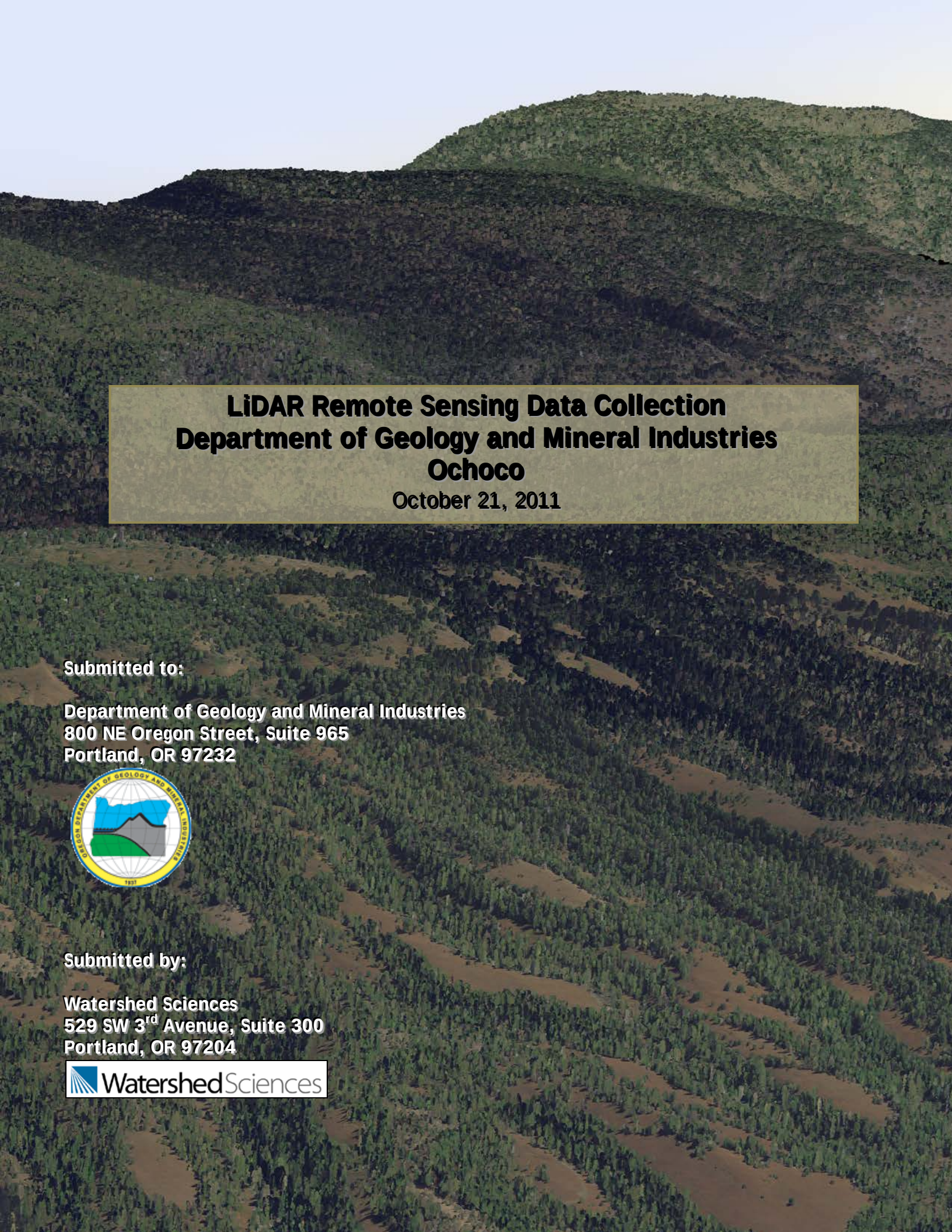

LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
Ochoco

October 21, 2011

Submitted to:

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

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Portland, OR 97204

Watershed Sciences

LiDAR Remote Sensing Data Collection:
DOGAMI, Ochoco Study Area

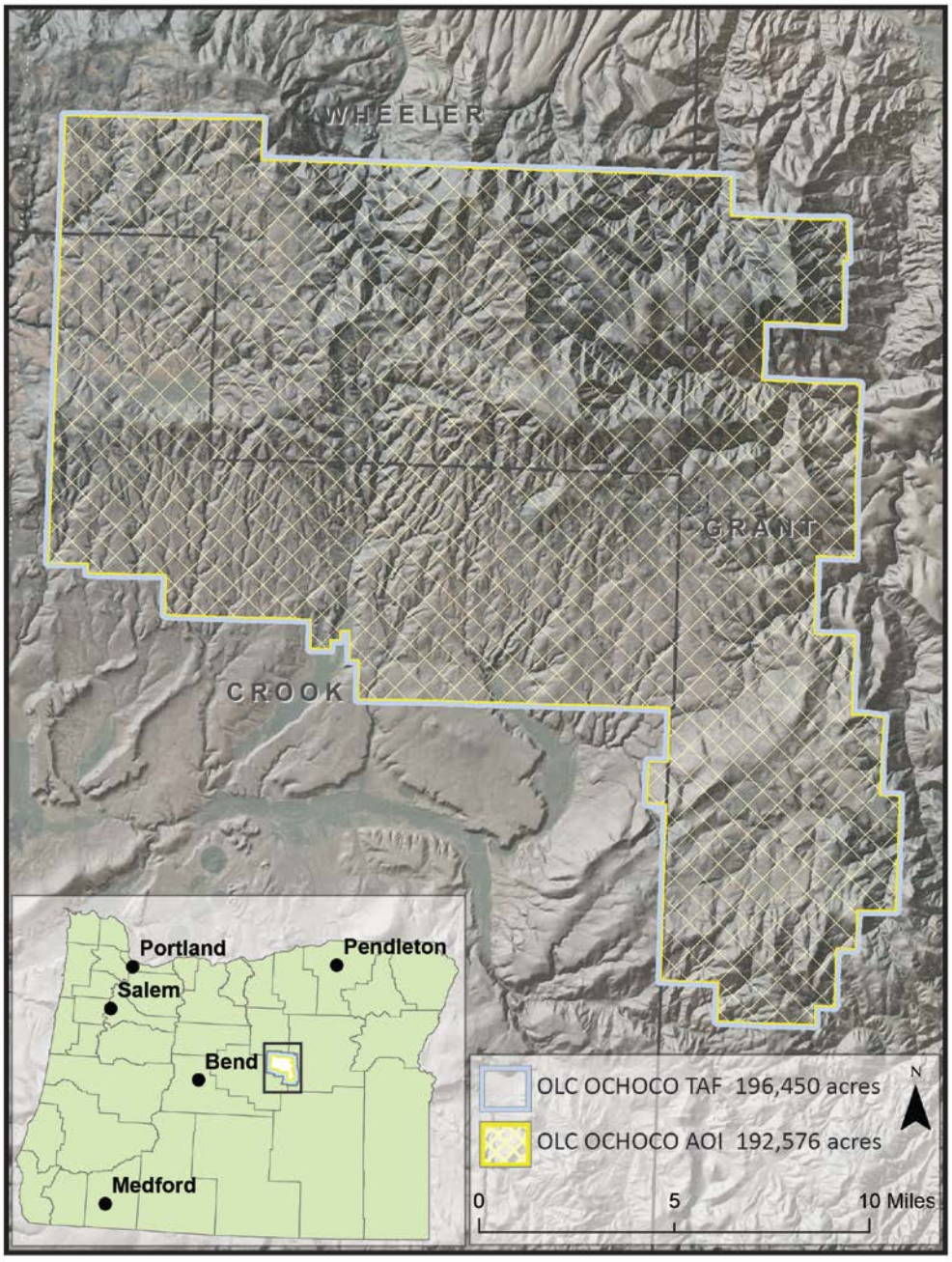
TABLE OF CONTENTS

1. Overview

1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Ochoco Study Area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 192,576 acres and the Total Area Flown (TAF) encompasses 196,450 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.

