LiDAR Mapping Project Report
San Gabriel Mountain
Acquisition - June 2009

Submitted to:
USGS
Prepared by:
Dewberry
Fairfax, VA
8-24-2009

8401 Arlington Boulevard
Fairfax, Virginia 22031-4666

703 849 0396
703 849 0182 fax
www.dewberry.com

Table of Contents

Introduction

The goal of the San Gabriel Mountain LiDAR Task Order is to provide high accuracy intensity image, first-return, last-return, and bare-earth processed gridded LiDAR data for approximately 81 square miles, located in the Los Angeles County California area. This data will support USGS science for the Multi-Hazards Southern California (SoCal) project. There are multiple science objectives which will be performed by the USGS and it's parntners with this data collect: earthquake hazards, flooding hazards, habitat mapping and fire science. The earthquake hazards objectives have the most stringent requirements. The collection of pre-earthquake imagery along two perpendicular profiles along the Sierra Madre fault system will be used to help characterize the geomorphic expression of compressional structures (faults and folds) – imagery will be combined with post-earthquake LiDAR acquisition to fully map surface rupture and possible image the full coseismic deformation field including possible fold growth.

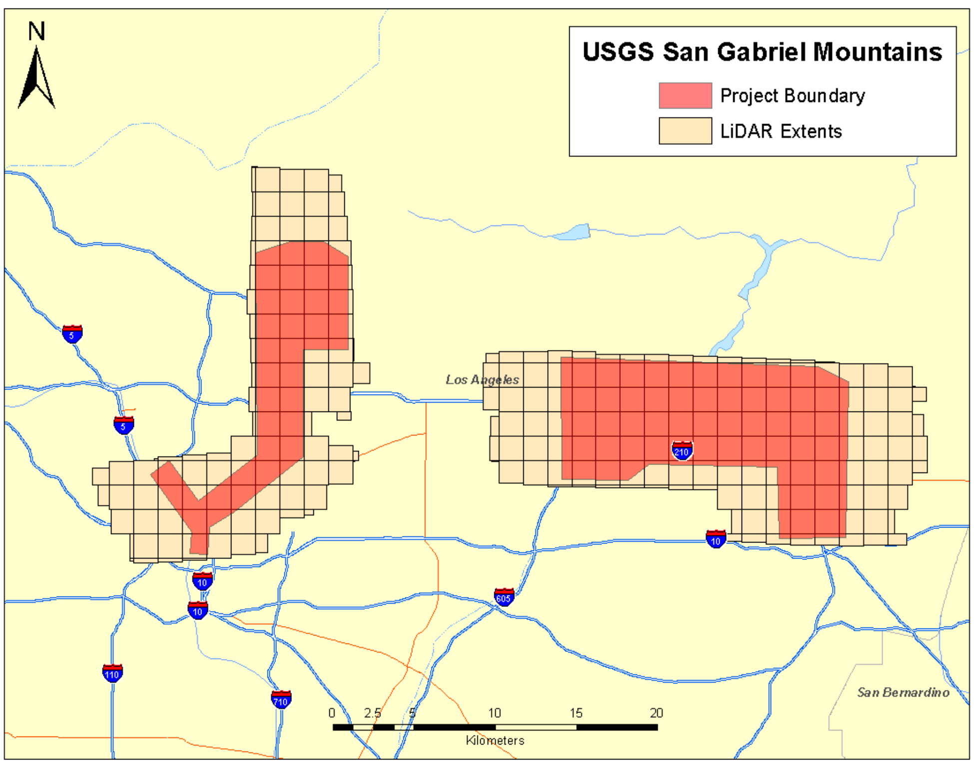


Figure 1 - Project Area; the project area (San Gabriel Mountain) is shown in red; the LiDAR extents in beige

The LAS data is in format 1.2 and in ASCII file format. The LAS are tiled based on the United States National Grid with a total of 114 tiles in the West Block and 142 tiles in the East Block. The LAS may contain the following ASPRS classes:

- Class 1 – Unclassified
- Class 2 – Ground
- Class 7 – Noise
- Class 9 – Water
- Class 12 – Overlap

All LiDAR points outside of the project boundary are classified as class 1 (unclassified) as specified in the scope of work. The data is not clipped to the project boundary, and as a result there are a total of 256 LAS files.

The DTM is clipped to the project boundary and contains 47 tiles in the West Block and 84 tiles in the East Block. Tiles which lie on the project boundary are not complete to the full extent of the tile. Two versions of the DTM have been created based on the lowest point and based on a Triangulated Irregular Network (TIN). The DTM generated from the TIN is provided as it is a more accurate representation of the bare earth.

The intensity images are clipped to the project boundary with 47 tiles in the West Block and 84 tiles in the East Block. They are created from the first return LiDAR points.

The RINEX data contains GPS observation files based on missions.

The RAW data folder contains the ABGPS and IMU text files for each mission, as well as intensity correction tables for different sensors.

FGDC compliant metadata is provided at the East and West project levels in two XML files.

LiDAR accuracy testing was performed by Dewberry using high accuracy quality control checkpoint distributed over the dataset in areas of bare earth with varying degrees of slope. The specification for this project is to meet a vertical bare earth accuracy of 15.0 cm in zero degrees of slope. **At this requirement, the combined dataset has an RMSE of 0.074m**. The data exceeds project specifications. The full accuracy testing results can be found in Survey and Vertical Accuracy Analysis.

A statistical and visual check was performed on the LiDAR. Each tile was checked to ensure that it had the correct classes, the correct number of points, the correct elevation ranges, and other requirements for LAS 1.2 files. Although the SOW requires the LAS in Point Data Record Format 3, it is not possible in LAS 1.2 as red, green, and blue do not exist. Therefore, the files are delivered in Point Data Record Format 1.

The DTMs are gridded to 0.5m resolution grid. To better match the DTMs, the resolution of the intensity imagery was increased from 1.0m to 0.5m. Both datasets passed a visual analysis finding no noticeable errors or sensor anomalies.

1 LiDAR Survey Report

Terrapoint

1.1 Executive Summary

This LiDAR project will support USGS science for the Multi-Hazards Southern California (SoCal) project by providing high accuracy, classified multiple return LiDAR and derivative products, for two areas totaling approximately 81 square miles, of the San Gabriel Area within Los Angeles County, California.

The LiDAR data were acquired and processed by Terrapoint USA to support Dewberry's USGS contract for geospatial products. The deliverable products are a high density mass point (4 returns per pulse) dataset with an average point density of 6 points per square meter. A bare earth DEM, first return full feature Intensity, RAW data, ABGPS_IMU, aircraft GPS and associated metadata and reports were also provided for this project.

The elevation data was verified internally prior to delivery to ensure it met fundamental accuracy requirements (1-foot contour accuracy) when compared to a total of 50 static Terrapoint GPS checkpoints in each block. Below is the summary for both tests:

East Block
The LiDAR dataset was tested to 0.073m vertical accuracy at 95 percent confidence level, based on consolidated RMSEz (0.037m x 1.9600) when compared to 26 GPS static check points.

West Block
The LiDAR dataset was tested to 0.076m vertical accuracy at 95 percent confidence level, based on consolidated RMSEz (0.039m x 1.9600) when compared to 24 GPS static check points.

All data delivered meet and exceeds Terrapoint's deliverable product requirements as set out by Terrapoint's I-PROVE program.

1.2 Introduction

LIDAR data is remotely sensed high-resolution elevation data collected by an airborne collection platform. By positioning laser range finding with the use of 1 second GPS with 100 Hz inertial measurement unit corrections; Terrapoint's LIDAR instruments are able to make highly detailed geospatial elevation products of the ground, man-made structures and vegetation.

The LiDAR ground extraction process takes place by building an iterative surface model. This surface model is generated using three main parameters: building size, iteration angle and iteration distance.

The purpose of this LiDAR data was to produce high accuracy 3D terrain geospatial products to assist in characterizing the geomorphic expression of compressional structures,

This section covers the mission parameter and details, processing step outlines and deliverables.

This report is submitted as a supporting overview document for the FGDC metadata reports and control survey report that are included as addendums to this report.

1.3 Acquisition Parameter Overview

The Airborne LiDAR survey was conducted using one OPTECH 3100EA systems flying at a nominal height of 800 meters AGL with lines were flown in multiple orientation blocks to best optimize flying time considering the layout for the project.

The Optech 3100EA system was configured in two scanner configurations for the acquisition of the San Gabriel LiDAR project. Terrapoint modified the scanner configuration during the acquisition stage of this project in order to maintain the planned efficiency while reducing the visual effects of the corn rows and maintaining the scanner field view limitations set out in the contract.

All missions acquired between June 2nd and June 15th, were acquired with Configuration 1 and all missions acquired between June 16th and June 22nd, were acquired with Configuration 2.

Configuration 1 – 2 Degrees of Cut-off	
Item	**Parameter**
Aircraft Speed	130 knots
Data Acquisition Height	800 m AGL
Swath Width	285 m
Distance Between Flight Lines	114 m
Overlap	60 %
Scanner Field Of View	+/- 12.1 Degrees
Scan Cutoff	2 Degrees either side of scan
Pulse Repetition Rate	71 KHz
Scan Frequency	58.9 Hz
Number of Returns Per Pulse	4
Beam Divergence	Narrow
Flight Line Length	< 70 km
Base Station Distance	< 30 km
Resultant Raw Point Density	6 pts/m2 without overlap

Configuration 2 – 6 Degrees of Cut-off	
Item	**Parameter**
Aircraft Speed	130 knots
Data Acquisition Height	800 m AGL
Swath Width	340 m
Distance Between Flight Lines	85 m
Overlap	75 %
Scanner Field Of View	+/- 18 Degrees
Scan Cutoff	6 Degrees either side of scan
Pulse Repetition Rate	71 KHz
Scan Frequency	47.8 Hz
Number of Returns Per Pulse	4
Beam Divergence	Narrow
Flight Line Length	< 70 km
Base Station Distance	< 30 km
Resultant Raw Point Density	6 pts/m2 without overlap

The breakdown of the configurations per mission per site is in the table below:

West Block	
Mission Name	**Configuration**
o109153a	1
o109166a	1
o109170a	2
o109172a	2
o109172b	2
o109173a	2
East Block	
Mission Name	**Configuration**
o109150a	1
o109151a	1
o109152a	1
o109155a	1
o109158a	1
o109167a	2
o109168a	2
o109169a	2

1.4 Aircraft

The aircraft used for the survey was a Piper PA-31 Navajo, registration C-FVTL. This aircraft has a flight range of approximately 7 hours or 1025 nautical miles under optimal conditions. The aircraft was staged from the El Monte Airport (KEMT), and ferried to the project site for flight operations.

