# LiDAR Remote Sensing Data Collection: Panther Creek, Oregon

May 13, 2011

**Submitted to:**

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

**Submitted by:**

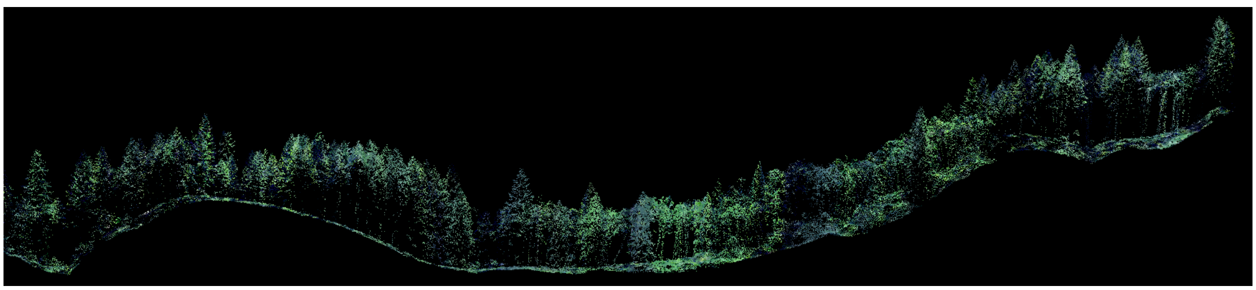
Watershed Sciences
529 SW 3rd Avenue, Suite 300
Portland, OR 97204

# LiDAR Remote Sensing Data:

## Panther Creek, Oregon

TABLE OF CONTENTS

**1. Overview** .......... 5
1.1 Project Area .......... 5
**2. Planning** .......... 6
2.1 Airborne Survey .......... 6
2.2 Ground Survey .......... 6
2.3 Safety and Field Preparations .......... 7
**3. Acquisition** .......... 8
3.1 Airborne Survey .......... 8
3.1.1 Instrumentation .......... 9
3.1.2 Methodology .......... 9
3.2 Ground Survey .......... 10
3.2.1 Instrumentation .......... 11
3.2.2 Monumentation .......... 11
3.2.3 Methodology .......... 12
**4. LiDAR Data Processing** .......... 14
4.1 Applications and Workflow Overview .......... 14
4.2 Aircraft Kinematic GPS and IMU Data .......... 14
4.3 Laser Point Processing .......... 15
**5. LiDAR Specifications** .......... 16
5.1 Laser Point Accuracy .......... 16
5.1.1 Relative Accuracy .......... 17
5.1.2 Absolute Accuracy .......... 19
5.2 Data Density/Resolution .......... 20
5.2.1 First Return Data Density .......... 20
5.2.2 Ground-Classified Data Density .......... 21
**6. Certifications** .......... 23
**7. Deliverables** .......... 24
7.1 Point Data .......... 25
7.2 Vector Data .......... 25
7.3 Raster Data .......... 25
7.4 Data Report .......... 25
7.5 Datum and Projection .......... 25
**8. Selected Imagery** .......... 26
**9. Glossary** .......... 29
**10. Citations** .......... 29

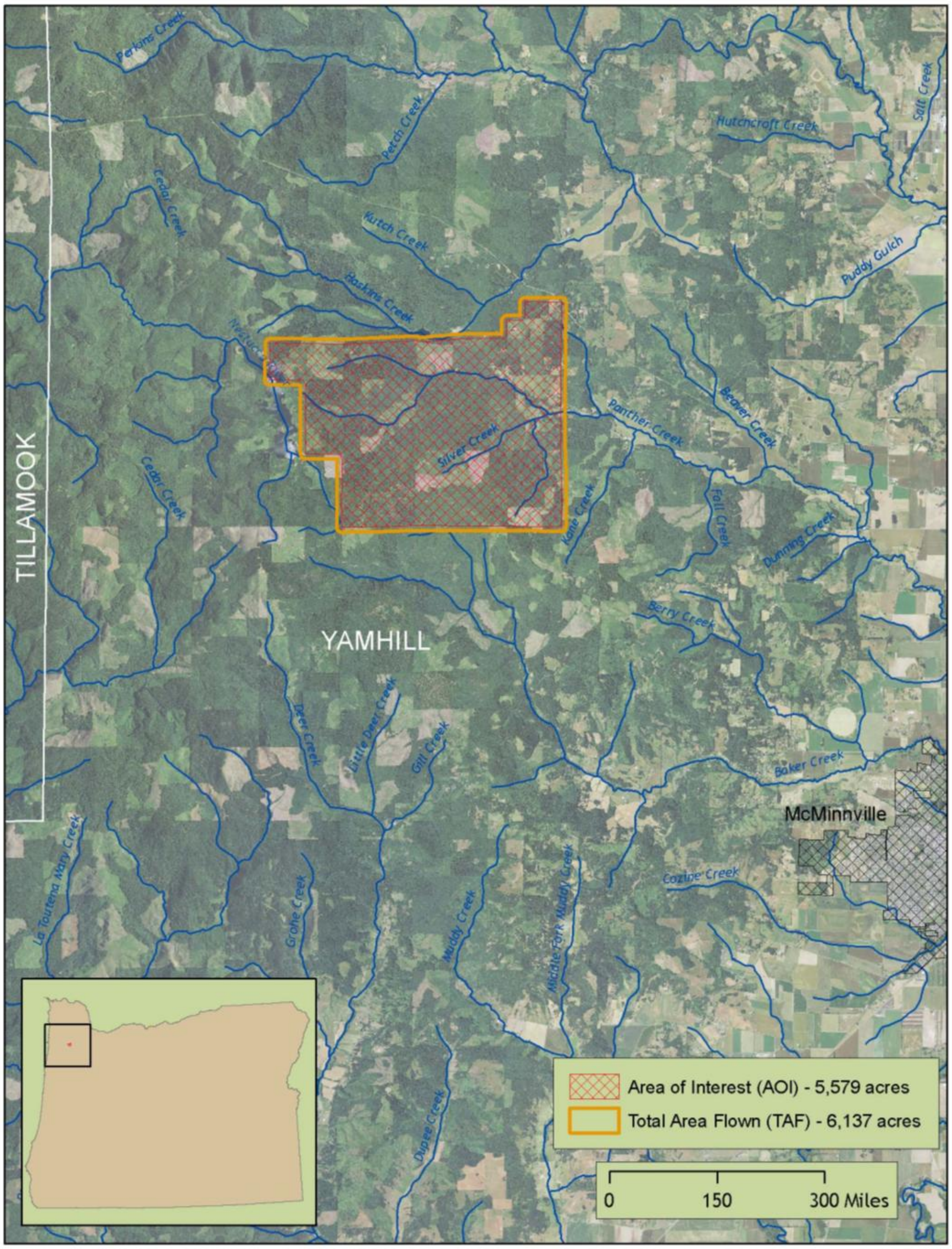


# 1. Overview

## 1.1 Project Area

Watershed Sciences, Inc. collected Light Detection and Ranging data (LiDAR) of the Panther Creek study area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The requested LiDAR Area of Interest (AOI) totals approximately 5,579 acres, and was buffered to ensure data coverage, resulting in a Total Area Flown (TAF) of 6,137 acres. This report reflects the planning, acquisition, and processing methodology, as well as statistics for the study area.

