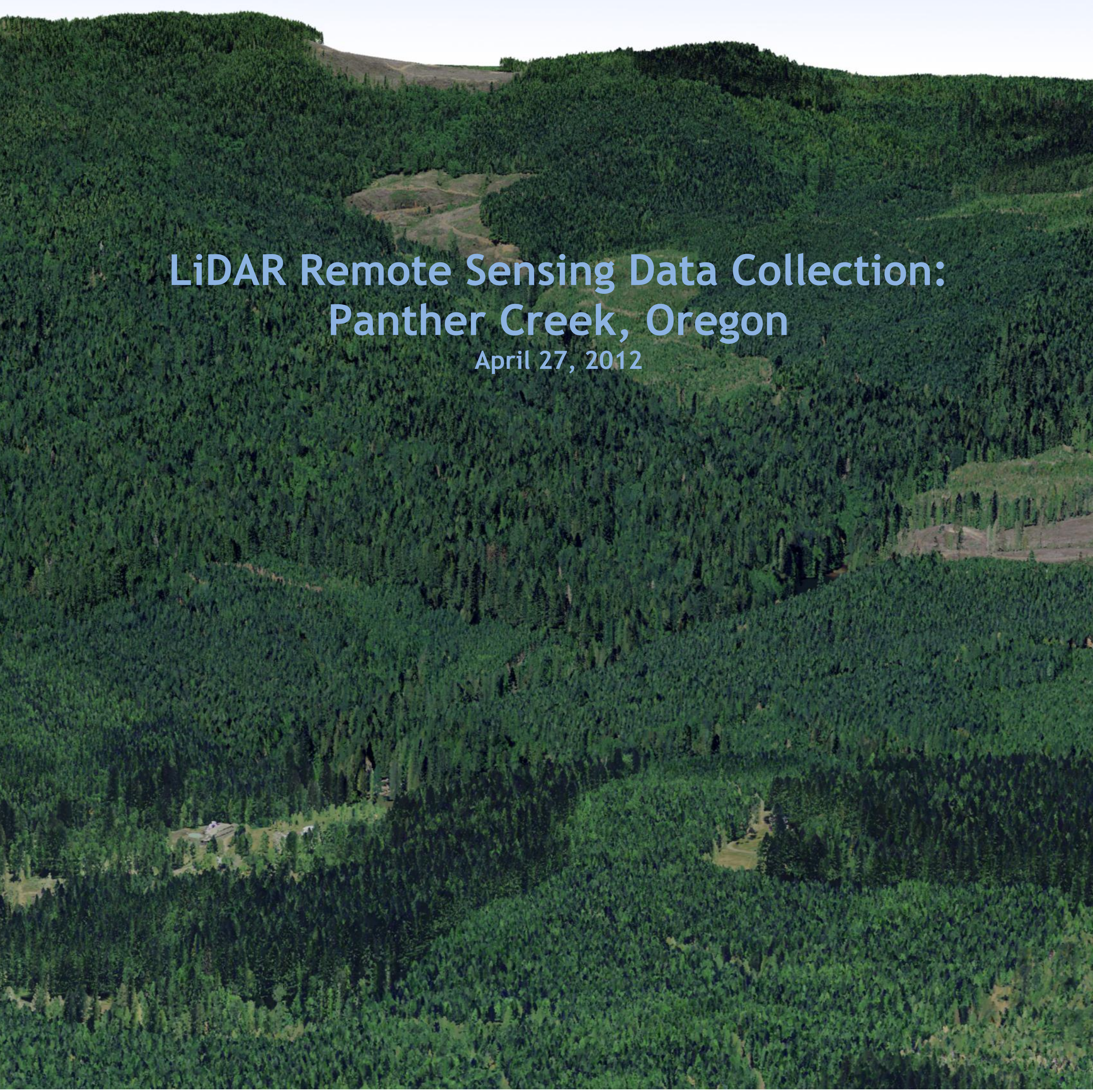


LiDAR Remote Sensing Data Collection: Panther Creek, Oregon

April 27, 2012

Submitted to:

Department of Interior
Bureau of Land Management
Oregon State Office
333 SW 3rd Ave
Portland, OR 97204

Submitted by:

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

LiDAR Remote Sensing Data:
Panther Creek, Oregon

TABLE OF CONTENTS

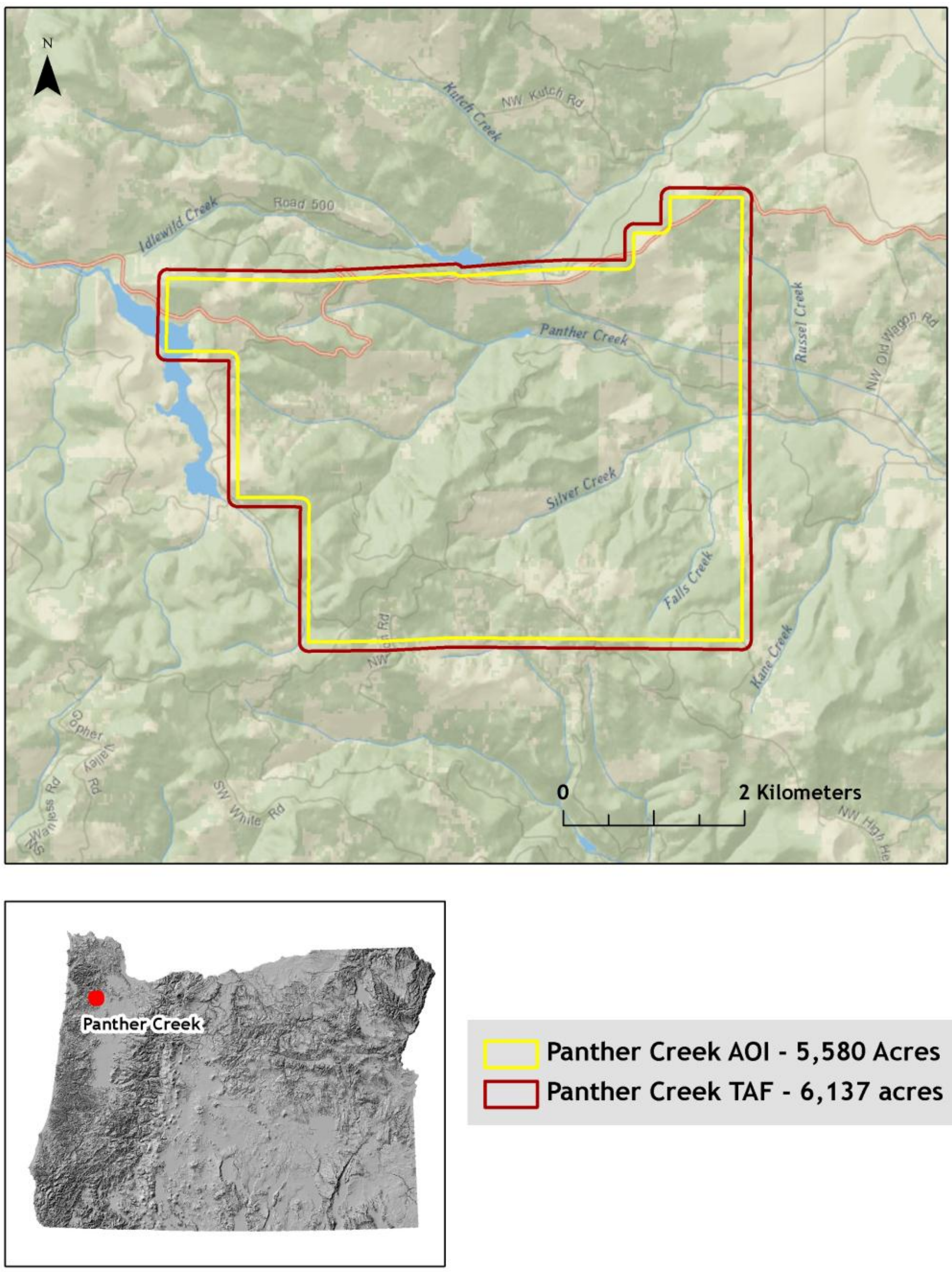
Watershed Sciences

1. Overview

1.1 Study Area

Watershed Sciences, Inc. collected Light Detection and Ranging data (LiDAR) of the Panther Creek study area for the United States Bureau of Land Management. The requested LiDAR Area of Interest (AOI) totals approximately 5,580 acres, and was buffered to ensure data coverage, resulting in a Total Area Flown (TAF) of 6,137 acres (**Figure 1.1**). This report reflects statistics for the overall LiDAR survey.