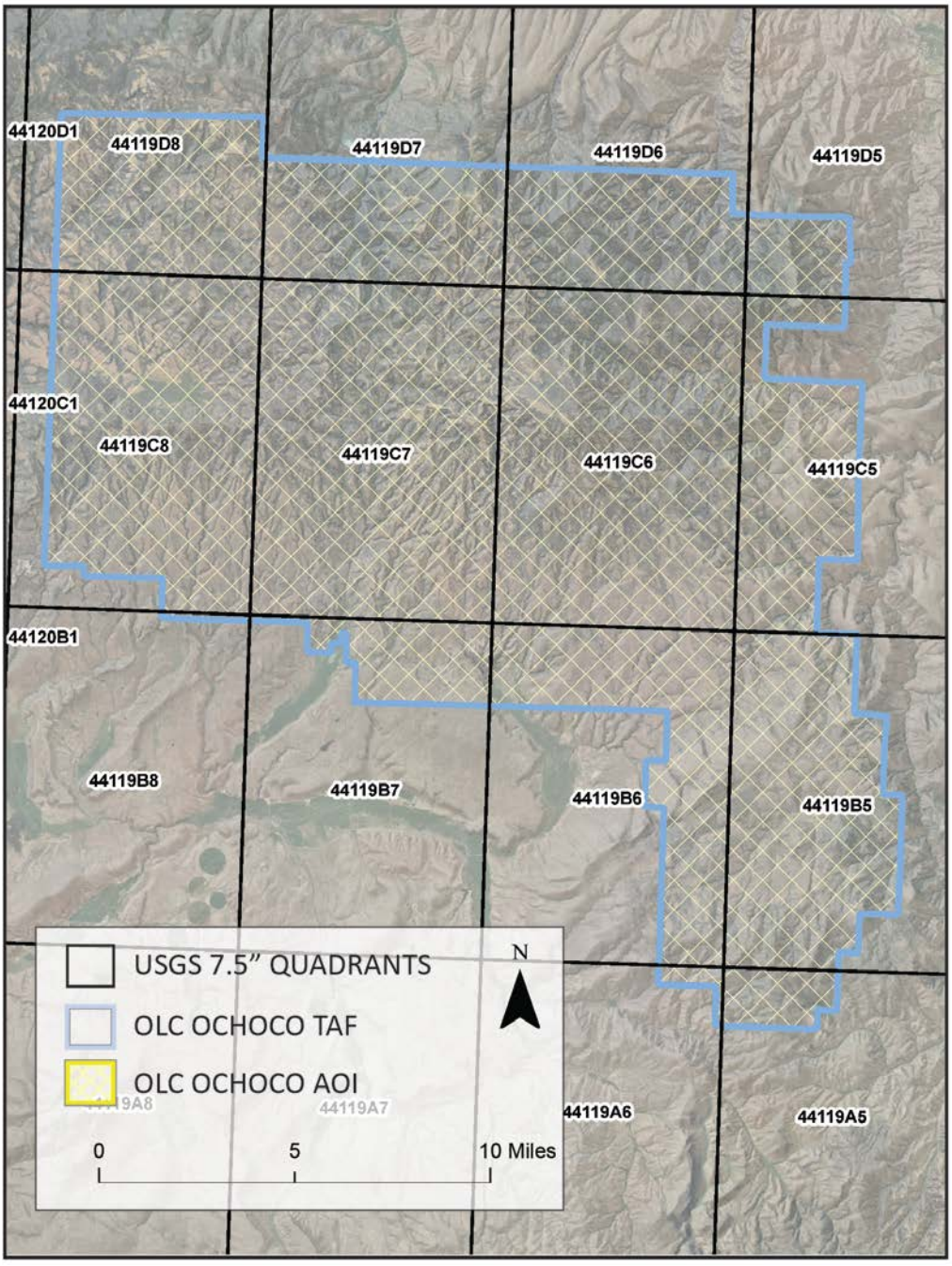
Figure 1.1. *Ochoco Study Area.*



1.2 Area Delivered

DOGAMI Ochoco Study Area				
	Delivery Date	**Acquisition Dates**	**AOI Acres**	**TAF Acres**
Delivery Area	October 21, 2011	July 8. 2011- July 16, 2011	**192,576**	**196,450**

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



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized dual-mounted Leica ALS50 sensors flown in a Cessna Caravan 208B. The Leica ALS50 systems acquired between 75,000 and 83,000 laser pulses per second (75-83 kHz pulse rate) and were flown at 1,300 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 may vary slightly 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*

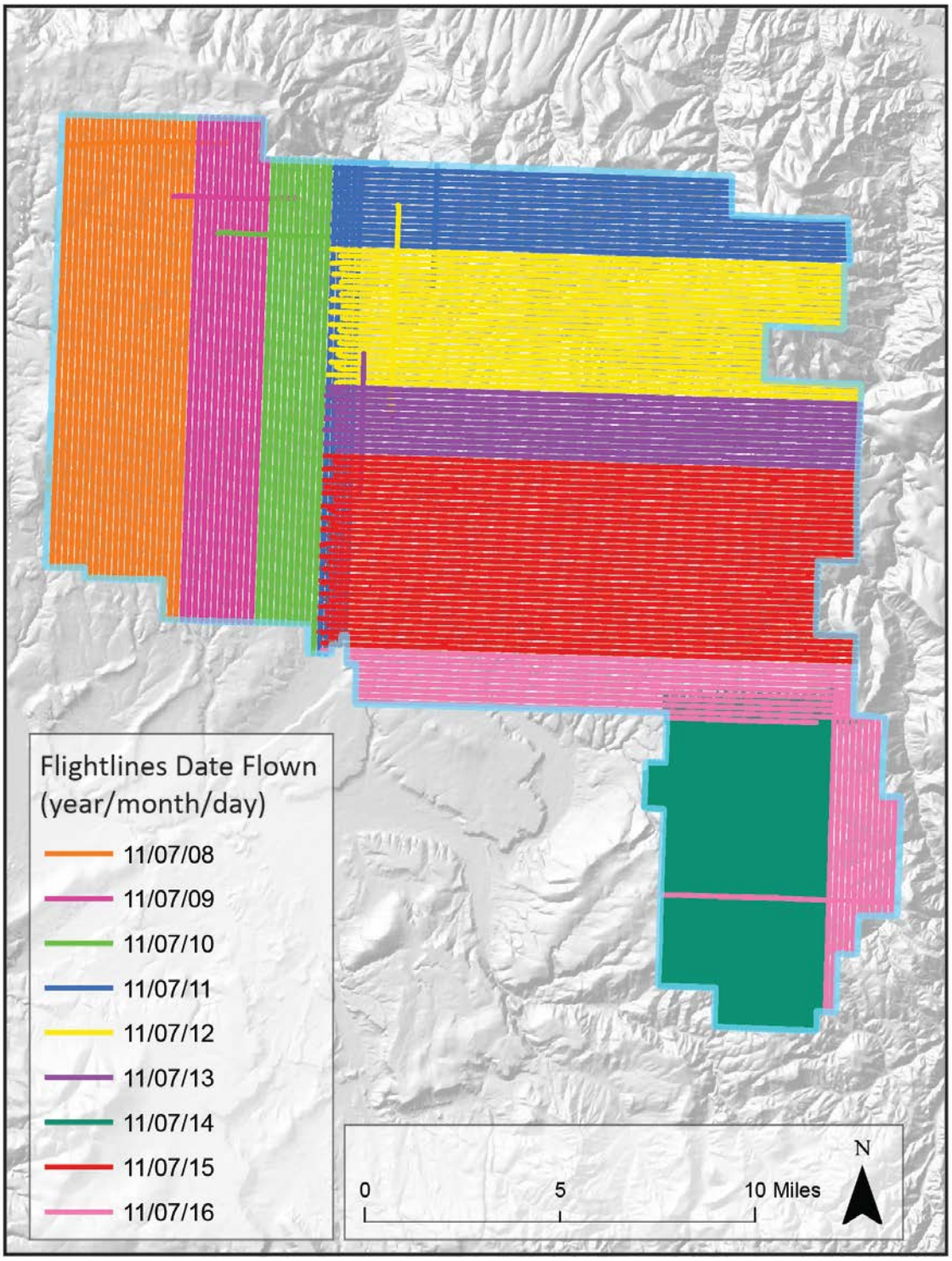
Sensors	Dual-mounted Leica ALS50's
Survey Altitude (AGL)	1300 m
Pulse Rate	75-83 kHz
Pulse Mode	Single
Mirror Scan Rate	47 Hz
Field of View	28 (±14° from nadir)
Roll Compensated	Up to 15°
Overlap	100% (50% Side-lap)

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 flightlines classified by date flown.

