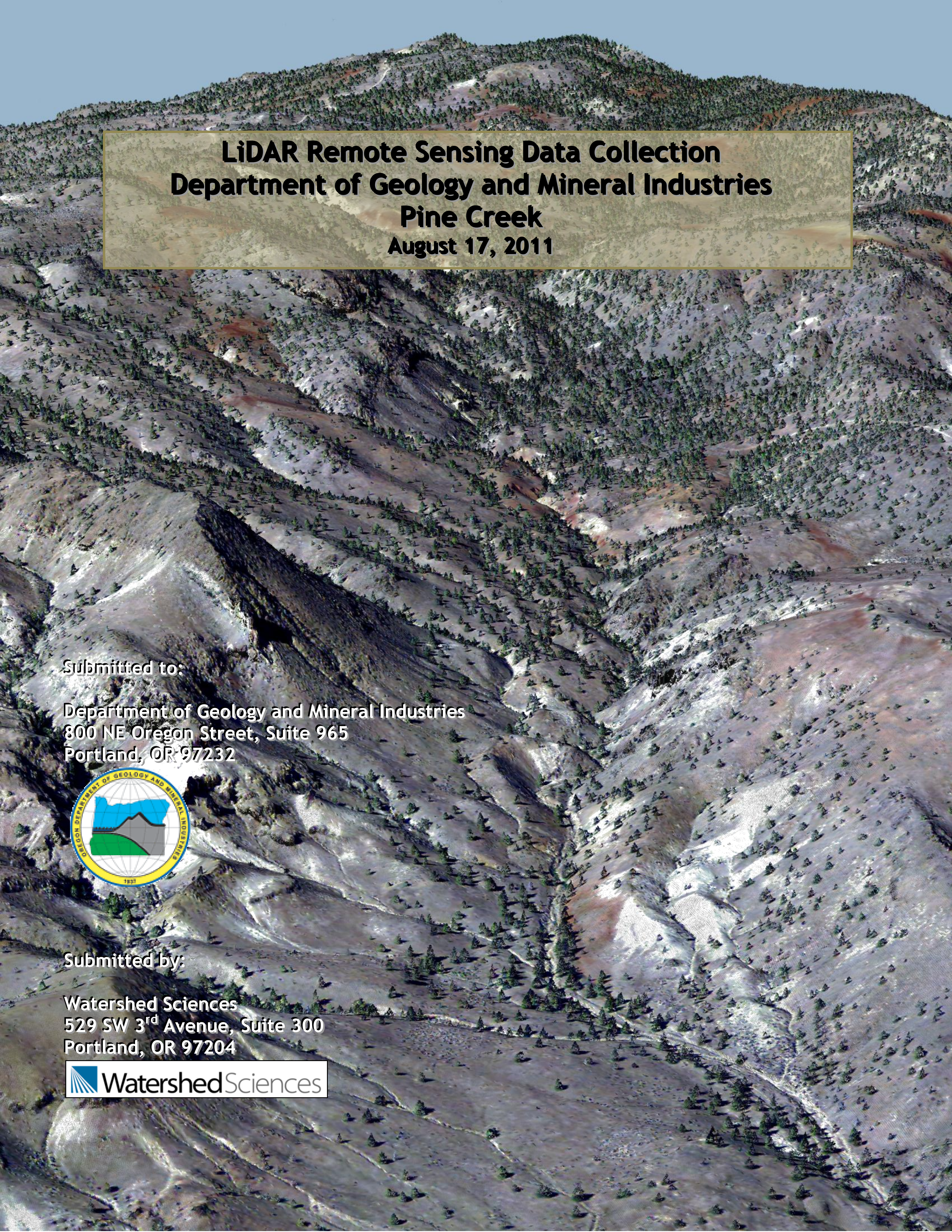

LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
Pine Creek
August 17, 2011

Submitted to:

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

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Watershed Sciences

LiDAR Remote Sensing Data Collection:
DOGAMI, Pine Creek Study Area

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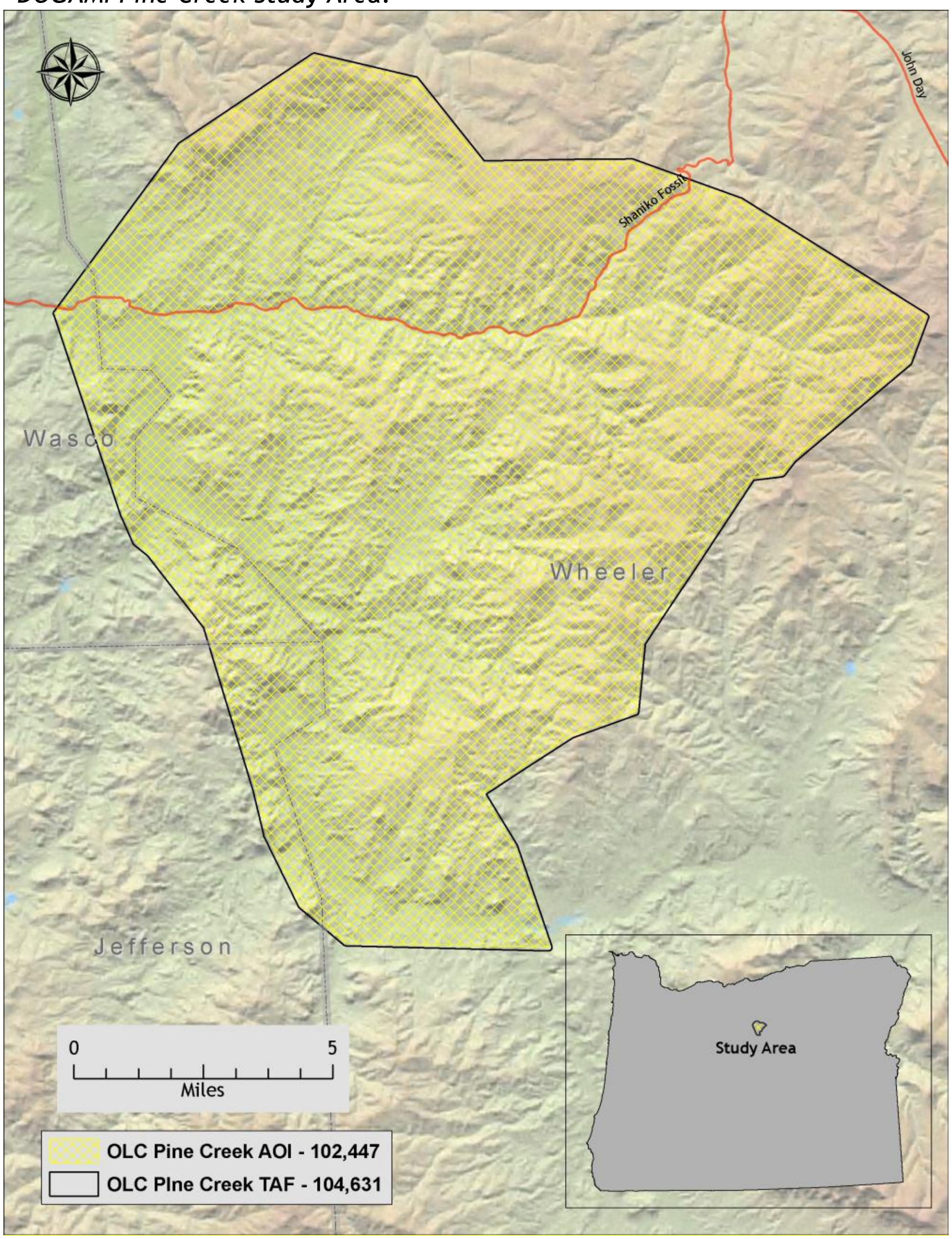
1. Overview

1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Pine Creek Study Area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 160 square miles (102,447 acres) and the total area flown (TAF) covers 163 square miles (104,631 acres). The TAF acreage is greater than the original AOI acreage due to buffering and flight planning optimization (**Figure 1.1** below). DOGAMI data are delivered in OGIC (HARN): Projection: Oregon Statewide Lambert Conformal Conic; horizontal and vertical datum: NAD83 (HARN)/NAVD88 (Geoid03); units: International Feet.

