LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
Klamath Study Area

January 7, 2011

Submitted to:

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LiDAR Remote Sensing Data Collection:
DOGAMI, Klamath Study Area

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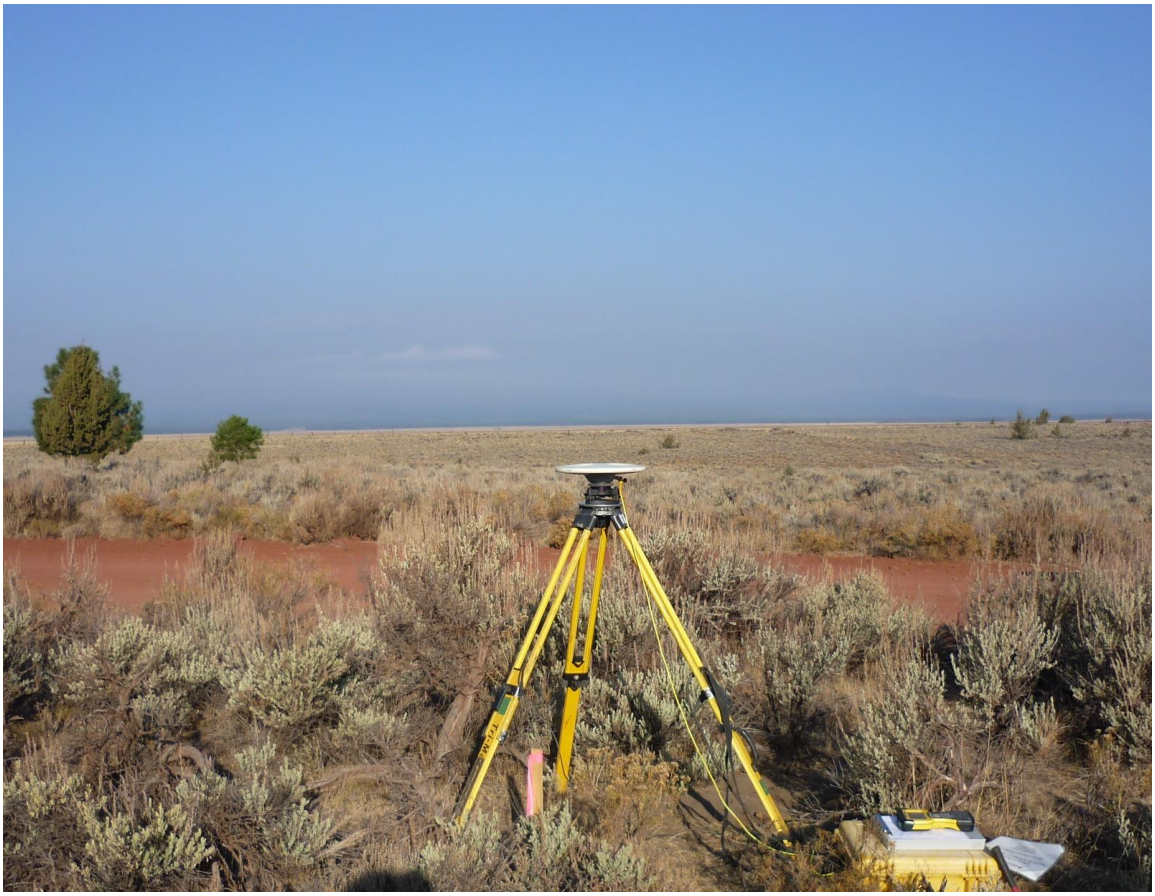
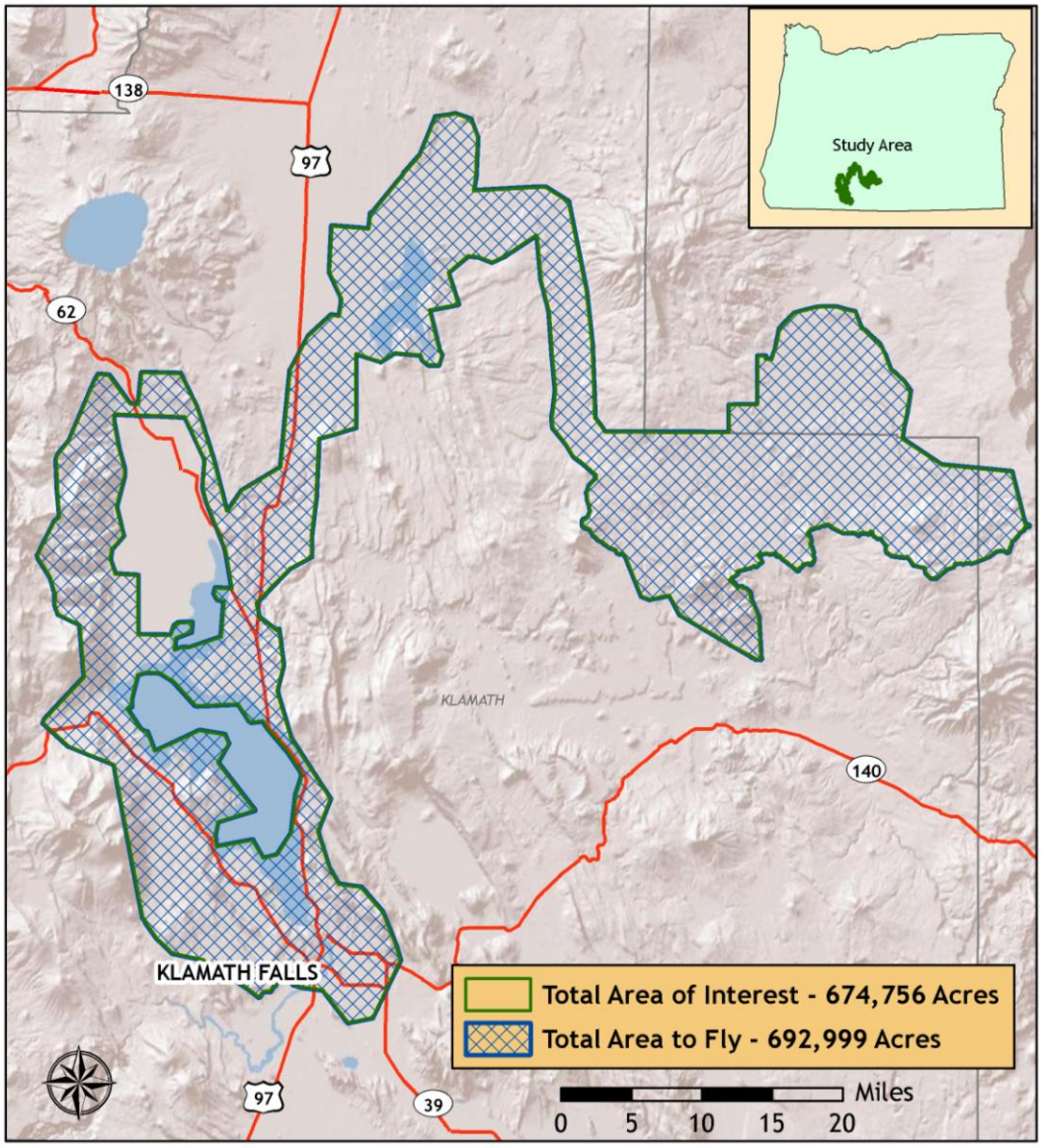


1. Overview

1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Klamath Study Area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 1054 square miles (674,756 acres) and the total area flown (TAF) covers 1083 square miles (692,999 acres). The TAF acreage is greater than the original AOI acreage due to buffering and flight planning optimization (**Figure 1.1** below). This report will be amended to reflect new data and cumulative statistics for the overall LiDAR survey with every delivery. 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 Klamath Study Area.*



1.2 Area Delivered to Date

Total delivered acreage to date is detailed below.

DOGAMI Klamath Study Area				
	Delivery Date	**Acquisition Dates**	**AOI Acres**	**TAF Acres**
Delivery Area 1	January 7, 2011	September 14, 2010 – September 22, 2010	**104,196**	**106,995**

Figure 1.2. *Klamath Study Area, illustrating the delivered portions of the TAF.*

