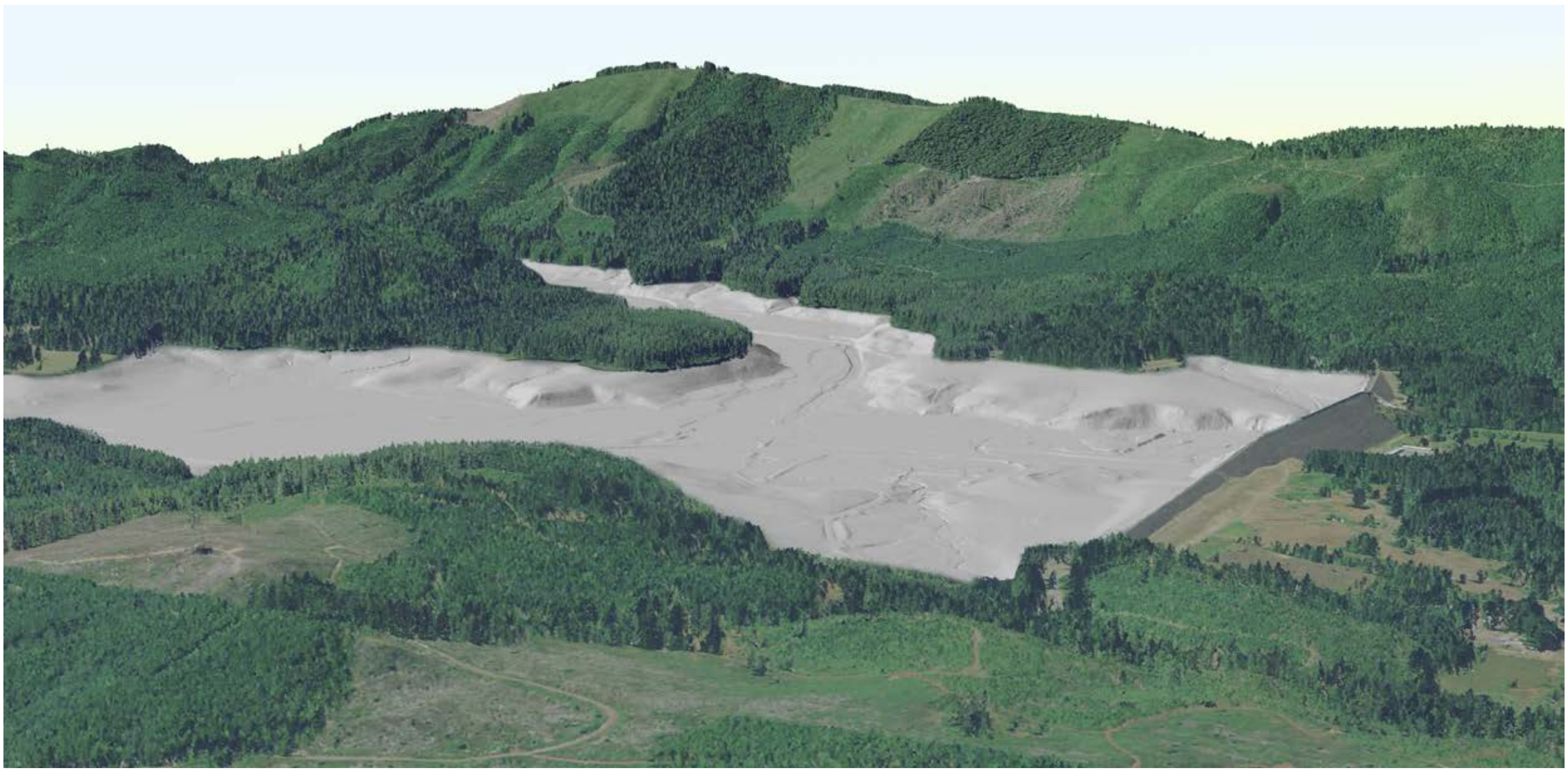
LIDAR REMOTE SENSING DATA COLLECTION
Fall Creek
MARCH 28, 2012



Bare earth DEM model of Fall Creek Lake with RGB-extracted point cloud data overlay. Lake has been drained, revealing below surface topography (gray). View to the South.

Submitted to:

David Smith & Associates
1734 SE Tacoma St
Portland, OR 97202

Submitted by:

Watershed Sciences
421 SW 6th Avenue, Suite 800
Portland, OR 97204

LiDAR Remote Sensing Data:
Fall Creek, OR

TABLE OF CONTENTS

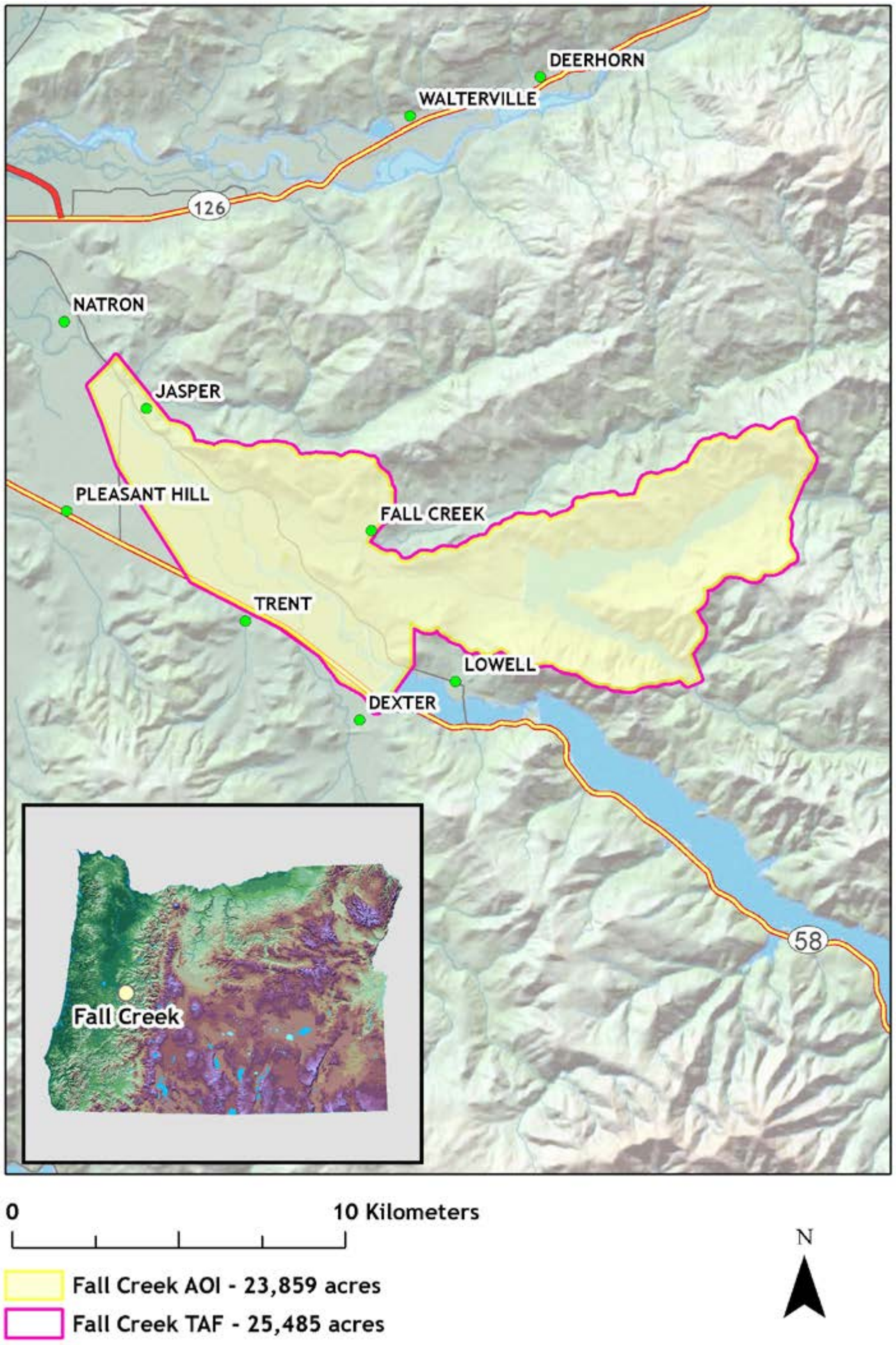
1. Overview 1
1.1 Study Area 1
2. Planning 2
2.1 Airborne Survey 2
2.2 Ground Survey 2
2.3 Field Operations 3
2.3.1 Safety 3
2.3.2 Field Preparations 3
3. Acquisition 4
3.1 Airborne Survey 4
3.1.1 LiDAR Instrumentation 5
3.1.2 Methodology 5
3.2 Ground Survey 6
3.2.1 Instrumentation 6
3.2.2 Monumentation 6
3.2.3 Methodology 7
3.2.4 Monument Accuracy 8
4. LiDAR Data Processing 9
4.1 LiDAR 9
4.1.1 Applications and Workflow Overview 9
4.1.2 Aircraft Kinematic GPS and IMU Data 10
4.1.3 Laser Point Processing 10
4.2 Intensity Normalization .... **Error! Bookmark not defined.**
5. LiDAR Accuracy and Resolution 11
5.1 Laser Point Accuracy 11
5.1.1 Relative Accuracy 12
5.1.2 Fundamental Vertical Accuracy 15
5.2 Data Density/Resolution 16
5.2.1 First Return Data Density 17
5.2.2 Ground-Classified Data Density 19
6. Deliverables 21
7. Selected Imagery 24
8. Glossary 26
9. Citations 26
Appendix A – Ground Survey Control Certification 27