***Figure 1.1**. Panther Creek study area.*



1.2 Accuracy 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 Panther Creek data have the following accuracy statistics:

RMSE	1-sigma absolute deviation	2-sigma absolute deviation
0.04 meter	0.04 meter	0.07 meter

Data resolution specifications are for ≥8 points per square meter. Total average and ground pulse density statistics Panther Creek are as follows:

Total Pulse Density	Ground Pulse Density
8.91 points per square meter	0.76 points per square meter

1.3 Data Format, Projection, and Units

Panther Creek data are delivered in UTM Zone 10; NAD83(CORS96); NAVD88(Geoid03); Units: meters.

Deliverables include:

- All return point data in *.las v 1.2 format (Point data attributed with RGB values to follow) 500 x 500 meter tiles
- 1-meter resolution bare ground model ESRI GRID.
- 0.5-meter resolution intensity images in GeoTIFF format 500 meter x 500 meter tiles
- Shapefile of delivery area in 500 meter x 500 meter tile delineations
- Data Report summarizing data acquisition, processing, and summary statistics.

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 ALS60 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 ±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 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.

The Cessna Caravan is a powerful and stable platform, ideal for the mountainous terrain of the Pacific Northwest. The Leica ALS60 sensor head installed in the Caravan is shown on the right.

The area of 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 discernible 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*

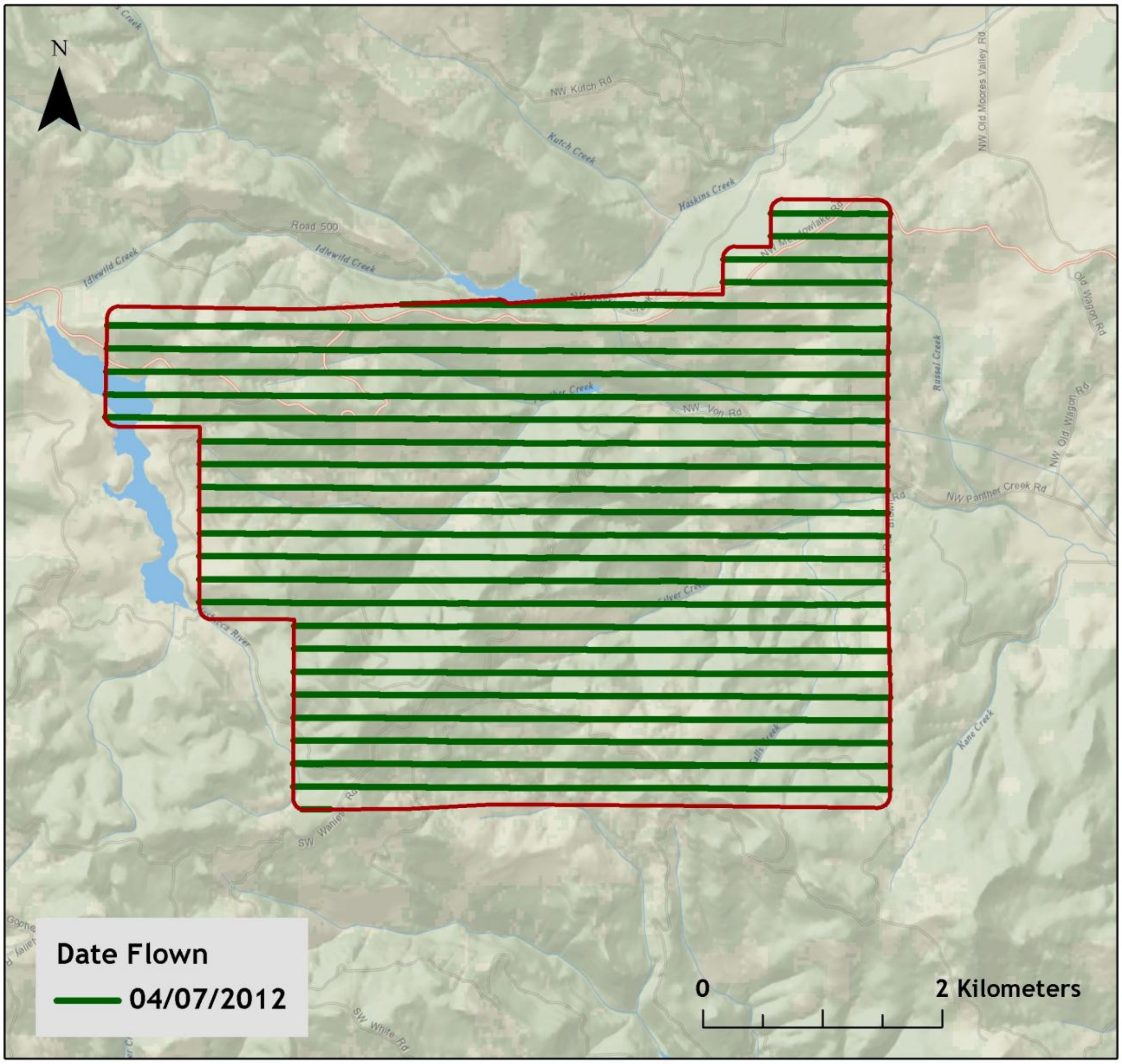
Sensor	Leica ALS60
Survey Altitude (AGL)	900 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	54 Hz
Field of View	28° (±14° from nadir)
Roll Compensated	Up to 20°
Overlap	100% (50% Side-lap)

[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".

2.2 LiDAR Acquisition

LiDAR data were collected for the Panther Creek study area on April 7, 2012. Flightlines are illustrated in **figure 2.1** below.

***Figure 2.1**. Panther Creek Flightlines.*



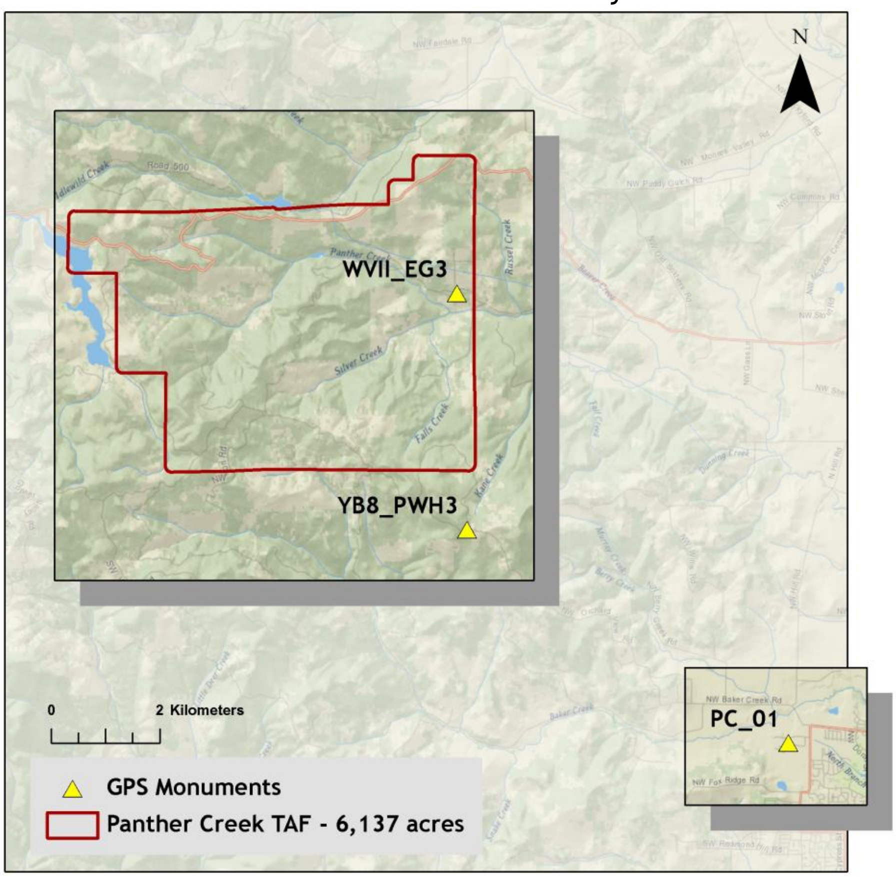
2.3 Ground Survey – Instrumentation and Methods

During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over monuments with known coordinates. Base station coordinates are provided in the table below. 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 each monument to confirm antenna height measurements and reported position accuracy. Base stations are listed in **Table 2.2** below and shown in **Figure 2.2**.