[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. *Flightlines for the Ochoco 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. For additional post-processing position adjustments, 2,555 RTK (Real-time kinematic) points were collected in the study area **(Figure 2.3)**.

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

	Datum NAD83 (HARN)		**GRS80**
Base Stations ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
OCH_01	441207.9707	1193534.953	1424.109
OCH_03	442007.2831	1195629.151	1520.751
OCH_04	442028.0132	1195201.765	1619.478
OCH_05	441929.3625	1194244.161	1935.739
OCH_06	442128.8472	1194409.058	1810.847
OCH_07	441349.256	1193818.671	1357.222

[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 Ochoco Study Area.*

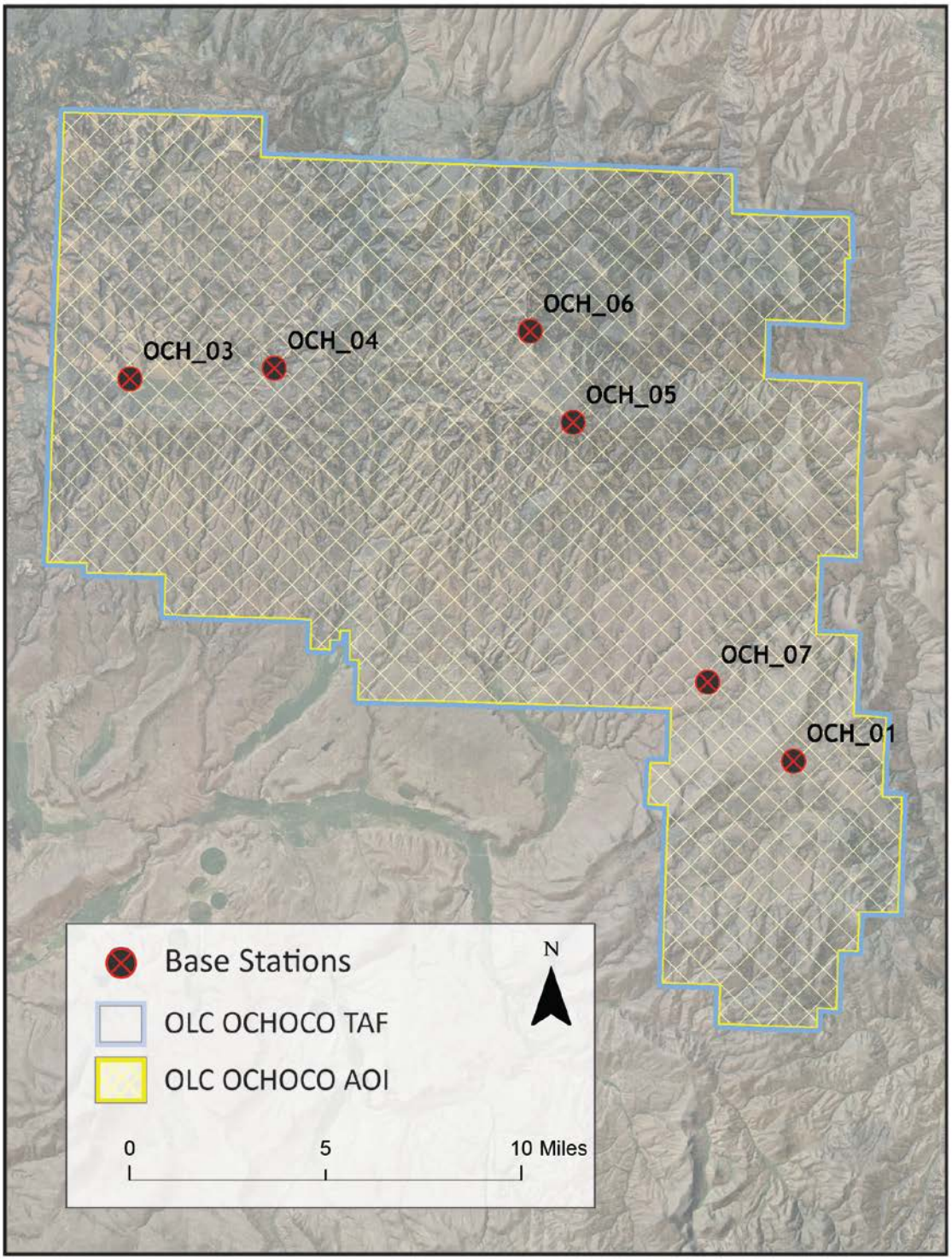
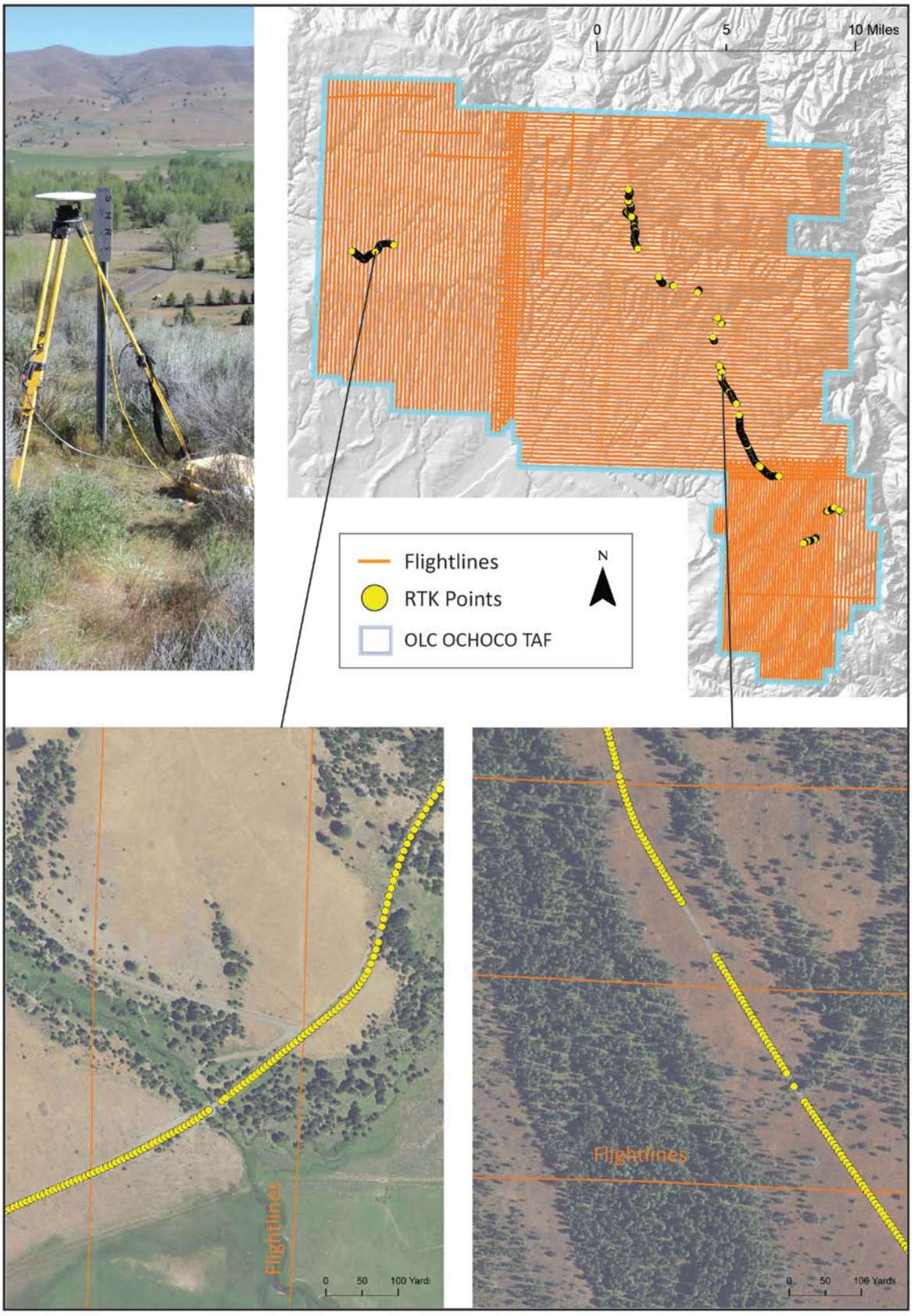


Figure 2.3. *Selected RTK point locations in the study area; images are 2009 NAIP orthophotos.*



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 445 flightlines and over 8 billion points. Relative accuracy is reported for the entirety of the study area as shown in **Figure 3.1** below.

