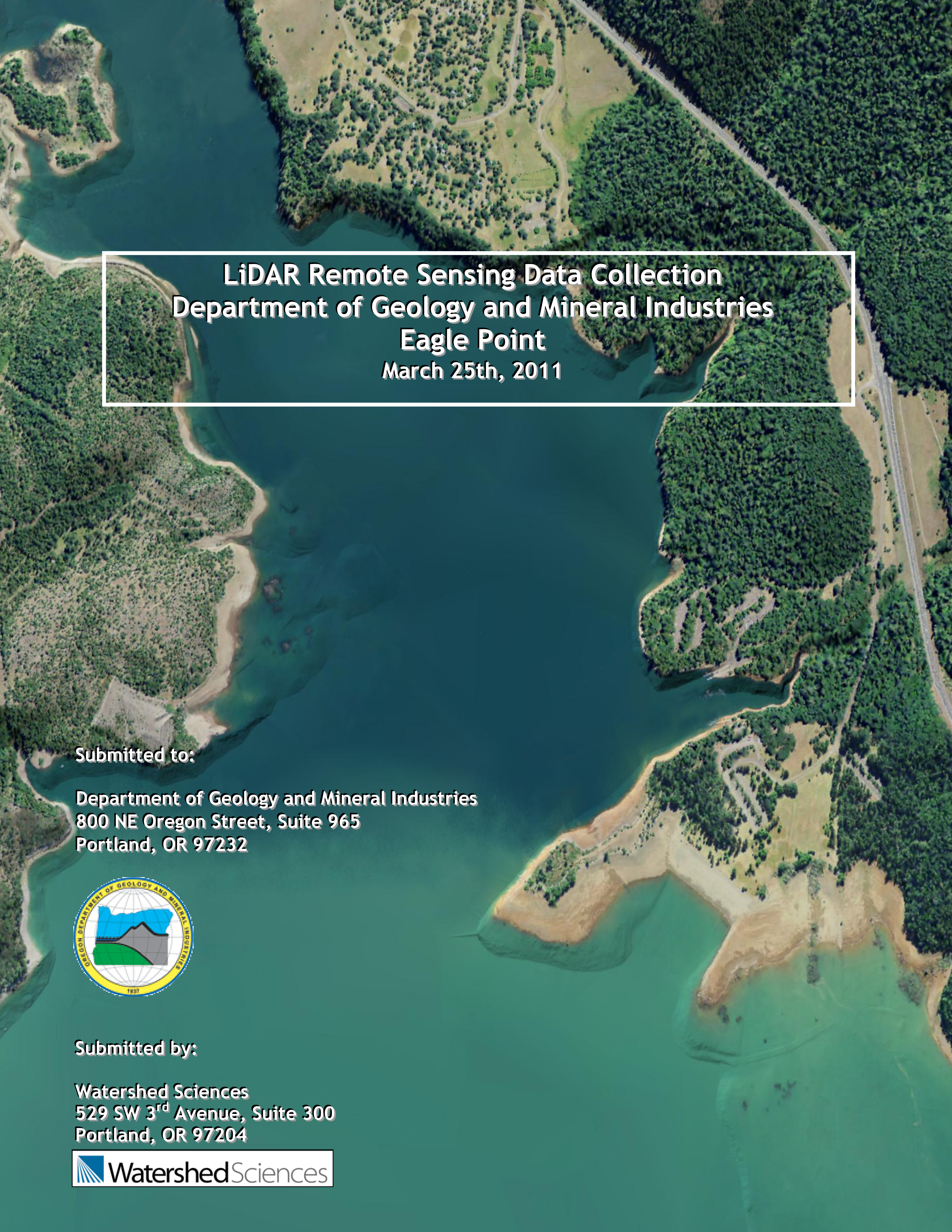

LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
Eagle Point
March 25th, 2011

Submitted to:

Department of Geology and Mineral Industries
800 NE Oregon Street, Suite 965
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Watershed Sciences
529 SW 3rd Avenue, Suite 300
Portland, OR 97204

LiDAR Remote Sensing Data Collection:
DOGAMI, Eagle Point Study Area

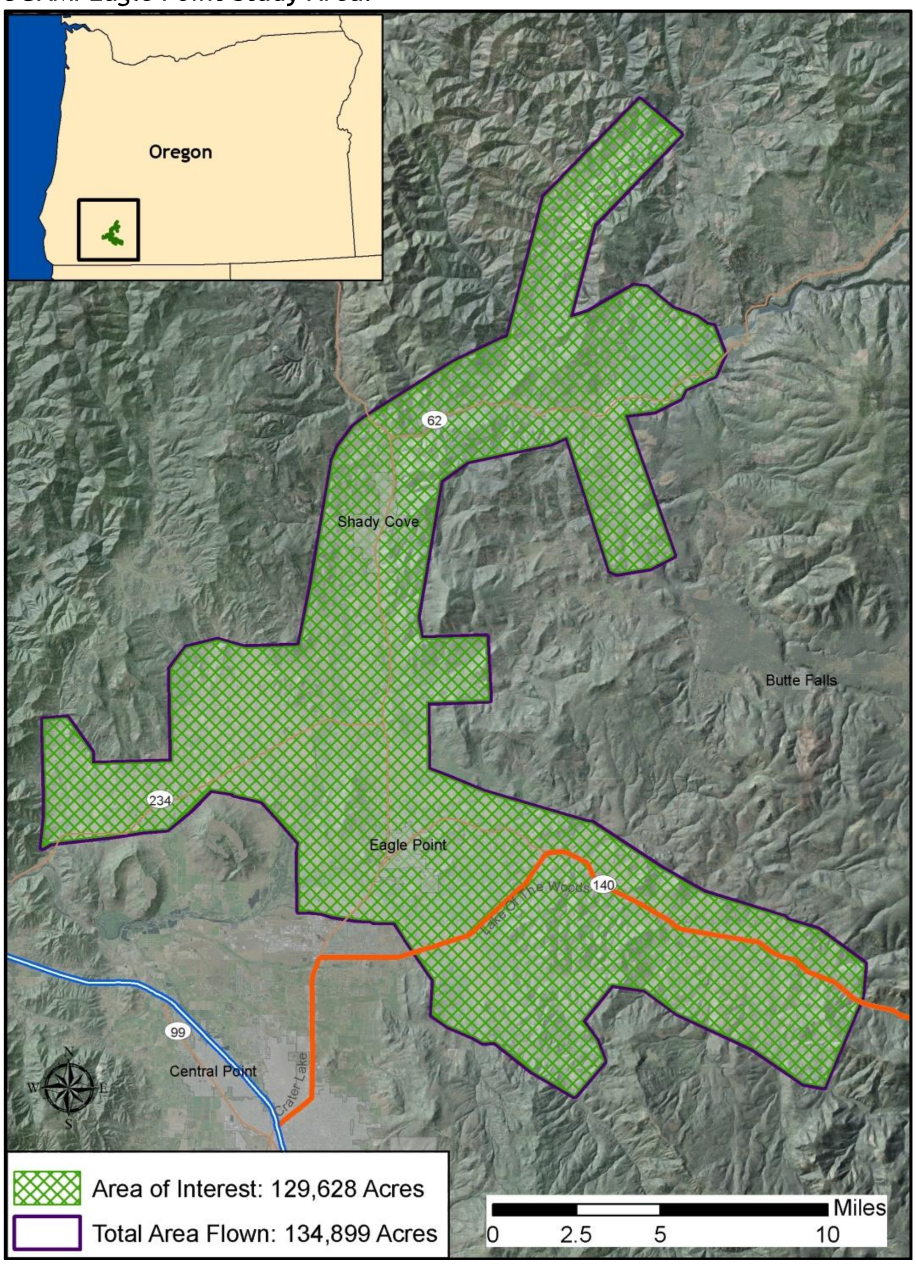
TABLE OF CONTENTS

1. Overview

1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Eagle Point study area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 203 square miles (129,628 acres) and the total area flown (TAF) covers 211 square miles (134,899 acres). The TAF acreage is greater than the original AOI acreage due to buffering and flight planning optimization (**Figure 1.1** below). This report reflects all data and cumulative statistics for the overall LiDAR survey. Eagle Point data are delivered in UTM Zone 10; NAD83(CORS96); NAVD88(Geoid 03); Units: meters.