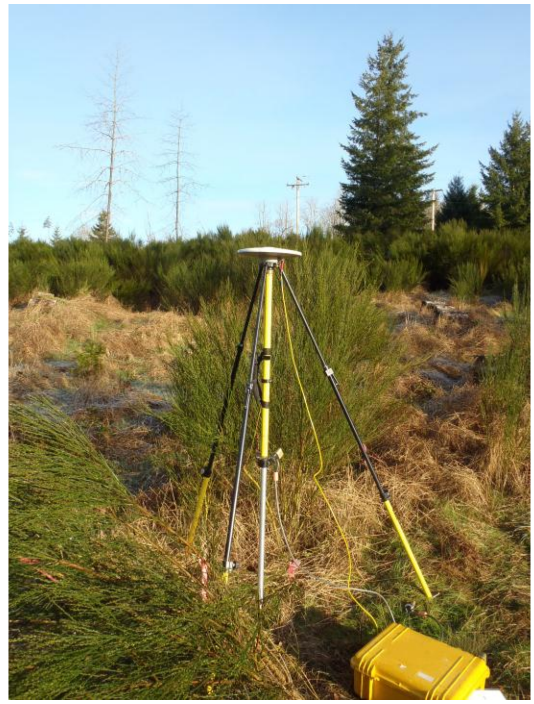
***Table 2.2**. Base Station Surveyed Coordinates, (NAD83/NAVD88, OPUS corrected) used for kinematic post-processing of the aircraft GPS data for the Panther Creek study area.*

	Datum NAD83(CORS96)		GRS80
Base Station ID	Latitude (North)	Longitude (West)	Ellipsoid Height (m)
WV11_EG3	45 17 56.90315	123 19 22.02617	117.408
YB8_PWH3	45 15 53.646	123 19 13.858	419.786
PC_01	45 13 27.015	123 13 57.963	26.952

***Figure 2.2**. GPS base station locations in the Panther Creek study area.*



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



2.2.1 Instrumentation

For the Panther Creek study area, all Global Navigation Satellite System (GNSS[3]) survey work utilizes a Trimble GPS receiver model R7 with a Zephyr Geodetic antenna with ground plane for static control points. The Trimble GPS R8 unit is used primarily for Real Time Kinematic (RTK) work, but may also be used as a static receiver. For RTK data, the collector begins recording after remaining stationary for 5 seconds, calculating the pseudo range position from at least three epochs, with the relative error under 1.5 cm horizontal and 2 cm vertical. All GPS measurements are made with dual frequency L1-L2 receivers with carrier-phase correction.

2.2.2 Monumentation

Whenever possible, existing and established survey benchmarks shall serve as control points during LiDAR acquisition including those previously set by Watershed Sciences. In addition to NGS, the county surveyor's offices and the Oregon Department of Transportation (ODOT) often establish their own benchmarks. NGS benchmarks are preferred for control points. In the absence of NGS benchmarks, county surveys, or ODOT monumentation, WSI will establish monuments. These monuments are spaced at a minimum of one mile and every effort is made to keep these monuments within the public right of way or on public lands. If monuments are required on private property, consent from the owner is required. All monumentation is done with 5/8" x 30" rebar topped with a 2" diameter aluminum cap stamped "Watershed Sciences, Inc.".

2.2.3 Methodology

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 allowed precise location measurement ($\sigma \leq 1.5$ cm). **Figure 2.3** shows a subset of these RTK locations.

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 control points are observed for a minimum of two survey sessions lasting no fewer than 2 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.

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

The ground crew uploads the GPS data to the Dropbox website on a daily basis to be returned to the office for Professional Land Surveyor (PLS) oversight, Quality Assurance/Quality Control (QA/QC) review and processing. OPUS processing triangulates the monument position using 3 CORS stations resulting in a fully adjusted position. CORPSCON[4] 6.0.1 software is used to convert the geodetic positions from the OPUS reports. After multiple days of data have been collected at each monument, accuracy and error ellipses are calculated. This information leads to a rating of the monument based on FGDC-STD-007.2-1998[5] Part 2 **(Table 2.2)** at the 95% confidence level.

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. 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 are readily identified and occupied during subsequent field visits in support of other quality control procedures described later. Examples of identifiable locations would include manhole and other flat utility structures that have clearly indicated center points or other measurement locations. In the absence of utility structures, a PK nail can be driven into asphalt or concrete and marked with paint.

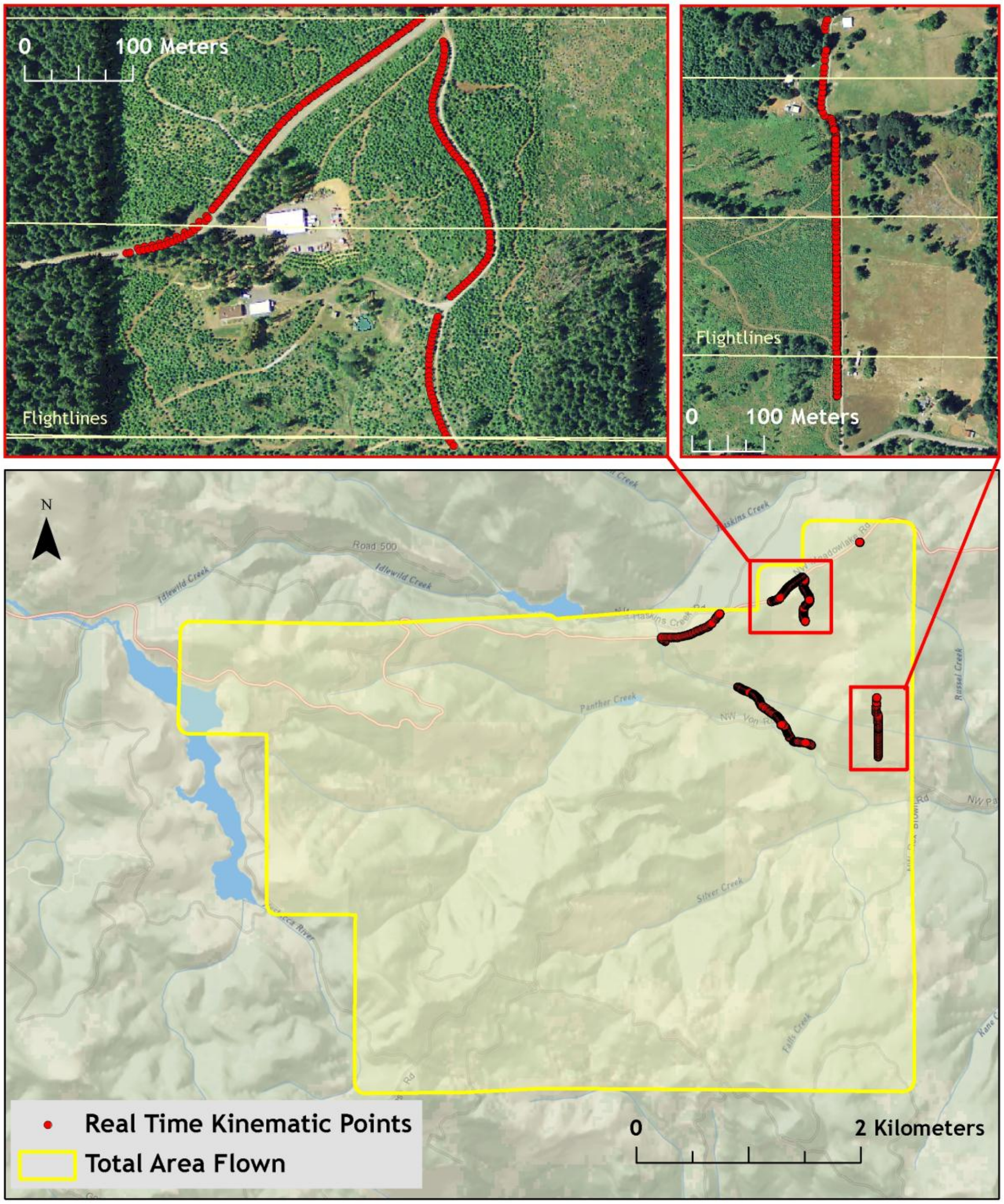
2.2.4 Monument Accuracy

FGDC-STD-007.2-1998[6] at the 95% confidence level for this project:

St Dev $_{NE}$: 0.010 m
St Dev $_{z}$: 0.020 m

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

__Figure 2.3__. Sample selection of RTK point locations in the study area, displayed over NAIP orthoimages.



3. LiDAR Data Processing

3.1 Applications and Work Flow 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: POSGNSS v. 5.3
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: ALS Post Processing Software v.2.74 Build 6 Beta
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.12, Custom Watershed Sciences software
5. Using 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.12, 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.12, ArcMap v 9.3 and 10.0, TerraModeler v.12, Custom Watershed Sciences software

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. POSGNSS v. 5.3 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. POSGNSS v.5.3 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 are computed using the POSGNSS software 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 maintaining the corresponding scan angle, return number (echo), intensity, and x, y, and z (easting, northing, and elevation) information.