- Project Average = 0.13 ft (0.04 m)
- Median Relative Accuracy = 0.12 ft (0.04 m)
- 1σ Relative Accuracy = 0.14 ft (0.04m)
- 2σ Relative Accuracy = 0.18 ft (0.05 m)

Figure 3.1. *Relative Accuracy Coverage Area.*

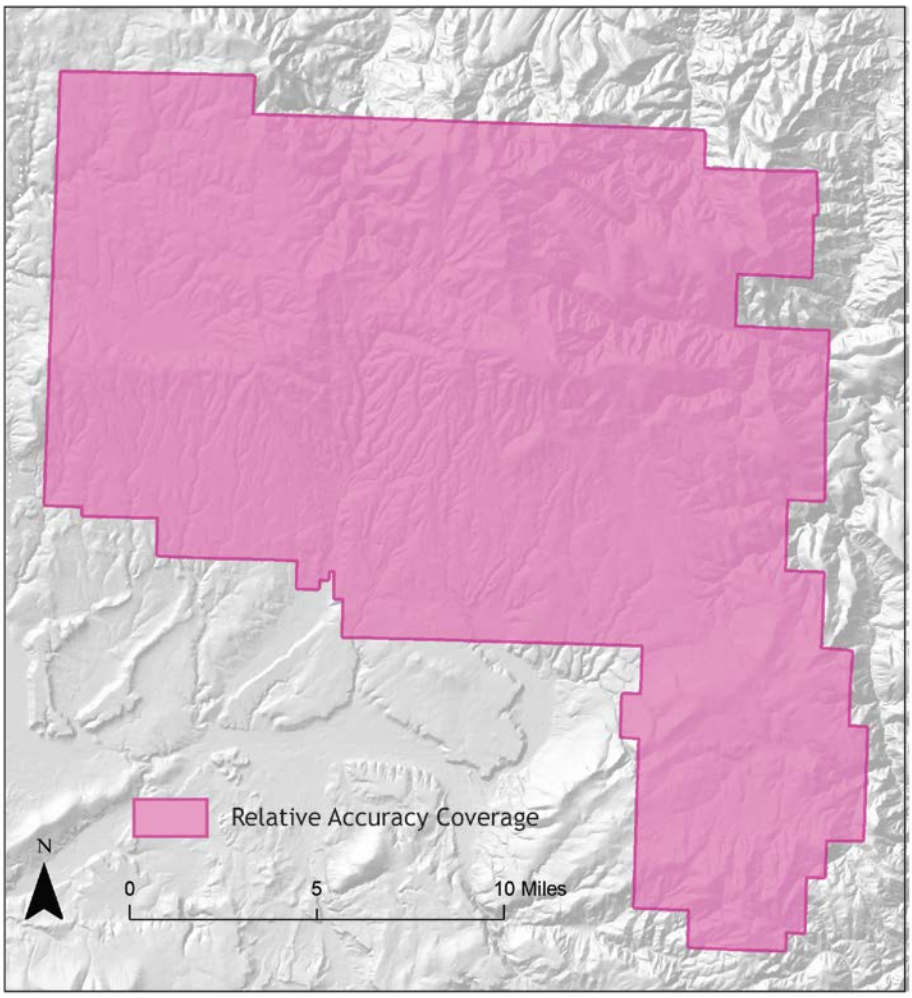


Figure 3.2. *Statistical relative accuracies, non slope-adjusted.*

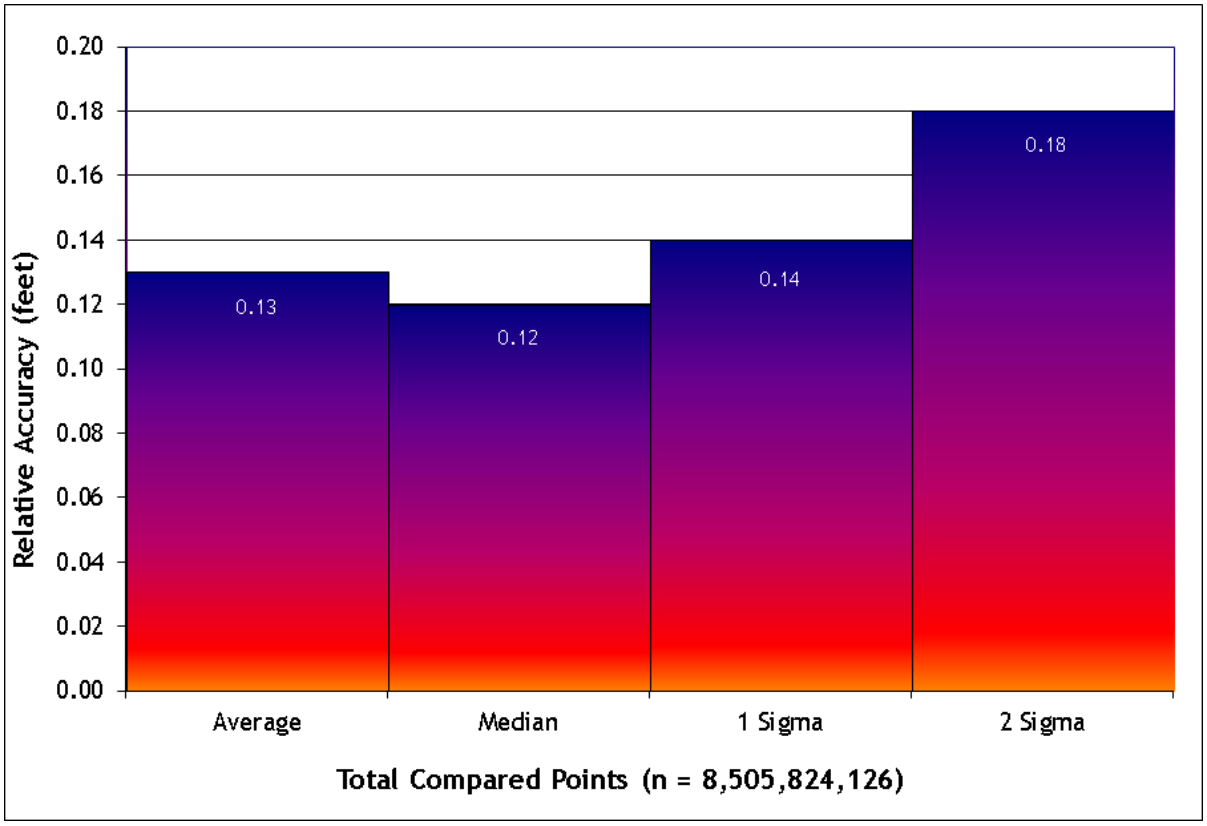
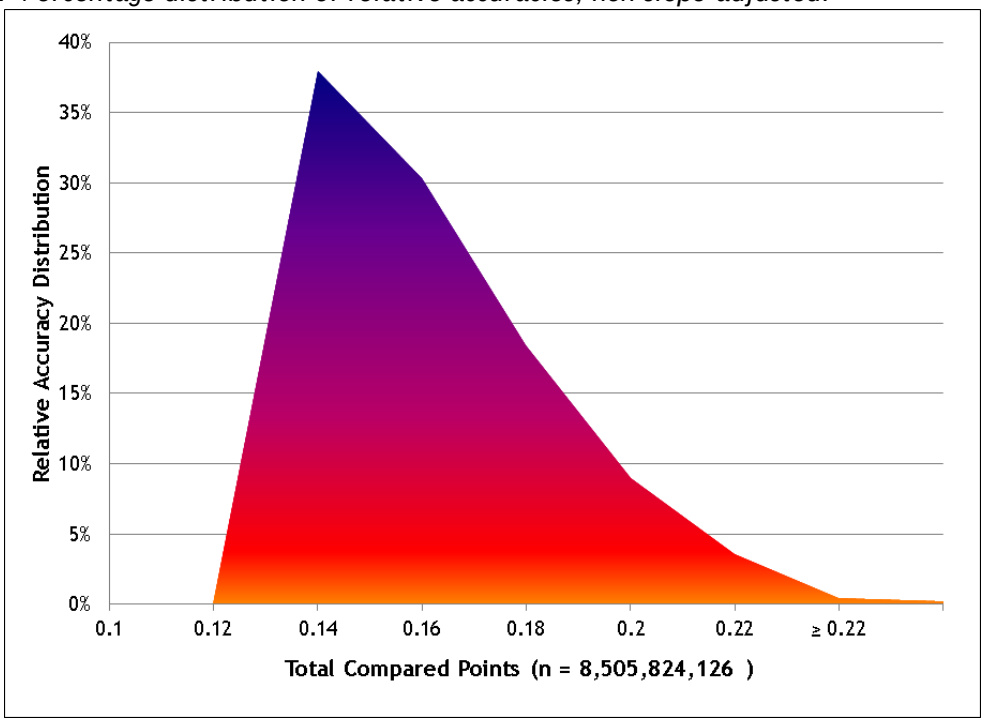