Figure 1.1. *DOGAMI Eagle Point Study Area.*

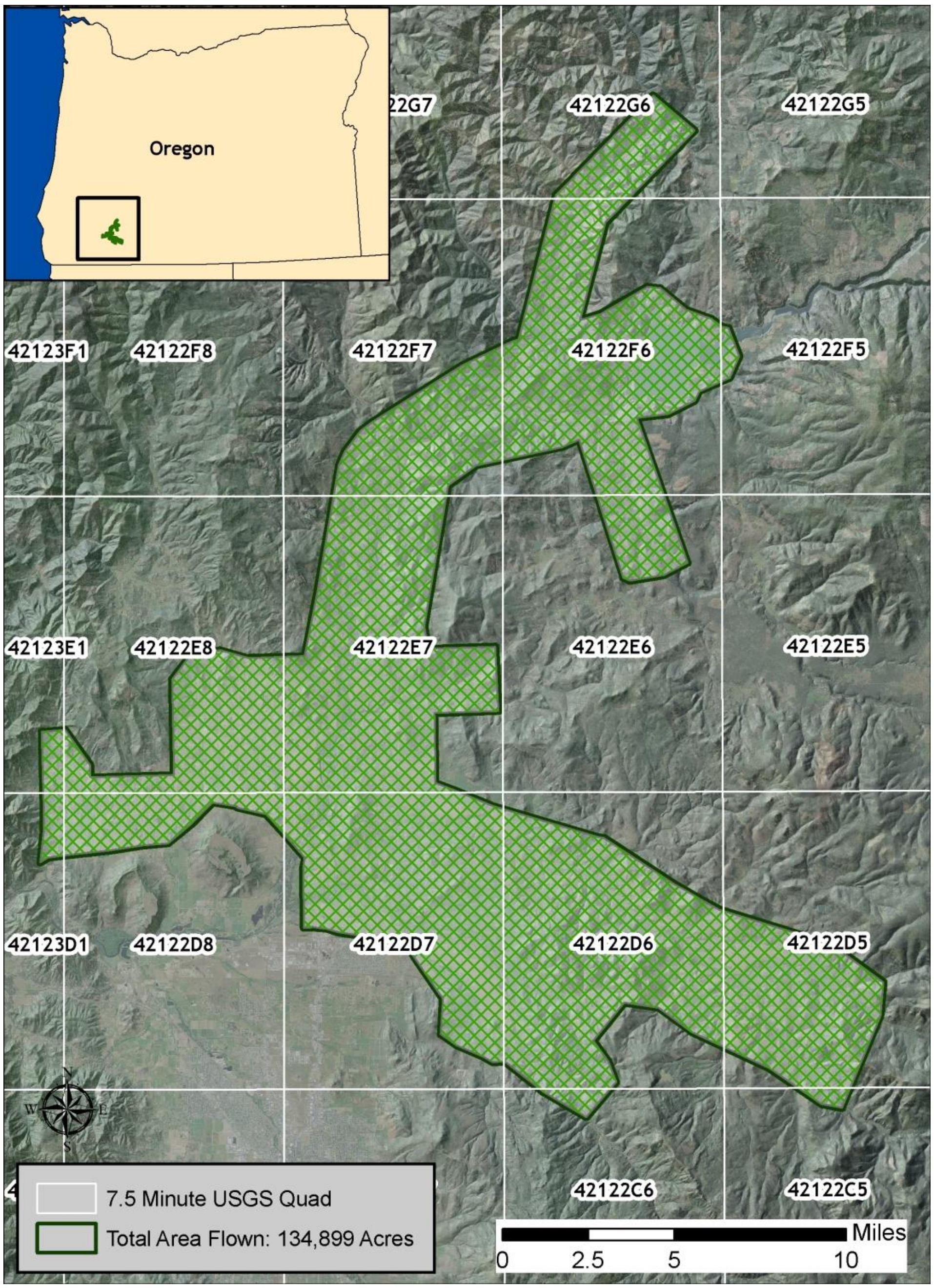


1.2 Data Delivered

Total delivered acreage is detailed below.

DOGAMI Eagle Point Study Area			
Delivery Date	**Acquisition Dates**	**AOI Acres**	**TAF Acres**
March 25thth, 2010	October 29th – November 4th, 2010	129,628	134,899

***Figure 1.2**. Eagle Point Study Area, illustrating the delivered 7.5 minute USGS quads.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized a Leica ALS60 sensor mounted in a Cessna Caravan 208B. The Leica 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*

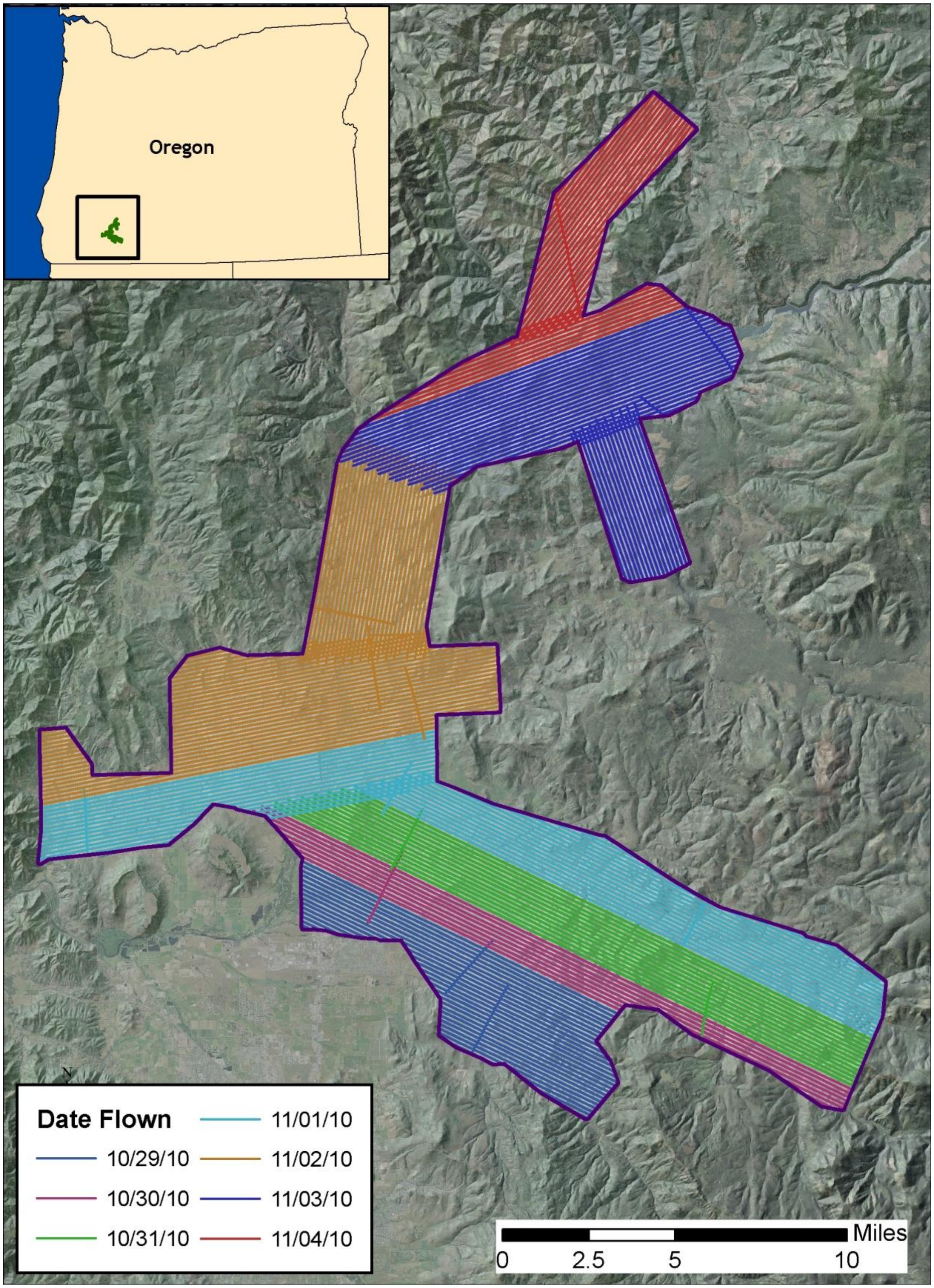
Sensors	Leica ALS60
Survey Altitude (AGL)	900 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	28° (±14° from nadir)
Roll Compensated	Up to 15°
Overlap	100% (50% Side-lap)

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 flight lines completed for the study area.

[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 Eagle Point Study Area.*



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

2.2.1 Instrumentation

For this study area all Global Navigation Satellite System (GNSS[3]) survey work utilized a Trimble GPS receiver model R7 with a Zephyr Geodetic antenna with ground plane (OPUS ID: TRM41249.00) and Trimble GNSS receiver model R7 with a Zephyr Geodetic Model 2 antenna with ground plane (OPUS ID: TRM55971.00) for static control points. The Trimble GNSS R8 unit is used primarily for Real Time Kinematic (RTK) work but can also be used as a static receiver. On this project the R8's were used for static data acquisition. All GPS measurements are made with dual frequency L1-L2 receivers with carrier-phase correction.

