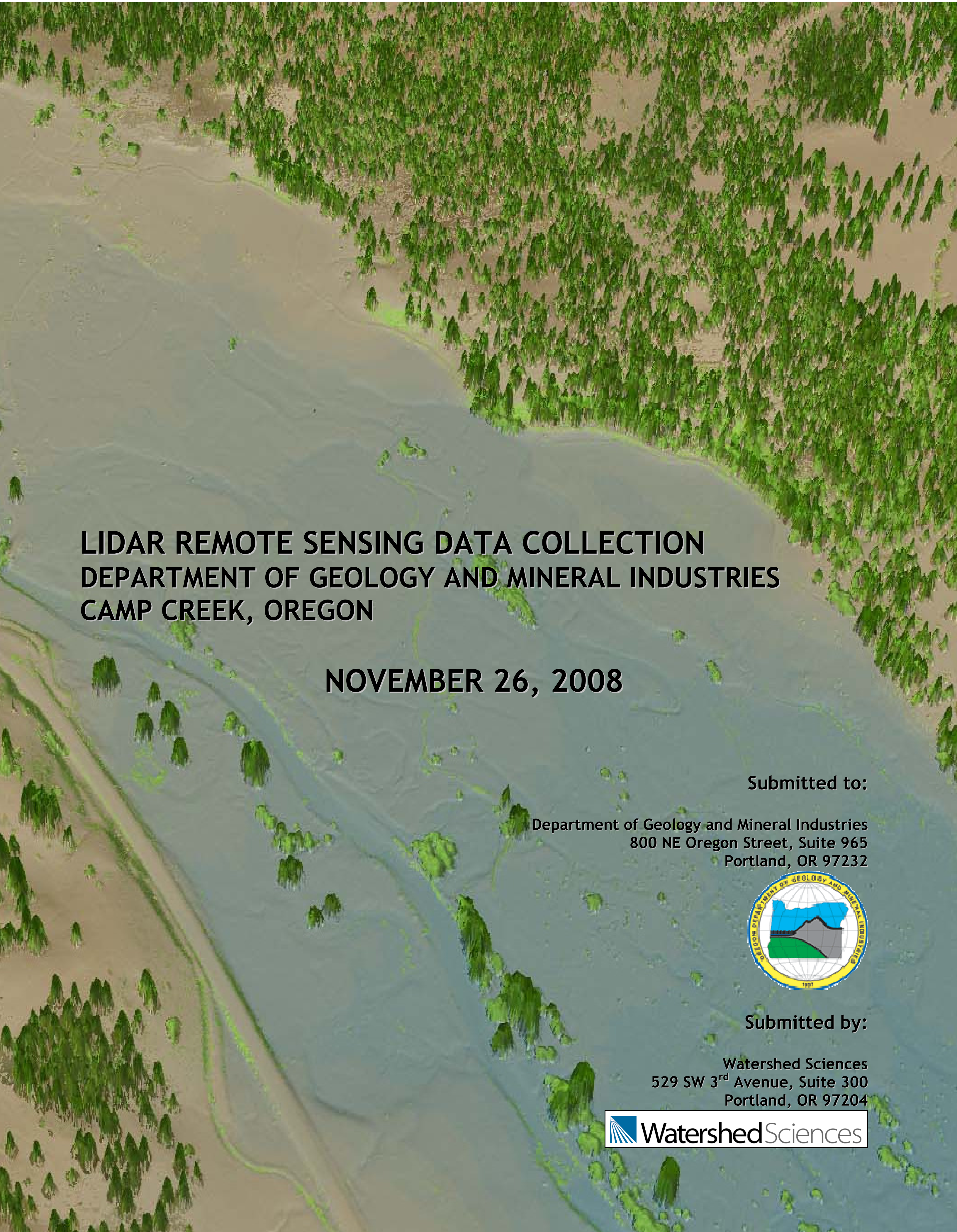

LIDAR REMOTE SENSING DATA COLLECTION
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
CAMP CREEK, OREGON

NOVEMBER 26, 2008

Submitted to:

Department of Geology and Mineral Industries
800 NE Oregon Street, Suite 965
Portland, OR 97232

Submitted by:

Watershed Sciences
529 SW 3rd Avenue, Suite 300
Portland, OR 97204

LiDAR Remote Sensing Data Collection:
DOGAMI, Camp Creek project area

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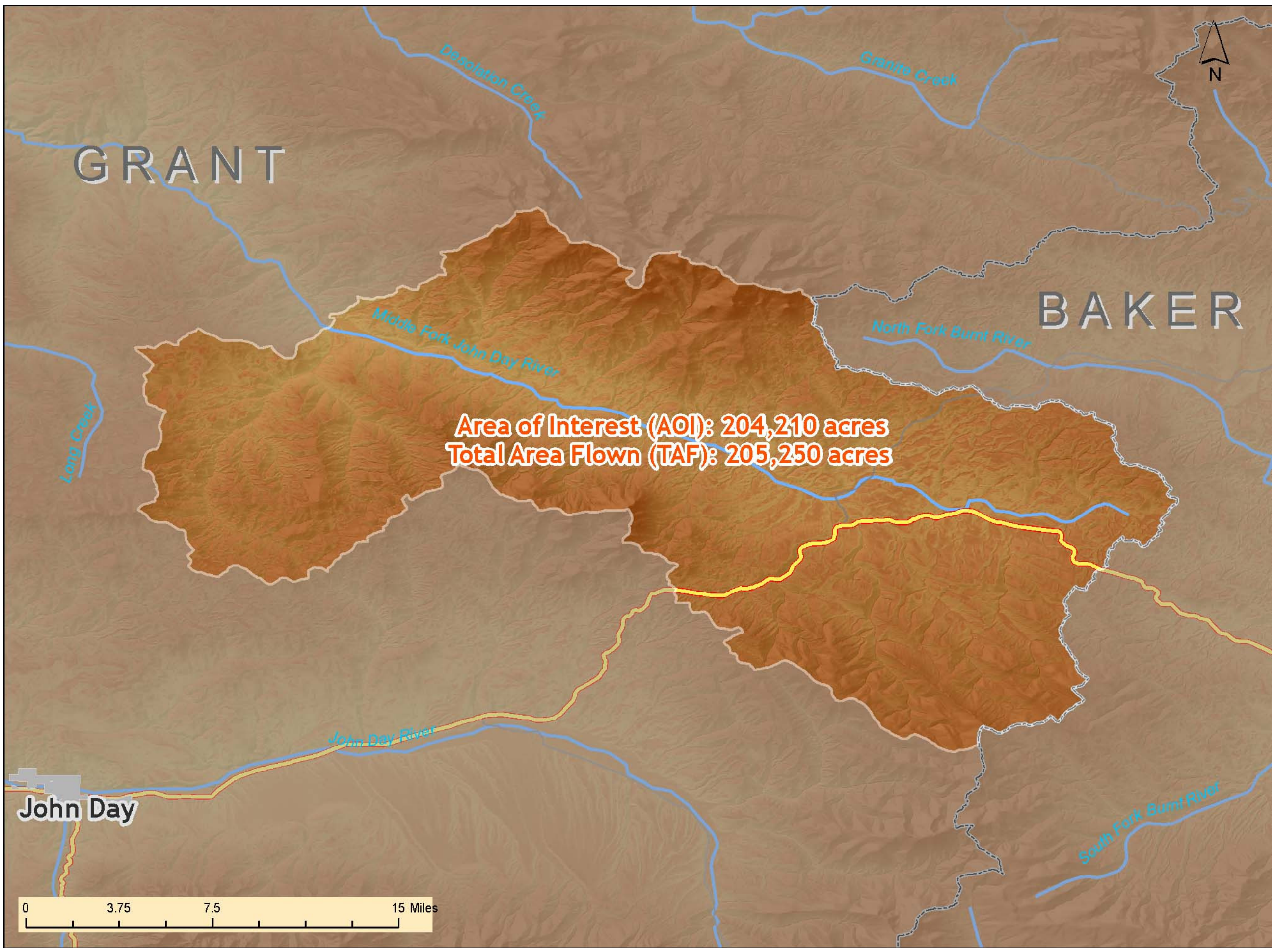
1. Overview

1.1 Study Area

Watershed Sciences, Inc. collected Light Detection and Ranging (LiDAR) data for the Department of Geology and Mineral Industries (DOGAMI) at the Camp Creek study area, at the easternmost edge of Grant County, Oregon. The requested LiDAR area of interest totals 319 square miles, or 204,210 acres; the map below shows the total area flown (TAF), which covers 320 square miles (205,250 acres). The TAF acreage is greater than the original AOI acreage due to buffering and flight planning optimization. These data are delivered and reported in entirety.

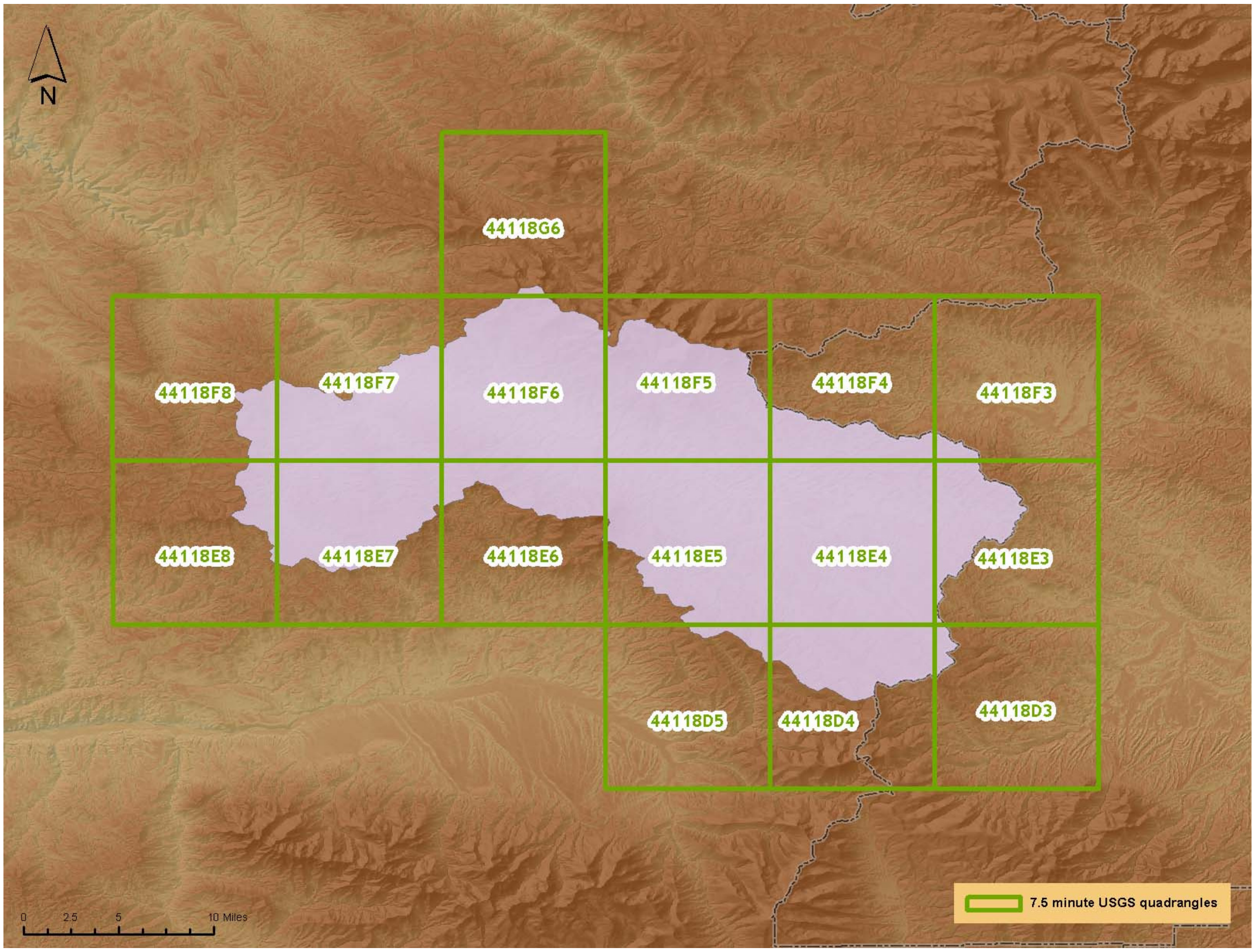
Figure 1.1. *DOGAMI Camp Creek study area.*



