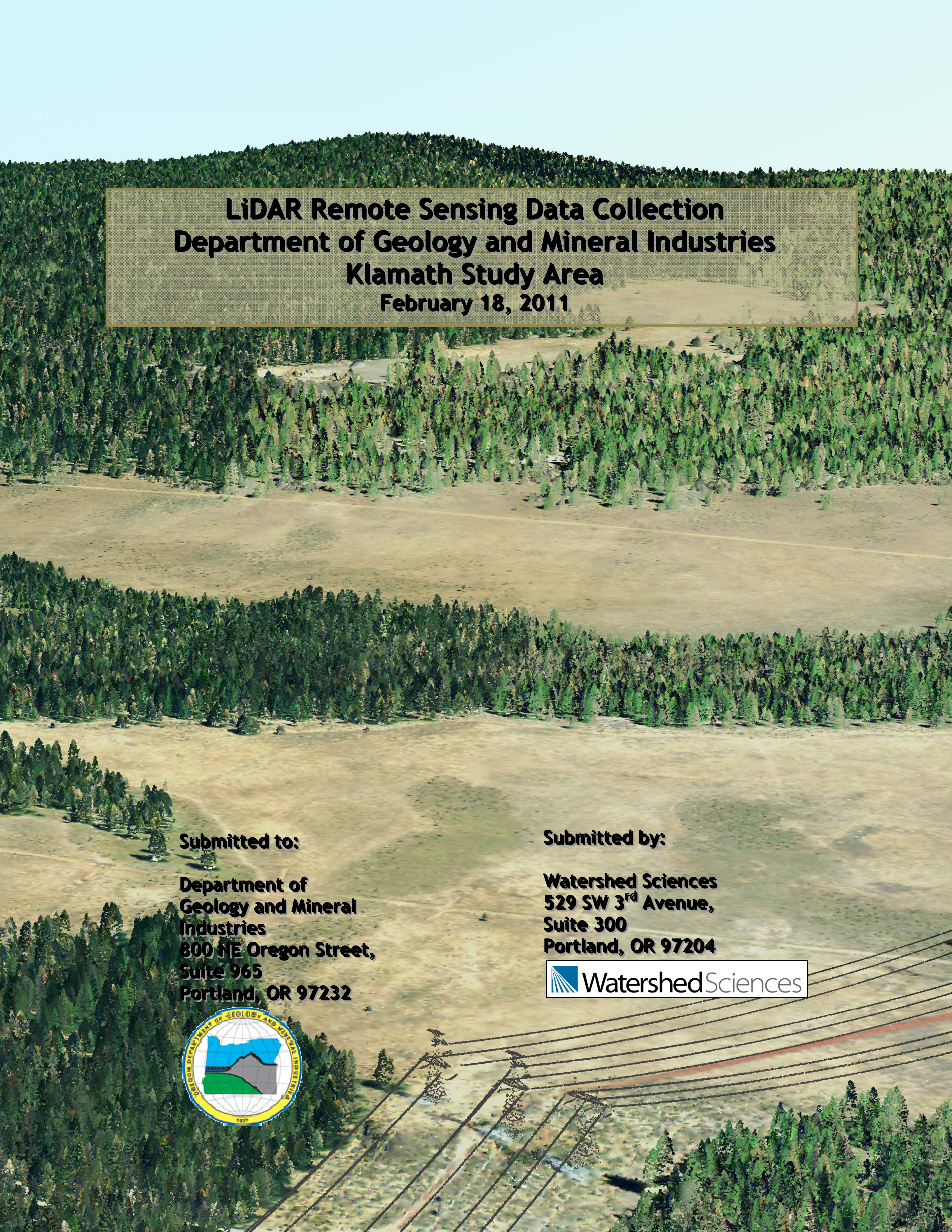

# LiDAR Remote Sensing Data Collection
# Department of Geology and Mineral Industries
# Klamath Study Area

**February 18, 2011**


**Submitted to:**

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

**Submitted by:**

**Watershed Sciences**
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**Portland, OR 97204**

Watershed Sciences

# LiDAR Remote Sensing Data Collection:
## DOGAMI, Klamath Study Area

**TABLE OF CONTENTS**

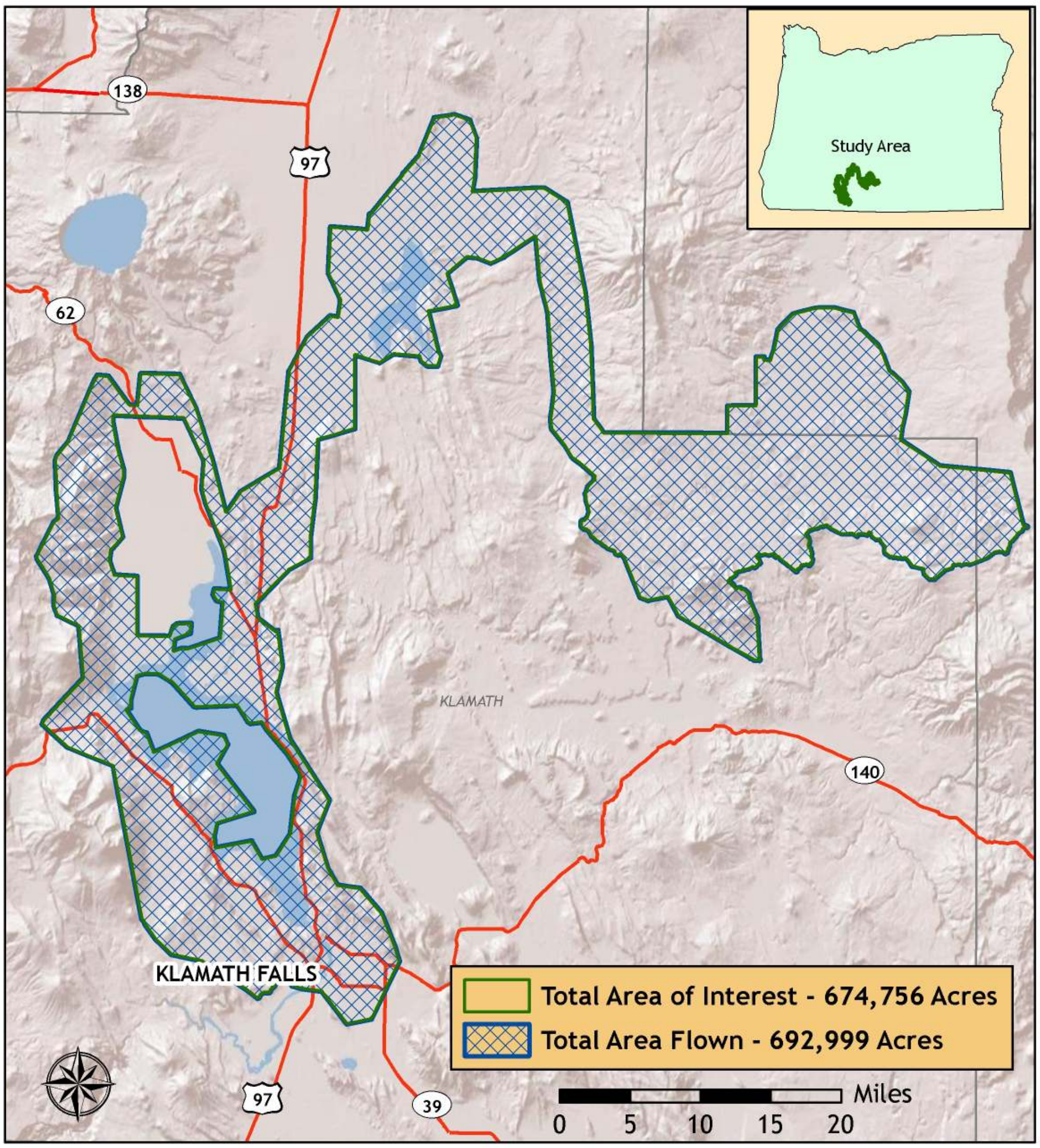


# 1. Overview

## 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** |
| **Delivery Area 2** | January 28, 2011 | September 20, 2010 - October 18, 2010 | **67,937** | **71,599** |
| **Delivery Area 3** | February 4, 2011 | September 14, 2010 - October 16, 2010 | **127,789** | **131,580** |
| **Delivery Area 4** | February 18, 2011 | October 6, 2010 - October 27, 2010 | **155,387** | **157,875** |

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

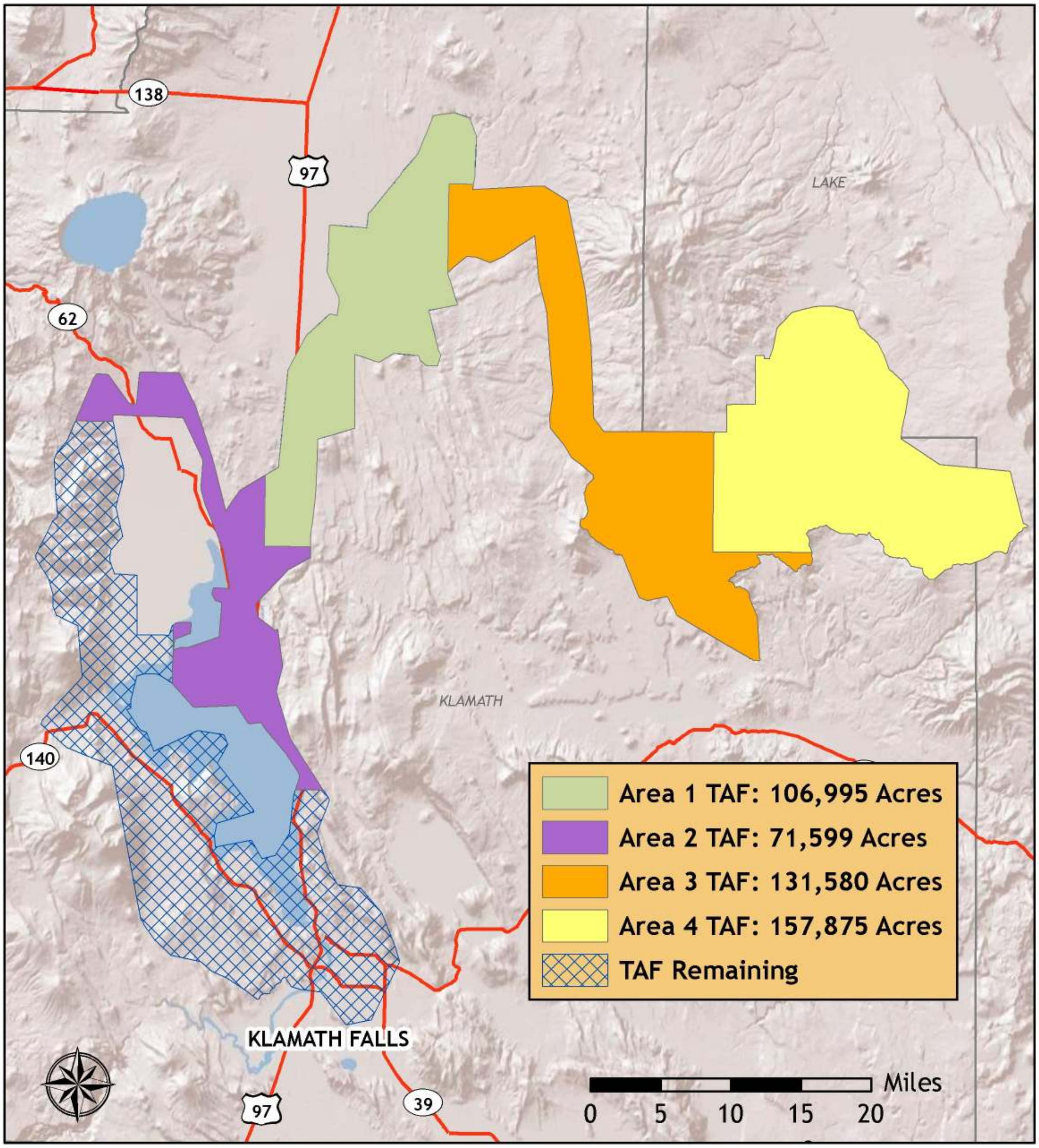
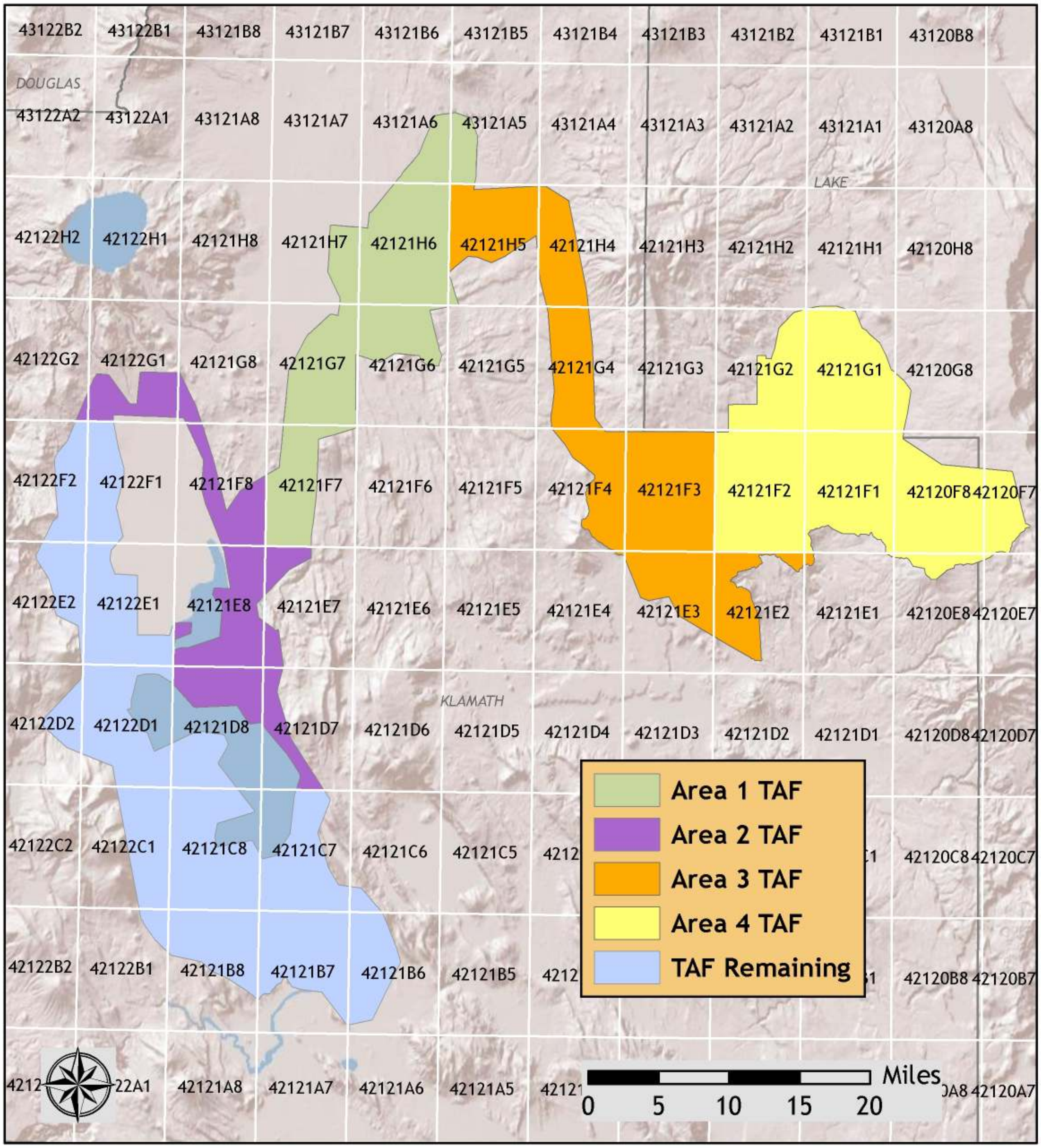