[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

2.2.2 Monumentation

Whenever possible, existing and established survey benchmarks shall serve as control points during LiDAR acquisition including those previously set by Watershed Sciences. In addition to NGS, the county surveyor's offices and the Oregon Department of Transportation (ODOT) often establish their own benchmarks. NGS benchmarks are preferred for control points. In the absence of NGS benchmarks, county surveys, or ODOT monumentation, Watershed Sciences produces our own monuments. These monuments are spaced at a minimum of one mile and every effort is made to keep these monuments within the public right of way or on public lands. If monuments are required on private property, consent from the owner is required. 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 or with an aluminum cap stamped with 'WATERSHED SCIENCES, INC." and the point name.

2.2.3 Methodology

Each aircraft is assigned a ground crew member with two R7 receivers and an R8 receiver. The ground crew vehicles are equipped with standard field survey supplies and equipment including safety materials. All data points are observed for a minimum of two survey sessions lasting no fewer than 6 hours. At the beginning of every session the tripod and antenna are reset, resulting in two independent instrument heights and data files. Data are collected at a rate of 1Hz using a 10 degree mask on the antenna.

The ground crew uploads the GPS data to the FTP site on a daily basis to be returned to the office for Professional Land Surveyor (PLS) oversight, Quality Assurance/Quality Control (QA/QC) review and processing. OPUS processing triangulates the monument position using 3 CORS stations resulting in a fully adjusted position. CORPSCON[4] 6.0.1 software is used to convert the geodetic positions from the OPUS reports. After multiple days of data have been collected at each monument, accuracy and error ellipses are calculated. This information leads to a rating of the monument based on FGDC-STD-007.2-1998[5] Part 2 table 2.1 at the 95% confidence level.

All GPS measurements are made during periods with PDOP less than or equal to 3.0 and with at least 6 satellites in view of both a stationary reference receiver and the roving receiver. RTK positions are

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

[5] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards

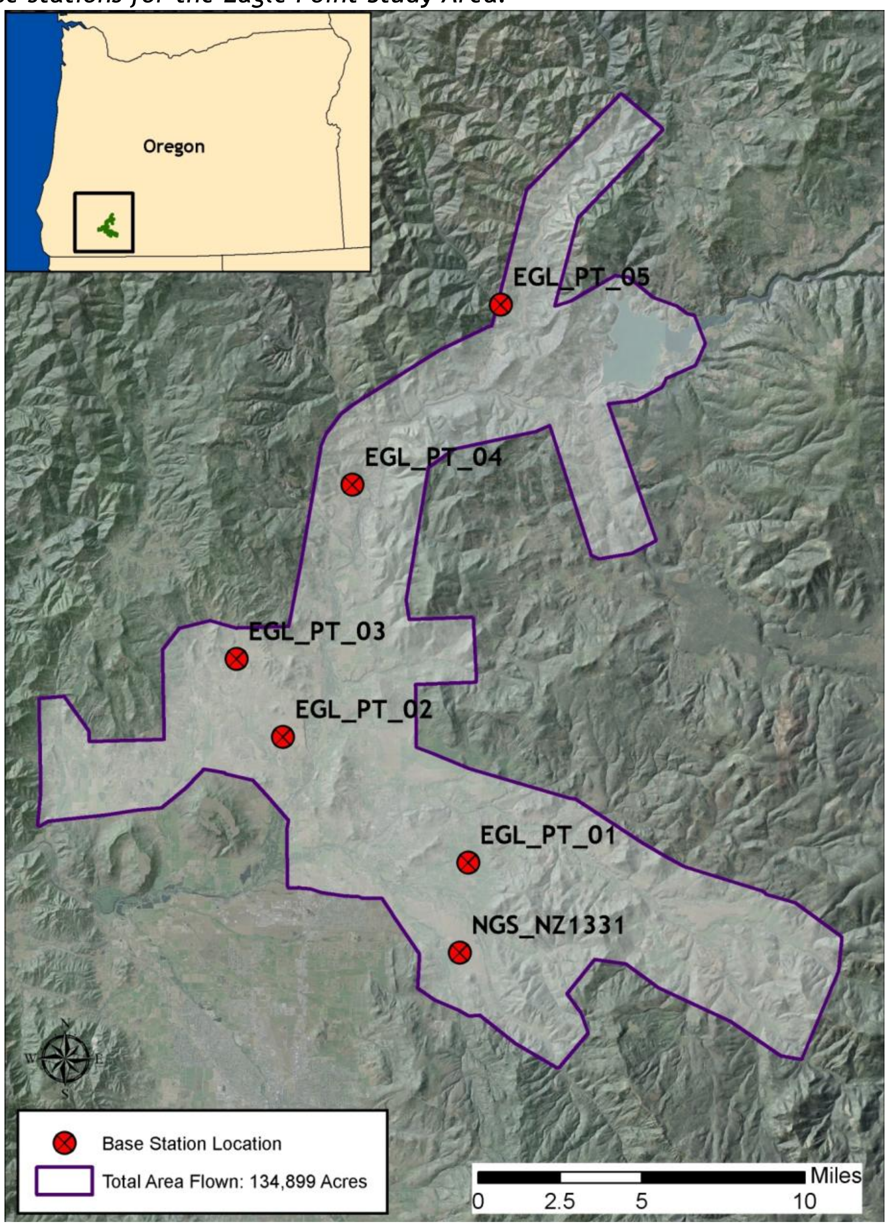
collected on 20% of the flight lines and on bare earth locations such as paved, gravel or stable dirt roads, and other locations where the ground is clearly visible (and is likely to remain visible) from the sky during the data acquisition and RTK measurement period(s). For RTK data, the collector begins recording after remaining stationary for 5 seconds then calculating the pseudo range position from at least three epochs with the relative error under 1.5 cm horizontal and 2 cm vertical. In order to facilitate comparisons with LiDAR measurements, RTK measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. RTK points were taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. In addition, it is desirable to include locations that can be readily identified and occupied during subsequent field visits in support of other quality control procedures described later. Examples of identifiable locations would include manhole and other flat utility structures that have clearly indicated center points or other measurement locations. In the absence of utility structures, a PK nail can be driven into asphalt or concrete and marked with paint.

Multiple differential GPS units were used in the ground based real-time kinematic (RTK) portion of the survey. To collect accurate ground surveyed points, a GPS base unit was set up over monuments to broadcast a kinematic correction to a roving GPS unit. The ground crew used a roving unit to receive radio-relayed kinematic corrected positions from the base unit. This RTK survey allowed precise location measurement ($\sigma \leq 1.5$ cm). **Figures 2.3 – 2.4** show subsets of these RTK locations.