*Panther Creek project area.*



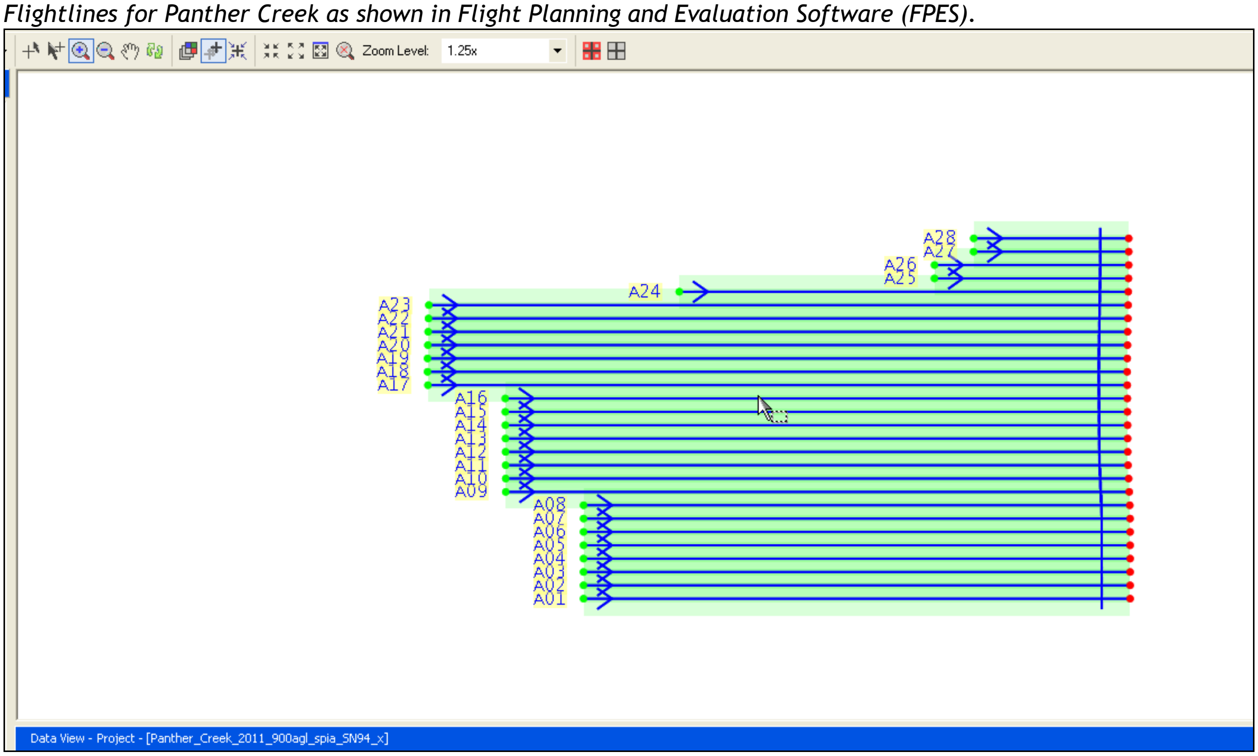
# 2. Planning

The Panther Creek mission planning conducted at WSI was designed to optimize flight efficiency while meeting or exceeding project accuracy and resolution specifications. In this process, we mitigated known factors such as Global Positioning System (GPS) constellation quality and resource allocation. In addition, we anticipated and prepared for a variety of logistical barriers, such as any possible air space restrictions and ground personnel operations. Finally, weather hazards and conditions affecting flight were continuously monitored, due to their impact on the success of airborne and ground operations.

## 2.1 Airborne Survey

In preparation for data collection, flightlines for the buffered study area were developed using Leica Geosystems Flight Planning and Evaluation Software (FPES 10.0.2.7). This ensured that data quality and coverage conditions were met while optimizing flight paths for minimal flight times. For the Panther Creek project, settings were configured in order to yield an average native pulse density of ≥8 pulses per square meter over terrestrial surfaces. While FPES assists in planning the spatial details of the project, this information is supplemented by temporal observations in the study area.

*Flightlines for Panther Creek as shown in Flight Planning and Evaluation Software (FPES).*




## 2.2 Ground Survey

During the LiDAR acquisition, two GNSS base stations continually collected static GNSS data. The data were 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 were determined prior to field deployment, and the suitability of these locations was verified in the field. National Geodetic Survey (NGS) benchmarks were unavailable; therefore, WSI established monuments within the study area in accordance with state survey protocol. In addition to these static sessions, a ground professional employee conducted real-time kinematic (RTK) surveys to collect ground control points for data accuracy verification during data processing. All acquisition occurred during optimal GPS conditions (e.g., 6 or more satellites and a Position Dilution of Precision [PDOP] below 3.0). Daily forecasts from Trimble Planning software ensured that these conditions were met. This information was then supplemented with observations in the field to determine ideal acquisition times and locations.

## 2.3 Field Operations

### 2.3.1 Safety

Safety is paramount during all WSI endeavors. At all times, safety in the field was 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 relied 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 FPES flight plan and acquisition maps to target the area
- Utilizing a Google Earth .kml of the flight plan to assess GPS monument and RTK collection locations
- Checking the satellite constellation forecast to ensure continual quality GPS coverage
- Verifying the presence and functionality of all operational and safety equipment
- Creating a detailed plan and communicating with all individuals involved

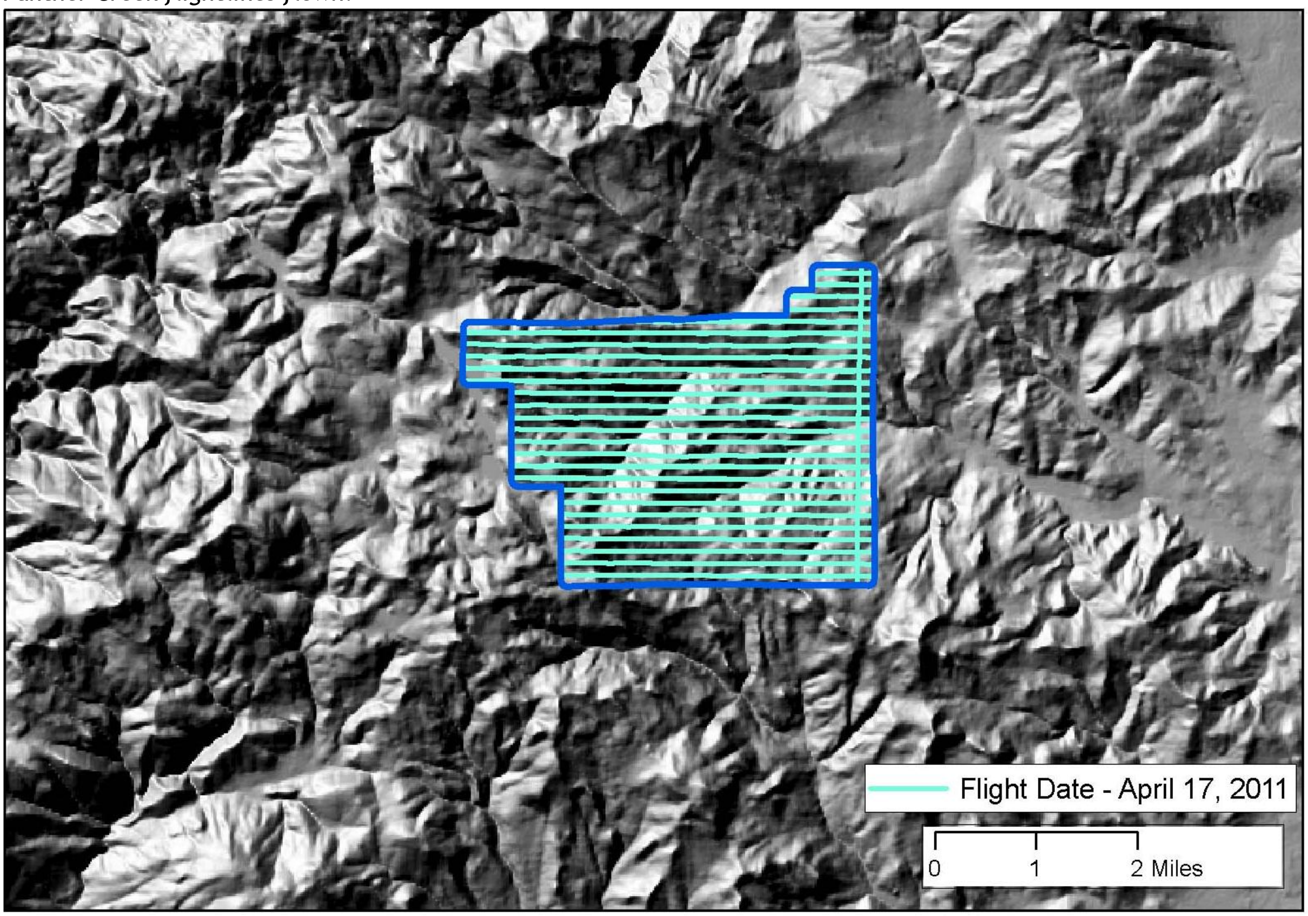
These preparations are designed to facilitate a safe, productive course of data acquisition. The details of acquisition and processing for the Panther Creek project are further described in the following sections.