1.5 GPS Receivers

A combination of Sokkia GSR 2600 and NovAtel DL-4+ dual frequency GPS receivers were used to support the airborne operations of this survey and to establish the GPS control network.

1.6 Missions Statistics

A total of 14 missions were flown for this project with a flight time ranging approximately 28.8 online production hours and 365 production flight lines under good meteorological and GPS conditions to provide complete coverage. The breakdown of the statistics per missions per site is in the table below:

9143U West Block Mission Name	Calendar Date	Number of Production Lines
o109153a	2009-06-02	32
o109166a	2009-06-15	25
o109170a	2009-06-19	36
o109172a	2009-06-21	17
o109172b	2009-06-21	62
o109173a	2009-06-22	33
Totals		6 missions 13.5 Production Hours 205 Production Lines

9143U East Block Mission	Calendar Date	Number of Production Lines
o109150a	2009-05-30	9
o109151a	2009-05-31	21
o109152a	2009-06-01	32
o109155a	2009-06-04	8
o109158a	2009-06-07	42
o109167a	2009-06-16	21
o109168a	2009-06-17	18
o109169a	2009-06-18	9
Total		8 missions 15.3 Production Hours 160 Production Lines

The breakdown of the air temperature from the aircraft and pressure at the airport per missions per site is in the table below:

West Block		
Mission Name	Temperature (Deg C)	Pressure (mbars)
o109153a	22.4	973.29
o109166a	12	973.63
o109170a	20	966.35
o109172a	14	969.22
o109172b	14	968.89
o109173a	23.4	966.5

East Block		
Mission Name	**Temperature (Deg C)**	**Pressure (mbars)**
o109150a	18.4	973.96544
o109151a	17.4	972.9495
o109152a	21.4	972.27224
o109155a	19.4	973.96544
o109158a	19.4	972.94952
o109167a	21.4	972.27224
o109168a	22.4	970.91768
o109169a	23.4	969.90176

A plot of the trajectory is provided in Appendix C.

1.7 Reference Coordinate System Used

Seven National Geodetic Survey (NGS) and two Southern California Integrated GPS Network (SCIGN) Continuously Operating Reference Stations were incorporated in a GPS control network to establish four new temporary control monuments for this project, to maintain base line distance requirements. The newly established temporary control points were used to control all flight missions, kinematic and static ground surveys.

The published horizontal datum of the control points is NAD83NSRS and the vertical datum NAVD88.

The following are the final coordinates of the control points used in this project:

Station Id	Latitude	Longitude	Ellipsoidal Height	Orthometric Height
914301	34 05 22.05520	-117 47 05.06989	268.0278	301.5868
914302	34 04 51.19350	-118 02 16. 26505	51.7520	86.1686
914303	34 10 47.78100	-118 10 52.20514	437.6259	471.3486
914304	34 05 04. 66812	-118 01 56. 81072	56.5790	90.9522

The following are the CORS stations observed to establish the new control points used in this project:

CORS-Agency	Station Id
CORS-NGS	AZU1
CORS-NGS	CIT1
CORS-NGS	CVHS
CORS-SCIGN	GVRS
CORS-SCIGN	LEEP

CORS-NGS	LORS
CORS-NGS	PKRD
CORS-NGS	PSDM
CORS-NGS	SPMS

For further details concerning the control used in this project including the network adjustment, please see the Geodetic Control Survey Report in Appendix D.

1.8 Geoid Model Used

The Geoid03 geoid model, published by the NGS, was used to transform all ellipsoidal heights to orthometric.

1.9 Airborne GPS Kinematic

Airborne GPS kinematic data was processed on-site using GrafNav kinematic On-The-Fly (OTF) software. Flights were flown with a minimum of 6 satellites in view (13o above the horizon) and with a PDOP of better than 4.5. Distances from base station to aircraft were kept to a maximum of 30 km, to ensure a strong OTF (On-The-Fly) solution. The GPS data can be classified as excellent, with GPS residuals of 5cm average but no larger than 12 cm being recorded.

1.10 Generation and Calibration of Laser Points (raw data)

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Subsequently the mission points are output using Optech's Dashmap, initially with default values from Optech or the last mission calibrated for system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality. All missions are validated against the adjoining missions for relative vertical biases and collected GPS kinematic validation points for absolute vertical accuracy purposes.

On a project level, a coverage check is carried out to ensure no slivers are present; however due to resale nature of this task order and the desire to maximize coverage, some minor slivers were detected and reported to the client via polygon shape files. The slivers are mainly located at the end of flight lines adjacent the outer project boundary.

Calibration Adjustment and Bias Resolutions

The following are the Optech System calibration values prior to acquiring the San Gabriel Project:

Roll Correction (Deg)	Pitch Correction (Deg)	Scale Correction
-0.0051	-0.0293	1.00268

The following are the post calibration results for the San Gabriel data outlined by mission:

West Block						
Mission Name	Roll Correction (Deg)	Pitch Correction (Deg)	Scale Correction	Droop Correction	Normalized Intensity	Resulting Calibration Vertical Bias
o109153a	-0.0104	-0.0629	1.00564	21R, 7L	No	- 5cm
o109166a	-0.0055	-0.0651	1.00711	21R, 7L	No	- 8cm
o109170a	-0.0051	-0.0594	1.00648	21R, 7L	Yes	0cm
o109172a	-0.0017	-0.0657	1.00714	21R, 7L	No	+ 8cm
o109172b	-0.007	-0.0655	1.00727	21R, 7L	No	+ 8cm
o109173a	0.0029	-0.06	1.00631	21R, 7L	No	+ 5cm
East Block						
Mission Name	Roll Correction (Deg)	Pitch Correction (Deg)	Scale Correction	Droop Correction	Normalized Intensity	Resulting Calibration Vertical Bias
o109150a	0.0214	-0.0593	1.00792	21R, 16L	No	0cm
o109151a	0.0144	-0.0616	1.007721	21R, 16L	No	0cm
o109152a	0.013259	-0.0587	1.007509	21R, 16L	No	0cm
o109155a	0.009643	-0.06817	1.007518	21R, 16L	No	+ 10cm
o109158a	0.0114	-0.06506	1.007612	21R, 16L	No	line 15844 (+ 0.05cm) Line 15845 (- 0.05cm)
o109167a	0.016712	-0.06161	1.00768	21R, 16L	No	0cm
o109168a	0.016712	-0.06161	1.00768	21R, 16L	No	Lines 16808 and 16809 - 0.05cm
o109169a	0.0207	-0.0561	1.0079	21R, 16L	No	- 10 cm

Please note that Terrapoint standard procedure is to not calibrate or normalize LiDAR intensity; but due to lower intensity returns for mission o109170a in comparison to the adjoining missions, Terrapoint used the normalize function in Dashmap for this particular mission.

The following biases were observed when verified with the GPS validation data post ground classification and review. The elevations of the LiDAR data were adjusted accordingly:

West Block	+5.9 cm
East Block	+13.4 cm

The following shift was applied to resolve a GPS Antenna Profile Error in the final LiDAR LAS deliverable and DEM:

West Block	+10.8 cm
East Block	+10.8 cm

1.11 Data Classification and Editing

The data was processed using the software Terrascan, and following the methodology described herein. The initial step is the setup of the Terrascan project, which is done by importing the Dewberry provided tile boundary index encompassing the entire project areas. The 3D laser point clouds, in binary format, were imported into the Terrascan project and divided in 1662 file size optimized tiles (2.5 million Raw LiDAR Points) in LAS 1.0 format. Once tiled, the laser points were classified using a proprietary routine in Terrascan. This routine removes any obvious outliers from the dataset following which the ground layer is extracted from the point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model. This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption is that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iteration. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model. The data is then manually quality controlled with the use of hillshading, cross-sections and profiles. Any points found to be of class vegetation, building or error during the quality control process, are removed from the ground model and placed on the appropriate layer. An integrity check is also performed simultaneously to verify that ground features such as rock cuts, elevated roads and crests are present. Once data has been cleaned and complete, it is then by a supervisor via manual inspection and through the use of a hillshade mosaic.

1.12 Deliverable Product Generation

1.12.1 Deliverable Tiling Scheme

All acquired LiDAR points were retiled in the provided USNG (United States National Grid) tiling scheme with a total of 142 tiles for the East Block and 114 tiles for the West Block being populated; the DEM and Intensity images were clipped to the project boundary and as result of the clipping were delivered in a total of 84 tiles for the East Block and 47 tiles for the West Block.

