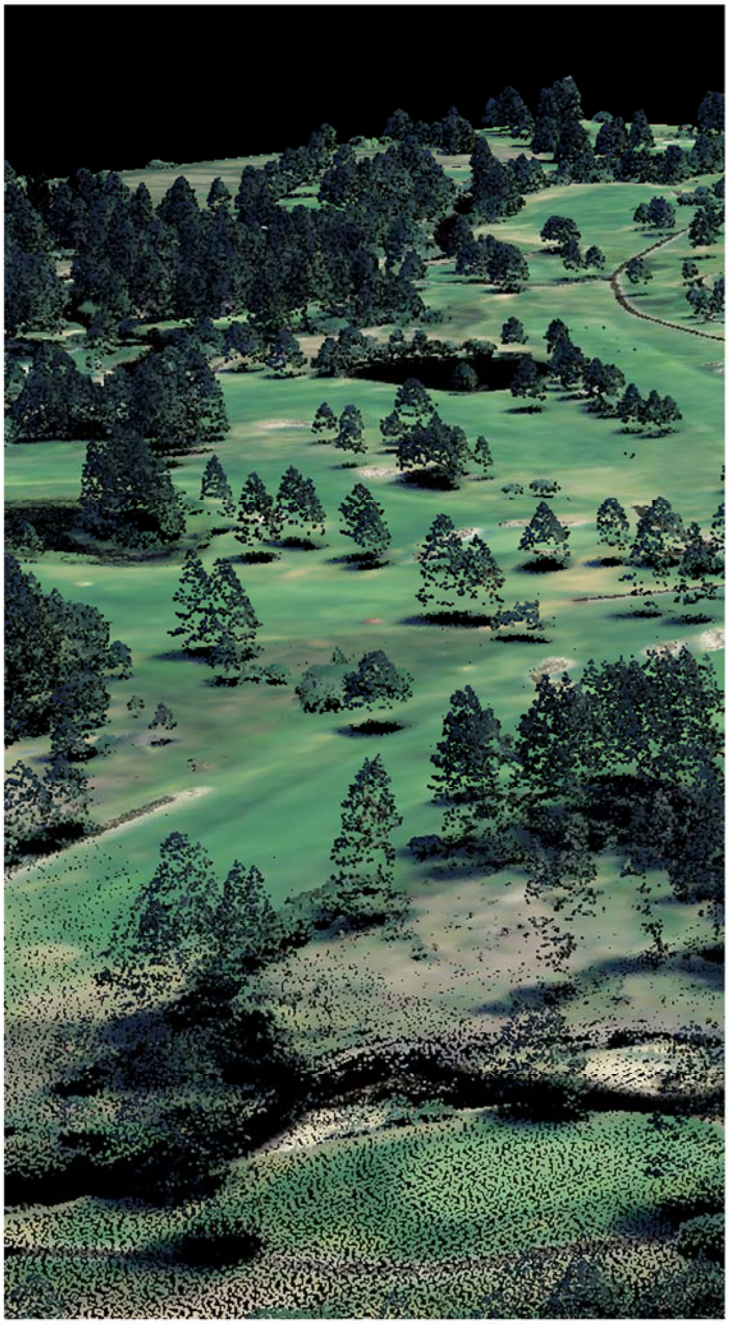
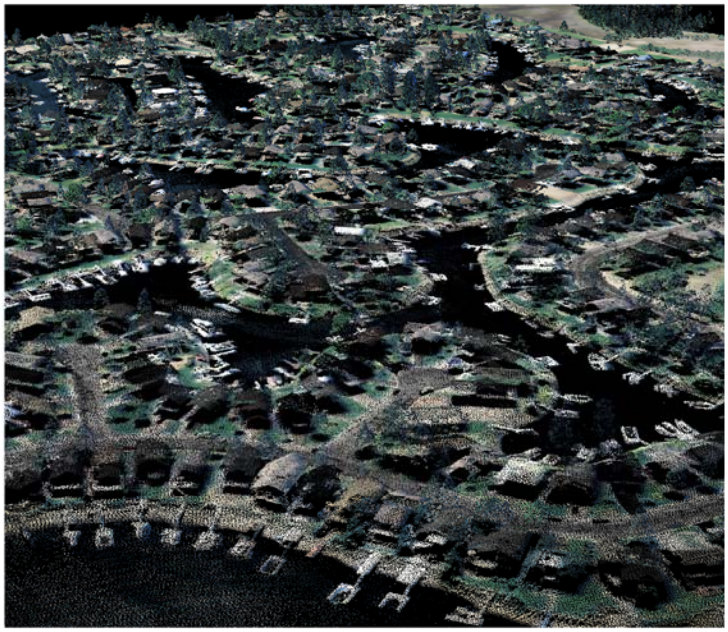
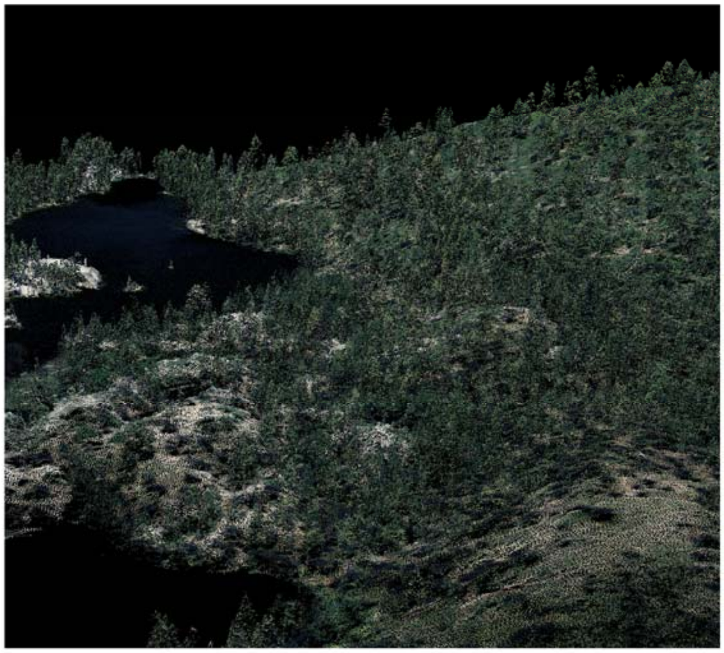
LiDAR REMOTE SENSING

LAKE TAHOE WATERSHED • CALIFORNIA / NEVADA

January 31, 2011







TAHOE REGIONAL PLANNING AGENCY

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LIDAR REMOTE SENSING DATA COLLECTION:
LAKE TAHOE

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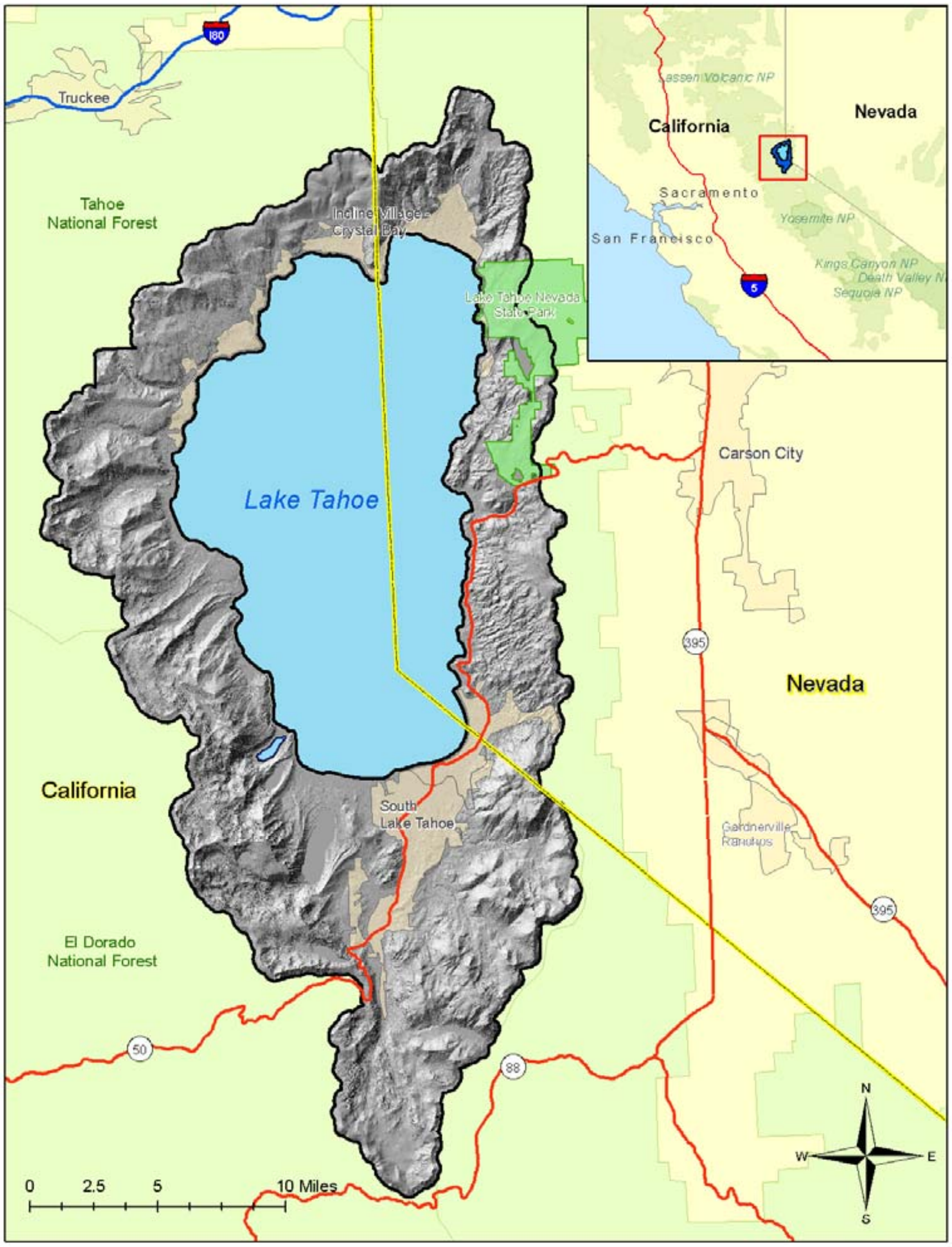
1. Overview

Watershed Sciences, Inc. (WSI) collected Light Detection and Ranging (LiDAR) data of land surrounding Lake Tahoe from August 11th to August 24th, 2010. This report documents the data acquisition, processing methods, accuracy assessment, and deliverables of that data. The requested area of interest (AOI), excluding the actual lake, was 224,725 acres. The area was expanded to include a 100m buffer to ensure complete coverage and adequate point densities around survey area boundaries, resulting in 232,536 acres of delivered LiDAR data. (**Figure 1**).

Figure 1. Lake Tahoe Area of Interest (AOI)



2. Acquisition

2.1 Airborne Survey – Instrumentation and Methods

The LiDAR survey used two Leica ALS50 Phase II laser systems mounted in a Cessna Caravan 208B. The Leica systems were set to acquire ≥83,000 – 105,900 laser pulses per second (i.e., 83 – 105.9 kHz pulse rate) and flown at 900 - 1300 meters above ground level (AGL) depending on weather and terrain, capturing a scan angle of ±14° from nadir. These settings were developed to yield points with an average native pulse density of ≥8 pulses per square meter over terrestrial surfaces. It is not uncommon for some types of surfaces (e.g. dense vegetation or water) to return fewer pulses than the laser originally emitted. These discrepancies between ‘native’ and ‘delivered’ density will vary depending on terrain, land cover, and the prevalence of water bodies.

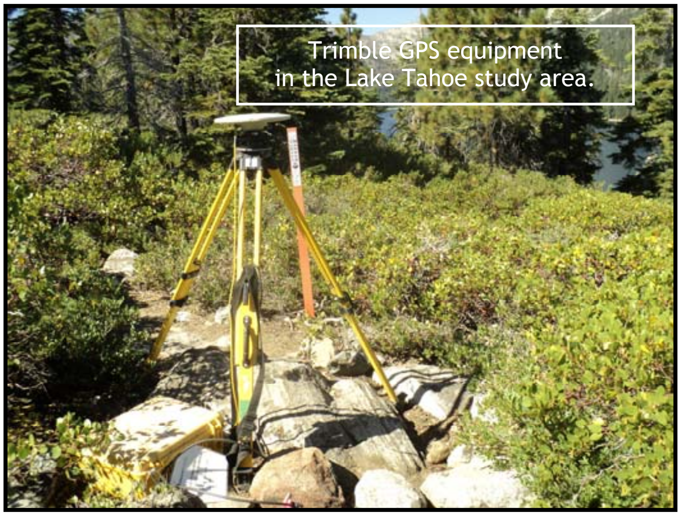
The Cessna Caravan is a stable platform, ideal for flying slow and low for high density projects. The Leica ALS50 sensor head installed in the Caravan is shown on the left.

