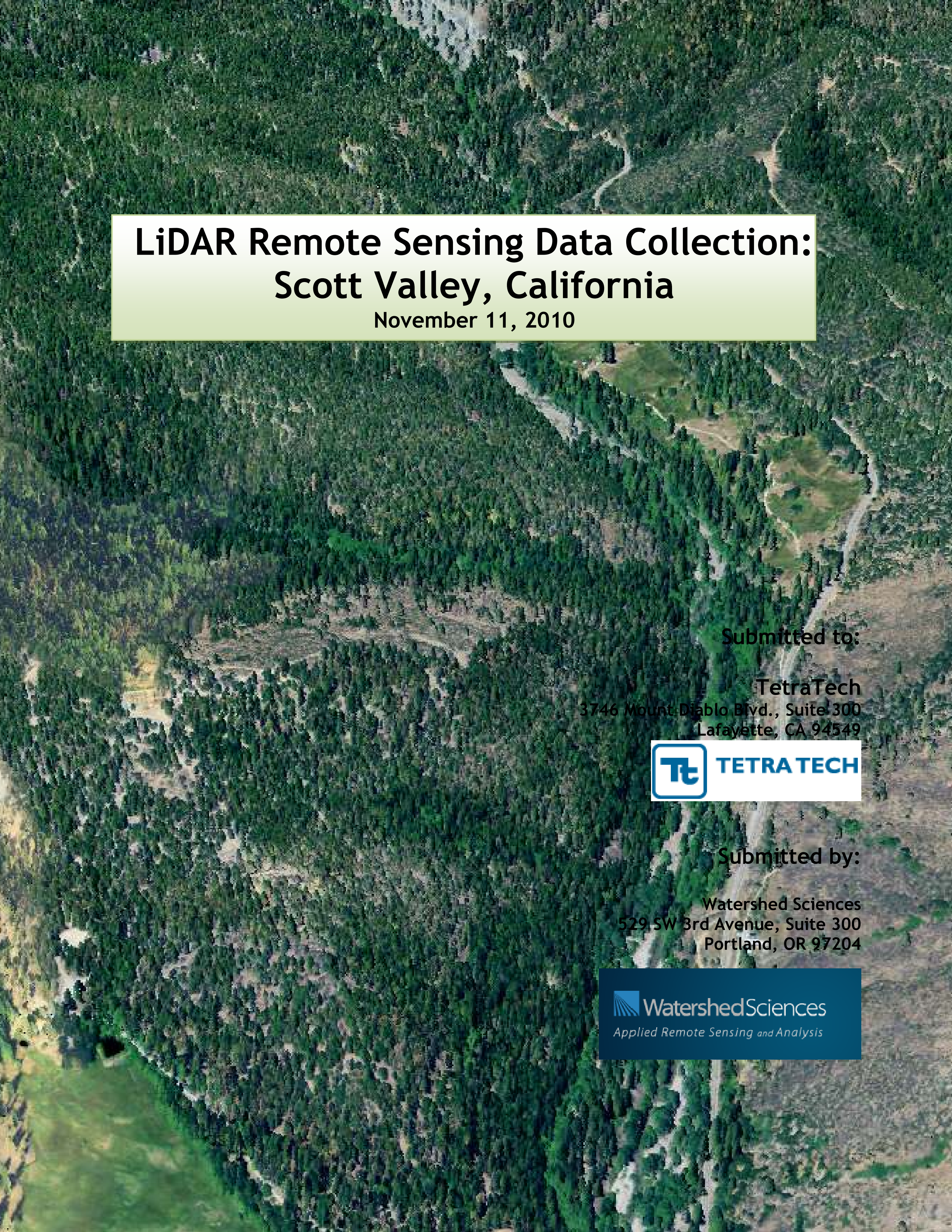

LiDAR Remote Sensing Data Collection: Scott Valley, California

November 11, 2010

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Applied Remote Sensing and Analysis

LIDAR REMOTE SENSING DATA:

SCOTT VALLEY, CALIFORNIA

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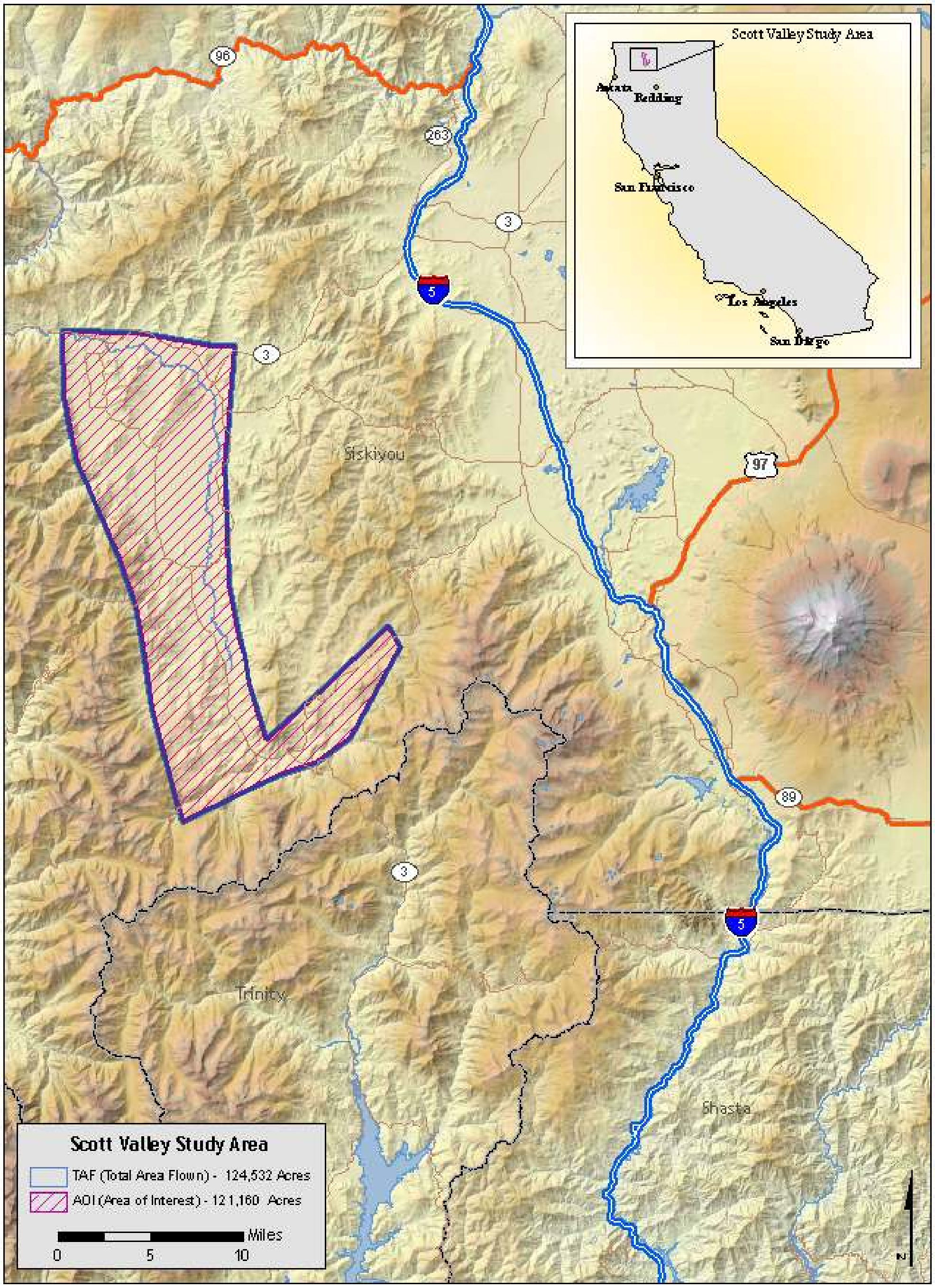
WatershedSciences