1. Overview

1.1 Study Area

Watershed Sciences, Inc. (WSI) has collected Light Detection and Ranging (LiDAR) data in Fall Creek, OR, for David C. Smith & Associates and the US Army Corp of Engineers. The requested LiDAR Area of Interest (AOI) totals approximately 23,859 acres and Total Area Flown (TAF) totals 25,485 acres. All data for the Fall Creek study area are delivered in Universal Transverse Mercator (UTM) 10; horizontal datum: NAD83 (CORS96)/NAVD88 (Geoid03); Units: meters.

Figure1.1 *Fall Creek project area.*



2. Planning

The Fall Creek mission planning conducted at WSI is designed to optimize flight efficiency while meeting or exceeding project accuracy and resolution specifications. In this process, we prepare for known factors such as GPS and Global Navigation Satellite System (GNSS[1]) constellation quality, and availability and resource allocation. In addition, a variety of logistical barriers are anticipated, including air space restrictions and ground personnel logistics. Finally, weather hazards and conditions affecting flight are continuously monitored, due to their impact on the daily success of airborne and ground operations.

2.1 Airborne Survey

In preparation for data collection, flightlines for the entire buffered project area are developed using ALTM Nav V2.6.1.5. This ensures that data quality and coverage conditions are met while optimizing flight paths for minimal flight times. For the Fall Creek project, settings are configured in order to yield an average native pulse density of ≥ 8 pulses per square meter over terrestrial surfaces. While ALTM Nav assists in planning the spatial details of the project, this information is supplemented by real-time temporal observations in the project area.

2.2 Ground Survey

During every LiDAR acquisition, two GNSS base stations continually collect static GNSS data. The data are collected over survey benchmark control points for the duration of the flight in order to provide redundancy in data coverage. The planned locations for these control points are determined prior to field deployment, and the suitability of these locations is verified in the field. National Geodetic Survey (NGS) benchmarks are preferred for control points, when available. When they are unavailable, WSI establishes additional monuments within the project area in accordance with state survey protocol. In addition to these static sessions, WSI conducts real-time kinematic (RTK) surveys to collect ground control points for data accuracy verification during data processing. All acquisition occurs during optimal GNSS conditions (e.g., 6 or more satellites and a Position Dilution of Precision [PDOP] below 3.0). Daily forecasts from Trimble Planning software ensure that these conditions are met. This information is then supplemented in the field with other factors to determine ideal acquisition times and locations.

Trimble base station collecting static data

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

2.3 Field Operations

2.3.1 Safety

Safety is paramount during all WSI endeavors. At all times, safety in the field is ensured by strict adherence to the WSI Field Safety Plan. This plan addresses among other topics, drug and alcohol policies, personal safety policies, communication, incident mitigation, emergency procedures, and vehicle safety. Safety pertaining to flight and ground procedures was ensured by adherence to the WSI Flight Operations Manual and Ground Support Operating Procedures documents, which outline responsibilities, procedures and safety policies particular to each task.

2.3.2 Field Preparations

Successful data acquisition relies on a concerted planning effort between the flight and ground crews. Prior to each flight, the most suitable times to target for acquisition were determined by the field crews using all available methods. These include:

- Monitoring weather conditions to ensure optimal and safe data collection conditions
- Utilizing the ALTM Nav flight plan and acquisition maps to target the area
- Utilizing a Google Earth .kml of the flight plan to assess control monument and RTK collection locations
- Checking the satellite constellation forecast to ensure continual quality GNSS coverage
- Verifying the presence and functionality of all operational and safety equipment
- Creating a detailed plan and communicating with all individuals involved

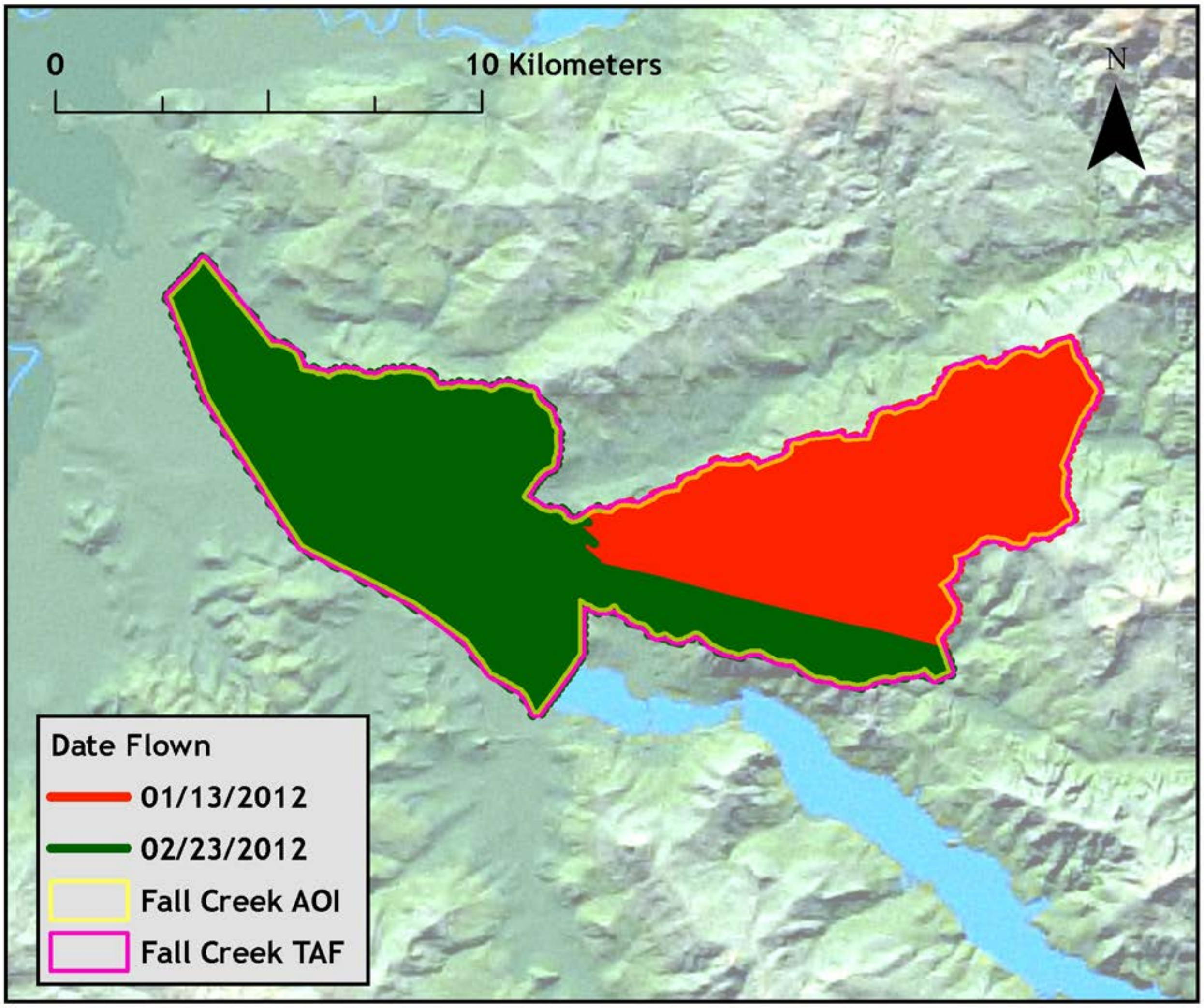
These preparations are designed to facilitate a safe, productive course of data acquisition. The details of acquisition and processing for the Fall Creek project are further described in the following sections.