# 3. Acquisition

## 3.1 Airborne Survey

The target time-period for acquisition was April, 2011 for the leaf-off to leaf-on transition period. The study was monitored for the first available clear weather day in mid-April, starting on April 12. The continual rain and cloud cover prevented an immediate acquisition, resulting in an acquisition date of April 17, 2011.

*Panther Creek flightlines flown.*



### 3.1.1 Instrumentation

The LiDAR survey utilized a Leica ALS60 sensor mounted in a Cessna Caravan 208B. The LiDAR system was set to acquire ≥105,000 laser pulses per second (i.e., 105 kHz pulse rate) and flown at 900 m above ground level (AGL), capturing a scan angle of ±14$^{o}$ from nadir[1]. 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 was measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude is described as pitch, roll, and yaw (heading) and was measured 200 times per second (200 Hz) from an onboard inertial measurement unit (IMU).

*Cessna Caravan 208B owned by WSI (left) and a Leica sensor head installed in the Caravan (right).*

*LiDAR Survey Specifications*

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

### 3.1.2 Methodology

During the acquisition, the sensor operator constantly monitored the data collection settings (e.g. pulse rate, power setting, scan rate, gain, field of view, pulse mode). At the beginning and the end of the 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. This LiDAR study was designed to capture leaf-on conditions.

*Acquisition Resource Utilization for the Panther Creek study area*

| Days on Project | Weather % Flyable | Utilized (hrs/day) | Productivity (acres/day) | Flight Time |
|---|---|---|---|---|
| 1 | 100% | 3.7 | 5,579 | 3.7 hours |

[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".

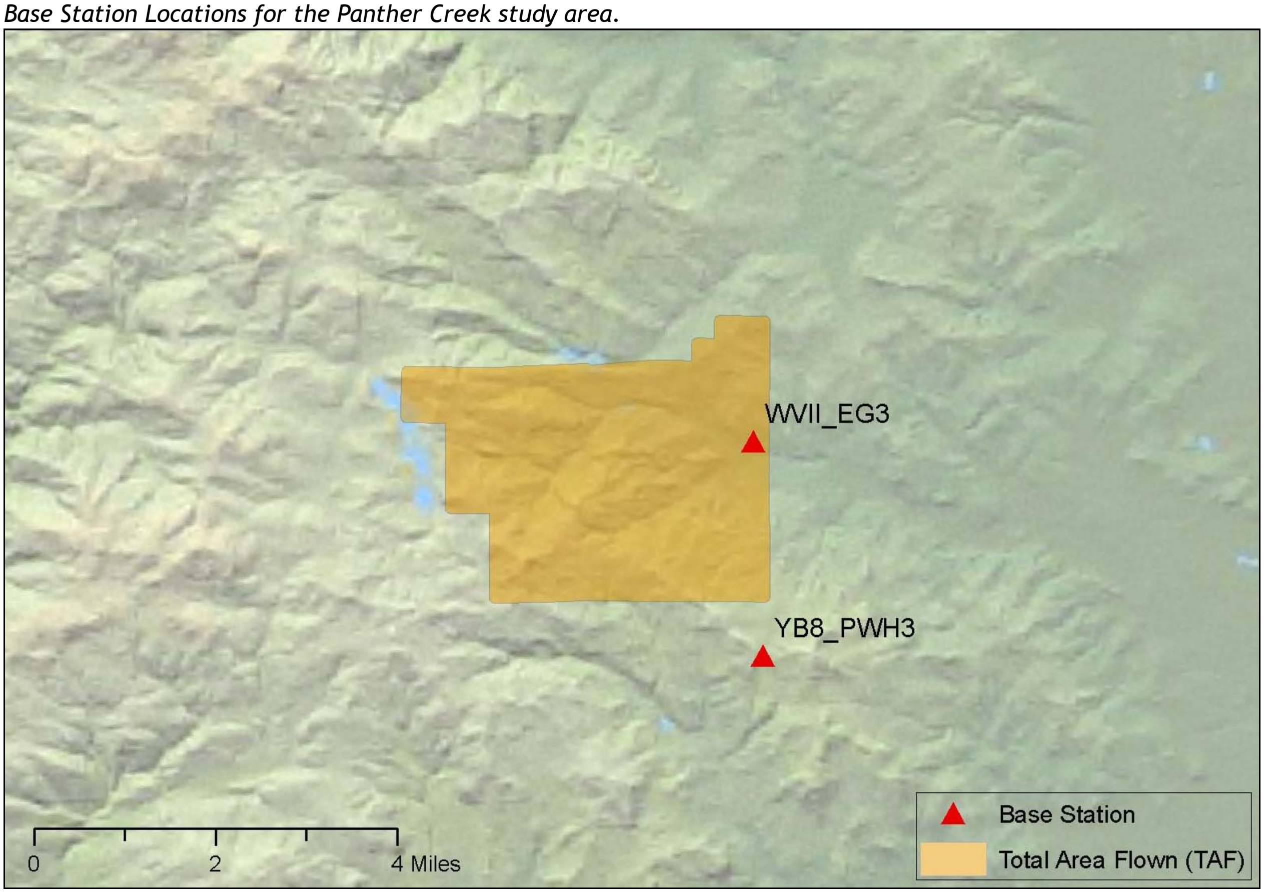
## 3.2 Ground Survey

During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over pre-existing monuments. Monument coordinates are provided in the table below and shown in the figure below. 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[2]) to quantify daily variance. Additionally, an RTK survey was conducted to collect ground control points. These data were then used in the processing of the LiDAR data.

*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 (HARN) | | GRS80 |
|---|---|---|---|
| **Base Stations ID** | **Latitude (North)** | **Longitude (West)** | **Ellipsoid Height (m)** |
| WVII_EG3 | 45 17 56.90299 | 123 19 22.02599 | 117.402 |
| YB8_PWH3 | 45 15 53.64619 | 123 19 13.85834 | 419.786 |

*Base Station Locations for the Panther Creek study area.*




[2] OPUS is run by the National Geodetic Survey to process corrected monument positions.

### 3.2.1 Instrumentation

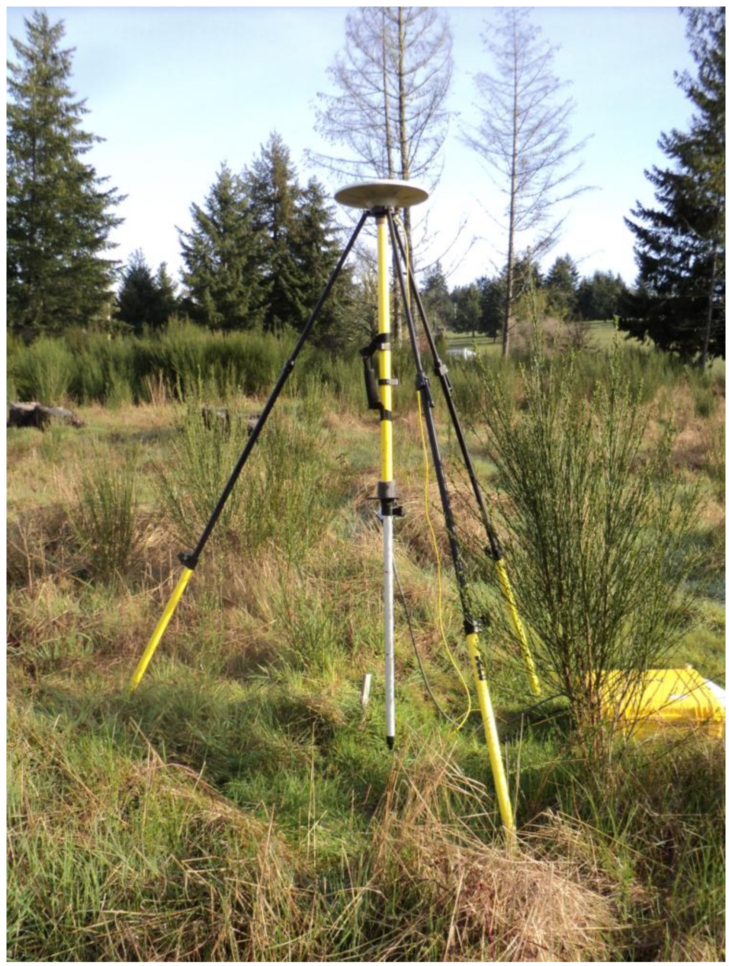
WSI owns and operates multiple sets of Trimble GPS and Global Navigation Satellite System (GNSS[3]) dual-frequency L1-L2 receivers used in both static and RTK surveys (listed in the table below).