**Figure 1.3.** *Klamath Study Area, illustrating the delivered 7.5 minute USGS quads.*



# 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$^o$ or ±12$^o$ 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*

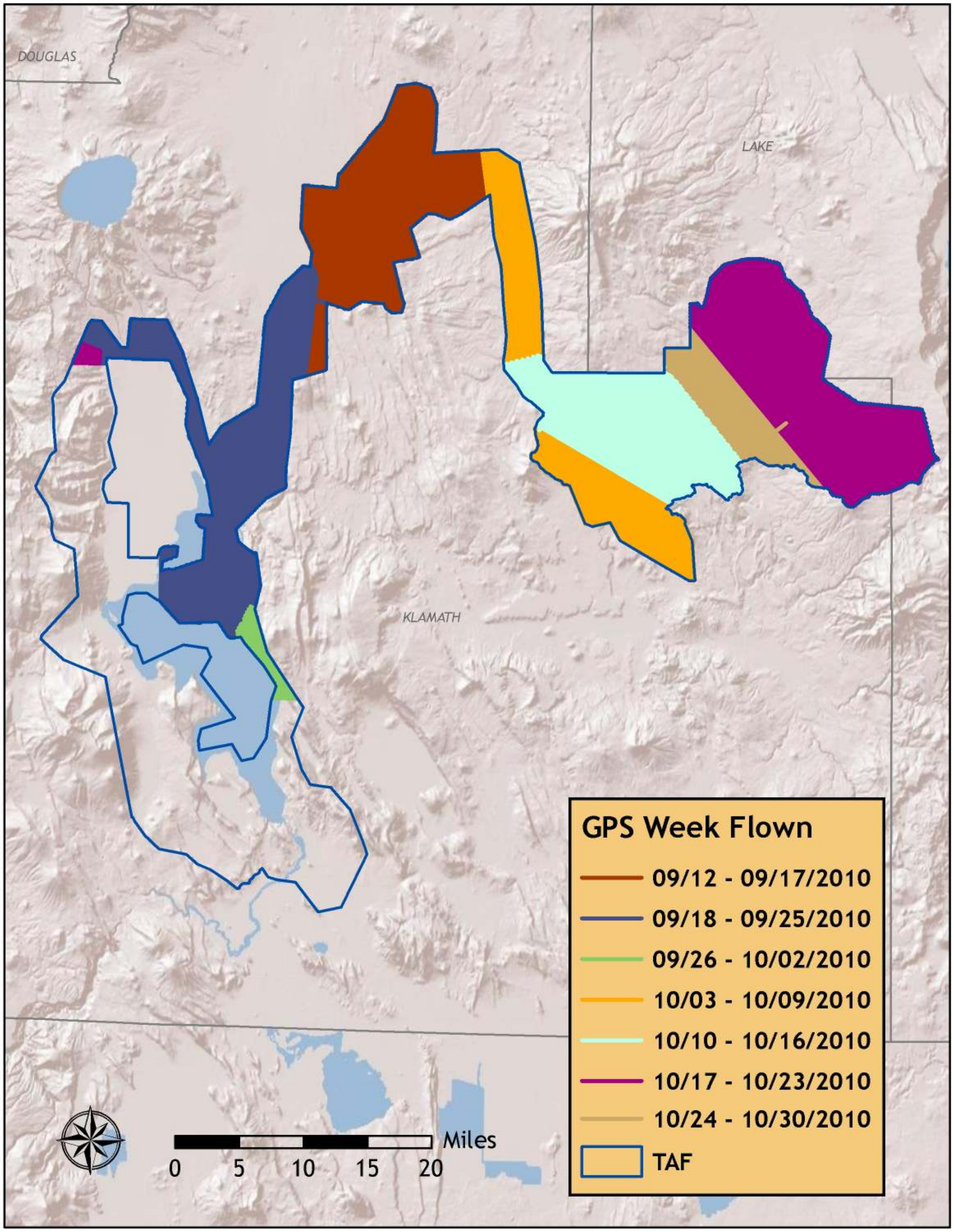
| | |
|---|---|
| Sensors | Leica ALS60 and ALS50 Phase II |
| Survey Altitude (AGL) | 900 m and 1500 m |
| Pulse Rate | >105 kHz and >150kHz |
| Pulse Mode | Single and Multi |
| Mirror Scan Rate | 52 Hz and 69 Hz |
| Field of View | 28$^o$ (±14$^o$ from nadir) and 24$^o$ (±12$^o$ from nadir) |
| Roll Compensated | Up to 15$^o$ |
| 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 4, all Global Navigation Satellite System (GNSS[3]) survey work used both Trimble R7 GPS receivers with a Zephyr Geodetic antenna with ground plane for static control points and Trimble R8 GNSS units for RTK data collection.

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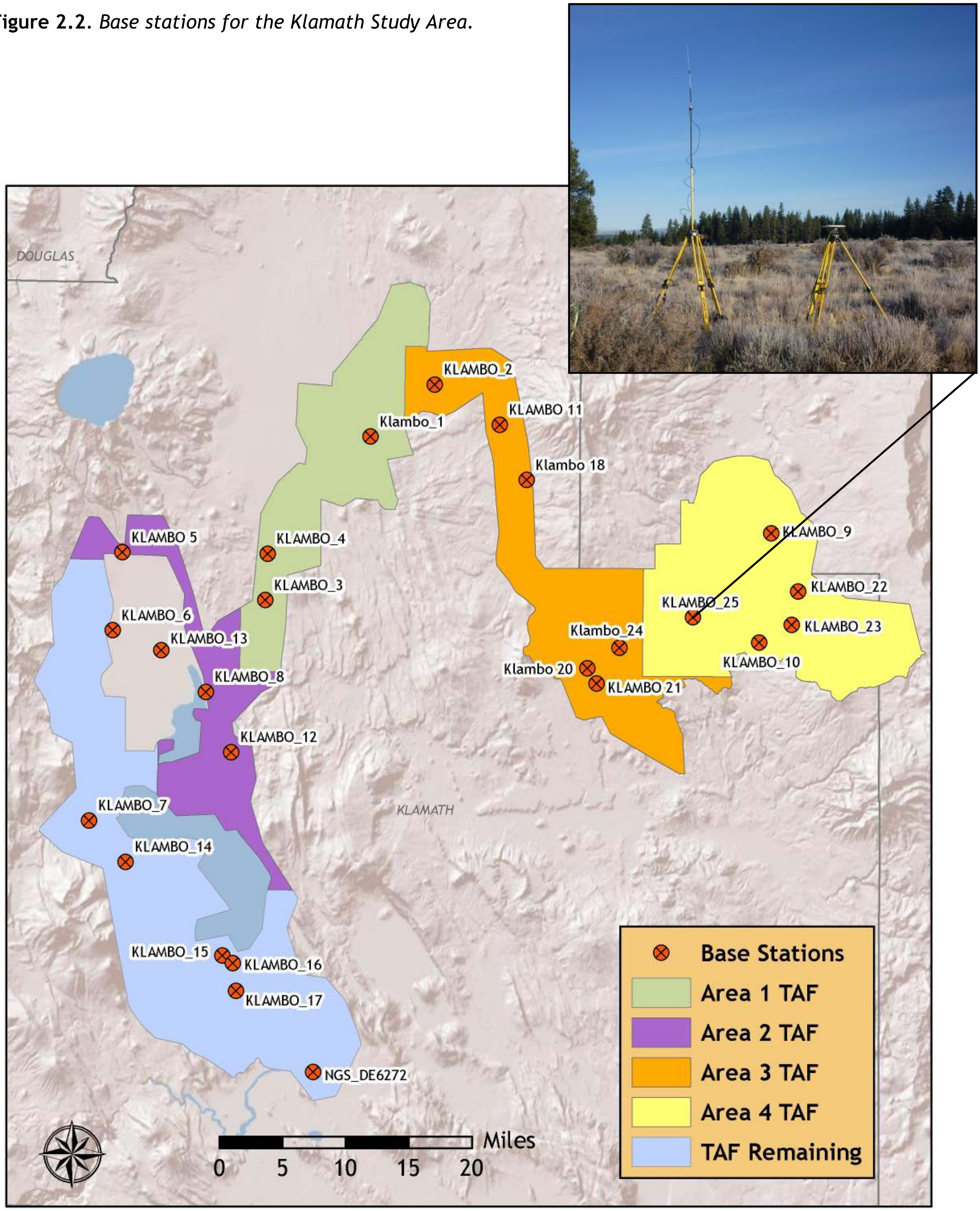
[2] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.
[3] GNSS: Global Navigation Satellite System consisting of the U.S. GPS constellation and Soviet GLONASS constellation

**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, 2,821 RTK (Real-time kinematic) points were collected in the study area. **Figures 2.3 through 2.6** show 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.*