1. Overview

1.1 Study Area

Watershed Sciences, Inc. collected Light Detection and Ranging data (LiDAR) of the Scott Valleystudyarea for TetraTech. The requested LiDARArea of Interest (AOI)totals approximately121,160 acres, and was buffered to ensure data coverage, resulting in a Total Area Flown (TAF) of 124,532acres.This report reflects statisticsfor the overall LiDAR survey.

Figure1.1.*Scott Valley study area, displayed over a 30-meter DEM.*



1.2Accuracy and Resolution

Real-time kinematic (RTK) surveys were conducted in the study area for quality assurance purposes. The accuracy of the LiDAR data is described as standard deviations of divergence (sigma ~ σ) from RTK ground survey points and root mean square error (RMSE) which considers bias (upward or downward). The Scott Valley data have the following accuracy statistics:

RMSE	1-sigma absolute deviation	2-sigma absolute deviation
0.03meter	0.03meter	0.07meter

Data resolution specifications are for ≥8 pulses per square meter. Total average and groundpulse densitystatisticsScott Valleyare as follows:

Total Pulse Density	Ground Pulse Density
8.18 pulses per square meter	1.78 pulses per square meter

1.3 Data Format, Projection, and Units

Scott Valley data are delivered in UTM Zone 10; NAD83(CORS96); NAVD88(Geoid 03);Units: meters.

Deliverables include:

- All return point data in *.las v 1.2 format
- Ground return point data in *.las v 1.2 format
- Shapefile of delivery area in 750m x 750 m tile delineations
- Data Report summarizing data acquisition, processing, and summary statistics.
- SBET in ASCII text format
- SBET in ESRI shapefile format

2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized a Leica ALS60 sensor mounted in Cessna Caravan 208B. The Leica systemset to acquire ≥105,000 laser pulses per second (i.e.,105 kHz pulse rate) and flown at 900 meters above ground level (AGL), capturing a scan angle of ±14° from nadir[1] (see **Table 2.1**). These settings are developed to yield points with an average native pulse density of ≥8 points per square meter over terrestrial surfaces. Some types of surfaces (i.e., dense vegetation) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and vary according to distributions of terrain, land cover, and water bodies.

The Cessna Caravan is a powerful and stable platform, ideal for the mountainous terrain of the Pacific Northwest. The Leica ALS50 Phase IIsensor head installed in the Caravan is shown on the right.

The areaof interest was surveyed with opposing flight line side-lap of ≥50% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per pulse, and all discernable laser returns were processed for the output dataset.To solve for laser point position, an accurate description of aircraft position and attitude is vital. Aircraft position is described as x, y, and z and 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).

Table 2.1 *LiDAR Survey Specifications.*

Sensor	Leica ALS60
Survey Altitude (AGL)	900 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	28° (±14° from nadir)
Roll Compensated	Up to 20°
Overlap	100% (50% Side-lap)

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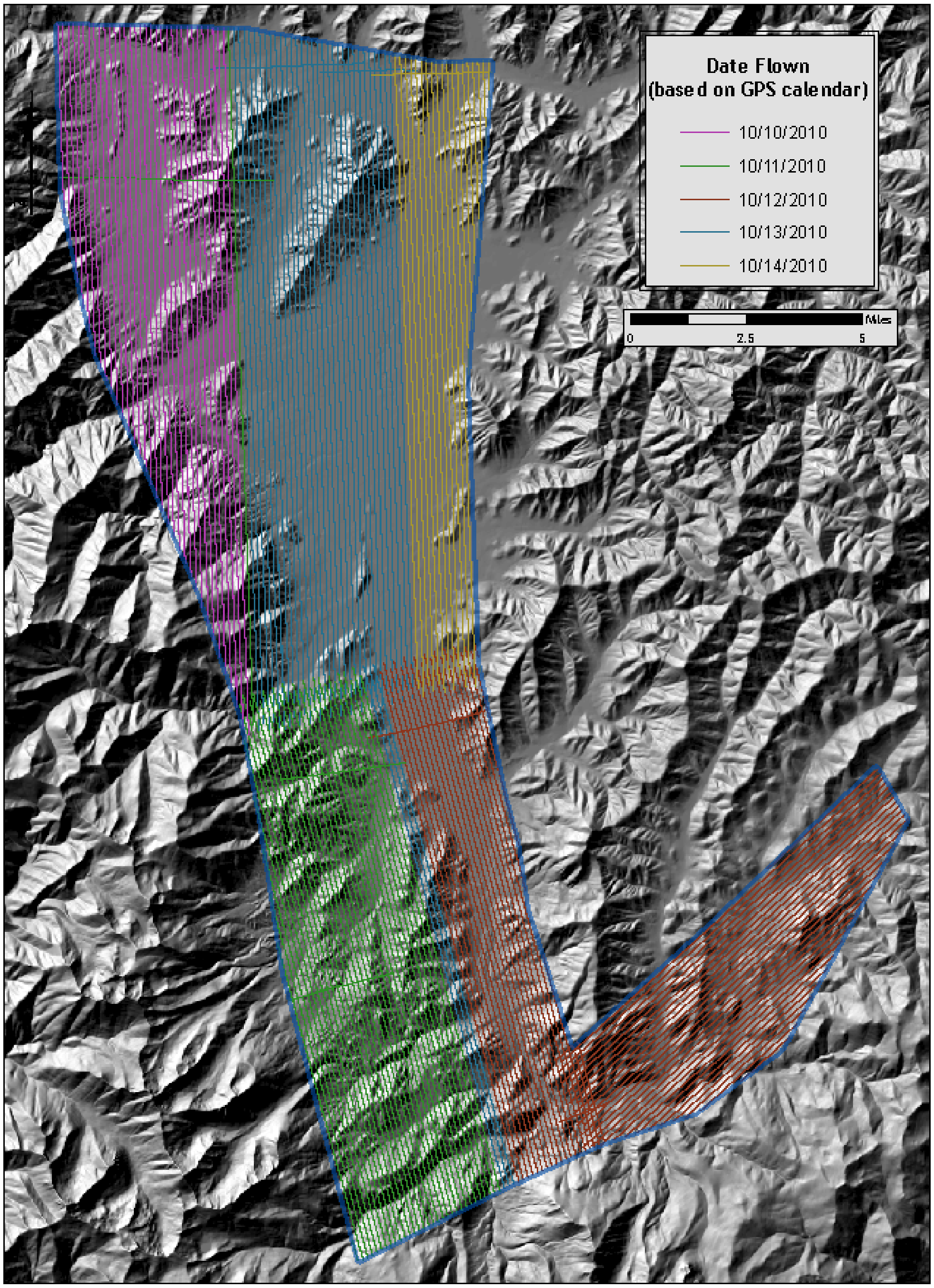
[1] Nadir refers to a vector perpendicular to the ground directly below the aircraft. Nadir is commonly used to measure the angle from the vector and is referred to as "degrees from nadir".