3. Acquisition

3.1 Airborne Survey

Acquisition on the Fall Creek project area was initiated on January 13, 2012 and completed on February 23, 2012 (see figure below).

Figure 3.1 *Fall Creek flightlines detailing date flown.*



3.1.1 LiDAR Instrumentation

This LiDAR survey utilized an Optech Orion mounted in a Cessna Caravan 208B aircraft. The LiDAR system was set to acquire ≥100,000 laser pulses per second (i.e., 100 kHz pulse rate) and flown at 800 m above ground level (AGL), capturing a scan angle of ±14^{o} from nadir[2]. The survey implemented opposing flight lines with side-lap of ≥50% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. 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 is measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude is described as pitch, roll, and yaw (heading) and is measured 200 times per second (200 Hz) from an onboard inertial measurement unit (IMU).

Cessna Caravan 208B owned by WSI

Table 3.1 *LiDAR Survey Specifications*

Sensor	Optech Orion
Survey Altitude (AGL)	800 m
Pulse Rate	>100kHz
Pulse Mode	Single
Mirror Scan Rate	70 Hz
Field of View	28^{o} (±14^{o} from nadir)
Roll Compensated	20^{o} available at max FOV
Overlap	100% (60% Side-lap)

3.1.2 Methodology

During the acquisition, the sensor operators constantly monitored the data collection settings (e.g. pulse rate, power setting, scan rate, gain, field of view, pulse mode). For each flight, the crew performed airborne calibration maneuvers designed to improve the calibration results during the data processing stage. They were also in constant communication with the ground crew to ensure proper ground GPS coverage for data quality. Weather conditions were constantly assessed in flight, as adverse conditions not only affect data quality, but can prove unsafe for flying.

[2] 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".

Table 3.2 *Acquisition Resource Utilization for project area flown.*

Days on Project	Weather % Flyable	Utilized (hrs/day)	Flight Time
5	31.33	1.88	9.4 hours

3.2 Ground Survey

During every LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over either pre-existing or newly set monuments. After the airborne survey, the static GNSS data were processed using triangulation with Continuously Operating Reference Stations (CORS) and checked using the Online Positioning User Service (OPUS[3]) to quantify daily variance. Additionally, a daily RTK survey was conducted to collect ground control points. These data are then used in the processing of the LiDAR data acquired during the flight.

3.2.1 Instrumentation

WSI owns and operates multiple sets of Trimble GPS and Global Navigation Satellite System (GNSS[4]) dual-frequency L1-L2 receivers used in both static and RTK surveys (listed in the table below).

Table 3.3 *GPS and GNSS Receivers used in the Fall Creek ground survey.*

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2	TRM55971.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_Model2	Static & RTK

3.2.2 Monumentation

Existing and established survey benchmarks serve as control points during LiDAR acquisition. All monumentation established by WSI is set using 5/8" x 30" rebar topped with a 2" aluminum cap marked with the monument name, date and "WATERSHED SCIENCES INC., CONTROL" across the top. For a list of monuments used in the project area (WSI and NGS), please see **Appendix A**.

[3] OPUS is run by the National Geodetic Survey to process corrected monument positions.
[4] GNSS consists of the U.S. GPS constellation and Soviet GLONASS constellation.

3.2.3 Methodology

During acquisition, each aircraft is assigned a ground crew of two members with two R7 receivers and one R8 receiver. The ground crew vehicles are equipped with standard safety and field survey supplies. For the Fall Creek project area, all static control points are observed for a minimum of one 2-hour session and one 4-hour session. At the beginning of every session the tripod and antenna are reset, resulting in two independent instrument heights and data files. Fixed height tripods are used when available. Data are collected at a rate of 1 Hz using a ten degree mask on the antenna.

The ground crew uploads the GPS data to our Dropbox website 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 three CORS stations resulting in a fully adjusted position. After multiple sessions of data are collected at each monument, accuracy is calculated. This information leads to a rating of the monument based on FGDC-STD-007.2-1998[5] at the 95% confidence level. When a statistically 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.

Multiple differential GNSS units are used in the ground-based RTK portion of the survey. A Trimble R7 base unit is set up over an appropriate monument to broadcast a kinematic correction to a roving R8 unit. This RTK survey allows for precise location measurement ($\sigma \leq$ 2.0 cm).

Trimble Base Station setup for RTK collection in Fall Creek study area.

All RTK measurements are made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 and in view of at least six satellites by the stationary reference and roving receiver. For RTK data, the collector begins recording after remaining stationary for five seconds then calculates the pseudo range position from at least three epochs with the relative error less than 1.5 cm horizontal and 2 cm vertical. 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 periods. In order to facilitate comparisons with LiDAR data, 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.

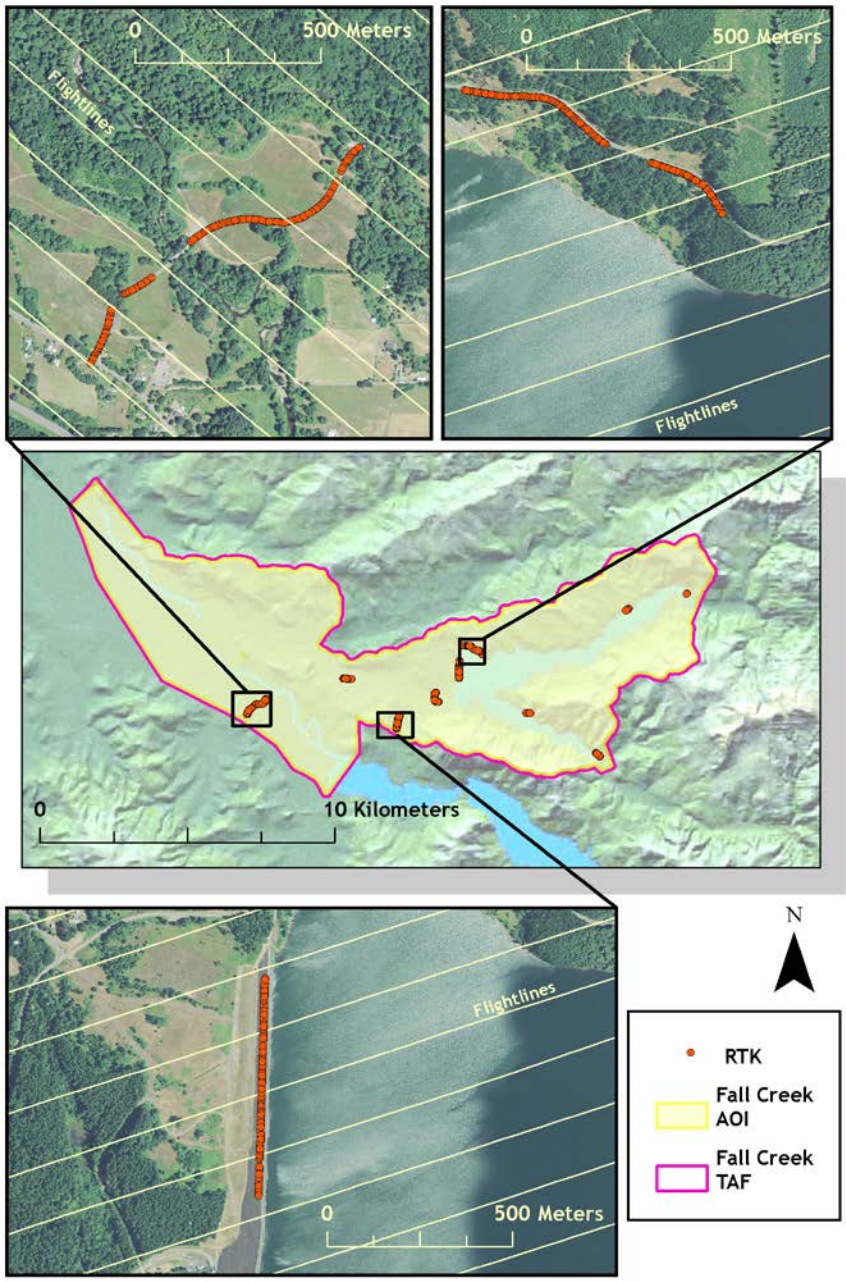
[5] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards (Part 2 table 2.1)
[6] U.S. Army Corps of Engineers , Engineer Research and Development Center Topographic Engineering Center software

3.2.4 Monument Accuracy

FGDC-STD-007.2-1998[7] at the 95% confidence level for this project:

St Dev $_{NE}$: 0.020 m
St Dev $_{z}$: 0.020 m

Figure 3.2 *Sample selection of RTK point locations of the Fall Creek project area, displayed over 2010 NAIP imagery.*



[7] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards (Part 2 table 2.1)

4. LiDAR Data Processing

4.1 LiDAR

LiDAR and GNSS ground data are received in the office on a daily basis, after having undergone a rapid quality assurance assessment in the field. Once in the office, the data enter into the workflow below.