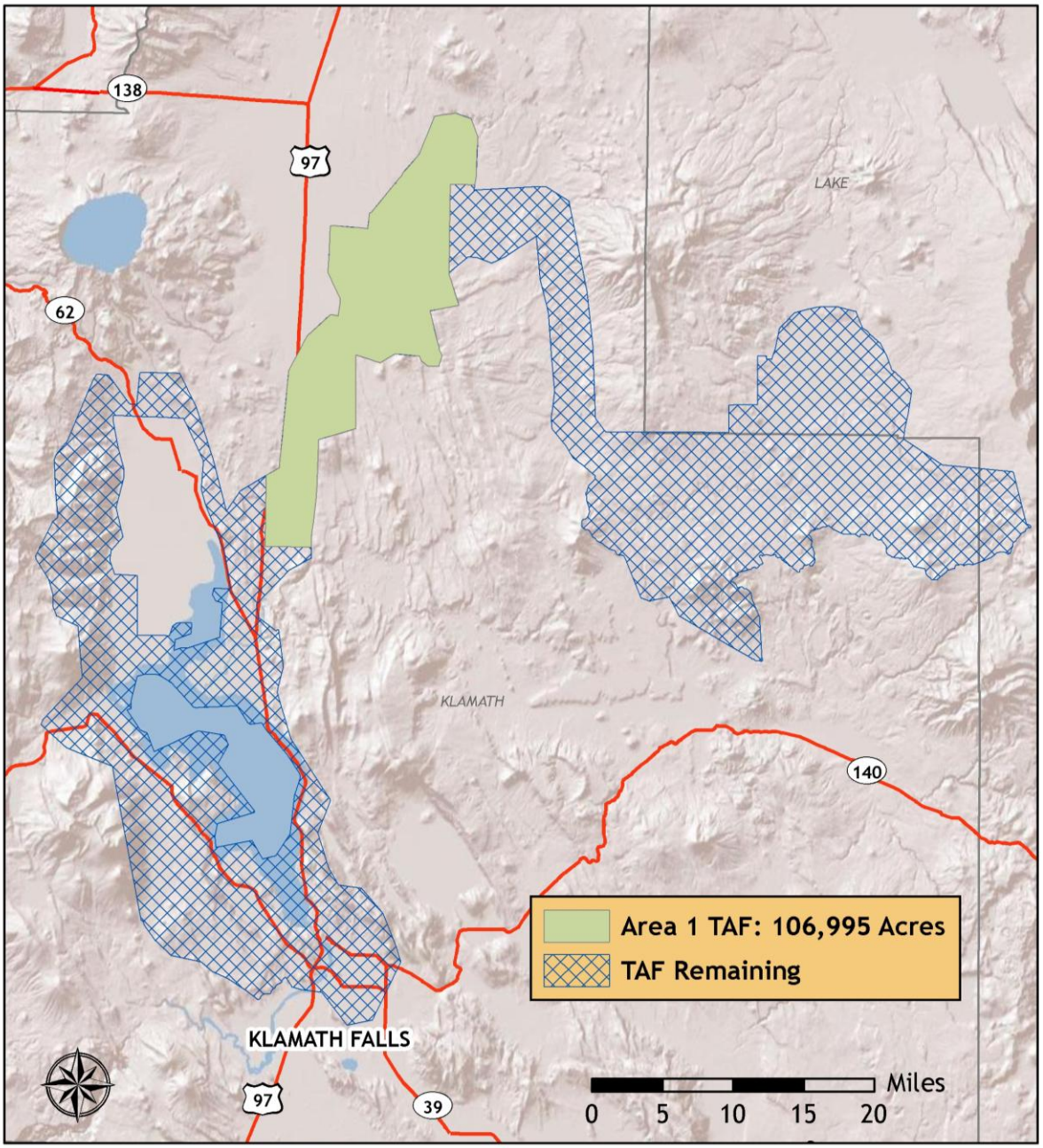
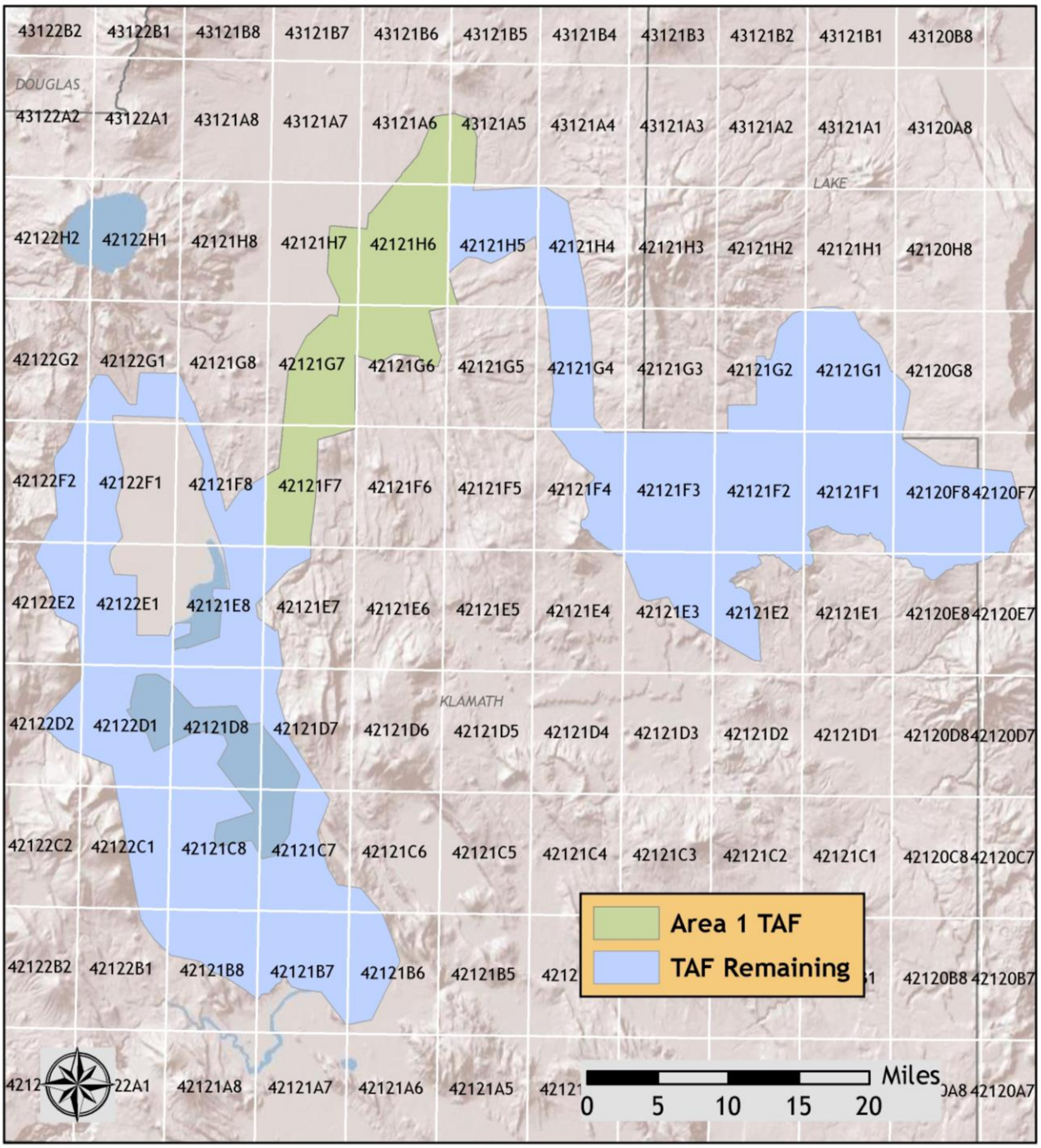


Figure 1.3. *Klamath Study Area, illustrating the delivered 7.5 minute USGS quads.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized Leica ALS60 and ALS50 Phase II sensors mounted in Cessna Caravan 208Bs. The Leica systems were set to acquire either ≥105,000 or ≥150,000 laser pulses per second (i.e. 105 kHz/150kHz pulse rate) and flown at 900 or 1500 meters above ground level (AGL), capturing a scan angle of ±14° or ±12° 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*

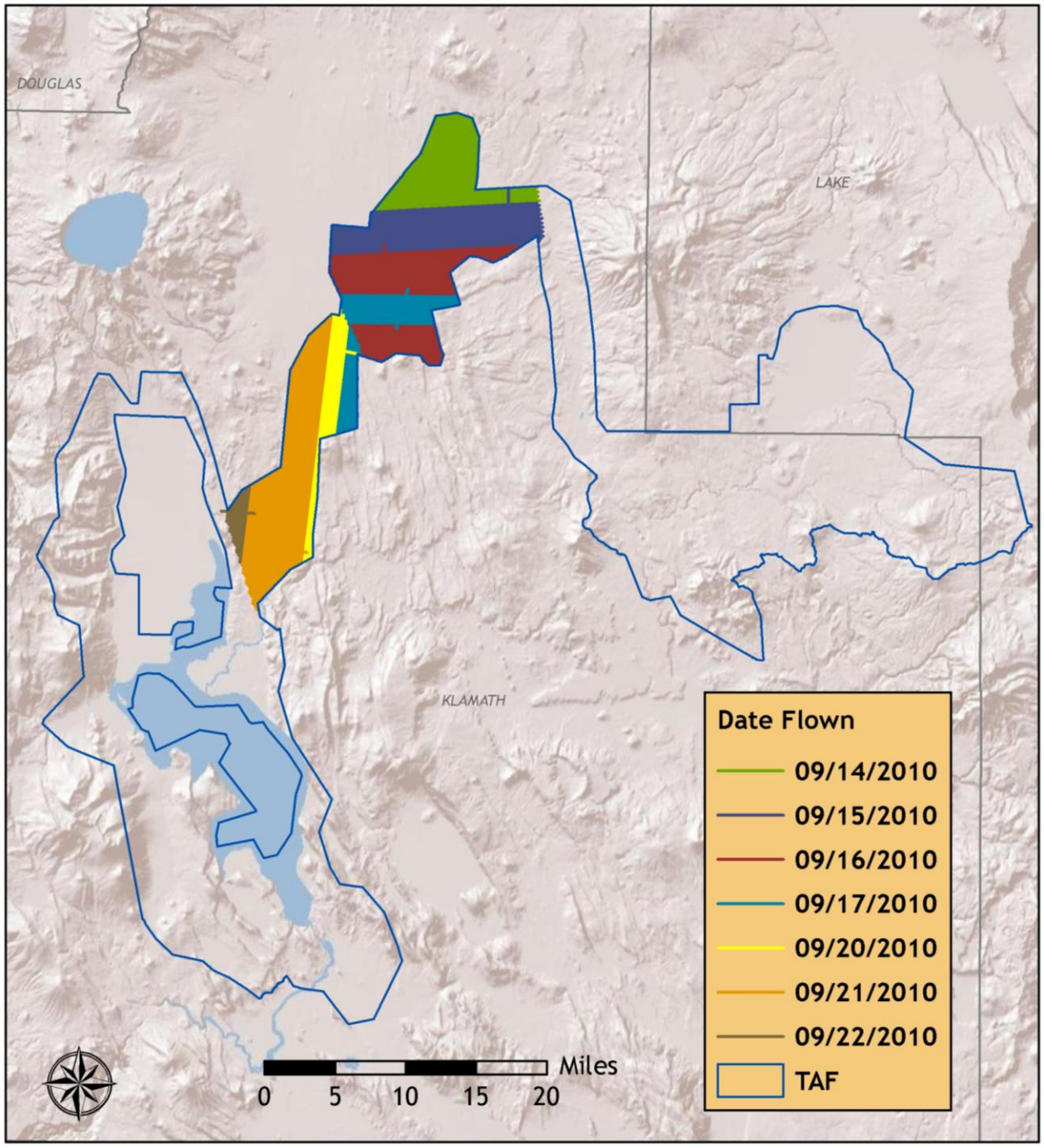
Sensors	Leica ALS60 and ALS50 Phase II
Survey Altitude (AGL)	900 m and 1500 m
Pulse Rate	>105 kHz and >150kHz
Pulse Mode	Single and Multi
Mirror Scan Rate	52 Hz and 69 Hz
Field of View	28° (±14° from nadir) and 24° (±12° from nadir)
Roll Compensated	Up to 15°
Overlap	100% (50% Side-lap)