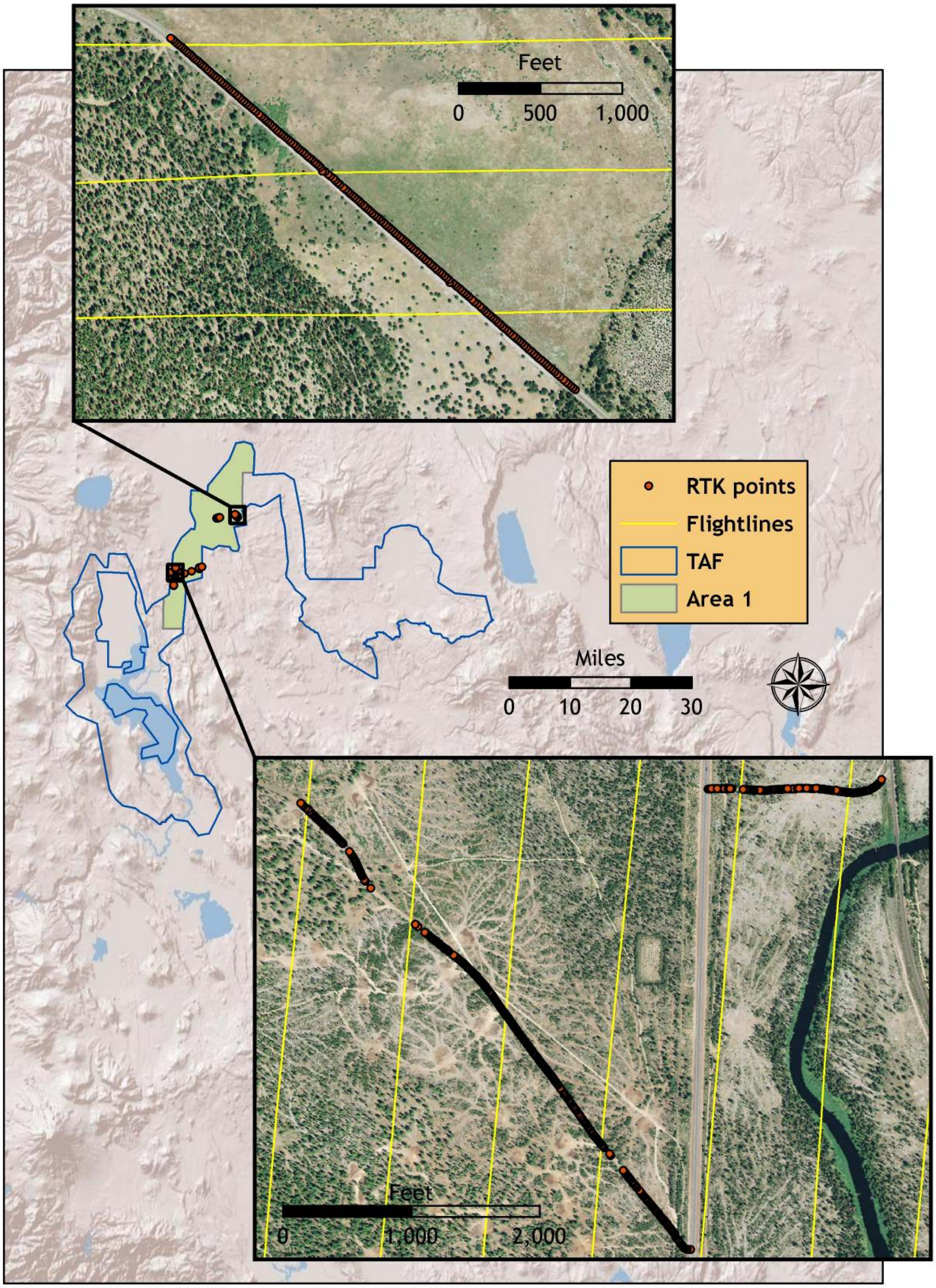


**Figure 2.4.** *Selected RTK point locations in the study area for delivery area 2; images are 2009 NAIP orthophotos.*

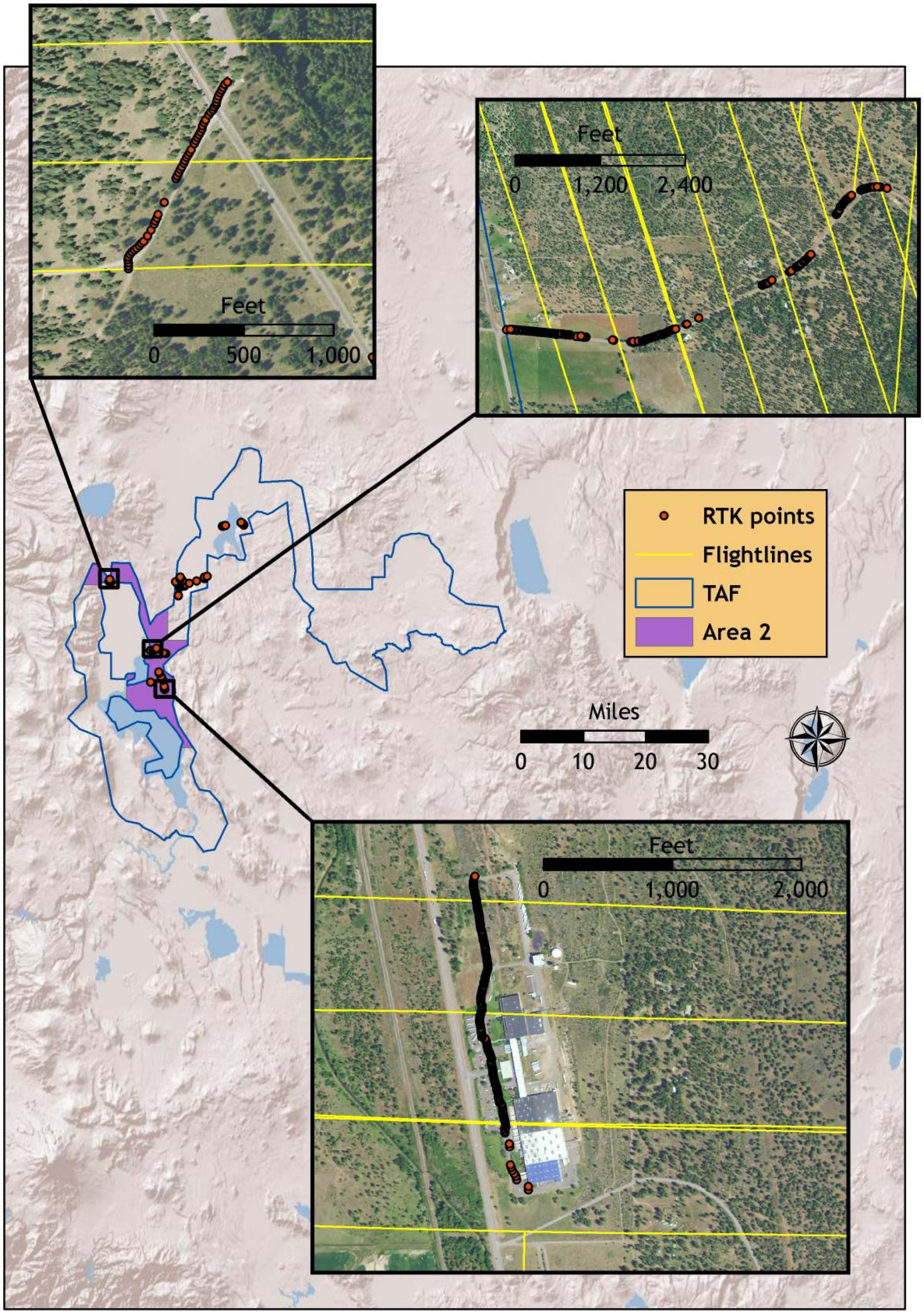


**Figure 2.5.** *Selected RTK point locations in the study area for delivery area 3; images are 2009 NAIP orthophotos.*

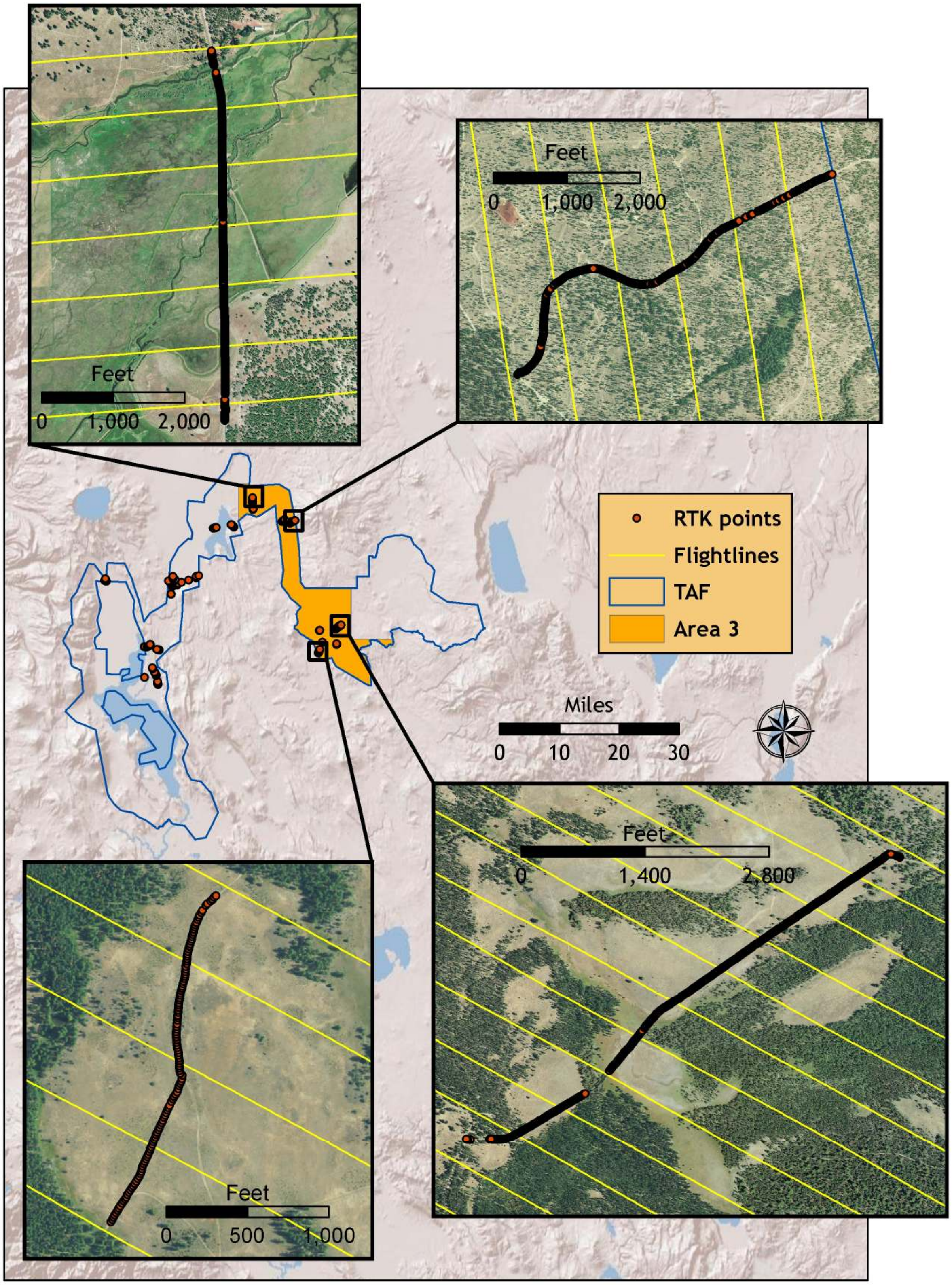
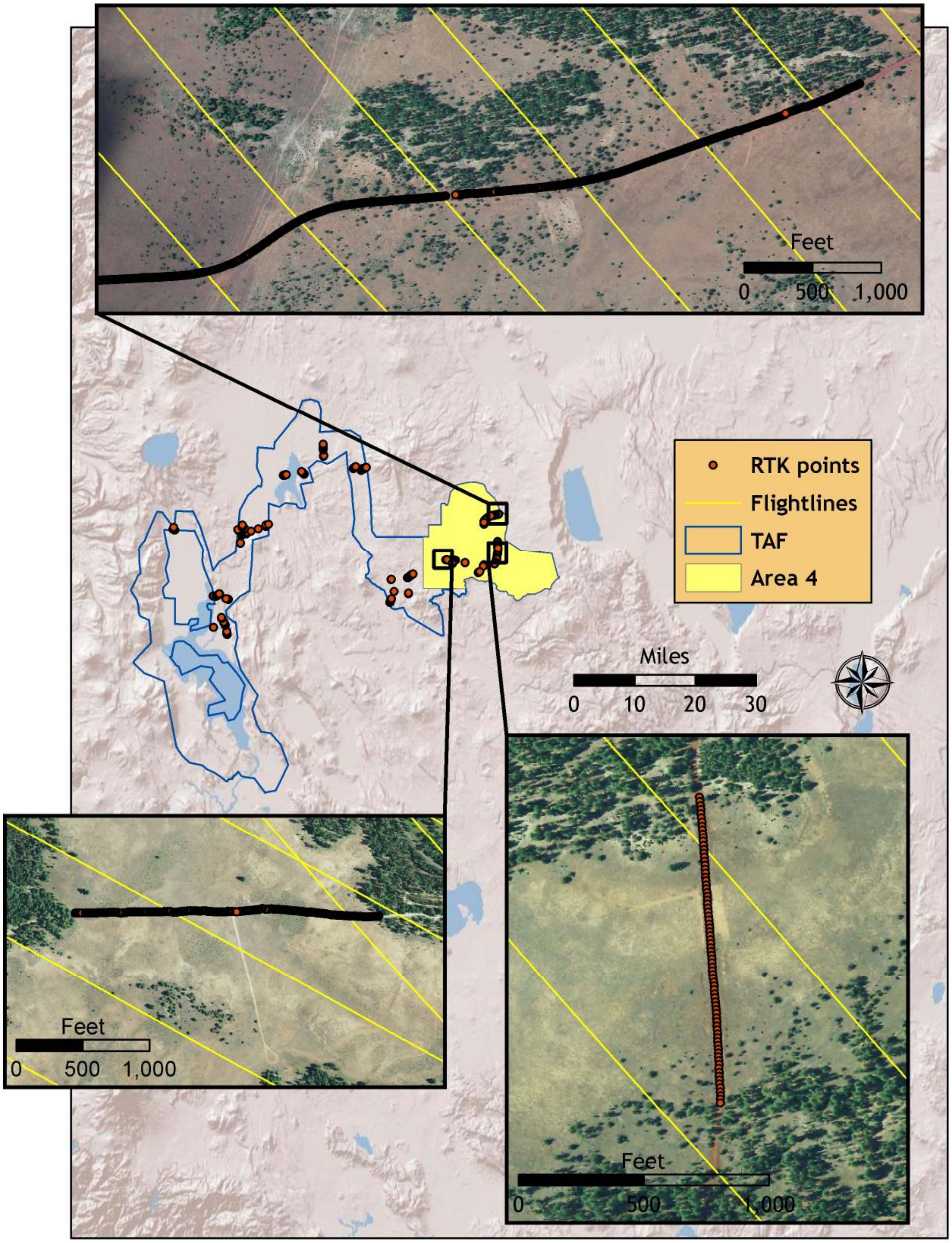