Figure 3.3. *Percentage distribution of relative accuracies, non slope-adjusted.*



3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Ochoco Study Area, 2,555 RTK points were collected. Absolute accuracy is reported for the entirety of the study area as 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): 2,555	
Root Mean Square Error (RMSE): 0.18 ft (0.05m)	
Standard Deviations	**Deviations**
1 sigma (σ): 0.18 ft (0.06 m)	**Minimum Δz:** -0.90 ft (-0.28 m)
2 sigma (σ): 0.32 ft (0.10 m)	**Maximum Δz:** 0.22 ft (0.07 m)
	Average Δz: -0.15 ft (-0.04 m)

Figure 3.4. *Absolute Accuracy Coverage Area.*

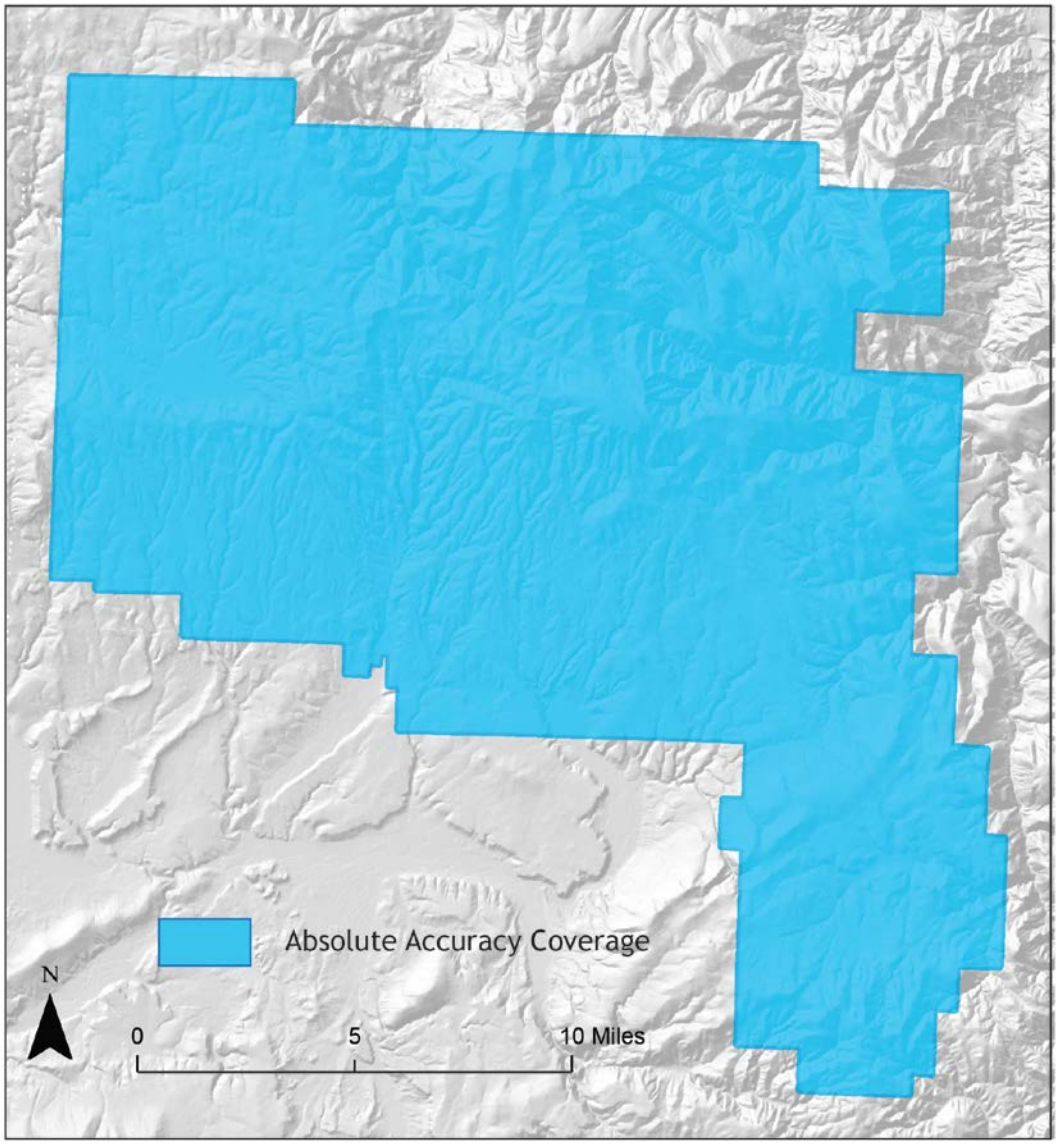


Figure 3.5. *Ochoco Study Area histogram statistics*

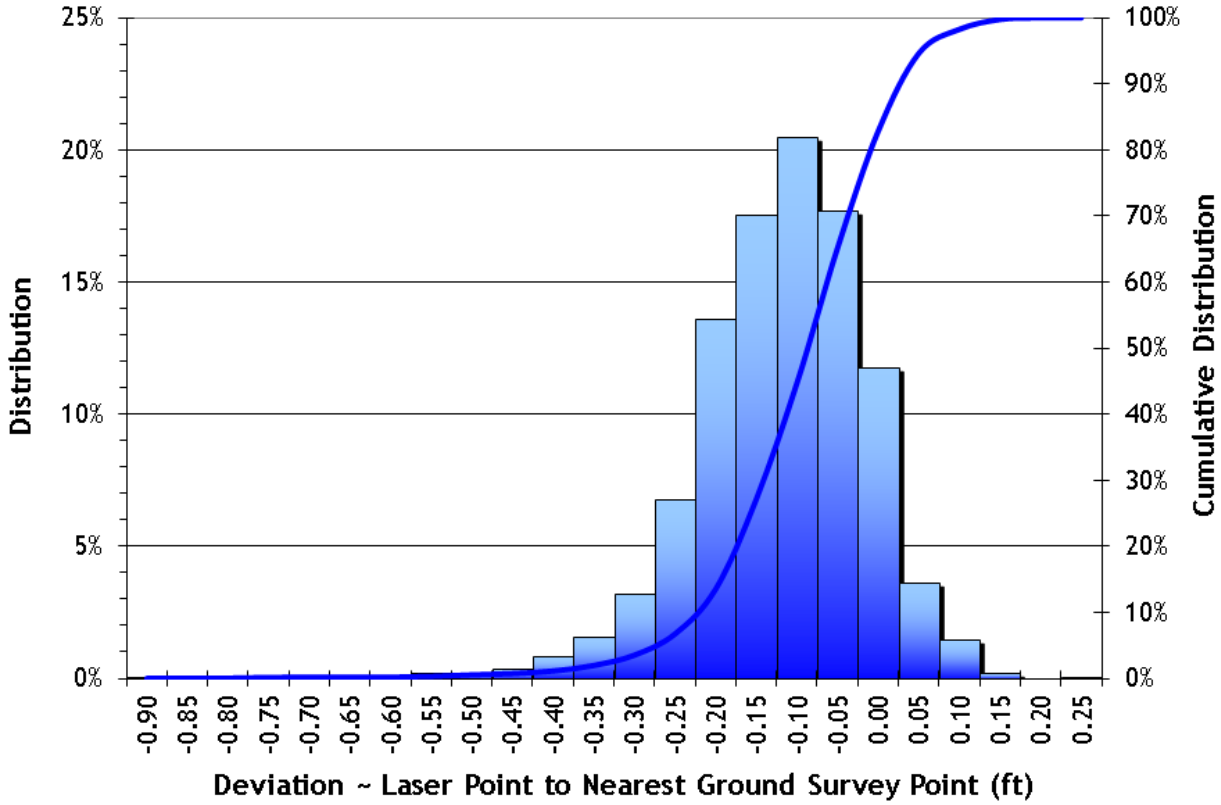
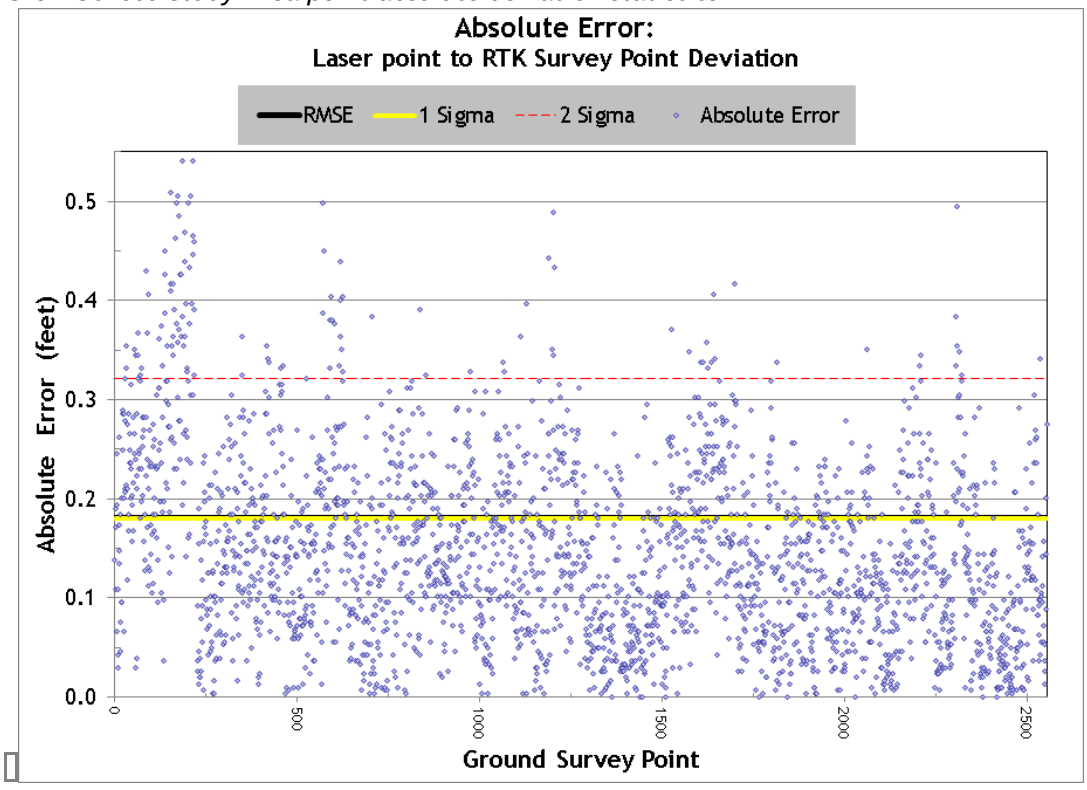


Figure 3.6. *Ochoco Study Area point absolute deviation statistics.*



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 Ochoco 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)
0.91	9.74	0.153	1.65