4.1.1 Applications and Workflow Overview

1. Resolve kinematic corrections for aircraft position data using kinematic aircraft GNSS and RTK QA/QC GNSS data.
   Software: POSGNSS v. 5.3, Trimble Business Center v.2.30
2. Develop a smoothed best estimate of trajectory (SBET) file blending post-processed aircraft position with attitude data. Sensor head position and attitude are calculated throughout the survey. The SBET data are used extensively for laser point processing.
   Software: IPAS Pro v.1.35
3. Calculate laser point position by associating the SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in .las (ASPRS v.1.2) format. Resolve mission wide IMU configuration offsets. Data conversion to orthometric elevation
   Software: LiDAR Management Suite (LMS) 2.1
4. Import raw laser points into computationally manageable blocks (fewer than 500 MB) to perform manual relative accuracy calibration and filtered for pits/birds. Ground points are then classified for individual flight lines (to be used for relative accuracy testing and calibration).
   Software: TerraScan v.10.009, Custom Watershed Sciences software
5. Use ground classified points for each flight line, the relative accuracy is tested. Automated line-to-line calibrations are then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calibrations are performed on ground classified points from paired flight lines. Every flight line is used for relative accuracy calibration.
   Software: TerraMatch v.11.003, Custom Watershed Sciences software
6. Import position and attitude data. Resulting data are classified as ground and non-ground points. Statistical absolute accuracy is assessed via direct comparisons of ground classified points to ground RTK survey data.
   Software: TerraScan v.10.009, ArcMap v9.3 and 10.0, TerraModeler v.10.006, Custom Watershed Sciences software

4.1.2 Aircraft Kinematic GPS and IMU Data

LiDAR survey datasets are referenced to 1 Hz static ground GNSS data collected over a pre-surveyed monument with known coordinates. While surveying, the aircraft collects 2 Hz kinematic GNSS data and the inertial measurement unit (IMU) collects 200 Hz attitude data. POSGNSS v. 5.3 is used to process the kinematic corrections for the aircraft. The static and kinematic GNSS data are then post-processed after the survey to obtain an accurate GNSS solution and aircraft positions. IPAS Pro v.1.35 is used to develop a trajectory file including corrected aircraft position and attitude information. The trajectory data for the entire flight survey session are incorporated into a final smoothed best estimated trajectory (SBET) file containing accurate and continuous aircraft positions and attitudes.

4.1.3 Laser Point Processing

Laser point coordinates are computed using the LMS 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) are assigned an associated (x, y, and z) coordinate along with unique intensity values (0-255). The data are output into large LAS v. 1.2 files; each point maintains the corresponding scan angle, return number (echo), intensity, and x, y, and z (easting, northing, and elevation) information. The system allows up to four range measurements per pulse, and all discernible laser returns are processed for the output dataset. Flightlines and LiDAR data are then reviewed to ensure complete coverage of the project area and positional accuracy of the laser points.

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

The LiDAR points are then filtered for noise, pits and birds by screening for absolute elevation limits, isolated points and height above ground. Supervision of point classes occurs, and spurious points are removed. For a *.las file 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, and haze.

Internal calibration is refined using TerraMatch. Points from overlapping lines are tested for internal consistency and final adjustments are made for system misalignments (i.e., pitch, roll, heading offsets and mirror scale). Automated sensor attitude and scale corrections yield 3-5 cm improvements in the relative accuracy. Once the system misalignments are corrected, vertical GNSS drift is resolved and removed per flight line, yielding a slight improvement (<1 cm) in relative accuracy. In summary, the data completes a robust calibration designed to reduce inconsistencies from multiple sources (i.e., sensor attitude offsets, mirror scale, GNSS 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: deeply incised stream banks and dense vegetation. In some cases, ground point classification includes known vegetation (e.g., understory, low/dense shrubs, etc.) and these points are then manually reclassified as non-grounds. Ground surface rasters are developed from triangulated irregular networks (TINs) of ground points.

5. LiDAR Accuracy and Resolution

5.1 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 5.1. *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

5.1.1 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 GNSS/IMU drift.

Operational measures taken to improve relative accuracy:

1. Low Flight Altitude: Terrain following is targeted at a flight altitude of 1,400 m 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 is reduced to a maximum of ±14° from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.
4. Quality GNSS: Acquisition occurs during optimal GNSS conditions (e.g., 6 or more satellites and PDOP 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., <2 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GNSS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution.
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.

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 are calculated and applied to resolve misalignments. The raw divergence between lines is computed after the manual calibration and reported for the project area.
2. Automated Attitude Calibration: All data are tested and calibrated using TerraMatch's automated sampling routines. Ground points are classified for each individual flight line and used for line-to-line testing. System misalignment offsets (pitch, roll and heading) and mirror scale, are solved for each individual mission. Attitude misalignment offsets (and mirror scale) occurs for each individual mission. The data from each mission are then blended when imported together to form the delivered area.
3. Automated Z Calibration: Ground points per line are utilized to calculate the vertical divergence between lines caused by vertical GNSS drift. Automated Z calibration is the final step employed for relative accuracy calibration.

Relative Accuracy Calibration Results

Relative accuracy refers to the internal consistency of the data set and is measured as the divergence between points from different flightlines within an overlapping area. Divergence is most apparent when flightlines 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.

Relative accuracy statistics are based on the comparison of 106 flightlines and over 1 billion points. Relative accuracy is reported for the portion of the study area shown in **Figure 5.1** below.

- Project Average = 0.05 m (0.15 ft.)
- Median Relative Accuracy = 0.04 m (0.14 ft.)
- 1σ Relative Accuracy = 0.06 m (0.18 ft.)
- 2σ Relative Accuracy = 0.07 m (0.24 ft.)