All areas were surveyed with an opposing flight line side-lap of ≥50% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. The Leica laser systems allow up to four range measurements (returns) per pulse, and all discernable laser returns were processed for the output dataset.

To accurately solve for laser point position (geographic coordinates x, y, z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data collection mission. Aircraft position was measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft/sensor position and attitude data are indexed by GPS time.

2.2 Ground Survey – Instrumentation and Methods

Andregg Geomatics, Auburn, CA (CA PLS 4567) located and certified all survey monuments and collected independent quality control checkpoints used for the LiDAR data collection. The survey control plan was designed to provide redundant control within 13 nm of the mission areas for LiDAR flights. The controls were set prior to the airborne missions (see **Appendix B**). Monument coordinates are provided in **Table 1** and shown in **Figure 2**.



Trimble GPS equipment in the Lake Tahoe study area.

Simultaneous with the airborne data collection mission, Watershed Sciences conducted multiple static (1 Hz recording frequency) ground surveys over the survey monuments. Indexed by time, these GPS data are used to correct the continuous onboard measurements of aircraft position recorded throughout the mission. After the airborne survey, the static GPS data are processed using triangulation with Continuously Operating Reference Stations (CORS) and checked using the Online Positioning User Service (OPUS[1]) to quantify daily variance. Multiple sessions are processed over the same monument to confirm antenna height measurements and reported position accuracy.

2.2.1 Instrumentation

For this project area, a Trimble GPS receiver model R7 with Zephyr Geodetic antenna with ground plane was deployed for all static control A Trimble model R8 GNSS unit was used for collecting check points using real time kinematic (RTK) survey techniques. For RTK data, the collector begins recording after remaining stationary for 5 seconds then calculating the pseudo range position from at least three epochs with the relative error under 1.5 cm horizontal and 2 cm vertical. All GPS measurements are made with dual frequency L1-L2 receivers with carrier-phase correction.

2.2.2 Monumentation

Watershed Sciences incorporated 16 control monuments that were set and certified by Andregg Geomatics, Inc (see Andregg Geomatics' *13910_Report found in Appendix B*). Monuments selected were found to have good visibility and optimal location to support a LiDAR Acquisition flight. (**Table 1**)

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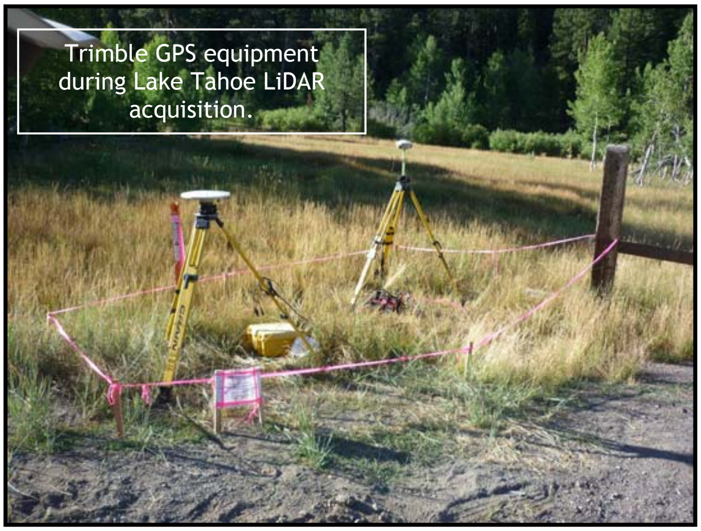
[1] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.

Table 1. Base Station control coordinates for the Lake Tahoe LiDAR Project. Controls were selected and certified by Andregg Geomatics (CA PLS 4567), see Appendix C

Base Station ID	Datum: NAD83 (CORS96)		GRS80
	Latitude	Longitude	Ellipsoid Z (meters)
ARP	38°53'38.467561"N	119°59'45.348090"W	1883.108
BROCKWAY	39°16'11.925401"N	120°05'07.603597"W	2020.251
D836	39°20'50.420265"N	120°07'39.964029"W	1754.035
DOT1	39°09'22.298820"N	119°45'48.327370"W	1416.321
EMERALD	38°57'50.378787"N	120°04'46.794268"W	1924.275
HPGN03FS	38°55'54.067100"N	119°58'43.741166"W	1880.323
MEEKS	39°02'12.183033"N	120°07'41.593703"W	1878.370
Q208	39°05'59.726160"N	119°54'37.633096"W	2120.177
RNO1	39°32'16.451590"N	119°53'08.880400"W	1531.169
ROSE 1	39°18'06.070485"N	119°55'06.476538"W	2580.882
ROSE 2	39°18'05.124461"N	119°55'02.339995"W	2577.916
SPOONER	39°06'02.964665"N	119°54'35.637736"W	2123.353
STAA	38°54'18.944475"N	119°59'29.784238"W	1881.291
TAHOE	39°10'03.168465"N	120°08'48.062822"W	1879.144
V1201	39°19'02.066917"N	120°19'03.604739"W	2046.179
ZOLE	39°25'17.998300"N	119°45'12.033760"W	1357.826

2.2.3 Methodology

Each aircraft is assigned a ground crew member with two Trimble R7 receivers and an R8 receiver. The ground crew vehicles are equipped with standard field survey supplies and equipment including safety materials. All control monuments are observed for a minimum of two survey sessions lasting no fewer than 6 hours. At the beginning of every session the tripod and antenna are reset, resulting in two independent instrument heights and data files. Data is collected at a rate of 1Hz using a 10 degree mask on the antenna.


Trimble GPS equipment during Lake Tahoe LiDAR acquisition.

The ground crew uploads the static GPS data collected during the flight to our FTP site on a daily basis to be returned to the office for Professional Land Surveyor (PLS) oversight, QA/QC review and processing. OPUS processing triangulates the monument position using 3 CORS stations resulting in a fully adjusted position. After multiple days of data have been collected at each monument, accuracy and error ellipses are calculated from the OPUS reports. This information leads to a rating of the monument based on FGDC-STD-007.2-1998[2] Part 2 table 2.1 at the 95% confidence level. When a statistical stable position is found CORPSCON[3] 6.0.1 software is used to convert the UTM positions to geodetic positions. Simultaneously to Watershed Sciences' internal review, all data was sent to Andregg Geomatics to include in their official analysis and certification. This geodetic position is used for processing the LiDAR data (see **Appendix C**).

RTK and aircraft mounted GPS measurements are made during periods with PDOP[4] less than or equal to 3.0 and with at least 6 satellites in view of both a stationary reference receiver and the roving receiver. Static GPS data collected in a continuous session average the high PDOP into the final solution in the method used by CORS stations. RTK positions are collected on bare earth locations such as paved, gravel or stable dirt roads, and other locations where the ground is clearly visible (and is likely to remain visible) from the sky during the data acquisition and RTK measurement period(s).

In order to facilitate comparisons with LiDAR measurements, RTK measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. RTK points were taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs.

Andregg Geomatics, Inc. collected additional fast static check points within the Lake Tahoe study area. The locations of these points can be seen along with Watershed Sciences RTK points in **Figure 2**.


Trimble GPS survey equipment configured for RTK collection near Lake Tahoe

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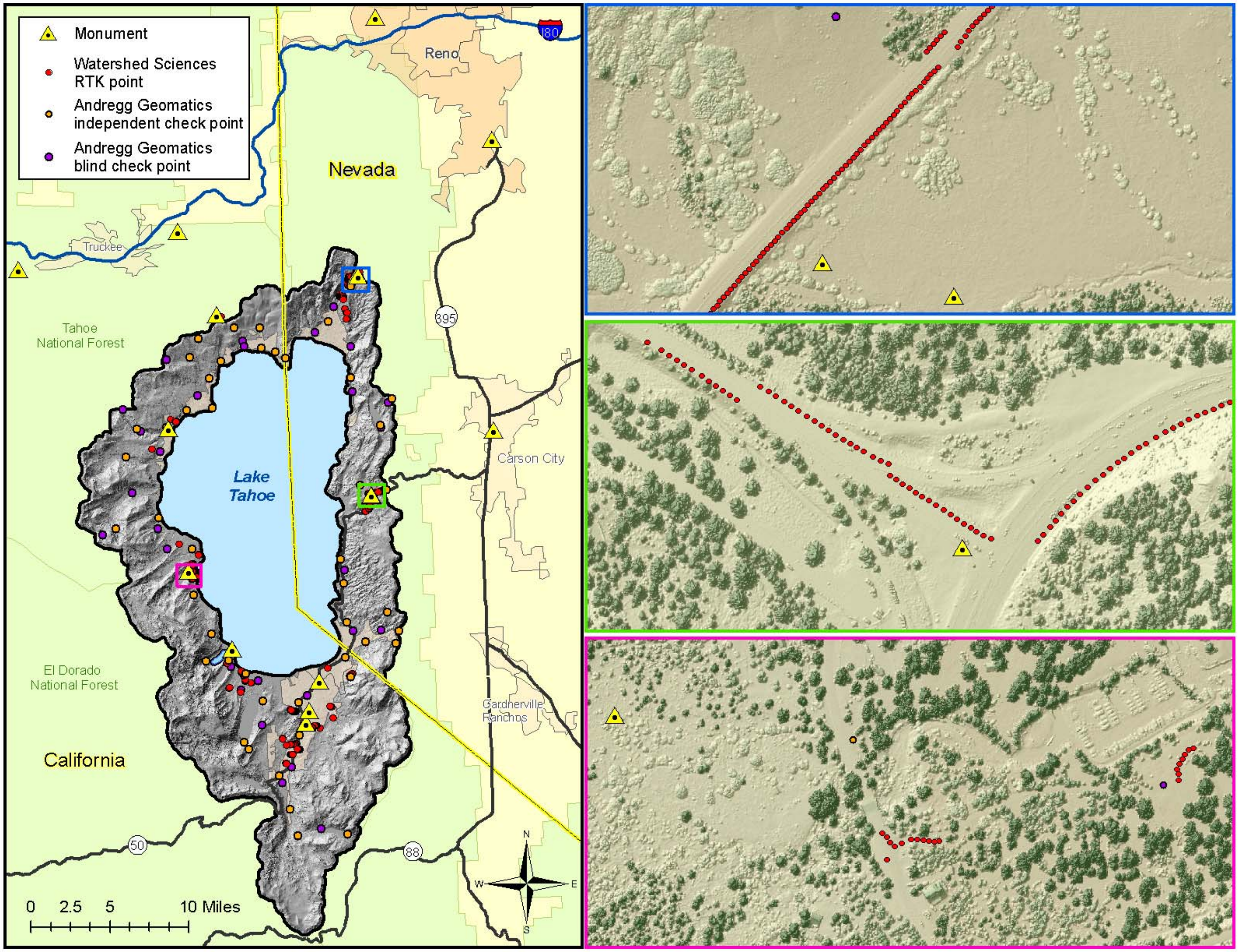
[2] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards

[3] U.S. Army Corps of Engineers , Engineer Research and Development Center Topographic Engineering Center software

[4] PDOP: Point Dilution of Precision is a measure of satellite geometry, the smaller the number the better the geometry between the point and the satellites.

Figure 2. RTK and fast static check point and control monument locations used for Lake Tahoe data acquisition, processing, and accuracy checks



3. LiDAR Data Processing

3.1 Applications and Work Flow Overview

1. Resolved kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data.

   Software: Waypoint GPS v.8.10, Trimble Geomatics Office v.1.62
2. Developed a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor head position and attitude were calculated throughout the survey. The SBET data were used extensively for laser point processing.

   Software: IPAS v.1.35
3. Calculated laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format. Data were converted to orthometric elevations (NAVD88) by applying a Geoid09 correction.

   Software: ALS Post Processing Software v.2.70, Corpscon 6
4. Imported raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter for pits/birds. Ground points were then classified for individual flight lines (to be used for relative accuracy testing and calibration).

   Software: TerraScan v.10.009
5. Using ground classified points per each flight line, the relative accuracy was tested. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calibrations were performed on ground classified points from paired flight lines. Every flight line was used for relative accuracy calibration.

   Software: TerraMatch v.10.006
6. Position and attitude data were imported. Resulting data were classified as ground and non-ground points. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. **Software:** TerraScan v.10.009, TerraModeler v.10.004
7. Bare Earth models were created as a triangulated surface and exported as ERDAS Imagine grids at a .5-meter pixel resolution. Highest Hit models were created for any class at .5-meter grid spacing and exported as ERDAS Imagine grids.

   Software: TerraScan v.10.009, ArcMap v. 9.3.1, TerraModeler v.10.004

3.2 Aircraft Kinematic GPS and IMU Data

LiDAR survey datasets were referenced to the 1 Hz static ground GPS data collected over pre-surveyed monuments with known coordinates. While surveying, the aircraft collected 2 Hz kinematic GPS data, and the onboard inertial measurement unit (IMU) collected 200 Hz aircraft attitude data. Waypoint GPS v.8.10 was used to process the kinematic corrections for the aircraft. The static and kinematic GPS data were then post-processed after the survey to obtain an accurate GPS solution and aircraft positions. IPAS v.1.35 was used to develop a trajectory file that includes corrected aircraft position and attitude information. The trajectory data for the entire flight survey session were incorporated into a final smoothed best estimated trajectory (SBET) file that contains accurate and continuous aircraft positions and attitudes.