2.2LiDAR Acquisition

LiDAR data were collected for the Scott Valleystudy area on October 10 through October 14, 2010.Flightlinesare illustrated in the figurebelow.

***Figure 2.1**.Flightlines displayed over a 30-meter DEMwithin the study area.*



2.3 Ground Survey – Instrumentation and Methods

During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over either known or set monuments. Monument coordinates are provided in **Table 2.2** and shown in **Figure 2.2** for the AOI. After the airborne survey, the static GPS data are processed using triangulation with continuous operation stations (CORS) and checked using the Online Positioning User Service (OPUS[2]) to quantify daily variance. Multiple sessions are processed over the same monument to confirm antenna height measurements and reported position accuracy.

***Table 2.2**. Base Station Surveyed Coordinates, (NAD83/NAVD88, OPUS corrected) used for kinematic post-processing of the aircraft GPS data for the Scott Valley study area.*

	Datum NAD83(HARN)		GRS80
Base Station ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
SV1	41 27 26.33813	122 51 54.26012	831.819
SV2	41 23 49.93368	122 50 13.33400	847.313
NGS 0207 (MX1300)	41 27 45.51590	122 53 48.65864	868.898
NGS 02 PF(DF5239)	41 18 47.87460	122 45 11.58325	988.807

2.3.1 Instrumentation

For the Scott Valley study area, all Global Navigation Satellite System (GNSS[3]) survey work uses a Trimble GPS receiver model R7 with a Zephyr Geodetic antenna with ground plane for static control points. The Trimble GPS R8 GNSS unit is used primarily for Real Time Kinematic (RTK) work but when needed, it can be used as a static receiver as well. 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 1.5cm horizontal and 2cm vertical. All GPS measurements are made with dual frequency L1-L2 receivers with carrier-phase correction.

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

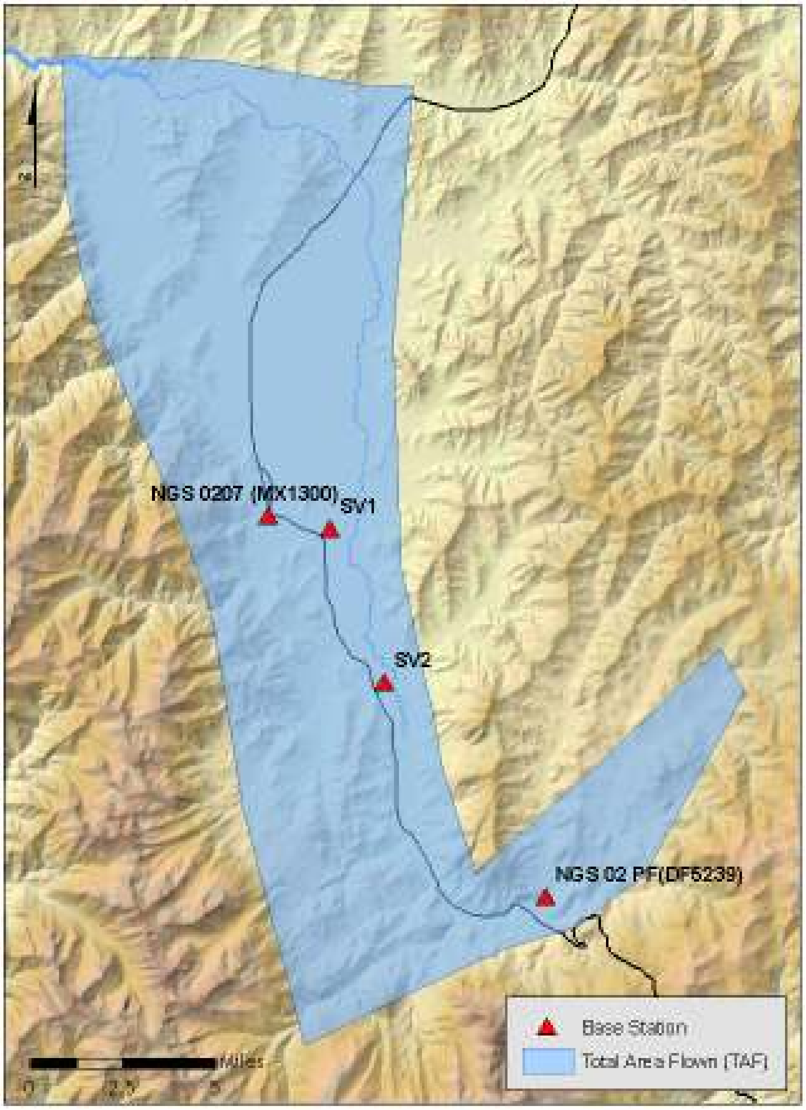
[3] GNSS: Global Navigation Satellite System consisting of the U.S. GPS constellation and Soviet GLONASS constellation

2.3.2 Monumentation

Whenever possible, existing and established survey benchmarks serve as control points during LiDAR acquisition including those previously set by Watershed Sciences.For this project, Watershed Sciences utilized the survey benchmarks 'NGS PID[4] # MX1300 and DF5239',which were set as part of Caltrans High Precision Geodetic Network densification projectsin 1991 and 1998 respectively. NGS benchmarks are preferred for control points. In the absence of NGS benchmarks or Caltrans monumentation, Watershed Sciences produces our own monuments. These monuments are spaced to allow the best coverage for the AOI and every effort is made to keep these monuments within the public right of way.

All monumentation is done with 5/8" x 24" or 30" rebar topped with a2" diameter aluminum cap stamped with "WATERSHED SCIENCES, INC."

Figure 2.2. *GPS base station locations in the Scott Valley study area, displayed overa30-meter DEM.*



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[4] NGS PID = National Geodetic Survey Permanent Identifier assigned to point when placed in the database.

2.3.3 Methodology

Each aircraft is assigned a ground crew member with two R7 receivers and an R8 receiver. The ground crew vehicles are equipped with standard field survey supplies and equipment including safety materials. All data points 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 are collected at a rate of 1Hz using a 10 degree mask on the antenna.

The ground crew uploads the GPS data 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[5] Part 2 table 2.1 at the 95% confidence level. When a statistical stable position is found CORPSCON[6] 6.0.1 software is used to convert the UTM positions to geodetic positions. This geodetic position is used for processing the LiDAR data.

RTK and aircraft mounted GPS measurements are made during periods with PDOP[7] 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. RTK positions are collected on 20% of the flight lines and 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 are taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. In addition, it is desirable to include locations that can be readily identified and occupied during subsequent field visits in support of other quality control procedures.Examples of identifiable locations include manhole covers and other flat utility structures that have clearly indicated center points. In the absence of utility structures, a PK nail is driven into asphalt or concrete and marked with paint.