1.2 Study Area Specifics

Data were collected in the Camp Creek study area from 8/19/2008 to 8/27/2008, as allowed by weather conditions. The delivery is tiled to conform to 7.5-minute USGS quadrangles, as shown in Figure 1.2.

Figure 1.2. *Camp Creek study area with the delivered 7.5-minute USGS quads overlaid.*



1.3 Accuracy and Resolution

Real-time kinematic (RTK) surveys were conducted in multiple locations throughout 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 measures bias upward or downward. For the Camp Creek study area, the data have the following accuracy statistics:

- RMSE of 0.15 feet
- 1-sigma absolute deviation of 0.15 feet
- 2-sigma absolute deviation of 0.29 feet

Data resolution specifications are for ≥ 8 pts per square meter. **Total pulse density for the Camp Creek study area is 8.11 points per square meter (0.75 points per square foot).**

1.4 Data Format, Projection, and Units

Deliverables include:

- Report of data collection methods and summary statistics
- All return and bare earth point data in *.las v 1.1 format delineated by USGS 7.5' quad
- 3-foot resolution bare ground model ESRI GRID delineated by USGS 7.5' quads
- 3-foot resolution highest hit modeled ESRI GRID delineated by USGS 7.5' quads
- 1.5-foot resolution intensity images in GeoTIFF format delineated by USGS .75' quads
- 3-foot resolution ground density rasters
- shapefiles of delivery area, pulse density, and RTK point data

DOGAMI data are delivered in Oregon Lambert (NAD 83), with horizontal and vertical units in International Feet, in the NAD83 HARN/NAVD88 datum (Geoid 03).

2. Acquisition

2.1 Airborne Survey – Instrumentation and Methods

The LiDAR survey utilized a Leica ALS50 Phase II mounted in Cessna Caravan 208B. The system was set 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 $\pm 14^{\circ}$ from nadir[1]. These settings are developed to yield points with an average native density of ≥8 points per square meter over terrestrial surfaces. The native pulse density is the number of pulses emitted by the LiDAR system. Some types of surfaces (i.e., dense vegetation or water) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and lightly variable according to distributions of terrain, land cover and water bodies.

The Cessna Caravan is a powerful, stable platform, which is ideal for the often remote and mountainous terrain found in the Pacific Northwest. The Leica ALS50 sensor head installed in the Caravan is shown on the right.

The completed areas were 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, it is vital to have an accurate description of aircraft position and attitude. Aircraft position is described as x, y and z and measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude is 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 ALS50 Phase II
Survey Altitude (AGL)	900 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	52.2 Hz
Field of View	28° ($\pm 14^{\circ}$ from nadir)
Roll Compensated	Up to 20°
Overlap	100% (50% Side-lap)

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

2.2 Ground Survey – Instrumentation and Methods

During the LiDAR survey of the study area, a static (1 Hz recording frequency) ground survey was conducted over monuments with known coordinates. Coordinates are provided in **Table 2.2** below and shown in **Figure 2.1**. After the airborne survey, the static GPS data were processed using triangulation with CORS stations and checked against the Online Positioning User Service (OPUS[2]) to quantify daily variance. Multiple sessions were processed over the same monument to confirm antenna height measurements and reported position accuracy.

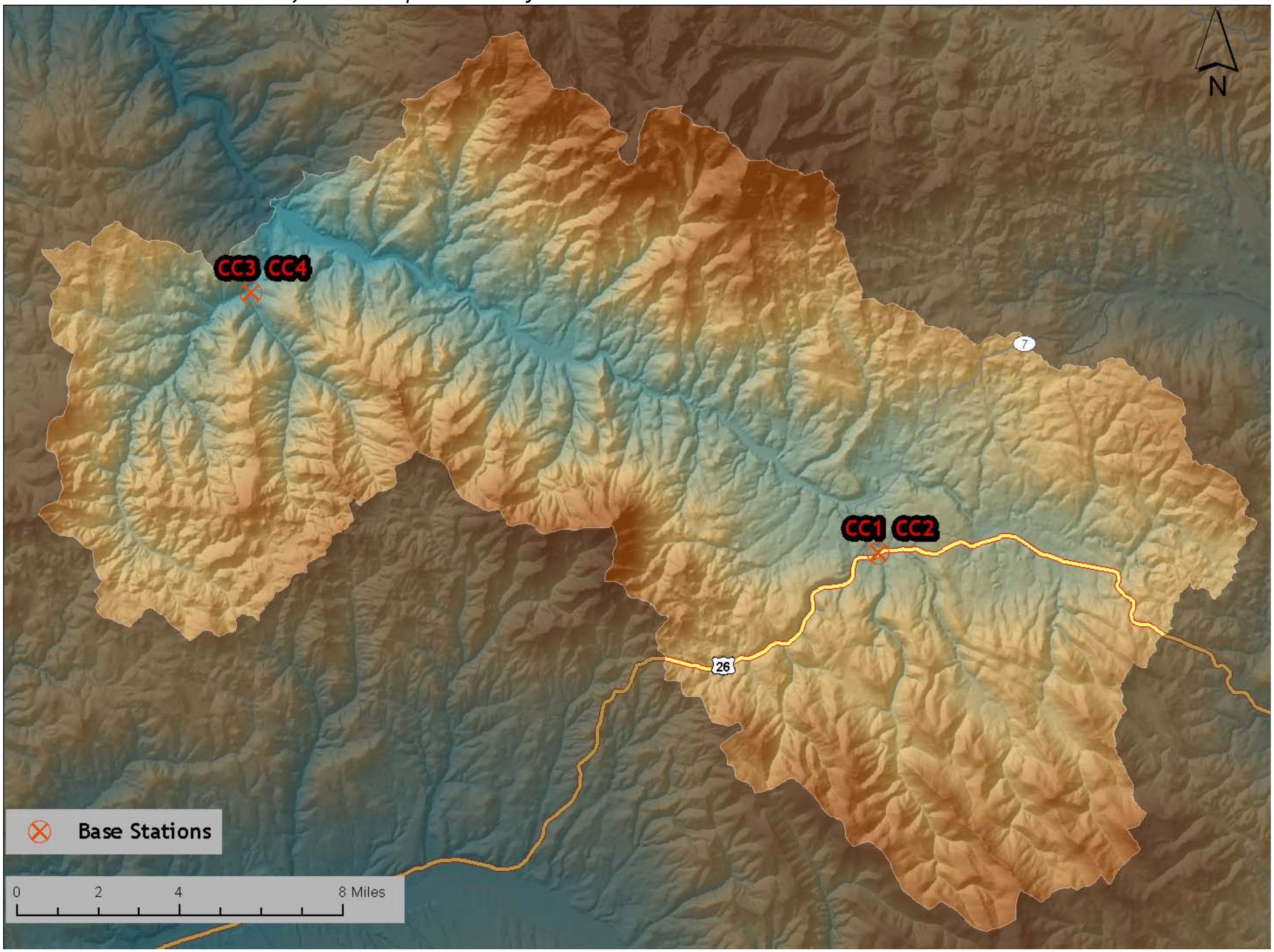
Whenever possible multiple sessions were observed at base station locations. All sessions were statistically compared to each other in order to ensure accurate base station coordinates and elimination of systematic errors that might otherwise be incorporated into the data. At least 3 observations and a standard deviation of 1 cm or less among observations in the Northing, Easting, and Ellipsoidal fields were required for a base station location to be used for LiDAR flight processing purposes. In some cases the 3 session minimum was not possible for RTK base station locations. For these locations a minimum 6 hour first session was taken and was then followed by a half-hour short session that was used to ensure that no errors occurred during the initial occupation.

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

	Datum NAD83(HARN)		**GRS80**
Base Station ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
CC1	44 34 29.93962	118 29 34.56816	1269.114
CC2	44 34 29.89962	118 29 34.52712	1268.956
CC3	44 39 47.56415	118 48 27.28725	1117.589
CC4	44 39 47.70873	118 48 27.92546	1115.590

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

Figure 2.1. *Base station locations for the Camp Creek study area.*



2.3 Real-Time Kinematic Survey Results

Multiple DGPS units wereused for the ground real-time kinematic (RTK) portion of the survey. To collect accurate ground surveyed points, a GPS base unit was set up over monuments to broadcast a kinematic correction to a roving GPS unit. The ground crew used a roving unit to receive radio-relayed kinematic corrected positions from the base unit. The RTK survey allowed precise location measurement ($\sigma \leq 1.5$ cm ~ 0.6 in). In the Camp Creek study area, 1,452 RTK points were collected across 41 of the 243 flightlines, resulting in 17% of all flight lines being intersected by RTK survey points. **Figure 2.2** shows detailed views of RTK point locations as they cross the flightlines in the study area.

Trimble GPS survey equipment configured for collecting RTK data.