Flightlines and LiDAR data are then reviewed to ensure complete coverage of the study 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 are 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. The data are then inspected for pits and birds manually, 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. These spurious non-terrestrial laser points are removed from the dataset. 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 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 are corrected, vertical GPS drift is 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. Sources of error are listed in **Table 4.1** below.

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 $\pm 14^{o}$ from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.
4. Quality GPS: Acquisition occurred during 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 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 are calculated and applied to resolve misalignments. The raw divergence between lines is computed after the manual calibration and reported for the study area.
2. Automated Attitude Calibration: All data are tested and calibrated using TerraMatch 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 entire area of interest.
3. Automated Z Calibration: Ground points per line are 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.

Relative Accuracy Calibration Results

Relative accuracy statistics shown in **Figures 4.2** and **4.3** are based on the comparison of 31 flightlines and over 61 million points. Relative accuracy is reported for the portion of the study area shown in **Figure 4.1** below.

- Project Average Relative Accuracy= 0.04 meters
- Median Relative Accuracy = 0.05 meters
- 1σ Relative Accuracy = 0.05 meters
- 2σ Relative Accuracy = 0.05 meters

Figure 4.1. Relative Accuracy covered area for Panther Creek study area.

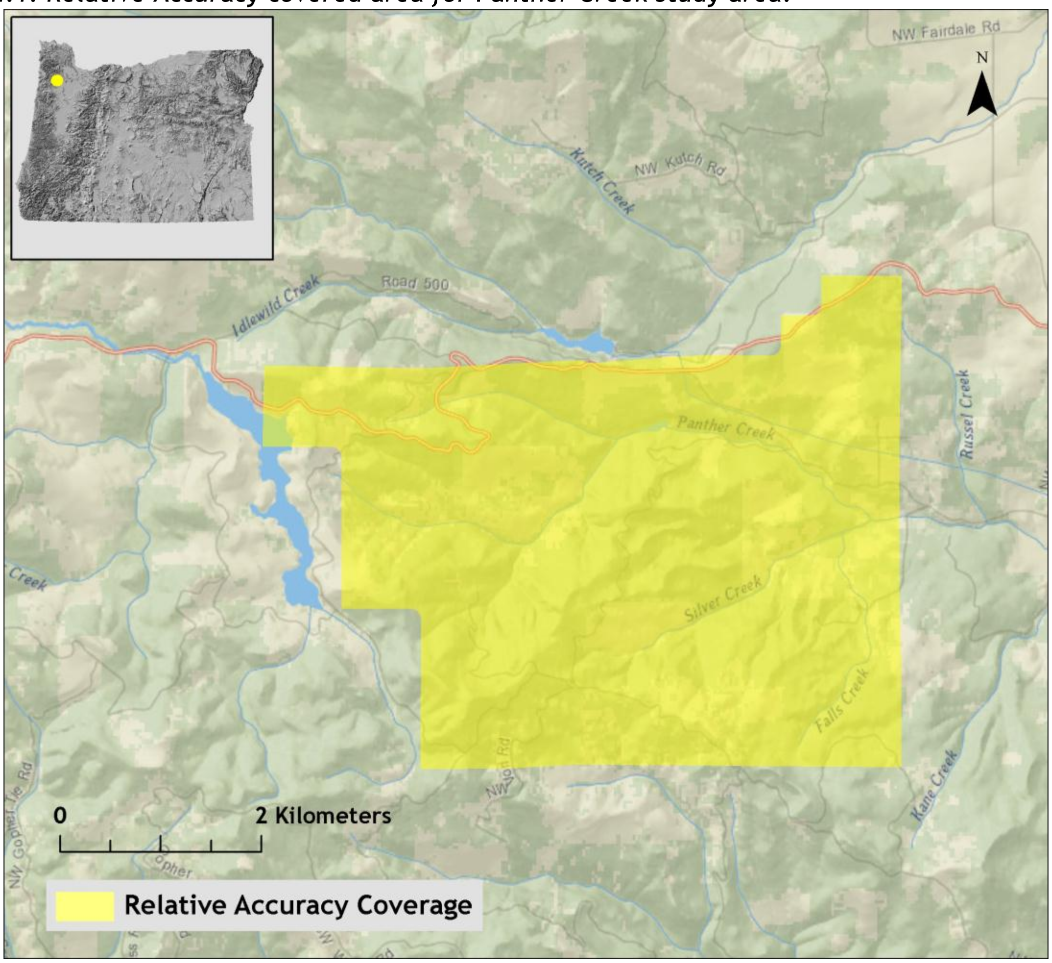


Figure 4.2. *Distribution of relative accuracies, non-slope-adjusted for Panther Creek.*

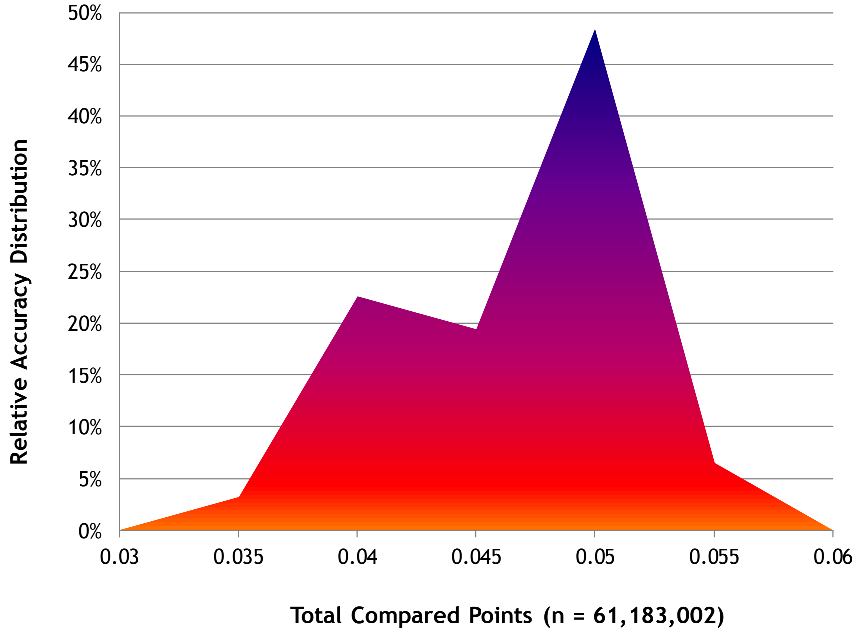
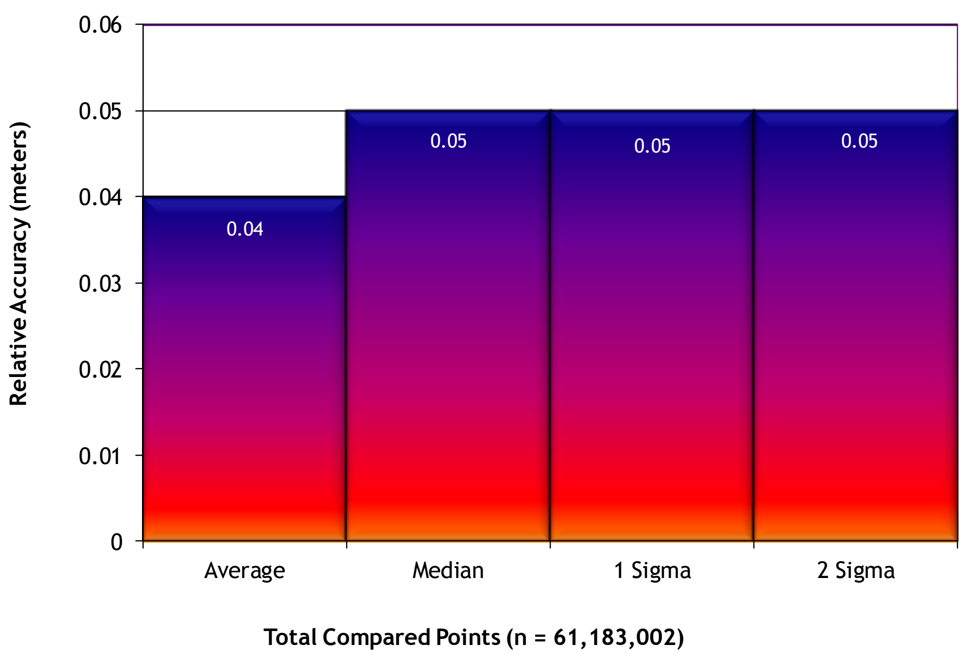