1.12.2 LiDAR Point Data

The LiDAR point data was delivered in LAS 1.2, POINTDATA RECORD FORMAT 1 adhering to the following ASPRS classification scheme:

Class 1 – Unclassified
Class 2 – Ground
Class 7 – Noise
Class 9 – Water
Class 12 – Overlap

Water is not included in the bare earth ground points for rivers (>10m wide), lakes or ponds (With an axis >100m), rather it is classified as water on Class 9; all remaining points within the water body were classified to class 1. Water body delineation was collected using hillshades and intensity images generated from ground DEM and LiDAR

The LAS files contain the following fields of information (Precision reported in brackets):

Class (Integer)
GPS Absolute Time (0.0001 seconds)
Easting (0.01 meter)
Northing (0.01 meter)
Elevation (0.01 meter)
Echo Number (Integer 1 to 4)
Echo (Integer 1 to 4)
Intensity (8 Bit Integer)
Flightline (Integer)
Scan Angle (Integer Degree)

Please note that the LiDAR intensity is not calibrated or normalized other than mission o109170a; due to lower intensity returns for this mission in comparison to the adjoining missions. The intensity value is meant to provide relative signal return strengths for features imaged by the sensor.

LiDAR point data was not clipped to the project boundary as specified in the scope of work – all points outside the project boundary were set to Class 1 – Unclassified

1.12.3 Bare Earth DEM

The bare earth DEM was generated from the bare earth LiDAR points and was gridded to 0.5 meter.

Areas corresponding to the lakes and ponds have been flattened to the mean water elevation derived from LiDAR points at time of collection. No underwater features were included in the DEM

Terrapoint has provided two versions of the DEM based on two different algorithms: Based on lowest point (please note that the interpolation method for pixels with no values is not provided in the software vendor documentation) and Triangulated Irregular Network (TIN) based within Terrasolid's Terrascan Software. The grids were generated in ASCII XYZ in the processing tiles; then they were subsequently merged into the USNG tiles and converted to ESRI Binary Raster using Terrapoint's proprietary PreTOPS software and ArcView.

Terrapoint has provided a DEM generated from alternative algorithm, as we believe the TIN is more representative of the true ground surface and is a more aesthetically pleasing product.

1.12.4 Intensity Image

The first return full feature Intensity products were generated from the first return full feature LiDAR points and generated to a 0.5 meter intensity gridded product.

The grids were generated in Terrascan in the processing tiles; then they were subsequently merged into the USNG tiles and converted to ESRI Binary Raster using Global Mapper 9 and ArcView 3.1 software.

Please note that the intensity used to produce the imagery is not fully calibrated, hence variations acquisition altitude will produce different intensity return values.

1.12.5 GPS RINEX

GPS RINEX Files of the airborne GPS were provided in softcopy

1.12.6 ABGPS/IMU Positions

ABGPS/IMU combined files containing x, y, z, pitch, roll, heading and GPS_Time were provided in a comma delimited ASCII format. All positions were provided in NAD83 UTM11, NAVD88 (Geoid03), GPS seconds (reported to a 10th of a millisecond), meters (reported to a centimeter) for the XYZ and degrees for the pitch, roll, heading (reported to 6 decimals of a degree).

1.12.7 RAW Data

Main Folder

o109XXXy.txt =>Laser operational log
mgps_o109XXXy.gps => Aircraft GPS/IMU
9143-01-0026-XXXy.epp => Graftnav Ephimeris - Base Station
9143-01-0026-XXXy.gpb => Graftnav format RAW GPS - Base Station
9143-01-0026-XXXy.sta => Graftnav by-product file
mgps_o109XXXy.epp => Graftnav Ephimeris - Airborne
mgps_o109XXXy.gpb => Graftnav format RAW GPS - Airborne
o109XXXy.pos => Backup of aircraft GPS/IMU
o109XXXy.range => RAW laser data
9143-01-0026-XXXy.pdc => RAW GPS base station
o109XXXy.tree => processing file from Dashmap
o109XXXy.html => processing file from Dashmap
109XXXy.dat => By-Product from NAV system
o109XXXy.dxf => DXF of trajectory

POSAV Subfolder

o109XXXy.* => Primary GPS IMU data from Aircraft (logged in 12MB segments)

Intensity_correction_table Subfolder

optech1_dashmapv3_5141.res => Configuration file for system hardware
100kHz_5141.txt => Intensity Correction Table when operating at 100Khz
70kHz_5141.txt => Intensity Correction Table when operating at 70Khz
50kHz_5141.txt => Intensity Correction Table when operating at 50Khz
33kHz_5141.txt => Intensity Correction Table when operating at 33Khz

1.12.8 FGDC Report

A FGDC compliant in eXtensible Markup Language (.xml) project level metadata file outlining the acquisition and post processing aspects of the San Gabriel LiDAR project was delivered in soft copy.

2 Quality Control

2.1 Quality Control for Data Acquisition

The acquisition of overlapping calibration lines for every mission is key to the QC process since it helps identify any systematic issues in data acquisition or failures on the part of the GPS, IMU or other equipment that may not have been evident to the LIDAR operator during the mission.

Ground truth validation is used to assess the data quality and consistency over sample areas of the project. To facilitate a confident evaluation, existing survey control is used to validate the LIDAR data. Published survey control, where the orthometric height (elevation) has been determined by precise differential levelling observation, is deemed to be suitable.

Ground truth validation points may be collected for each of the terrain categories to establish RMSE accuracies for the LIDAR project. These points must be gathered in flat or uniformly sloped terrain (<20% slope) away from surface features such as stream banks, bridges or embankments. If collected, these points will be used during data processing to test the RMSEz accuracy of the final LIDAR data products.

The Field Project Manager performs kinematic post-processing of the aircraft GPS data in conjunction with the data collected at the Reference Station. Double difference phase processing of the GPS data is used to achieve the greatest accuracy. The GPS position accuracy is assessed by comparison of forward and reverse processing solutions and a review of the computational statistics. Any data anomalies are identified and the necessary corrective actions are implemented prior to the next mission.

The quality control of LIDAR data and data products has proven to be a key concern by Dewberry. Many specifications detail how to measure the quality of LIDAR data given RMSE statistical methods to a 95% confidence level. In order to assure meeting all levels of QC concerns, Terrapoint has quality control and assurance steps in both the data acquisition phase and the data processing phase. Any acquired data sets that fail these checks are flagged for re-acquisition.

QC Step 1 - The system logging software performs automatic system and subsystem tests on power-up to verify proper functionality of the entire data acquisition system. Any anomalies are immediately investigated and corrected by the LIDAR operator if possible. Any persistent problems are referred to the engineering staff, which can usually resolve the issue by telephone and/or email. In the unlikely event that these steps do not resolve the problem, a trained engineer is immediately dispatched to the project site with the appropriate test equipment and spare parts needed to repair the system.

QC Step 2 - The system logging software continuously monitors the health and performance of all subsystems. Any anomalies are recorded in the System Log and reported to the LIDAR operator for resolution. If the operator is unable to correct the problem, the engineering staffs are immediately notified. They provide the operator with instructions or on-site assistance as needed to resolve the problem.

If any aspect of the data does not appear to be acceptable, the operator will review system settings to determine if an adjustment could improve the data quality. Navigation aids are provided to alert both the pilot and operator to any line following errors that could potentially compromise the data integrity. The pilot and operator review the data and determine whether an immediate re-flight of the line is required.

QC Step 3 - After the mission is completed, raw LIDAR data on the removable disk drive is transferred to the Field PC at the field operations staging area. An automated QA/QC program scans the System Log as well as the raw data files to detect potential errors. Any problems identified are reported to the operator for further analysis. Data is also retrieved from all GPS Reference Stations, which were active during the mission and transferred to the Field PC. The GPS data is processed and tested for internal consistency and overall quality. Any errors or limit violations are reported to the operator for more detailed evaluation.

QC Step 4 - The Field Project Manager utilizes a data viewer installed on the Field PC to review selected portions of the acquired LIDAR data, this permits a more thorough and detailed analysis of the data corrupted files or problems in the data itself are noted. If the data indicates improper settings or operation of the LIDAR sensor, the Field Project Manager determines the appropriate corrective actions needed prior to the next mission.

QC Step 5 - All LIDAR and GPS data is copied from the Field PC onto two separate removable hard drives: one for transfer to Calibration, and one for local backup. Each hard drive is reviewed to ensure data completeness and readability.

2.2 Quality Control for Data Processing

Quality assurance and quality control procedures for the raw LIDAR data and processed deliverables for the DEM and derivative products are performed in an iterative fashion through the entire data processing cycle. All final products pass through a six-step QC control check to verify that the data meets the criteria specified by Dewberry.

The following list provides a step-by-step explanation of the process used by Terrapoint to review the data prior to customer delivery.

The QC Step 1 and 2 pertain to the LiDAR point cloud calibration portion of the project life cycle; while QC Step 3 to 7 pertains to the Production portion of the project life cycle, which includes bare earth and deliverable product generation.

2.3 Calibration

QC Step 1 - Data collected by the LIDAR unit is reviewed for completeness and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database. At this time, the data will be confirmed to have been acquired using instrumentation that records multiple returns per laser pulse.

QC Step 2 - The LIDAR data is post processed and calibrated as a preliminary step for product delivery initially with default values from the LiDAR system manufacturer or the last mission calibrated for the system. The initial point generation for each mission calibration is inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the LIDAR unit or GPS. If a calibration error greater than the project specification is observed within the mission; the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality. Flight line swath overlap is confirmed to the adjacent flight lines at the tolerance specified by Dewberry for overlap throughout the project area thus enabling an evaluation of data reproducibility throughout the areas.

A preliminary RMSEz and RMSExy error check is performed at this stage of the project life cycle in the raw LiDAR dataset against GPS static and kinematic data and compared to project specifications RMSEz. The LiDAR data is examined in open, flat areas away from breaks and under specified vegetation categories. This step is repeated in QC Step 6 against the final bare earth LiDAR model.

QC Step 3 – Once the data enters the bare earth extraction stage, a checklist (Pre-production checklist) verifies all the components of the project have been received in good order.