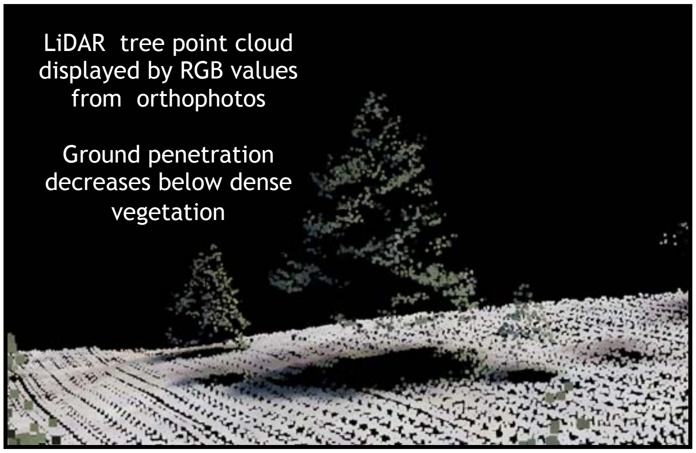
3.3 Laser Point Processing

Laser point coordinates were computed using the IPAS and ALS Post Processor software suites based on independent data from the LiDAR system (pulse time, scan angle), and aircraft trajectory data (SBET). Laser point returns (first through fourth) were assigned an associated (x, y, z) coordinate along with unique intensity values (0-255). The data were output into large LAS v. 1.2 files with each point maintaining the corresponding scan angle, return number (echo), intensity, and x, y, z (easting, northing, and elevation) information.

These initial laser point files were too large for subsequent processing. To facilitate laser point processing, bins (polygons) were created to divide the dataset into manageable sizes (< 500 MB). Flightlines and LiDAR data were then reviewed to ensure complete coverage of the survey area and positional accuracy of the laser points.

Laser point data were imported into processing bins in TerraScan, and manual calibration was performed to assess the system offsets for pitch, roll, heading and scale (mirror flex). Using a geometric relationship developed by Watershed Sciences, each of these offsets was resolved and corrected if necessary.

LiDAR points were then filtered for noise, pits (artificial low points), and birds (true birds as well as erroneously high points) by screening for absolute elevation limits, isolated points and height above ground. Each bin was then manually inspected for remaining pits and birds and spurious points were removed. In a bin containing approximately 7.5-9.0 million points, an average of 50-100 points are typically found to be artificially low or high. Common sources of non-terrestrial returns are clouds, birds, vapor, haze, decks, brush piles, etc.



LiDAR tree point cloud displayed by RGB values from orthophotos

Ground penetration decreases below dense vegetation

Internal calibration was refined using TerraMatch. Points from overlapping lines were tested for internal consistency and final adjustments were made for system misalignments (i.e., pitch, roll, heading offsets and scale). Automated sensor attitude and scale corrections yielded 3-5 cm improvements in the relative accuracy. Once system misalignments were corrected, vertical GPS drift was then resolved and removed per flight line, yielding a slight improvement (<1 cm) in relative accuracy.

The TerraScan software suite is designed specifically for classifying near-ground points (Soininen, 2004). The processing sequence began by 'removing' all points that were not 'near' the earth based on geometric constraints used to evaluate multi-return points. The resulting bare earth (ground) model was visually inspected and additional ground point modeling was performed in site-specific areas to improve ground detail. This manual editing of ground often occurs in areas with known ground modeling deficiencies, such as: bedrock outcrops, cliffs, deeply incised stream banks, and dense vegetation. In some cases, automated ground point classification erroneously included known vegetation (i.e., understory, low/dense shrubs, etc.). These points were manually reclassified as default. Ground surface rasters were then developed from triangulated irregular networks (TINs) of ground points.

Once the points were finalized, GPS week was incorporated into the ASCII format of LiDAR points.

4. LiDAR Accuracy Assessment

4.1 Laser Noise and Relative Accuracy

Laser point absolute accuracy is largely a function of laser noise and relative accuracy. To minimize these contributions to absolute error, we first performed a number of noise filtering and calibration procedures prior to evaluating absolute accuracy.

Laser Noise

For any given target, laser noise is the breadth of the data cloud per laser return (i.e., last, first, etc.). Lower intensity surfaces (roads, rooftops, still/calm water) experience higher laser noise. The laser noise range for this survey was approximately 0.02 meters.

Relative Accuracy

Relative accuracy refers to the internal consistency of the data set - the ability to place a laser point in the same location over multiple flight lines, GPS conditions, and aircraft attitudes. Affected by system attitude offsets, scale, and GPS/IMU drift, internal consistency is measured as the divergence between points from different flight lines within an overlapping area. Divergence is most apparent when flight lines are opposing. When the LiDAR system is well calibrated, the line-to-line divergence is low (<10 cm). See Appendix A for further information on sources of error and operational measures that can be taken to improve relative accuracy.

Relative Accuracy Calibration Methodology

1. Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each survey area.

2. Automated Attitude Calibration: All data were tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flight line and used for line-to-line testing. System misalignment offsets (pitch, roll and heading) and scale were solved for each individual mission and applied to respective mission datasets. The data from each mission were then blended when imported together to form the entire area of interest.
3. Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

4.2 Absolute Accuracy

To minimize the contributions of laser noise and relative accuracy to absolute error, a number of noise filtering and calibration procedures were performed prior to evaluating absolute accuracy. The LiDAR quality assurance process uses the data from the real-time kinematic (RTK) ground survey conducted in the AOI. For this project a total of 1912 RTK GPS measurements were collected by Watershed Sciences, Inc. on hard surfaces distributed among multiple flight swaths. Andregg Geomatics, Inc. also independently collected 48 fast static check points within the study area on hard surfaces with varying degrees of slope. To assess absolute accuracy, the location coordinates of these known ground points were compared to those calculated for the closest ground-classified laser points.

The vertical accuracy of the LiDAR data is described as the mean and standard deviation (sigma ~ σ) of divergence of LiDAR point coordinates from RTK ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y, and z are normally distributed, thus we also consider the skew and kurtosis of distributions when evaluating error statistics.

Statements of statistical accuracy apply to fixed terrestrial surfaces only and may not be applied to areas of dense vegetation or steep terrain (See Appendix A).

In addition to the 48 fast static check points, Andregg Geomatics, Inc. also collected 31 blind checkpoints on hard surfaces with varying degrees of slope. Watershed Sciences was given the x and y coordinates of these points and calculated the z value from the LiDAR data. Andregg Geomatics was then given the LiDAR derived z for a comparison with the known z value. (**Table 5, Figure 2, Appendix B**)

6. Study Area Results

Summary statistics for point resolution and accuracy (relative and absolute) of the LiDAR data collected in the Lake Tahoe survey area are presented below in terms of central tendency, variation around the mean, and the spatial distribution of the data (for point resolution by tile).

6.1 Data Summary

Table 2. LiDAR Resolution and Accuracy - Specifications and Achieved Values

	Targeted	Achieved
Resolution:	≥ 8 points/m^2	11.82 points/m^2
Vertical Accuracy (1 σ):	<15 cm	3.5 cm

6.2 Data Density/Resolution

The average first-return density of delivered dataset is 11.82 points per square meter (Table 2). The initial dataset, acquired to be ≥8 points per square meter, was filtered as described previously to remove spurious or inaccurate points. Additionally, some types of surfaces (i.e., dense vegetation, breaks in terrain, water, steep slopes) may return fewer pulses (delivered density) than the laser originally emitted (native density).

Ground classifications were derived from automated ground surface modeling and manual, supervised classifications where it was determined that the automated model had failed. Ground return densities will be lower in areas of dense vegetation, water, or buildings. **Figures 5** and **6** show the distribution of average native and ground point densities for each 1/100th USGS quad tile.

Cumulative LiDAR data resolution for the Lake Tahoe AOI:

- Average Point (First Return) Density = 11.82 points/m^2
- Average Ground Point Density = 2.26 points/m^2