Figure 1.1. *DOGAMI Pine Creek Study Area.*

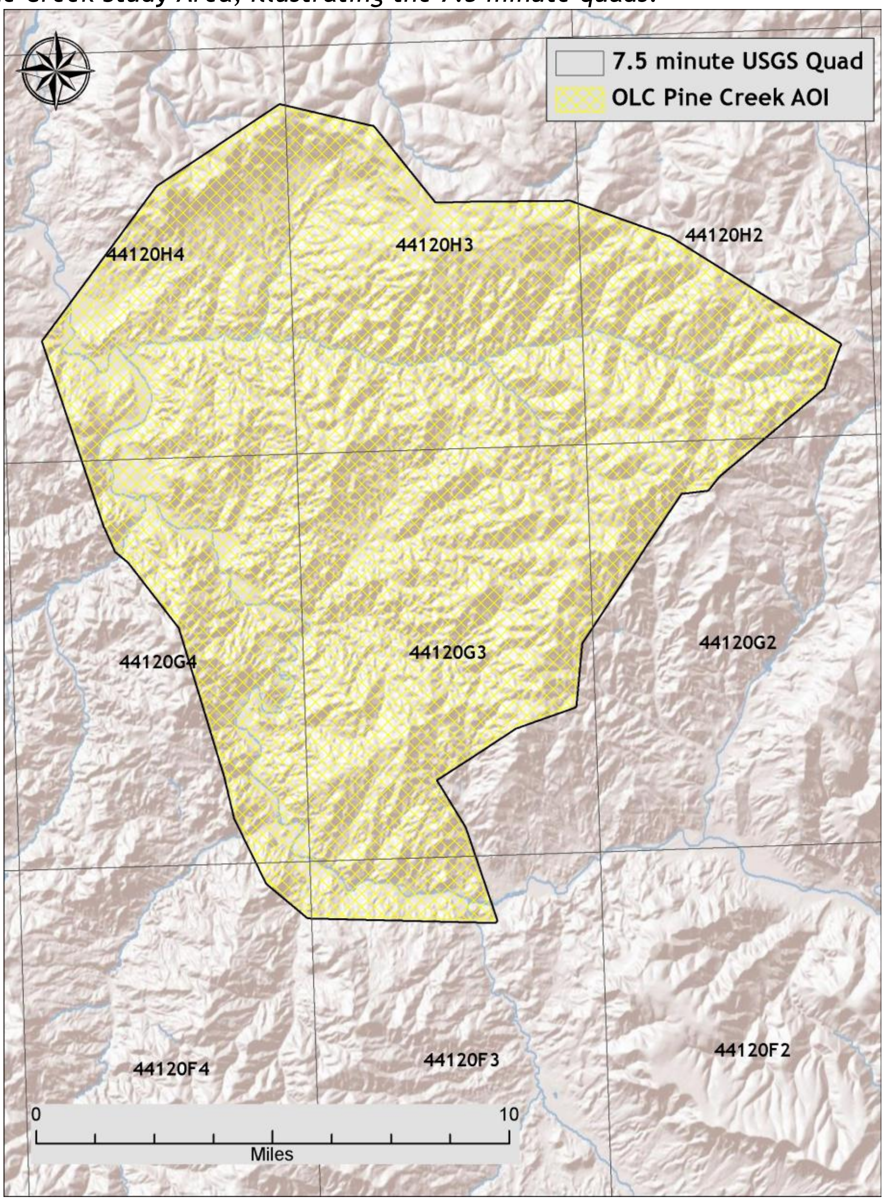


1.2 Area Delivered to Date

Total delivered acreage to date is detailed below.

DOGAMI Pine Creek Study Area				
	Delivery Date	Acquisition Dates	AOI Acres	TAF Acres
Delivery Area	August 17, 2011	May 19. 2011- May 20, 2011	**102,447**	**104,631**

Figure 1.2. *Pine Creek Study Area, Illustrating the 7.5 minute quads.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

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

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

Table 2.1 *LiDAR Survey Specifications*

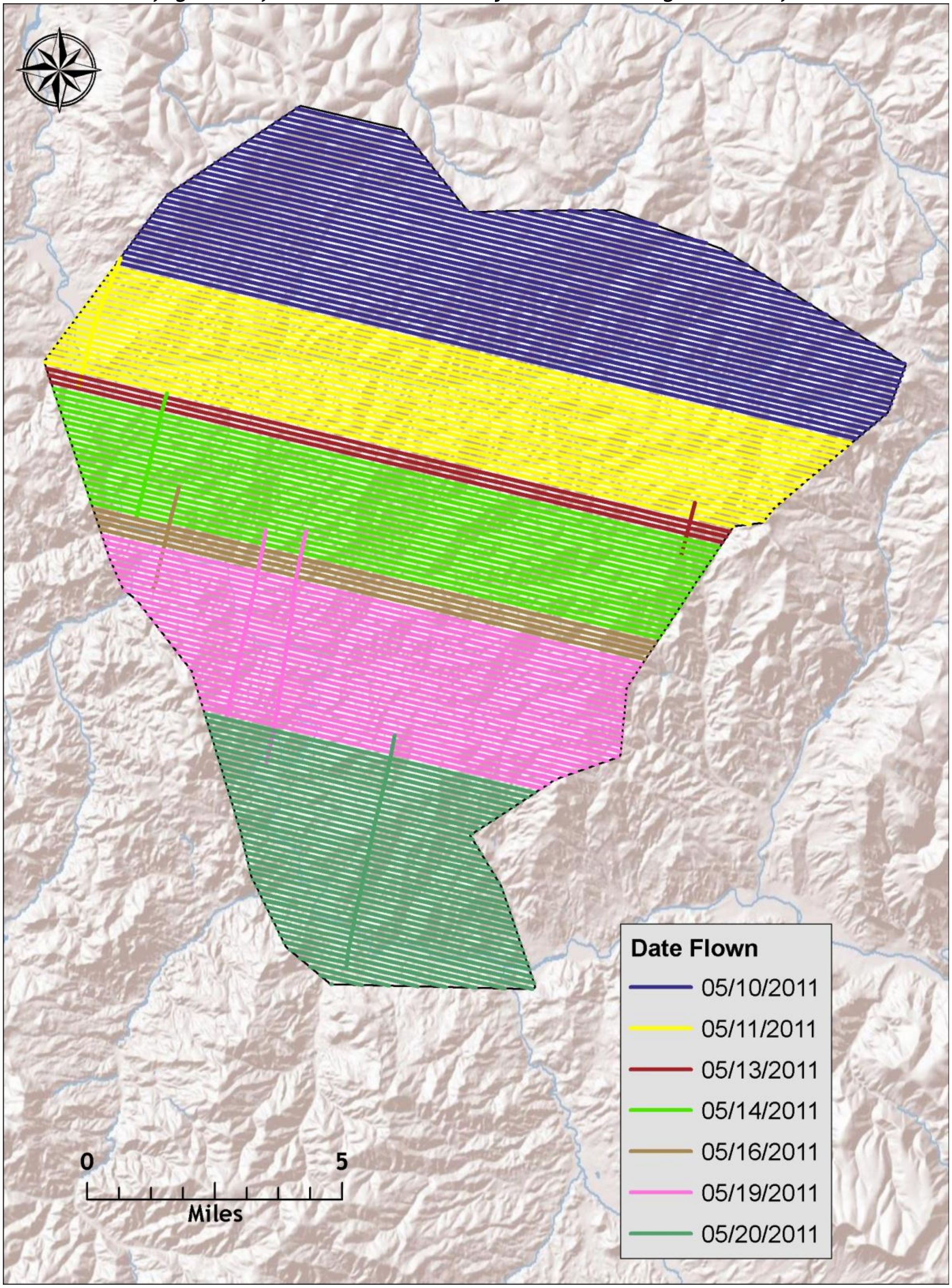
Sensor	Leica ALS50
Survey Altitude (AGL)	900 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	30 (±14° from nadir)
Roll Compensated	Up to 15°
Overlap	100% (50% Side-lap)

The study area was surveyed with opposing flight line side-lap of ≥50% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per pulse, and all discernable laser returns were processed for the output dataset.

To solve for laser point position, it is vital to have an accurate description of aircraft position and attitude. Aircraft position is described as x, y and z and measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude is measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). **Figure 2.1** shows the flight lines completed for current processing.

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

Figure 2.1. *Actual flightlines for the Pine Creek Study Area illustrating the dates flown.*