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

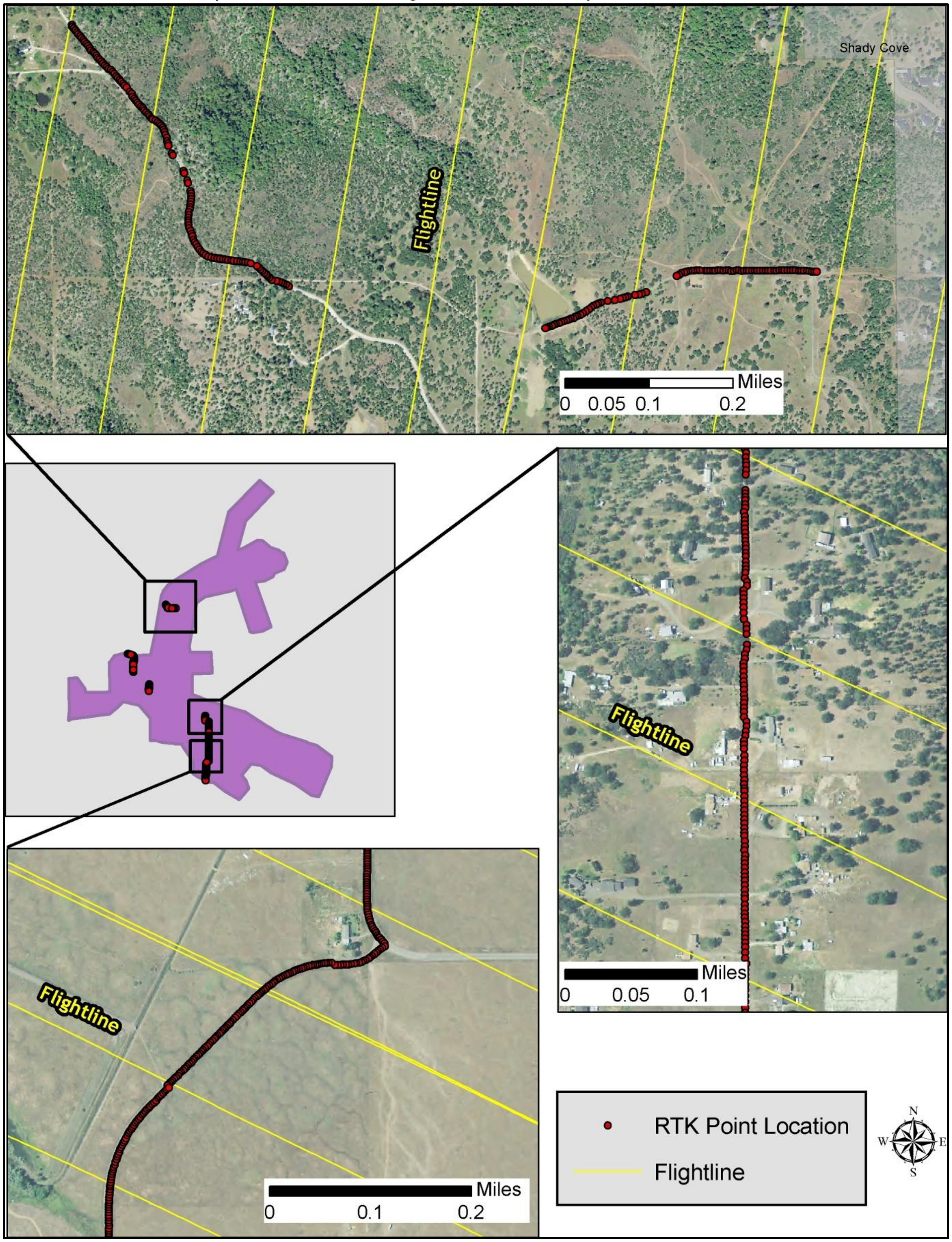
	Datum NAD83 (HARN)		GRS80
Base Stations ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
EGL_PT_01	42 27 12.01634	122 45 24.35164	411.673
NGS_NZ1331	42 24 48.62662	122 45 43.34680	440.413
EGL_PT_02	42 30 33.59924	122 52 03.21845	390.990
EGL_PT_03	42 32 38.60678	122 53 43.73523	411.831
EGL_PT_04	42 37 16.07617	122 49 32.14722	444.931
EGL_PT_05	42 42 03.26814	122 44 10.13792	508.072

Figure 2.2. *Base stations for the Eagle Point Study Area.*



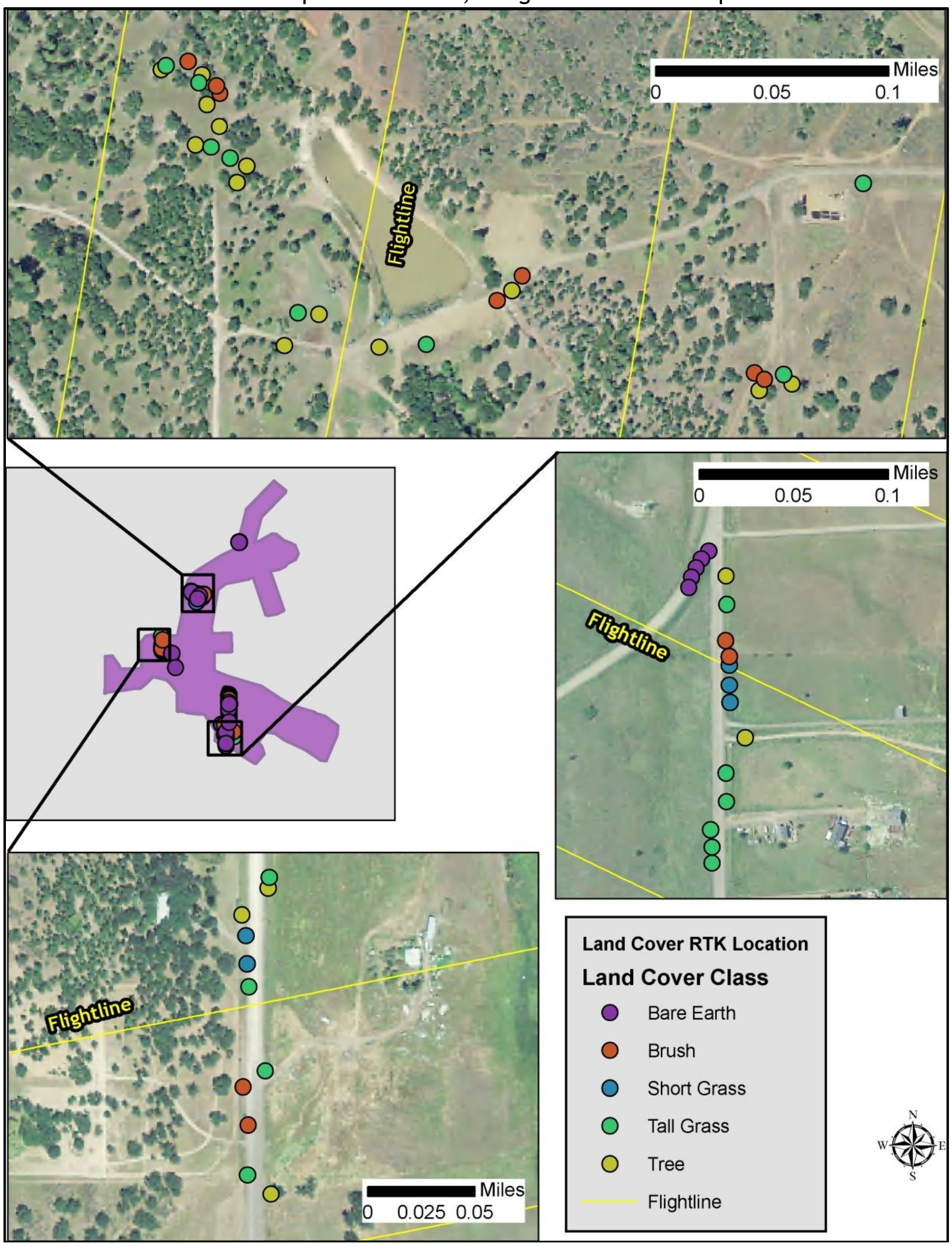
For the Eagle Point study area, 3,595 RTK (Real-time kinematic) points were collected. **Figures 2.3** shows detailed views of selected RTK locations.

Figure 2.3 Selected RTK point locations; images are NAIP orthophotos.



In addition to the hard surface RTK data collection, RTK check points were also collected by Watershed Sciences, Inc. in dominant land cover types within the study area. These types are identified using the U.S. Geological Survey's Land Cover Institute's land cover class definitions as a guideline (USGS LCI). The classes are refined based on the specific vegetation present in the Eagle Point study area using field-based observations. Any land cover type that comprises more than 10% of the study area is included in the land cover type RTK data collection. Accuracies are calculated for each of these land cover types to assess confidence in the LiDAR-derived ground models, and are discussed in the Absolute Accuracy section of this report.

Figure 2.4 Selected land cover RTK point locations; 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 249 flightlines and over 2 billion points. Relative accuracy is reported for the entire of the study area.

- Project Average = 0.03 m
- Median Relative Accuracy = 0.03 m
- 1σ Relative Accuracy = 0.03m
- 2σ Relative Accuracy = 0.04 m