Figure 4.3. *Statistical relative accuracies, non-slope-adjusted for Panther Creek.*



4.1.2 Fundamental Vertical Accuracy

Fundamental Vertical Accuracy (FVA) 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 Panther Creek LiDAR survey, 1,183 RTK points were collected.

For the Panther Creek 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 (Flood, 2004). The table below details summary statistics for FVA. Fundamental Vertical accuracy is reported for the portion of the study area shown in **Figure 4.4** and reported in **Table 4.2** below. Histogram and absolute deviation statistics are reported in **Figures 4.5 and 4.6.**

RTK survey points include multiple years of ground control.

Figure 4.4. *Fundamental Vertical Accuracy Covered for Panther Creek study area.*

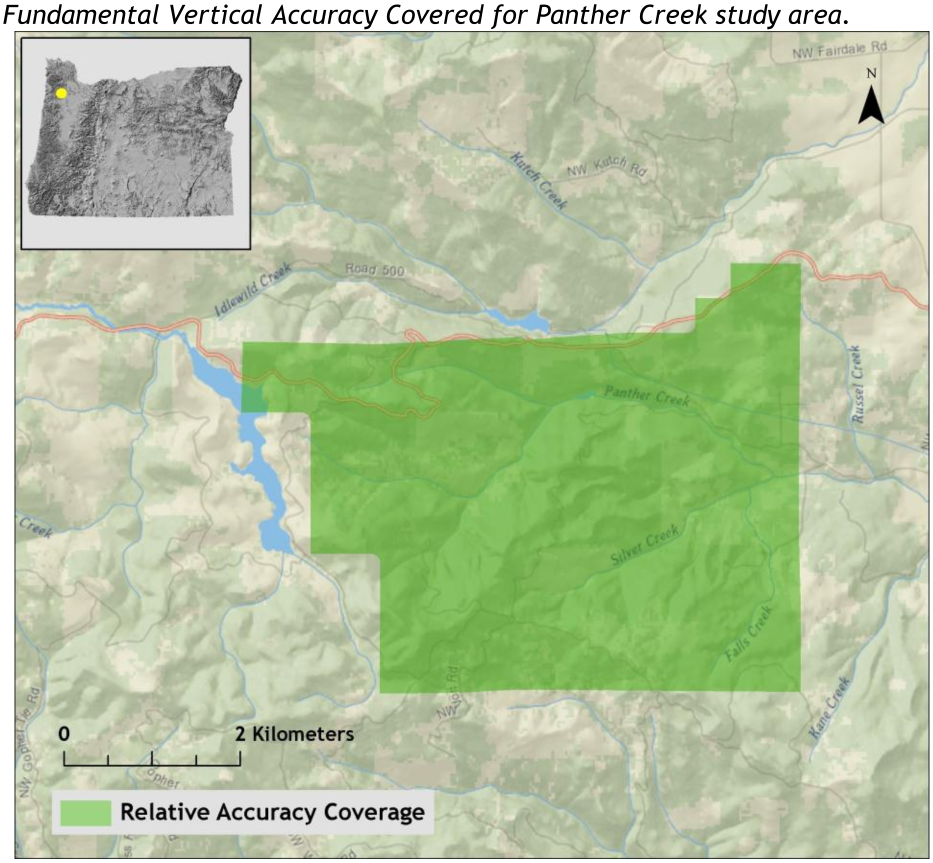


Table 4.2 *Fundamental Vertical accuracy: deviation between laser points and hard surface RTK survey points.*

Sample Size (n): 1,183	
Root Mean Square Error (RMSE): 0.04m	
Fundamental Vertical Accuracy: Compiled to Meet 0.05m fundamental vertical accuracy at 95% confidence level (1.96 x $RMSE_z$) in open terrain	
Standard Deviations	**Minimum Δz:** -0.12 m
1 sigma (σ): 0.04 m	**Maximum Δz:** 0.22 m
2 sigma (σ): 0.07 m	**Average Δz:** 0.01 m

Figure 4.5. *Panther Creek study area fundamental vertical accuracy histogram statistics.*

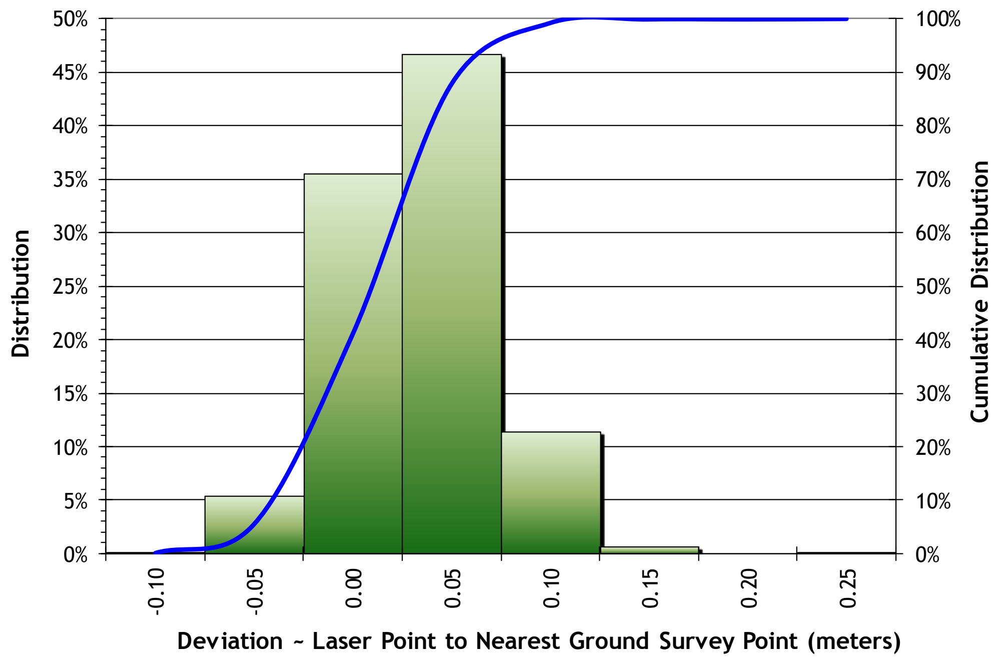
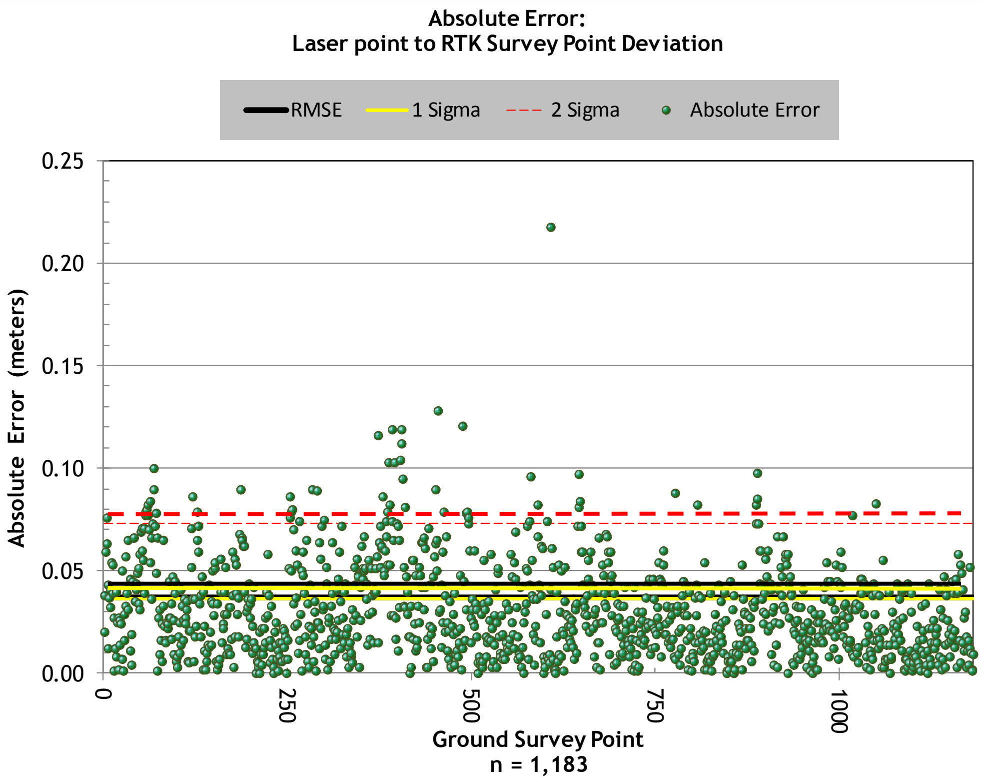