*GPS and GNSS Receivers*

| Receiver Model | Antenna | OPUS Antenna ID | Use |
|---|---|---|---|
| Trimble R7 GNSS | Zephyr GNSS Geodetic Model 2 | TRM55971.00 | Static |
| Trimble R8 | Integrated Antenna R8 Model 2/3 | TRM_R8_Model2 | Static & RTK |

### 3.2.2 Monumentation

Existing and established survey benchmarks serve as control points during LiDAR acquisition. Every effort is made to keep these monuments within the public right of way or on public lands. All monumentation is done with 5/8” x 24” or 30” rebar topped with an orange plastic cap stamped “WS” with the point name noted in black marker.



[3] GNSS consists of the U.S. GPS constellation and Soviet GLONASS constellation.

### 3.2.3 Methodology

During acquisition, the aircraft was assigned a ground crew member with two R7 receivers and one R8 receiver. The ground crew vehicle was equipped with standard safety and field survey supplies. All static control points were observed for a minimum of one 2-hour session and one 4-hour session. At the beginning of every session, the tripod and antenna were reset, resulting in two independent instrument heights and data files. Fixed height tripods were used when exclusively. Data were collected at a rate of 1Hz using a ten degree mask on the antenna.

*Trimble Base Station collecting static data in the Panther Creek study area.*

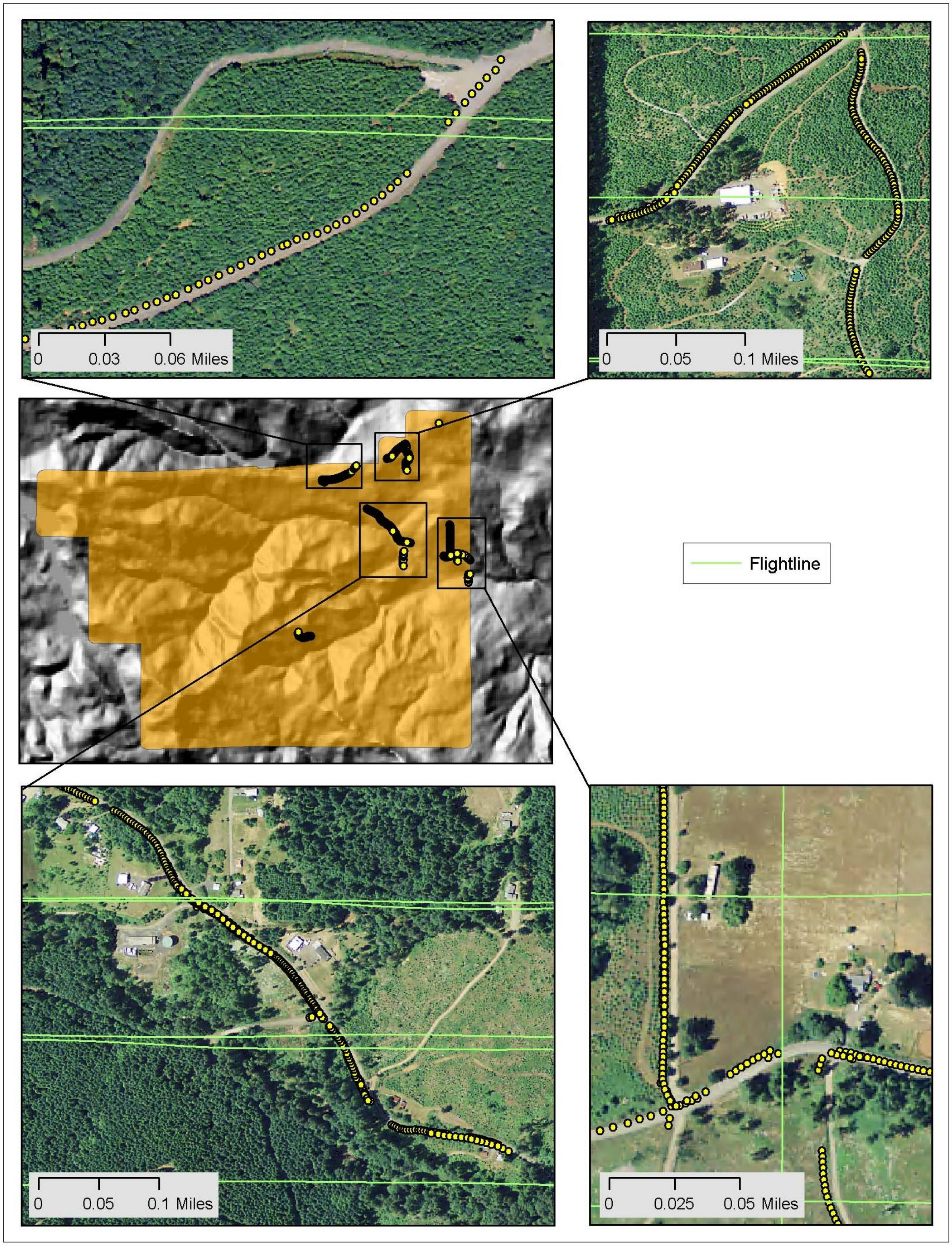
After acquisition, the ground crew immediately uploaded the GPS data to the FTP site, to be returned to the office for Professional Land Surveyor (PLS) QA/QC and oversight. OPUS processing triangulated the monument position using three CORS stations resulting in a fully adjusted position. CORPSCON[4] 6.0.1 software was used to convert the geodetic positions from the OPUS reports. After multiple sessions of data were collected at each monument, accuracy was calculated.

Multiple differential GNSS units were used in the ground-based RTK portion of the survey. A Trimble R7 base unit was 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).

All RTK measurements were 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 began recording after remaining stationary for 5 seconds then calculated 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 were collected on bare earth locations such as paved, gravel or stable dirt roads, and other locations where the ground was clearly visible (and was 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 were not taken on highly reflective surfaces such as center line stripes or lane markings on roads.

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

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


0 0.03 0.06 Miles
0 0.05 0.1 Miles
Flightline
0 0.05 0.1 Miles
0 0.025 0.05 Miles

# 4. LiDAR Data Processing

LiDAR and GPS ground data were received in the office the day after the flight, after having undergone a rapid quality assurance assessment in the field. Once in the office, the data entered into the workflow below.

## 4.1 Applications and Workflow Overview

1. Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data.
   **Software:** Waypoint GraphNav v.8.20, Trimble Geomatics Office v.1.63
2. 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.
   **Software:** ALS Post Processing Software v.2.70
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
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.10.009
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. Data are then converted to orthometric elevations (NAVD88) by applying a Geoid09 correction.
   **Software:** TerraScan v.10.009, TerraModeler v.10.009

## 4.2 Aircraft Kinematic GNSS and IMU Data

The LiDAR survey dataset was referenced to 1 Hz static ground GNSS data collected over pre-surveyed monuments with known coordinates. While surveying, the aircraft collected 2 Hz kinematic GNSS data and the inertial measurement unit (IMU) collected 200 Hz attitude data. Waypoint GraphNav v.8.20 was used to process the kinematic corrections for the aircraft. The static and kinematic GNSS data were then post-processed after the survey to obtain an accurate GNSS solution and aircraft positions. IPAS Pro v.1.35 was used to develop a trajectory file including corrected aircraft position and attitude information. The trajectory data for the entire flight survey session were incorporated into a final smoothed best estimated trajectory (SBET) file containing accurate and continuous aircraft positions and attitudes.

## 4.3 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 coordinate (x, y, and z). The data were output into large LAS v. 1.2 files; each point maintaining the corresponding scan angle, return number (echo), intensity, and x, y, and z (easting, northing, and elevation) information. The system allowed up to four range measurements per pulse, and all discernable laser returns were processed for the output dataset. Flightlines and LiDAR data were then reviewed to ensure complete coverage of the project area and positional accuracy of the laser points.