Figure 3.1 *Statistical relative accuracies, non slope-adjusted.*

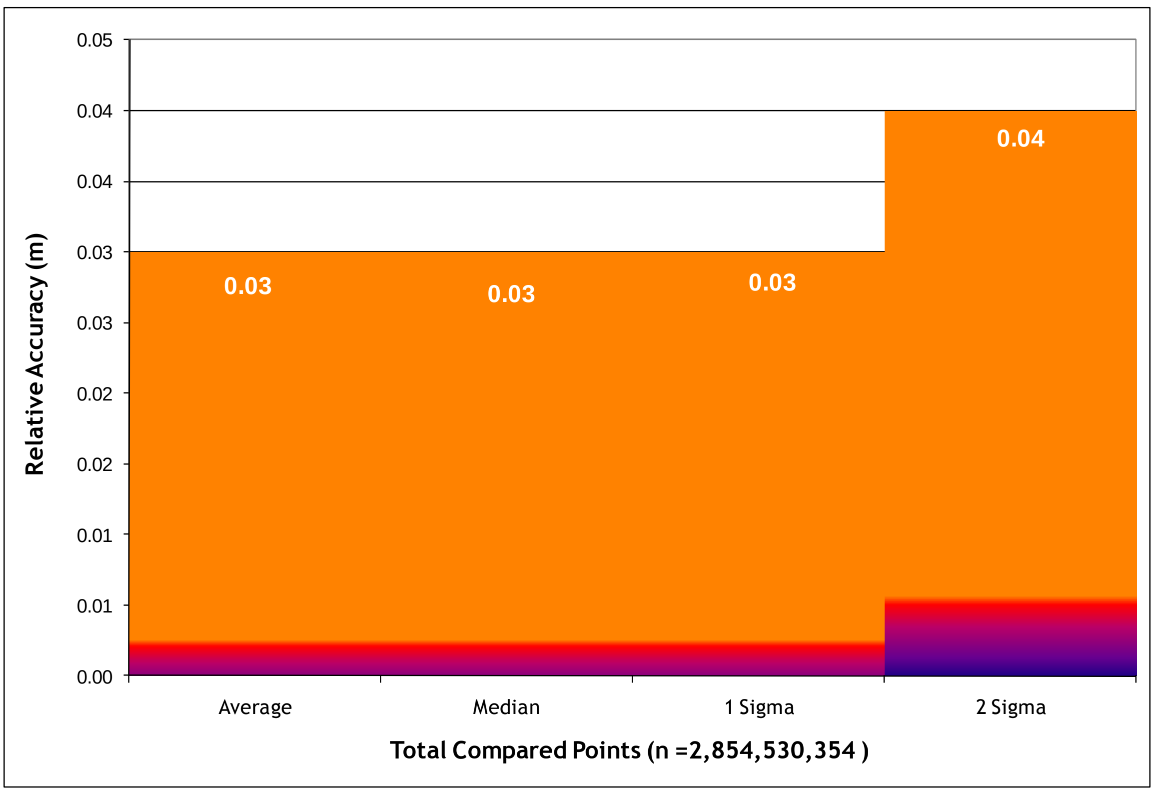
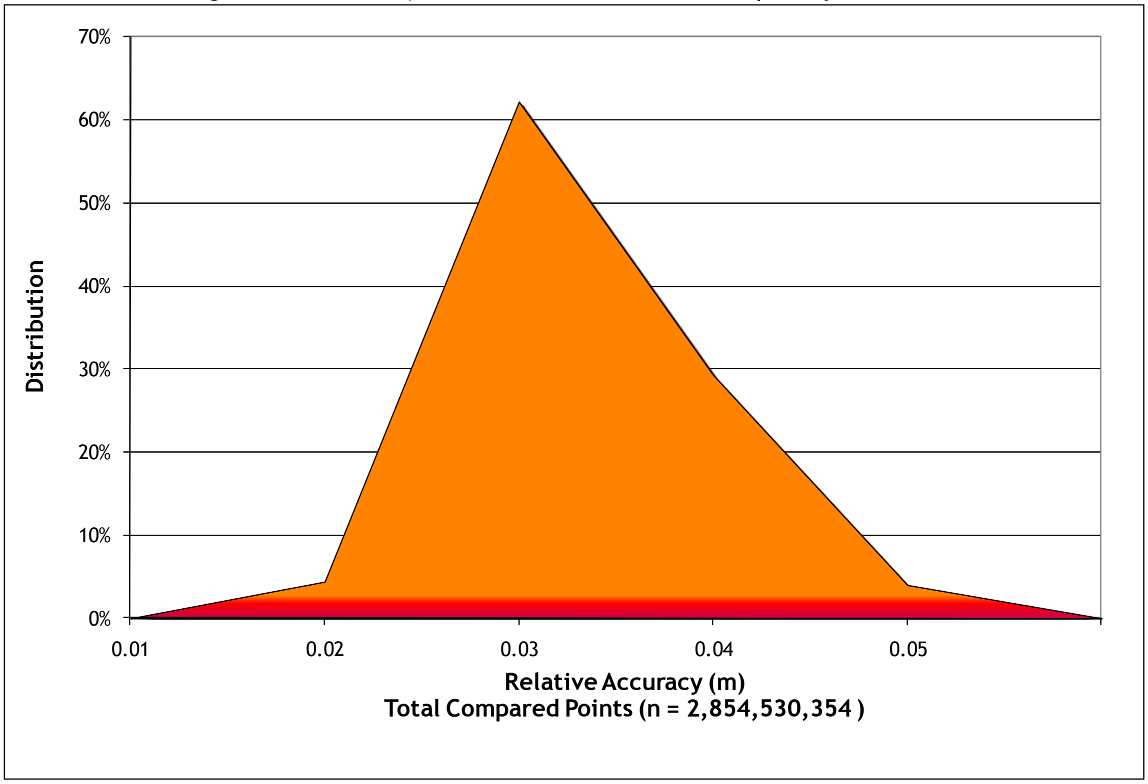


Figure 3.2. *Percentage distribution of relative accuracies, non slope-adjusted.*



3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Eagle Point study area, 3,595 RTK points were collected for data in the study area. Absolute accuracy is reported for the entire the study area and shown in **Table 3.1** below**.**

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

Sample Size (n): 3,595	
Root Mean Square Error (RMSE): 0.03m	
Standard Deviations	**Deviations**
1 sigma (σ): 0.03 m	**Minimum Δz:** -0.11 m
2 sigma (σ): 0.07 m	**Maximum Δz:** 0.14 m
	Average Δz: 0.00 m

Figure 3.3 Eagle Point Study Area histogram statistics

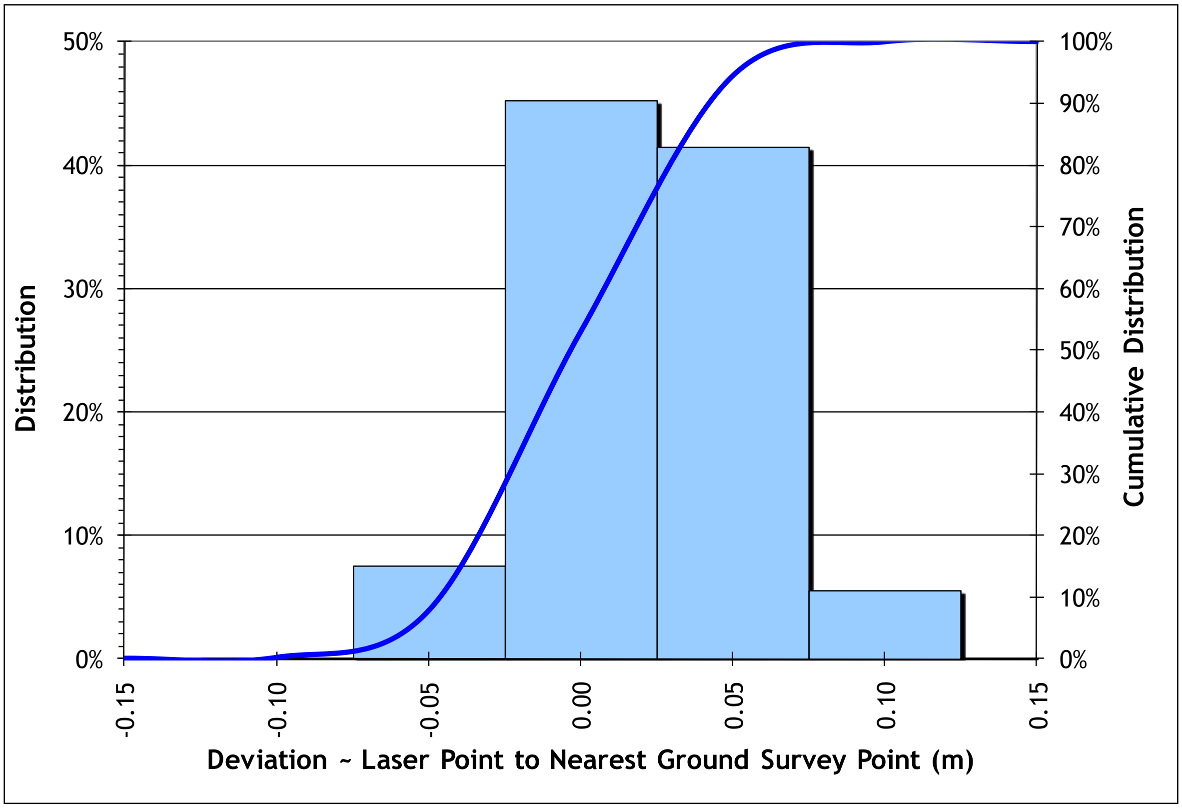
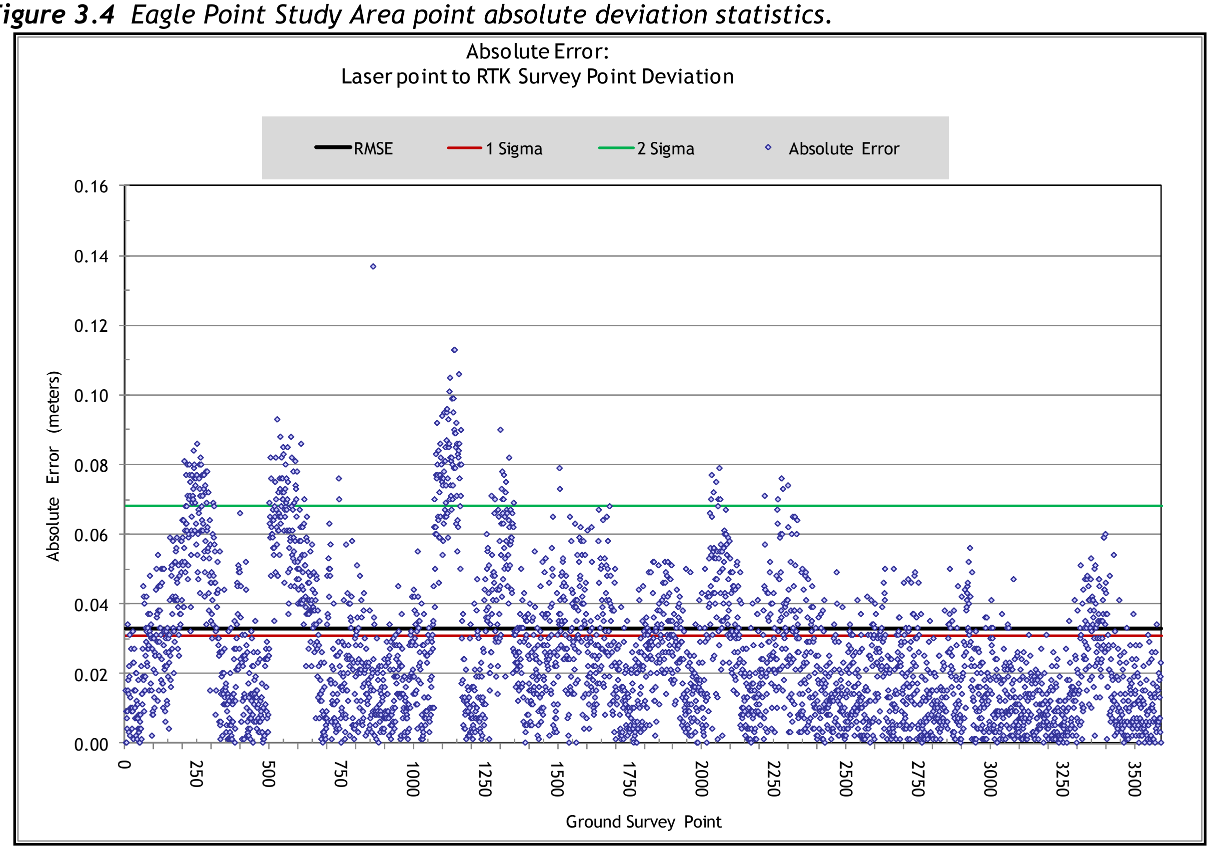