Figure 5.1 *Relative Accuracy Covered Area.*

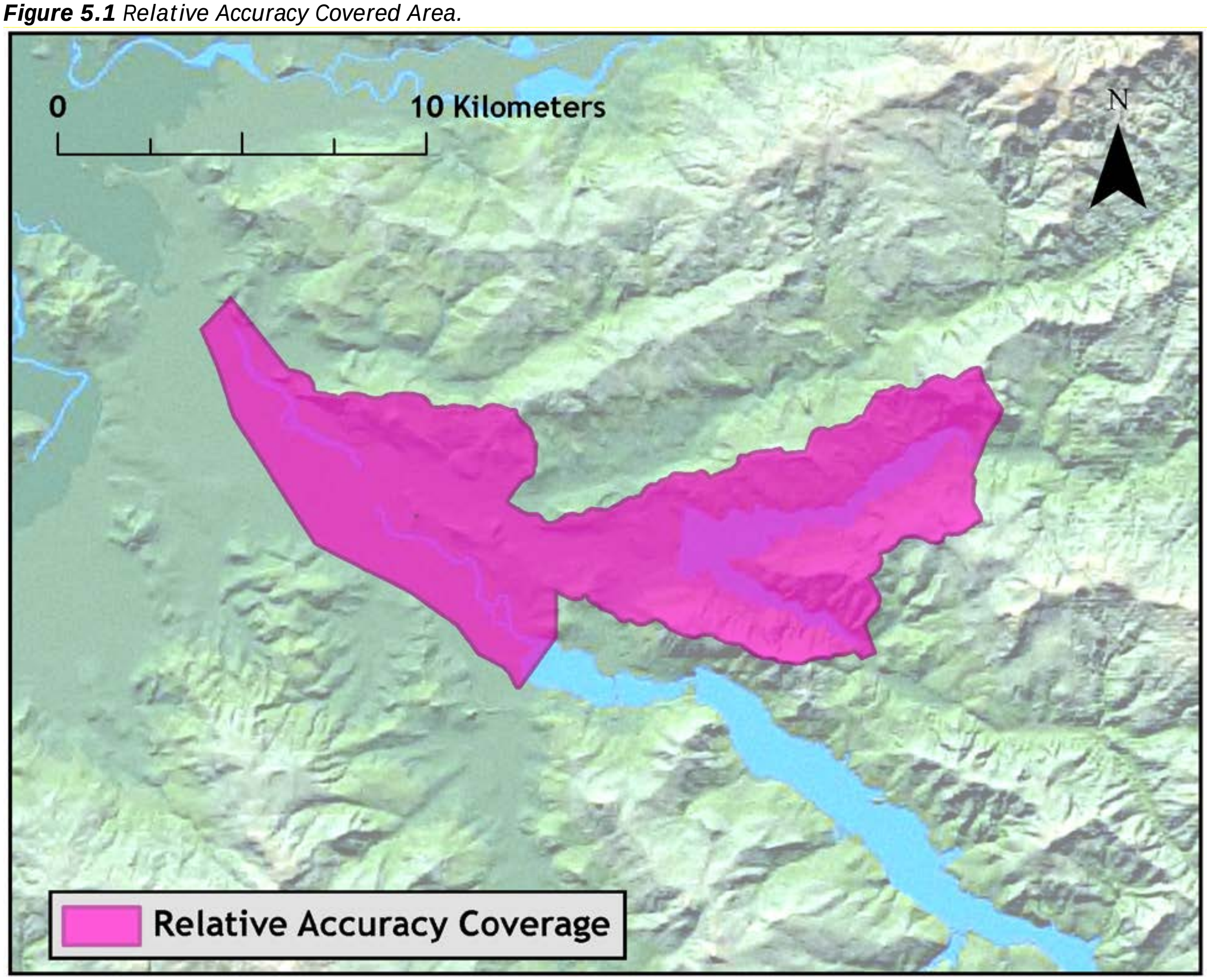


Figure 5.2 *Statistical relative accuracies, non-slope-adjusted.*

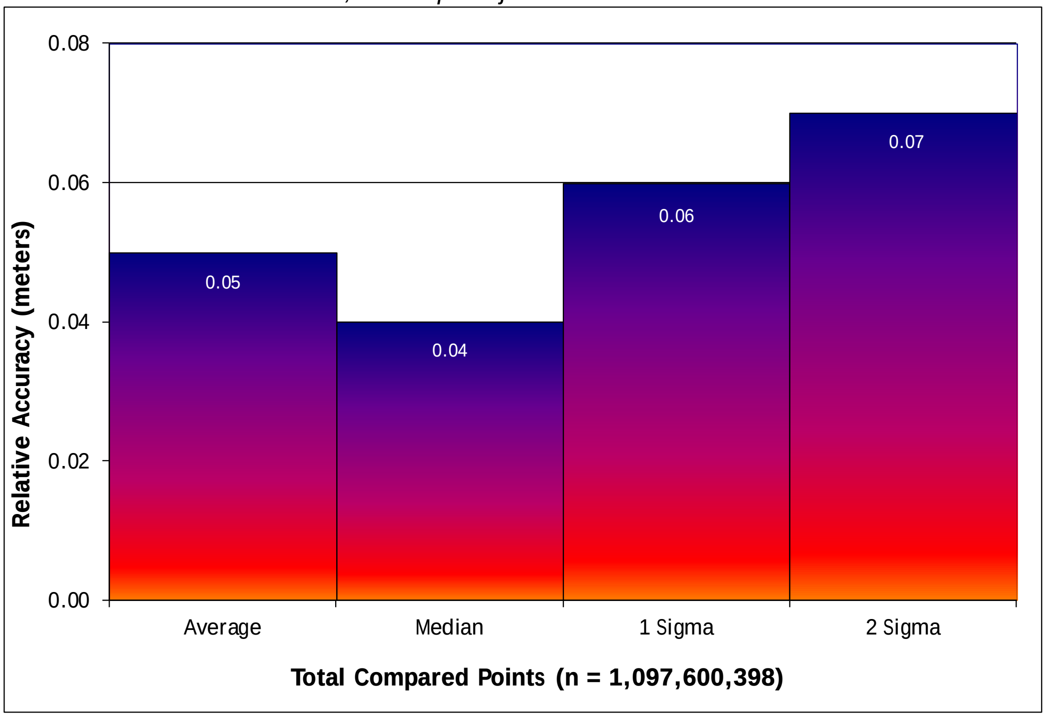
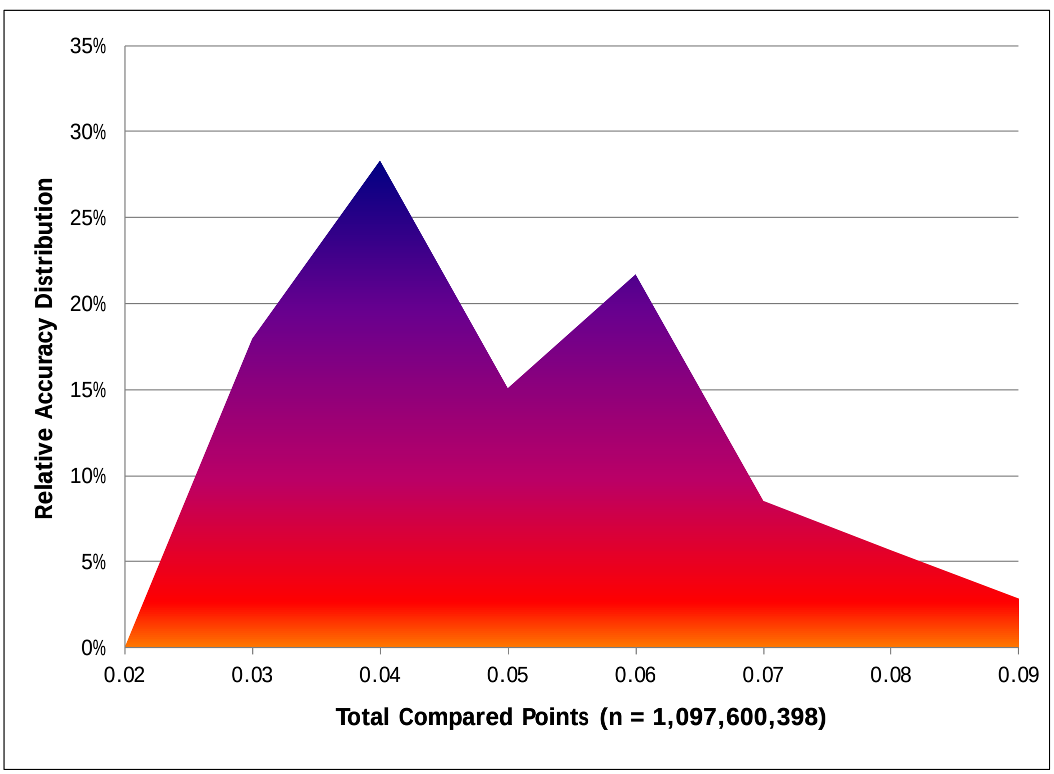


Figure 5.3 *Percentage distributions of relative accuracies, non-slope-adjusted.*



5.1.2 Fundamental Vertical Accuracy

FVA accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998). FVA compares known RTK ground survey points to the closest laser point. FVA uses ground control points in open areas where the LiDAR system has a "very high probability" that the sensor will measure the ground surface and is evaluated at the 95% percentile of $RMSE_{Z.}$ For the Fall Creek LiDAR survey, 606 RTK points were collected.

For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet," in accordance with the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). The table below details summary statistics for FVA.

Table 5.2 *Fundamental Vertical accuracy: deviation between laser points and hard surface RTK survey points.*

Sample Size (n): 606	
Root Mean Square Error (RMSE): 0.02m	
<u>Fundamental Vertical Accuracy</u>: Compiled to Meet 0.05m fundamental vertical accuracy at 95% confidence level (1.96 x $RMSE_z$) in open terrain	
Standard Deviations	**Minimum Δz:** -0.09 m
1 sigma (σ): 0.02 m	**Maximum Δz:** 0.09 m
2 sigma (σ): 0.05 m	**Average Δz:** 0.00 m