QC Step 4 – Once the raw LiDAR data is ready for the bare earth extraction stage, all points are classified as ground and non-ground features and the subsequent quality control takes place to ensure an accurate data set is produced:

The non-ground LiDAR point cloud product is reviewed as LiDAR points and/or surface and attention is placed on locating and eliminating any outlier or anomalous points beyond three-sigma values. LIDAR points returning from low clouds, birds, pollution, or noise in the system can cause spikes. Pit-like low returns can come from returns on building windows (corner reflectors) or from system noise. Either type of point needs to be classified as an error point and eliminated from use by any DEM or derivative products. In addition to these outliers, the no ground LiDAR point cloud is reviewed for regular looking non-surface errors like scan lines appearing in the data. Also, any localized errors remaining between flight lines are measured and adjusted as needed.

Unusual or odd-looking features and questionable returns are checked for validity and compared against additional source material such as aerial photos, USGS digital maps, local maps, or by field inspection. Most errors found at this QC step can be resolved by re-calibration of the data set or by eliminating specific problem points.

Any valid non ground LiDAR points representing vegetation, buildings and non regular structures or features like radio towers, water bodies, bridges, piers, are confirmed to be classified into the category specified by Dewberry for these feature types. Additional data sets like commercially available data sources or data sources provided by Dewberry may be used to assist and verify that points are assigned into correct classifications.

After the non ground LiDAR points are certified as passing for completeness and for the removal of outliers, attention is shifted to quality controlling the bare-earth model. This product may take several iterations to create it to the quality level that Dewberry is looking for. As Terrapoint and Dewberry inspect the bare-earth model, adjustments are made to fine-tune and fix specific errors.

Adjustments to the bare-earth model are generally made to fix errors created by over-aggressive bare earth extraction algorithm results along mountaintops, shorelines, or other areas of high percent slope. Also, vegetation artefacts leave a signature surface that appears bumpy or rough. Every effort is made to remove any vegetation remnants from the bare-earth model. All adjustments are made by re-classifying points from ground to non-ground or vice versa. All adjustments are made to the LiDAR points and not gridded products to achieve the highest quality results.

QC Step 5 - Both RMSEz and RMSExy are inspected in the classified bare-earth model and compared to project specifications. RMSEz is examined in open, flat areas away from breaks and under specified vegetation categories. All accuracy results are reported to the 95% confidence interval for the different categories as available and required.

Neither RMSEz nor RMSExy are compared to orthoimagery or existing building footprints. Comparison against imagery can skew the determination of accuracy because of the lean and shadows in the imagery.

Instead, a point comparison of a recently acquired or existing high confidence ground survey point to a TIN generated from the final bare earth LIDAR surface. The tolerance for comparisons of control data to the LIDAR TIN elevation is that all sides of the TIN triangle must not be longer than 4.5m to ensure an accurate comparison of surface to the discrete points.

QC Step 6 – Two additional QC step are made against all deliverables before they are sent to Dewberry: A primary deliverable product review is carried out by the Project Leader and a identical peer review is carried out by a fellow Project Leader, Production Manager or QMS Manager as an independent verification. The deliverables are checked against a deliverable checklist (Deliverable checklist & Peer Review checklist) to ensure all product correctness, consistency, absolute accuracy, internal consistency, graphic quality and data integrity requirements are met as per Terrapoint and Dewberry standards.

3 Positional Accuracy

3.1 Internal Vertical Positional Accuracy

The elevation data was verified internally prior to delivery to Dewberry to ensure it met fundamental accuracy requirements when compared to Terrapoint static GPS checkpoints. Below is the summary for the two validation datasets:

East Block
The LiDAR dataset was tested to 0.073m vertical accuracy at 95 percent confidence level, based on consolidated RMSEz (0.037m x 1.9600) when compared to 26 GPS static check points.

West Block
The LiDAR dataset was tested to 0.076m vertical accuracy at 95 percent confidence level, based on consolidated RMSEz (0.039m x 1.9600) when compared to 24 GPS static check points.

Please note that Terrapoint was unable to acquire reliable kinematic GPS to verify the LiDAR on this project as per Terrapoint standard procedure due to significant amount of GPS signal obstructions caused by trees, overhead utilities and buildings. As alternative means of validating the LiDAR data, Terrapoint acquired a total of 50 static check points on flat hard surface.

A detailed comparison is provided in Appendix B Static GPS Validation

3.2 Internal Horizontal Positional Accuracy

Compiled to meet 0.98 meter horizontal accuracy at the 95 percent confidence level

4 Issues and Resolutions

Project delays

Due to inclement weather and aircraft mechanical problems during acquisition - 10 weather, 1 plane in comparison to 14 production days, longer than anticipated calibration timeline, additional efforts to minimize the corn rows and longer than anticipated delivery generation timeline; the delivery of the final product was delayed to August 10th, 2009 from the original plan date of July 10th, 2009.

	mob	demob	production	weather	plane
Thursday, May 28, 2009	1				
Friday, May 29, 2009				1	
Saturday, May 30, 2009			1		

Sunday, May 31, 2009			1		
Monday, June 01, 2009			1		
Tuesday, June 02, 2009			1		
Wednesday, June 03, 2009				1	
Thursday, June 04, 2009			1		
Friday, June 05, 2009				1	
Saturday, June 06, 2009				1	
Sunday, June 07, 2009			1		
Monday, June 08, 2009					1
Tuesday, June 09, 2009				1	
Wednesday, June 10, 2009				1	
Thursday, June 11, 2009				1	
Friday, June 12, 2009				1	
Saturday, June 13, 2009				1	
Sunday, June 14, 2009				1	
Monday, June 15, 2009			1		
Tuesday, June 16, 2009			1		
Wednesday, June 17, 2009			1		
Thursday, June 18, 2009			1		
Friday, June 19, 2009			1		
Saturday, June 20, 2009			1		
Sunday, June 21, 2009			1		
Monday, June 22, 2009			1		
Tuesday, June 23, 2009		1			
Wednesday, June 24, 2009		1			
total	1	2	14	10	1

Obstructions hindering GPS Kinematic acquisition

Please note that Terrapoint was unable to acquire reliable kinematic GPS to verify the LiDAR on this project as per Terrapoint standard procedure due to significant amount of GPS signal obstructions caused by trees, overhead utilities and buildings.

As alternative means of validating the LiDAR data, Terrapoint acquired a total of 50 static check points on flat hard surface.

Corn row effect reduction

As means to minimize corn effects; Terrapoint supplemented our standard acquisition standards and processing procedures with the following:

Increased the scan cut off on either side of the scan to minimize effects of the scanner lag, and

Augmented the scanner field of view during the course of the project, to allow for an increased scan cut-off, while maintaining the efficiency of the acquisition and the scanner field of view requirements of the survey

In Terrapoint's analysis of the data, the above actions greatly reduced the visibility of the corn rows in the data and increased the usability of the data for the USGS's application. In conjunction with our data analysis, Optech has confirmed that the scanner used in this survey is working within the published nominal accuracy tolerances.

Mission o109170a Intensity

During the final QC of the data it was observed that the intensity returns for mission o109170a were lower in comparison to the adjoining missions flown at the same altitude and parameters.

As a result Terrapoint used the normalize function in Dashmap for this particular mission. Terrapoint standard procedure is to not calibrate or normalize LiDAR intensity; but in the interest to provide a homogeneous dataset, Terrapoint employed this method.

Intensity Deliverables

In Terrapoint's interpretation of the Task order deliverables, the statement "Shall be 1-meter resolution grid" contradicts "Shall match the gridded DEM" which is delivered as a 0.5m resolution product; hence the delivery of a 0.5m resolution product. In reviewing the acquired point density, Terrapoint maintains that the density of the dataset far exceeds the requirements for a 0.5m product.

Scan Angle Encoding

During the final Calibration review stage of the project it was observed that Optech's DASHMAP is not encoding the scan angle's correctly in the LAS files.

In our thorough analysis corroborated by Optech, the error presents itself as:
A negative one degree offset in the LAS file from the scan angle being recorded from the scanner
Points being encoded as "0" in the LAS file have a scanner angle range of negative 1.5 to positive 0.5 (example in table below)
As a result of the two errors above the points represented as a 0 degree scan angle is larger than any other angle and the maximum negative angle is one degree less than the positive as illustrated below:

True Scanner Angle	Dashmap reported LAS Angle
-1.506002	-1
-1.441133	0
-0.802635	0
0.498908	0
0.500088	1
0.82169	1

Optech has committed to fix this software glitch in the upcoming version of its DASHMAP software.

LAS file size

Due to the large delivery tile footprint resulting in extremely large point files (up to ~56 million points), GPS Absolute time and LAS 1.2 version requirements, Terrapoint was unable to fully validate the LAS files according to Terrapoint I-PROVE requirements. To ensure a quality product delivery, alternate means were utilized to check the LAS files by reading at full resolution and validating against ground control in the smaller footprint processing source LAS 1.0 files and using our in house LAS Validate tool to confirm the integrity of the interim LAS 1.1 files. A parsed read was completed on the deliverable large footprint GPS Absolute LAS 1.2 files to ensure readability.

Initial Delivery Quality - Intensity

Upon Dewberry's QC review of the data it was brought to Terrapoint's attention that 48 intensity files failed to open. To remedy the issue Terrapoint provided a fix within 24 hours of the notice of defect.

Initial Delivery Quality – Antenna Profile Error

Upon Dewberry's QC review of the data it was brought to Terrapoint's attention that the data blind check point validation test results did not meet the project requirements.

Subsequently, Terrapoint conducted an internal review of the Geodetic Control Network and discovered that the antenna profile was not properly applied due to the following:

> *The error was caused by a software processing check box that was inadvertently checked on which ignores the antenna profile. It therefore did not reduce the input coordinates to the L1 phase center using the antenna model parameters, but rather it processed the data to bottom of mount. Once reprocessed, the error was a simple shift in the vertical to account for the antenna L1 phase center.*

To correct the deliverables Terrapoint regenerated the Geodetic Control Report with the revised positions, shifted the LAS and DEM by the bias amount of +0.108m.