Figure 2.2. *Selected RTK point locations displayed on NAIP orthophotos.*

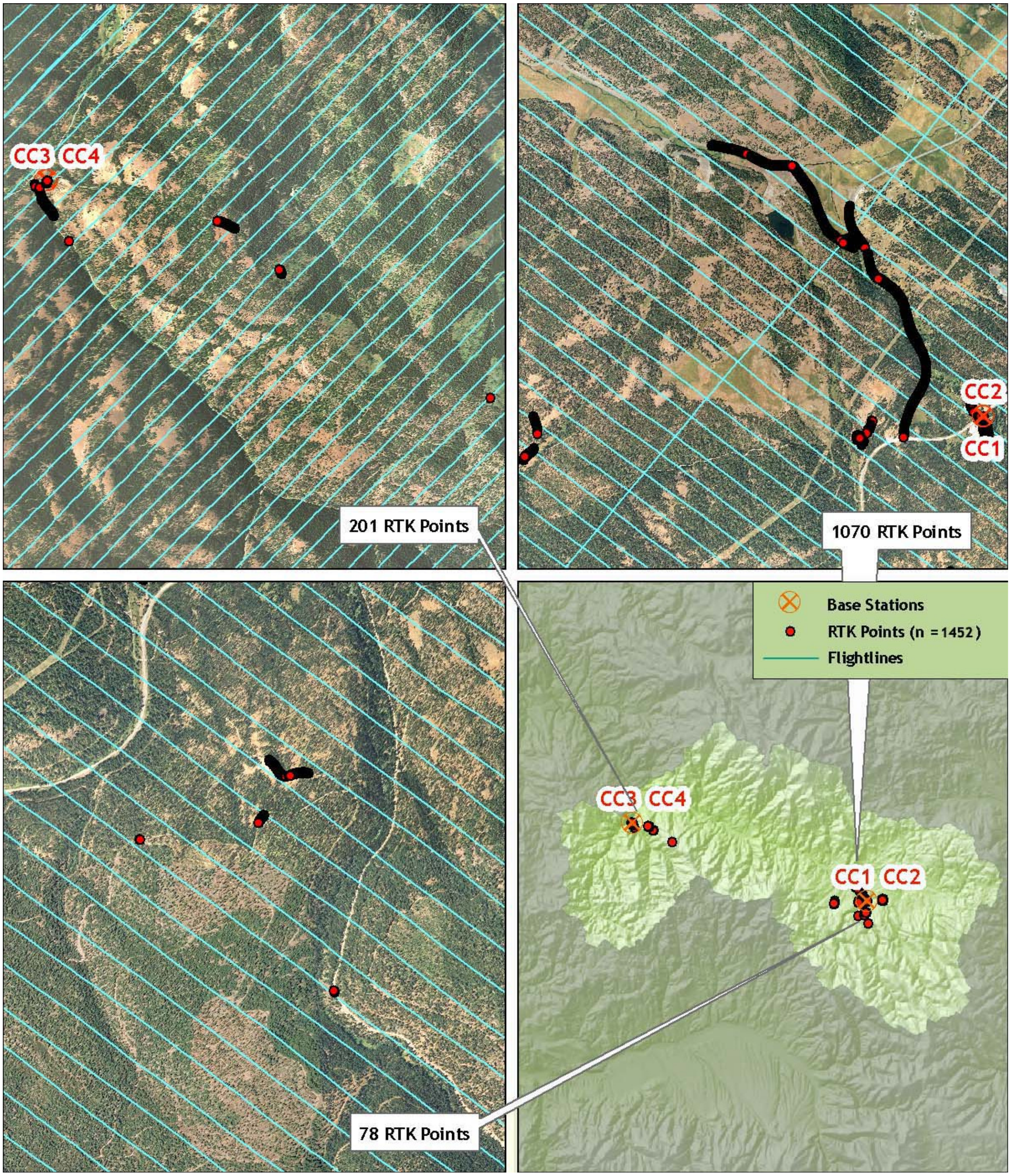
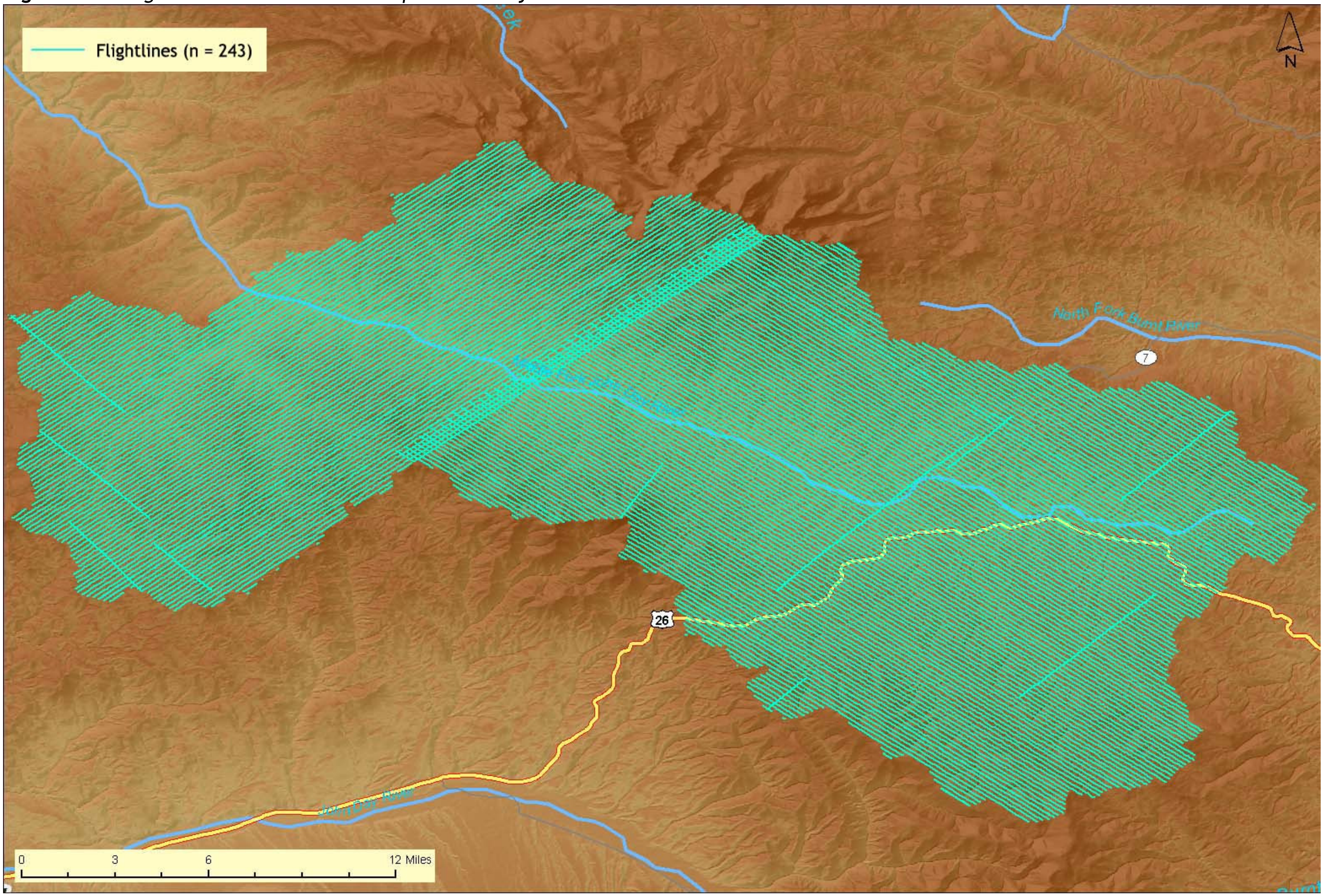


Figure 2.3. *Flightlines as collected in Camp Creek study area.*



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.7.80, Trimble Geomatics Office v.1.62
2. Developed a smoothed best estimate of trajectory (SBET) file to blend the 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.1.4
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 v1.1) format.
   Software: ALS Post Processing Software
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.8.001
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.8.001
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 at a 3-foot pixel resolution.
   Software: TerraScan v.8.001, ArcMap v9.2, TerraModeler v.8.001

3.2 Aircraft Kinematic GPS and IMU Data

LiDAR survey datasets were referenced to 1 Hz static ground GPS data collected over pre-surveyed monuments with known coordinates. While surveying, the aircraft collected 2 Hz kinematic GPS data. The onboard inertial measurement unit (IMU) collected 200 Hz aircraft attitude data. Waypoint GPS v.7.80 was used to process the kinematic corrections for the aircraft. The static and kinematic GPS data were post-processed after the survey to obtain an accurate GPS solution and aircraft positions. IPAS v.1.4 was used to develop a trajectory file that included 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, z) coordinate along with unique intensity values (0-255). The data were output into large LAS v. 1.1 files; each point maintains 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 to process. 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 study area and positional accuracy of the laser points.

Once the laser point data were imported into bins in 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. Each bin was inspected for pits and birds manually; spurious points were removed. For a bin 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 were removed from the dataset. Common sources of non-terrestrial returns are clouds, birds, vapor, and haze.

The 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 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. At this point in the workflow, data had passed a robust calibration designed to reduce inconsistencies from multiple sources (i.e. sensor attitude offsets, mirror scale, GPS drift) using a comprehensive procedure (i.e. uses all of the overlapping survey data). Relative accuracy screening was complete.

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 (over a 50-meter radius) to improve ground detail. This was 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 included known vegetation (i.e., understory, low/dense shrubs, etc.) and these points were manually reclassified as non-grounds. Ground surface rasters were 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 2 centimeters.

- **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, etc.

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 surfaces with even the slightest relief.
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 $\pm 14^{o}$ 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 16 km (10 miles) at all times.
5. Ground Survey: Ground survey point accuracy increases 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. The ground survey collected 1,452 RTK points that are distributed throughout multiple flight lines across the study areas.
6. 50% Side-Lap (100% Overlap): Overlapping areas are 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 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 is computed after the manual calibration is completed and reported for each 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. ***The resulting overlapping ground points (per line) total over 3 billion points from which to compute and refine relative accuracy***. System misalignment offsets (pitch, roll and heading) and mirror scale were solved for each individual mission. The application of 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 is the final step employed for relative accuracy calibration.

Relative Accuracy Calibration Results

Relative accuracy statistics are based on the comparison of 243 flightlines and over 3 billion points.