Multiple differential GPS units are used in the ground based real-time kinematic (RTK) portion of the survey. To collect accurate ground surveyed points, a GPS base unit is set up over monuments to broadcast a kinematic correction to a roving GPS unit. The ground crew uses a roving unit to receive radio-relayed kinematic corrected positions from the base unit. This RTK survey allows precise location measurements ($\sigma \leq 1.5$ cm).

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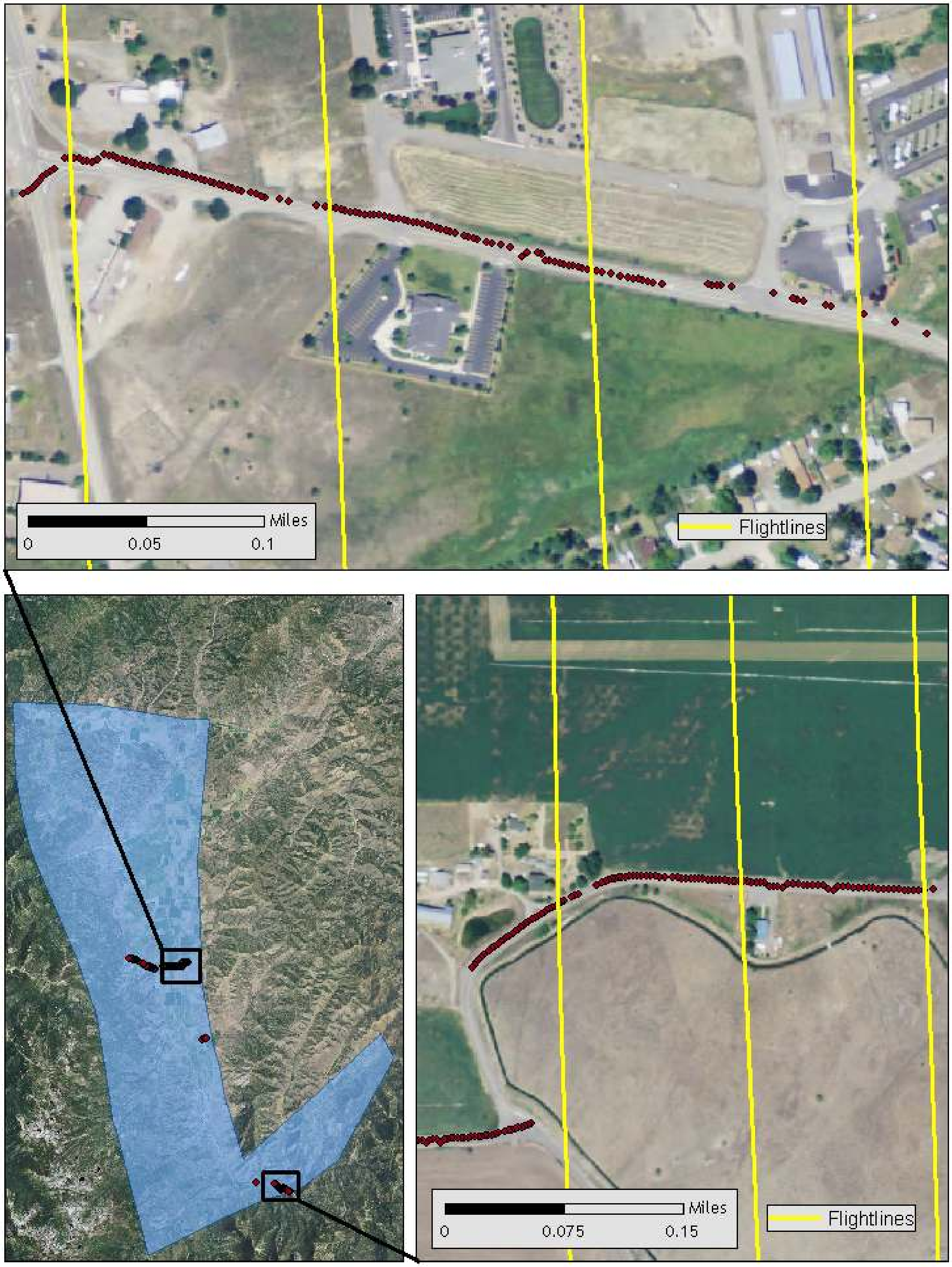
[5] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards

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

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

Figure 2.3*. Sample selection of RTK point locationsin the study area, displayed over an aerial image.*



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 GraphNav v.8.20, Trimble Geomatics Office v.1.63
2. Developed a smoothed best estimate of trajectory (SBET) file blending 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 Pro v.1.35
3. Calculated laser point position by associating the 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.
   Software: ALS Post Processing Software v.2.70
4. Imported raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filtered 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 for 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.10.004
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. Data were then converted to orthometric elevations (NAVD88) by applying a Geoid03 correction. Ground models were created as a triangulated surface and exported as ArcInfo ASCII grids.
   Software: TerraScan v.10.009, TerraModeler v.10.006

3.2 Aircraft Kinematic GPS and IMU Data

LiDAR survey datasets were referenced to 1 Hz static ground GPS data collected over a pre-surveyed monument with known coordinates. While surveying, the aircraft collected 2 Hz kinematic GPS data and the inertial measurement unit (IMU) collected 200 Hz attitude data. Waypoint GraphNav v.8.20 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 Pro v.1.35 was used to develop a trajectory file including 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 containing 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, and z) coordinate along with unique intensity values (0-255). The data were output into large LAS v. 1.2 files; each point maintaining the corresponding scan angle, return number (echo), intensity, and x, y, and z (easting, northing, and elevation) information.

Flightlines and LiDAR data were then reviewed to ensure complete coverage of the study area and positional accuracy of the laser points.

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

The LiDAR points were then filtered for noise, pits and birds by screening for absolute elevation limits, isolated points and height above ground. The data were then inspected for pits and birds manually, and spurious points were removed. For a .las file containing approximately 7.5-9.0 million points, an average of 50-100 points were typically found to be artificially low or high. These spurious non-terrestrial laser points must be removed from the dataset. Common sources of non-terrestrial returns are clouds, birds, vapor, and haze.

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

The TerraScan software suite is designed specifically for classifying near-ground points (Soininen, 2004). The processing sequence begins by ‘removing’ all points that are not ‘near’ the earth based on geometric constraints used to evaluate multi-return points. The resulting bare earth (ground) model is visually inspected and additional ground point modeling is performed in site-specific areas (over a 50-meter radius) to improve ground detail. This is only done in areas with known ground modeling deficiencies, such as: bedrock outcrops, cliffs, deeply incised stream banks, and dense vegetation. In some cases, ground point classification includes known vegetation (i.e., understory, low/dense shrubs, etc.) and these points are manually reclassified as non-grounds. Ground surface rasters are developed from triangulated irregular networks (TINs) of ground points.