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

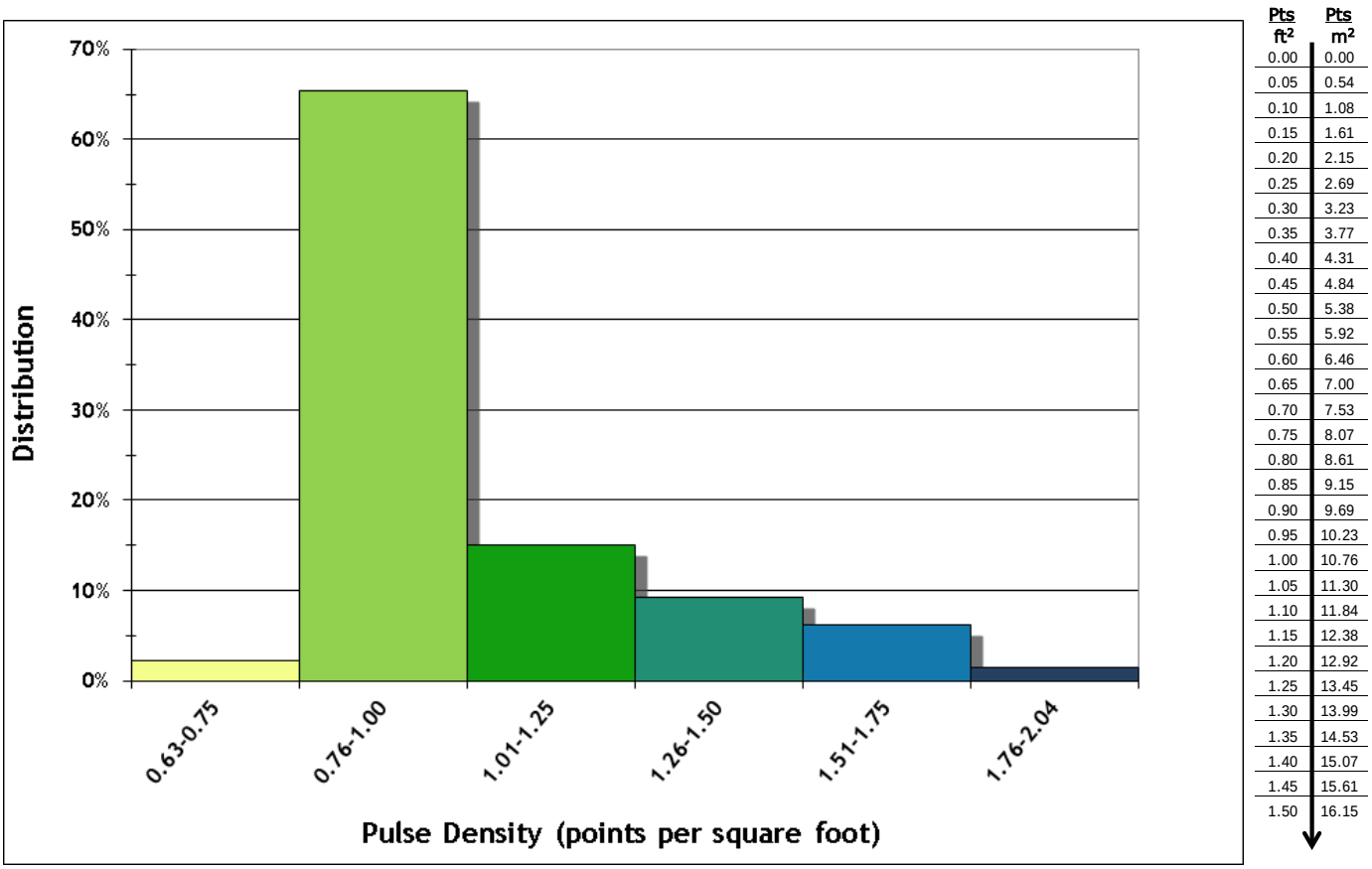
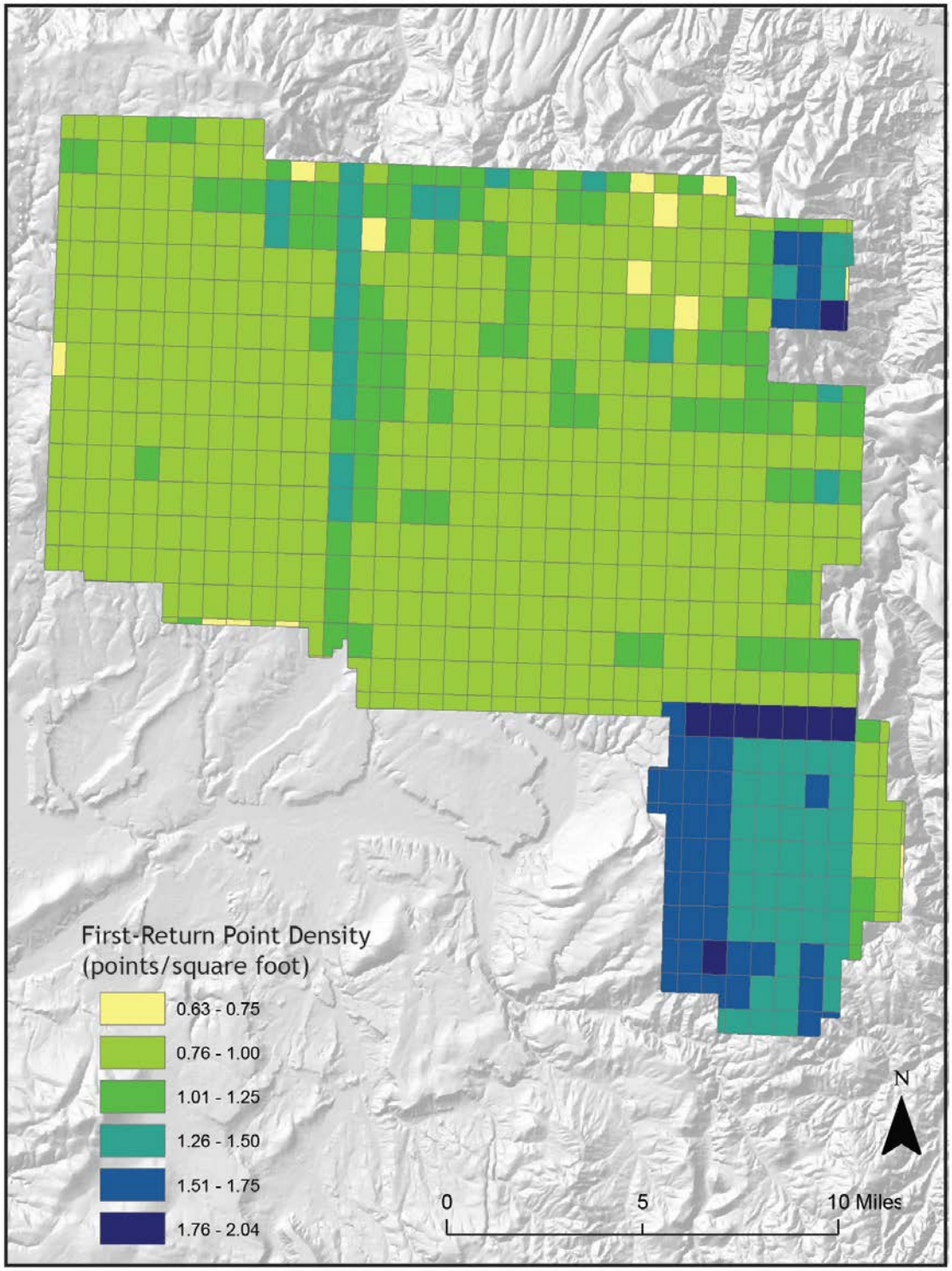