5 LiDAR Conclusion

Overall the LiDAR data products submitted to Dewberry meet and exceed both the absolute and relative accuracy requirements set out in the task order for this project.

6 Checkpoint Survey Report

McGee Survey Consultant Survey Report

**Survey Report for the San Gabriel Mountain LiDAR QA/QC Survey in Eastern Los Angeles County,
California for Dewberry & Davis**

6.1 OVERVIEW

Surveyed by: *McGee Surveying Consulting (MSC) at 5290 Overpass Rd., Ste#107 Santa Barbara, CA 93111*
Survey Method: *GPS static and RTK*
Client: *Dewberry & Davis LLC*; **Project. Number**: ____; **Project Name**: *San Gabriel Mountain LiDAR/USGS*
Location: *Los Angeles County, California*
City: ***Los Angeles, Pasadena, Duarte, San Dimas etc.***; **County:** *Los Angeles*; **State:** *California*

Attachments: *Find the following Documents*
-XLS Spreadsheet Listing Control Points with Geodetic Coordinate, Ellipsoid Heights, UTM grid
coordinate and NAVD88 Heights in meters with Point Meta Data
-NGS Data Sheets for Control Points Referenced in this Survey
CSRC NGS Sanctioned Positions and Orthometric Heights (two files)
-Photos of Points

Appendix: *GPS Network Control Network enlargements of the East and West Sites, aerial photos with point locations of the East and West Sites, and aerial photos of the three Control Points in each Site for Terrestrial Scanning*

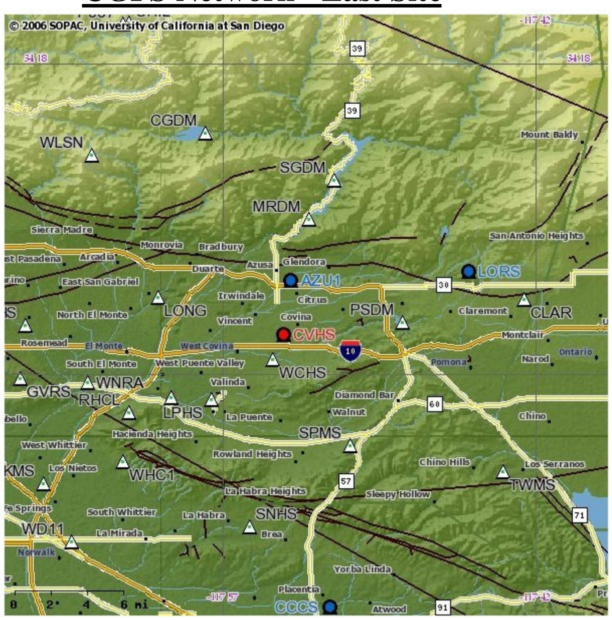
This document serves as a summary report on the above referenced QAQC survey. The purpose of this survey is to establish ground truthing points for validation of LiDAR measurements and the DEM. The lidar mapping was performed by TerraPoint in June 2009. There existed sufficient and CGPS (CORS) stations to establish reliable redundant horizontal positions and ellipsoid heights, and sufficient benchmarks to establish reliable redundant vertical control for this project. This survey is based on the NAVD88 vertical datum and the national re-adjustment of the NAD83 Datum published as the 2007.00 Epoch Adjustment. This Epoch supersedes the 1991.35 Epoch which 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.

The project is located in two irregular sites in Los Angeles County referred to as the East Site and the West Site. The East Site is about 5 x 11 miles along the I-210 corridor from the I-605 to the 57 Freeway, and the West Site is about 3 x 12 miles along the I-110 and I-210 from downtown LA to Pasadena. At the nearest point the two Sites are about 8 miles apart. The project required the establishment of 80 checkpoints with 40 in the East Site and 40 in the West Site. In each Site, 20 points were to be located on open (clear) ground and 20 points in vegetated areas. Within each set of 20 points, 12 points were to be located on level ground, 4 points on an approximate 20 degree slope, and 4 points on an approximate 40 degree slope for a total of 40 points per Site. Slopes between 15 and 30 degrees were considered in the 20 degree category and slopes 30-50 were considered in the 40 degree category. As agreed, points in obstructed sites were collected in nearby pairs for reasons of economy to facilitate the use of conventional instruments to obtain accurate elevations under trees. Prior to initiating the field surveys it was agreed with the USGS (Dewberry client) in a telephone conference to substitute 3 QAQC check points in each site for permanent control points for the use of Gerald Bawden in controlling terrestrial scanning as a supplement to the QAQC process. Additionally, photos of each location were taken and are named with the point number and direction i.e. #101 would appear in a photo titled “101-N.jpg” viewed looking northerly.

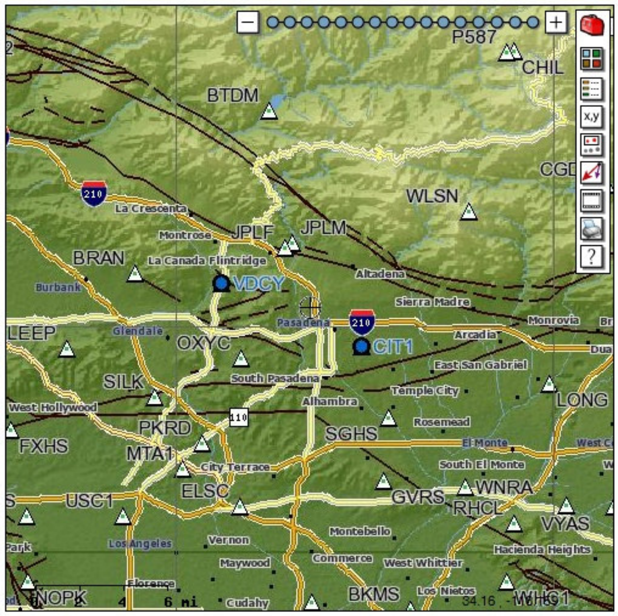
PROJECT DATUMS, REFERENCE SYSTEM

Horizontal Datum: *North American Datum of 1983 (NAD83) per NGS*; **Epoch:** *2007.00*
Reference Network: *CGPS (continuously operated GPS stations in California, similar to CORS)*
Vertical Datum: *NAVD88 per NGS*
Reference Network: *NGS Benchmarks in the NSRS and CGPS Stations (Data Sheets attached)*
Geoid Model: *Geoid 03;* **Projection:** *UTM Zone 11;* **Units for Deliverables:** *Meters*
Notes: *The CGPS Network is shown below. Stations AZU1, CIT1, GVRS, LORS, OXYC, and VDCY were included in this survey. The blue dot indicates a station with leveled NAVD88 heights except AZU1.*

CGPS Network - East Site



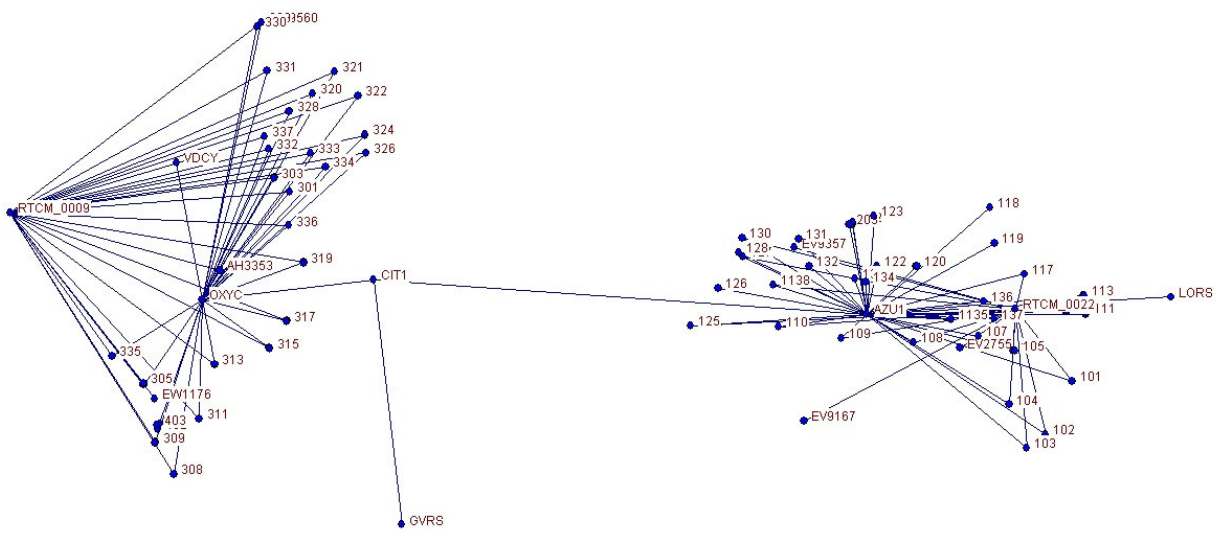
CGPS Network - West Site



6.2 NETWORK

The network includes 95 points consisting of test points, benchmarks and CGPS Stations. Primary Control stations are the CGPS Stations taking their assigned four letter ID, and NGS benchmarks are identified by their NGS PID designation. Points numbered in the 101-137 range are test points in the East Site, and 301-338 are test points in the West Site. Points 201-203 in the northwest portion of the in the East Site and 401-403 in the southern portion of the West Site are permanent control points set for the use of the USGS in conducting terrestrial scanning. These locations were selected because of the vertical relief, smooth near level surfaces and varying site conditions presenting fundamental and supplemental testing conditions. See the attached Spreadsheet Listing of Control Points and Coordinates for a detail description of these points. The survey was conducted as a static radial network from CGPS Stations. A second vector was measured on a different day utilizing static data or the Leica regional RTK Spyder Network. The two vectors to each point had to agree less than 5 centimeters in the vertical component and four points required a third measurement. The GPS Network (East and West Sites combined) is shown below. An enlargement of each site is included in the Appendix along with aerial photos showing the locations of the QAQC Test Points and the three control points established in each site for terrestrial scanning.