- Project Average = 0.15 ft
- Median Relative Accuracy = 0.15 ft
- 1σ Relative Accuracy = 0.16 ft
- 2σ Relative Accuracy = 0.22 ft

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

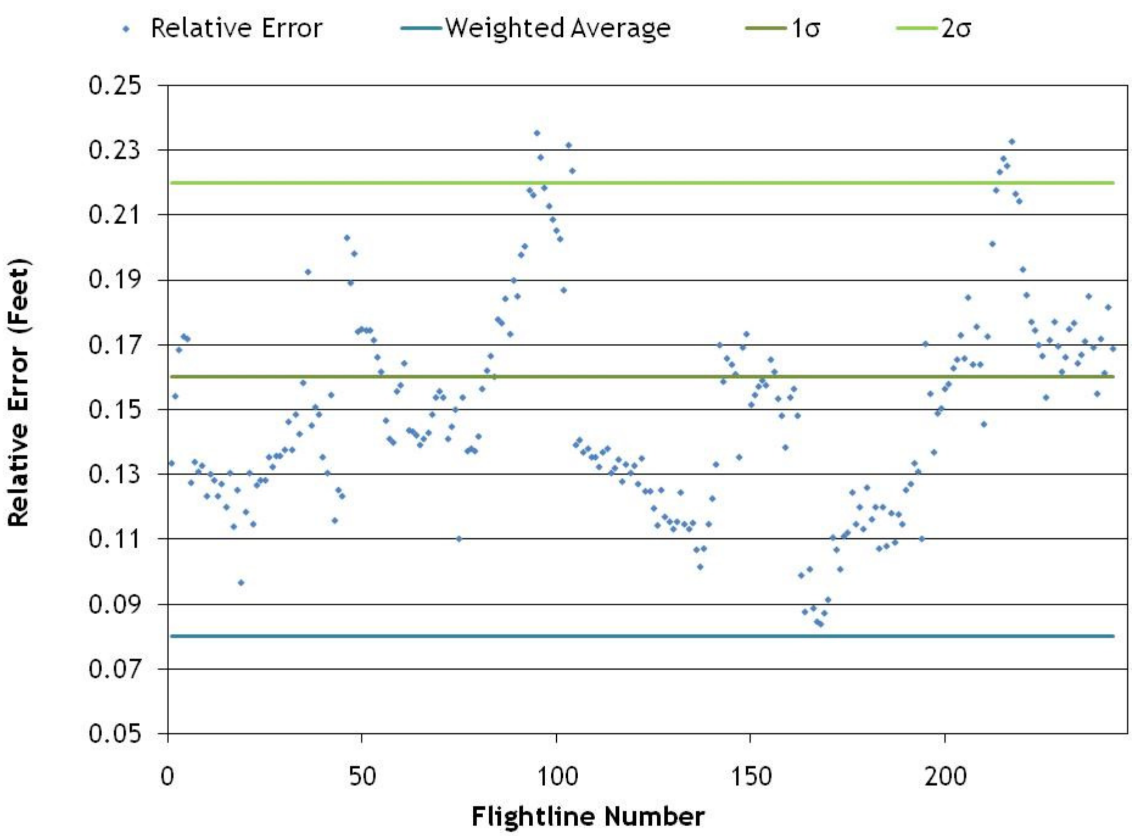


Figure 4.2. *Statistical relative accuracies, non slope-adjusted.*

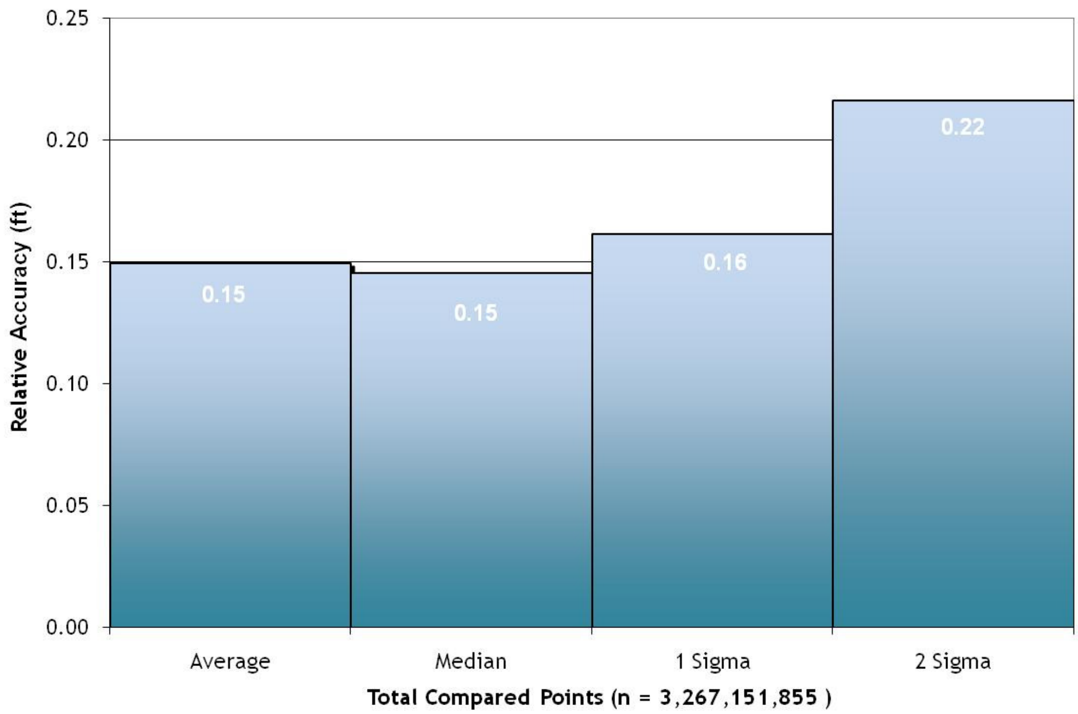
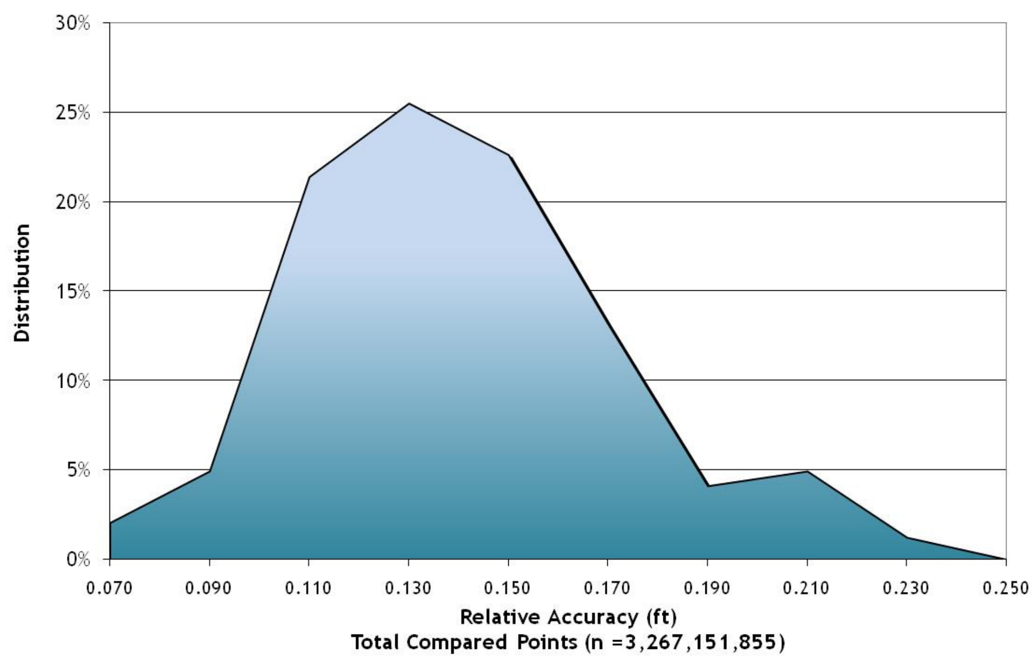


Figure 4.3. *Percentage distribution of relative accuracies, non slope-adjusted.*



4.1.2 Absolute Accuracy

The final quality control measure is a statistical accuracy assessment that compares known RTK ground survey points to the closest laser point. For the Camp Creek study area, 1,452 RTK points were collected. Accuracy statistics are reported in **Table 4.2** and shown in Figures **4.4-4.5.**

Table 4.2. *Absolute Accuracy – Deviation between laser points and RTK survey points.*

Sample Size (n): 1452	
Root Mean Square Error (RMSE): 0.15 feet	
Standard Deviations	**Deviations**
1 sigma (σ): 0.15 feet	**Minimum Δz:** -0.51 feet
2 sigma (σ): 0.29 feet	**Maximum Δz:** 0.67 feet
	Average Δz: -0.01 feet

Figure 4.4. *Camp Creek Study area histogram statistics*

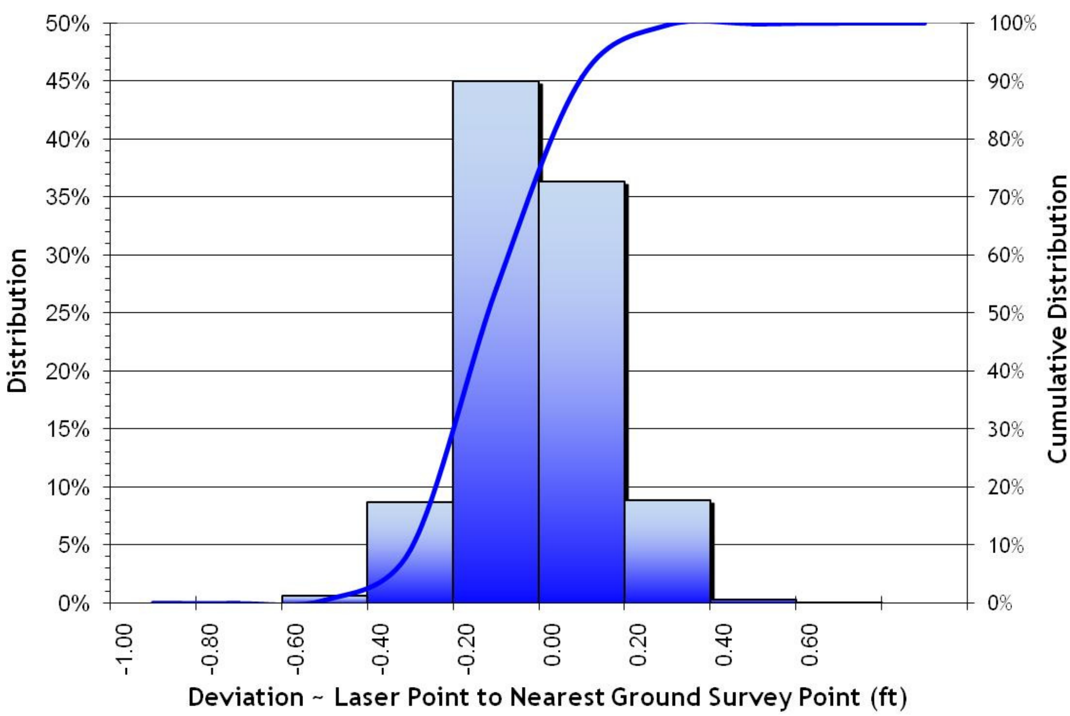
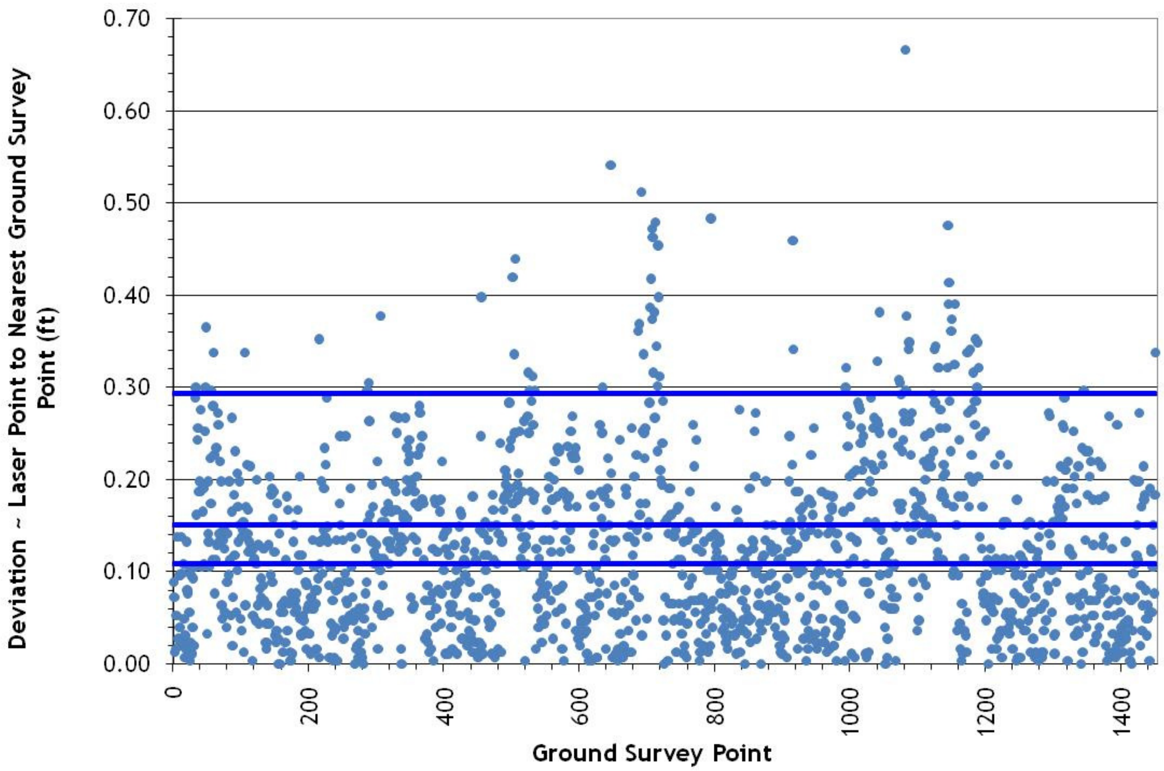