Figure 3. Density distribution for first return laser points

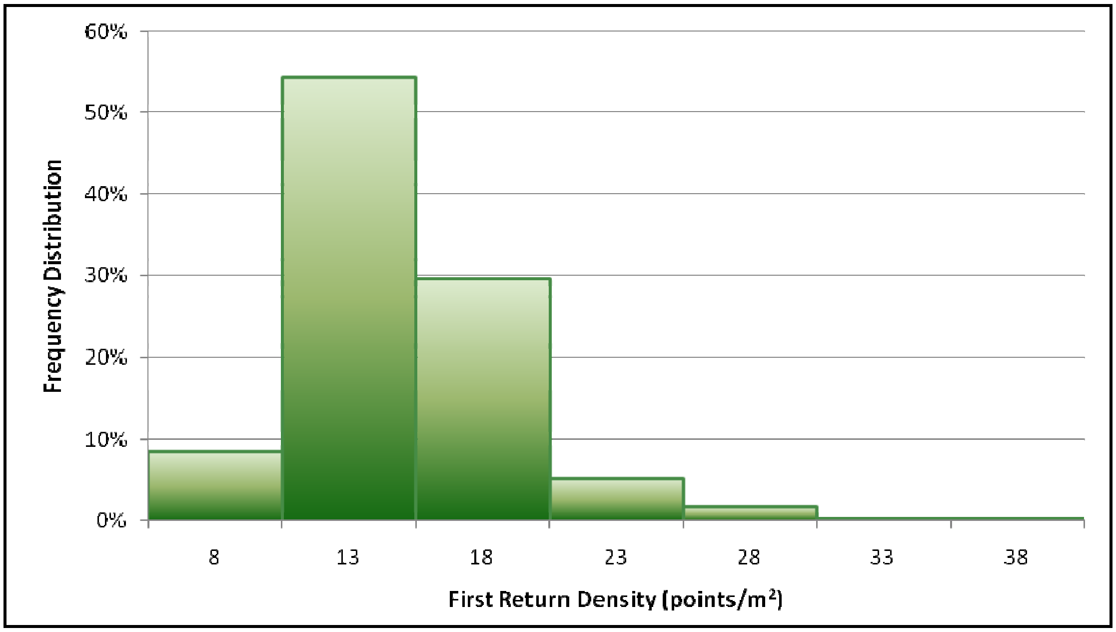


Figure 4. Density distribution for ground classified laser points

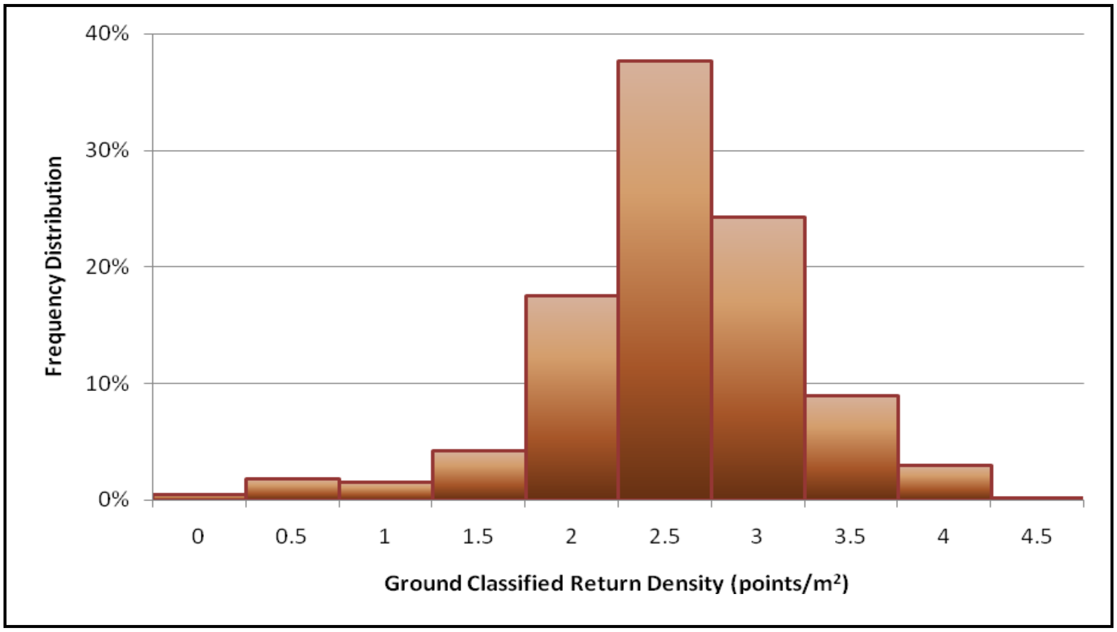


Figure 5. Density distribution map for first return points by 1/100th USGS Quad

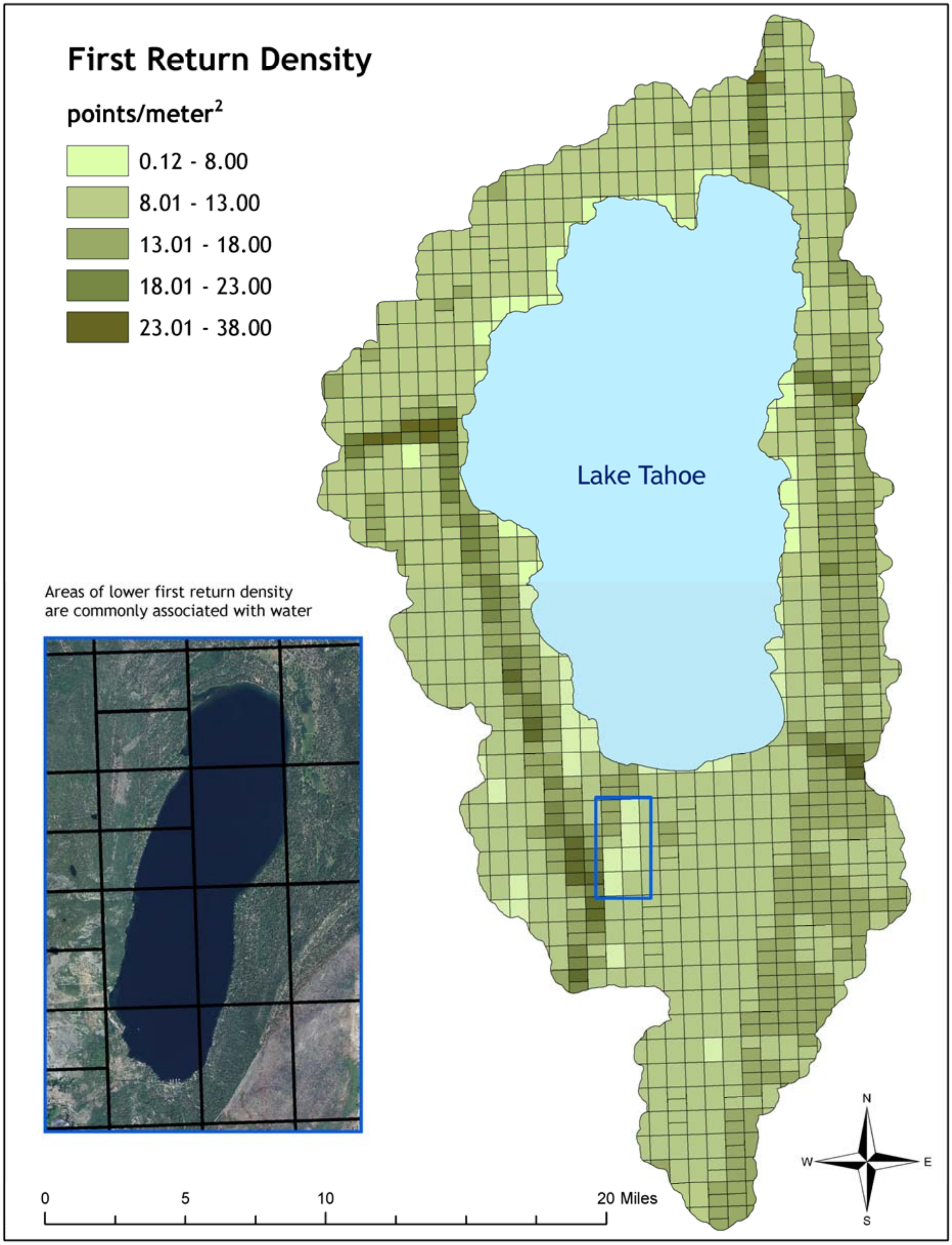
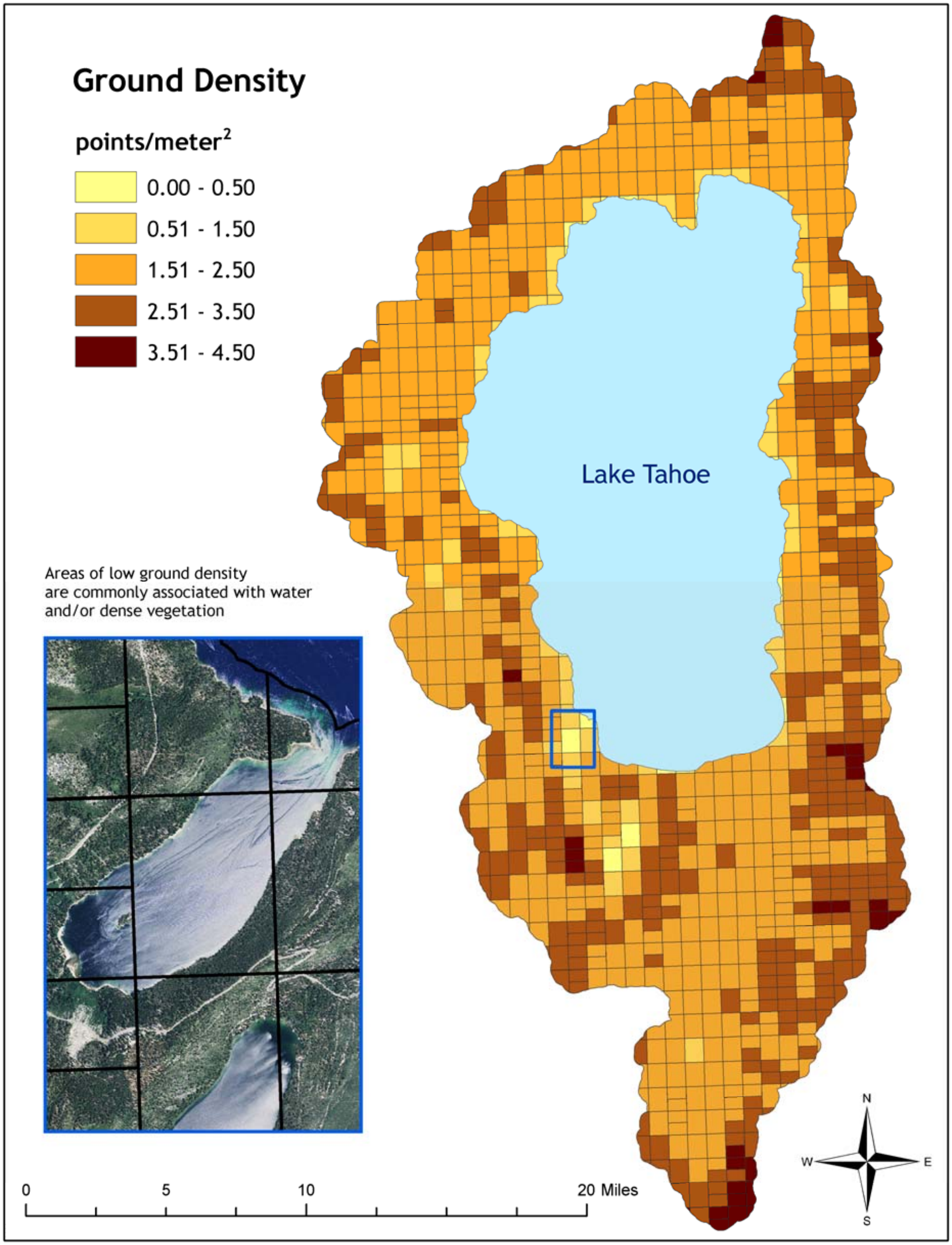


Figure 6. Density distribution map for ground return points by 1/100th USGS Quad

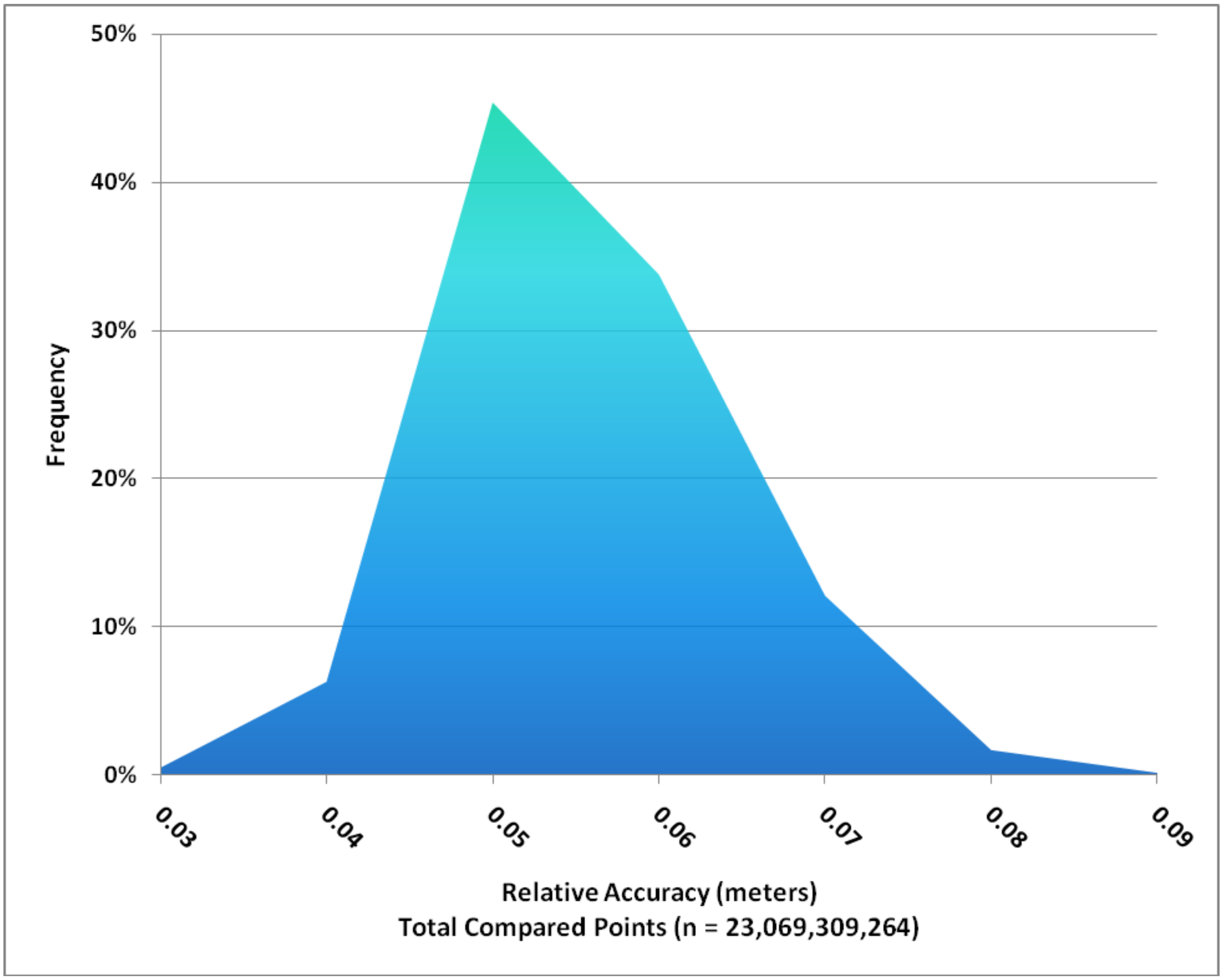


6.3 Relative Accuracy Calibration Results

Relative accuracy statistics for the Lake Tahoe dataset measure the full survey calibration including areas outside the delivered boundary:

- Project Average = 0.053 m
- Median Relative Accuracy = 0.050 m
- 1σ Relative Accuracy = 0.008 m
- 1.96σ Relative Accuracy = 0.016 m

Figure 7. Distribution of relative accuracies per flight line, non slope-adjusted



6.4 Absolute Accuracy

Absolute accuracies for the Lake Tahoe survey area:

Table 3. Watershed Sciences Absolute Accuracy – Deviation between laser points and RTK hard surface survey points

Watershed Sciences, Inc. Absolute Accuracy Assessment	
RTK Survey Sample Size (n): 1912	
Root Mean Square Error (RMSE) = 0.036 m	Minimum Δz = -0.113 m
Standard Deviations	Maximum Δz = 0.093 m
1 sigma (σ): 0.035 m 1.96 sigma (σ): 0.068 m	Average Δz = -0.008 m