GPS Network



ADJUSTMENTS & ANALYSIS

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

VDCY (CGPS) was fixed 3D in a Minimally Constrained Adjustment to determine latitude, longitude, ellipsoid heights, and to compare with other stations as shown below. The adjustment results follow with coordinate changes from record to computed in meters.

Station	dN	dE	dZ	
AZU1	-0.008	-0.002	0.000	CGPS
CIT1	-0.001	-0.000	-0.007	CGPS
EV9357	0.003	0.009	-0.032	HARN Station
EW9560	0.458	-0.402	0.061	1991.35 Epoch Second Order Triangulation (no EH)
GVRS	-0.001	-0.001	-0.019	CGPS
LORS	-0.004	-0.000	0.010	CGPS
OXYC	0.000	0.001	-0.010	CGPS
VDCY	0.000	0.000	0.000	CGPS Fixed

Notes: *Excluding EV9357 and EV9560, the average vertical closure is -0.004 meters on other CGPS Stations. EV9357 has a Network Accuracy in N, E, Up of 1,1,6 centimeters whereas the CGPS is 0,0,0. The horizontal difference at EV9560 is consistent with the velocities for the difference in the Epochs and the 2nd Order Accuracy; the vertical is derived from the Geoid 03 Height applied to the orthometric height to obtain an estimated ellipsoid height.*

Adjustment 2: 3D/Ellipsoid Heights - Constrained Adjustment

All CGPS stations (listed below) were fixed 3D in a Constrained Adjustment to determine final latitude, longitude, ellipsoid heights, and UTM plane coordinates. The adjustment results follow with coordinate changes from record to computed in meters. The results of this adjustment are listed in the attached XLS Spreadsheet Coordinate Listing

Station	dN	dE	dZ	
AZU1	0.000	0.000	0.000	Fixed CGPS
CIT1	0.000	0.000	0.000	Fixed CGPS
EV9357	0.012	0.011	-0.028	Free HARN Station
EW9560	0.458	-0.403	0.071	Free 1991.35 Epoch Second Order Triangulation
GVRS	0.000	0.000	0.000	Fixed CGPS
LORS	0.000	0.000	0.000	Fixed CGPS
OXYC	0.000	0.000	0.000	Fixed CGPS
VDCY	0.000	0.000	0.000	Fixed CGPS

Adjustment 3: Orthometric Heights - Minimally Constrained

VDCY (CGPS) was fixed horizontally and vertically in a Minimally Constrained Adjustment to determine NAVD88 orthometric heights by combining the measured ellipsoid height differences with Geoid 03 and compare with other stations as shown below. The height changes from record to computed are listed in meters.

Station	dZ	
AH3353	-0.037	BM 1st Order
AZU1	*-0.049*	CGPS with geoidal modeled height to nearest 0.1 meters
CIT1	-0.014	CGPS with 3rd Order NAVD88 Height
EV2755	-0.063	BM 1st Order ?
EV9167	-0.097	BM 1st Order
EV9357	-0.147	HARN Station with geoidal modeled height to nearest 0.1 meters
EW1176	-0.071	BM 1st Order
EW9560	0.031	BM 3rd Order/Vertcon
GVRS	-0.075	CGPS with 3rd Order NAVD88 Height
LORS	-0.058	CGPS with 3rd Order NAVD88 Height
VDCY	0.000	Fixed – CGPS with 2nd Order NAVD88 Height

Notes: *Excluding AZU1 and EV9357 which are not leveled heights, the differences demonstrate an E-W and a N-S trend. Three CGPS Stations VDCY, CIT1 and LORS are on an E-W axis that runs through the center of the project. The following solution vertically fixes these Stations.*

Adjustment 4: Orthometric Heights - Partially Constrained

VDCY was fixed horizontally and vertically, and CIT1 and LORS were fixed vertically in a Partially Constrained Adjustment to determine an alternate solution for NAVD88 orthometric heights by combining the measured ellipsoid height differences with Geoid 03 and compare with other stations as shown below. The height changes from record to computed are listed in meters. The results of this adjustment are listed in the attached XLS Spreadsheet Coordinate Listing under "Ortho. Ht. Adj#4".

Station	dZ	
AH3353	-0.030	
AZU1	-0.012	
CIT1	0.000	Fixed CGPS
EV2755	-0.026	
EV9167	-0.061	
EV9357	-0.110	
EW1176	-0.064	
EW9560	0.038	
GVRS	-0.061	
LORS	0.000	Fixed CGPS
VDCY	0.000	Fixed CGPS

Notes: *As stated above, AZU1 and EV9357 are excluded from the analysis because their vertical accuracy is 0.1 meters and are shown as a matter of information. The remaining stations vary between +0.04 and -0.06 meters and as expected demonstrate a N-S trend. The trends indicate a best fit transformation of the Geoid03* *model to known orthometric heights across the project will result in the best NAVD88 Heights. To evaluate the validity of a transformation, the following solution best fits the geoid surface through all stations except AZU1 and EV9357.*

Adjustment 5: Orthometric Heights –Solving for Rotations - Unconstrained

No Stations were fixed. Excluding AZU1 and EV9357 for reasons stated above, rotations were solved around the N-S and E-W axis to best fit the orthometric heights at known stations utilizing Geoid03 (combining the measured ellipsoid height differences with Geoid 03 heights) and determine a second alternate solution for NAVD88 orthometric heights and compare with other stations as shown below.

```
   Station      dZ                     |             GPS Datum Transformation Results
   AH3353    -0.010                    |     Scale Factor 1.00000000000:  0.000000 PPM (None)
   AZU1       0.007  Excluded          |     Rotation Around North Axis:  0.128526 Sec
(Solved)
   CIT1       0.020                    |     Rotation Around East Axis :  1.211193 Sec
(Solved)
   EV2755     0.003                    |     Rotation Around Vert Axis : -0.015944 Sec
(Solved)
   EV9167    -0.018
   EV9357    -0.109  Excluded
   EW1176    -0.015
   EW9560     0.001
   GVRS       0.018
   LORS       0.002
   VDCY       0.001
```

Notes: *Excluding AZU1 and EV9357, the average vertical difference is 0.000 meters, as expected, resulting from a best fit geoid surface. The average of the absolute values is 0.010 meters and the maximum is 0.020 meters. These differences validate the transformation solution and the following adjustment solves for rotations and then constrains vertically to these stations.*

Adjustment 6: Orthometric Heights –Solving for Rotations and Constrained

All Stations were fixed vertically excluding AZU1 and EV9357 for reasons stated above. Rotations were solved around the N-S and E-W axis to best fit the orthometric heights utilizing Geoid03 (combining the measured ellipsoid height differences with Geoid 03 heights) resulting in NAVD88 orthometric heights consistent with the NAVD88 leveling in the region. See below for comparison with other stations as shown. The results of this adjustment are listed in the attached XLS Spreadsheet Coordinate Listing under "Ortho. Ht. Adj#6".

```
   Station      dZ                      |             GPS Datum Transformation Results
   AH3353     0.000                     |     Scale Factor 1.00000000000:  0.000000 PPM (None)
   AZU1      -0.003   Excluded          |     Rotation Around North Axis:  0.206399 Sec
(Solved)
   CIT1       0.000                     |     Rotation Around East Axis :  1.144053 Sec
(Solved)
   EV2755     0.000                     |     Rotation Around Vert Axis : -0.016413 Sec
(Solved)
   EV9167     0.000
   EV9357    -0.114   Excluded
   EW1176     0.000
   EW9560     0.000
   GVRS       0.000
   LORS       0.000
   VDCY       0.000
```

6.3 DATA COLLECTION & PROCESSING

Date of Field Surveys: *June 08-21, 2009*

GPS Survey Parameters:
Epoch Rate (seconds): *15" for 15-25 minute static occupations for static connections from the CGPS Stations.*
Minimum Satellites: *5* **; GDOP=<** *6* **; Elevation Mask for Data Collection & Processing (degrees):** *12*
GPS Observables: *L1 & L2 Carrier wave, C/A Code and P-Code;* **Boulder K Index:** *1-2*

Equipment:

GPS Base Receiver Unit No.: *M3,* **Operator:** *McGee;* **Station Identification:** *vary*
Receiver Make & Model: *Leica 530* **; Antenna Make & Model:** *Leica AT502*
Antenna Mount: *Fixed Pole*; **Antenna Height:** *2.085m*
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:** *2.085m*
GPS Rover Receiver Unit No.: *M5,* **Operator:** *McGee,* **Station Identification:** *varies*
Receiver Make & Model: *Leica 1200* **; Antenna Make & Model:** *ATX1230*
Antenna Mount: *Fixed Pole*; **Antenna Height:** *2.085m*

CGPS & Ephemeris: *The rapid ephemeris and rinex files for the CGPS were imported from the NGS and SOPAC. Rapid ephemeris used for static post-processing to CGPS Stations.*

6.4 ACCURACY

Vectors: *Vectors average 7.9 km with a maximum of 15.8 km. In the minimally constrained adjustment, the two dimensional residuals averaging 0.5 cm with a standard deviation of 0.4 cm and a maximum of 1.6 cm. The absolute value of the vertical residuals average 0.8cm with a standard deviation of 0.9 cm and as maximum of 3.7 cm.*

Accuracy: *Relative on site is expected to be 2 centimeters horizontal and vertical except the relative accuracy within each set of Control Points set for terrestrial scanning (201, 202, 203) and (401, 402, 403) is expected to be sub-centimeter. Absolute is expected to be 2 centimeters horizontal and vertical relative to the constraints introduced in the adjustments.*