2.2 Ground Survey – Instrumentation and Methods

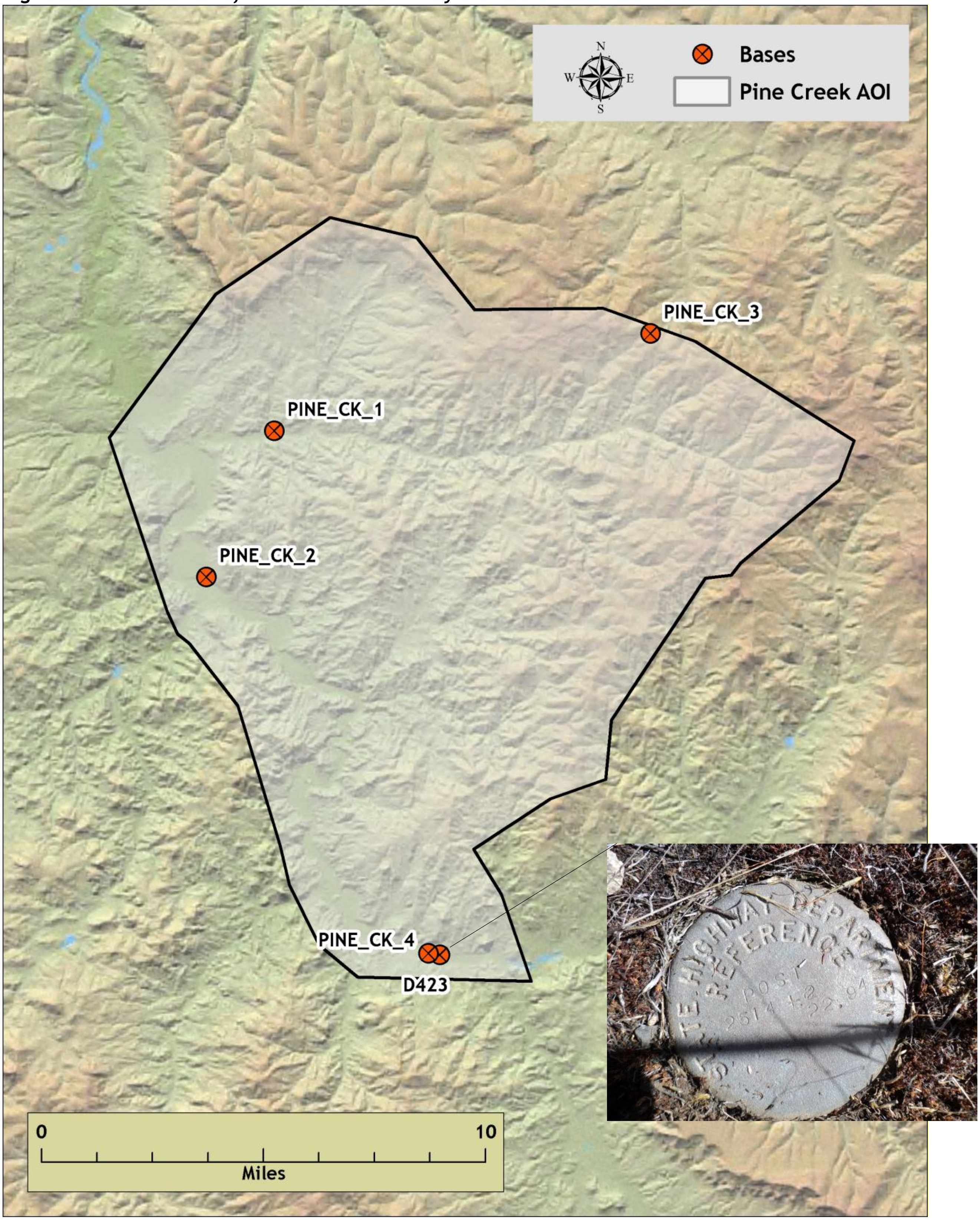
During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over monuments with known coordinates. Monument coordinates are provided in **Table 2.2** and shown in **Figure 2.2**. After the airborne survey, the static GPS data were processed using triangulation with CORS stations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

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

	Datum NAD83 (HARN)		GRS80
Base Stations ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
PINE_CK_1	44 54 44.77041	120 24 21.98918	456.676
PINE_CK_2	44 51 55.55910	120 26 22.00505	426.743
PINE_CK_3	44 56 24.59395	120 13 54.74135	1116.102
D423	44 44 23.35823	120 20 17.05407	453.736
PINE_CK_4	44 44 25.44416	120 20 35.80124	450.666

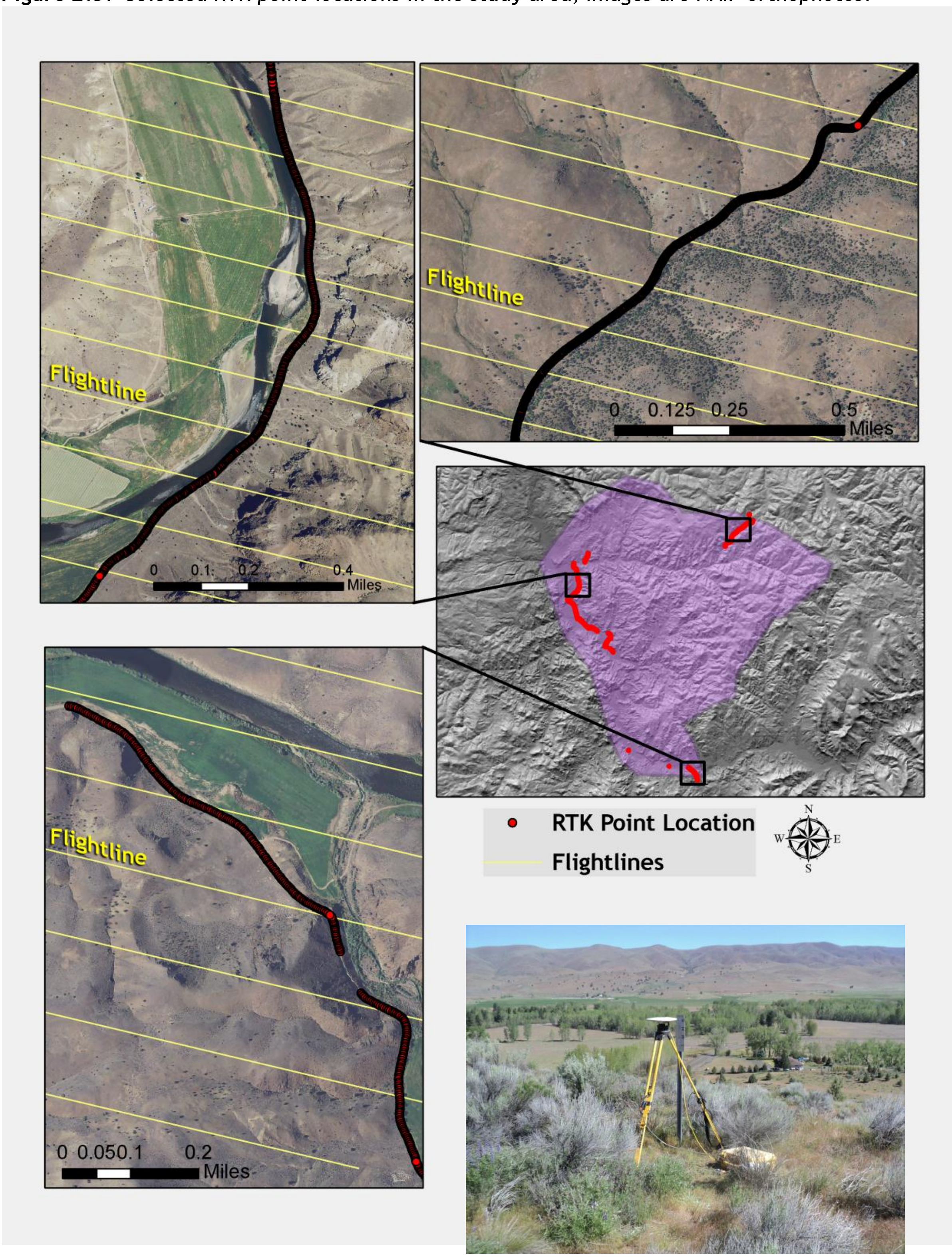
[2] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.

Figure 2.2. *Base stations for the Pine Creek Study Area.*



For data delivered to date, 2,817 RTK (Real-time kinematic) points were collected in the study area.

Figure 2.3. *Selected RTK point locations in the study area; images are NAIP orthophotos.*



3.Accuracy

3.1 Relative Accuracy

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 179 flightlines and over 5 billion points. Relative accuracy is reported for the portion of the study area shown in **Figure 3.1** below.

- Project Average = 0.12 ft (0.04 m)
- Median Relative Accuracy = 0.12 ft (0.04 m)
- 1σ Relative Accuracy = 0.13 ft (0.04m)
- 2σ Relative Accuracy = 0.15 ft (0.05 m)