Figure 8. Absolute Accuracy - Histogram Statistics

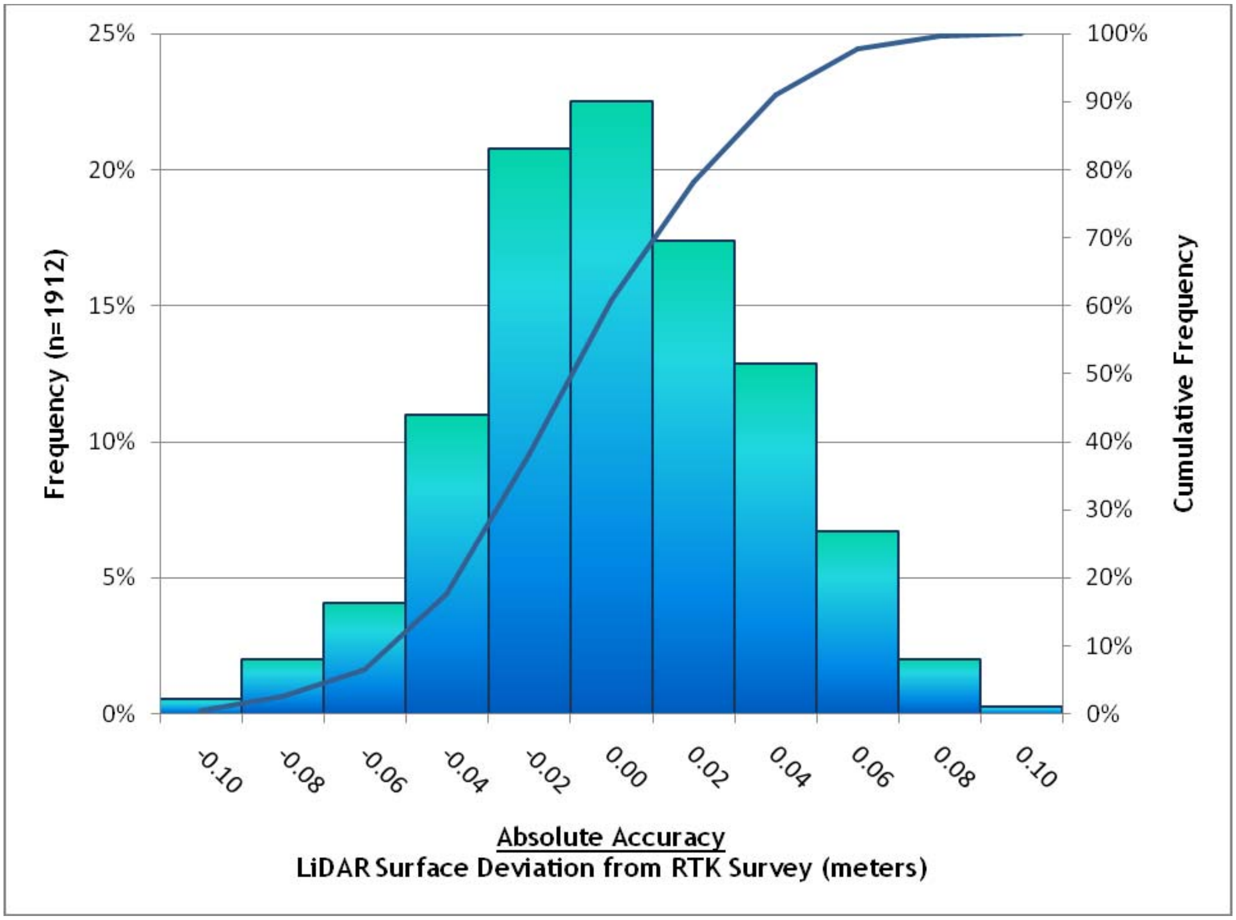


Table 4. Andregg Geomatics Absolute Accuracy – Deviation between laser points and RTK fast static check points

Andregg Geomatics, Inc. Independent Accuracy Assessment		
Sample Size (n): 48		
Root Mean Square Error (RMSE) = 0.057 m		Minimum Δz = -0.120 m
Standard Deviations		Maximum Δz = 0.130 m
1 sigma (σ): 0.057 m	1.96 sigma (σ): 0.111 m	Average Δz = -0.012 m

Figure 9. Absolute Accuracy - Histogram Statistics

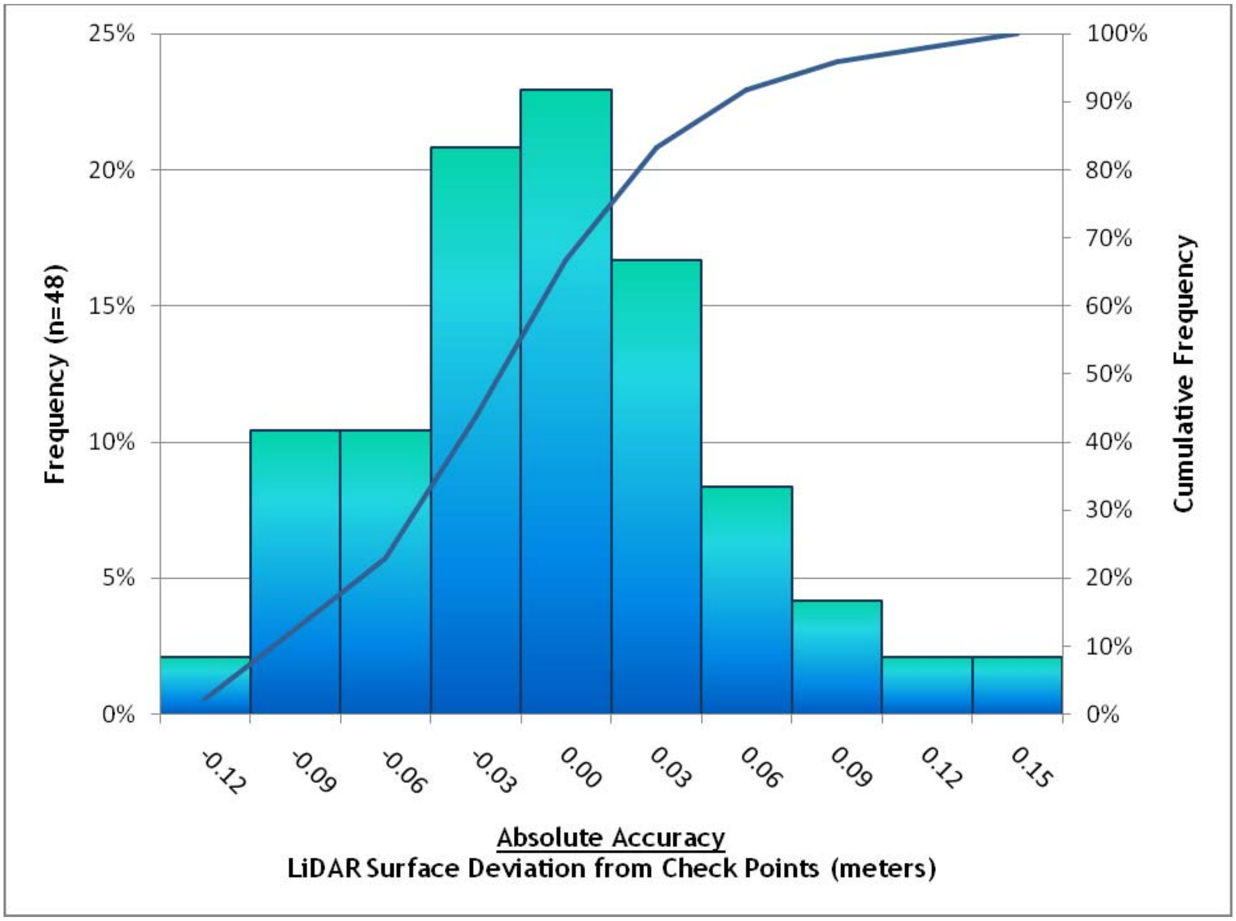


Table 5. Andregg Geomatic blind check point elevations compared with Watershed Science's LiDAR-derived elevations (see Appendix B)

Northing (m)	Easting (m)	Andregg Geomatics Elevation (m)	Watershed Sciences Elevation (m)	Elevation Difference (m)	Slope (degrees)
4341217.456	741910.542	1908.35	1908.36	-0.01	18.96
4329068.691	745496.960	2028.48	2028.45	0.03	15.77
4315106.077	752984.795	1970.29	1970.28	0.01	4.52
4309141.692	756112.695	2116.53	2116.53	0.00	23.84
4332411.342	767114.222	2149.18	2149.24	-0.06	4.62
4354971.457	765734.385	2616.27	2616.34	-0.07	8.84
4351669.767	763430.525	2184.00	2183.97	0.03	3.8
4348221.356	754169.466	1954.60	1954.64	-0.04	2.13
4342659.288	749549.896	2019.46	2019.58	-0.12	2.15
4339010.970	743763.546	1895.73	1895.73	0.00	5.39
4336956.483	745714.562	2003.25	2003.28	-0.03	4.12
4332737.575	742916.643	1940.29	1940.26	0.03	0.84
4313668.431	755726.440	1911.65	1911.67	-0.02	0.45
4312673.541	753986.546	1955.90	1955.92	-0.03	2.19
4312164.137	760706.880	1901.83	1901.93	-0.10	1.46
4303297.157	758153.229	1939.43	1939.51	-0.08	0.61
4298580.135	762147.591	2341.19	2341.40	-0.21	19.04
4318744.155	765371.059	1926.69	1926.81	-0.12	2.87
4318809.772	768236.427	2158.64	2158.64	0.00	19.52
4341933.718	768956.079	2520.95	2521.07	-0.12	1.91
4339417.893	768253.576	2433.43	2433.62	-0.19	16.61
4349090.236	761469.845	1955.78	1955.85	-0.07	27.46
4324714.073	749059.612	1901.46	1901.48	-0.02	0.29
4327019.010	746478.525	1965.80	1965.73	0.07	1.29
4328457.629	739899.058	2337.73	2337.70	0.03	8.49
4346275.471	746360.302	2403.99	2403.99	0.00	3.77
4343063.191	765324.516	1903.30	1903.33	-0.03	3.2
4304879.781	759109.667	1933.04	1933.12	-0.08	1.42
4324872.024	764540.643	1985.39	1985.58	-0.19	14.37
4347667.943	765171.283	1929.72	1929.68	0.04	2.66
4347617.901	754274.762	1902.06	1902.08	-0.02	1.21

100% of Points	RMSEz (m)	ACCURACYz (m) 1.96xRMSEz Spec=0.20m	Mean (m)	Std Dev (m)	# of Points	Min (m)	Max (m)
	0.08	0.16	0.01	0.01	31	0.0	0.04

7. Model Development

7.1 Hydro Flattened & Breakline Enforced Terrain Models

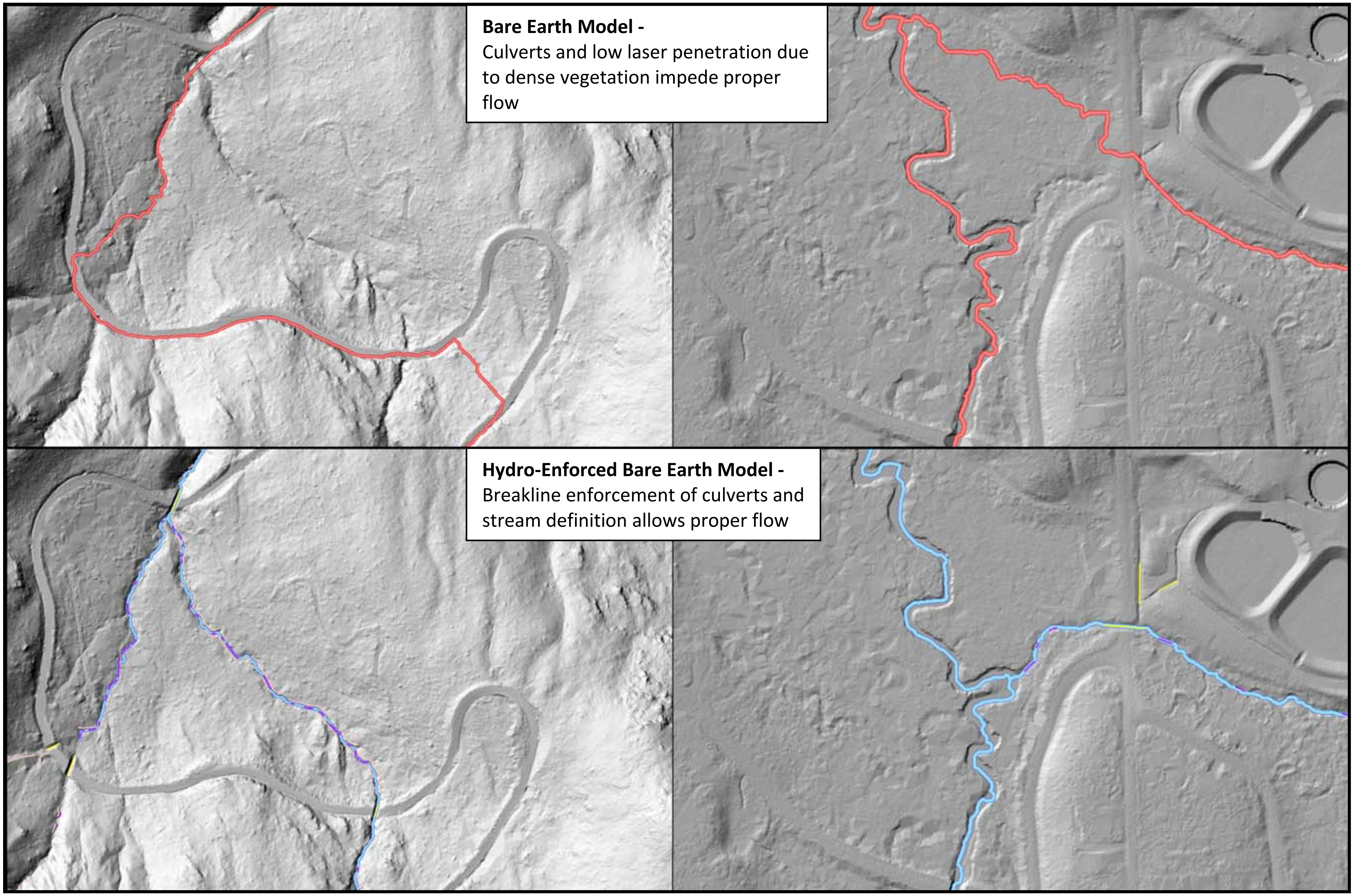
David C. Smith and Associates (DSA), Portland, OR created breaklines for the Lake Tahoe study area using LiDAR-grammetry. **Table 6** describes the type and definition of each breakline collected. The breaklines were used to supplement the LiDAR data in creation of a hydro-flattened and hydro-enforced ground model.