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

NGS STATIONS and CGPS DESCRIPTIONS (see attached file)

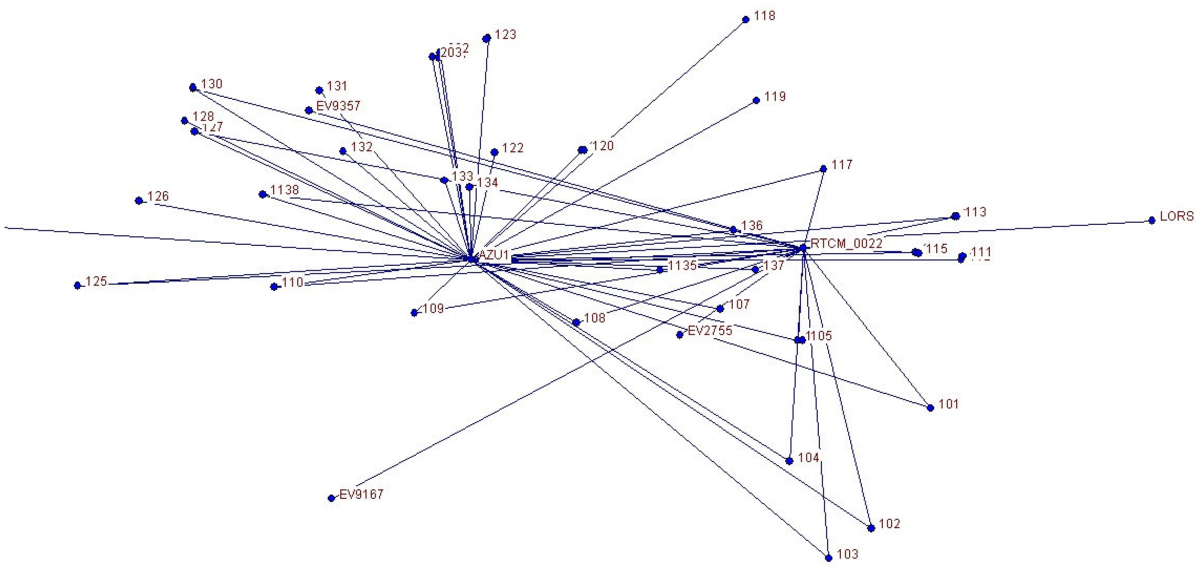
SURVEYOR'S STATEMENT

Dewberry
8401 Arlington Boulevard
Fairfax, Virginia 22031-4666
703 849 0396
703 849 0182 fax
www.dewberry.com

This Report on the criteria and procedures used on this QAQC Survey was prepared by me on July 3, 2009 for the purpose of validating LiDAR data and the digital elevation model (DEM) at the request of Tim Blak of Dewberry & Davis Inc.

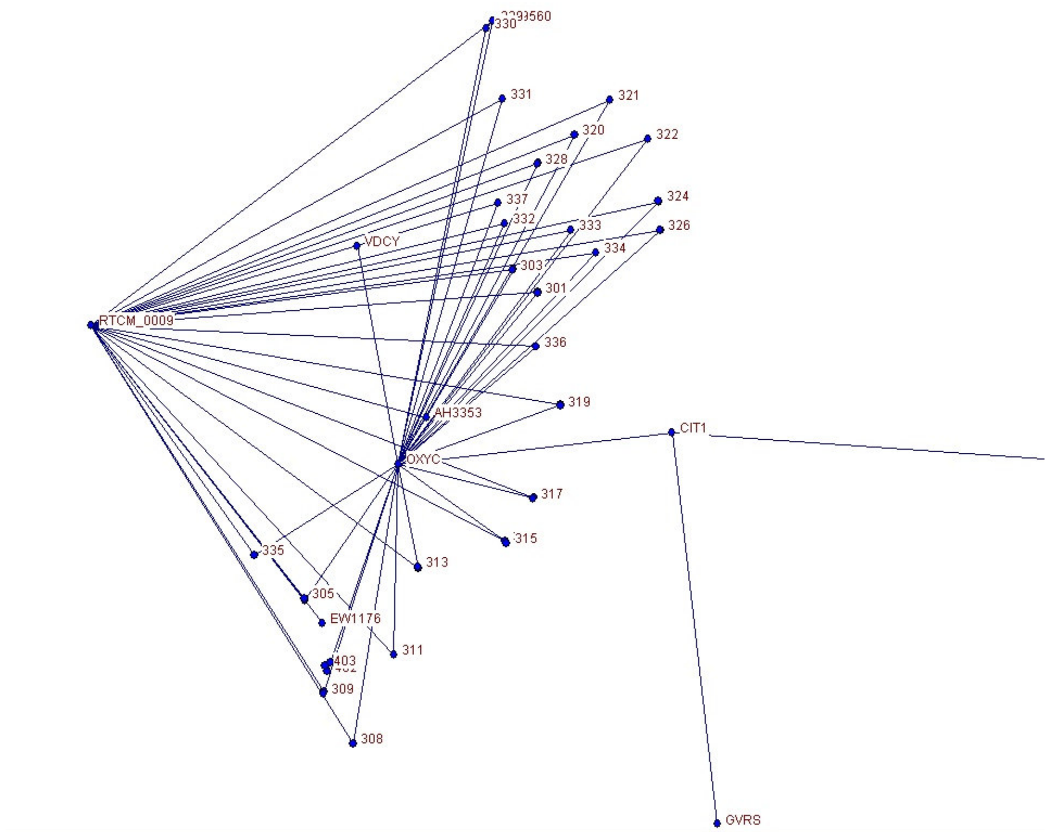
____
Michael R. McGee, PLS 3945 (CA)

East Site - GPS Network

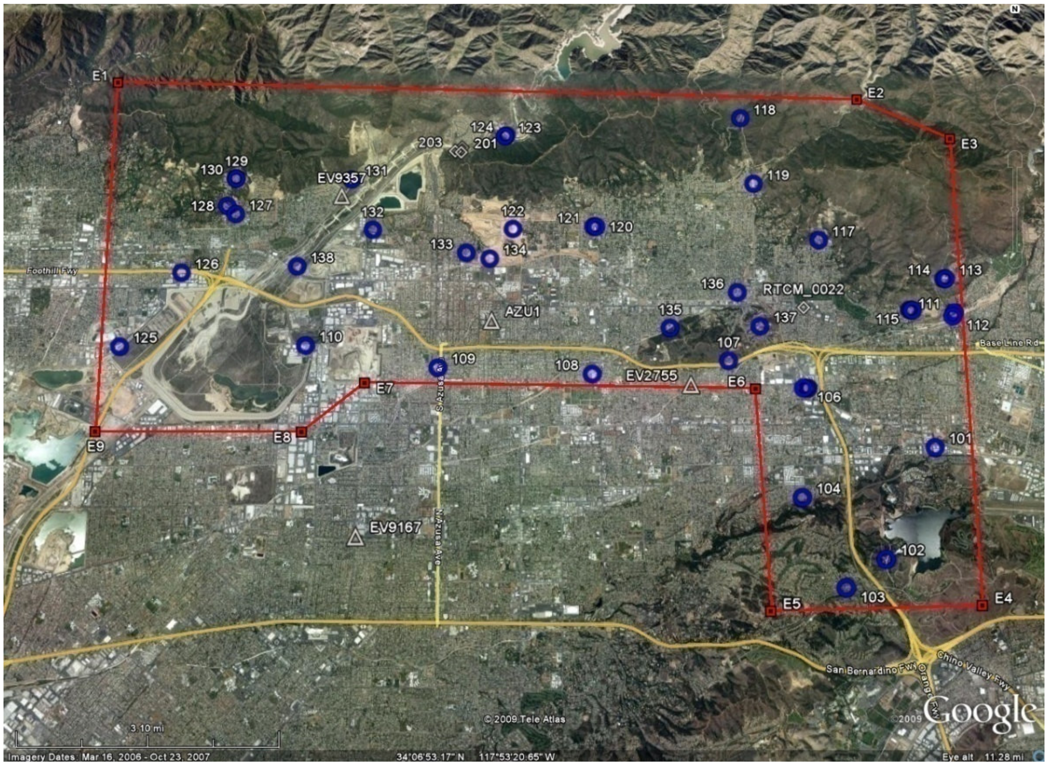


Dewberry
8401 Arlington Boulevard
Fairfax, Virginia 22031-4666
703 849 0396
703 849 0182 fax
www.dewberry.com