**Figure 2.6.** *Selected RTK point locations in the study area for delivery area 4; images are 2009 NAIP orthophotos.*



# 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 654 flightlines and over 14.8 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)
- $1\sigma$ Relative Accuracy = 0.10 ft (0.03 m)
- $2\sigma$ Relative Accuracy = 0.14 ft (0.04 m)

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

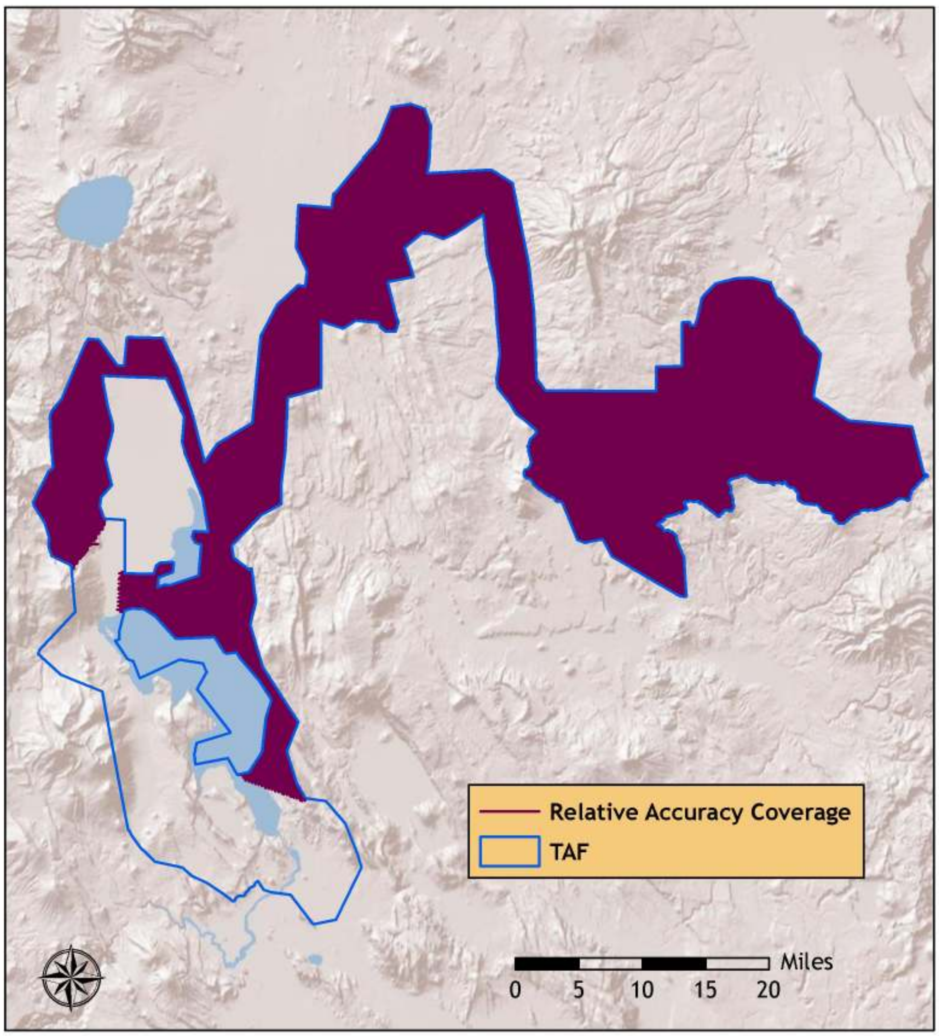


**Figure 3.2.** *Statistical relative accuracies, non slope-adjusted.*

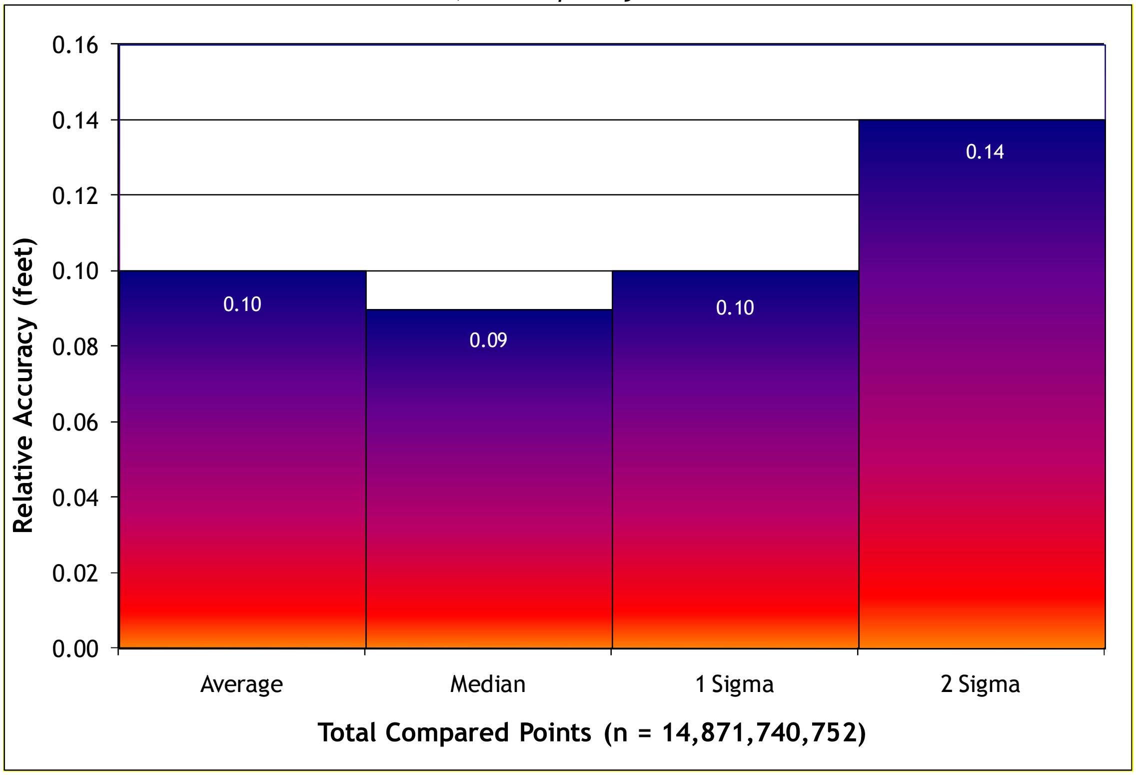
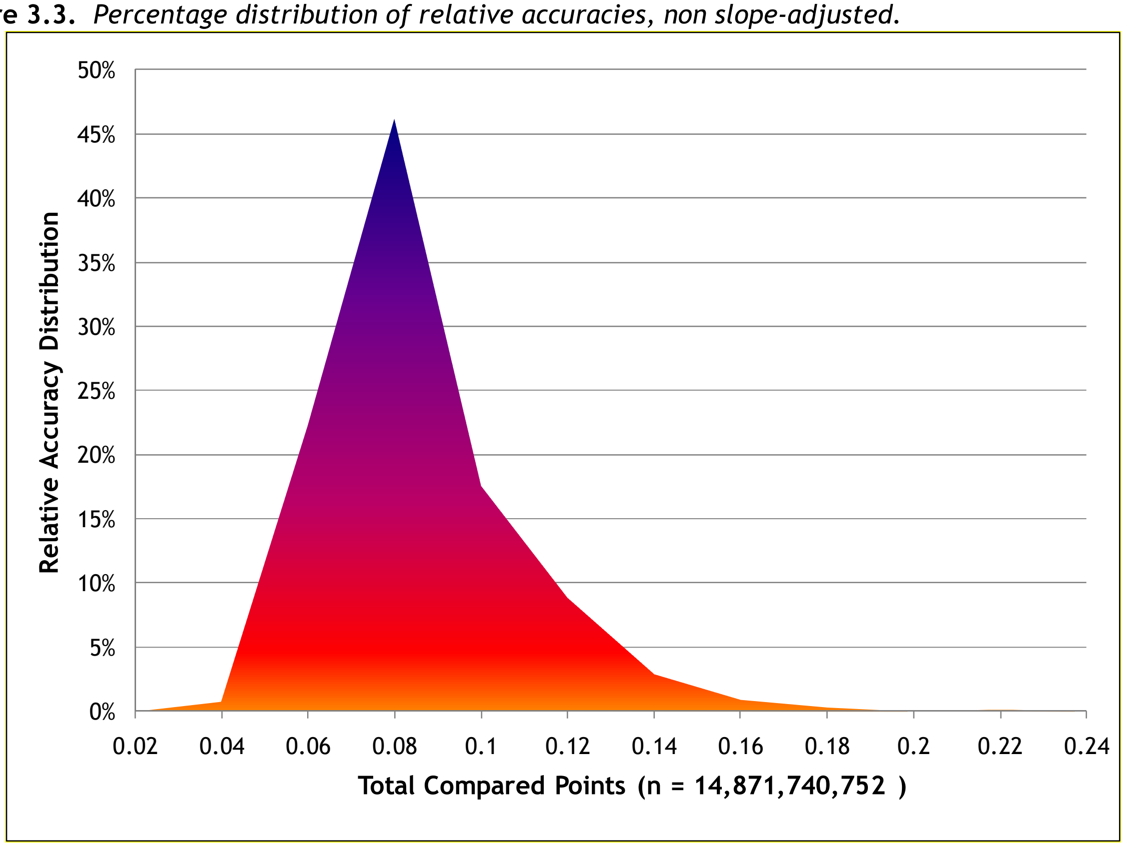



**Figure 3.3.** *Percentage distribution of relative accuracies, non slope-adjusted.*



## 3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Klamath Study Area, 5,428 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): 5,428** | |
|---|---|
| **Root Mean Square Error (RMSE):** 0.11 ft (0.03m) | |
| **Standard Deviations** | **Deviations** |
| **1 sigma (σ):** 0.10 ft (0.03 m) | **Minimum Δz:** -0.39 ft (-0.12 m) |
| **2 sigma (σ):** 0.21 ft (0.06 m) | **Maximum Δz:** 0.32 ft (0.10 m) |
| | **Average Δz:** 0.09 ft (0.03 m) |