- Water boundaries were enforced using hard breaklines and water surfaces were flattened based on the elevation from the breaklines. The breakline boundaries were also used to reassign any ground classified points within the water delineated areas to a water class.
- Hard breaklines (lake edges, islands, etc.) were incorporated into the TIN by enforcing triangle edges (adjacent to the breakline) to the elevation values derived from the LiDAR-grammetric breakline. This implementation corrected interpolation along the hard edge.
- Culverts and artificial impediments to drainage flow were identified with hard breaklines. LiDAR data points within three meters of a culvert breakline were ignored from the ground classification, giving precedence to breakline Z values. This enforces proper drainage flow in development of the ground model.
- ArcHydro Tools 9 was run on resulting ground models as a quality inspection of stream definition. (**Figure 15**) In areas where stream definition deviated from bare earth ground model and breaklines, LiDAR data was reexamined to provide increased detail (adding or subtracting appropriate ground classified points).

Table 6. Breaklines collected for the Lake Tahoe study area.

Feature	Implementation	Description
Water_Lake	Hard Breakline	Lake Bodies
Water_Stream	Hard Breakline	Streams wider than ~3 meters
Water_Island	Hard Breakline	Islands
Hydro_Breakline	Hard Breakline	High Confidence breakline to enforce flow
Hydro_Connector	Hard Breakline	Low Confidence breakline to enforced flow
Culvert_Breakline	Hard Breakline	High Confidence breakline through culvert
Culvert Connector	Hard Breakline	Low Confidence breakline through culvert
Breakline	Hard Breakline	High Confidence breakline to supplement LiDAR data
Breakline_Obscured	Hard Breakline	Low confidence breakline to supplement LiDAR data

Figure 10. ArcHydro Tools 9 Stream Direction laid over LiDAR bare earth and hydro-enforced bare earth hillshaded models



Projection/Datum and Units

Projection:		UTM Zone 10, NAD 83
Datum	**Vertical:**	NAVD88 Geoid09
	Horizontal:	NAD83 (CORS 96)
Units:		meters

8. Deliverables

Point Data:	LAS 1.2 format • All Returns ASCII format • All Returns
Vector Data:	• Tile Index of LiDAR Points (1/100 USGS quad, shapefile format) • Tile Index of DEMs (1/4 USGS quad, shapefile format) • SBETs (shapefile format) • Ground points (ESRI file geodatabase format) • Lake Edge Boundaries (ESRI file geodatabase format) • Hydrologic Breaklines (ESRI file geodatabase format)
Raster Data:	• Elevation Models (0.5 m resolution) • Hydro-Flattened Bare Earth Model (IMG format) • Hydro-flattened/Hydro-Enforced Bare Earth Model (IMG format) • Highest Hit Model (IMG format) • Intensity Images (0.5 m resolution, IMG format)
Data Report:	• Full report containing introduction, methodology, and accuracy

9. Selected Images

Figure 11. 3D point cloud of Lake Tahoe Airport (colored by 2009 NAIP)

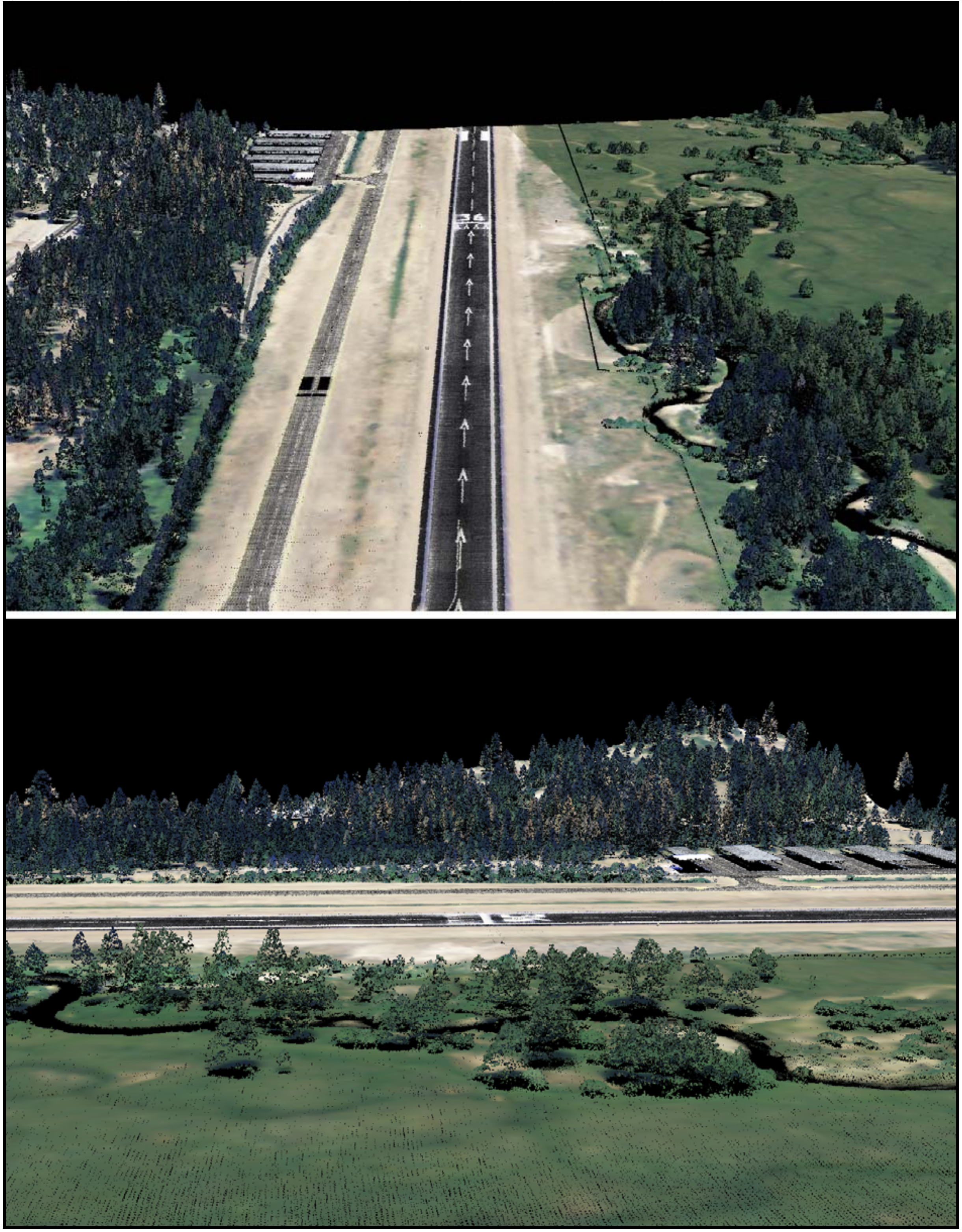


Figure 12. 3D LiDAR point cloud looking southwest from the marina at Tahoe Keys Resort (colored by 2009 NAIP)

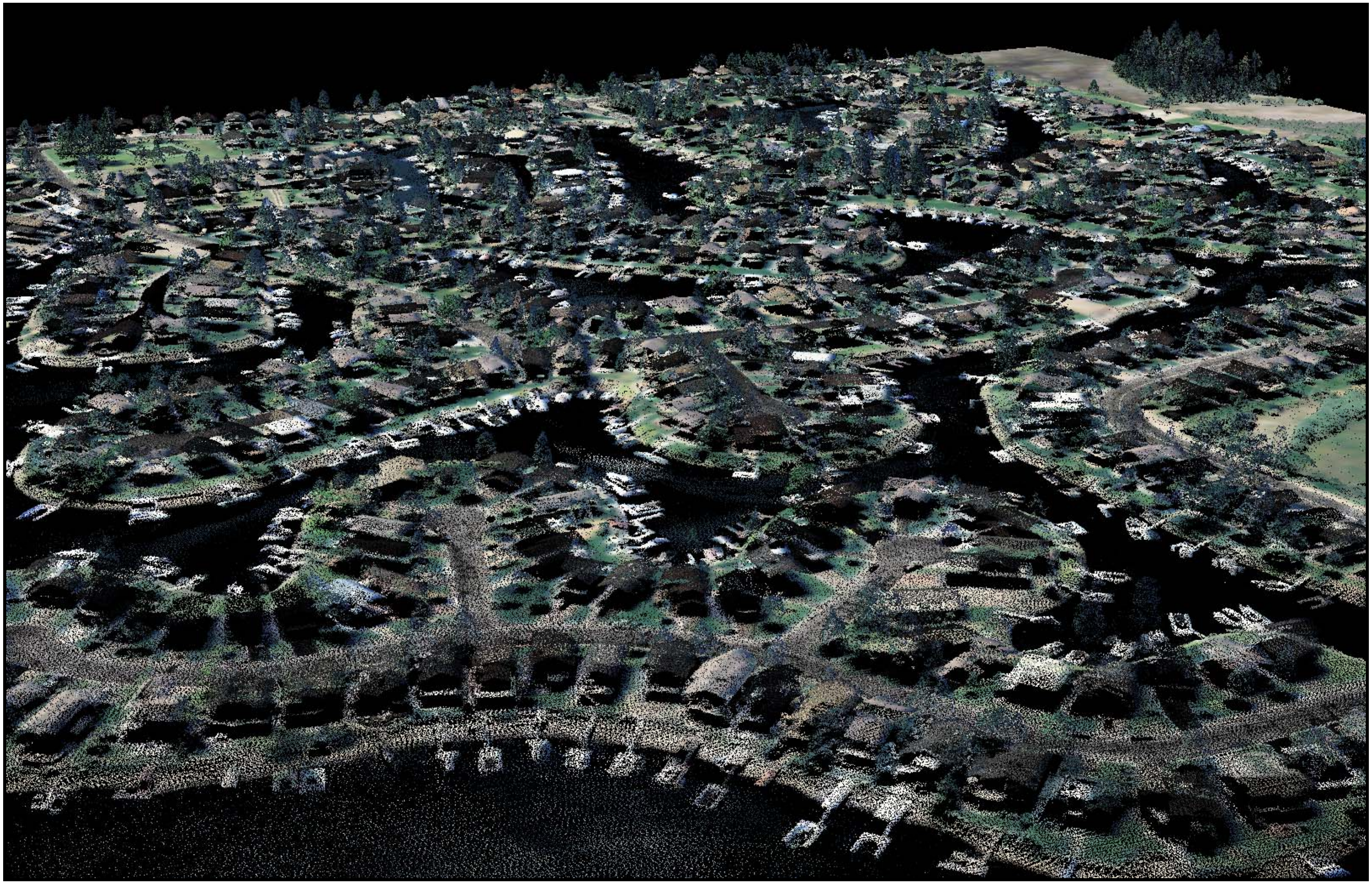


Figure 13. 3D LiDAR point cloud looking west over Lake Tahoe Dam (colored by 2009 NAIP)

Figure 14. 3D LiDAR point cloud, looking northwest across Crag Lake (colored by 2009 NAIP)