Once the laser point data were 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 was resolved and corrected.

The LiDAR points were then filtered for noise, pits and birds by screening for absolute elevation limits, isolated points and height above ground. Supervision of point classes occurred, and spurious points were classified as "noise". For a *.las file containing approximately 7.5-9.0 million points, an average of 50-100 points were typically found to be artificially low or high. Common sources of non-terrestrial returns are clouds, birds, vapor, and haze.

Internal calibration was refined using TerraMatch. Points from overlapping lines were tested for internal consistency and final adjustments 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. In summary, the data were calibrated 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 began 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 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 (e.g., understory, low/dense shrubs, etc.) and these points were then manually reclassified as non-grounds.

Point data for this LiDAR survey are attributed with intensity values. Intensity is a unitless index of the voltage received from a discrete LiDAR return. It is largely a measure of the reflectivity and composition of the object that reflected the laser radiation. During the flight, the receiver collected photos per LiDAR return and translated these to volts per return. These voltage returns were then scaled from a theoretical maximum and intensity values were derived and stored as 8-bit unitless values (0-255).

# 5. LiDAR Specifications

## 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.
- **Relative Accuracy**: Internal consistency refers to the ability to place a laser point in the same location over multiple flight lines, GNSS conditions, and aircraft attitudes.
- **Absolute Accuracy**: RTK GNSS measurements taken in the project area 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.

*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 |
|---|---|---|
| GNSS (Static/Kinematic) | Long Base Lines | Addressed in Field |
| | Poor Satellite Constellation | Addressed in Field |
| | 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 was targeted at a flight altitude of 900 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 $\pm 14^{o}$ 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**

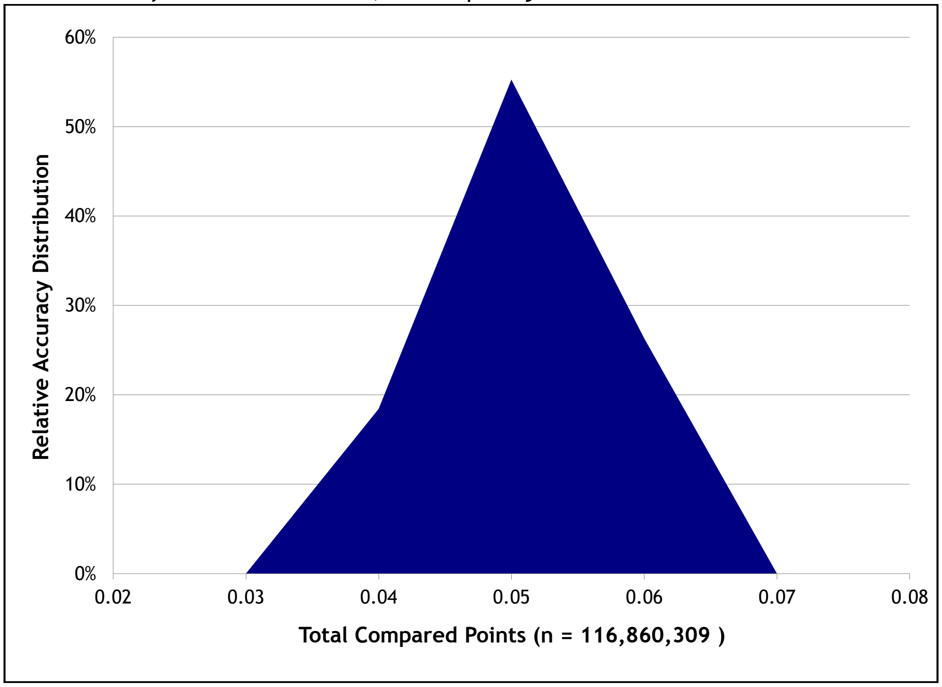
1. Manual System Calibration: Calibration procedures for each mission require solving geometric relationships relating measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets are calculated and applied to resolve misalignments. 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 GPS drift. Automated Z calibration is the final step employed for relative accuracy calibration.

**Relative Accuracy Calibration Results**

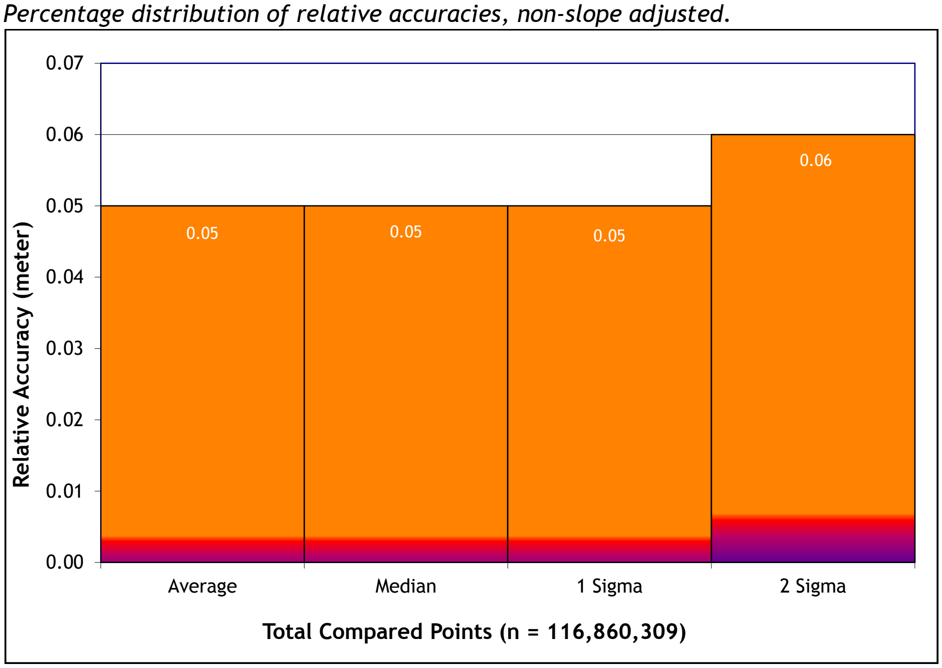
Relative accuracy statistics for the Panther Creek study area are based on the comparison of 38 flightlines and over 115 million points.

- Project Average = 0.05 meters
- Median Relative Accuracy = 0.05 meters
- 1σ Relative Accuracy = 0.05 meters
- 2σ Relative Accuracy = 0.06 meters

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




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



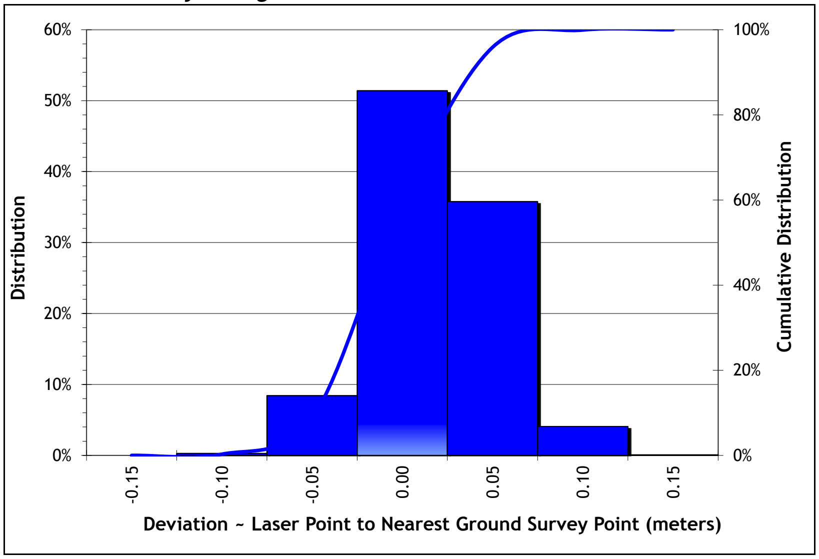
### 5.1.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Panther Creek study area, 1,426 hard-surface RTK points have been collected by WSI; the statistics derived from these points are presented in the figures below.