Figure 5.4 *Fundamental Vertical Accuracy coverage.*

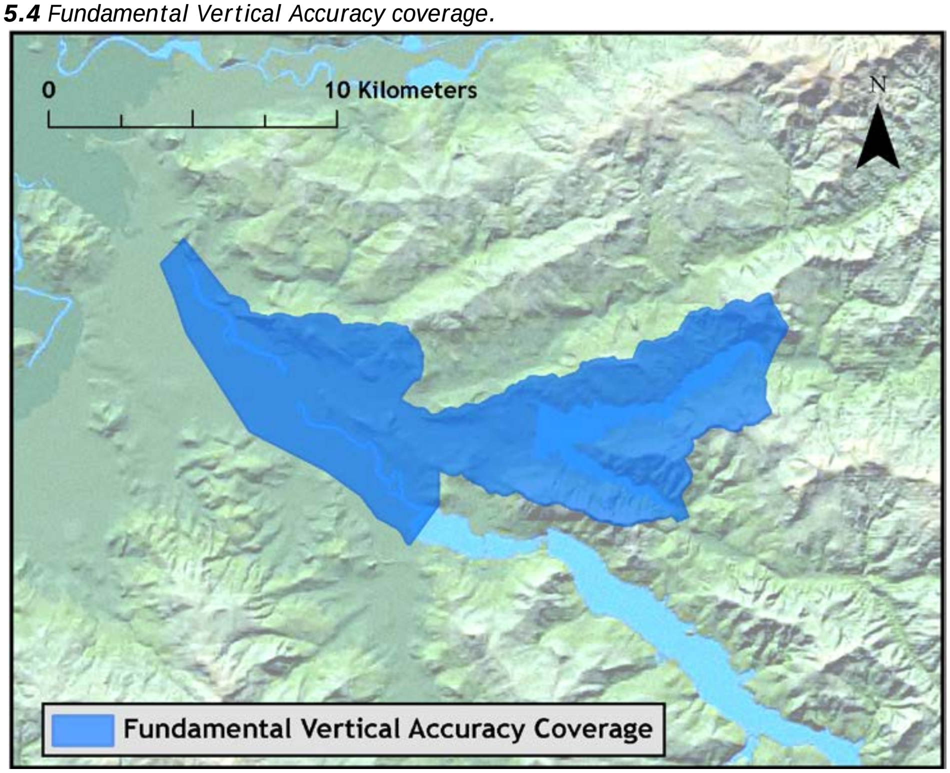


Figure 5.5 *Fundamental Vertical accuracy histogram statistics.*

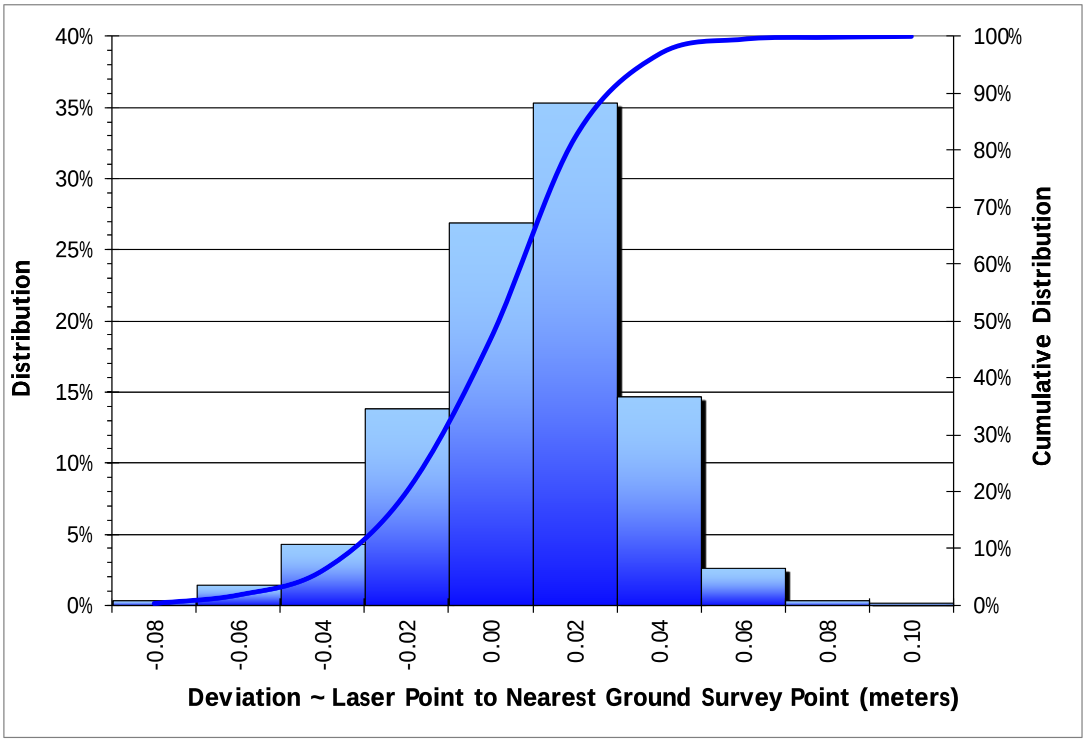
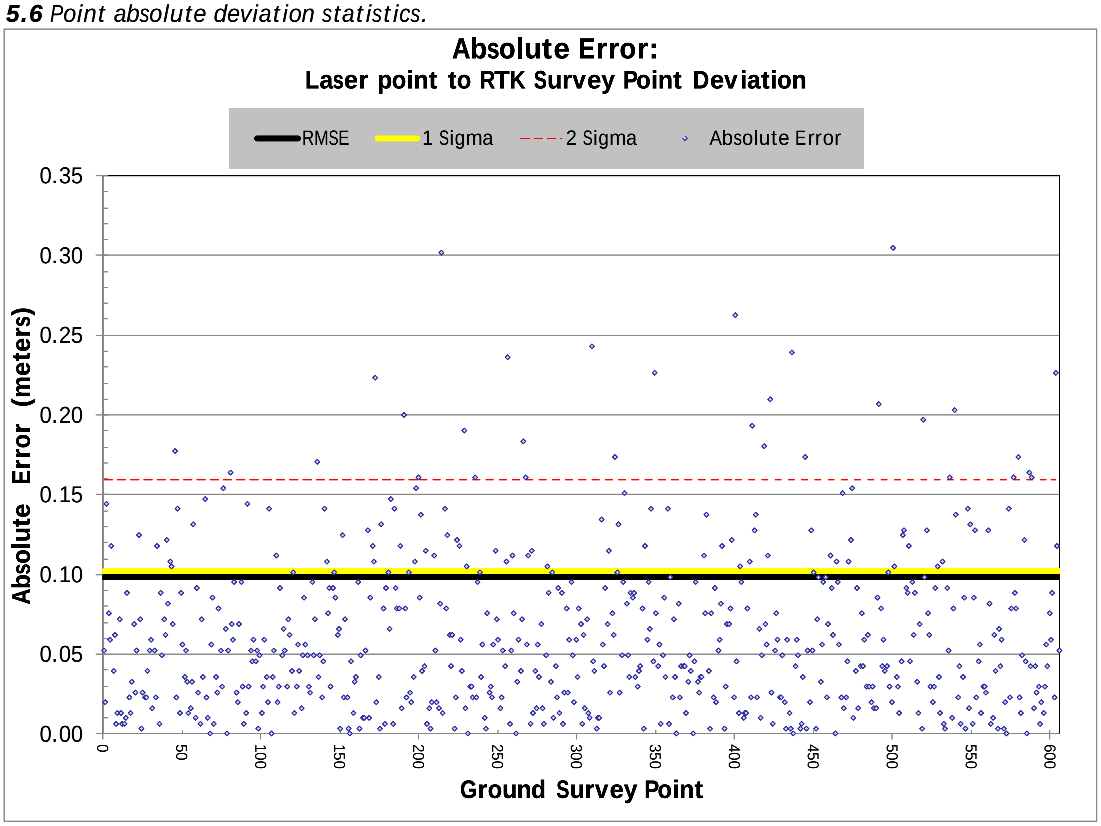


Figure 5.6 *Point absolute deviation statistics.*



5.2 Data Density/Resolution

Some types of surfaces (e.g., open 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 (shown below) have been calculated based on first return laser pulse density and ground-classified laser point density.

Table 5.3 *Average densities for the Fall Creek project area.*

Average Pulse Density	Average Ground Density
10.88 pts./m^2	1.81 pts./m^2

5.2.1 First Return Data Density

Figure 5.7 *Histogram of first return laser pulse density for the Fall Creek project area.*