**Figure 3.4.** *Absolute Accuracy Covered Area.*

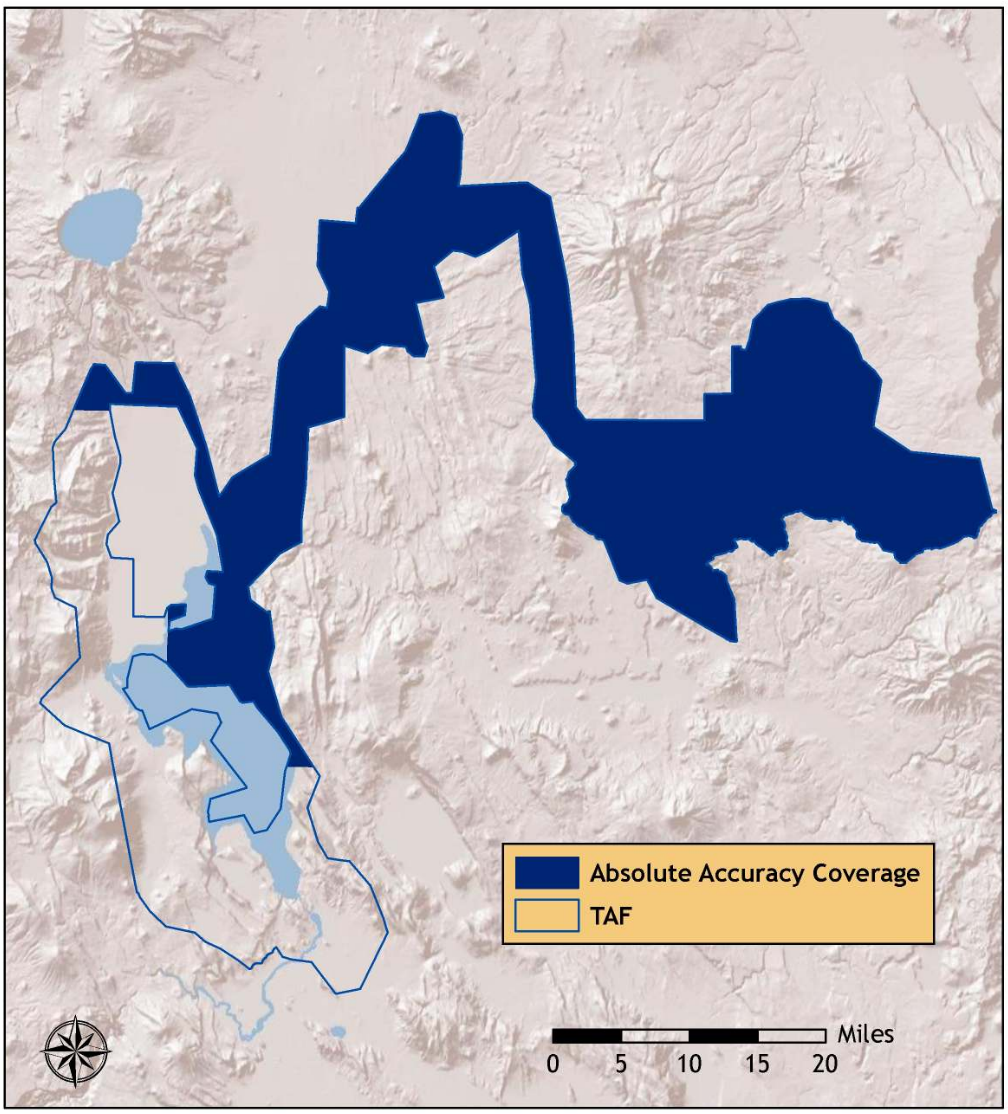


**Figure 3.5.** *Klamath Study Area histogram statistics.*

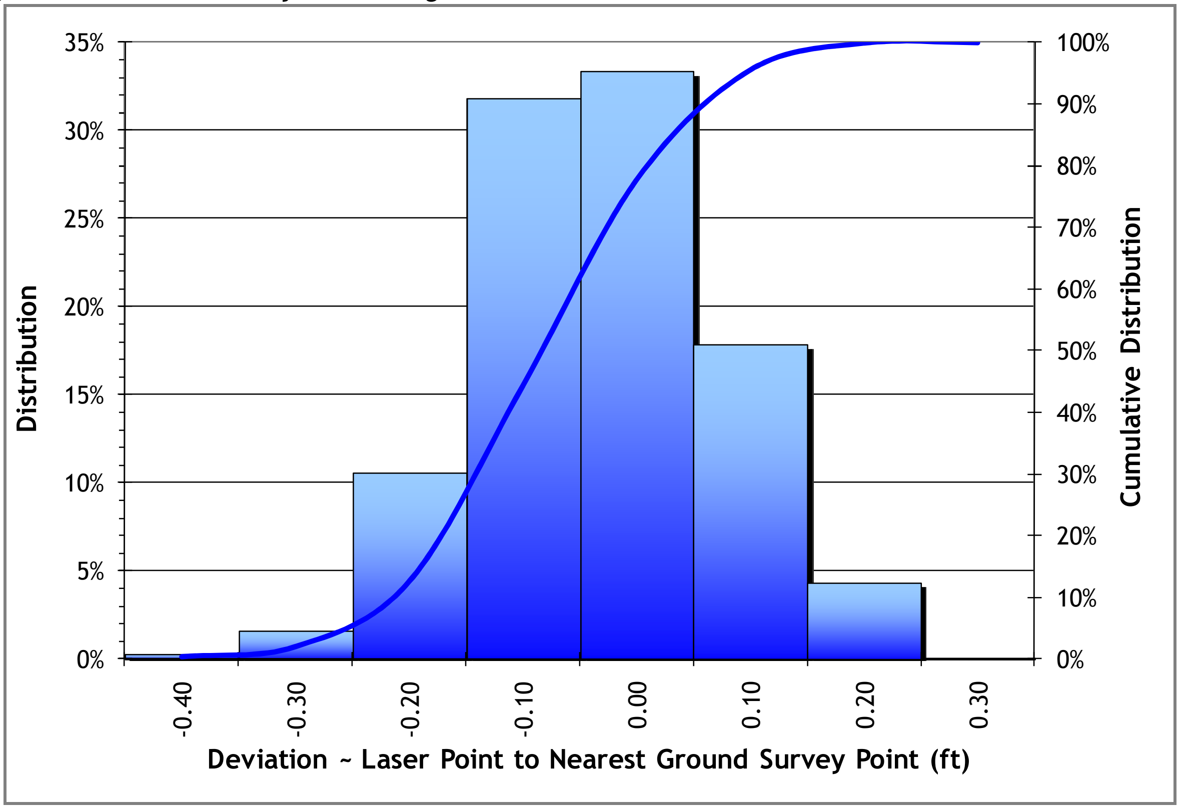
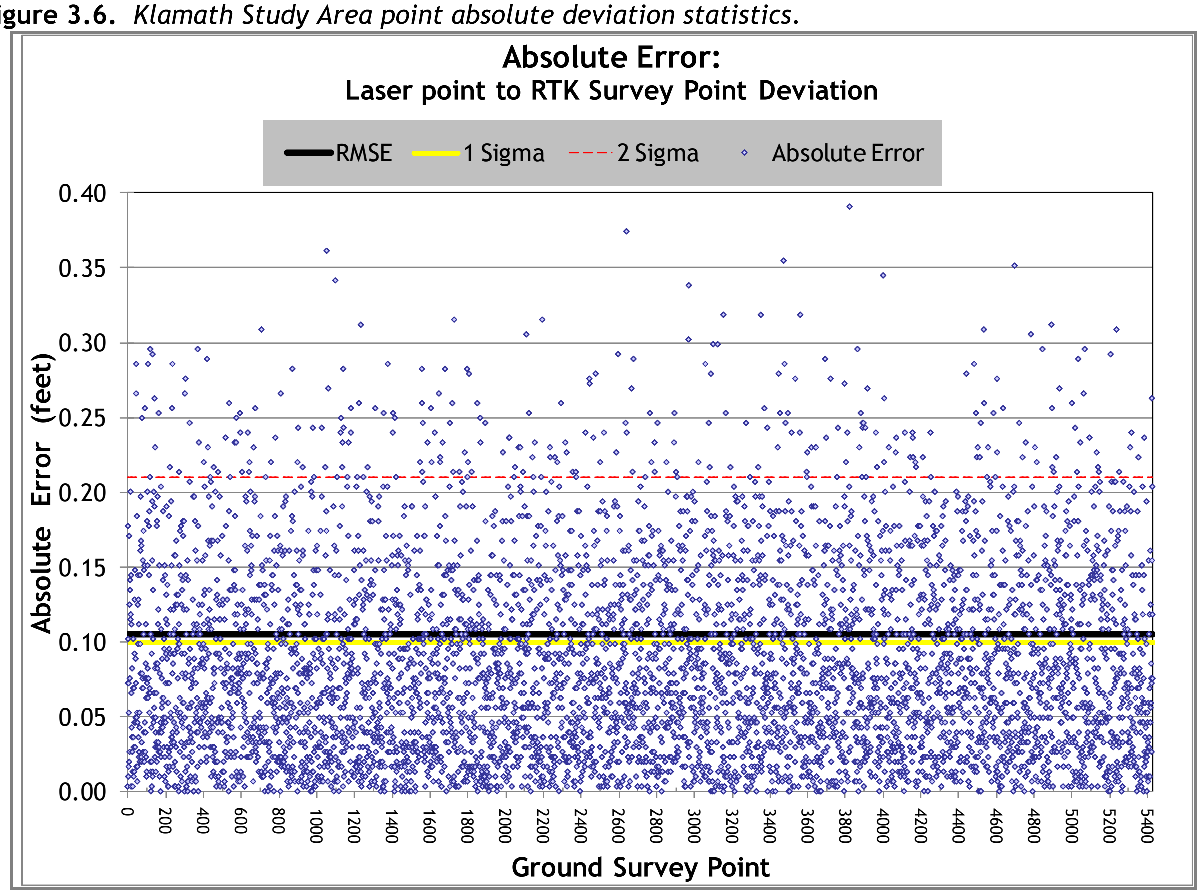



