Number of Stations	61	Minimum Vector Length	4,821 usft
Degrees of Freedom	501	Maximum Vector Length	176,017 usft
Number of Observations	236	Largest residual (Hz)	0.060 usft
Reference Factor	1.00	Largest residual (Vt)	0.211 usft

*More specific information regarding this adjustment is contained in Appendix 2.

Fully Constrained Adjustment

The constrained adjustment holds the position of specified horizontal and vertical control and scales and rotates the GPS network to fit the control held fixed. For this project the five control stations were held fixed either horizontally or vertically to determine the rotational biases. These five stations were selected based upon their overall agreement with the minimally constrained network adjustment result and their geographic location. Due to the previously mentioned subsidence issues in the San Joaquin River valley we had no confidence in the vertical accuracy of control stations situated within the valley. For this reason, the points selected to constrain the network are spaced around the outside perimeter and are located at the edges of the San Joaquin River valley. These points should provide stable control locations for any future re-observation or network densification. Geoid03 was utilized to achieve orthometric elevations.

Stations held fixed in the primary network constrained adjustment:

Pt	Designation	Northing (usft)	Easting (usft)	Elevation
119	109.28			111.276’
128	F 928			619.257’
138	HPGN CA 10 04	2423374.062	5929562.855	
139	HPGN D CA 06 NF	2099649.706	6250234.978	
145	J 1233	2199134.508	6397420.403	494.094’
146	K 361	2275034.315	5961519.299	285.344’

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Network Statistics:

Number of Stations	61	Minimum Baseline Length	4,821 usft
Degrees of Freedom	506	Maximum Baseline Length	176,017 usft
Number of Observations	236	Largest residual (Hz)	0.060 usft
Reference Factor:	1.05	Largest Residual (Vt)	0.211 usft

Deflection in Latitude: 0.107 sec **(95%)** 0.030 sec
Deflection in Longitude: 0.068 sec **(95%)** 0.037 sec
Azimuth Rotation: -0.052 sec **(95%)** 0.010 sec
Scale Factor: 1.00000012**(95%)** 0.00000005

The horizontal datum is NAD 1983 (2007), California Coordinate System of 1983, Zone 4, U. S. Survey Feet.

The vertical datum is NAVD 1988. Geoid model *Geoid03* was selected for use to determine orthometric elevations in the final adjustment. Geoid09 was originally planned for use in the final adjustment. However, after comparing orthometric elevations determined using Geoid09 with the record elevations of our "fixed" control we came to the conclusion that Geoid03 produced elevations more consistent with the record data. As our selected control to be held "fixed" is located in the foothills of the Sierra and Coastal ranges, we have a high degree of confidence that these stations are not subject to the subsidence issues observed in portions of the central valley. The larger elevation differences, as determined by Geoid09, may be caused by stations constrained in the creation of Geoid09 having subsided since their last observation, forcing inaccuracies into the geoid model.

Coordinate differences at known control as reported by the fully constrained adjustment (Negative elevations denote observed elevations lower than record NGS elevations).

Pt. #	PID	Designation	Northing (usft)	Easting (usft)	Elev. Diff.	Yrs since rec. obs.[1]	Comments
101	GU0753	X 989	-0.049	-0.014	-0.98’	4	
119	HS4510	109.28	-83.116	49.791	FIXED	23	NGS Hz Co-ords scaled (+/- 6")
121	GU0762	375 USE	-0.111	-0.122	-1.38’	3	
122	DH6668	ALEX 5	-0.002	0.012	-0.57’	3	
124	HS1103	D 158 RESET	0.004	0.017	-0.76’	3	
125	DH6676	DWIGHT	0.015	-0.059	-0.40’	8	
126	HS4523	E 1420	0.088	-0.012	0.10’	23	
128	GU0588	F 928	0.025	-0.078	FIXED	7	
129	GU4281	FIREPORT	-0.024	-0.054	-0.72’	3	
130	HS1919	FREMONT	0.030	-0.088	-0.15’	2	
131	HS1204	G 706 RESET 1962	-5.578	-4.193	0.21’	46	NGS Hz Co-ords per Hand Held