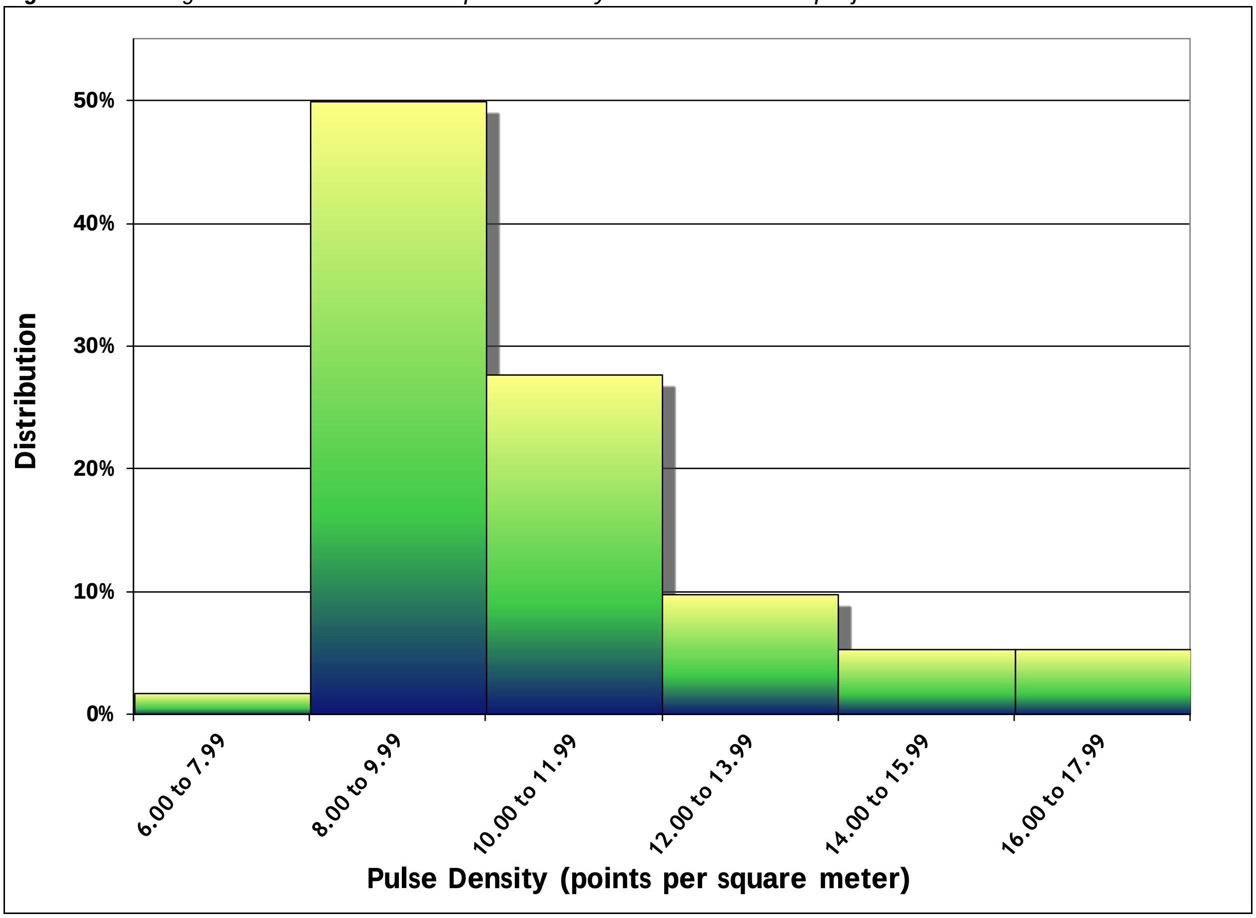
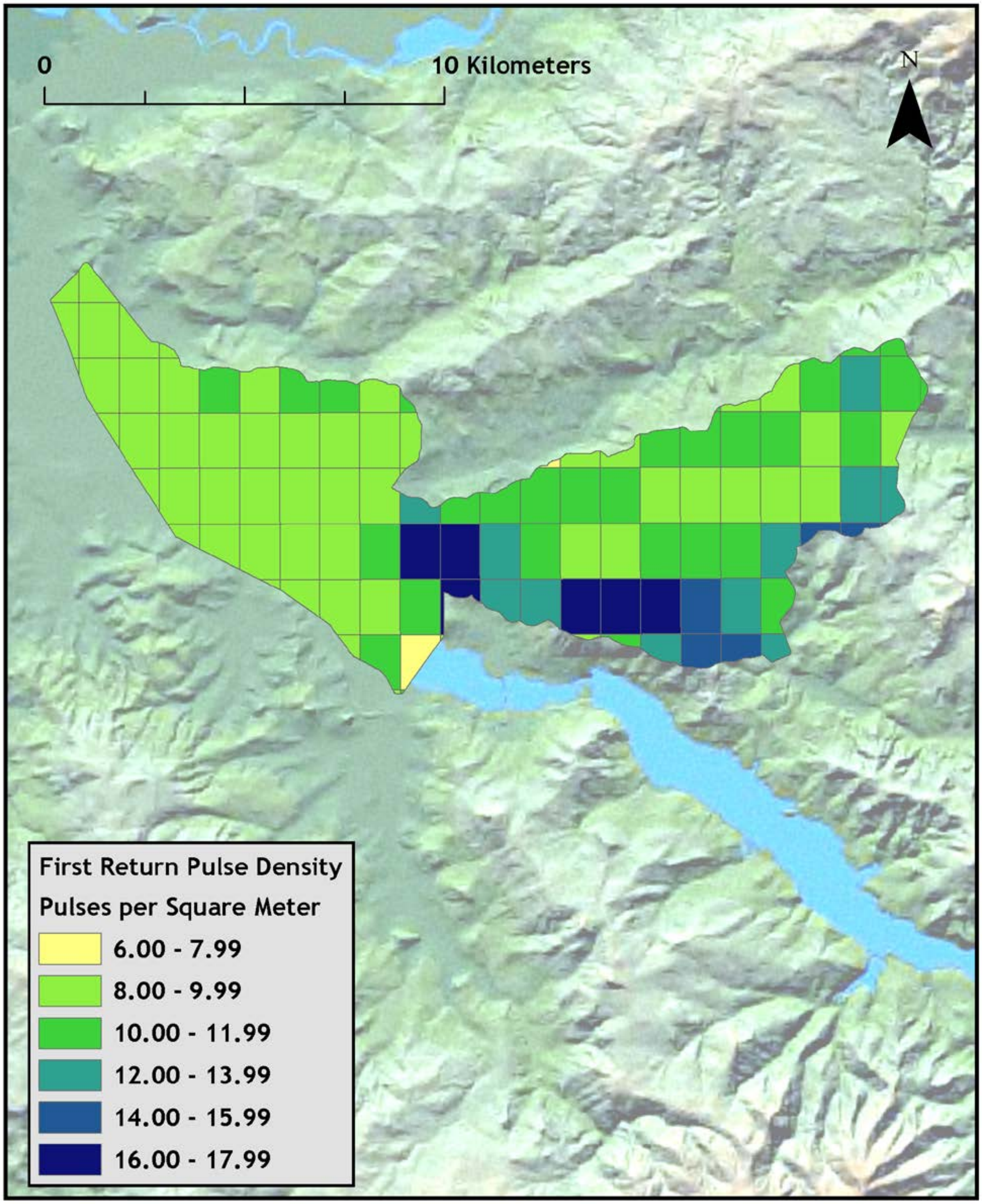


Figure 5.8 *First return laser pulse data density for the Fall Creek project area.*



5.2.2 Ground-Classified Data Density

Figure 5.9 *Histogram of ground-classified laser point density for the Fall Creek project area.*