4. LiDAR Accuracy and Resolution

4.1 Laser Point Accuracy

Laser point absolute accuracy is largely a function of internal consistency (measured as relative accuracy) and laser noise:

- **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 mission is approximately 0.02 meters.
- **Relative Accuracy**: Internal consistency refers to the ability to place a laser point in the same location over multiple flight lines, GPS conditions, and aircraft attitudes.
- **Absolute Accuracy**: RTK GPS measurements taken in the study areas compared to LiDAR point data.

Statements of statistical accuracy apply to fixed terrestrial surfaces only, not to free-flowing or standing water surfaces, moving automobiles, et cetera.

Table 4.1*. LiDAR accuracy is a combination of several sources of error. These sources of error are cumulative. Some error sources that are biased and act in a patterned displacement can be resolved in post processing.*

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

4.1.1 Relative Accuracy

Relative accuracy refers to the internal consistency of the data set and 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). Internal consistency is affected by system attitude offsets (pitch, roll and heading), mirror flex (scale), and GPS/IMU drift.

Operational measures taken to improve relative accuracy:

1. Low Flight Altitude: Terrain following was targeted at a flight altitude of 900 meters above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground; lower flight altitudes decrease laser noise on all surfaces.
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 maintained.
3. Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of ±14^o from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.
4. Quality GPS: Acquisitionoccurredduring optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). 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 point was less than 24 km (13 nautical miles).
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 less than 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution.
6. 50% Side-Lap (100% Overlap): Overlapping areas were optimized for relative accuracy testing. Laser shadowing was 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.

Relative Accuracy Calibration Methodology

1. Manual System Calibration: Calibration procedures for each mission require solving geometric relationships relating 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 and reported for the study 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 mirror scale were solved for each individual mission. Attitude misalignment offsets (and mirror scale) occurs for each individual mission. 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 utilized to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

4.1.2 Relative Accuracy Calibration Results

Relative accuracy statistics are based on the comparison of 185flightlines and over 3 billion points. **Figures 4.1**and **4.2**show the distribution and the statistical analyses.

- Project Average = 0.03 meters
- Median Relative Accuracy = 0.03 meters
- 1σ Relative Accuracy = 0.04 meters
- 2σ Relative Accuracy = 0.04 meters

Figure 4.1. *Distribution of relative accuracies, non-slope adjusted.*

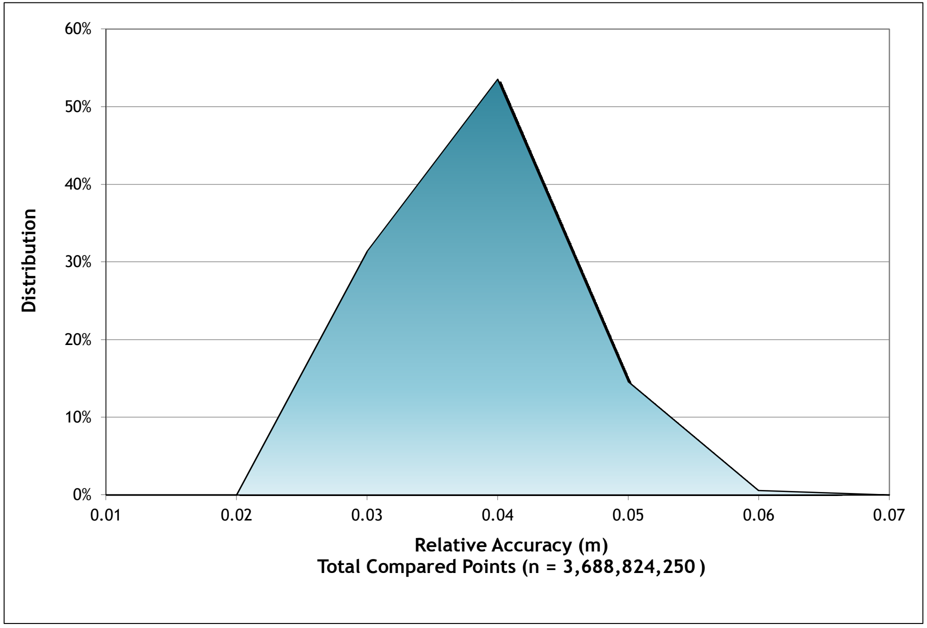
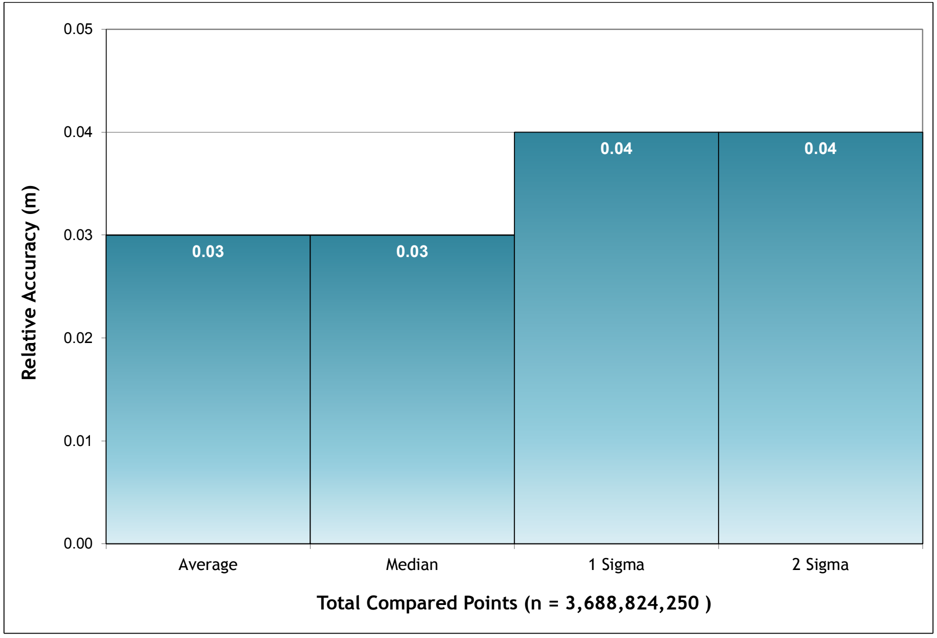


Figure 4.2. *Statistical relative accuracies, nonslope-adjusted.*



4.1.3 Absolute Accuracy

Absolute accuracy compares known Real Time Kinematic (RTK) ground survey points to the closest laser point. For the Scott Valley study area, Watershed Sciences collected 860 RTK points. Absolute accuracy is reported in **Table 4.2** and **Figures 4.3**and **4.4,** below.