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 Klamath Study Area illustrating the dates flown for current processing.*

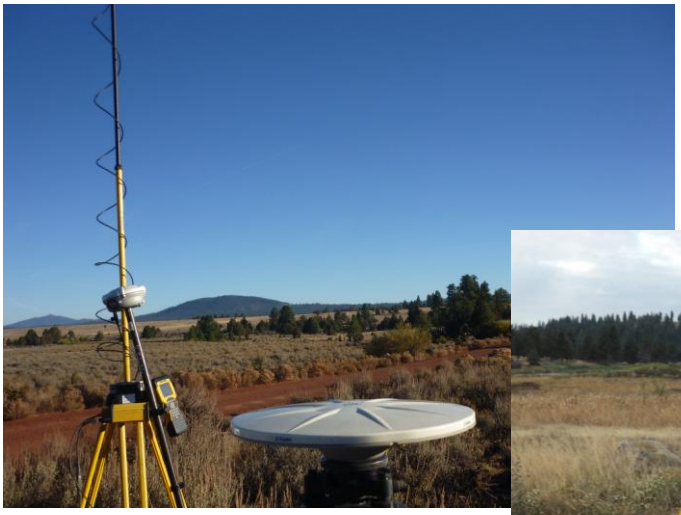


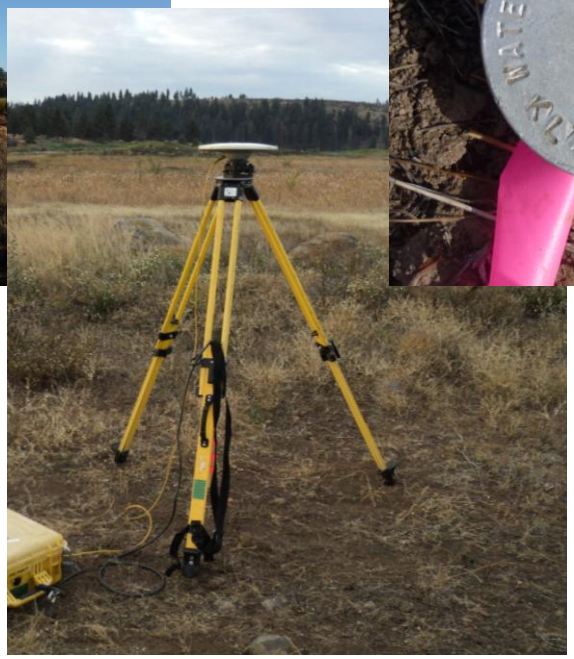
2.2 Ground Survey – Instrumentation and Methods

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

Indexed by time, these GPS data records are used to correct the continuous onboard measurements of aircraft position recorded throughout the mission. Control monuments were located within 13 nautical miles of the survey area(s).

This project used National Geodetic Survey (NGS) benchmark DE6272; additional monuments were placed by Watershed Sciences. All monumentation was done with 5/8" x 30" rebar topped with a 2" diameter aluminum cap stamped "WATERSHED SCIENCES, INC" plus year and point name. For delivery area 1, all Global Navigation Satellite System (GNSS[3]) survey work used both Trimble R7 GPS and GNSS receivers with a Zephyr Geodetic or Zephyr Geodetic Model 2 antenna with ground plane for static control points and Trimble R8 GNSS units for RTK data collection.



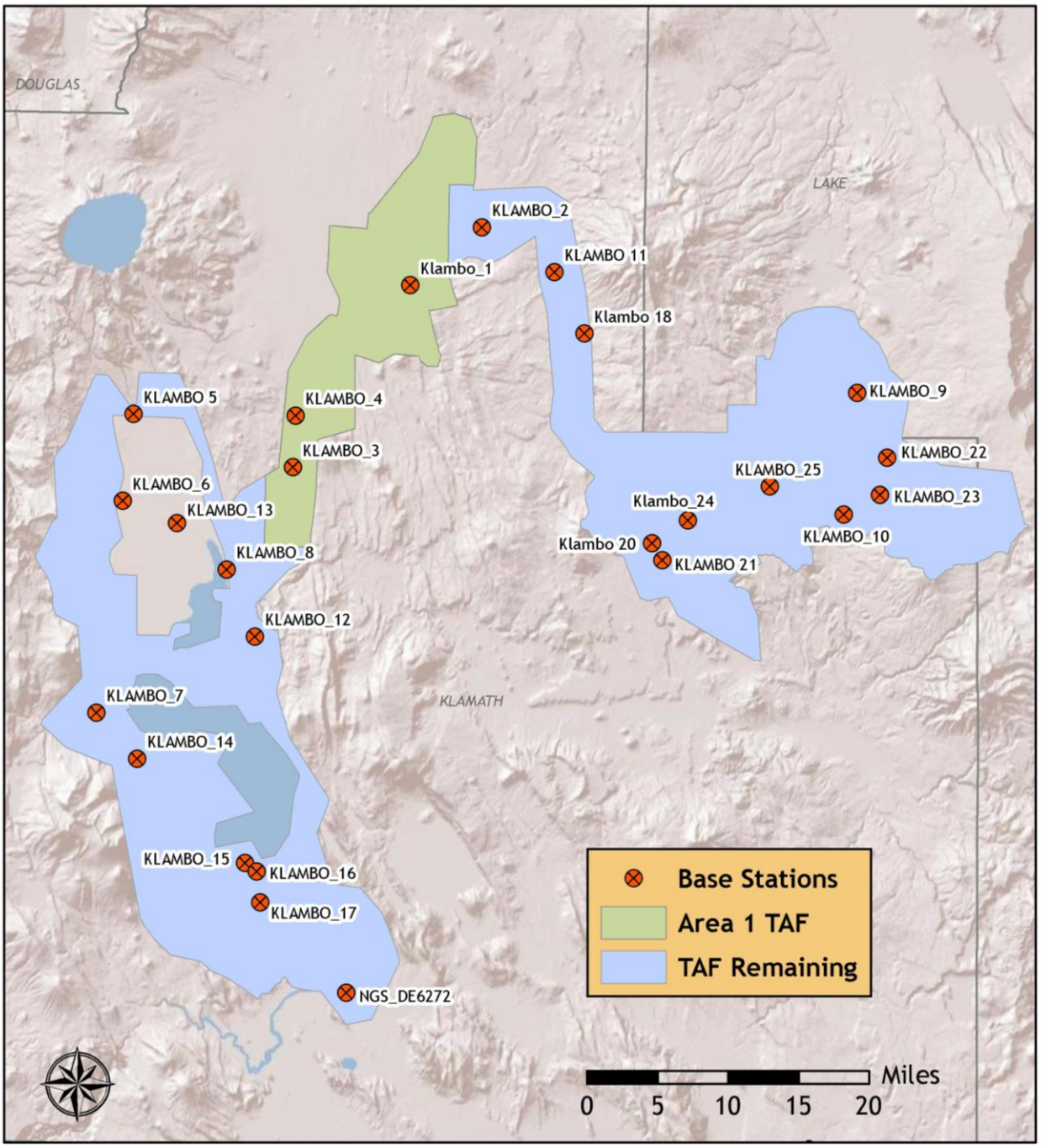


[2] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.
[3] GNSS: Global Navigation Satellite System consisting of the U.S. GPS constellation and Soviet GLONASS constellation