Figure 4.6. *Panther Creek study area point absolute deviation statistics.*



4.2 Data Density/Resolution

Some types of surfaces (i.e., dense vegetation or water) may return fewer pulses than 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 water bodies. Density histograms and maps (**Figures 4.5-4.8**) 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)
8.91	**0.76**

4.2.1 First Return Data Density

Figure 4.7. *Histogram of first return laser point density for data Panther Creek study area.*

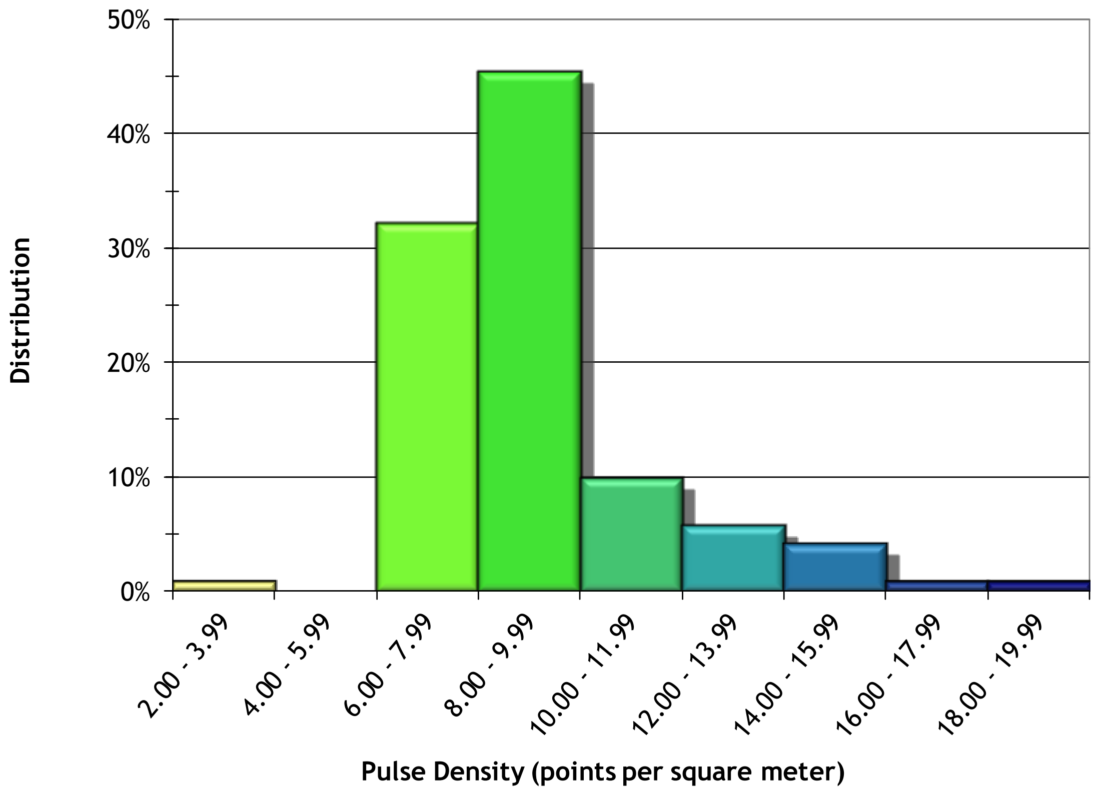
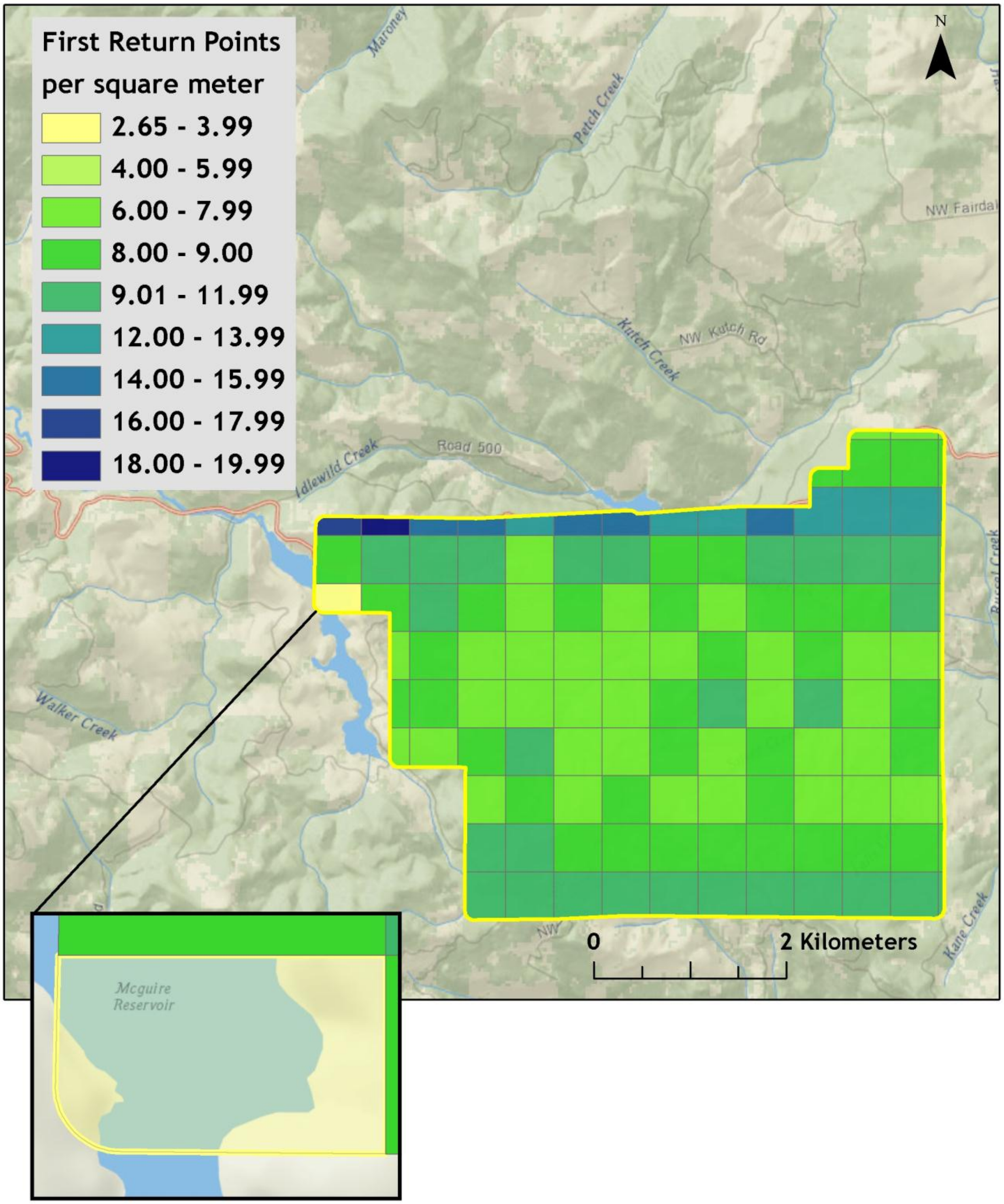