***Figure 3.1**. Relative Accuracy Covered Area.*

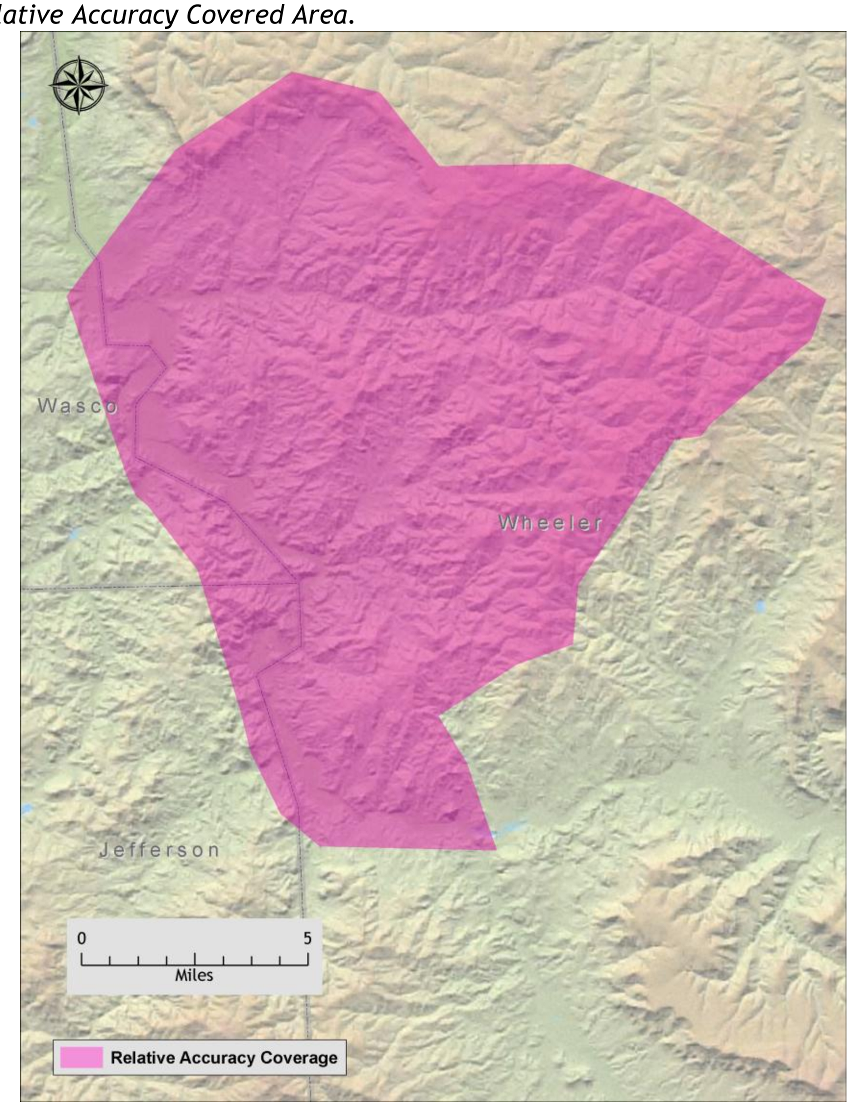


Figure 3.2. *Statistical relative accuracies, non slope-adjusted.*

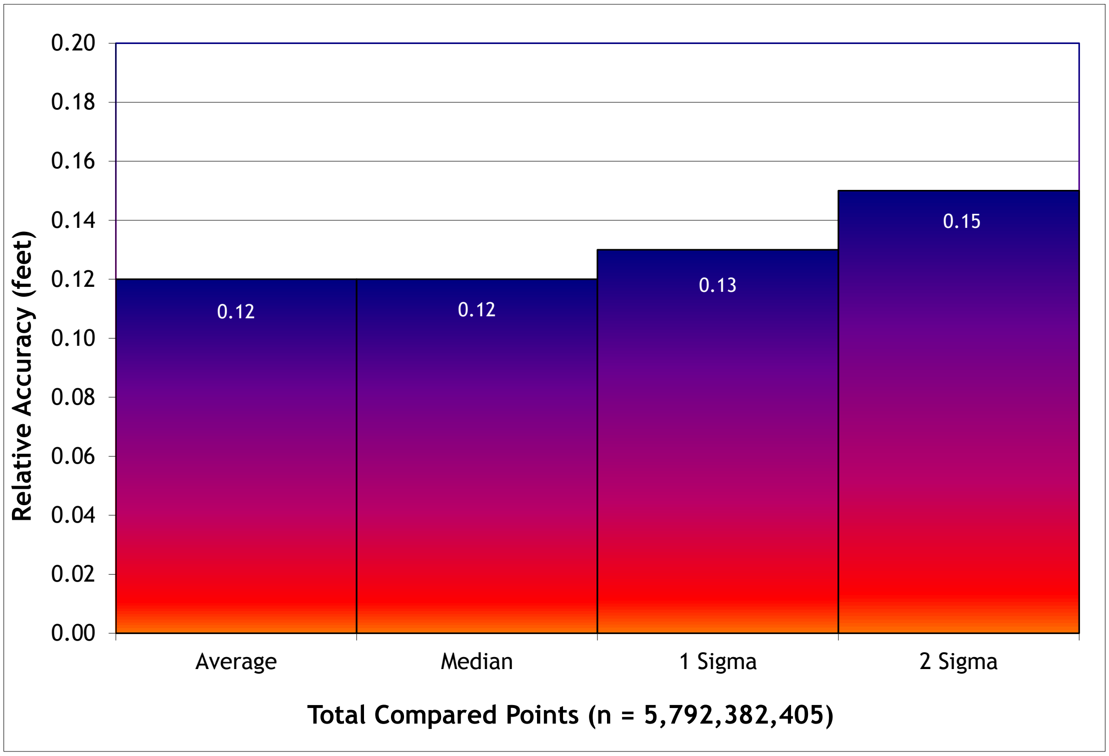
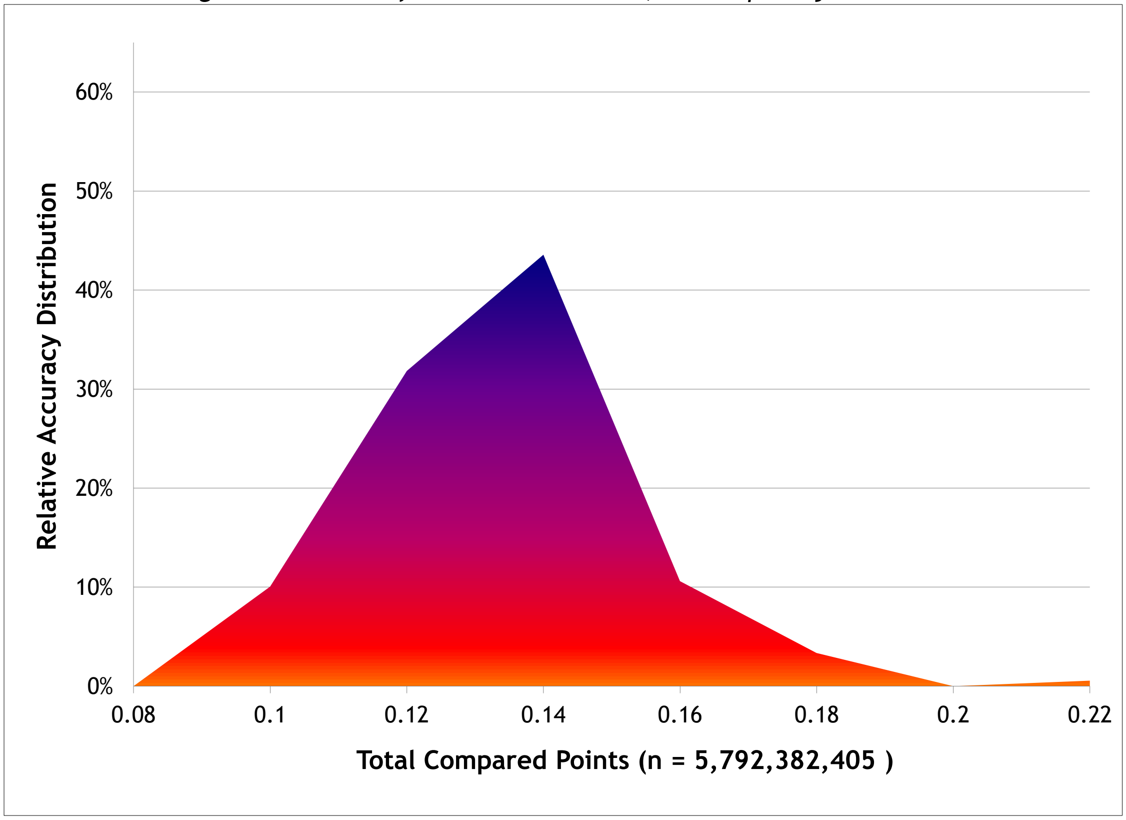


Figure 3.3. *Percentage distribution of relative accuracies, non slope-adjusted.*



3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Pine Creek Study Area, 2,817 RTK points were collected for data delivered to date. Absolute accuracy is reported for the portion of the study area shown in **Figure 3.4** and reported in **Table 3.1** below. Histogram and absolute deviation statistics are reported in **Figures 3.5 and 3.6**.