**Figure 3.6.** *Klamath Study Area point absolute deviation statistics.*



# 4. Data Density/Resolution

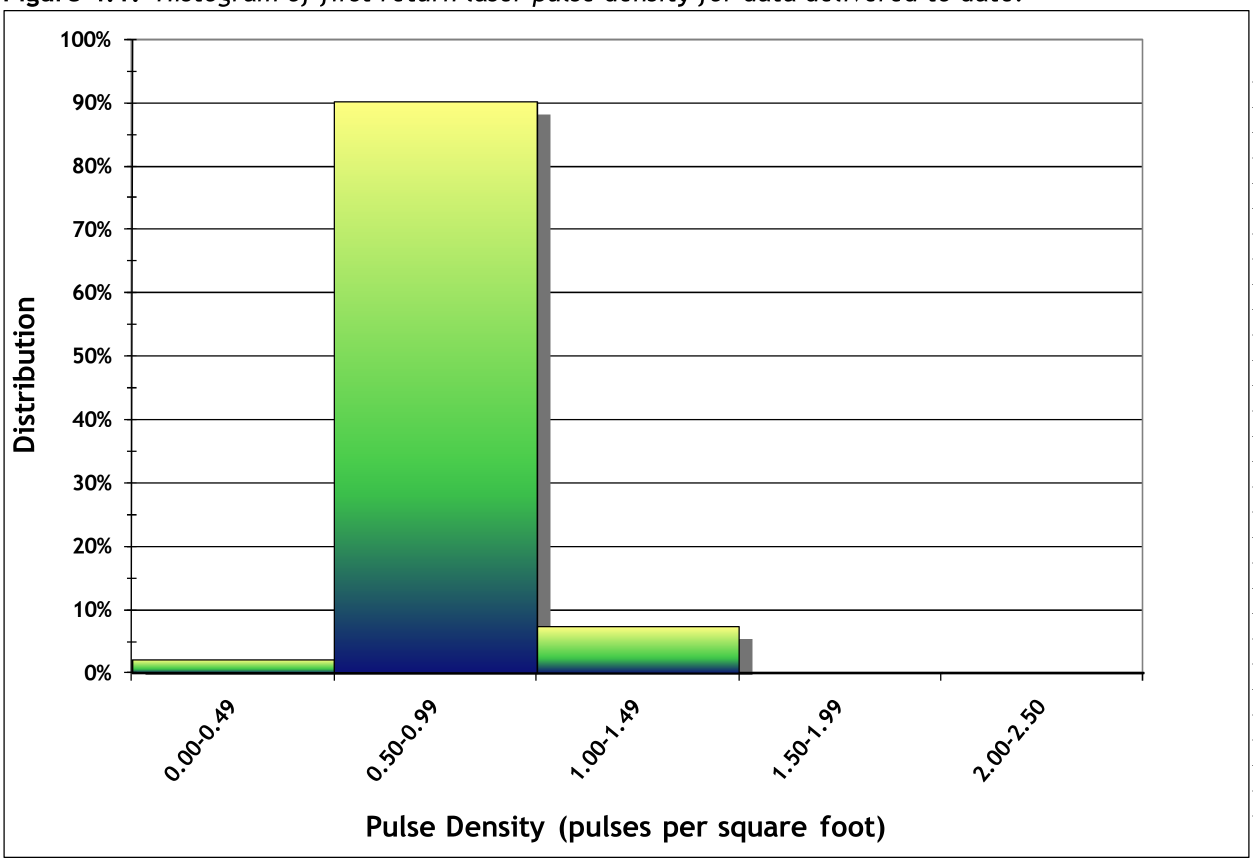
## 4.1 Density Statistics

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.*

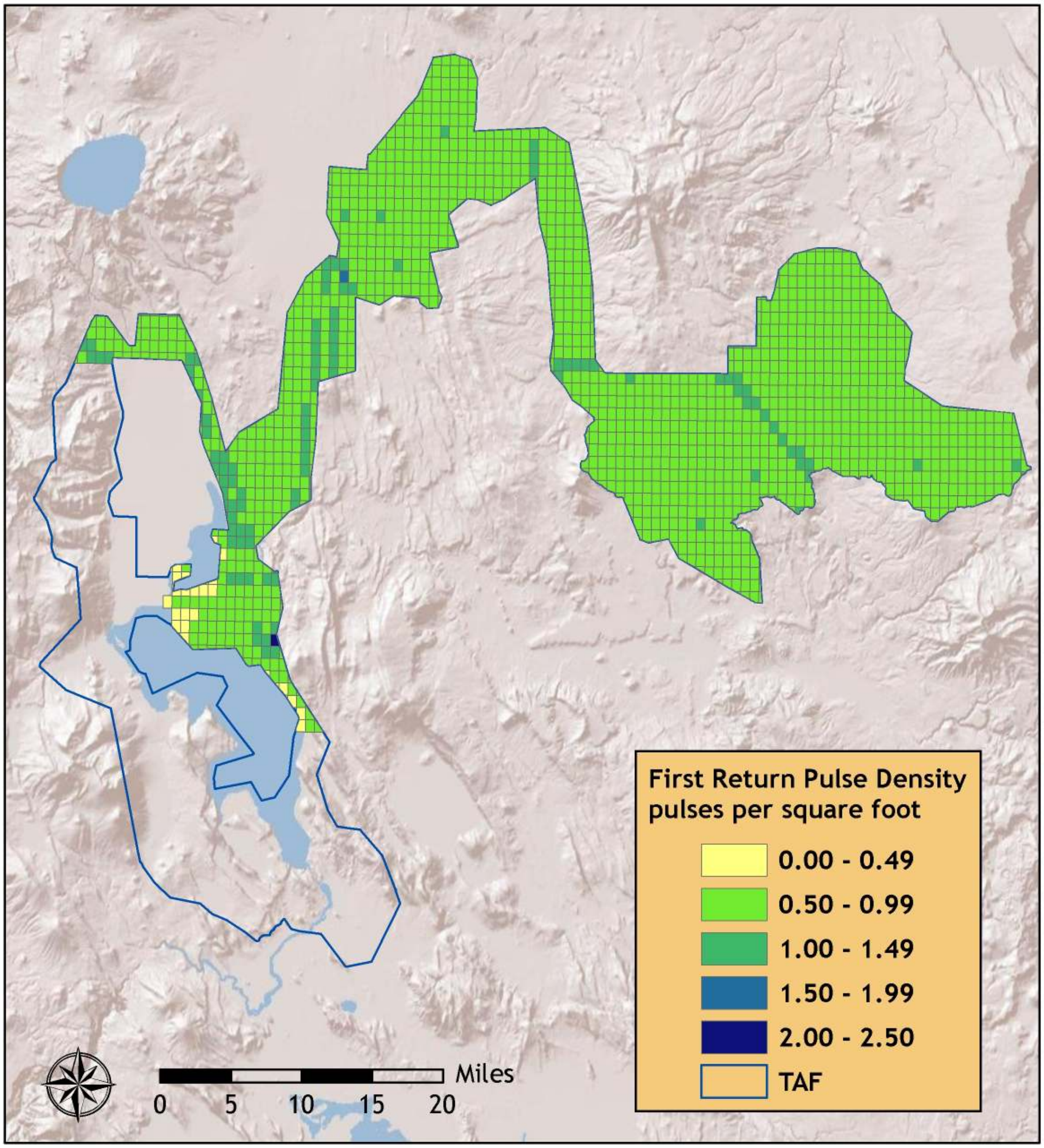
| Average Pulse Density (per square ft) | Average Pulse Density (per square m) | Average Ground Density (per square ft) | Average Ground Density (per square m) |
|---|---|---|---|
| 0.80 | 8.66 | 0.19 | 2.07 |

**Figure 4.1.** *Histogram of first return laser pulse density 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 |

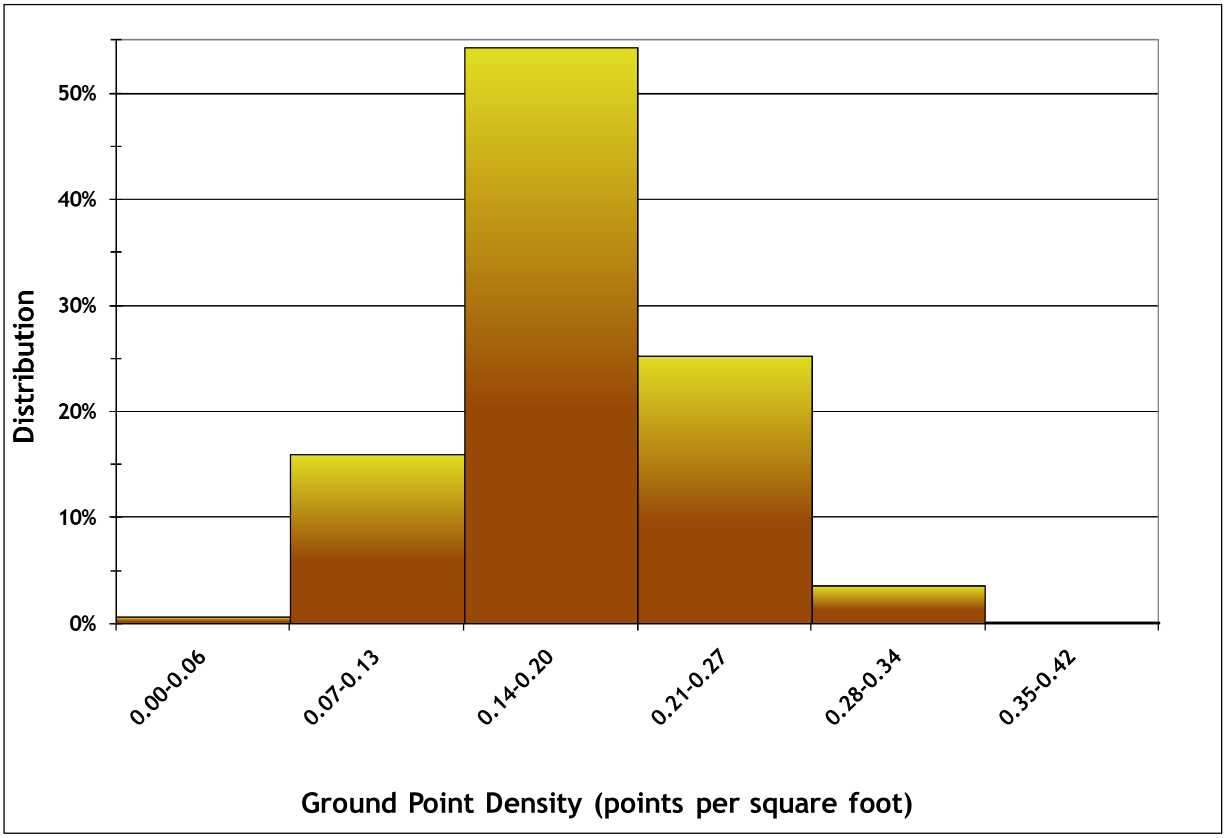
**Figure 4.2.** *First return laser pulse densities per 0.75' USGS Quad for data delivered to date.*




| 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 |

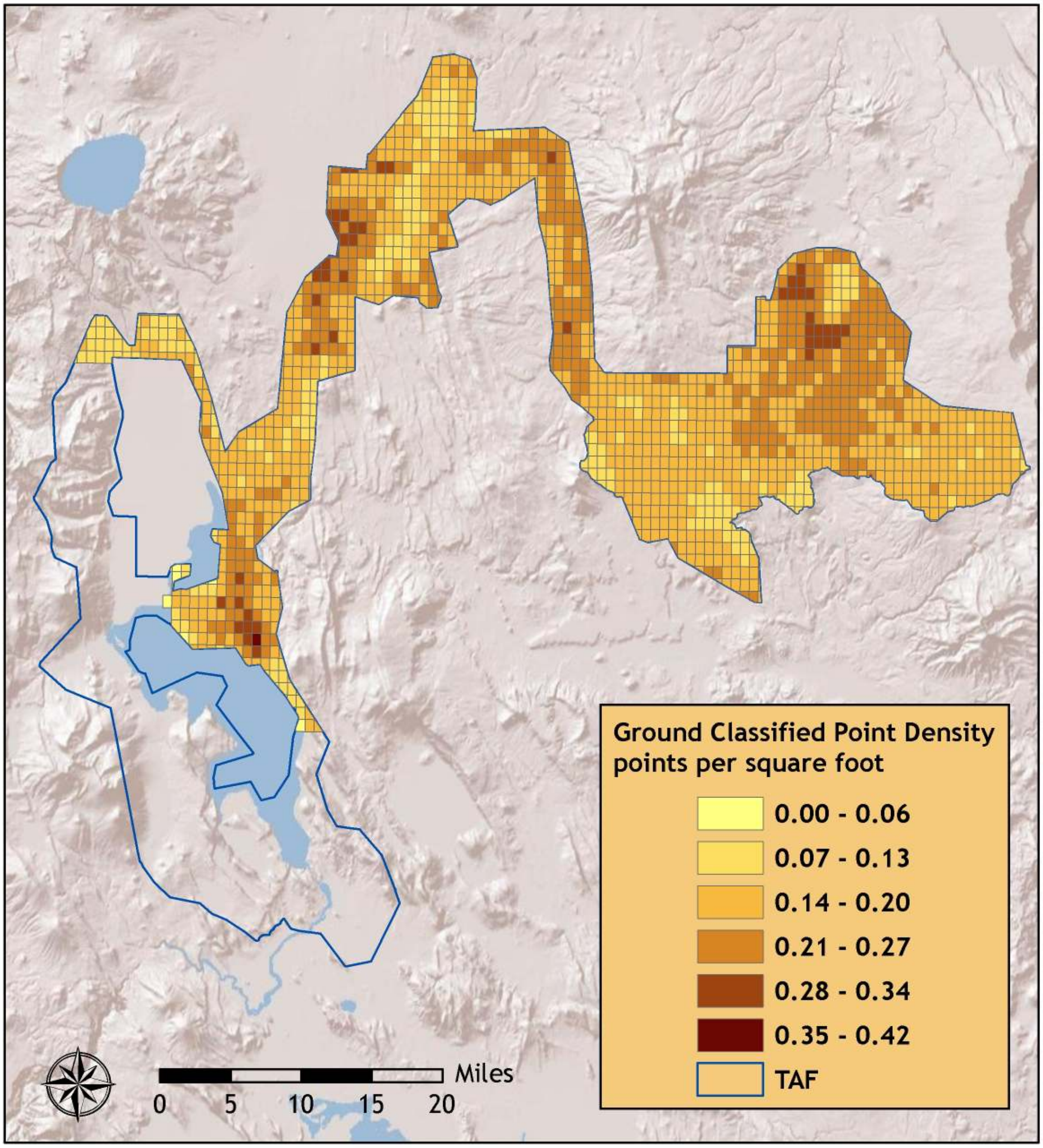
Ground classifications were derived from ground surface modeling. Classifications were performed by reseeding of the ground model where it was determined that the ground model failed, usually under dense vegetation and/or at breaks in terrain, steep slopes and at bin boundaries.

**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 |
| 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 |
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| 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

2/17/2011

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.** *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.*

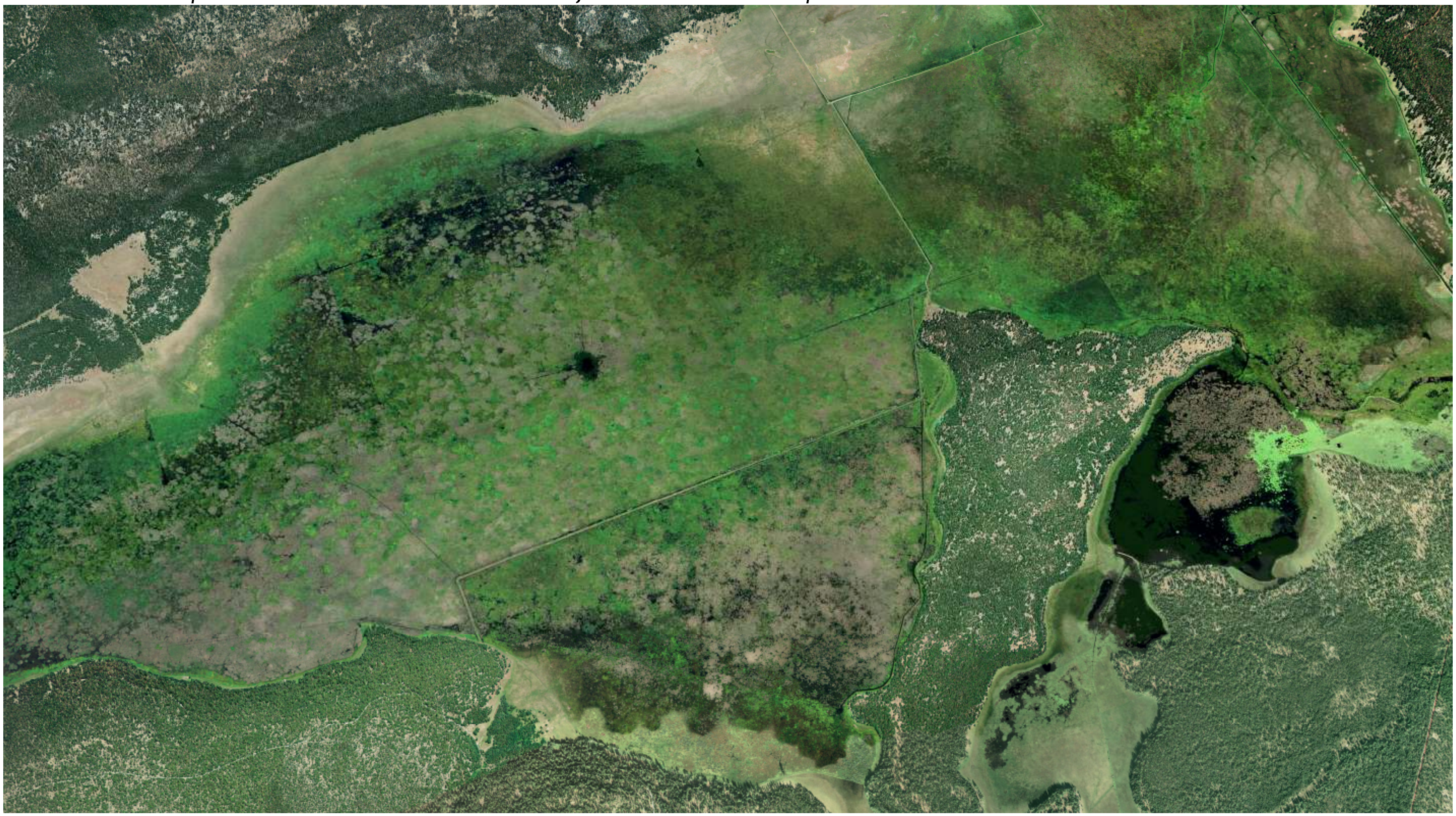

**Figure 5.2.** *View from the north of Klamath Marsh National Wildlife Refuge, 20 miles east of Crater Lake National Park, OR. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