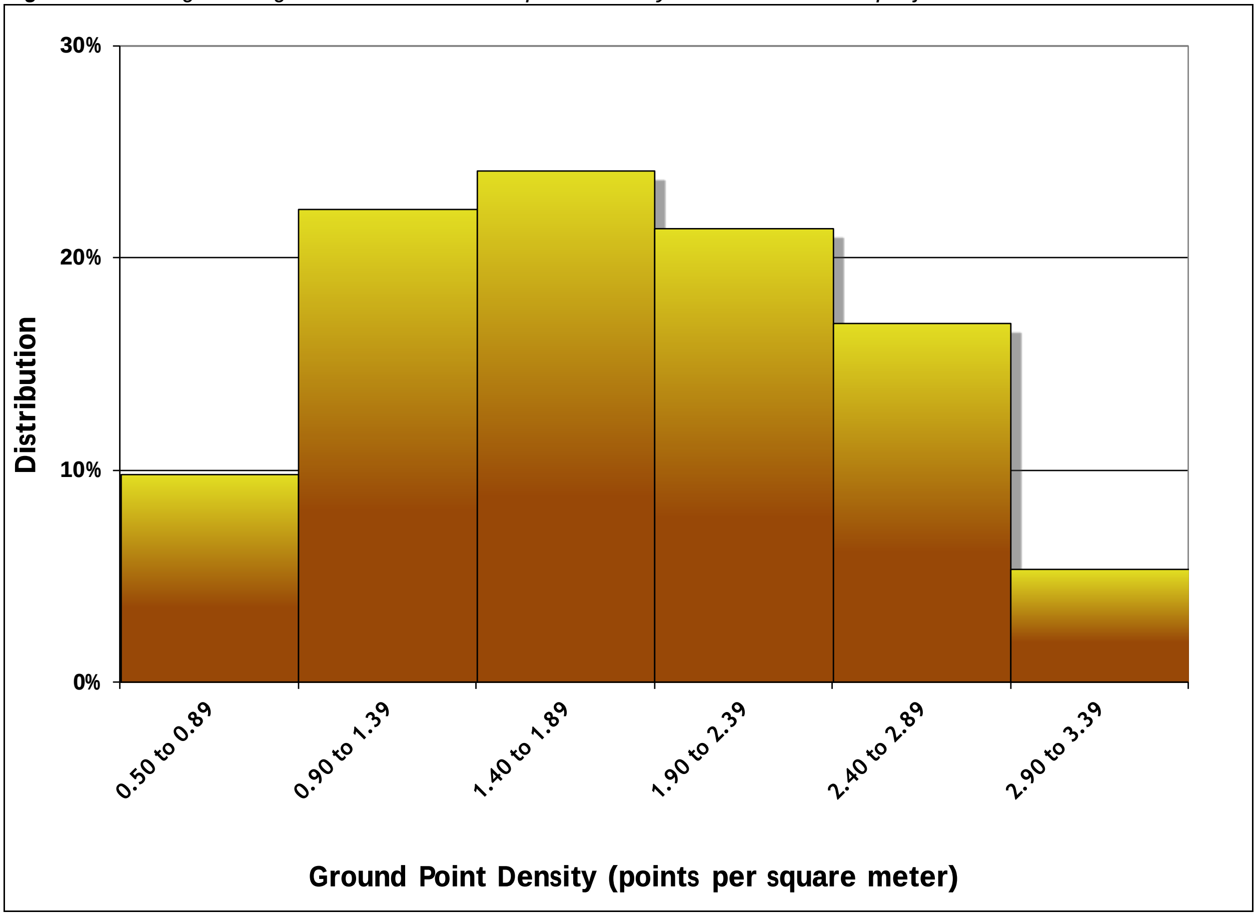
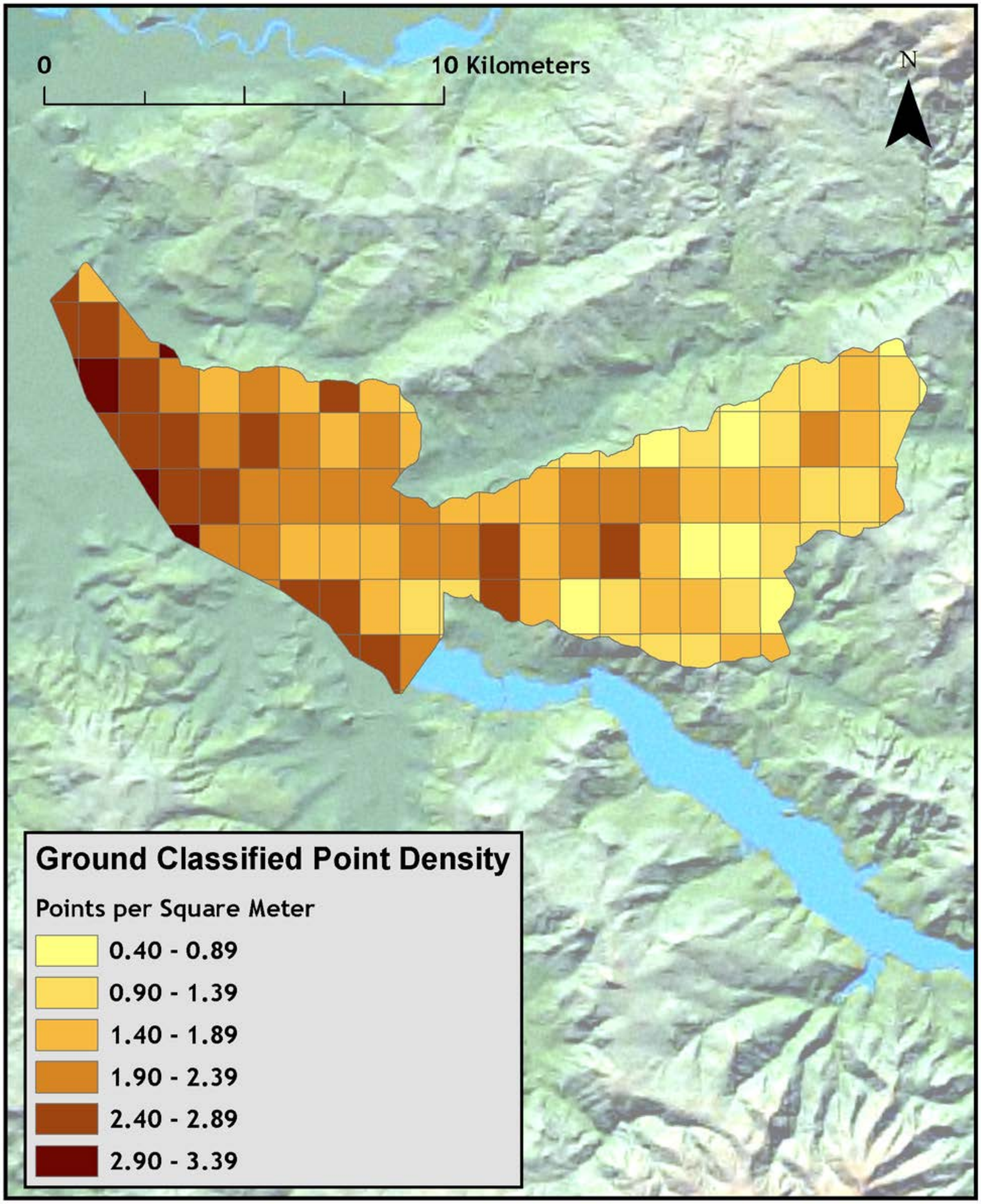


Figure 5.10 *Ground-classified laser point data density for the Fall Creek project area.*



6. Deliverables

Point Data

- All return point data with intensity values in *.las v1.2.1 format (750m^2 tiles)
    - Classifications include Ground, Default, Water, and Model Key Points

Vector Data

- Intensity Tile delineations (750m^2 tiles)
- Area of interest
- Total Area Flown (project area and delivery area)
- Smoothed Best Estimated Trajectory (SBET)

Data Report

- Technical report (Word and PDF format) of survey summarizing:
    - Mission planning
    - Data acquisition
    - Point cloud processing
    - Summary statistics
    - Sample imagery
- FGDC compliant Metadata

Raster Data

- Intensity Images in GeoTiff format 0.5 meter resolution
    - 750 m^2 tile
- Bare Earth DEM 0.5 meter resolution
    - 1/4th USGS Quad
- Highest Hit DEM 0.5 meter resolution
    - 1/4th USGS Quad

Datum and Projection

Universal Transverse Mercator (UTM) 10 NAD83 (CORS96); NAVD88 (Geoid 03); Horizontal Units: meters; Vertical units: meters.

WSI

7. Certifications

Watershed Sciences provided LiDAR services for the Fall Creek study area as described in this report.

I, Mathew Boyd, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

Mathew Boyd
Principal
Watershed Sciences, Inc.

I, Christopher W. Yotter-Brown, being first dully sworn, say that as described in the Ground Survey subsection of the Acquisition section of this report was completed by me or under my direct supervision and was completed using commonly accepted standard practices. Accuracy statistics shown in the Accuracy Section have been reviewed by me to meet National Standard for Spatial Data Accuracy.

Christopher W. Yotter-Brown, PLS Oregon & Washington
Watershed Sciences, Inc
Portland, OR 97204

REGISTERED
PROFESSIONAL
LAND SURVEYOR
3/28/2012
OREGON
JULY 13, 2004
Christopher W. Yotter - Brown
60438 LS
RENEWAL DATE: 6/30/2012

8. Selected Imagery

Figure 7.1 Middle fork of the Willamette River fork, near Fall Creek Oregon. 3-D point cloud with RGB color extraction from 2010 NAIP orthophoto. View to the Southeast.

Figure 7.2 Dexter Reservoir. 3-D point cloud with RGB color extraction from 2010 NAIP orthophoto. View to the East.

9. 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.

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.

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.

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 50 and ALS 60 systems 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.

10. Citations

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

Federal Geographic Data Committee, 1998. Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy. Subcommittee for Base Cartographic Data, 25p.

Flood, M, (Ed.), 2004. ASPRS Guidelines-Vertical Accuracy Reporting for Lidar Data, V1.0. American Society for Photogrammetry and Remote Sensing (ASPRS) Lidar Committee, 20p.

Appendix A – Ground Survey Control Certification

Adjusted coordinates for the Fall Creek project areas.

	Datum NAD83(HARN)		GRS80
Base Station ID	Latitude (North)	Longitude (West)	Ellipsoid Height (m)
AI2001	43 55 19.2024	122 47 41.085	195.984
DSA_FALL_CK_01	43 57 12.9725	122 45 45.748	215.503

GPS base station locations for the Fall Creek project areas.