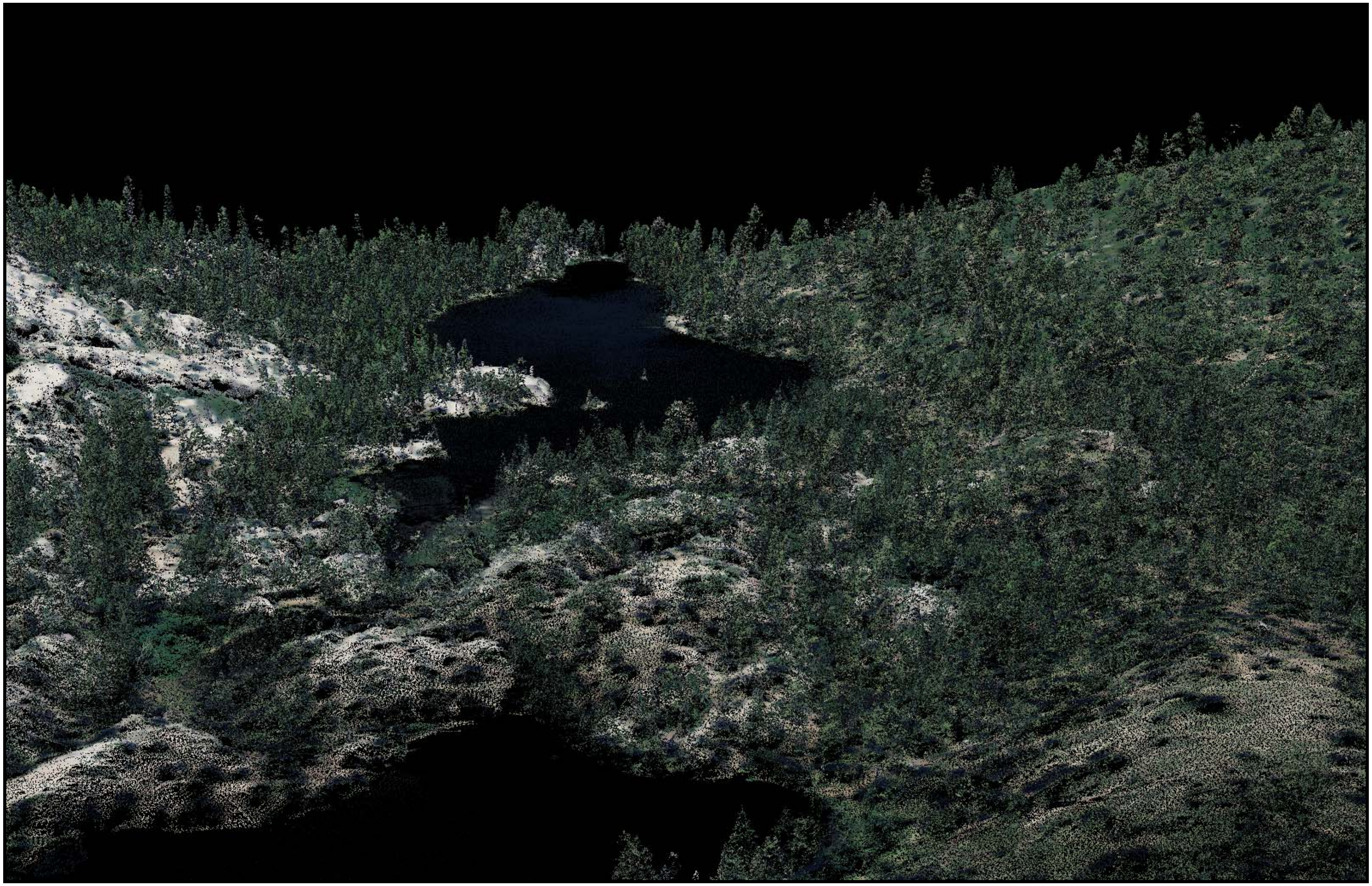


Figure 15. 3D LiDAR point cloud looking at Heavenly Ski Resort slopes (colored by 2009 NAIP)

Figure 16. 3D LiDAR point cloud looking northeast over the golf course at Lake Valley State Recreation Area (colored by 2009 NAIP)

10. Glossary

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

1.96-sigma (σ) Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set.

Root Mean Square Error (RMSE): A statistic used to approximate the difference between real-world points and the LiDAR points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured as thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the Leica ALS 50 Phase II system can record *up to four* wave forms reflected back to the sensor. Portions of the wave form that return earliest are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma, σ) and root mean square error (RMSE).

Intensity Values: The peak power ratio of the laser return to the emitted laser. It is a function of surface reflectivity.

Data Density: A common measure of LiDAR resolution, measured as points per square meter.

Spot Spacing: Also a measure of LiDAR resolution, measured as the average distance between laser points.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Overlap: The area shared between flight lines, typically measured in percents; 100% overlap is essential to ensure complete coverage and reduce laser shadows.

DTM / DEM: These often-interchanged terms refer to models made from laser points. The digital elevation model (DEM) refers to all surfaces, including bare ground and vegetation, while the digital terrain model (DTM) refers only to those points classified as ground.

Real-Time Kinematic (RTK) Survey: GPS surveying is conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

11. Citations

Soininen, A. 2004. TerraScan User's Guide. TerraSolid.

Appendix A

LiDAR accuracy error sources and solutions:

Type of Error	Source	Post Processing Solution
GPS (Static/Kinematic)	Long Base Lines	None
	Poor Satellite Constellation	None
	Poor Antenna Visibility	Reduce Visibility Mask
Relative Accuracy	Poor System Calibration	Recalibrate IMU and sensor offsets/settings
	Inaccurate System	None
Laser Noise	Poor Laser Timing	None
	Poor Laser Reception	None
	Poor Laser Power	None
	Irregular Laser Shape	None

Operational measures taken to improve relative accuracy:

1. Low Flight Altitude: Terrain following is employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (i.e., ~ 1/3000th AGL flight altitude).
2. Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return is a function of laser emission power, laser footprint, flight altitude and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased and low flight altitudes can be maintained.
3. Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of ±15° from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.
4. Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day. During all flight times, a dual frequency DGPS base station recording at 1-second epochs was utilized and a maximum baseline length between the aircraft and the control points was less than 19 km (11.5 miles) at all times.
5. Ground Survey: Ground survey point accuracy (i.e. <1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. Ground survey RTK points are distributed to the extent possible throughout multiple flight lines and across the survey area.
6. 50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the most nadir portion of one flight line coincides with the edge (least nadir) portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.
7. Opposing Flight Lines: All overlapping flight lines are opposing. Pitch, roll and heading errors are amplified by a factor of two relative to the adjacent flight line(s), making misalignments easier to detect and resolve.

Appendix B

Tahoe Regional Planning Agency
High-Resolution LiDAR Data for the Lake Tahoe Watershed

REPORT BY: Michael Farrauto, LSIT
Sr. PROJECT MANAGER: Mark J. Bardakjian, PLS

I. Project Background:

The Tahoe Regional Planning Agency (TRPA) in coordination with the US Geological Survey was interested in acquiring a terrestrial LiDAR dataset for the entire Lake Tahoe Watershed (~1,100km^2), California, Nevada, including a 1km buffer surrounding the watershed boundary. Post-processed LiDAR data will be used to derive thematic derivative products necessary for planning, monitoring and research.

II. Overview:

ANDREGG Geomatics conducted office and field work for this project to develop and certify a survey control network within the study region to be used in airborne LiDAR data acquisition and the collection/processing of ground check points (GCPs). These efforts were conducted between the months of June 2010 – January 2011 under contract with Watershed Sciences through the direction of Russell Faux.

Horizontal Datum:

The horizontal datum is based on the North American Datum of 1983 (NAD83) UTM Zone 10, Meters.

Vertical Datum:

The vertical datum is based on the North American Vertical Datum of 1988 (NAVD88), Meters and derived from Geoid09.

Task 1: Develop and Certify a Survey Control Network:

Network Design and Reconnaissance:
This task required initial research of all NGS published stations, county & local agencies benchmarks or other stations that could be incorporated into a Primary Control Network. This process involved searching the National Geodetic Survey's Database, contacting County Surveyors, and other local agencies for information of all stations within project.

Once the initial research was completed and flightlines were received from Watershed Sciences, a preliminary Primary Control Network of "ideal" locations was prepared in order to determine areas for reconnaissance. In discussions with Watershed Sciences, it was decided that in order to reach all project accuracy specifications these Primary Control Network stations would need to be located within 13 nautical miles (24km) of all flightlines.

As part of the reconnaissance effort, any stations that existed within the approximated "ideal" area it was then necessary to determine each station's condition and assess the station based on the criteria listed below. To encourage its future use and to perpetuate the network, the stations should be situated in easy access locations, preferably near highways and road systems. The actual site location for all stations must meet the following conditions in order to be incorporated into the network.
Ease of access by vehicle, personnel and equipment without disturbing property owners. The site must be safe to occupy by personnel, vehicles, and equipment.
Permanence and security of the site for protection and preservation of the monument. Preferably within public rights of way or improved areas.
GPS visibility, that the site is visible to the majority of GPS satellites.

As part of the reconnaissance, all stations were visited to confirm their existence and suitability to support the airborne LiDAR data acquisition requirements. Sketches of the stations were prepared with drive-to directions and photographs, (see Attachment 1). This reconnaissance was necessary in finalizing the Primary Control Network design.

After completion of the reconnaissance efforts, the Primary Network Design was finalized (see Attachment 2). The network included eight National Geodetic Surveys (NGS) published stations, three NGS CORS stations and five newly established stations.
NGS Published Stations:

Designation	PID
AP 1967 STA A	JR1334
ARP	JR0864
BROCKWAY	DH6447
D836	KS0133
HPGH D CA 03 FS	AE9848
EMERALD	DH6450
Q 208 RESET	AI3453
V 1201	KS0107

NGS CORS Stations:

CORS ID	PID

DOT1	DH8860
RNO1	DE6254
ZOLE	DE6252

New Stations:

Station Name
MEEKS
ROSE 1
ROSE 2
SPOONER
TAHOE CITY

GPS Observations and Data Collection

All receivers are owned and operated by ANDREGG GEOMATICS. The equipment used included 4 Trimble 4000SSi dual-frequency, full-wavelength GPS receivers with Compact L1/L2 geodetic-quality antennas with ground planes. Different makes and models of antennas have different phase patterns and if not accounted for could result in vertical discrepancies up to 10cm. A 2-meter fixed-height, force centered tripods were used to minimize station occupation errors. The fixed height tripods are checked and calibrated weekly. The equipment models, both receivers and antennas, have been tested and approved on the Federal Geodetic Control Subcommittee test network.

GPS observations of the Primary Control Network stations were conducted in accordance to the project specifications. Existing (published) stations were observed with a minimum of one session of at least two hours and newly established stations were observed with a minimum of two sessions of at least two hours. Three NGS CORS stations were incorporated in the post processing; all of these NGS CORS stations were located with 80 km of the Primary Control Network. Additional observation data of the Primary Network Control collected by Watershed Sciences were incorporated into the processing and adjustment, adding redundancy to the network.

Each baseline was observed at least twice on 2 different days at 2 different times of day. Satellite coverage and positional dilution of precision (PDOP) charts were reviewed to insure a difference in satellite geometry and atmospheric conditions between the multiple observations. All GPS measurements were made during periods with PDOP less than or equal to 3.0 and with at least six common satellites. Observation log sheets were created at each station setup and occupation. The log sheets contain station names, PID (if applicable), session number, operator name, Julian date, date & time (local and UTC), monument description and receiver/antenna make and model information. Each station setup included a pre- and post-observation checklist to insure proper antenna height, magnetic north orientation, tripod plumb and eccentricity.

Data Processing

Trimble's GPSurvey software (Version 2.35a) was used in reviewing, analyzing and processing of the GPS data. GPSurvey was used for baseline vector processing of the data to optimal double differenced fixed integer ionosphere free solutions for all observed vectors. Station and vector solutions were reviewed to insure station naming and occupations were consistent. Redundant vectors were reviewed for consistency and discrepancies and analyzed for errors and blunders.

Minimally Constrained Network Adjustment:

A minimally constrained least squares adjustment was performed to determine the integrity of the baseline observations. For this adjustment only one NGS CORS station was constrained to its published NAD83 (CORS96) geodetic latitude, longitude and ellipsoid height. All statistics were evaluated at the 95% confidence level.

The final network consisted of 154 accepted GPS vectors between 16 stations. The observational standard error of each vector component was used as the initial, or a priori, weighting of the vector observation. The average a priori standard errors for each vector component were 0.02009 seconds of arc for azimuth, 0.01397 meters for ellipsoid height difference, and 0.00256 meters for distance.

The standard error of unit weight (Reference Variance Factor) for the minimally constrained network was determined at 1.00 by applying a priori station weighting and scaling of the observational standard errors with 492 degrees of freedom. Using an a priori error scalar of 5.92 for adjusted weighting of the GPS observational errors and a station occupation error of 0.01 ft in both antenna height and centering the Chi Square statistical test passed indicating good agreement between a priori error weighting estimation and the a posteriori adjusted values. The average standard error, at 95% confidence, was 0.0042 m (0.013 ft) in latitude, 0.0036 m (0.011 ft) in longitude and 0.0141 m (0.043 ft) in ellipsoid height. The average precision on all possible lines was 0.391 PPM. These statistics indicate the network observations are of high quality and the network integrity is very strong. With the network fitting well within itself, indicating no blunders or other unreasonable errors, a final fully constrained adjustment was undertaken, (see Attachment 3).

Fully Constrained Network Adjustment:

The final fully constrained least squares adjustment consisted of constraining to the NGS NAD83 (CORS96) published horizontal of 3 NGS CORS Stations. In addition, 1 NAVD88 First Order Vertical Control station (V 1201) was constrained to its published orthometric height (elevations) and with 6 other Height Modernization and NGS CORS Stations. The orthometric values for these six were computed from the published high order ellipsoid height and applying the Geoid separation. All observations were adjusted in the network by least squares to fit these constraints.