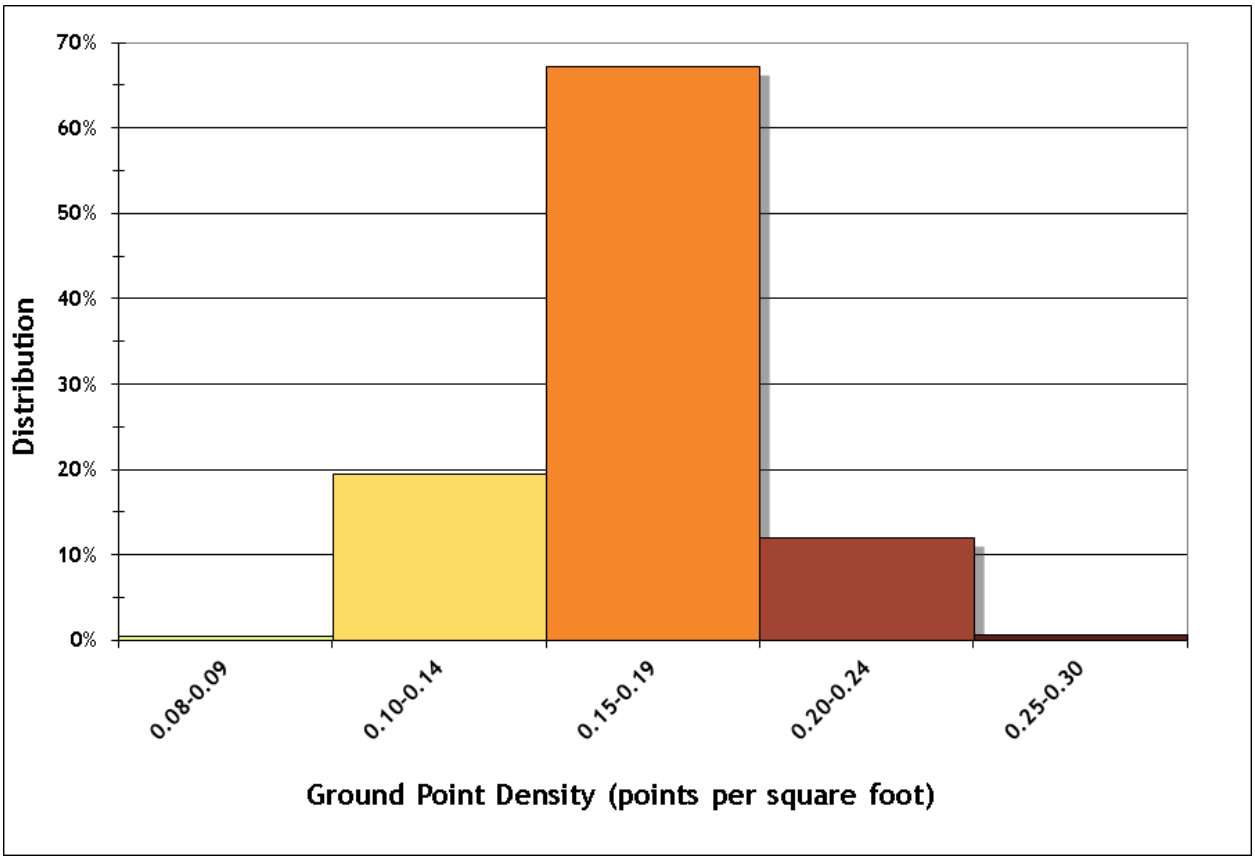
Figure 4.2. *First return laser point densities per 0.75' USGS Quad for data delivered to date.*