Figure 4.8. *First return laser point data density for Panther Creek study area. The area of low density is over McGuire Reservoir.*



4.2.2 Ground-Classified Data Density

Figure 4.9. *Histogram of ground-classified laser point density for Panther Creek study area.*

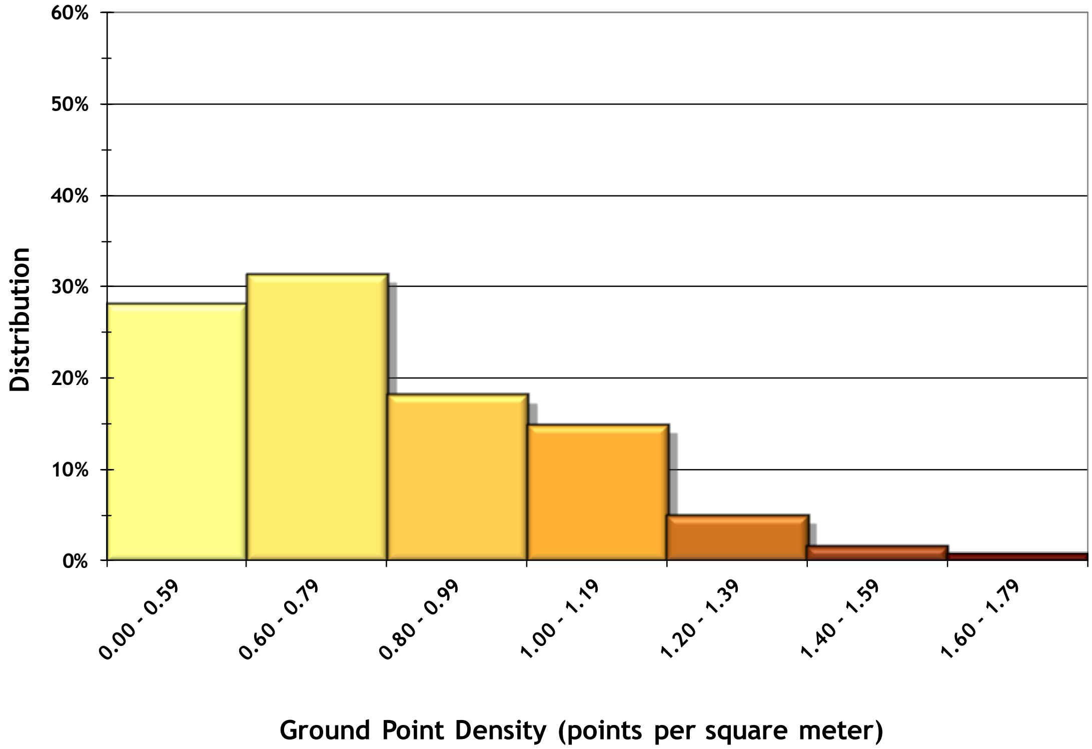
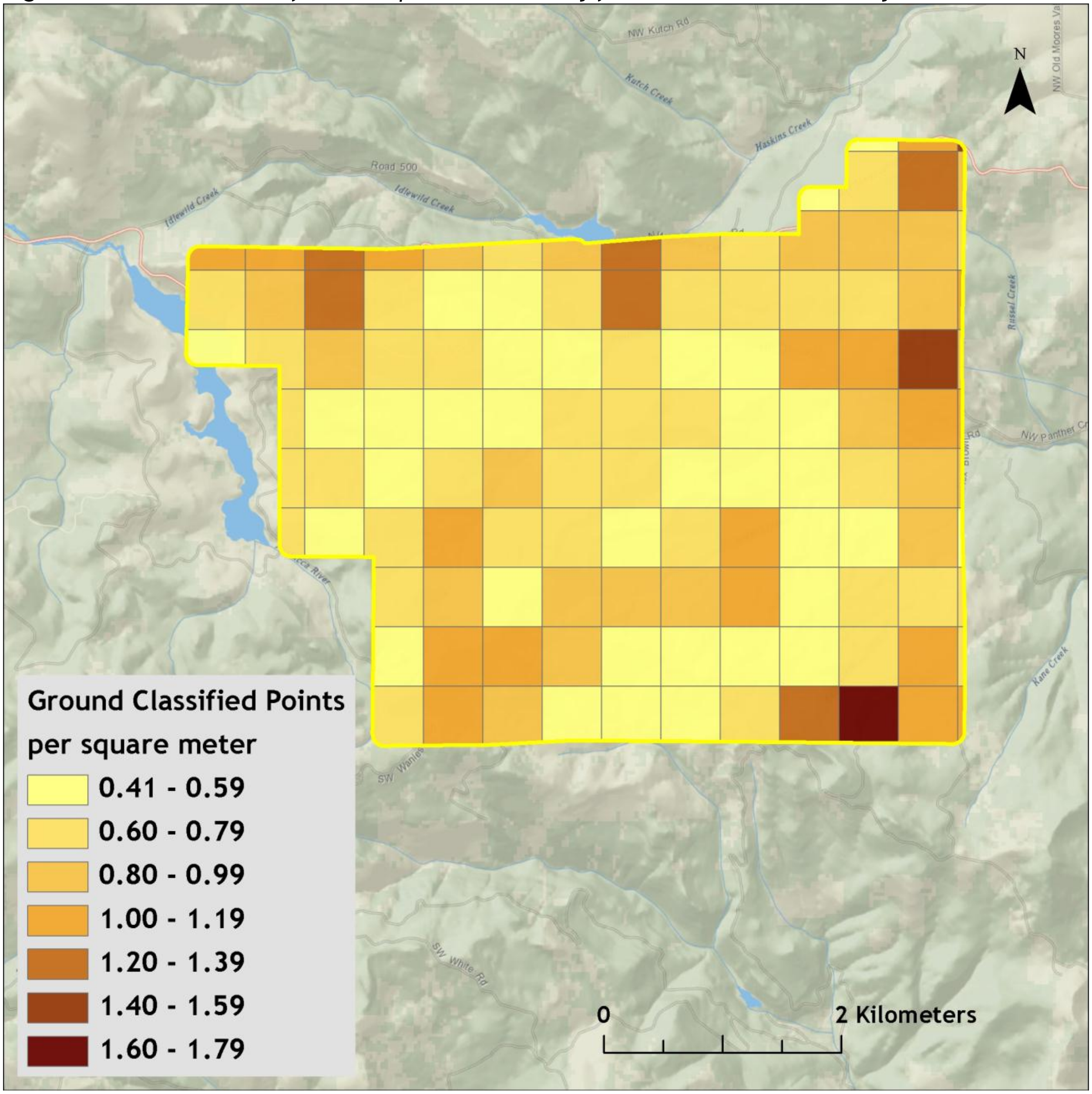


Figure 4.10. Ground-classified laser point data density for the Panther Creek Study Area.



5. Deliverables

5.1 Point Data

- All Return Point data in *.las v 1.2 format (delineated in 500 m x 500 m tiles)

5.2 Vector Data

- Total Area Flown *.shp (delineated in 500 m x 500 m tiles)

5.3 Raster Data

- ESRI GRID of LiDAR-derived Bare Earth Model (1-meter resolution)
- Intensity Images in GeoTIFF format (0.5-meter resolution, 500 m x 500 m tiles)

5.4 Data Report

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

5.5 Datum and Projection

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

6. Certifications

Watershed Sciences provided LiDAR services for the Panther 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.

REGISTERED
PROFESSIONAL
LAND SURVEYOR

4/26/2012

OREGON
JULY 13, 2004
Christopher W. Yotter - Brown
60438 LS

RENEWAL DATE: 6/30/2012

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

[This page intentionally left blank]

7. Selected Images

Figure 7.1. Haskins Creek (right) and Carlton (left) reservoirs, ten miles northwest of McMinnville, Oregon. View to the East. Image is a three dimensional LiDAR point cloud with RGB values extracted from a NAIP orthophoto.