Table 4.2. *Absolute accuracy:deviation between laser points and RTK survey points.*

Sample Size (n): 860	
Root Mean Square Error (RMSE): 0.03m	
Standard Deviations	**Deviations**
1 sigma (σ): 0.03 m	**Minimum Δz:** -0.17 m
2 sigma (σ): 0.07 m	**Maximum Δz:** 0.09m
	Average Δz: 0.02 m

Figure 4.3. *Histogram statistics.*

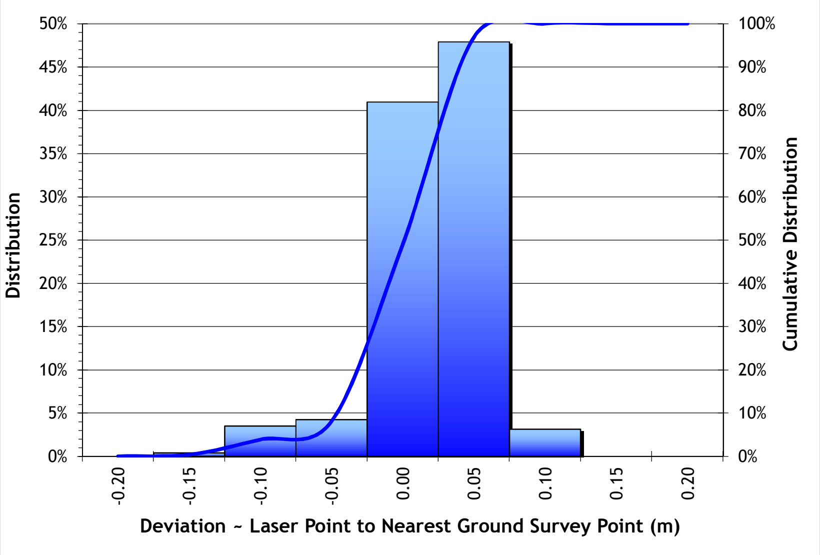
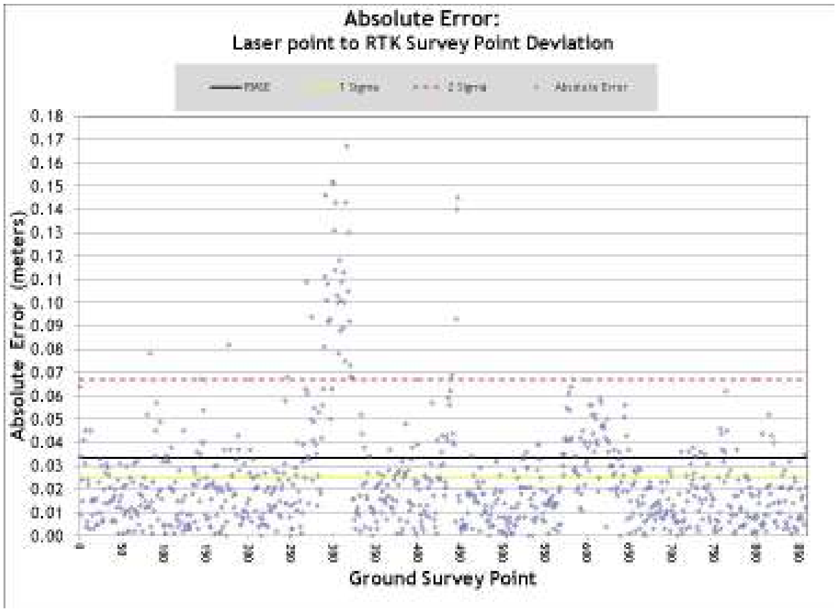


Figure 4.4. *Point absolute deviation statistics.*



4.2 Data Density/Resolution

Some types of surfaces (i.e., dense vegetation or water) may return fewer pulses than originally emitted by the laser. Delivered density may therefore be less than the native density and vary according to distributions of terrain, land cover, and vegetation. Density histograms and maps(**Figures 4.5-4.10**) have been calculated based on first return laser point density and ground-classified laser point density.

Table 4.3. *Average densities.*

Average Pulse Density (per square m)	Average Ground Density (per square m)
8.18	**1.78**

4.2.1 First Return Data Density

Figure 4.5. *Histogram of first return laser point density for data Scott Valley study area.*