***Figure 4.5**. Camp Creek study area point absolute deviation statistics.*



4.2 Data Density/Resolution

Some types of surfaces (i.e., dense vegetation or water) 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. Density histograms and maps (**Figures 4.6-4.9**) have been calculated based on first return laser point density and ground-classified laser point density.

***Table 4.3**. Average density statistics for Camp Creek study area.*

Average Pulse Density (per square ft)	Average Pulse Density (per square m)	Average Ground Density (per square ft)	Average Ground Density (per square m)
0.75	8.11	0.15	1.65

***Figure 4.6**. Histogram of first return laser point density.*

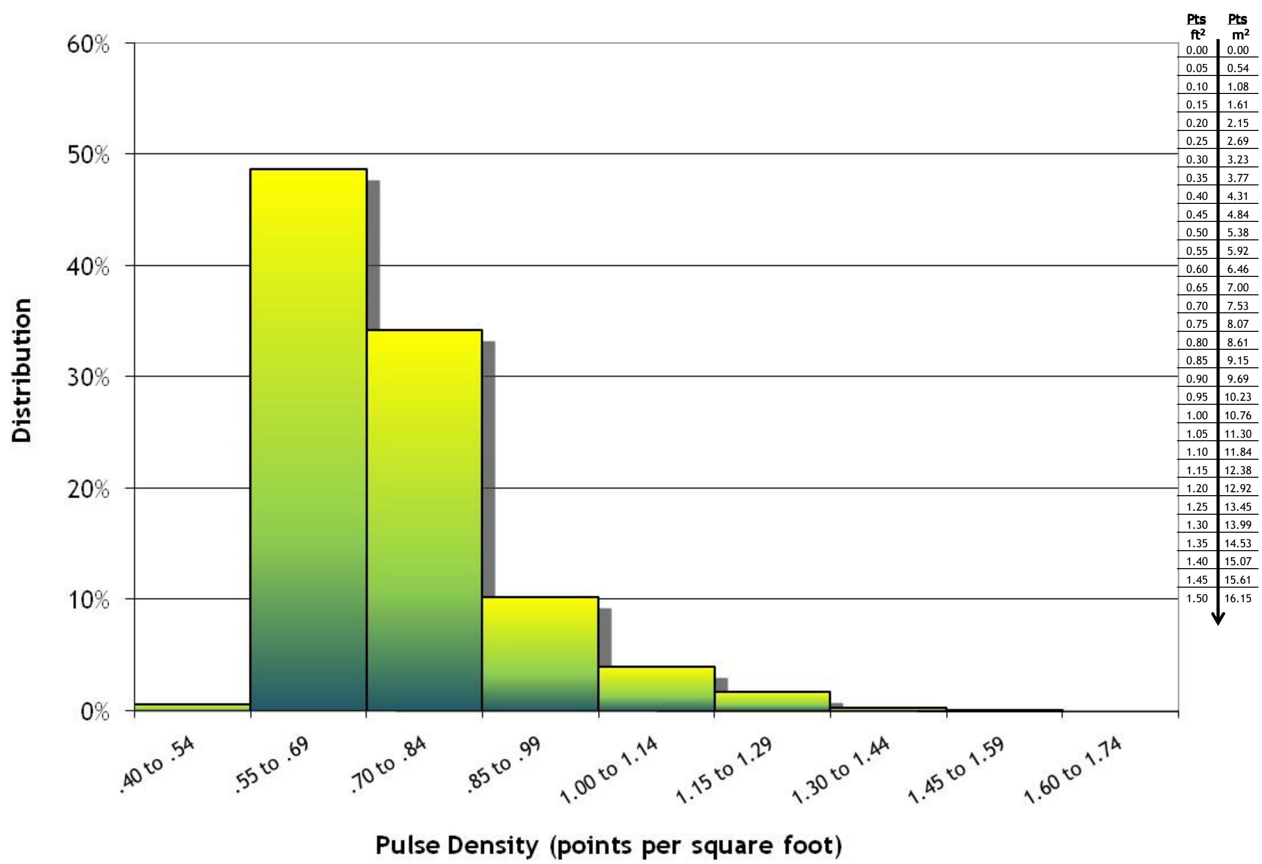
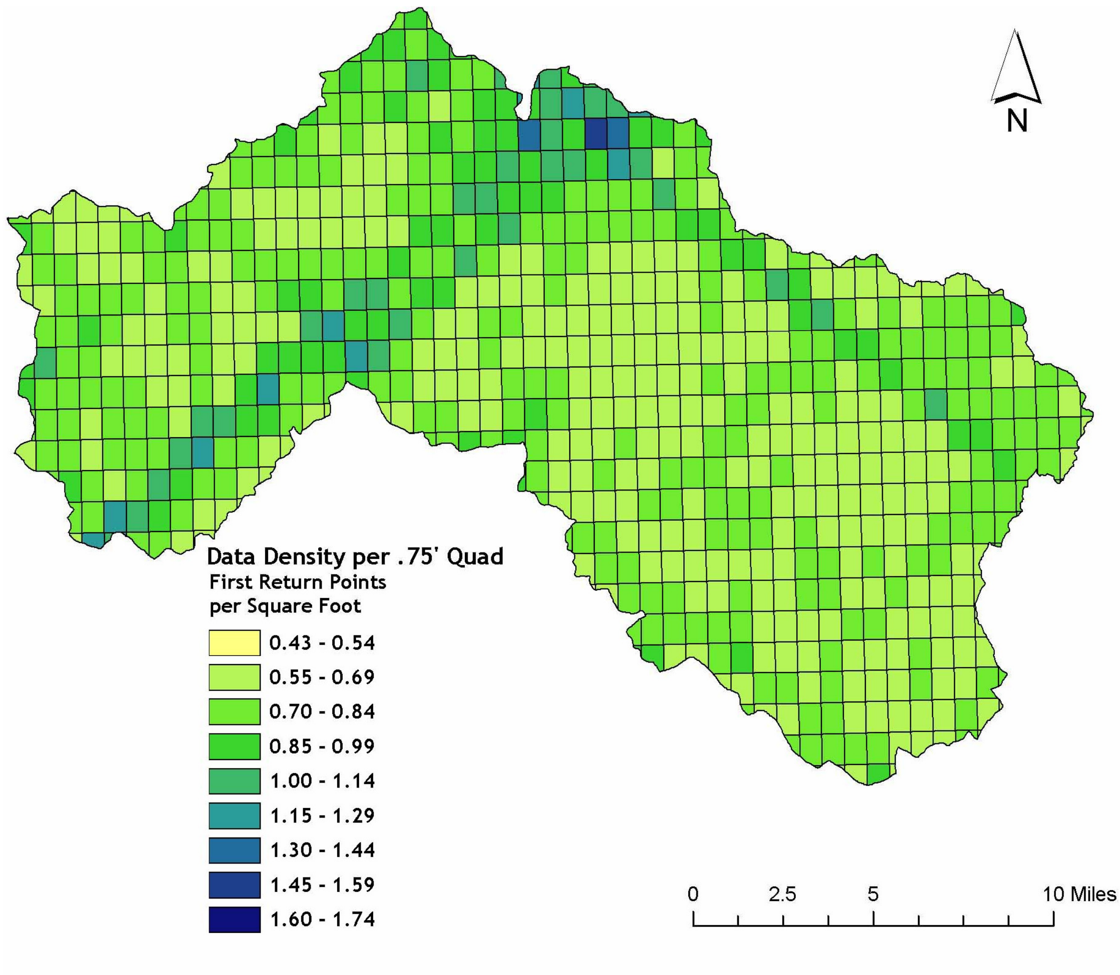


Figure 4.7. Image shows first return laser point per 0.75’ USGS Quad.



Pts ft^2	Pts m^2
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

Ground classifications were derived from ground surface modeling. Supervised classifications were performed by reseeding of the ground model where it was determined that the ground model failed, usually under dense vegetation and/or at breaks in terrain, steep slopes and at bin boundaries.