Table 3.1. *Absolute Accuracy – Deviation between laser points and RTK survey points.*

Sample Size (n): 2,817	
Root Mean Square Error (RMSE): 0.10 ft (0.03m)	
Standard Deviations	**Deviations**
1 sigma (σ): 0.10 ft (0.03 m)	**Minimum Δz:** -0.52 ft (-0.16 m)
2 sigma (σ): 0.19 ft (0.06 m)	**Maximum Δz:** 0.29 ft (0.09 m)
	Average Δz: -0.03 ft (-0.01 m)

Figure 3.4. *Absolute Accuracy Covered Area.*

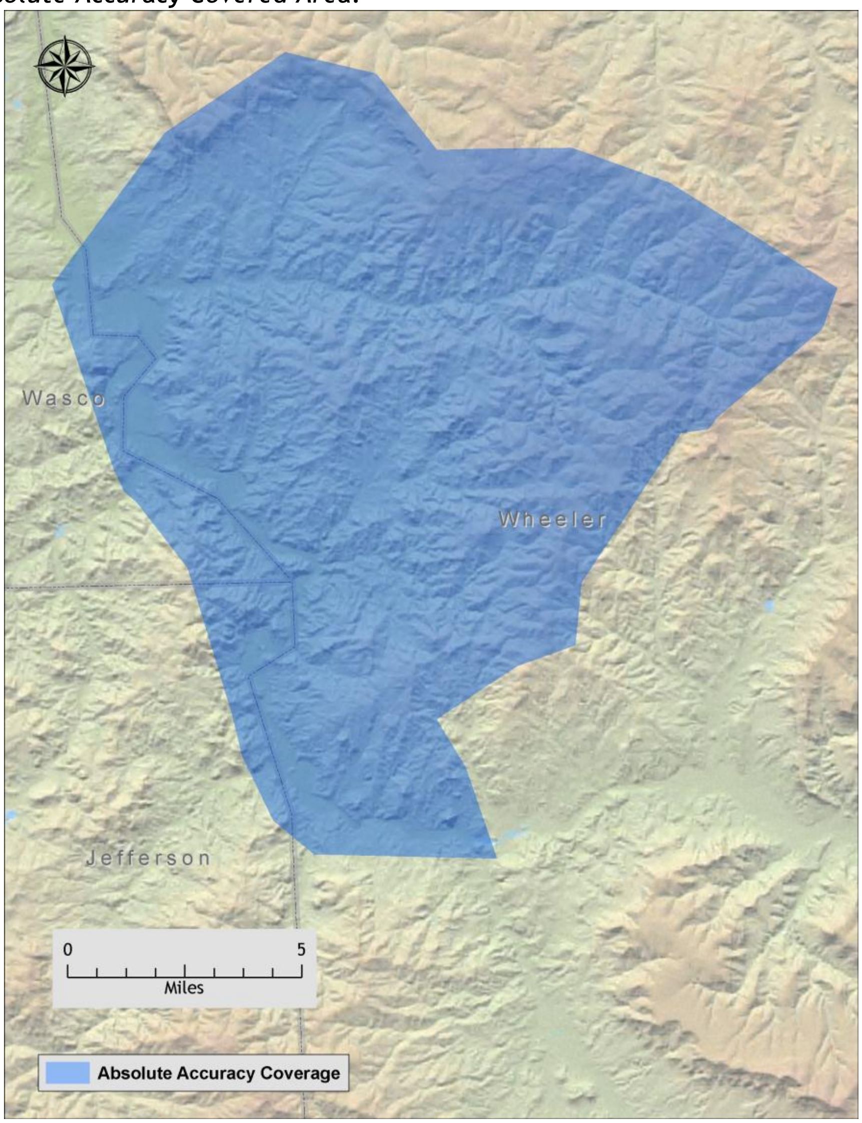


Figure 3.5. Pine Creek Study Area histogram statistics

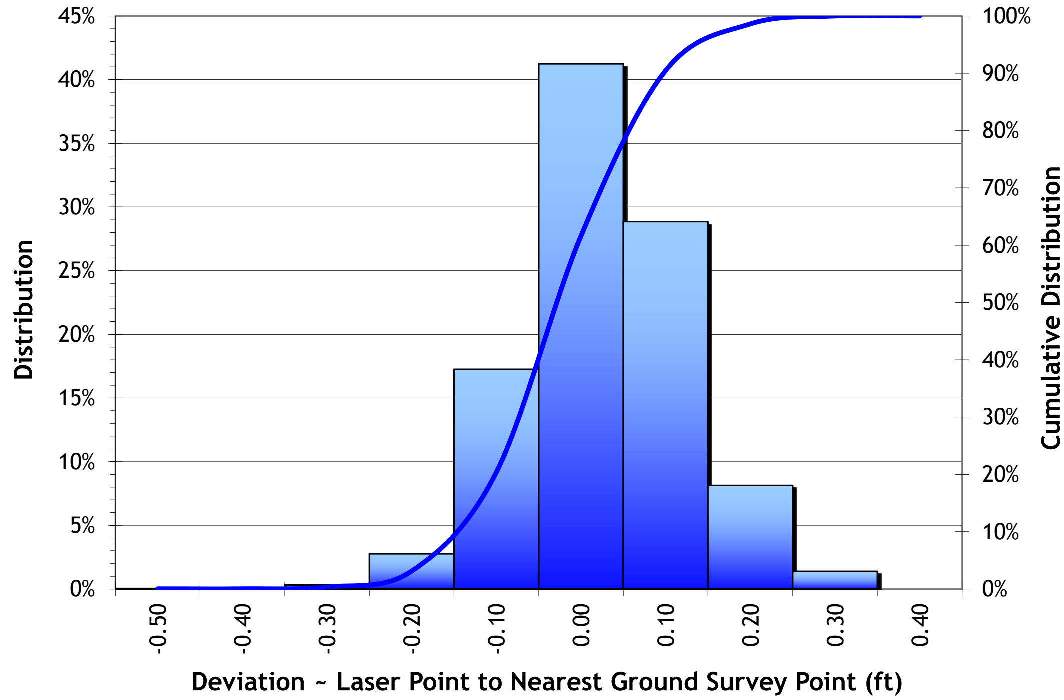
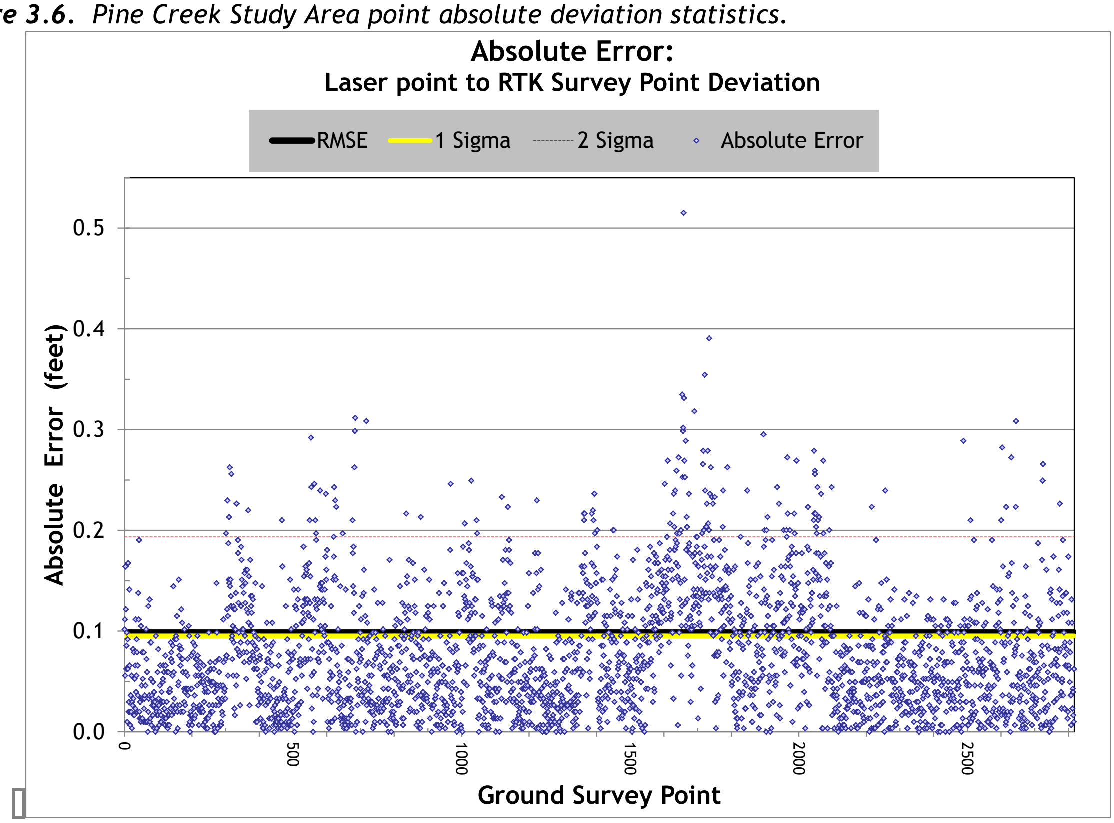


Figure 3.6. Pine Creek Study Area point absolute deviation statistics.