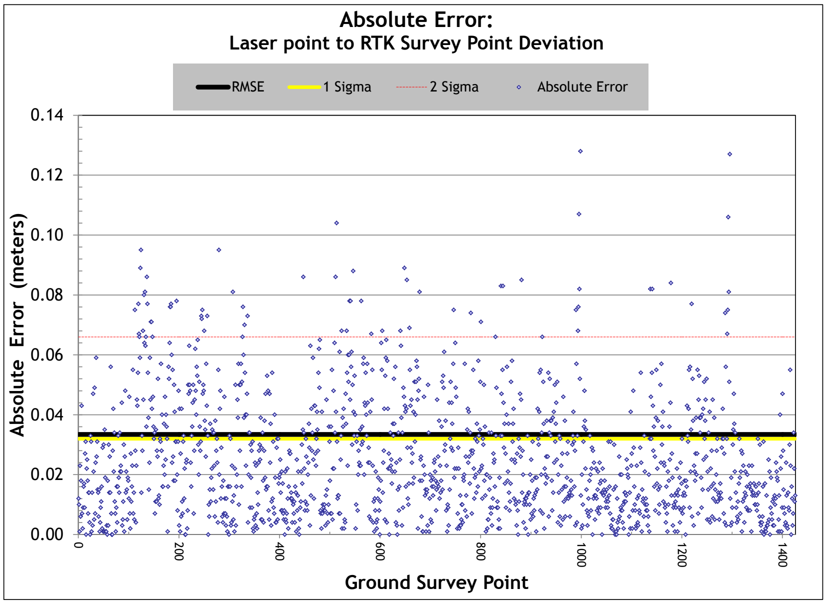
*Absolute accuracy: deviation between laser points and hard surface RTK survey points.*

| **Sample Size (n):** 1,426 | |
|---|---|
| **Root Mean Square Error (RMSE):** 0.03 m | |
| **Standard Deviations** | **Minimum Δz:** -0.13 m |
| **1 sigma (σ):** 0.03 | **Maximum Δz:** 0.10 m |
| **2 sigma (σ):** 0.07 | **Average Δz:** 0.03 m |

*Absolute accuracy histogram statistics.*




*Point absolute deviation statistics.*



## 5.2 Data Density/Resolution

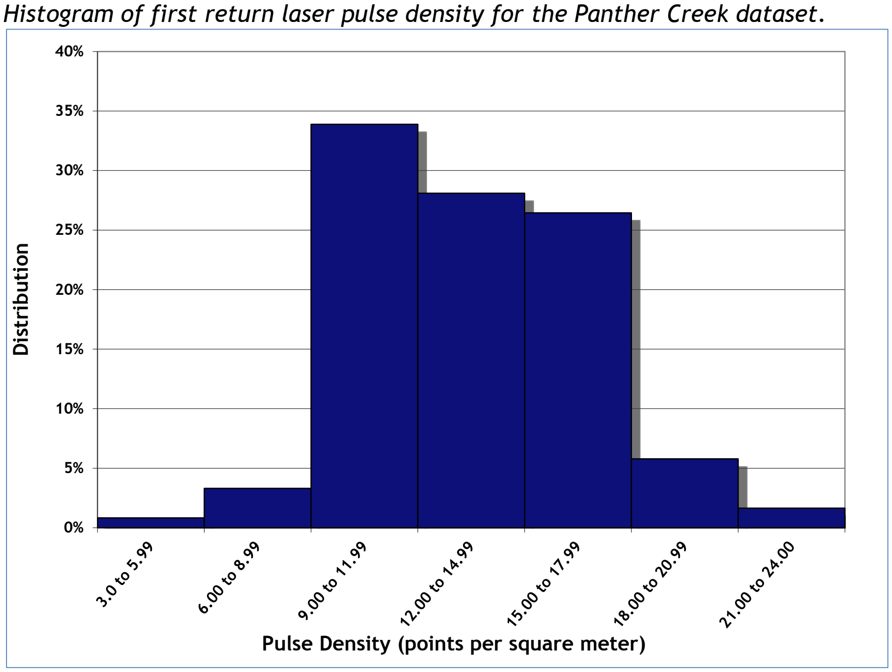
Some types of surfaces (e.g., open water) may return fewer pulses than originally emitted by the laser. Delivered density may therefore be less than the native density and vary according to distributions of terrain, land cover, and vegetation. Density histograms and maps (shown below) have been calculated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

*Average densities for data delivered to date.*

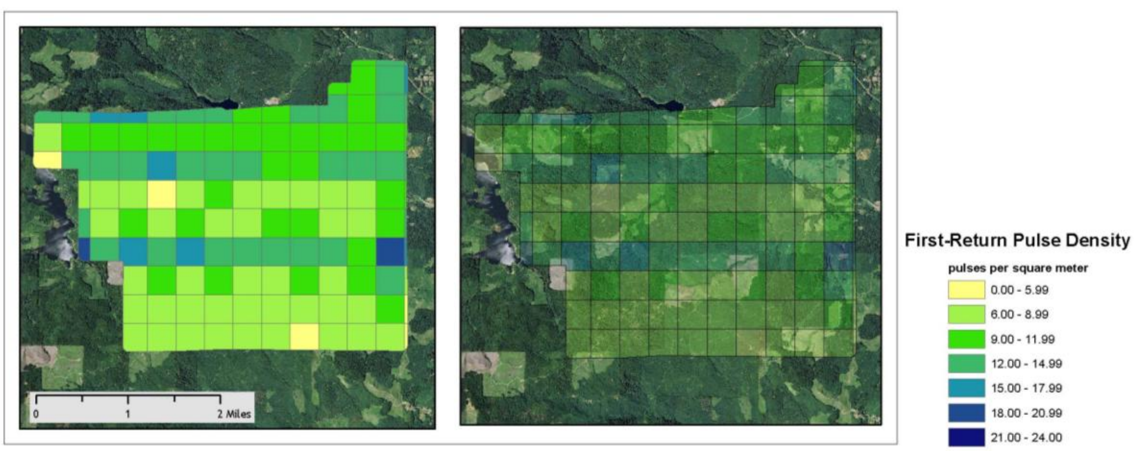
| Average Pulse Density | Average Ground Density |
|---|---|
| 10.18 pt/$m^2$ | 0.87 pt/$m^2$ |