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

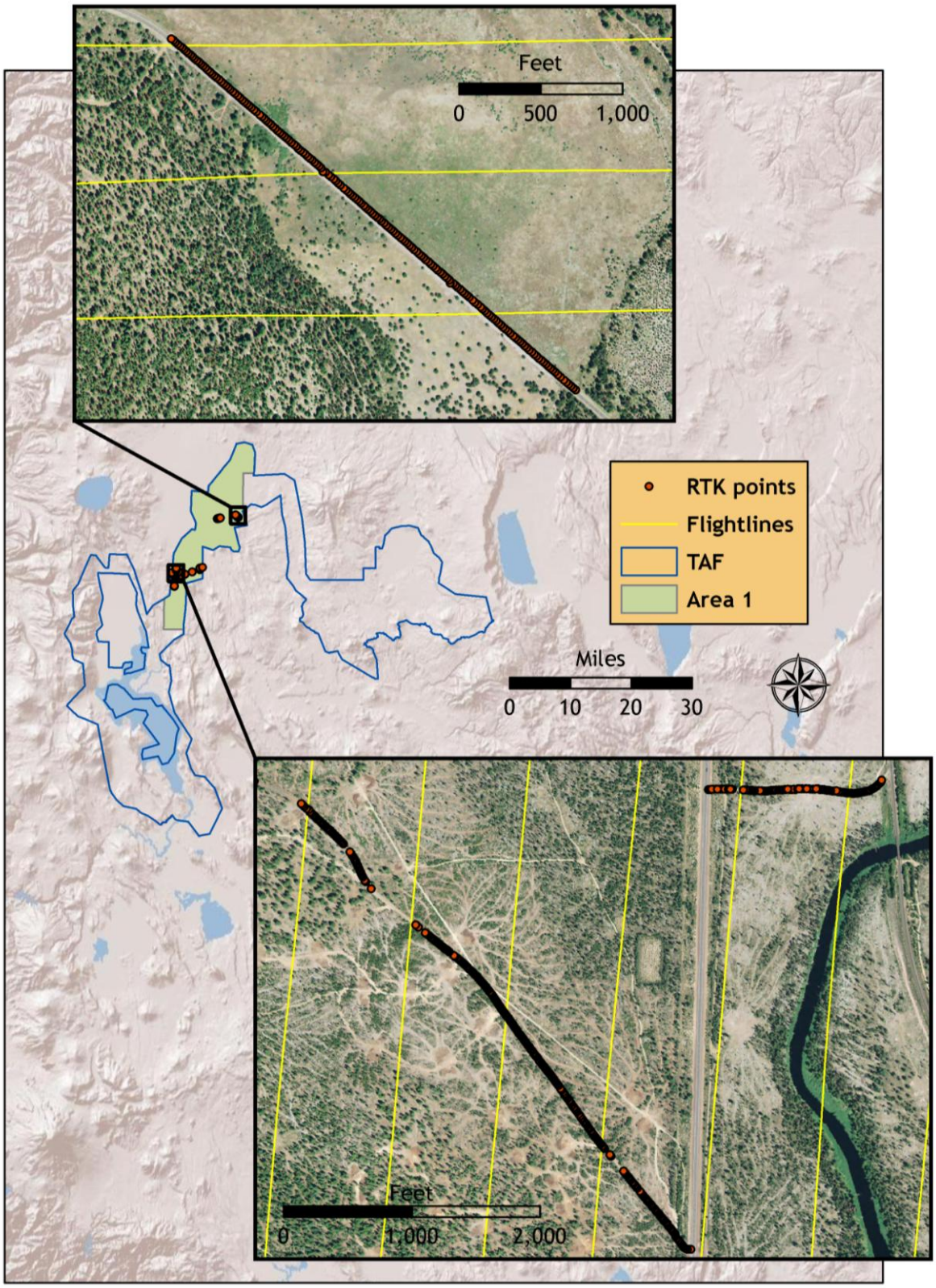
	Datum NAD83 (HARN)		GRS80
Base Stations ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
Klambo_1	42 53 43.71642	121 40 38.27174	1355.950
KLAMBO_2	42 57 21.88367	121 34 41.92137	1360.844
KLAMBO_3	42 42 22.24624	121 50 15.06756	1378.253
KLAMBO_4	42 45 33.96875	121 50 05.47497	1356.049
KLAMBO 5	42 45 28.87103	122 03 38.72856	1303.705
KLAMBO_6	42 40 06.46660	122 04 25.29518	1244.416
KLAMBO_7	42 27 00.37667	122 06 16.53728	1243.680
KLAMBO_8	42 35 59.54419	121 55 38.39378	1251.524
KLAMBO_9	42 47 21.56079	121 03 05.81828	1513.408
KLAMBO_10	42 39 50.99391	121 04 08.38555	1584.146
KLAMBO 11	42 54 39.03565	121 28 34.33564	1369.459
KLAMBO_12	42 31 52.57239	121 53 11.73293	1248.090
KLAMBO_13	42 38 48.44766	121 59 51.10786	1242.990
KLAMBO_14	42 24 12.78169	122 02 49.59374	1241.442
KLAMBO_15	42 17 52.55647	121 53 40.37085	1239.413
KLAMBO_16	42 17 22.80941	121 52 42.70475	1240.545
KLAMBO_17	42 15 27.72528	121 52 20.62533	1241.032
Klambo 18	42 50 52.34971	121 26 00.12285	1398.852
Klambo 20	42 37 57.96109	121 20 08.65664	1506.732
KLAMBO 21	42 36 56.30202	121 19 16.60668	1506.633
KLAMBO_22	42 43 22.34670	121 00 31.57376	1615.060
KLAMBO_23	42 41 05.10513	121 01 07.14800	1613.039
Klambo_24	42 39 25.07952	121 17 09.62288	1507.262
KLAMBO_25	42 41 32.78706	121 10 20.40501	1544.572
NGS_DE6272	42 09 58.16101	121 45 05.91981	1223.551

Figure 2.2. *Base stations for the Klamath Study Area.*



For data delivered to date, 887 RTK (Real-time kinematic) points were collected in the study area. **Figure 2.3** shows detailed views of selected RTK locations for the area delivered to date.

Figure 2.3. *Selected RTK point locations in the study area for delivery area 1; 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 187 flightlines and over 4.5 billion points. Relative accuracy is reported for the portion of the study area shown in **Figure 3.1** below.

- Project Average = 0.10 ft (0.03 m)
- Median Relative Accuracy = 0.09 ft (0.03 m)
- 1σ Relative Accuracy = 0.10 ft (0.03 m)
- 2σ Relative Accuracy = 0.14 ft (0.04 m)