4. Data Density/Resolution

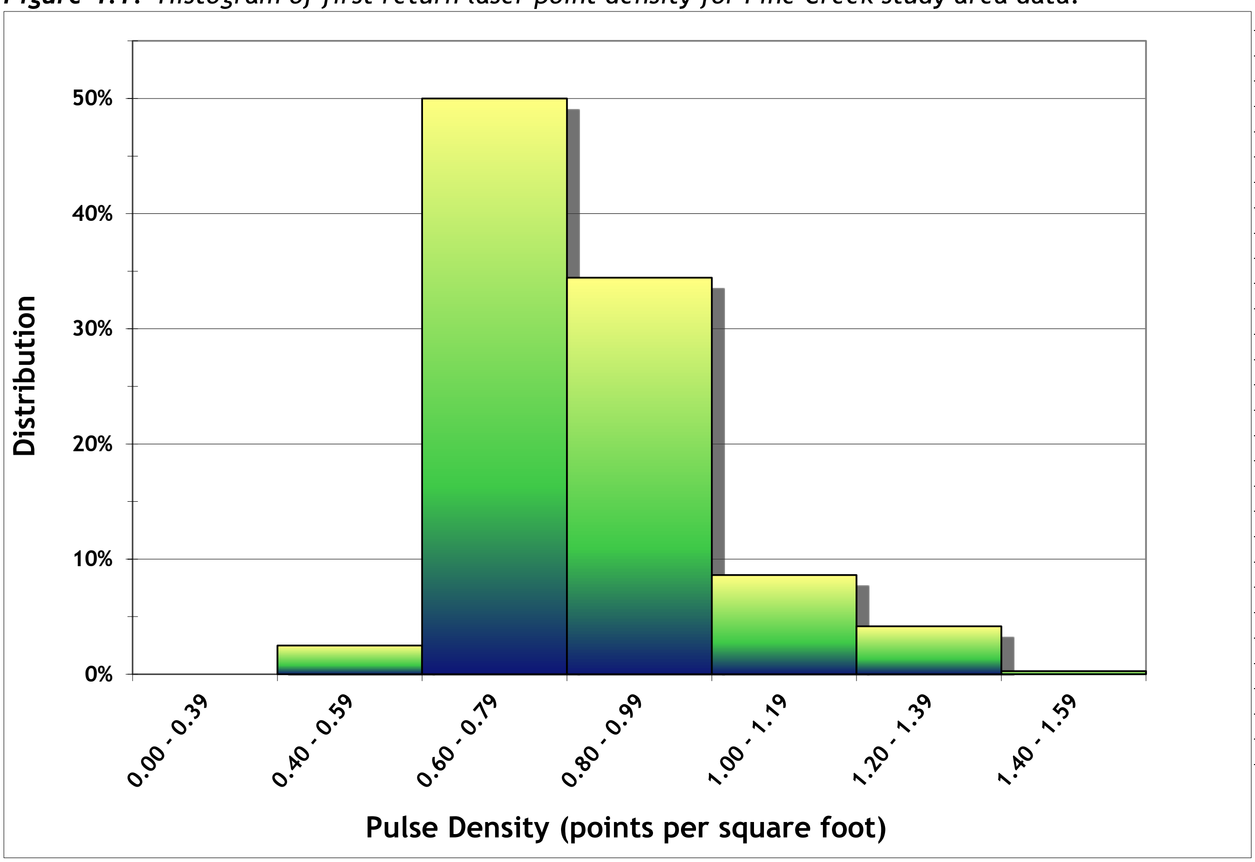
4.1 Density Statistics

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 terrain, land cover and water bodies. Density histograms and maps (**Figures 4.1 – 4.4)** have been calculated based on first return laser point density and ground-classified laser point density.

***Table 4.1**. Average density statistics for Pine Creek Study Area data.*

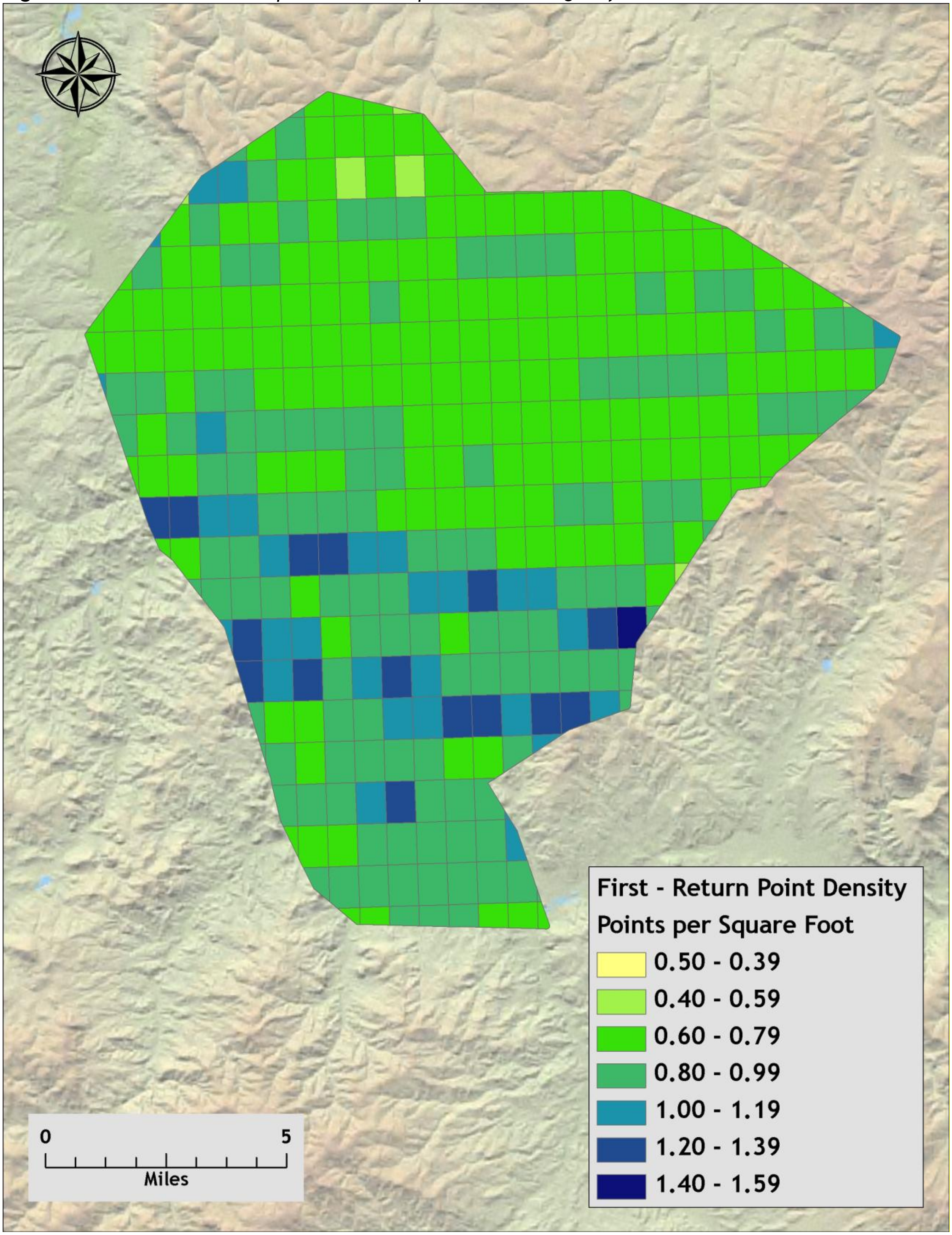
Average Pulse Density (per square ft)	Average Pulse Density (per square m)	Average Ground Density (per square ft)	Average Ground Density (per square m)
0.83	8.89	0.25	2.72

***Figure 4.1**. Histogram of first return laser point density for Pine Creek study area data.*



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

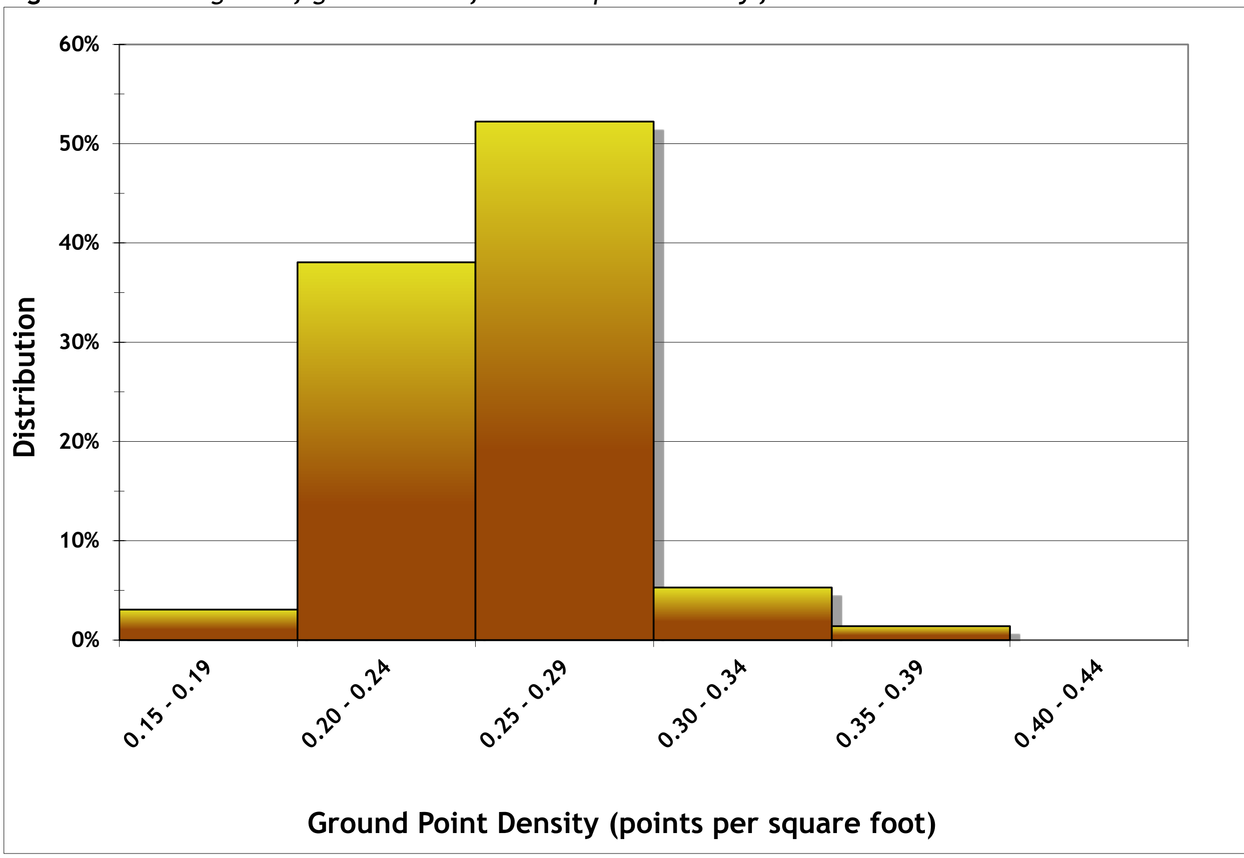
Figure 4.2. *First return laser point densities per 0.75' USGS Quad for data delivered to date.*