Figure 3.4 Eagle Point Study Area point absolute deviation statistics.



3.3 Accuracy by Land Cover

In addition to the hard surface RTK data collection, check points are also collected across the project area on five different land cover types. All data collection is completed by Watershed Sciences, Inc. Individual accuracies are calculated for each land cover type to assess confidence in the LiDAR derived ground model across various types of ground cover. Accuracy statistics for each are reported.

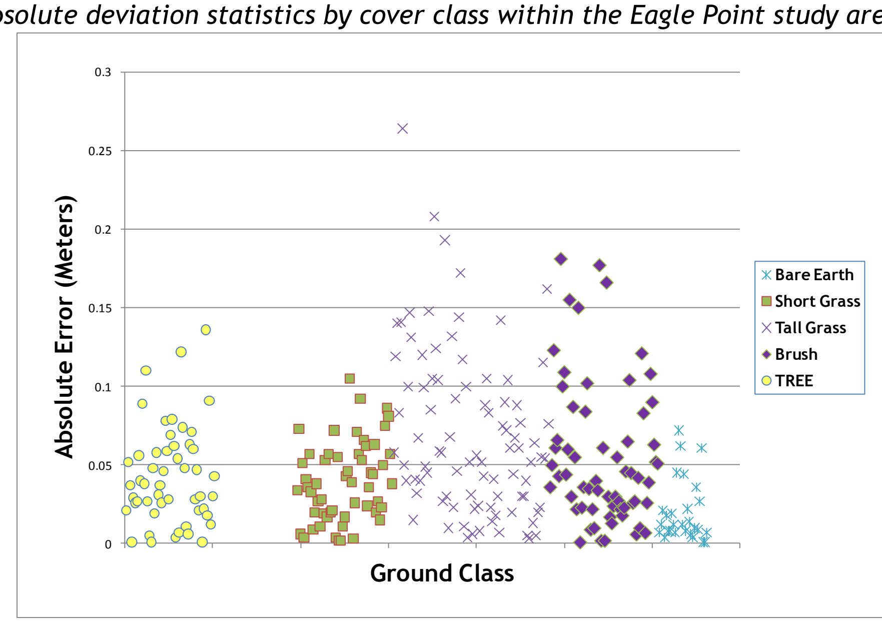
The dominant land cover classes within the Eagle Point study area are listed below. The descriptions provide further detail regarding the actual vegetation. This analysis demonstrates that the vertical accuracy of the interpolated ground surface, across all land cover classes, meets or exceeds vertical accuracy specifications.

Bare Earth:	Fallow cropland, seasonally dormant or unplanted
Grass - short:	Grasses <2 feet in height
Grass - tall:	Grasses >2 feet in height
Brush:	Woody vegetation under 6 feet in height
Tree:	Woody vegetation >6 feet in height

***Table 3.2** Accuracy by land cover class for data delivered to date.*

Land cover	Sample size	RMSE: m(ft)	Ave Dz :	1 sigma (σ):	2 sigma (σ):
Bare Earth	28	0.03 m	-0.01 m	0.02 m	0.06 m
Grass - short (<2.0 ft)	55	0.05 m	0.02 m	0.05 m	0.08 m
Grass - tall (>2.0 ft)	89	0.09 m	0.06 m	0.08 m	0.16 m
Brush	62	0.07 m	0.03 m	0.06 m	0.15 m
Tree	97	0.05 m	0.02 m	0.05 m	0.10 m

***Figure 3.5** Absolute deviation statistics by cover class within the Eagle Point study area.*



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 have been calculated based on first return laser point density and ground-classified laser pulse density.

***Table 4.1**. Average density statistics for the Eagle Point Study Area.*

Average Pulse Density (per square m)	Average Ground Density (per square m)
8.08	1.99