Figure 4.8*. Histogram of ground-classified laser point density.*

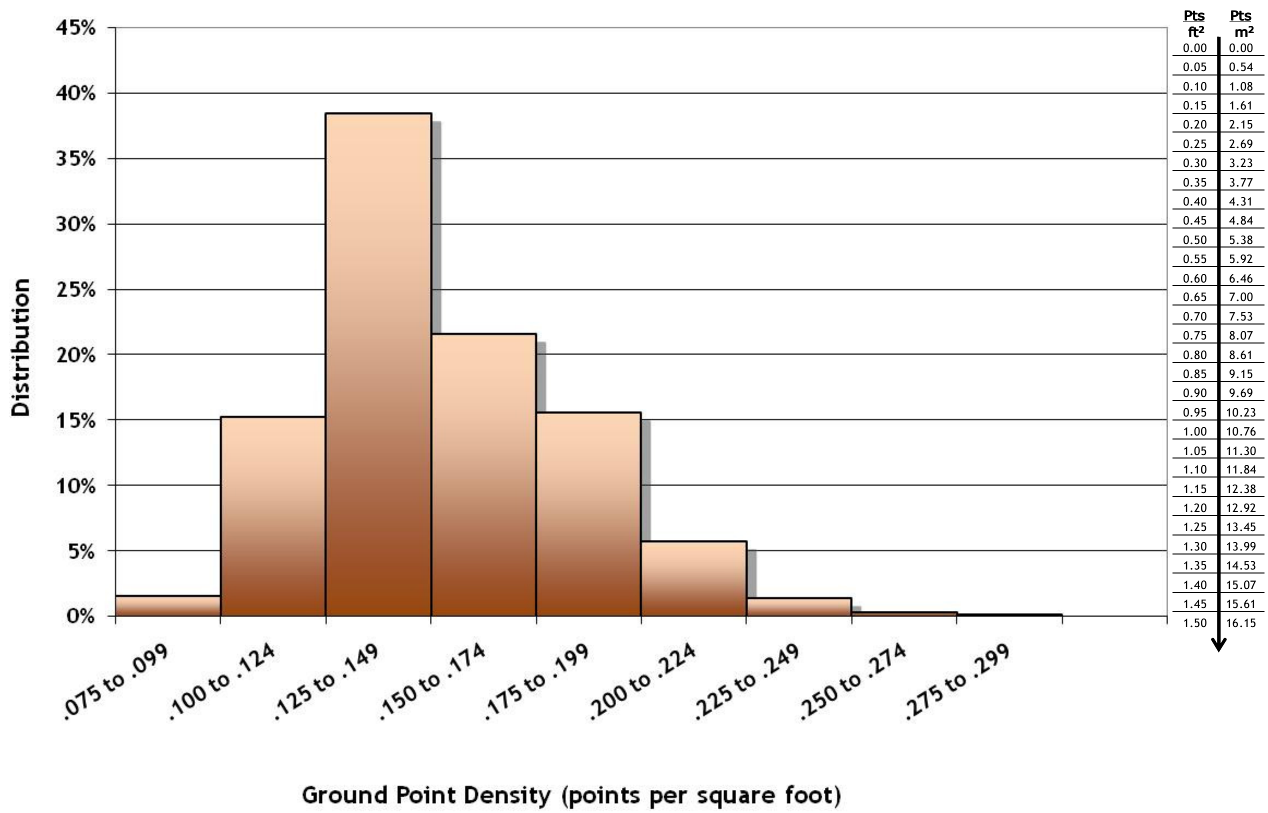
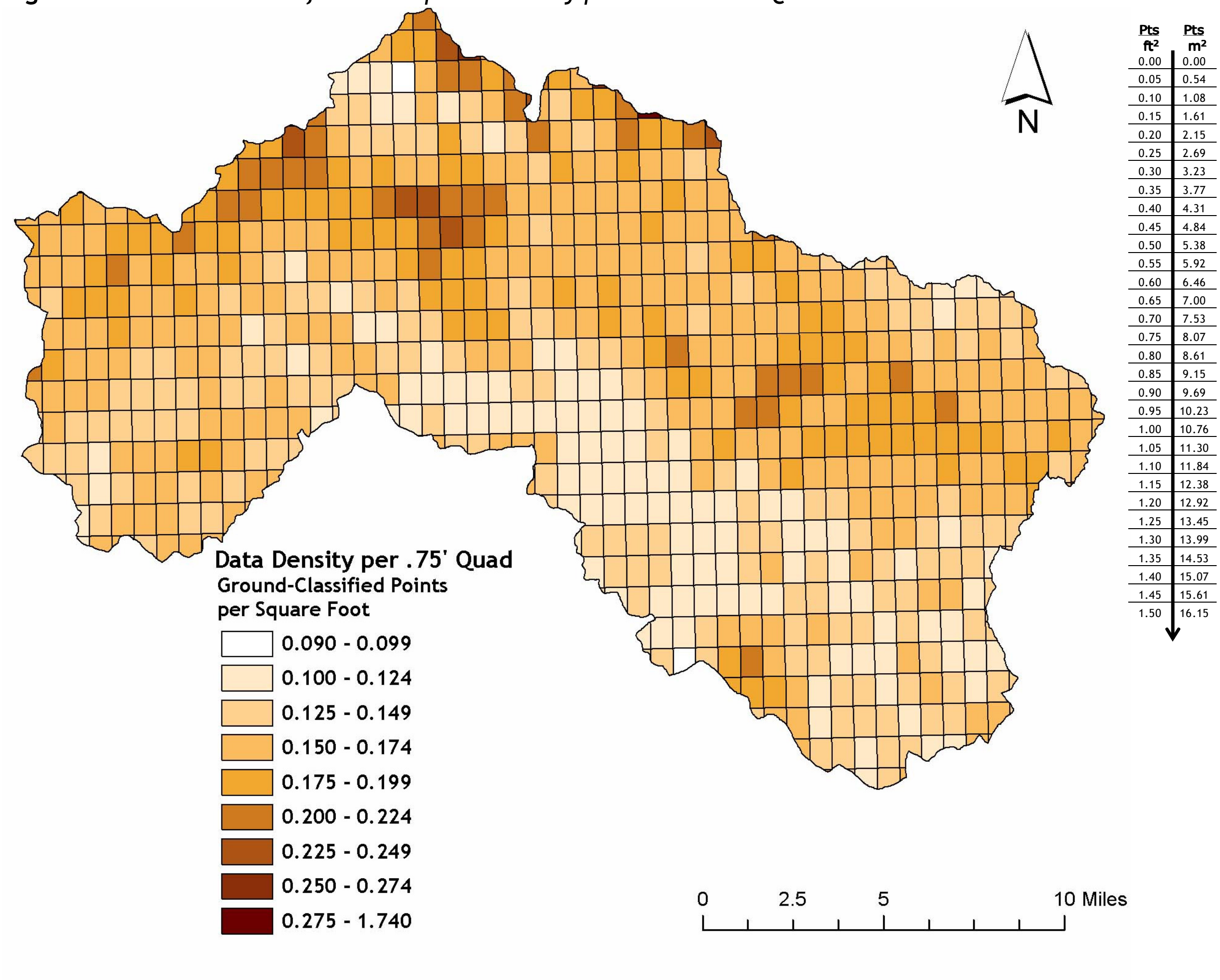


Figure 4.9*. Ground-classified laser point density per 0.75' USGS Quad.*



Variation in first return and ground-classified point densities occurs due to several factors. Intersecting or overlapping flightlines will cause higher first return point densities (seen in Figure 4.10.) Dense vegetation and reflective surfaces such as still water return fewer pulses than the laser originates. Owing to this, higher ground classified point densities can be found on areas of bare ground, as shown in Figure 4.11.

Figure 4.10. *Quads with high first return densities correlate to intersecting flightline patterns.*