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

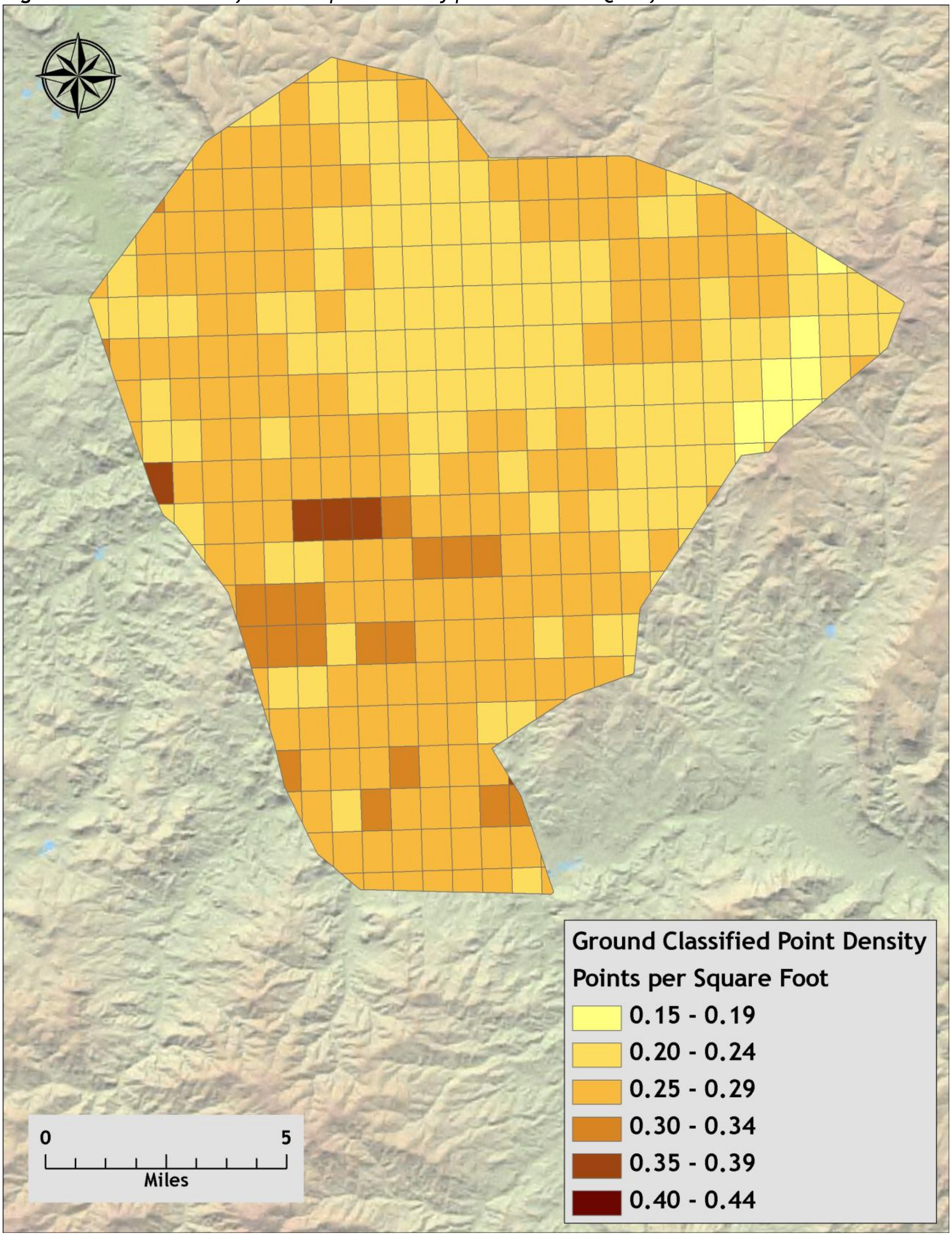
Ground classifications were derived from ground surface modeling. Classifications were performed by reseeding of the ground model where it was determined that the ground model failed, usually under dense vegetation and/or at breaks in terrain, steep slopes and at bin boundaries.

Figure 4.3. *Histogram of ground-classified laser point density for Pine Creek data.*



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

Figure 4.4. *Ground-classified laser point density per 0.75' USGS Quad for data delivered to date.*



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

5. Certifications

Watershed Sciences provided LiDAR services for the Pine 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
8/17/2011

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

RENEWAL DATE: 6/30/2012

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6. Selected Imagery

Figure 5.1. Northern view of John Day River at the northwest border of Jefferson and Wheeler County. Image is a LiDAR point cloud colored with RGB values from NAIP imagery

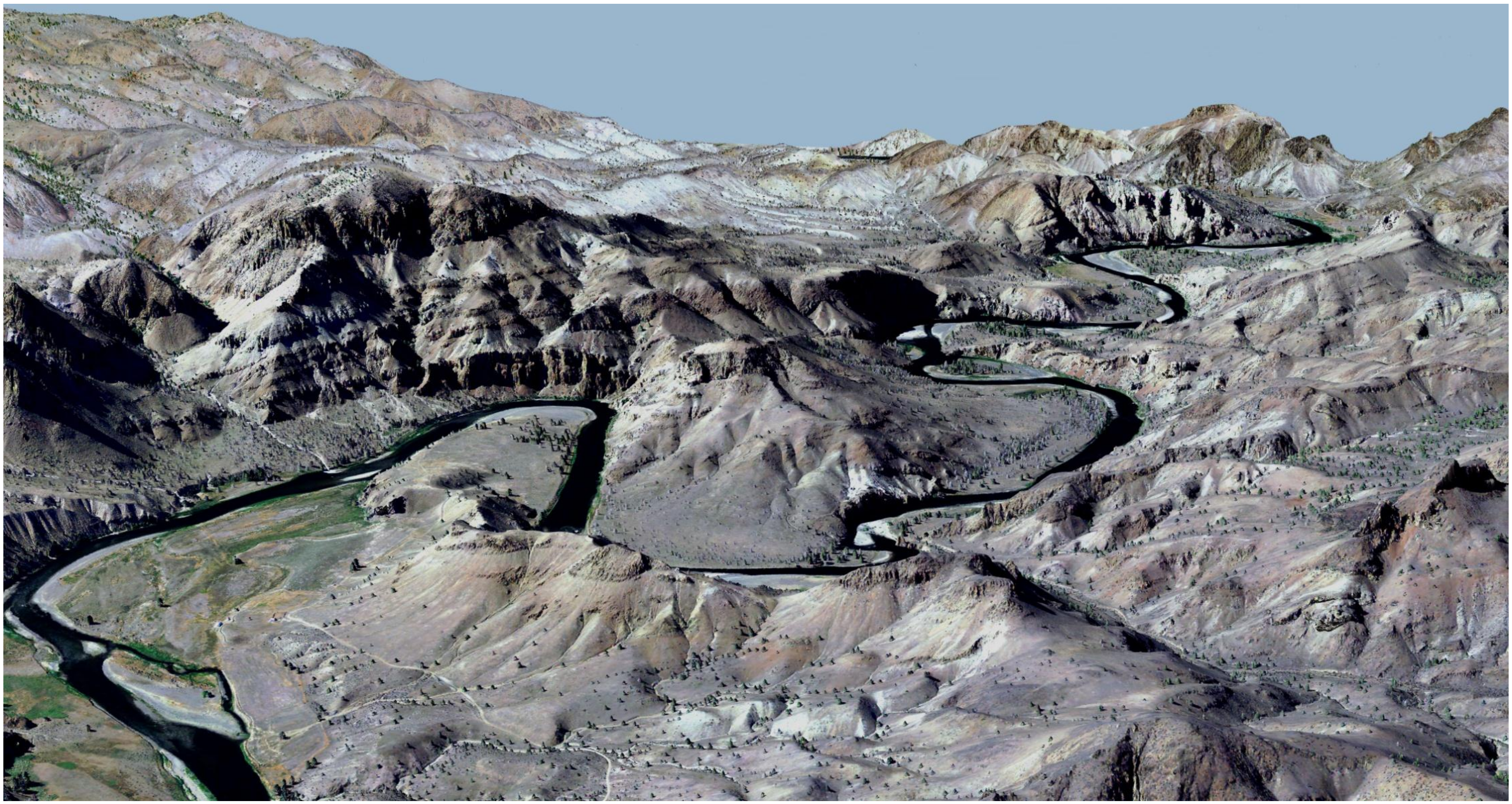

Figure x.x. Eastern view of Shaniko-Fossil Highway (Hwy 218) just west of Clarno, Oregon. Image is a LiDAR point cloud colored with RGB values from NAIP imagery