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

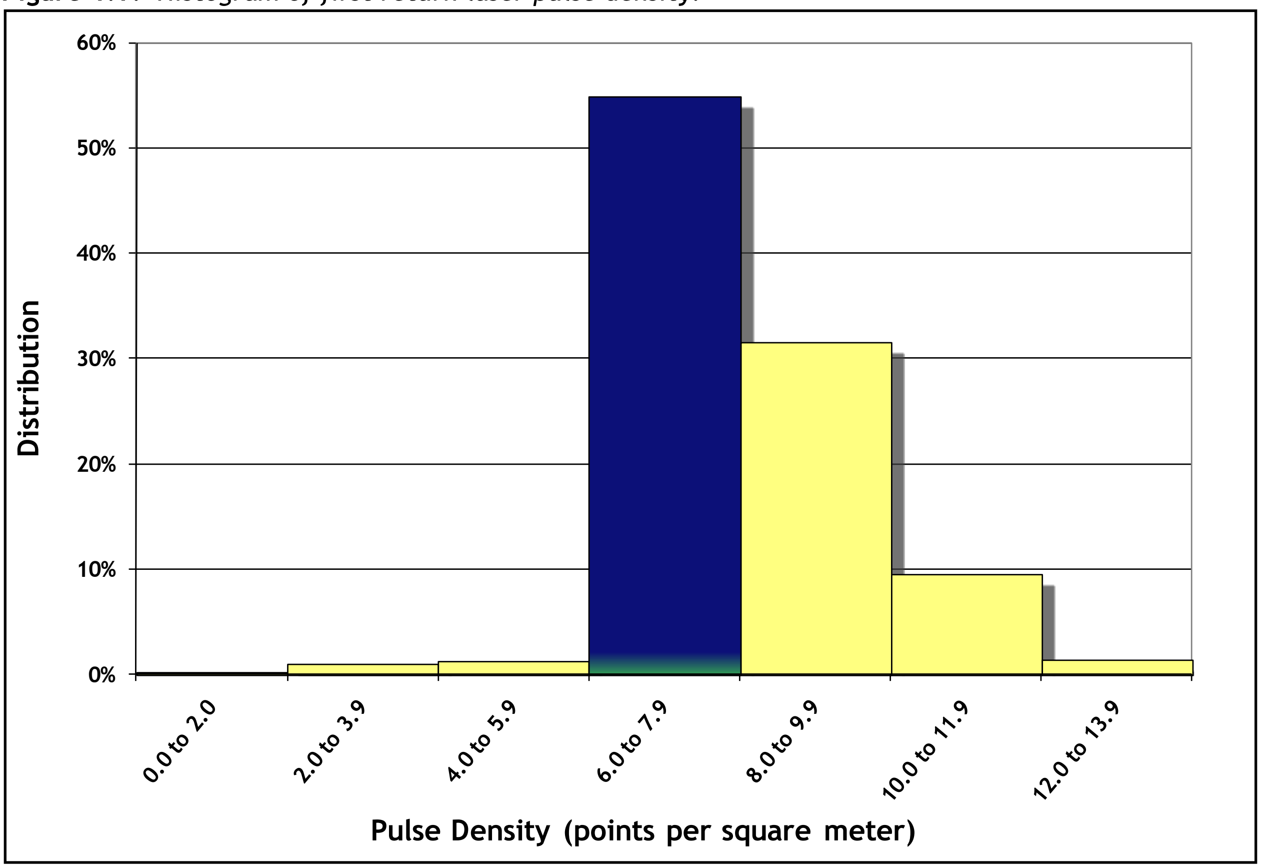


Figure 4.2. First return laser pulse densities per 0.75' USGS Quad.

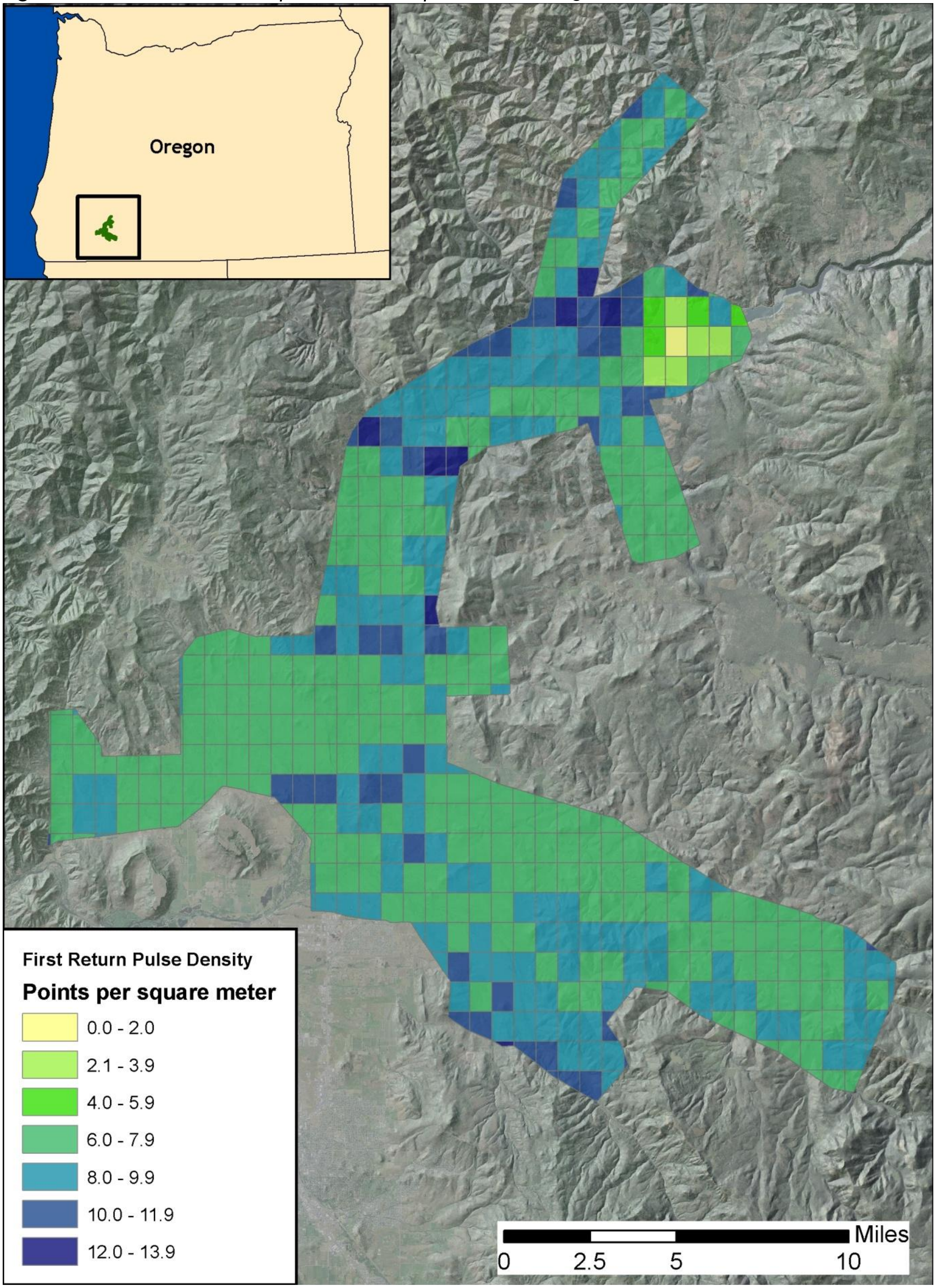
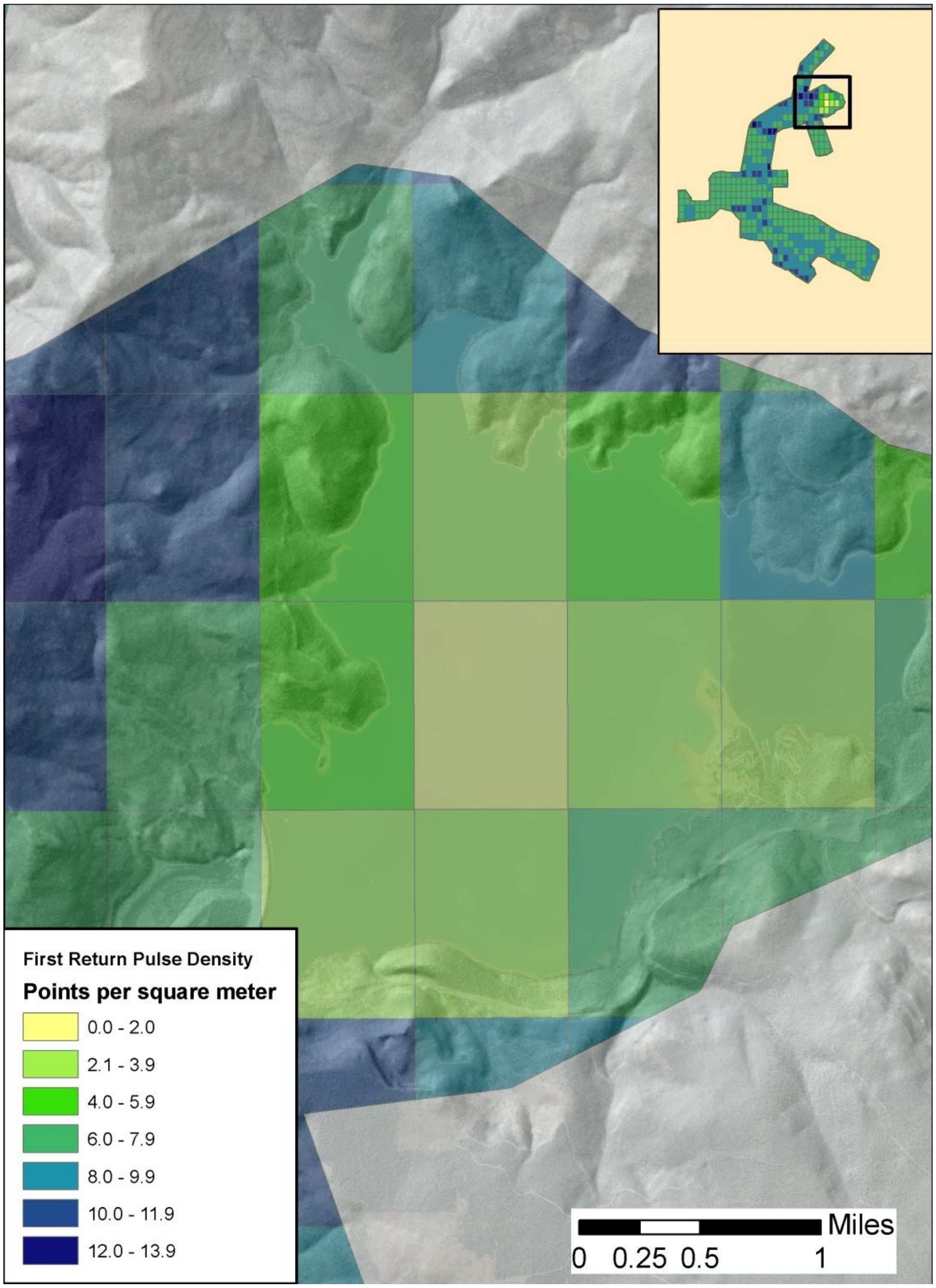


Figure 4.3*. The area in the northern portion of the study area covers the Lost Creek reservoir. This large water body has a low rate of laser returns resulting in a low pulse density.*



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 4.4. Histogram of ground-classified laser point density.