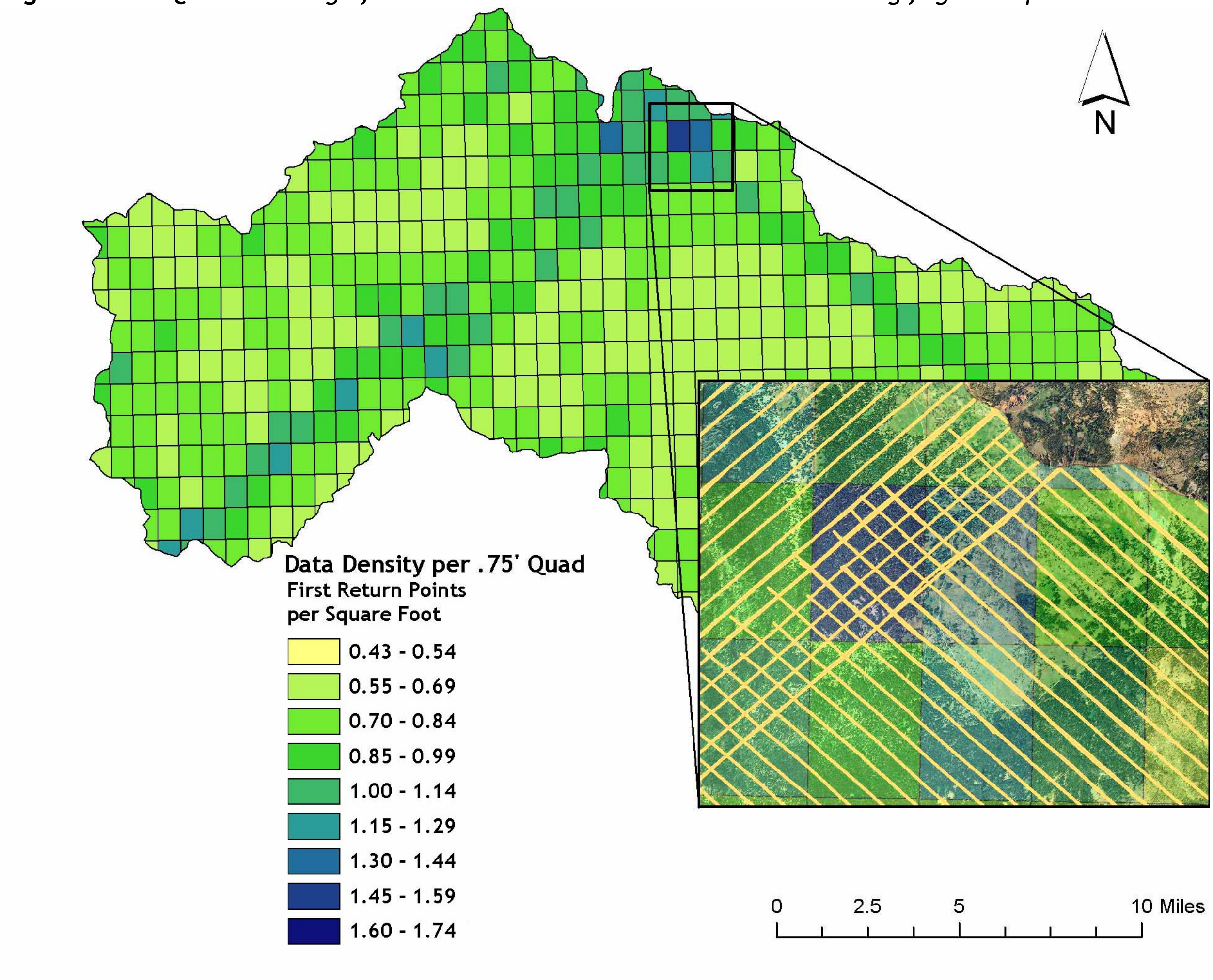
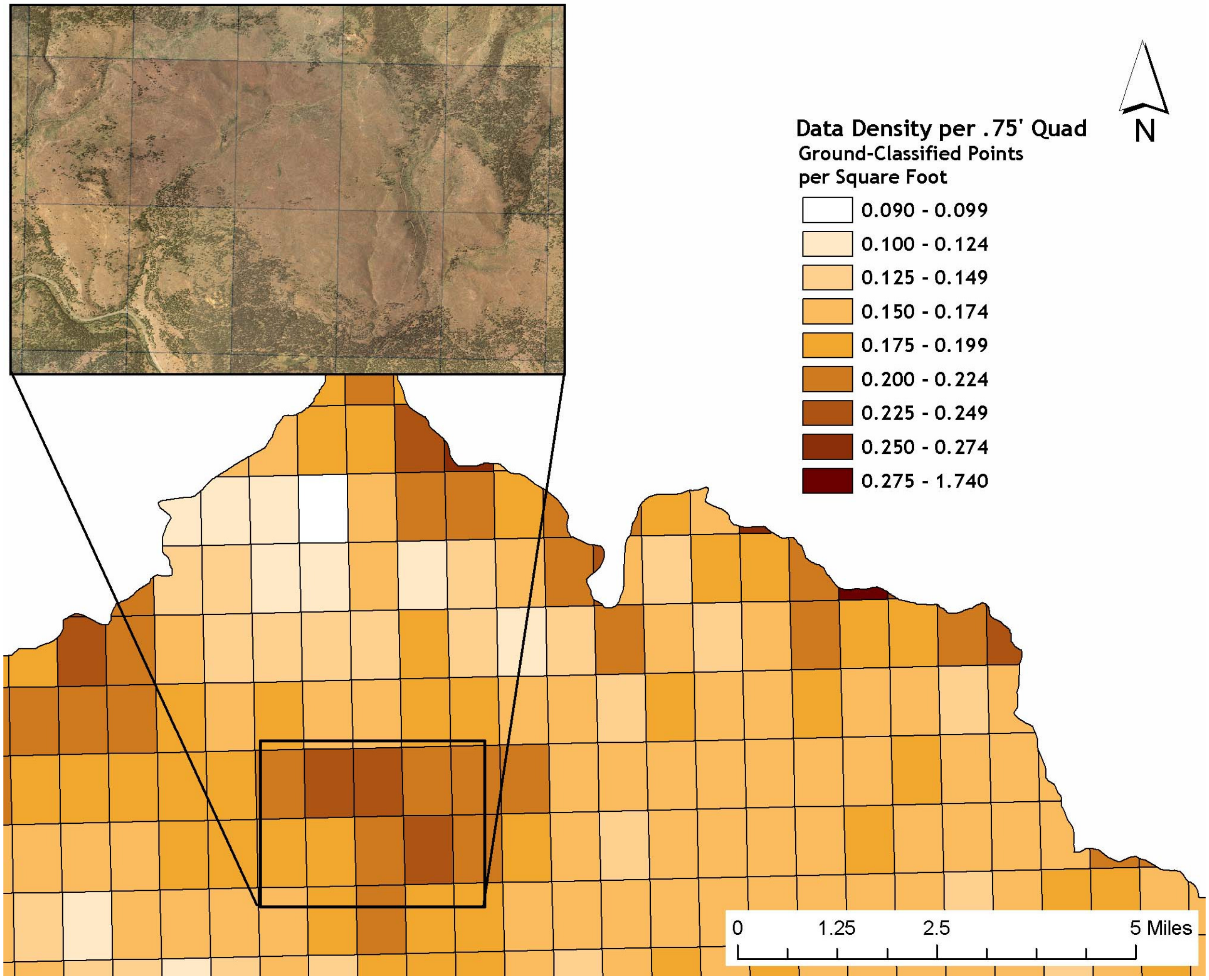


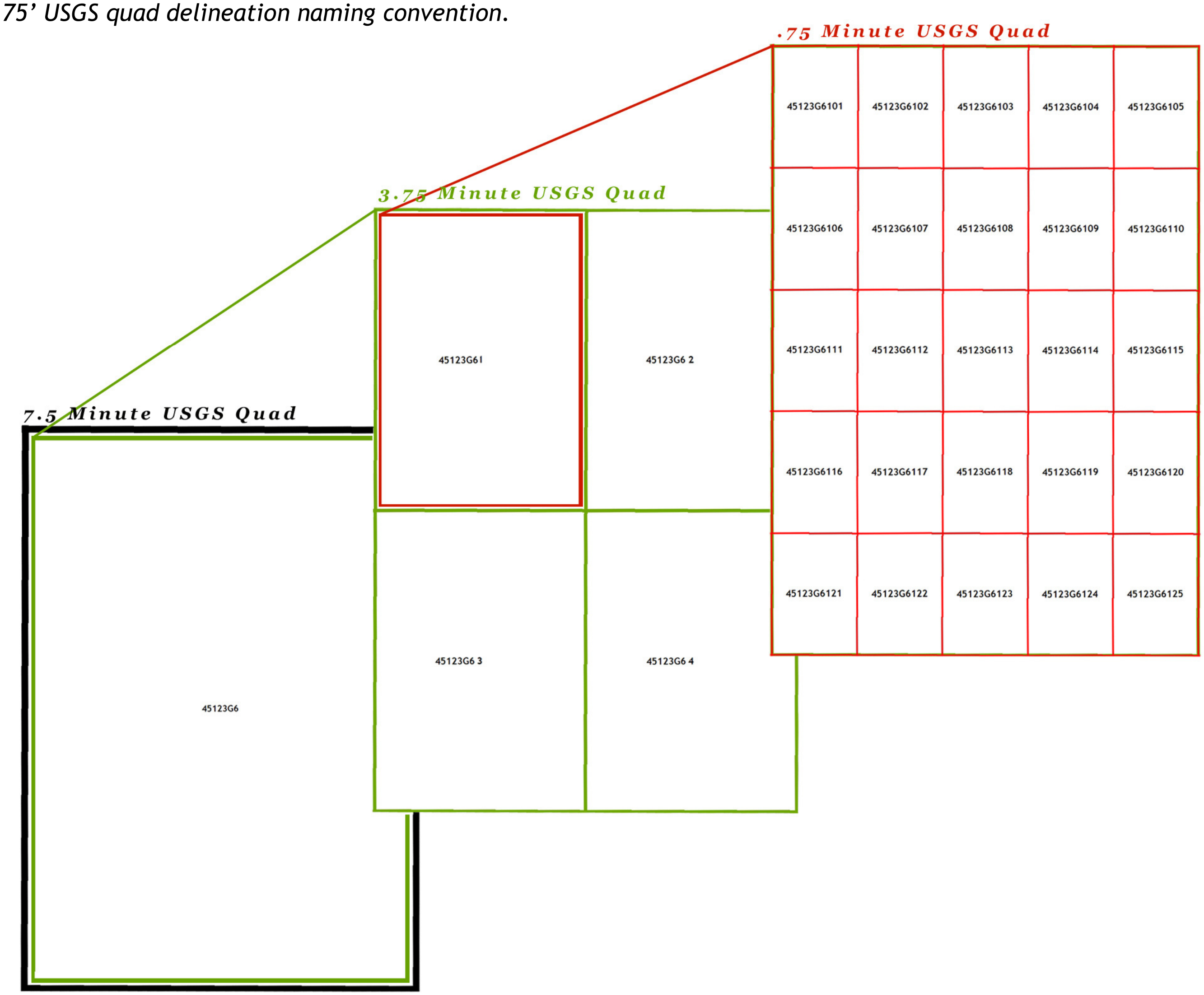
Figure 4.11. Quadrants containing many ground classified points include areas of sparse vegetation.



5. Deliverables

The delivered data conform to the following tiling scheme:

Figure 5.1. *0.75' USGS quad delineation naming convention.*



5.1 Point Data

- All return and ground classified points in LAS v 1.1 format, delineated by 1/100th quad

5.2 Vector Data

- 7.5-minute quadrangle delineation in shapefile and *.dgn format
- 0.75-minute quadrangle delineation in shapefile and *.dgn format (See **Figure 5.1** for illustration)
- Ground control point data
- Study area shapefile
- Trajectory (*.traj) file with flight attitude information
- Pulse density shapefile in 7.5' USGS quad

5.3 Raster Data

- ESRI GRID of bare earth modeled LiDAR data points (3-foot resolution) delivered in 7.5' USGS quad delineation
- ESRI GRID of above ground modeled LiDAR data points (3-foot resolution) delivered in 7.5' USGS quad delineation
- Intensity images in GeoTIFF format (1.5-foot resolution) delivered in 0.75' quads
- Ground density rasters in GeoTIFF format (3-foot resolution) delivered in 0.75' quads

5.4 Data Report

- Full report containing introduction, methodology, and accuracy.

5.5 Datum and Projection

The data were processed as ellipsoidal elevations and required a Geoid transformation to be converted into orthometric elevations (NAVD88). In TerraScan, the NGS published Geiod03 model was applied to each point. The data were processed using meters in the Universal Transverse Mercator (UTM) Zone 10 and NAD83 (CORS96)/NAVD88 datum and converted to the following projections.

- DOGAMI data are delivered in Oregon Lambert (NAD 83), with horizontal and vertical units in International Feet, in the NAD83 HARN/NAVD88 datum (Geoid 03).

6. Selected Imagery

Example areas are presented to show sample imagery (see **Figures 6.1-6.7**).

Figure 6.1. Plan view over Middle Fork John Day River in quad 44118f6. Top image represents bare earth LiDAR, middle image is highest hit LiDAR, lower image is NAIP orthophoto.