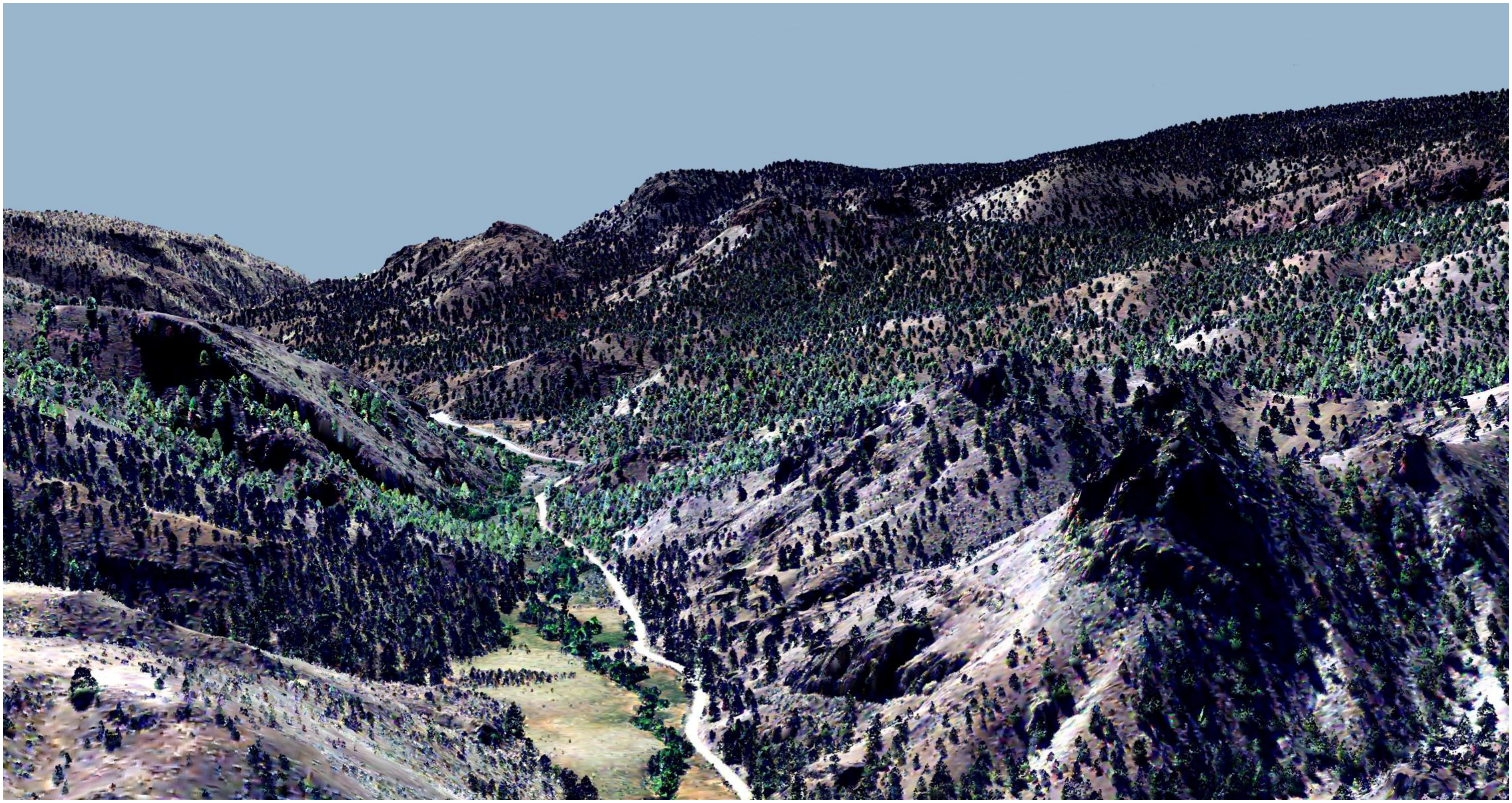

Figure x.x. Northern view of Shaniko-Fossil Highway (Hwy 218) just west of Clarno, Oregon. Image is a LiDAR point cloud colored with RGB values from NAIP imagery

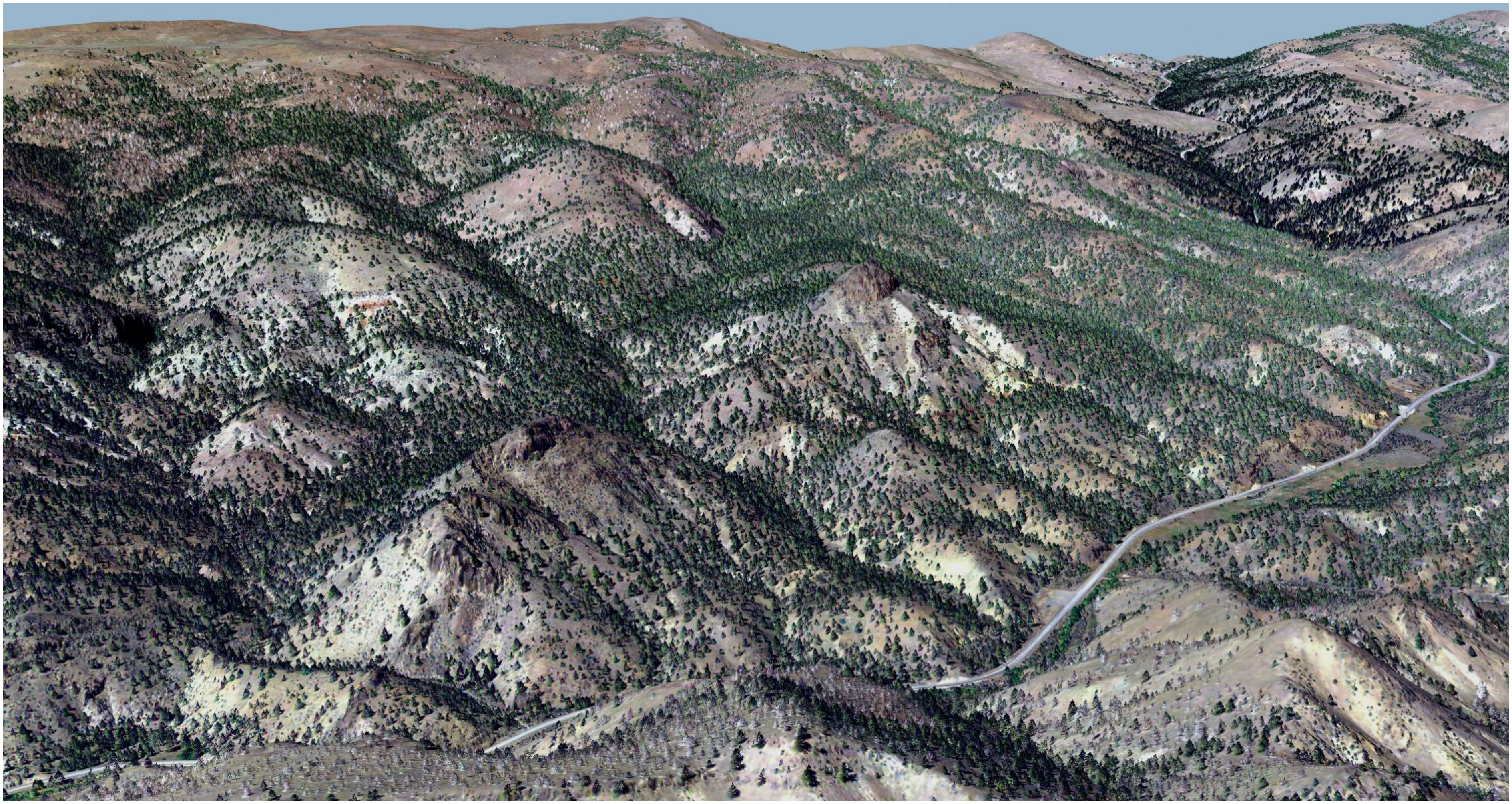

Figure x.x (Cover). Northern view of Eastern Oregon landscape just North of John Day River and Bridge Creek Road. Image is a LiDAR point cloud colored with RGB values from NAIP imagery