Before proceeding with the horizontal and vertical adjustment, however, another set of observations, i.e. geoid heights, were introduced into the network. The geoid height is the difference between the orthometric height (elevation) and ellipsoid height (mathematical surface) and is a non-linear relationship. These modeled estimated values for separation obtained from Geoid09 typically have standard errors larger than those of GPS observations. Using the standard error as the initial *a priori* weighting in the observation network adjustment the Geoid09 correlated separation values will be subjected to the least squares adjustment for best fit. Using the published high order values as constraints for ellipsoid heights and values of separation for the published stations, all of the orthometric heights for the stations in the network were adjusted to fit. Therefore the adjusted Geoid09 modeled estimated geoid heights, constrained to the higher order values for ellipsoid and separation values, were subjected to a least squares adjustment in order to derive the best value for orthometric heights of the stations that were not constrained.

In an iterative manner, beginning with the minimally constrained adjustment, individual station constraints were added to the network adjustment. Following each adjustment, the adjusted values for horizontal and vertical positions were compared to their published values. If those values agreed within 0.05m then they were held as constraints in the next adjustment. And so on, until all available constraints had been considered and those that fell within the acceptable range were used. Using the same station weighting and an a priori error scalar of 7.19 the fully constrained Network Reference Variance Factor (Standard Error of Unit Weight) was found to be 1.00 with the Chi Square test passing. The fully constrained average standard error in horizontal position, at the 95% confidence level, for both latitude and longitude in the fully constrained adjustment were 0.0492m (0.015 ft) and 0.0427m (0.013 ft) respectively. The fully constrained average standard error, again at 95% confidence, for the ellipsoid height and orthometric height was 0.157m (0.048 ft) and 0.174m (0.053 ft) respectively. The average precision over all possible baselines was 0.067 PPM. The average adjusted geoid height for the network was –78.315 meters, (see Attachment 4).

Adjustment Conclusion:

The procedures, methodology and techniques implemented through the acquisition and processing of the data, introducing reasonable error weighting and a logical progression of the least squares adjustment process, along with the statistical results of the minimally and fully constrained adjustments all lead to the conclusion that the data collected is sound, the errors are reasonable, small and random, the weighting schemes are judicious, the constraints are good within their own published positional standard errors and the resultant values for horizontal and vertical positions of the new unconstrained stations are precise and accurate for the intended purposes. With these indications of precision and accuracy there is a high expectation that the actual directly observed measurements and resulting positional and height values should fall within the project specifications.

The final fully constrained adjustment results, in both US Survey feet and meters, geodetic positions with ellipsoid and orthometric heights along with their associated standard errors and NAD83 (CORS96) UTM Zone 10, grid coordinates in meters are shown in Attachment 5.

Task 2: Collection and Processing of Ground Check Points (GCPs):

The intent of the GCPs survey was to provide a minimum of 50 LiDAR Calibration points to Watershed Resources to use to register and calibrate the LiDAR data sets to bare earth and a minimum of 30 ‘blind’ points for an internal vertical accuracy assessment. The horizontal values for the ‘blind’ points would be sent to Watershed Sciences and the LiDAR elevation values would be returned and compared to the actual surveyed vertical value as an internal quality control check. Elevation residuals of the ‘blind’ points would be reviewed and analyzed to determine if there were any problems to correct or adjustments to be made to the LiDAR data sets.

Initial locations for the GCPs were provided to Watershed Sciences for review of their geographic location in comparison to the proposed acquisition flight lines, (see Attachment 6). The locations of the GCPs were evenly distributed throughout the limits of airborne LiDAR data acquisition to obtain a wide area assessment of the LiDAR dataset and to obtain internal checks of data in the different terrain types. The 'blind' points were also positioned outside of the vicinity of the LiDAR calibration points to avoid any bias. Using available imagery and local knowledge of the project area, GCP locations were approximated. Both the LiDAR calibration and 'blind' points were field adjusted to conform to the required terrain types and to accommodate any rights of entry issues. Public outreach efforts were conducted to gain access to private property in remote areas where the point could not be established within public access. Continual communications between office and field personal assisted in proper placement of all GCPs and overall work flow progress. Each location was selected on flat or uniformly sloping terrain within 5 meters in all directions and marked by a survey marker set flush with surface. A lath was set at each location with a station ID number written on it. Photographs were taken at all locations to verify the terrain type. All field materials were collected and processed weekly to insure that all the data was being collected and recorded in compliance with specifications.

Standard GPS data collection methods were followed for all GCPs. These procedures and methodologies included the use of Fast Static techniques and incorporation of Primary Control Network stations that had recently been adjusted to final network values. This was accomplished using a 3-person crew with dual frequency geodetic GPS receivers together with geodetic antenna with ground planes. To eliminate instrument height errors, 2 meter fixed height, force center antenna tripods were used. The field survey data collection was designed and coordinated so that there were always 2 known base stations occupied while 3 roving receivers occupied the desired GCPs. Vector observations were designed so that nearest adjacent stations were directly observed promoting the use of short baselines and to obtain ionospheric free solutions tying into previously established control stations. All data collection was at least 20 minutes with 5 satellites. 5 Trimble 4000 SSI dual frequency GPS receivers were used for the GPS observations.

Post Processing

Using the above mentioned procedures and methodology for post processing of the GCPs; it was anticipated that final coordinates and elevations of all of the GCPs would achieve acceptable accuracies and precision. The final GCPs survey consisted of 1101 accepted GPS vectors between 92 stations, including 845 redundant observations.

'Blind' GCP Internal Vertical Accuracy Assessment:

A spreadsheet containing the 'Blind GCP's X and Y values were provided to Watershed Sciences. The spreadsheet was returned with the elevation data of each 'blind' GCPs based on the LiDAR dataset, (see Attachment 7). The following tables summarize the statistical and residual results of the 'blind' GCP surveys compared to the LiDAR data point readings.

Vertical Accuracy Analysis:

100% of Points	RMSEz (m)	ACCURACYz (m) 1.96xRMSEz Spec=0.20m	Mean (m)	Std Dev (m)	# of Points	Min (m)	Max (m)
	0.08	0.16	0.01	0.01	31	0.0	0.04

The Fundamental Vertical Accuracy$_z$ (FVA) at the 95% confidence level is equal to 1.96 times the RMSE$_z$. The FVA was calculated for the all 'blind' GCPs and was below the project specification of 0.20m at 0.16m. Any systematic errors or problems with the LiDAR sensor would be exposed if this specification was not met.

It is with confidence that the adjustment values resulting from this effort meet project specifications. I therefore certify that this work was done correctly and professionally by me or under my direct supervision.

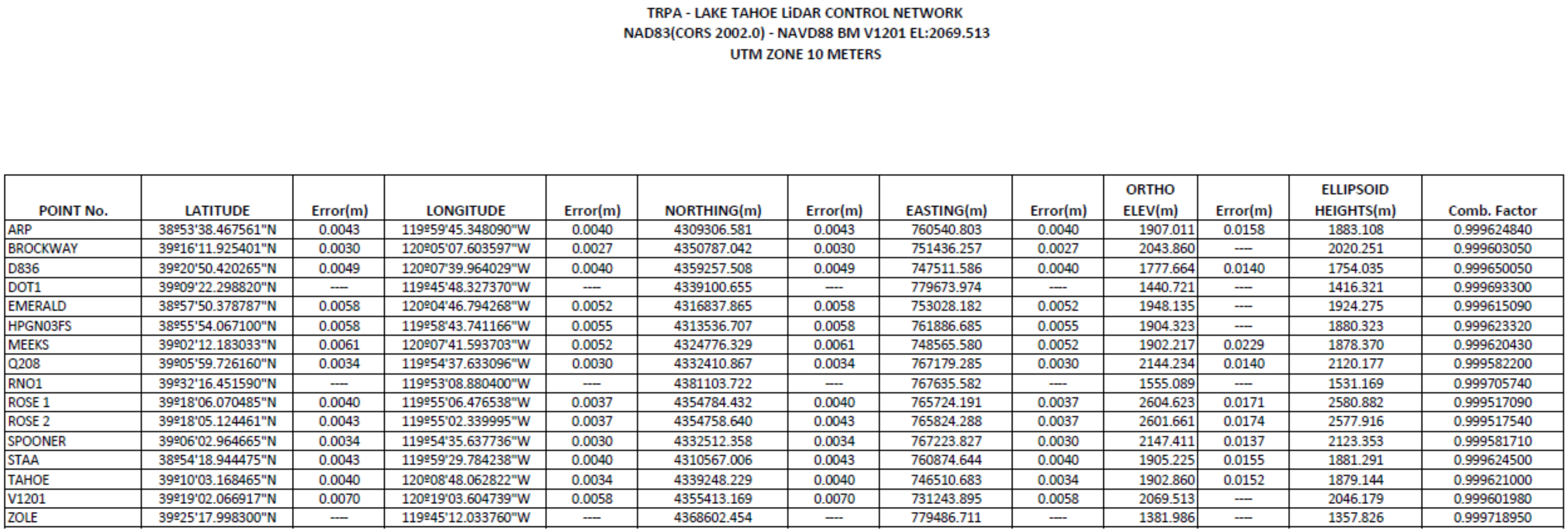
Respectfully Submitted;
ANDREGG GEOMATICS

Mark J. Bardakjian PLS 4567
Principal, Chief Operations Officer

PROFESSIONAL LAND SURVEYOR
MARK JAMES BARDAKJIAN
LS 4567
EXPIRES SEPT 30, 2011
STATE OF CALIFORNIA

Appendix C

Andregg Geomatics’ Certification of Control Network:



TRPA - LAKE TAHOE LiDAR CONTROL NETWORK
NAD83(CORS 2002.0) - NAVD88 BM V1201 EL:2069.513
UTM ZONE 10 METERS

POINT No.	LATITUDE	Error(m)	LONGITUDE	Error(m)	NORTHING(m)	Error(m)	EASTING(m)	Error(m)	ORTHO ELEV(m)	Error(m)	ELLIPSOID HEIGHTS(m)	Comb. Factor
ARP	38º53'38.467561"N	0.0043	119º59'45.348090"W	0.0040	4309306.581	0.0043	760540.803	0.0040	1907.011	0.0158	1883.108	0.999624840
BROCKWAY	39º16'11.925401"N	0.0030	120º05'07.603597"W	0.0027	4350787.042	0.0030	751436.257	0.0027	2043.860	----	2020.251	0.999603050
D836	39º20'50.420265"N	0.0049	120º07'39.964029"W	0.0040	4359257.508	0.0049	747511.586	0.0040	1777.664	0.0140	1754.035	0.999650050
DOT1	39º09'22.298820"N	----	119º45'48.327370"W	----	4339100.655	----	779673.974	----	1440.721	----	1416.321	0.999693300
EMERALD	38º57'50.378787"N	0.0058	120º04'46.794268"W	0.0052	4316837.865	0.0058	753028.182	0.0052	1948.135	----	1924.275	0.999615090
HPGN03FS	38º55'54.067100"N	0.0058	119º58'43.741166"W	0.0055	4313536.707	0.0058	761886.685	0.0055	1904.323	----	1880.323	0.999623320
MEEKS	39º02'12.183033"N	0.0061	120º07'41.593703"W	0.0052	4324776.329	0.0061	748565.580	0.0052	1902.217	0.0229	1878.370	0.999620430
Q208	39º05'59.726160"N	0.0034	119º54'37.633096"W	0.0030	4332410.867	0.0034	767179.285	0.0030	2144.234	0.0140	2120.177	0.999582200
RNO1	39º32'16.451590"N	----	119º53'08.880400"W	----	4381103.722	----	767635.582	----	1555.089	----	1531.169	0.999705740
ROSE 1	39º18'06.070485"N	0.0040	119º55'06.476538"W	0.0037	4354784.432	0.0040	765724.191	0.0037	2604.623	0.0171	2580.882	0.999517090
ROSE 2	39º18'05.124461"N	0.0043	119º55'02.339995"W	0.0037	4354758.640	0.0043	765824.288	0.0037	2601.661	0.0174	2577.916	0.999517540
SPOONER	39º06'02.964665"N	0.0034	119º54'35.637736"W	0.0030	4332512.358	0.0034	767223.827	0.0030	2147.411	0.0137	2123.353	0.999581710
STAA	38º54'18.944475"N	0.0043	119º59'29.784238"W	0.0040	4310567.006	0.0043	760874.644	0.0040	1905.225	0.0155	1881.291	0.999624500
TAHOE	39º10'03.168465"N	0.0040	120º08'48.062822"W	0.0034	4339248.229	0.0040	746510.683	0.0034	1902.860	0.0152	1879.144	0.999621000
V1201	39º19'02.066917"N	0.0070	120º19'03.604739"W	0.0058	4355413.169	0.0070	731243.895	0.0058	2069.513	----	2046.179	0.999601980
ZOLE	39º25'17.998300"N	----	119º45'12.033760"W	----	4368602.454	----	779486.711	----	1381.986	----	1357.826	0.999718950