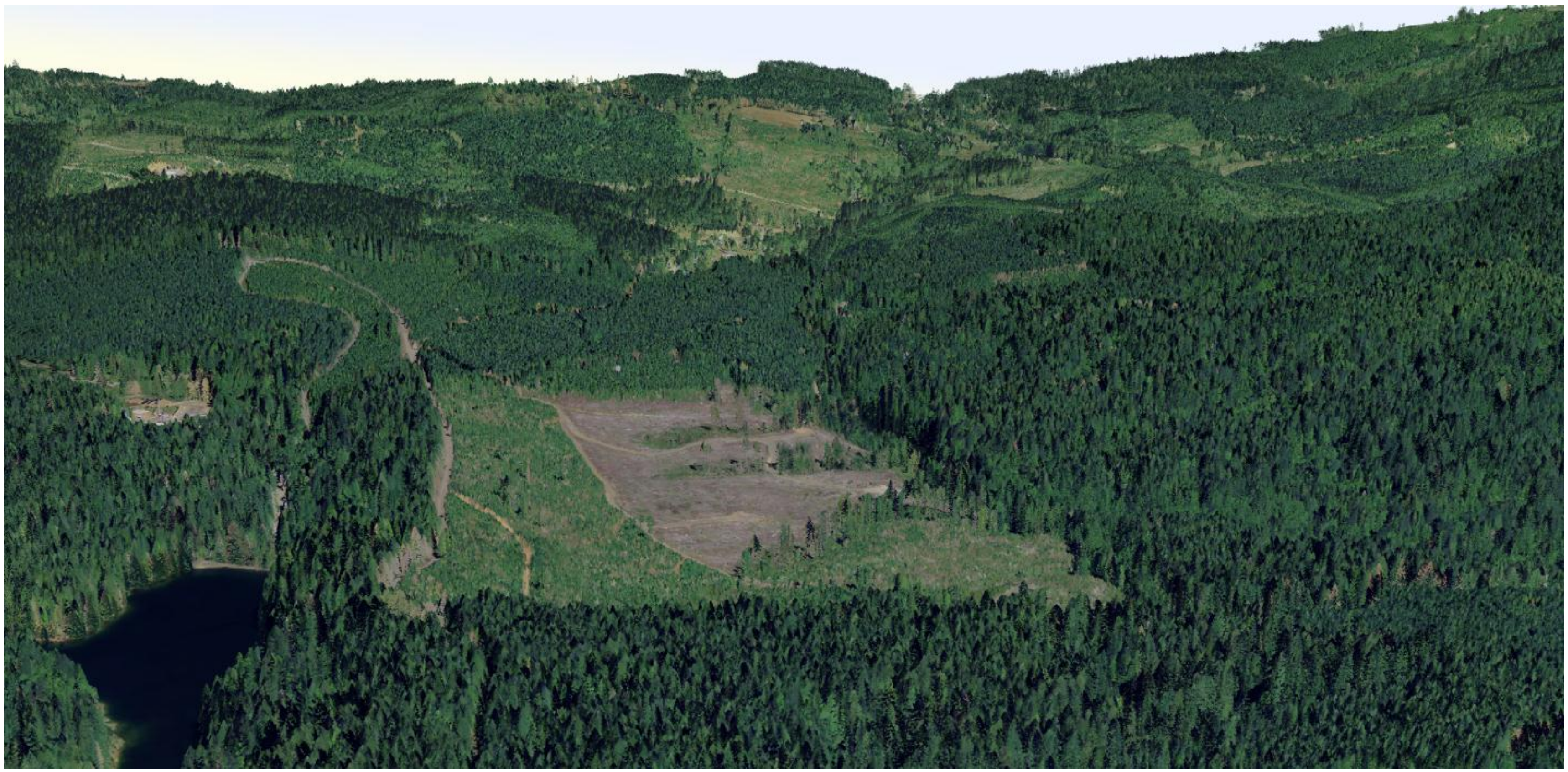
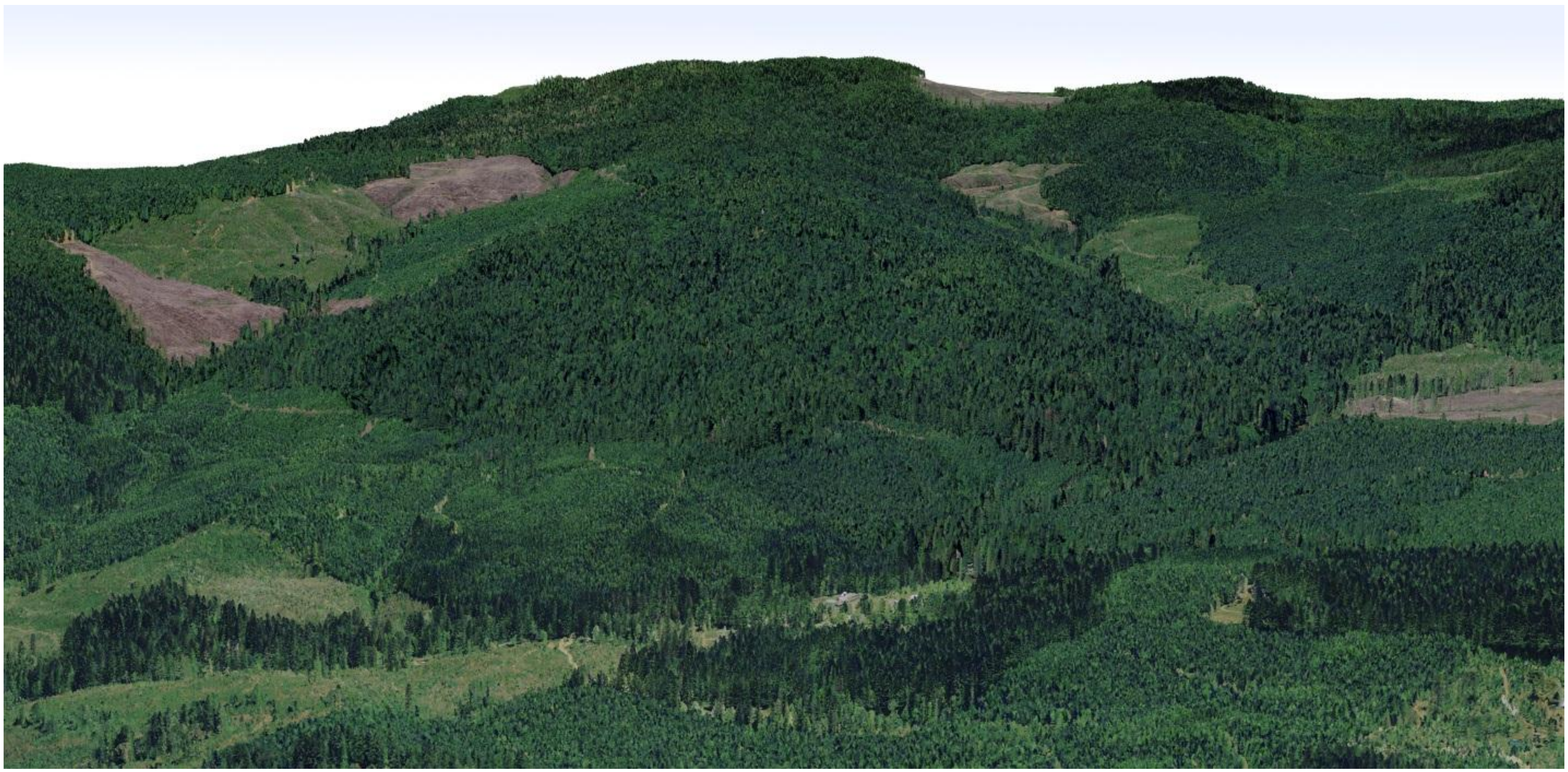


Figure 7.2. (Cover Image): Panther Creek study area, Yamhill County, Oregon. View to the Southwest. Image is a three dimensional LiDAR point cloud with RGB values extracted from a NAIP orthophoto.



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.

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

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

Pulse Returns: For every laser pulse emitted, the Leica ALS 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.

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.

9. Citations

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

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.

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