Figure 3.1. *Relative Accuracy Covered Area.*

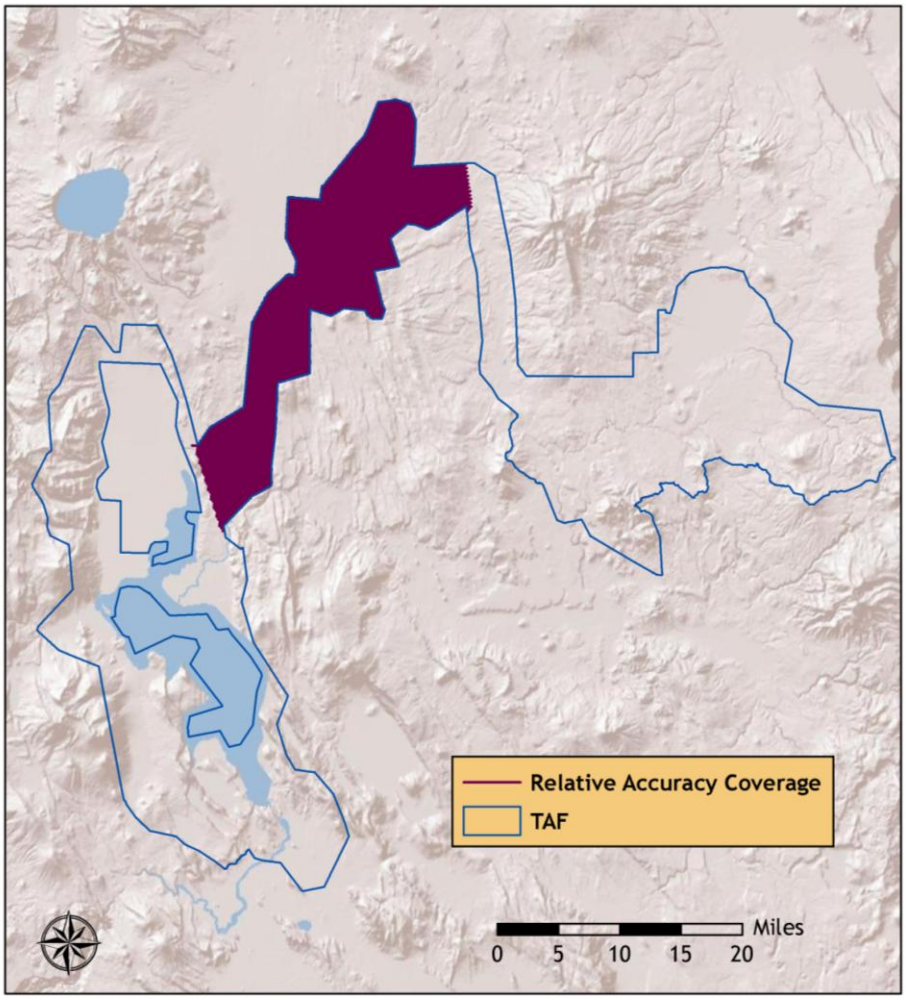


Figure 3.2. *Statistical relative accuracies, non slope-adjusted.*

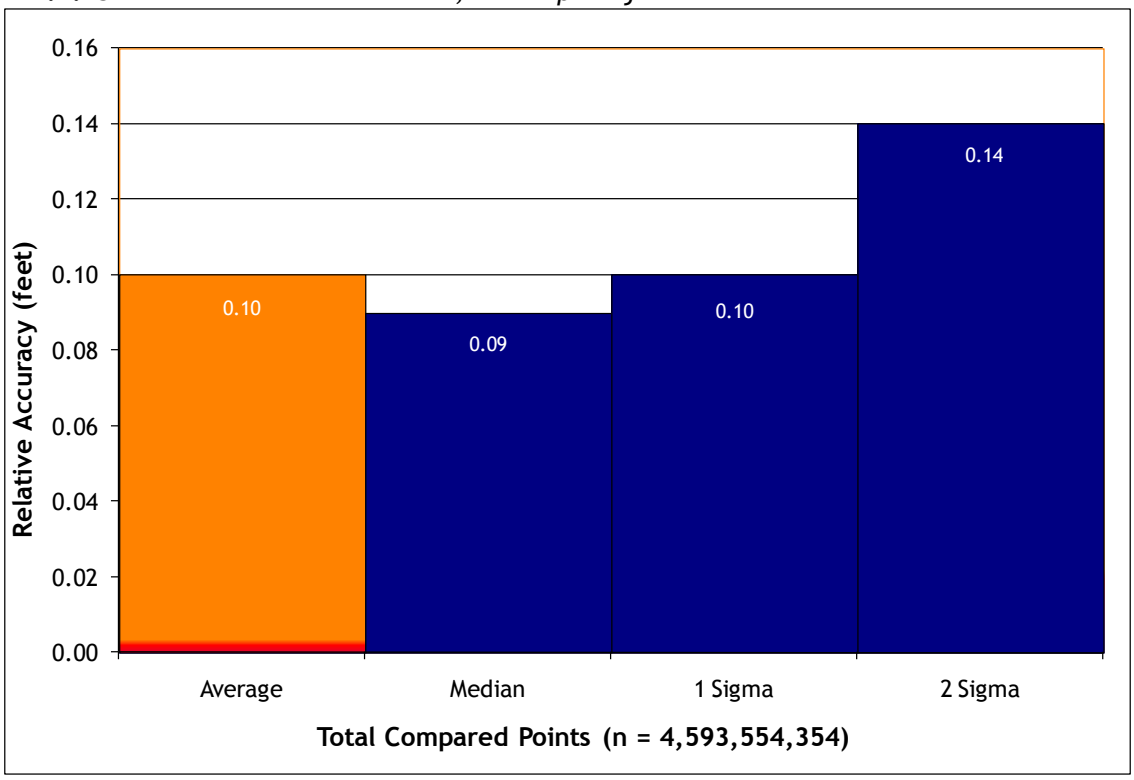
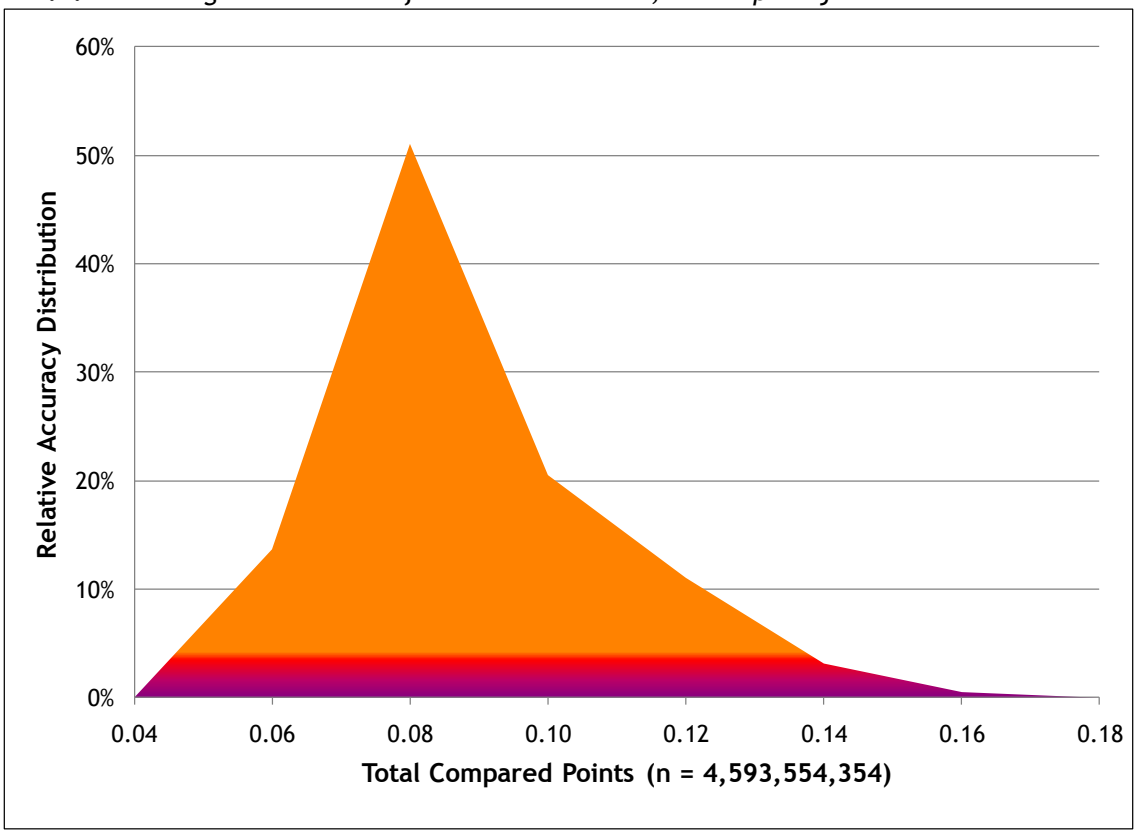


Figure 3.3. *Percentage distribution of relative accuracies, non slope-adjusted.*



3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Newberry Study Area, 887 RTK points were collected for data delivered to date. Absolute accuracy is reported in **Table 3.1** for the portion of the study area shown in **Figure 3.4.** 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): 887	
Root Mean Square Error (RMSE): 0.09 ft (0.03m)	
Standard Deviations	**Deviations**
1 sigma (σ): 0.09 ft (0.03 m)	**Minimum Δz:** -0.28 ft (-0.09 m)
2 sigma (σ): 0.19 ft (0.06 m)	**Maximum Δz:** 0.30 ft (0.09 m)
	Average Δz: 0.08 ft (0.02 m)