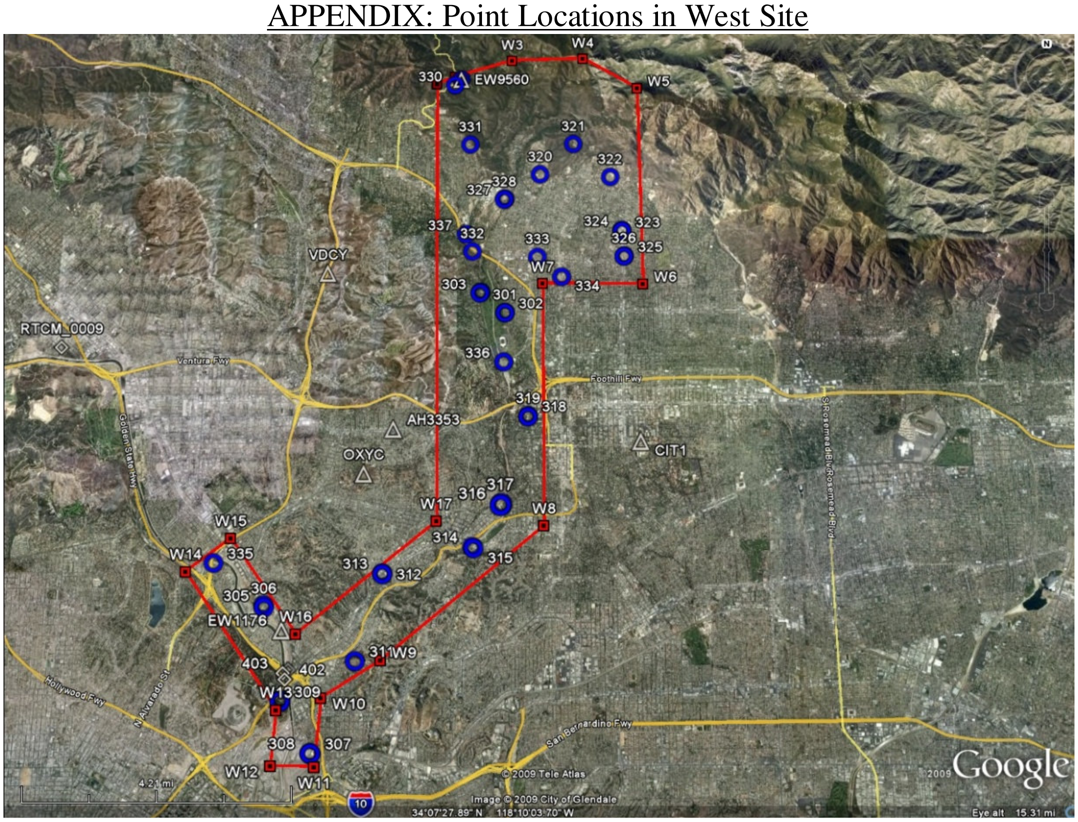
West Site - GPS Network



APPENDIX: Point Locations in East Site



APPENDIX: Point Locations in West Site



APPENDIX: Control Points 201, 202 and 203 for Terrestrial Scanning in the East Site

APPENDIX: Control Points 401, 402 and 403 for Terrestrial Scanning in the West Site

7 Vertical Accuracy Analysis

The LiDAR was verified two ways for accuracy; internally by the LiDAR provider, and by utilizing an independent surveyor. In both cases a combination of GPS techniques were used which consisted of static observations, and real time kinematic (RTK). The internal survey as stated above in the Terrapoint portion of the report, used static positioning and tested to an accuracy of 7.3 cm for the east block and 7.6 cm for the west block at the 95% confidence level. The LiDAR data was then verified utilizing the independent surveyor's checkpoints. McGee Survey Consulting (MSC) provided a total of 76 checkpoints using both static and RTK methods. To ensure conformity to the LiDAR data, MSC surveyed common control points that were used in the Terrapoint control network survey (results can be seen in the MSC report above).

To verify the accuracy of the data the SOW stated that the checkpoint survey should conform to the FEMA Guidelines and Specifications for Flood Hazard Mapping Partners Appendix A: Guidance for Aerial mapping and Surveying. This methodology collects a minimum of 20 points for each of the predominant land cover types (i.e. bare-earth, weeds and crop, forest, urban etc.). However due to the requirement to test in different slope categories the survey was performed in both bare-earth and vegetated areas with the emphasis on bare-earth (fundamental check). This fundamental check ensures that the LiDAR system is performing to specification as there should be no valid reason why the data should fail in open terrain since the laser is not influenced by any vegetation.

The vertical bare-earth accuracy specifications under this Task Order are categorized by varying degrees of slope:

1. 15.0 cm RMS in 0 degrees of slope
2. 35.0 cm RMS in 20 degrees of slope
3. 70.0 cm of RMS in 40 degrees of slope
4. 100 cm of RMS in 50 degrees of slope

To test the vertical accuracy of the survey checkpoints, the elevation values of the checkpoints are compared against a TIN created from the bare-earth LiDAR at the same horizontal locations. The results of the statistical computations are presented below. **Error! Not a valid bookmark self-reference.** and Table 2 display the statistics based on the FEMA methodology of computing RMSE that assumes errors follow a normal distribution.

Table 1 – RMSE method for testing accuracy, East

East

100 % of Totals	RMSE Specs (m)	RMSE (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.185	0.071	-0.027	-0.033	-0.979	0.067	38	-0.268	0.094
Level	0.150	0.057	-0.032	-0.033	-0.196	0.047	24	-0.141	0.070
One to Twenty	0.350	0.057	-0.050	-0.056	0.578	0.033	4	-0.078	-0.009
Twenty-One to Forty	0.700	0.063	0.033	0.040	-0.605	0.057	8	-0.052	0.094
Forty One to Fifty	1.000	0.191	-0.153	-0.153	NA	0.163	2	-0.268	-0.038

Table 2 – RMSE method for testing accuracy, West

West

100 % of Totals	RMSE Specs (m)	RMSE (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.185	0.076	-0.033	-0.040	0.306	0.070	37	-0.190	0.127
Level	0.150	0.064	-0.024	-0.026	0.143	0.061	24	-0.141	0.108
One to Twenty	0.350	0.075	0.009	-0.010	0.596	0.082	6	-0.071	0.127
Twenty-One to Forty	0.700	0.108	-0.100	-0.102	-1.438	0.046	7	-0.190	-0.057
Forty One to Fifty	1.000	--	--	--	--	--	--	--	--

Table 3 – RMSE method for testing accuracy, combined East and West

Combined

100 % of Totals	RMSE Specs (m)	RMSE (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.185	0.074	-0.030	-0.034	-0.308	0.068	75	-0.268	0.127
Level	0.150	0.061	-0.028	-0.030	0.098	0.054	48	-0.141	0.108
One to Twenty	0.350	0.068	-0.015	-0.034	1.197	0.070	10	-0.078	0.127
Twenty-One to Forty	0.700	0.087	-0.029	-0.052	-0.028	0.085	15	-0.190	0.094
Forty One to Fifty	1.000	0.191	-0.153	-0.153	NA	0.163	2	-0.268	-0.038

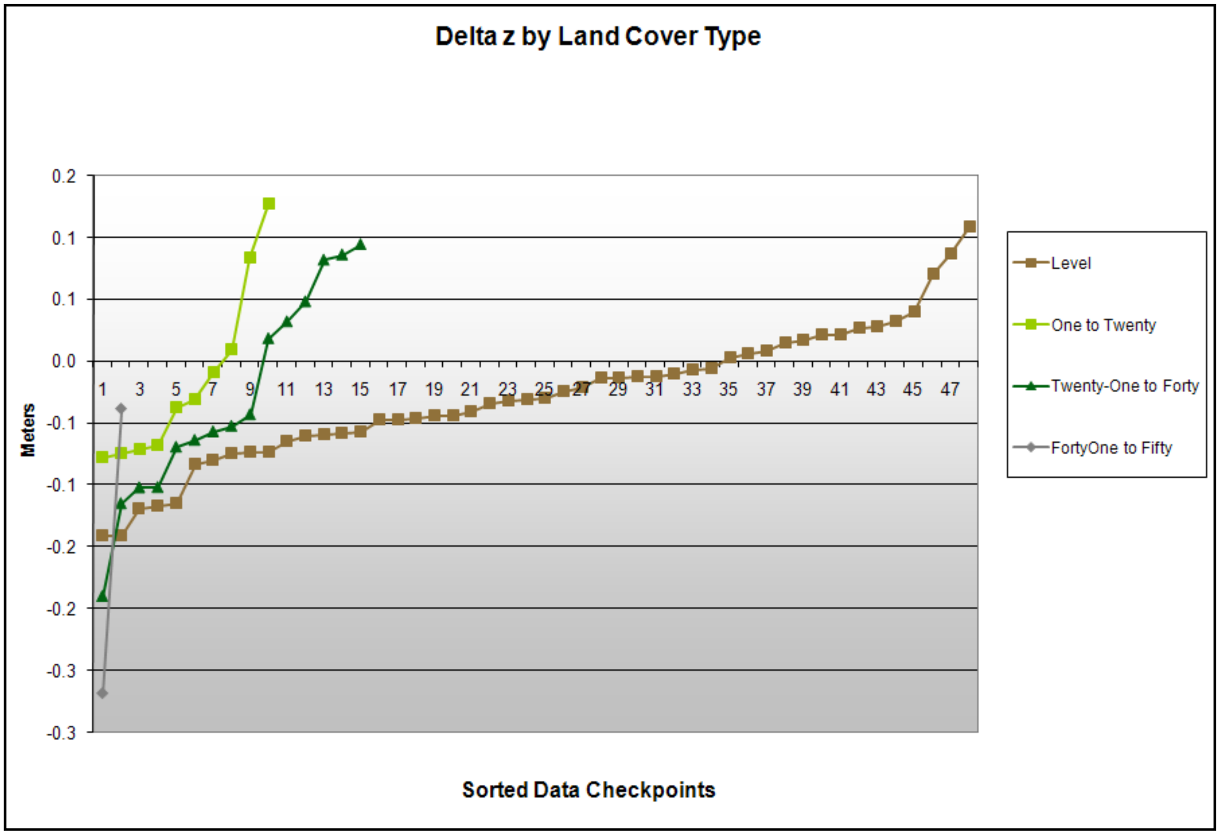


Figure 2 - Sorted data checkpoints illustrating the difference between the LiDAR and the checkpoints, categorized by degrees of slope

Combined whether vegetated or bare-earth, even at the highest levels of slope the RMSE is 19.1 cm well within specification.

8 Conclusion

The data is comprised of highly dense point spacing where the relative and absolute accuracy is excellent and well within project specifications. It is also evident that accuracy limits are pushed to the limits especially for repeatability from flightline to flightline and also from point to point. One of the goals is to be free from striping (corn rows) and this can somewhat be accomplished through good calibration and positional accuracy from flight line to flight line as well as a myriad of other parameters, however the current whisk broom scanners still have inherent issues that do not complete negate this affect at the 2 cm level. Again given the current state of technology the data meets project specifications and is of high accuracy.