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

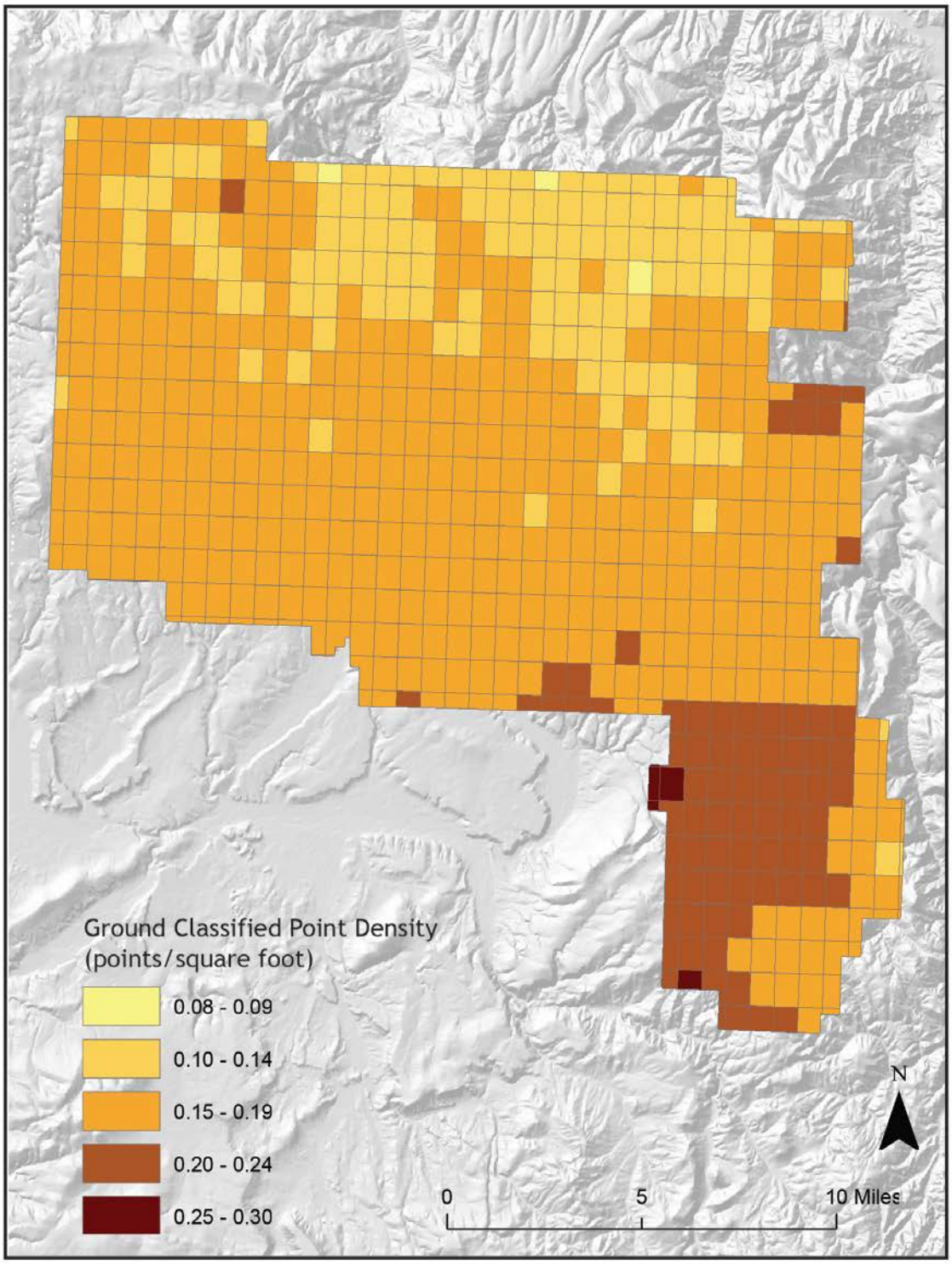
Ground classifications were derived from ground surface modeling. Classifications were performed by reseeding of the ground model where it was determined that the ground model failed, usually under dense vegetation and/or at breaks in terrain, steep slopes and at data tile boundaries.

Figure 4.3. *Histogram of ground-classified laser point density for Ochoco 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 Ochoco 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

10/21/2011

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(cover). Forested hills within the Ochoco study area, view to the Northeast. Image is a LiDAR point cloud colored with RGB values from NAIP imagery.

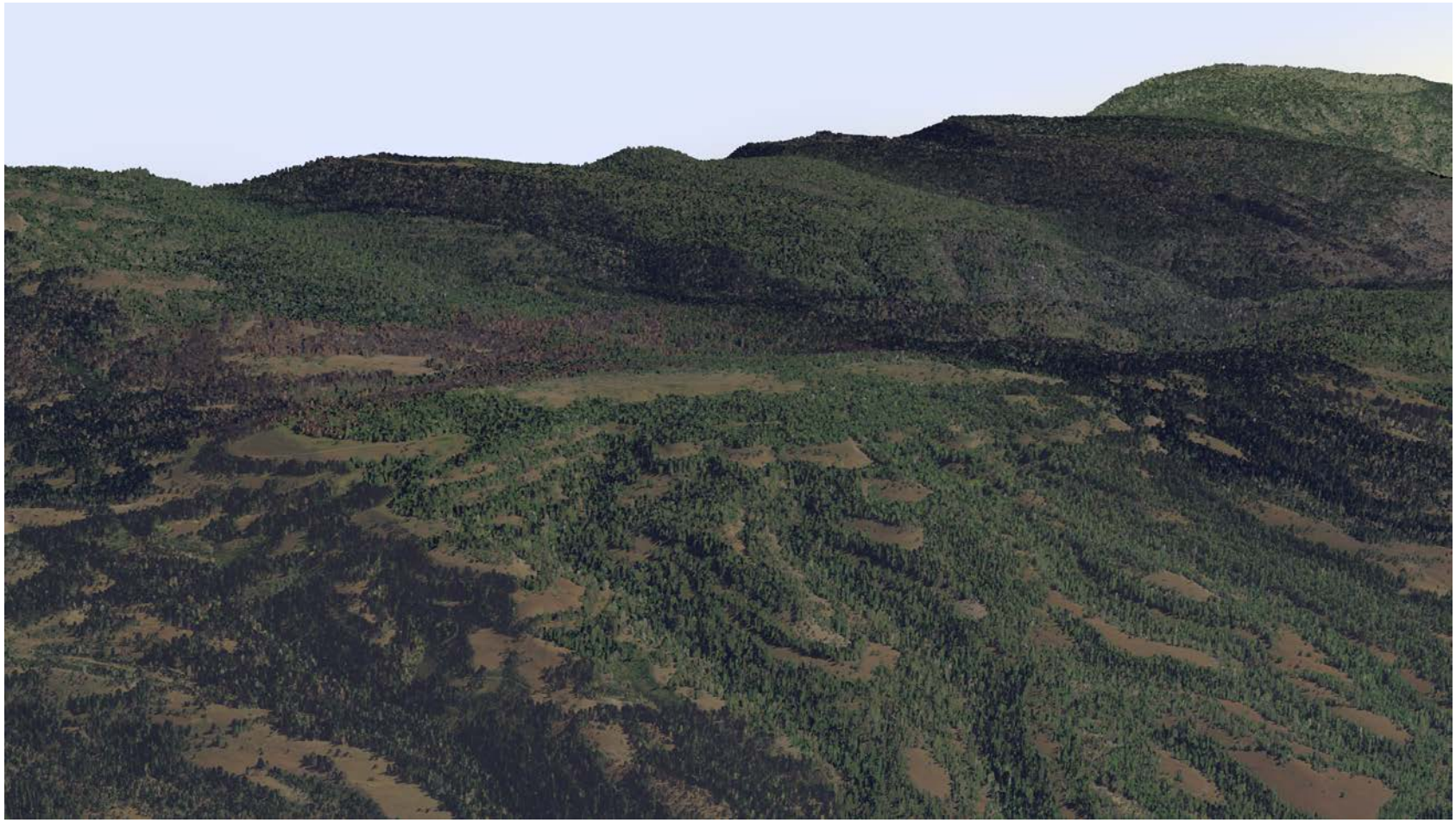

Figure 5.2. Valley in Ochoco study area, view to the West. Image is a LiDAR point cloud colored with RGB values from NAIP imagery.