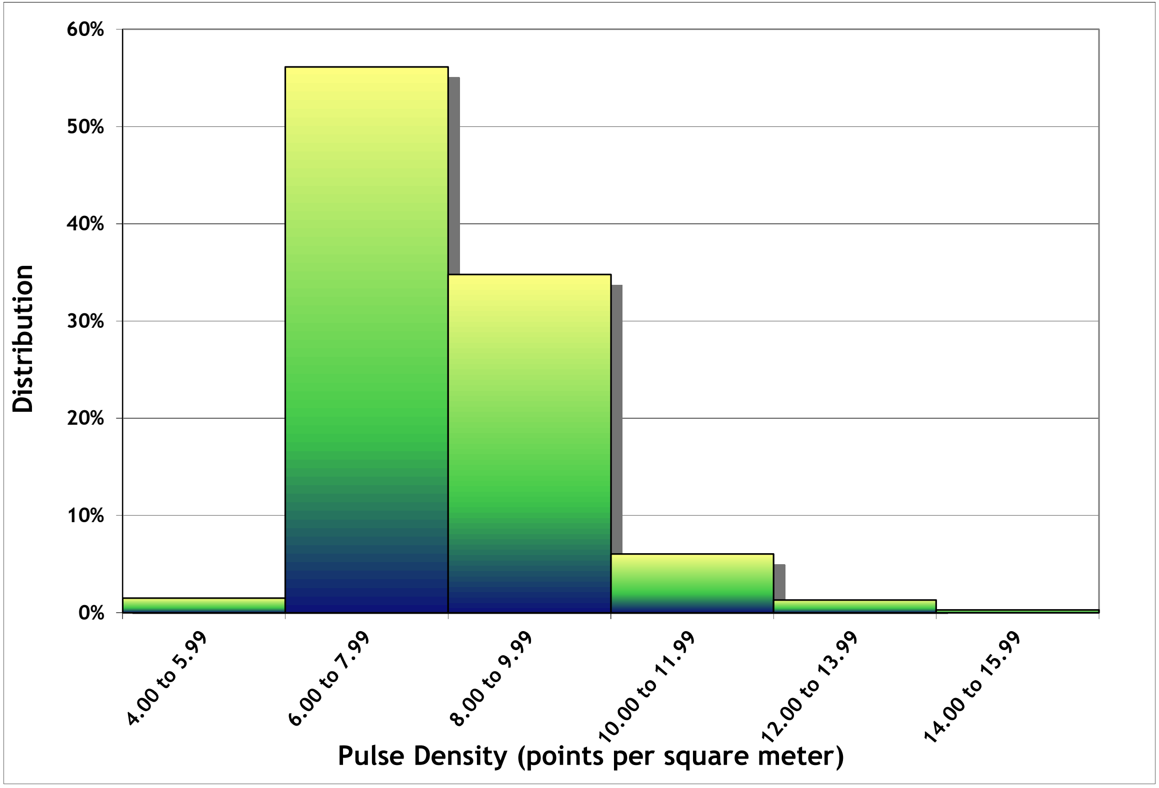


***Figure 4.6**. First return laser point data density for Scott Valley study area.*

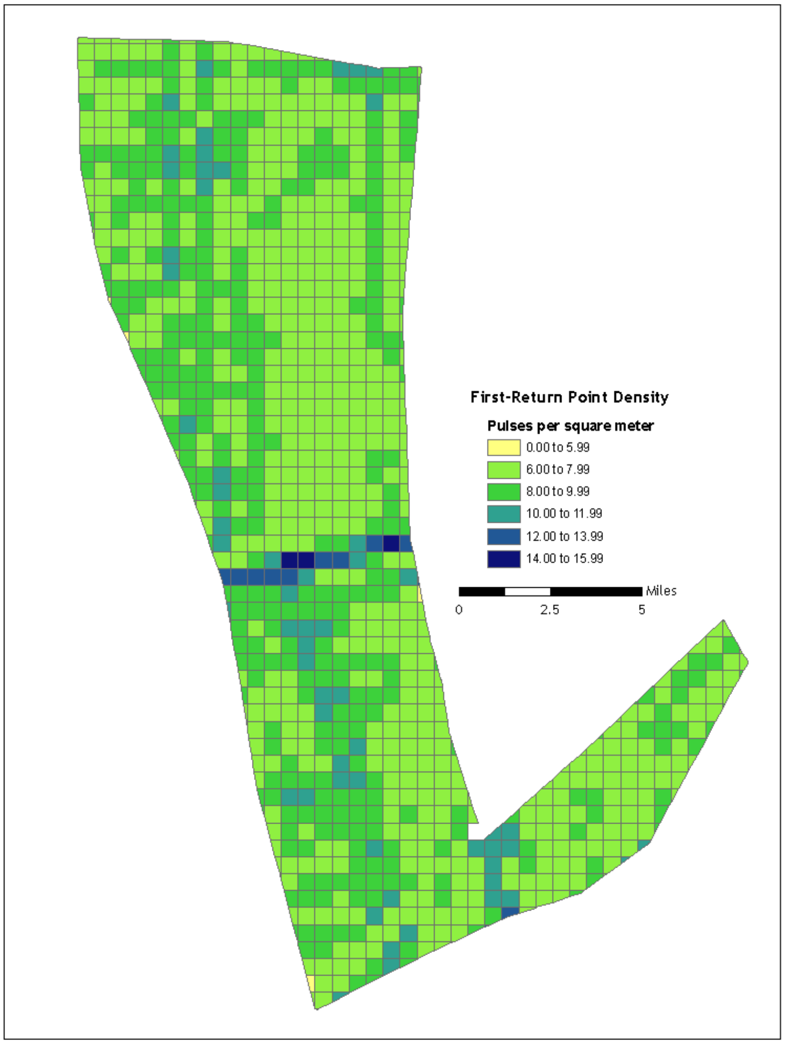
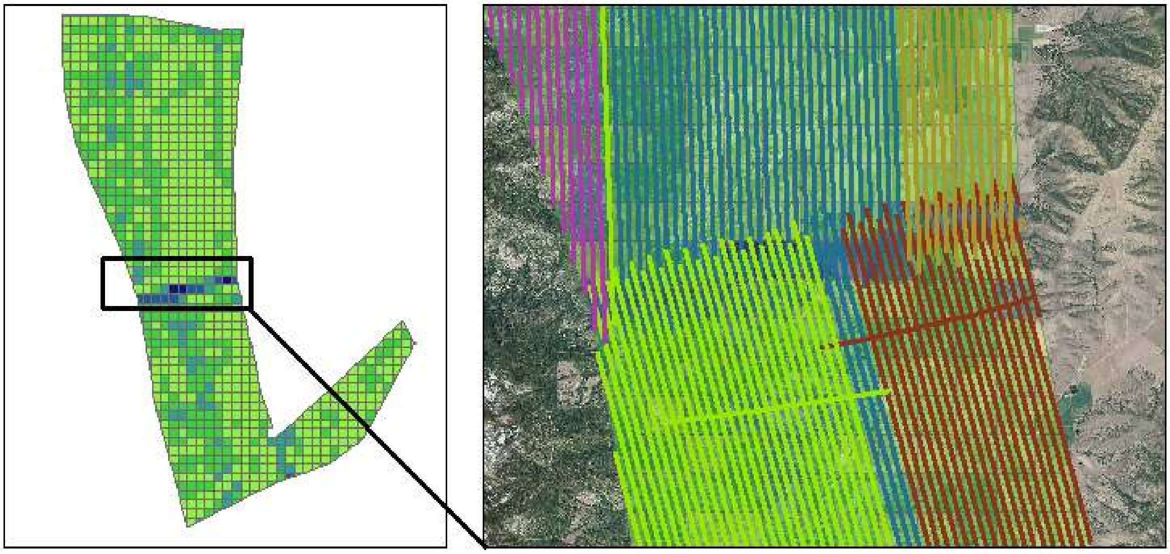


***Figure 4.7**. Areas containing high pulse density classified points include areas with overlapping flightlines.*



4.2.2 Ground-Classified Data Density

***Figure 4.8**. Histogram of ground-classified laser point density for Scott Valley study area*

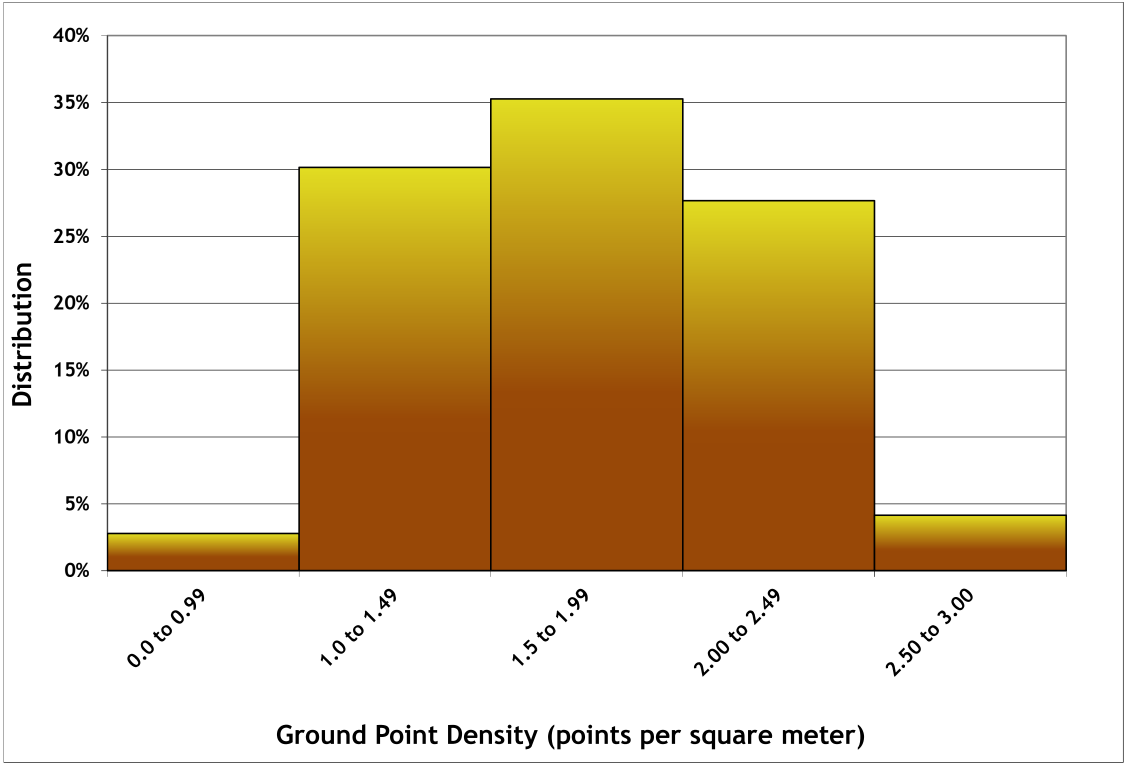


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Figure 4.9.*Ground-classified laser pulse data density.*