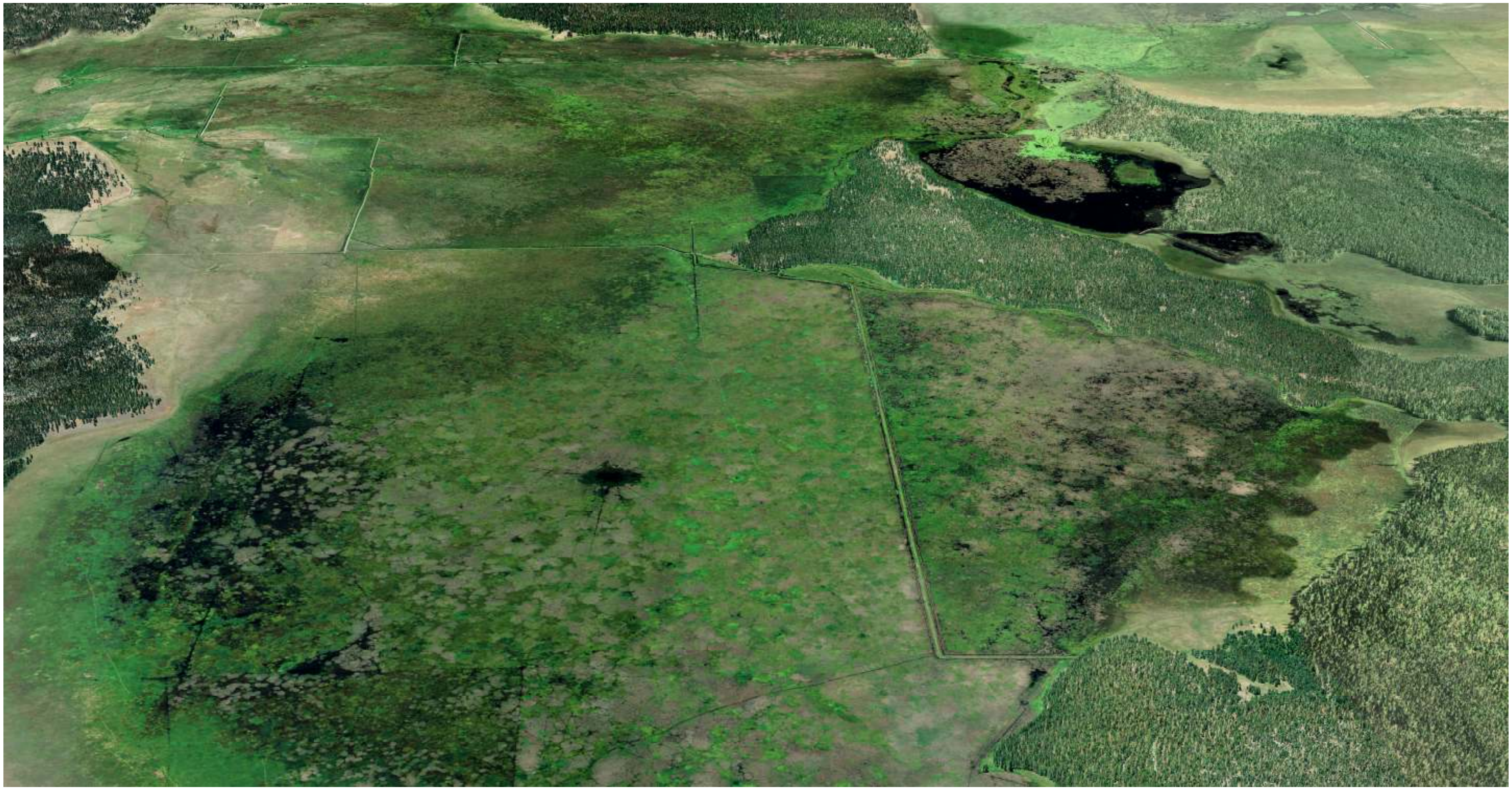

**Figure 5.3.** *View from the north of an area three miles south of Kirk, OR, including the Williamson River valley, on the Fremont-Winema National Forest. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

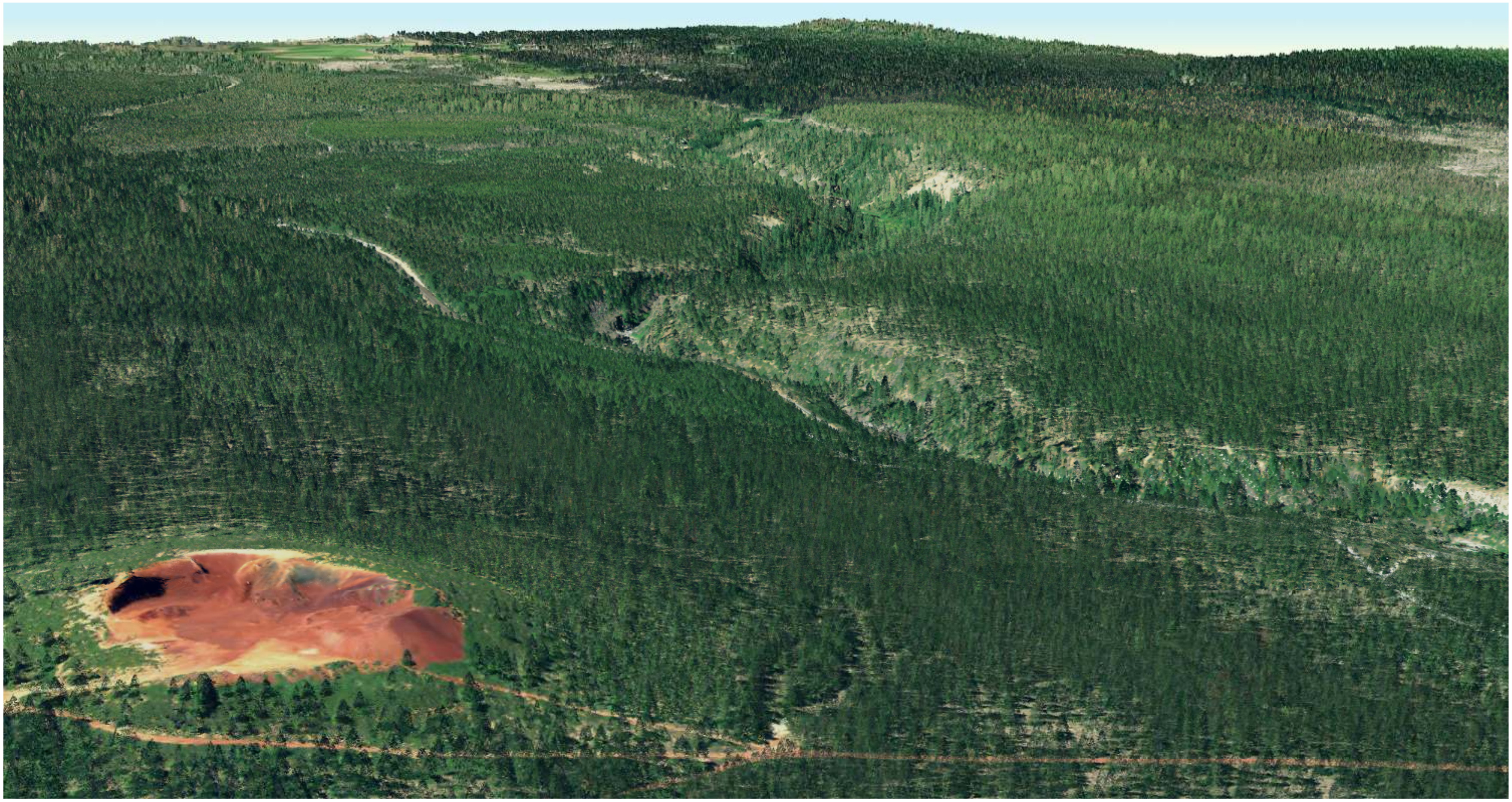

**Figure 5.4**. *View from the northeast of the Williamson River, adjacent to Forest Road 973i, and a mile and a half east of Highway 97. South of Kirk, Oregon on the Fremont-Winema National Forest. Image is a three dimensional LiDAR point cloud with RGB values extracted from a NAIP orthophoto.*

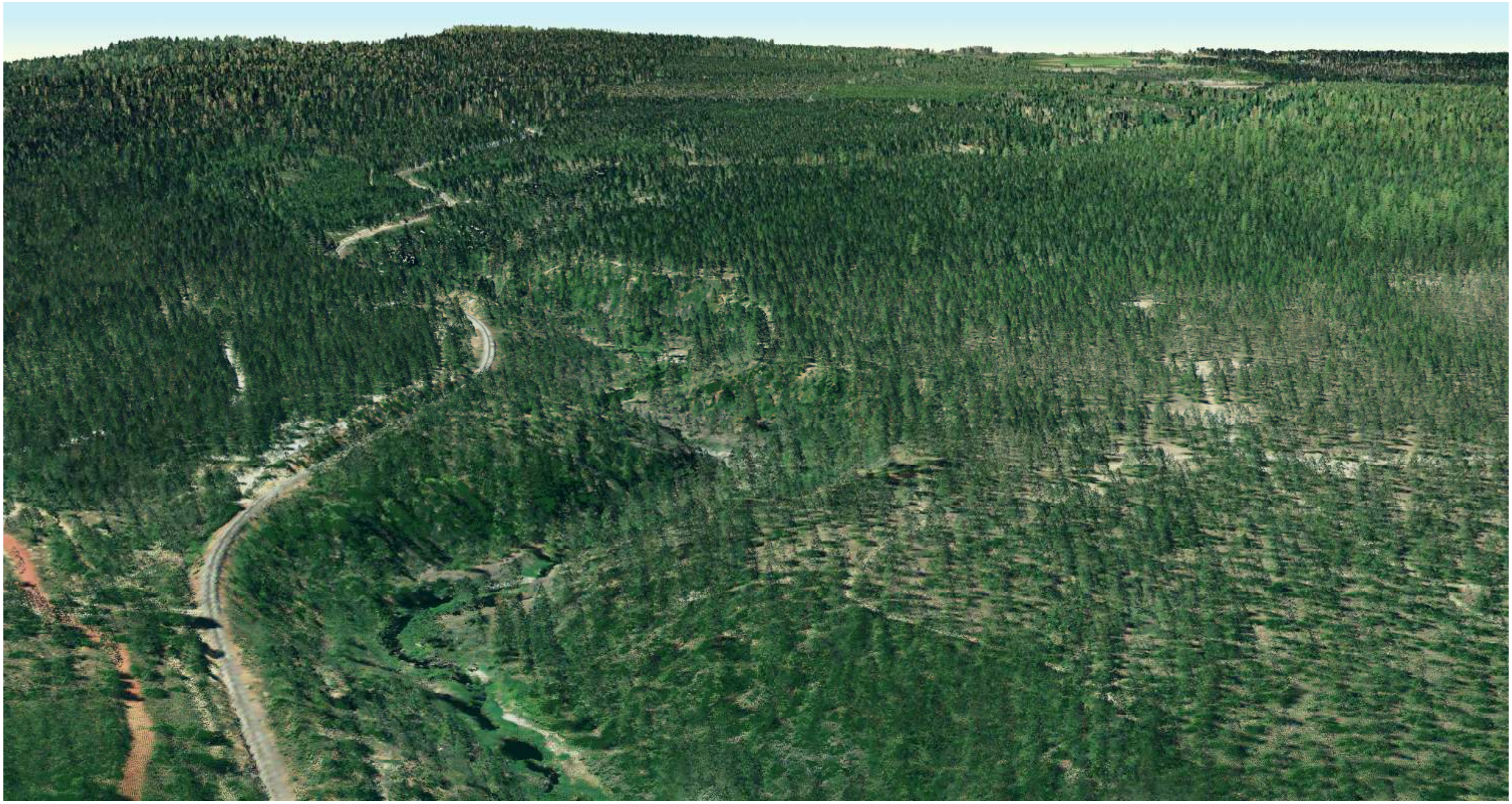

**Figure 5.5.** *View from the southwest of the Williamson River, next to Forest Road 9731 and a mile and a half east of Highway 97. South of Kirk, Oregon on the Fremont-Winema National Forest. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