### 5.2.1 First Return Data Density

*Histogram of first return laser pulse density for the Panther Creek dataset.*

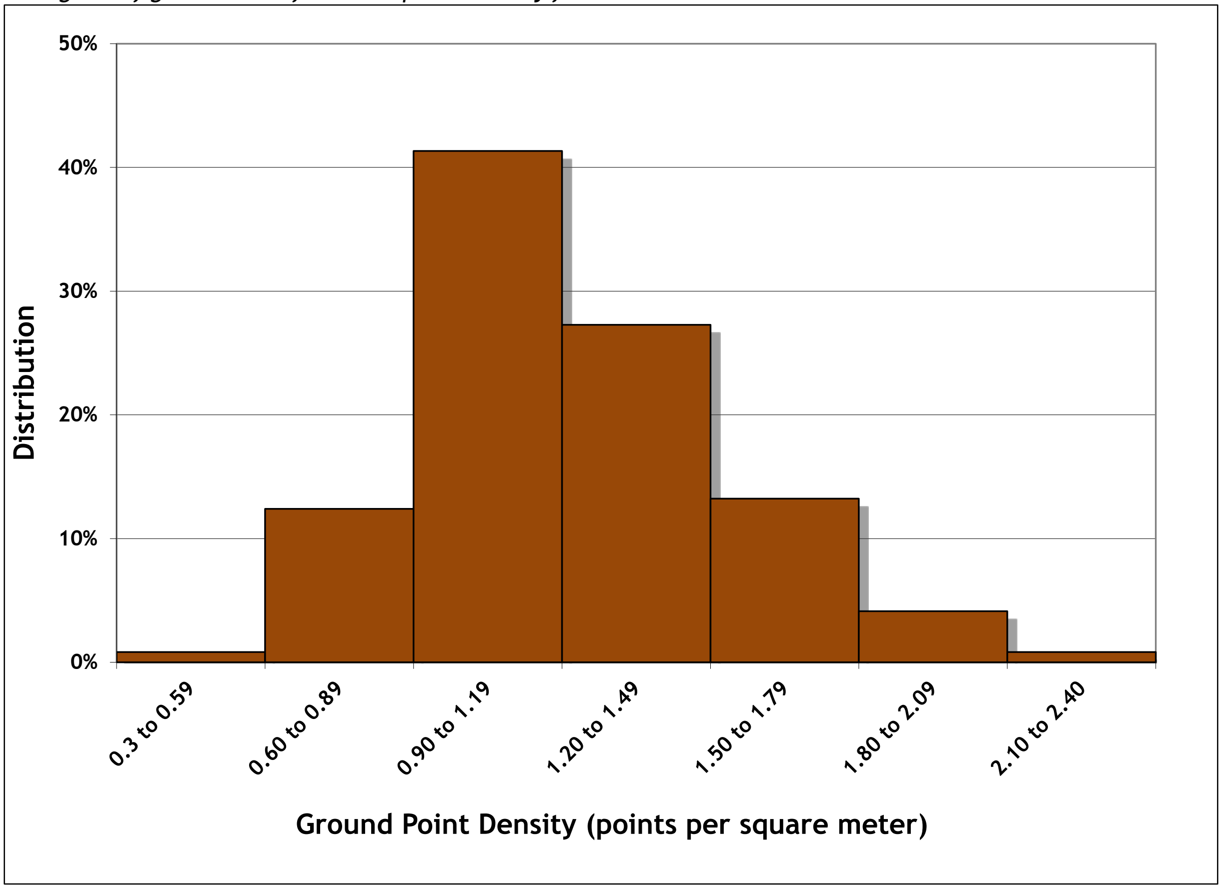



*First return laser pulse data density for the Panther Creek dataset.*

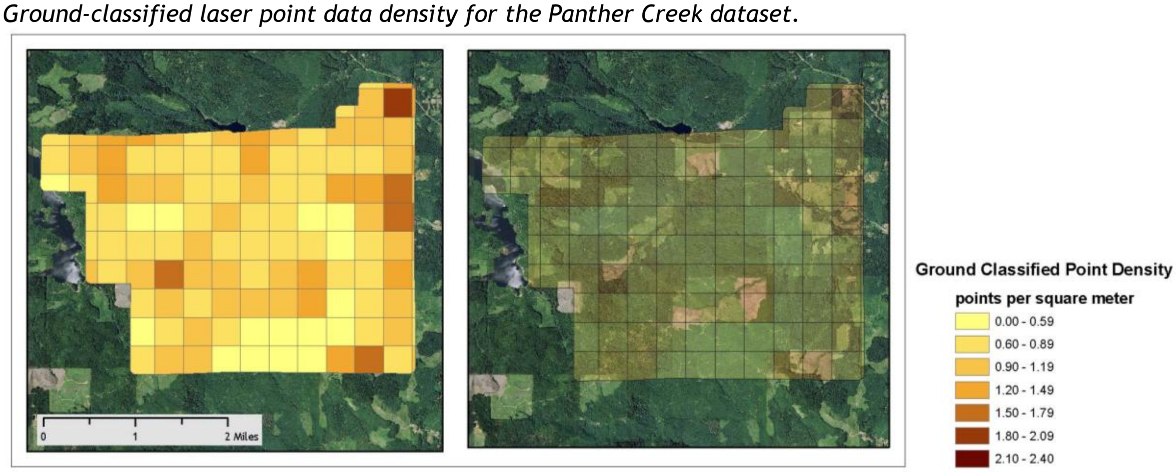


### 5.2.2 Ground-Classified Data Density

*Histogram of ground-classified laser point density for the Panther Creek dataset.*




*Ground-classified laser point data density for the Panther Creek dataset.*



**[This page left blank intentionally]**

# 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 Section (3.2) 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 Laser Point Accuracy Section (5.1) have been reviewed by me to meet the National Standard for Spatial Data Accuracy.

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

REGISTERED
PROFESSIONAL
LAND SURVEYOR
5/12/2011

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

RENEWAL DATE: 6/30/2012

**[This page left blank intentionally]**

# 7. Deliverables

## 7.1 Point Data

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

## 7.2 Vector Data

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

## 7.3 Raster Data

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

## 7.4 Data Report

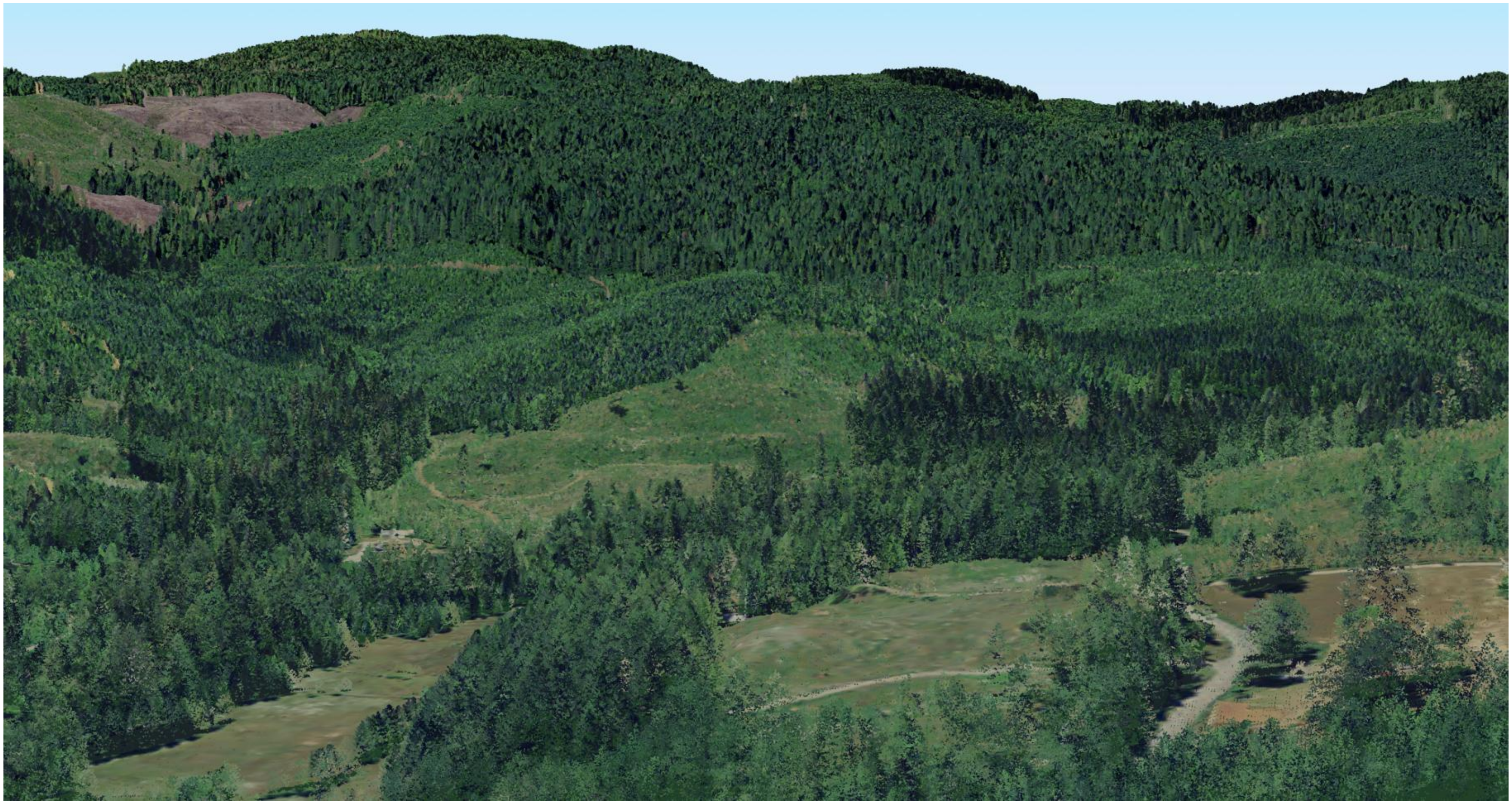
- Full Report containing introduction, methodology, accuracy, and sample imagery.
    - Word Format (*.doc)
    - PDF Format (*.pdf)