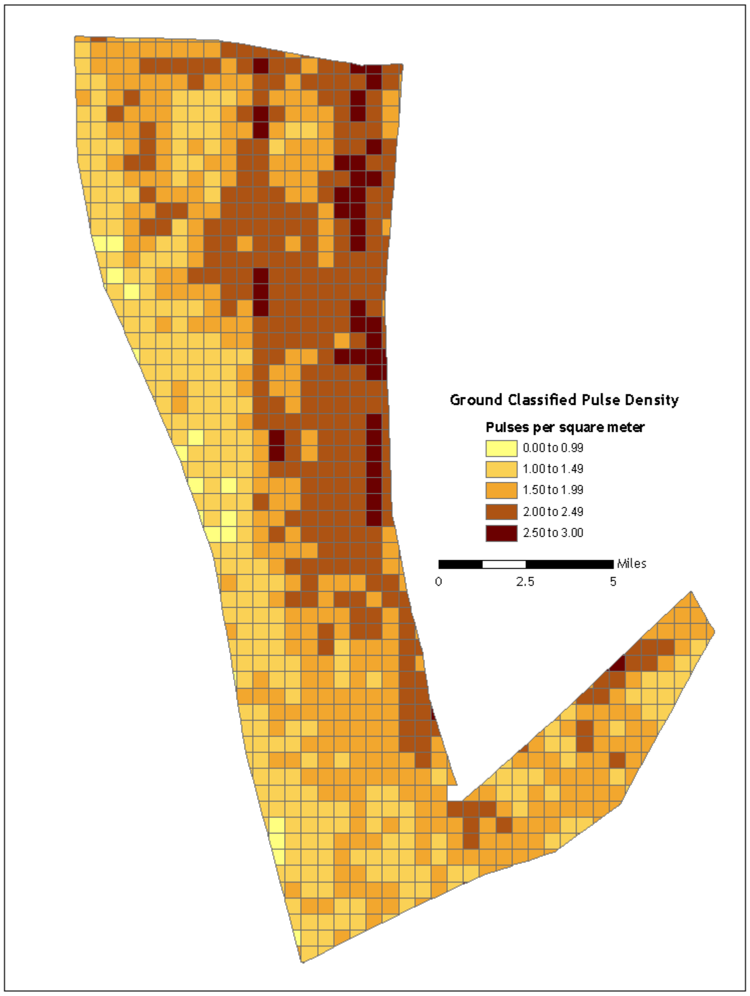
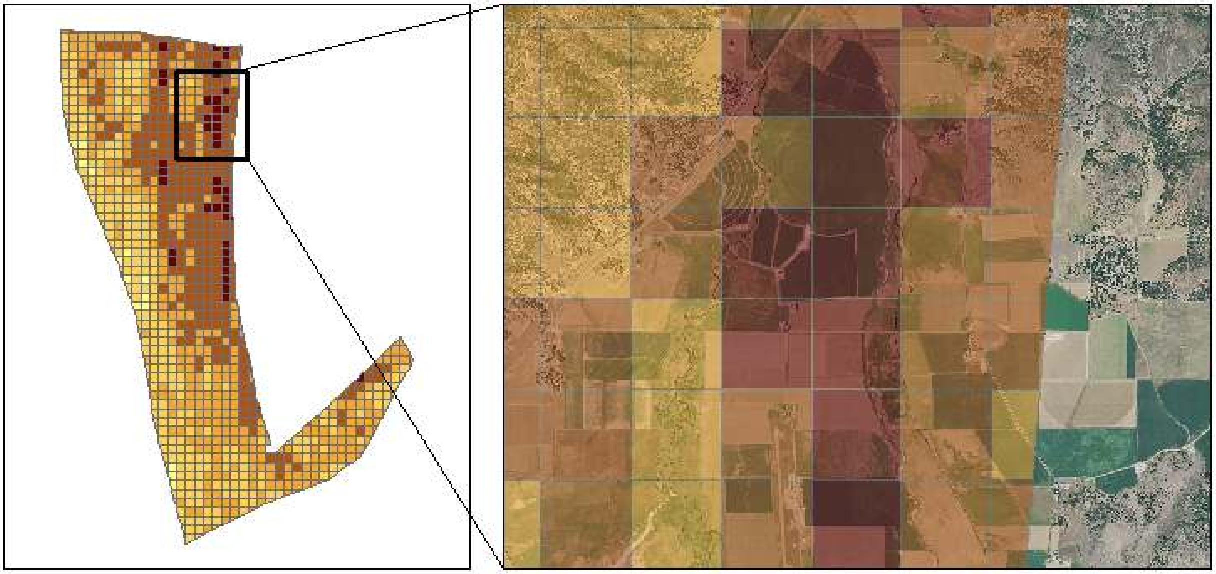


Figure 4.10.*This area illustrates a high number of ground classified points because of areas of little or no ground cover.*



5. Certifications

Watershed Sciences provided survey work for the Scott Valley area as described in **Section 2.3 andFigure 2.2**. Accuracy statistics are shown in Section 4.1.3.

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971.223.5152

6. Deliverables

6.1 Point Data

- All Return Point data in las v 1.2 (delineated in 100 m x 100 m tiles) including RGB extraction and Building Classification
- Ground classified point data in las v 1.2

6.2 Vector Data

- Total Area Flown (delineated in 100 m x 100 m tiles)
- SBETS

6.3 Data Report

- Full Report containing introduction, methodology, accuracy, and sample imagery.
    - Word Format (*.doc)
    - PDF Format (*.pdf)

6.5 Datum and Projection

Universal Transverse Mercator (UTM) Zone 10; NAD83(CORS96); NAVD88(Geoid03); Units: meters.

7. Selected Images

Figure 7.1.Water reservoir above the city of Callahan, California. Image created by extracting RGB values from a NAIP orthophoto onto a three dimensional LiDAR point cloud.

Figure 7.2. The South Fork of the Scott River just above confluence with East Fork and city of Callahan, California. Image created by extracting RGB values from a NAIP orthophoto onto a three dimensional LiDAR point cloud.

Figure 7.3. Scott River, downstream of Callahan, California. Image created by extracting RGB values from a NAIP orthophoto onto a three dimensional LiDAR point cloud.

8. 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.

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

95th Percentile: Per the National Standard for Spatial Data Accuracy (NSSDA) equals $RMSE_z$ x 1.9600 for vertical and $RMSE_r$ x 1.7308 for horizontal.

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).

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

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

Global Navigation Satellite System (GNSS): consists of both the U.S. GPS constellation and Soviet GLONASS constellation

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

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.

National Geodetic Survey Permanent Identifier (NGS PID):a permanent record assigned to a survey point when placed in the database.

Online Positioning User Service (OPUS):A service directed by the National Geodetic Survey to process corrected monument positions.

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

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 60 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.

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.

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.

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

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

9. Citations

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