Pt. #	PID	Designation	Northing (usft)	Easting (usft)	Elev. Diff.	Yrs since rec. obs.[1]	Comments
132	GU0763	G 990 (SDP)	-26.98	775.368	-5.90’	46	NGS Hz Co-ords scaled (+/- 6")[2]
133	AB5019	H 1235 RESET	27.229	111.161	-1.62’	4	NGS Hz Co-ords scaled (+/- 6")
134	DG9695	H1 1941	-0.058	0.066	0.01’	7	
135	HS5409	HPGN CA 06 03	0.011	-0.036	-0.78’	7	
137	HS5410	HPGN CA 10 01	0.042	-0.038	-0.34’	19	
138	HS5412	HPGN CA 10 04	FIXED	FIXED	-0.39’	19	
139	AC6109	HPGN CA 06 NF	FIXED	FIXED	-1.30’	2	
140	AC6102	HPGN CA 06 QF	-0.058	0.095	-0.05’	7	
141	AC6103	HPGN CA 06 RF	-0.044	0.021	-0.19’	7	
142	AC6105	HPGN CA 06 RG	0.000	-0.001	-0.05’	11	
143	AC6106	HPGN CA 06 SG	0.062	-0.041	-0.09’	18	
144	AA4253	HPGN CA 10 BK	0.053	-0.137	-0.17’	7	
145	GT1583	J 1233	FIXED	FIXED	FIXED	3	
146	HS2341	K 361	FIXED	FIXED	FIXED	23	
147	DH6674	KELLIE	0.014	-0.069	-0.69’	8	
148	HS5446	LIVINGSTON RESET	0.043	0.058	0.16’	17	
150	HS2391	NEWMAN NW BASE	0.274	0.300	0.05’	68	
152	HS1827	SALT RM 1	-0.028	0.079	-0.62’	24	
153	DH6679	SHAWN	-0.013	-0.013	-0.43’	8	
154	GU3389	SPEAK AZ MK CADH	-0.010	0.035	-0.31’	18	
155	HS1894	T 987 CADWR	5.147	-375.83	-1.36’	46	NGS Hz Co-ords scaled (+/- 6")
156	HS1953	W 990 CADWR (SWA)	-130.00	-88.276	-6.15’	46	NGS Hz Co-ords scaled (+/- 6")
157	DH6673	WILLIAM 3	-0.010	-0.067	-0.93’	8	

[1]Year of observation for record values is based upon best information available on NGS datasheet; this year has been subtracted from December 2011 to calculate the approximate total elapsed years.
[2]Large differences in Easting value of point 132 exposes a possible datasheet coordinate error, being transcribed numbers in the seconds’ position of the Longitude on the NGS datasheet. Point was recovered as described on NGS datasheet.

The primary network adjustments, both minimal and fully constrained, along with all coordinate listings are included in the following appendices. Please be aware, TBC refers to Ellipsoid Heights as “Height” and Orthometric Elevations as “Elevation”.

VI. SUMMARY

Subsidence is a known issue and our survey has hopefully provided more data for analysis and future monitoring. Our computations show approximately 1.38 feet of subsidence in almost three years at station 375 USE (PID GU0762), affirming subsidence rates noted by RBF Consulting and the U.S. Geological Survey. Additionally, our survey has exposed significant, nearly 6 feet since 1965, subsidence at station G 990 (PID GU0763). While in other areas we show subsidence as low as a couple tenths of a foot over nearly half a century. Furthermore, our survey seems to have exposed a related issue with Geoid09 in this locale. Based upon our observations and data analysis, along with conversations with representatives of the National Geodetic Survey, it appears the validity of Geoid09 in this region has been degraded by subsidence of local passive control stations. The rate of subsidence in areas of the San Joaquin River valley has caused orthometric elevations on known passive control to change more rapidly than published control data can be updated. Due to this, stations were constrained during the creation of Geoid09 which in actuality differed (sometimes greatly) from their published values. In conclusion, this survey provides the start of a stable means for passive monitoring of future subsidence in the San Joaquin River valley.

VII. APPENDICES