## 7.5 Datum and Projection

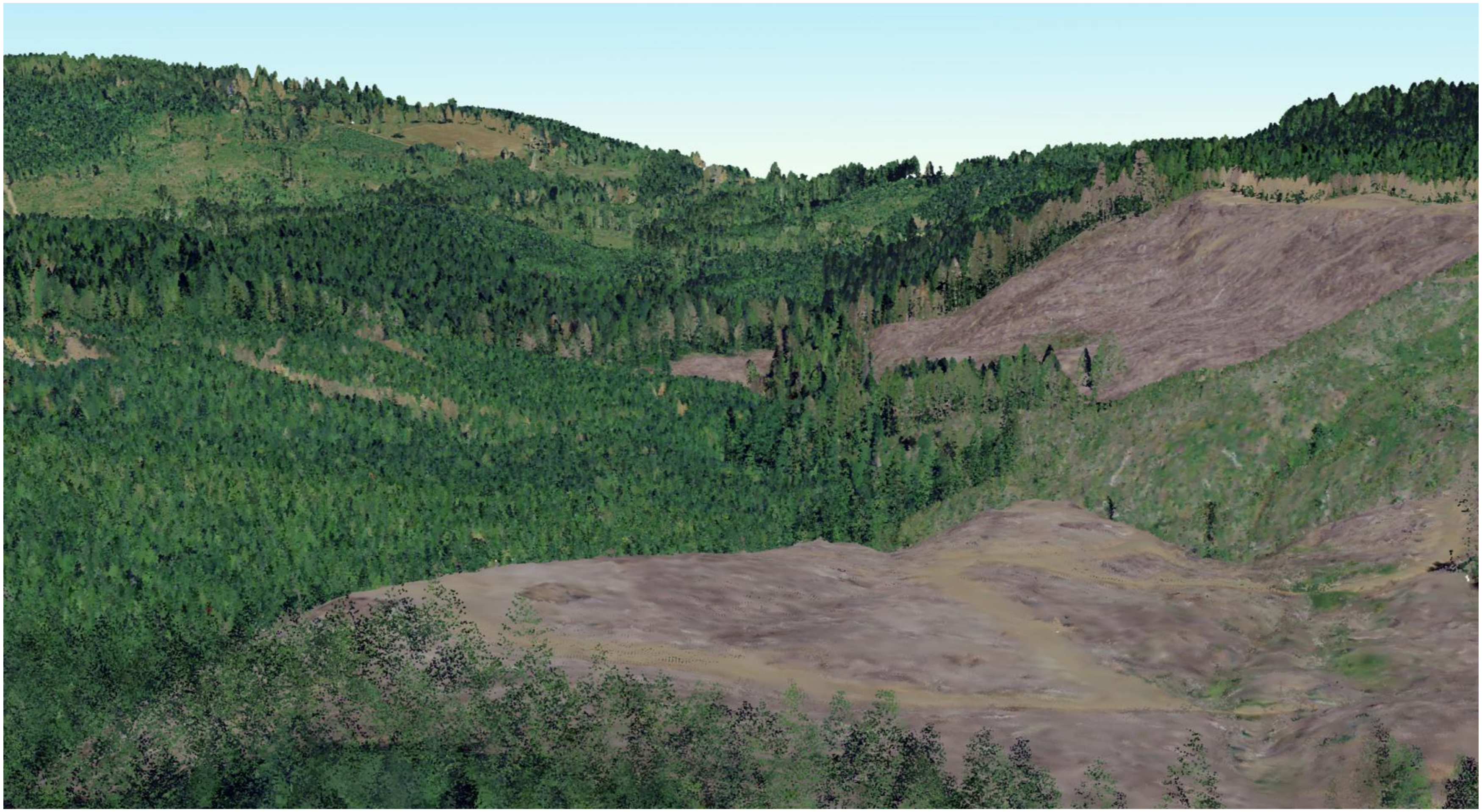
Universal Transverse Mercator (UTM) Zone 10; NAD83(CORS96); NAVD88(Geoid03); Units: meters.

## 8. Selected Imagery

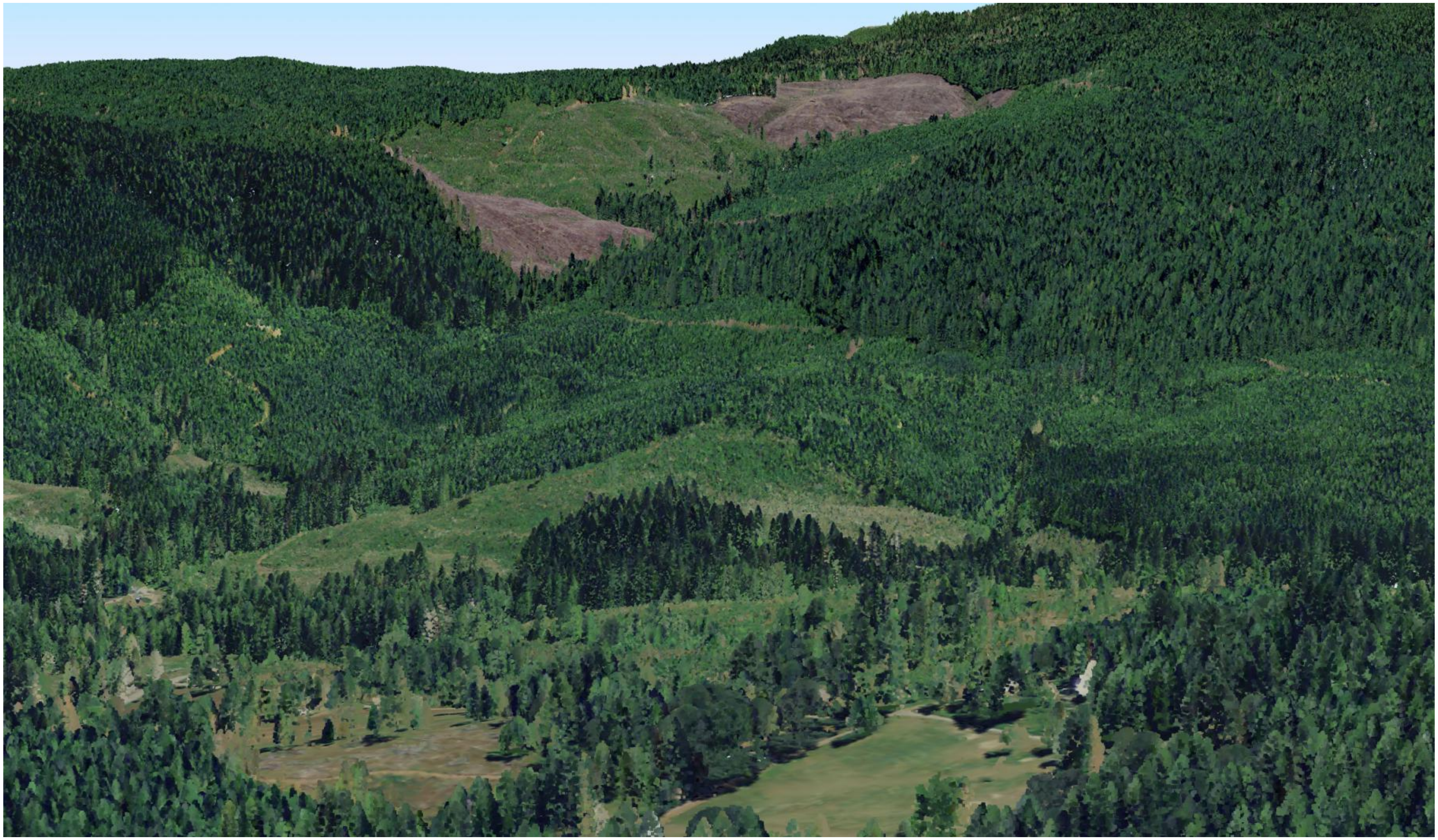
View of northwest Panther Creek Road winding through a forested area, ten miles northwest of McMinnville, Oregon. View to the west. Image is derived from LiDAR point cloud data with RGB extraction from 2009 NAIP orthophotos.



View of a forest clear cut, two miles east of McGuire Reservoir in Yamhill County. View to the east.  Image is derived from LiDAR point cloud data with RGB extraction from 2009 NAIP orthophotos.



View of the hills surrounding Panther Creek. View to the southwest. Image is derived from LiDAR point cloud data with RGB extraction from 2009 NAIP orthophotos.



## 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.

**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**: GNSS surveying is conducted with a GNSS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GNSS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

## 10. Citations

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