Figure 3.4. *Absolute Accuracy Covered Area.*

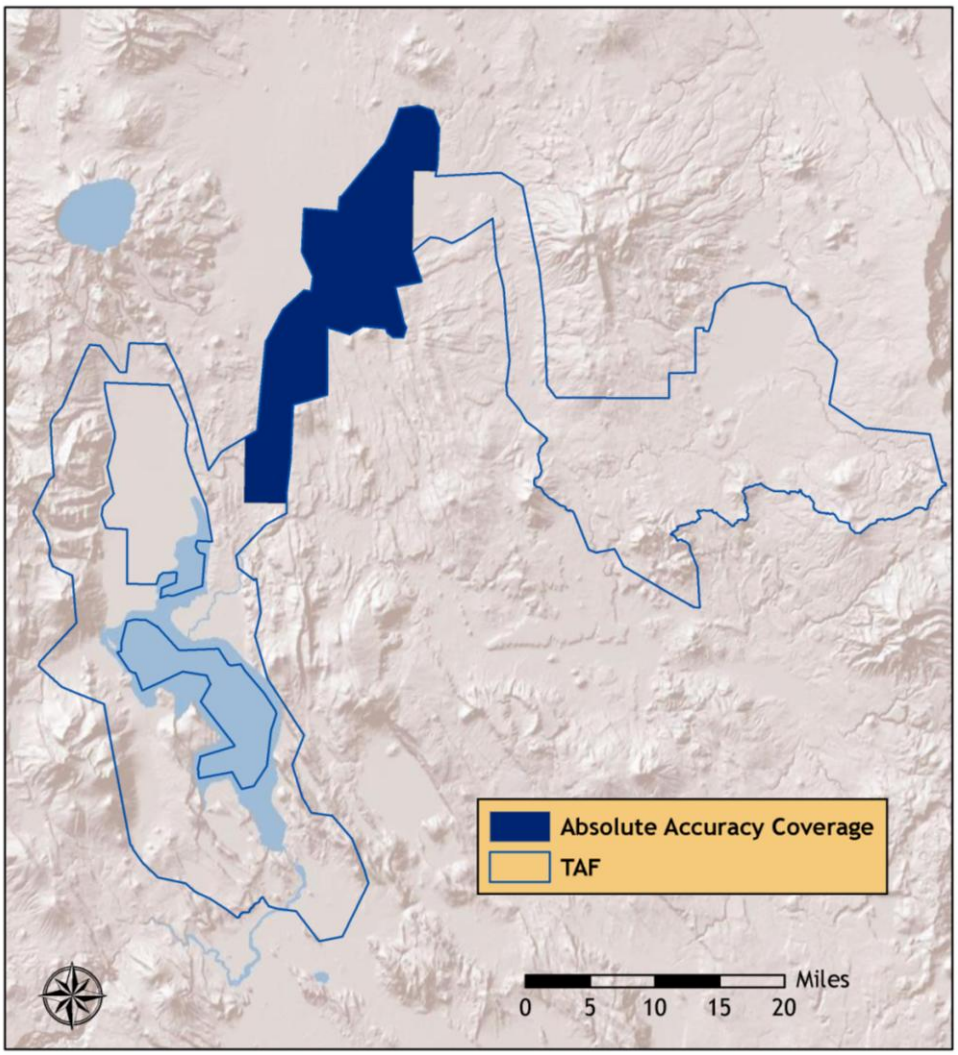


Figure 3.5. *Klamath Study Area histogram statistics*

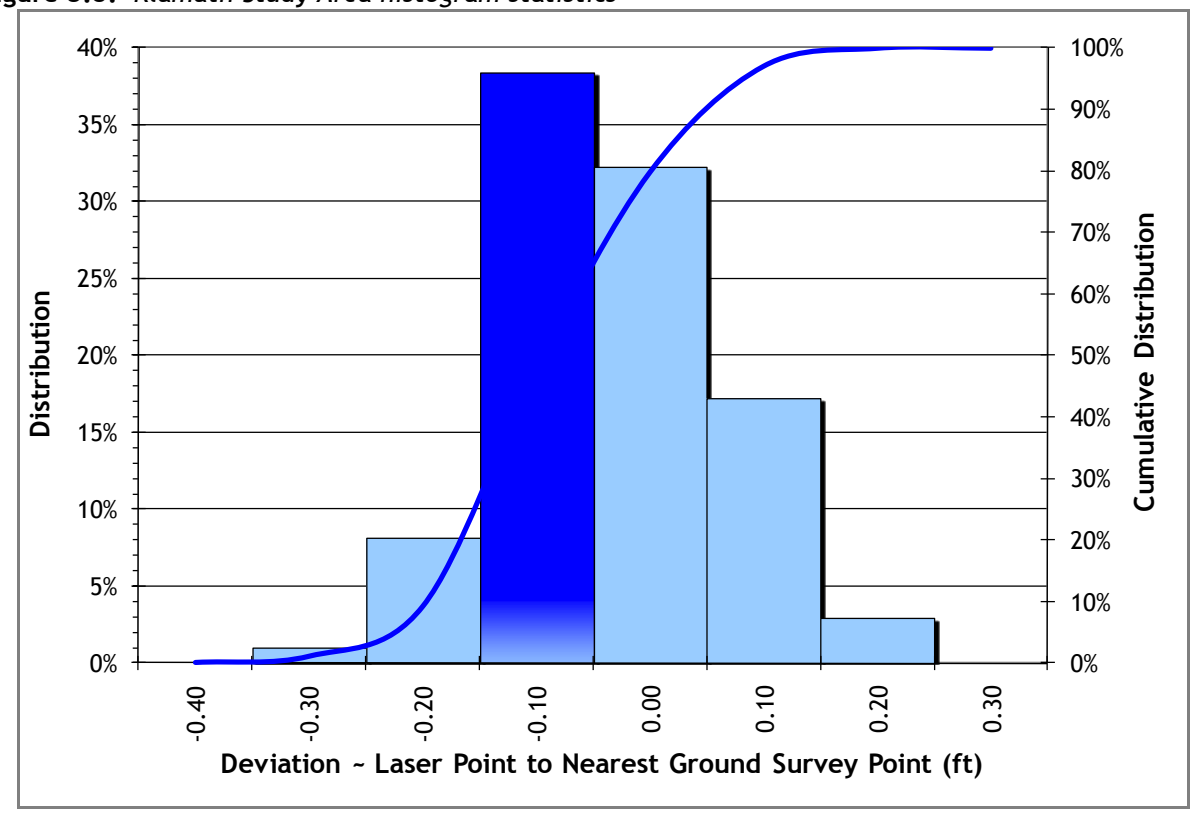
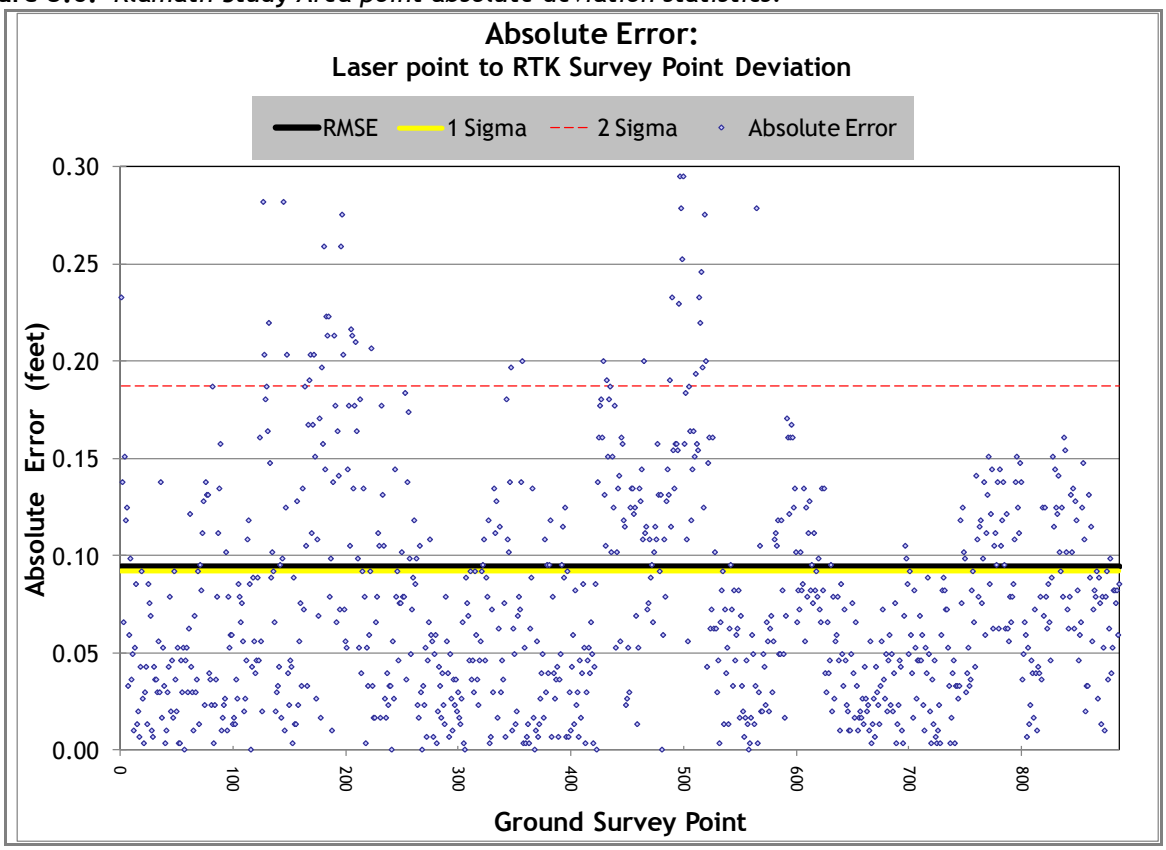


Figure 3.6. *Klamath Study Area point absolute deviation statistics.*



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 pulse density and ground-classified laser point density.

Table 4.1. *Average density statistics for Klamath Study Area data delivered to date.*

Average Pulse Density (per square ft)	Average Pulse Density (per square m)	Average Ground Density (per square ft)	Average Ground Density (per square m)
0.82	8.84	0.19	2.02

Figure 4.1. *Histogram of first return laser pulse density for data delivered to date.*

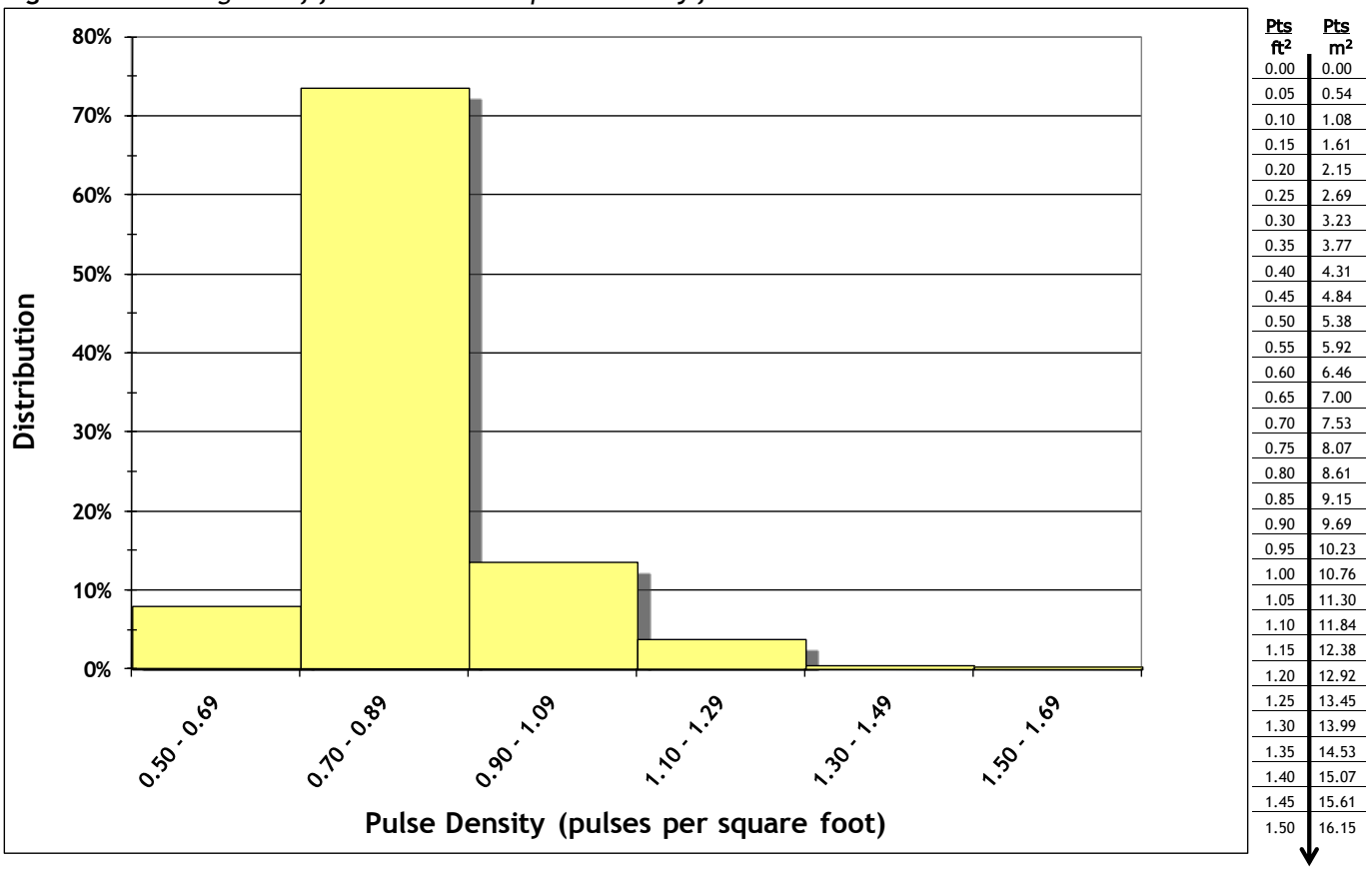
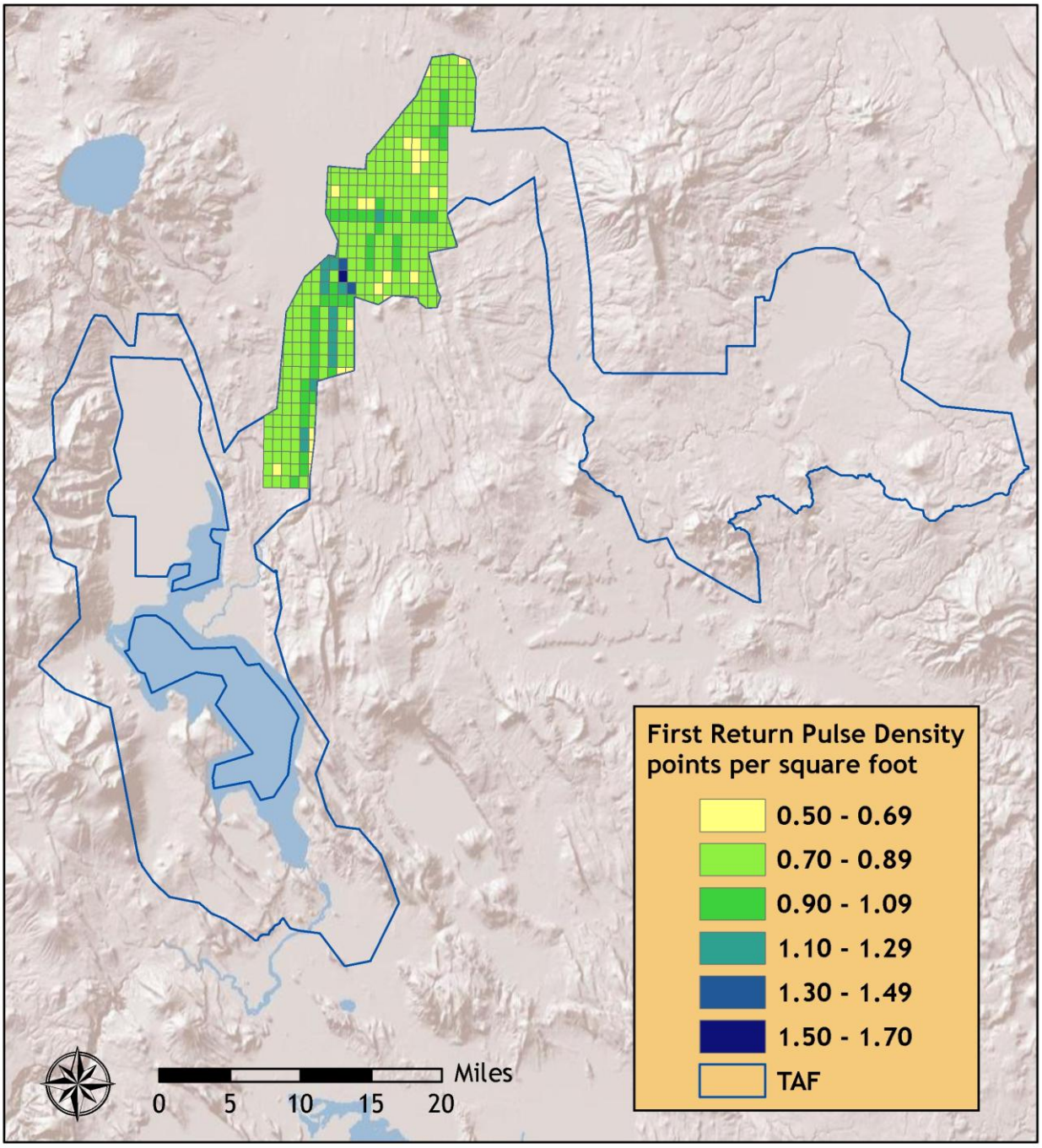