**Figure 5.6.** *Residential development located one1 mile west of Highway 97 and Highway 62 intersection, four miles south of Chiloquin, OR. View looking East. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

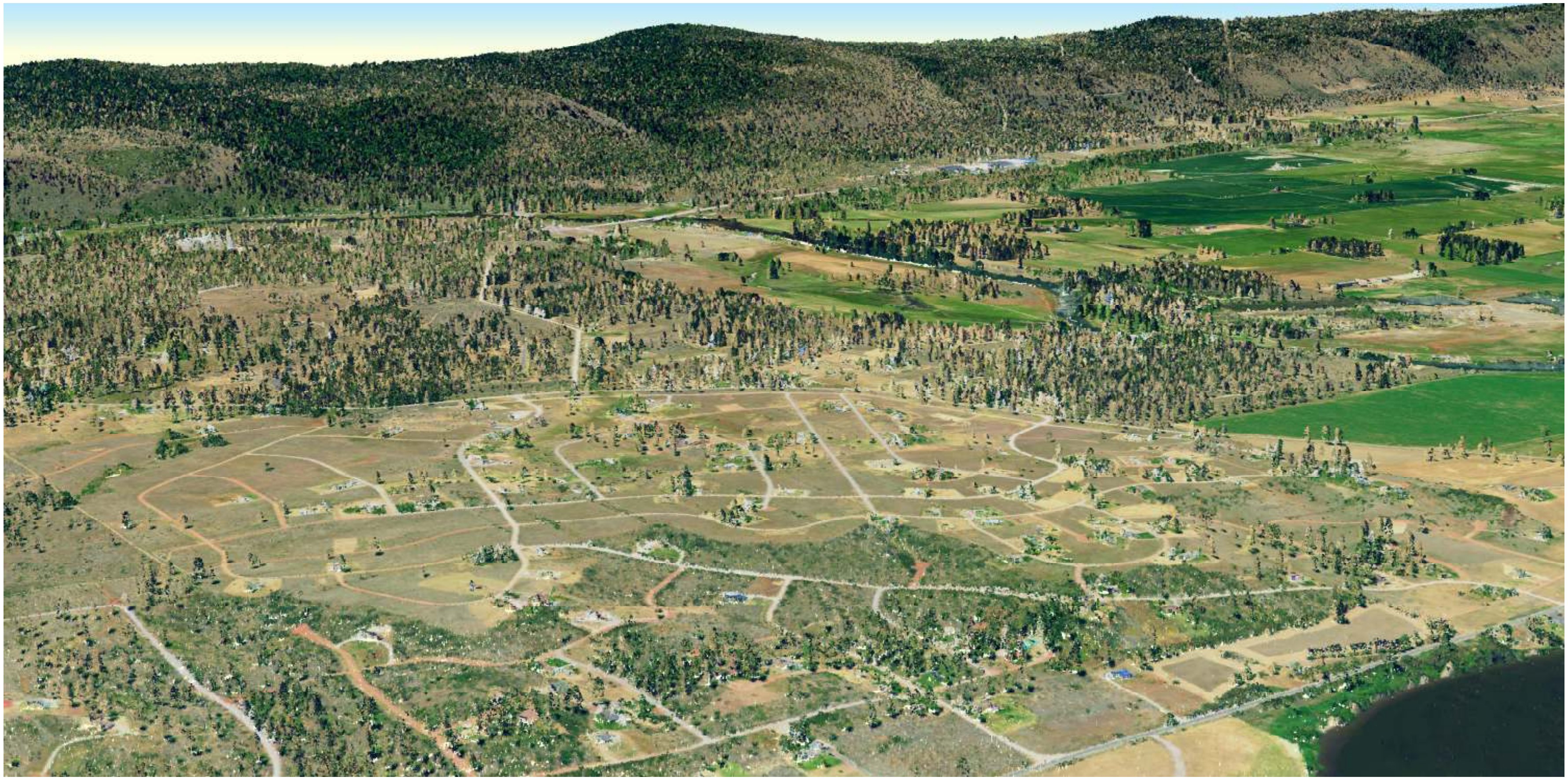

**Figure 5.7.** *Agricultural land between Agency Lake and Upper Klamath Lake, off of Hwy 97 just north of Modoc Point. View to the northeast. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

**Figure 5.8.** *Agricultural land between Agency Lake and Upper Klamath Lake, off of Hwy 97 just north of Modoc Point. View to the southeast. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

**Figure 5.9.** *Fremont-Winema National Forest, south of Sycan Marsh, 20 miles north of Beatty, OR. View looking north. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

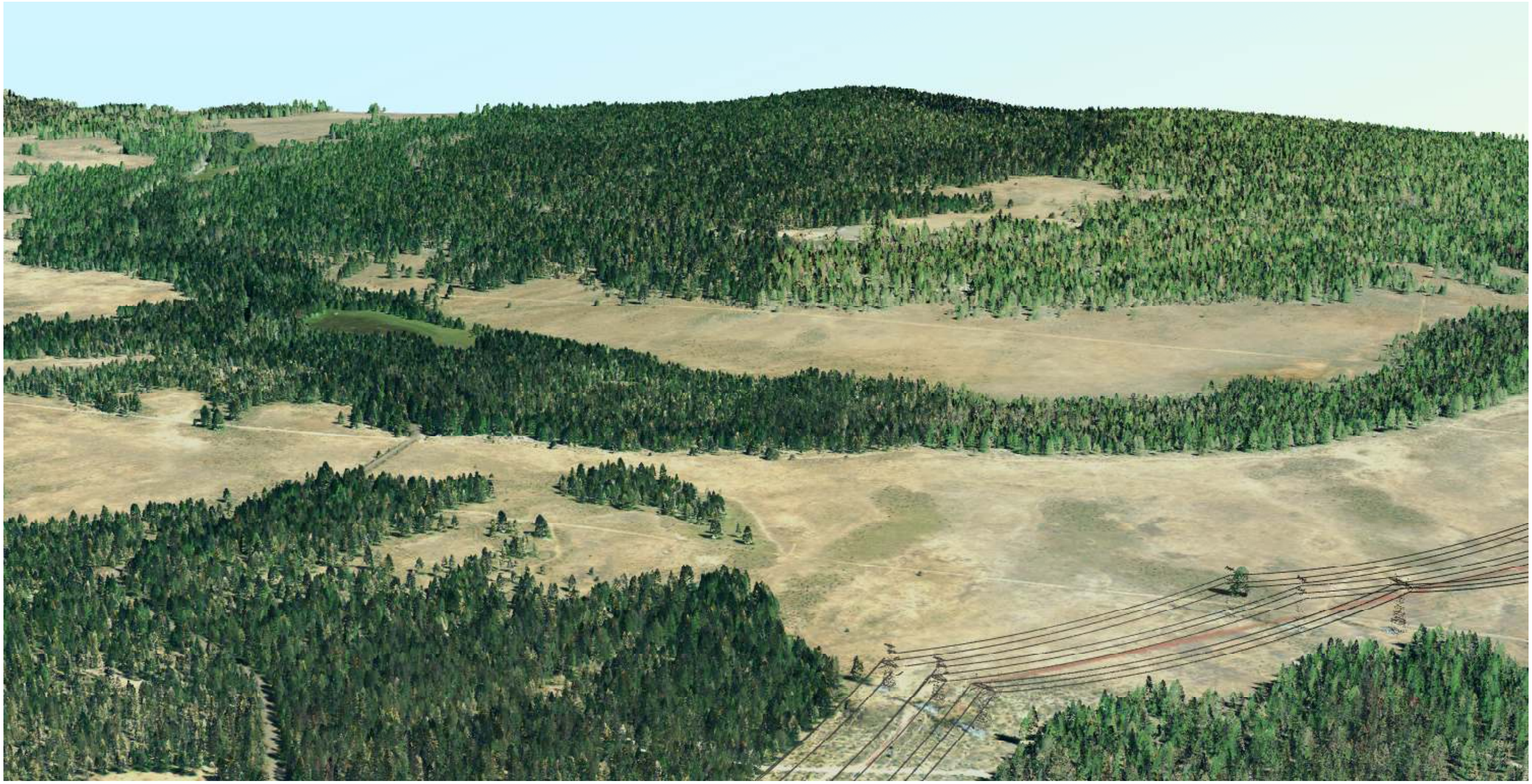

**Figure 5.10.** *Fremont-Winema National Forest, south of Sycan Marsh, 20 miles north of Beatty, OR. View looking north. Image is a bare earth DEM shaded by intensity value.*

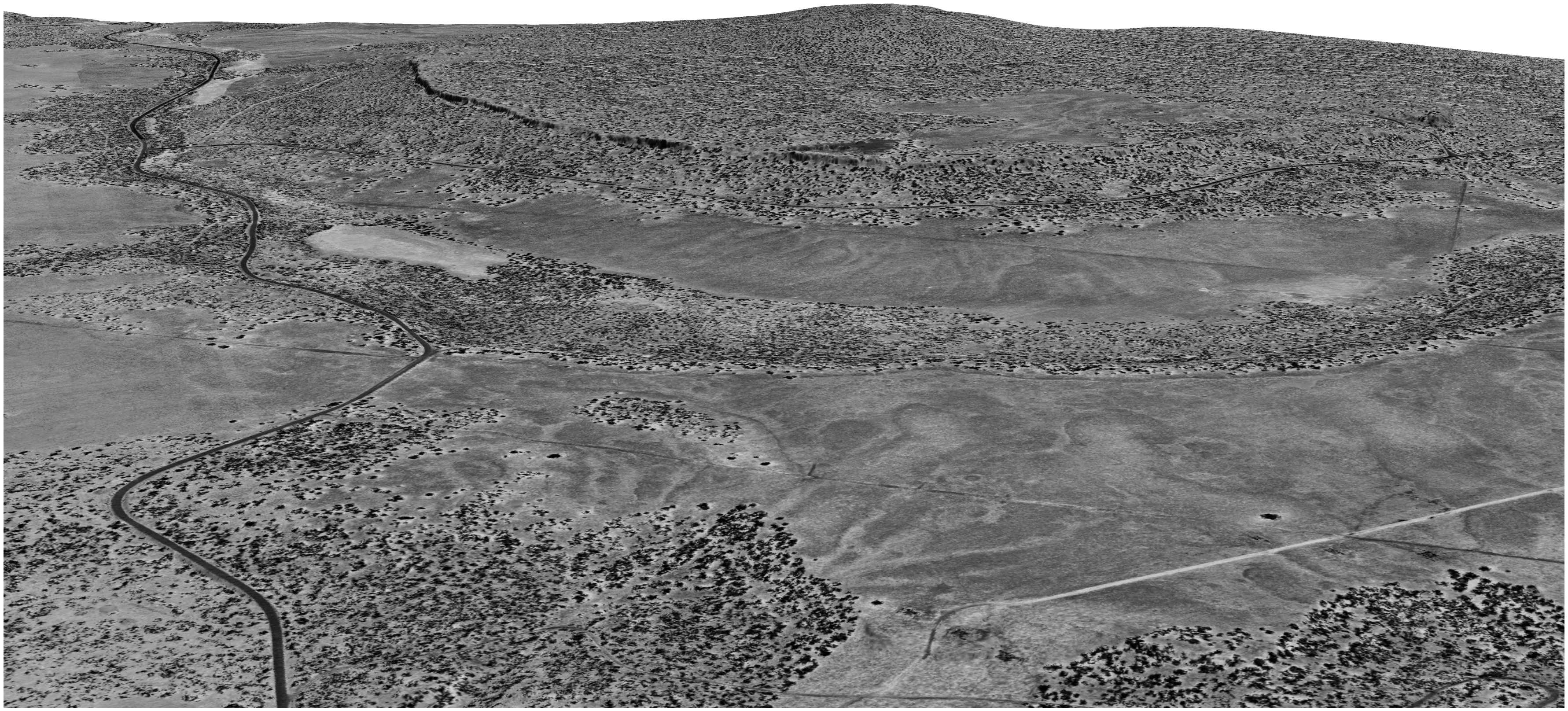

**Figure 5.11.** *Fremont-Winema National Forest, south of Sycan Marsh, 20 miles north of Beatty, OR. View looking north. Image is a three dimensional lidar point cloud shaded by intensity value overlaid on a bare earth DEM also shaded by intensity value.*

**Figure 5.12**. *Sycan Marsh, located on the Fremont-Winema National Forest, 20 miles west of Summer Lake and Highway 31. View looking east. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*

**Figure 5.13.** *Fremont-Winema National Forest, southeast of Shake Butte, 15 miles south of Summer Lake and Highway 31. View looking east. Image is a three dimensional LiDAR point cloud with RGB values extracted from a 2009 NAIP orthophoto.*