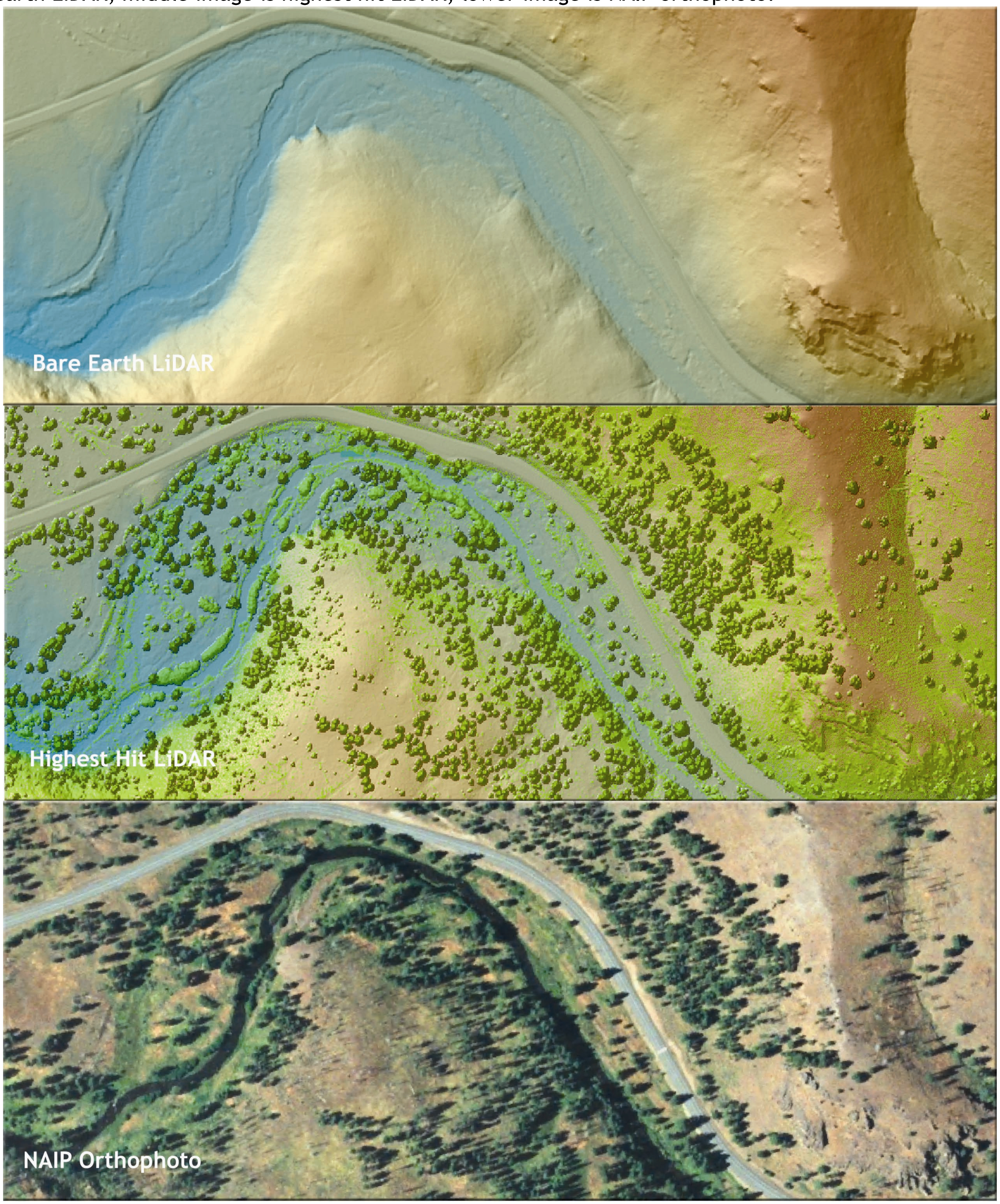


Figure 6.2. Plan view Camp Creek and Cottonwood Creek confluence (tile 44118f7). Top image derived from bare earth LiDAR, center image derived from highest hit LiDAR, lower image is NAIP orthophoto.

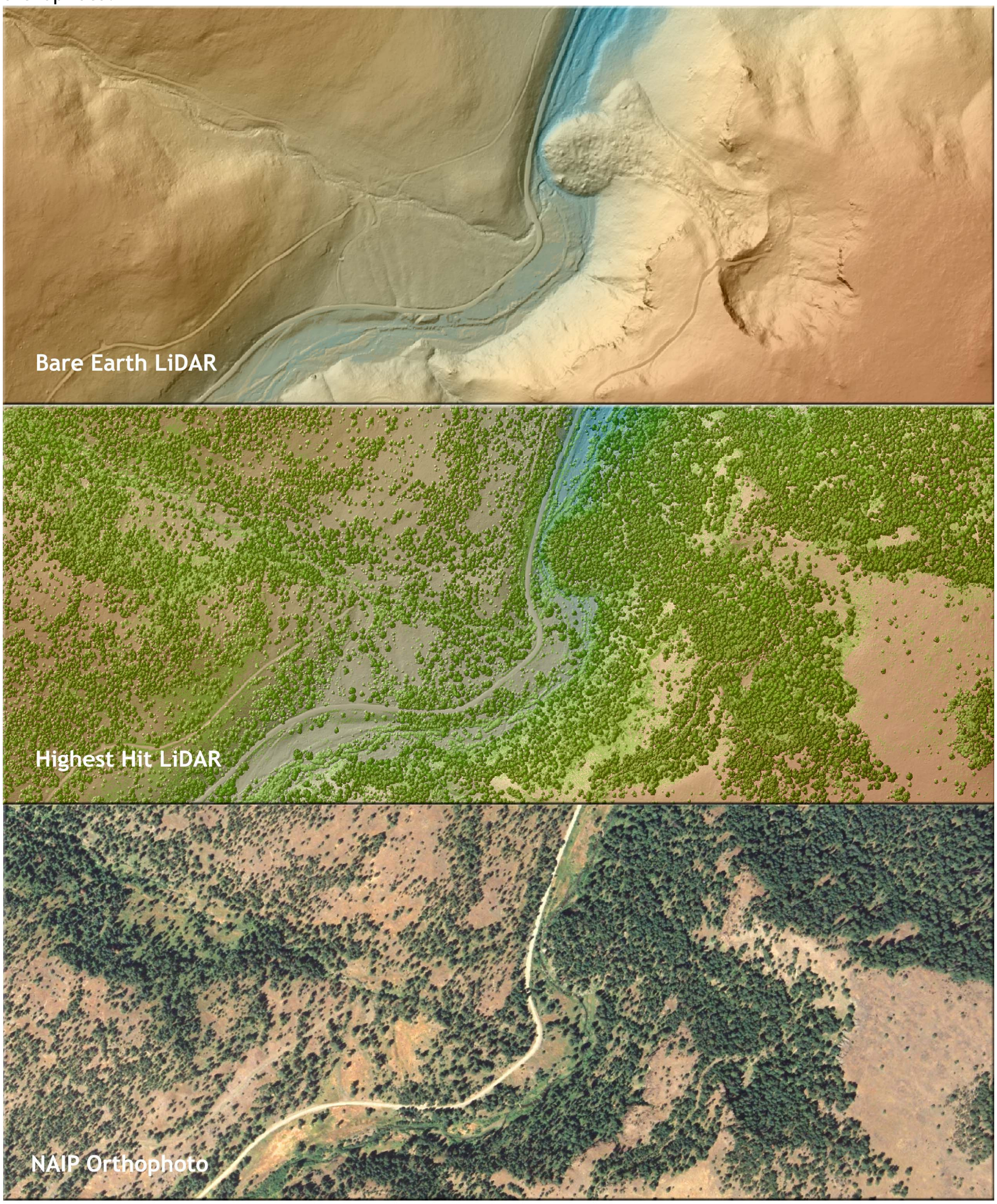
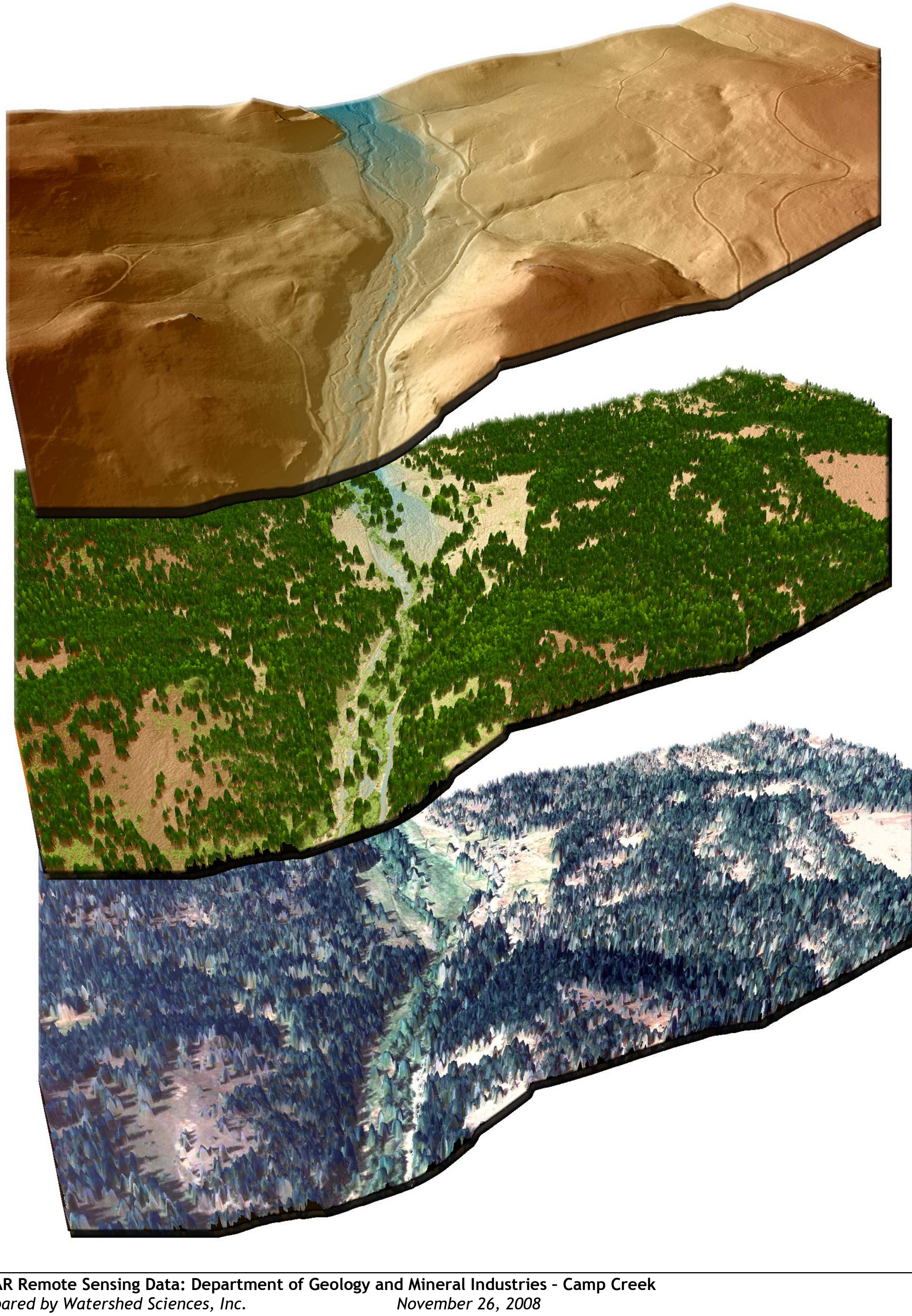


Figure 6.3. Oblique view south over Camp Creek (quad 44118f7). Top image derived from bare earth LiDAR, middle image from highest hit LiDAR, and lower image is a NAIP orthophoto draped over highest hit LiDAR.



7. Glossary

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

2-sigma (σ) Absolute Deviation: Value for which the data are within two standard deviations (approximately 95^{th} 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 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.

8. Citations

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