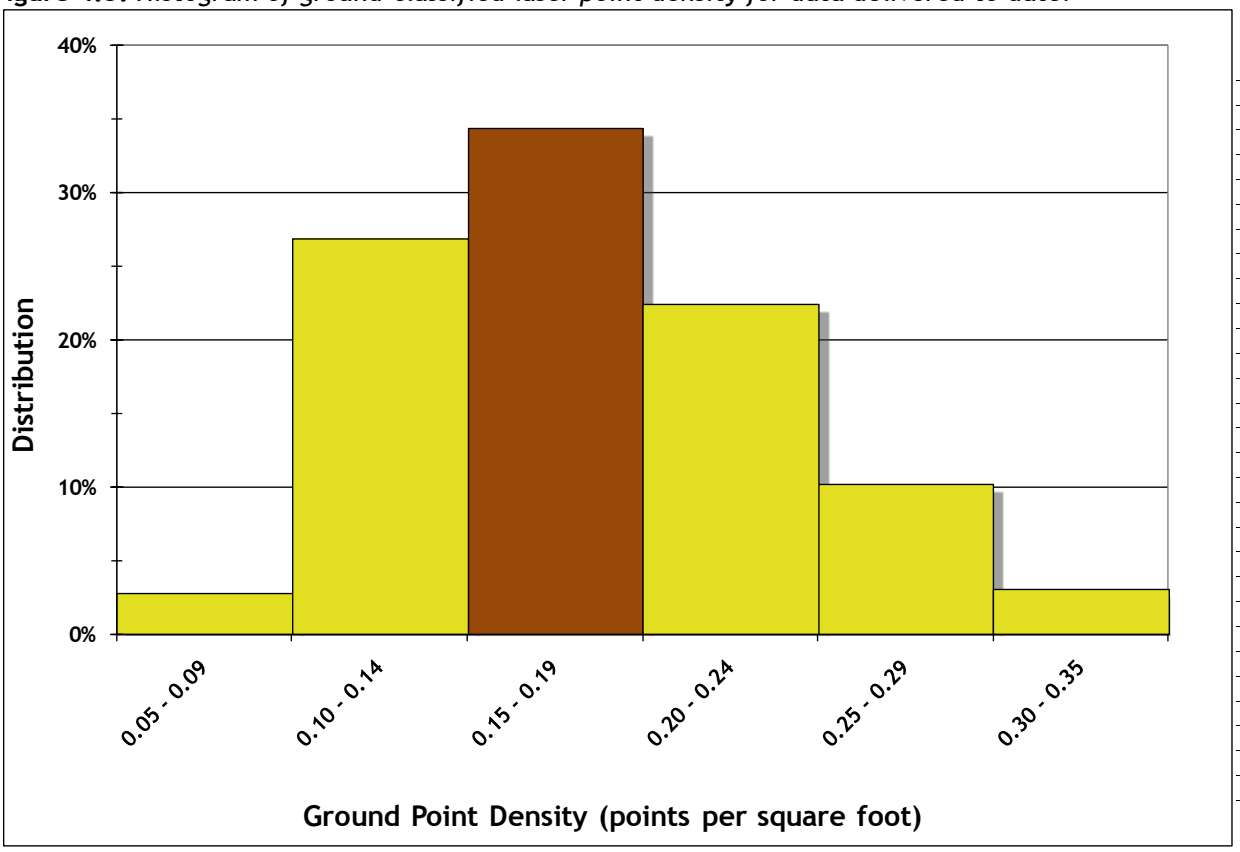
Figure 4.2. *First return laser pulse densities per 0.75' USGS Quad for data delivered to date.*



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 data delivered to date.*



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
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0.40	4.31
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0.50	5.38
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0.85	9.15
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0.95	10.23
1.00	10.76
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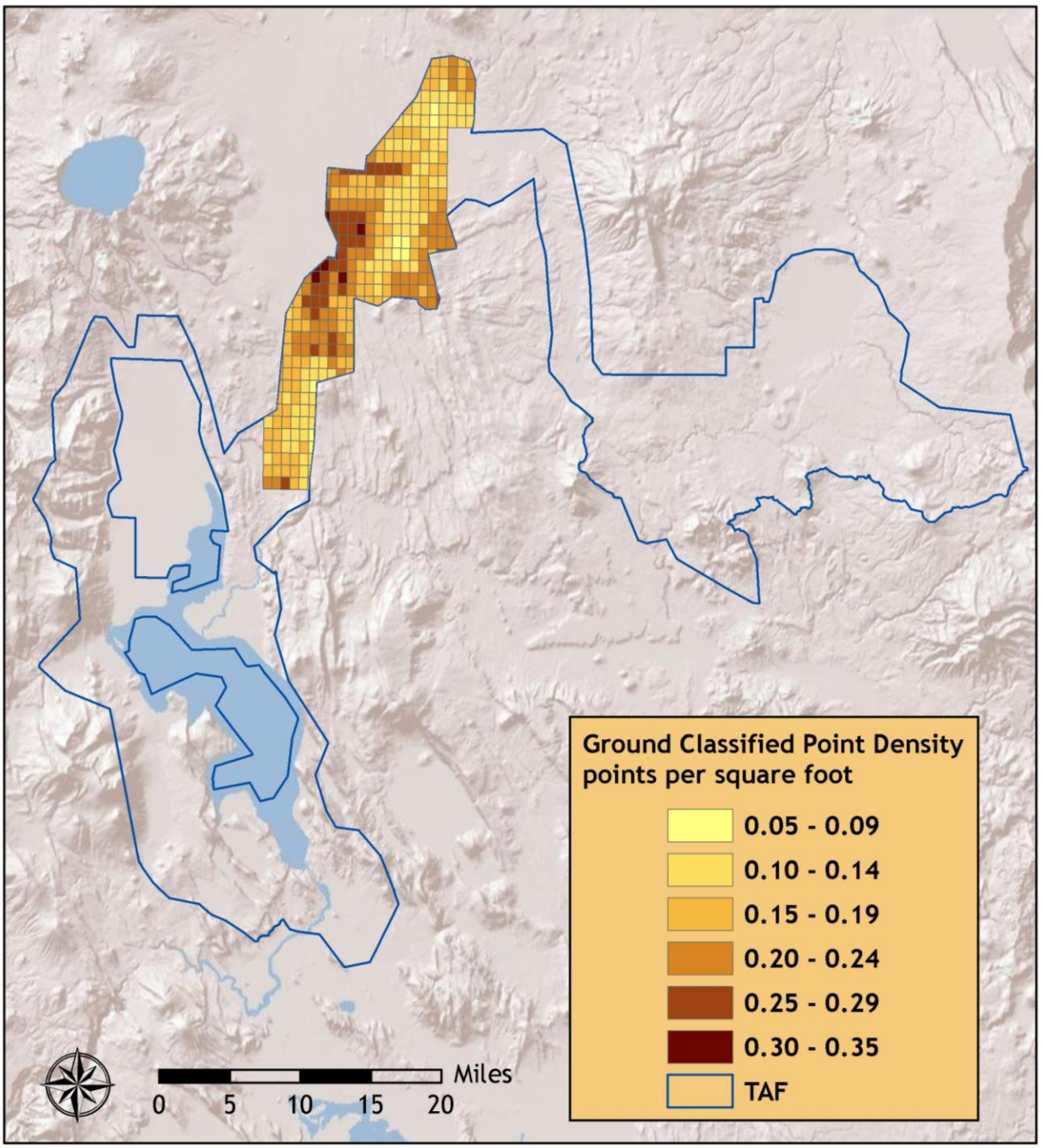
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

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 Klamath 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 1/4/2011
OREGON
JULY 18, 2004
Christopher W. Yotter - Brown
60433 LS
RENEWAL DATE: 6/30/2012

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6. Selected Imagery

Figure 5.1. *Aerial view of Klamath Marsh National Wildlife Refuge, 20 miles east of Crater Lake National Park, Oregon. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

Figure 5.2. *View from the north of Klamath Marsh National Wildlife Refuge, 20 miles east of Crater Lake National Park, OR. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

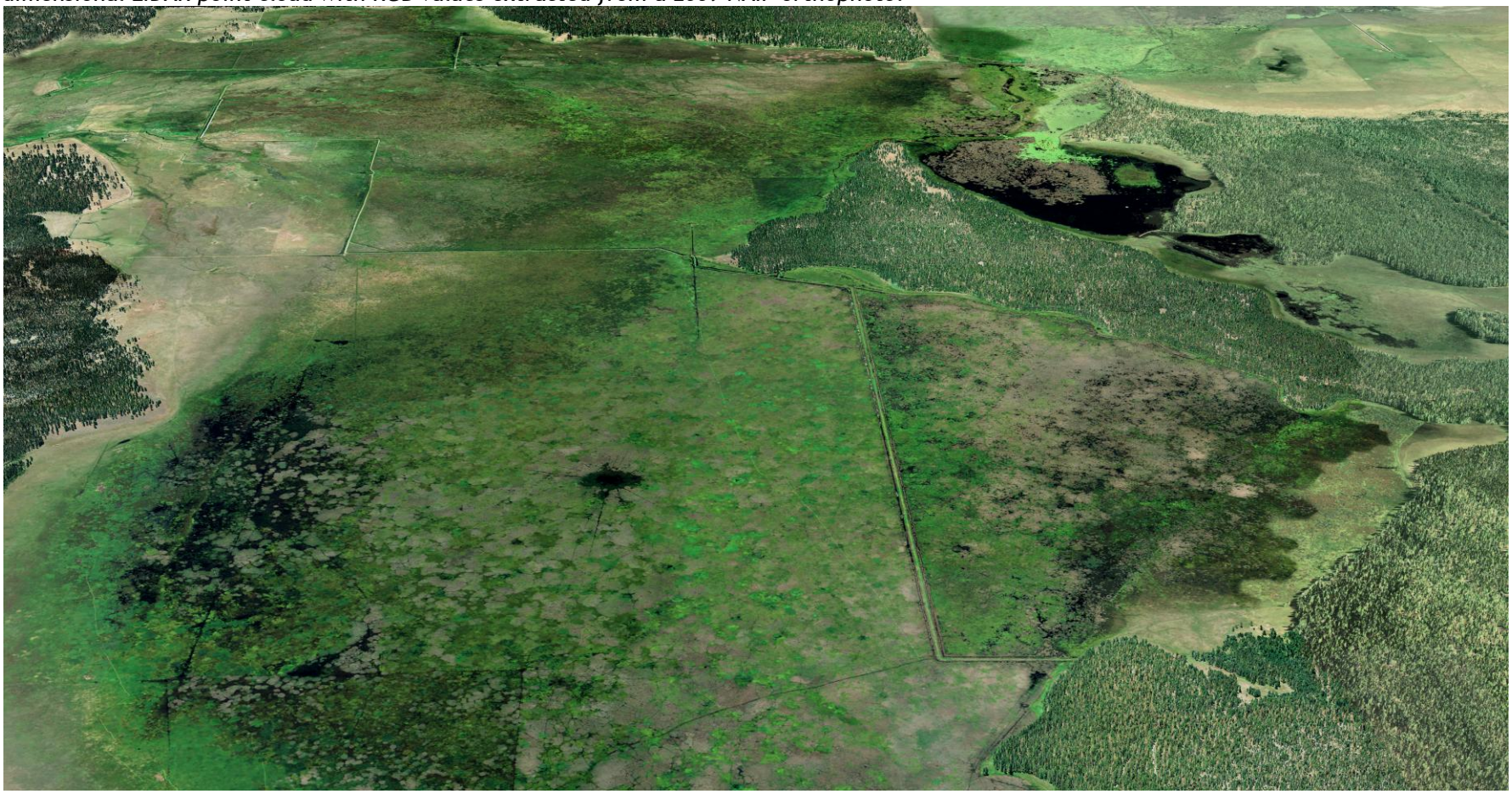

Figure 5.3. *View from the north of an area three miles south of Kirk, OR, including the Williamson River valley, on the Fremont-Winema National Forest. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

Figure 5.4. *View from the northeast of the Williamson River, adjacent to Forest Road 973i, and a mile and a half east of Highway 97. South of Kirk, Oregon on the Fremont-Winema National Forest. Image is a three dimensional LiDAR point cloud with RGB values extracted from a NAIP orthophoto.*

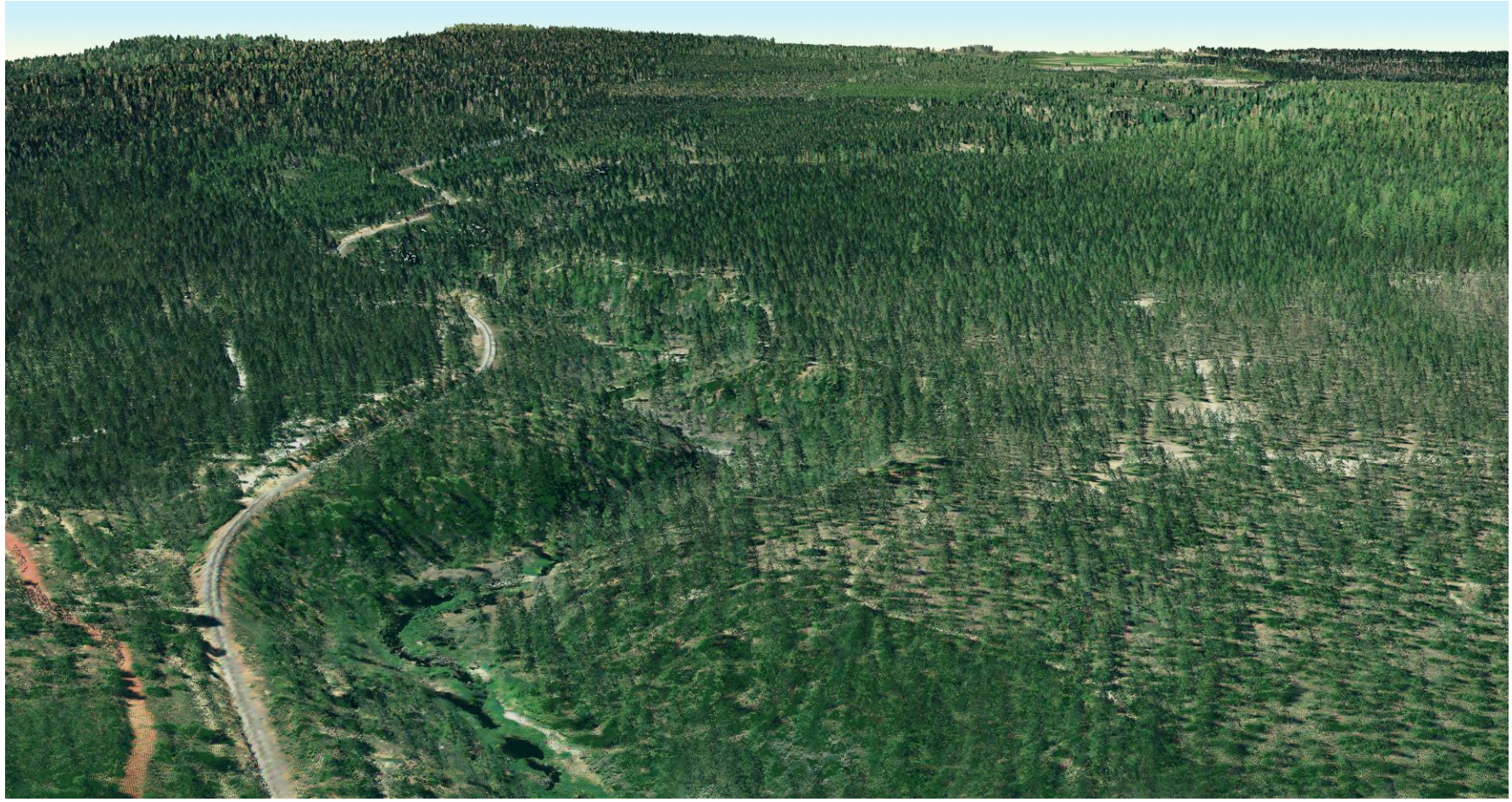

Figure 5.5. *View from the southwest of the Williamson River, next to Forest Road 9731 and a mile and a half east of Highway 97. South of Kirk, Oregon on the Fremont-Winema National Forest. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*