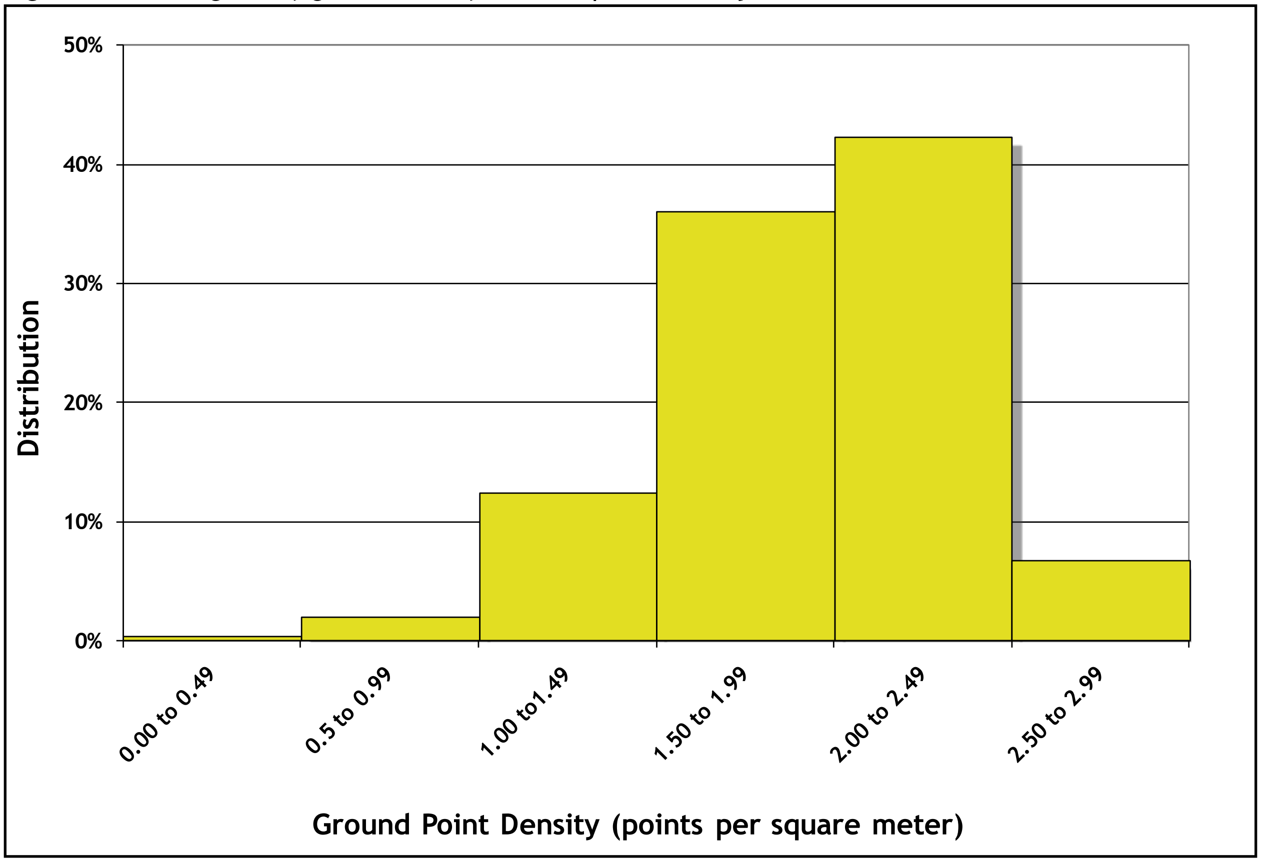
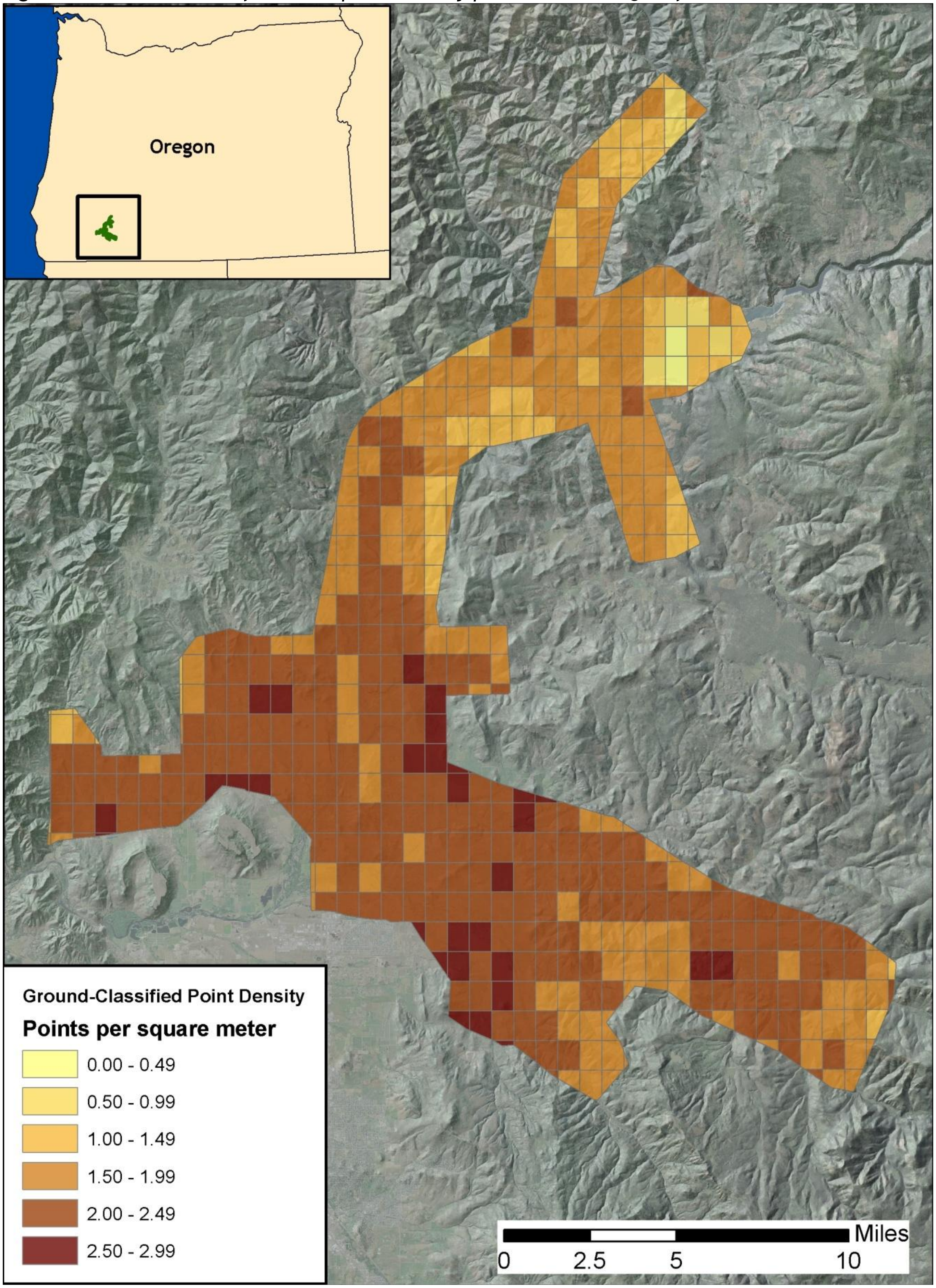


Figure 4.5. *Ground-classified laser point density per 0.75' USGS Quad for data delivered to date.*



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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

3/28/2011

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

RENEWAL DATE: 6/30/2012

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6. Selected Imagery

Figure 6.1. Northeast view of the deconstruction of the Elk Creek Dam (pre-notch), located just north of the confluence of Elk Creek and the Rogue River. Image is a LiDAR point cloud colored with RGB values from NAIP imagery.

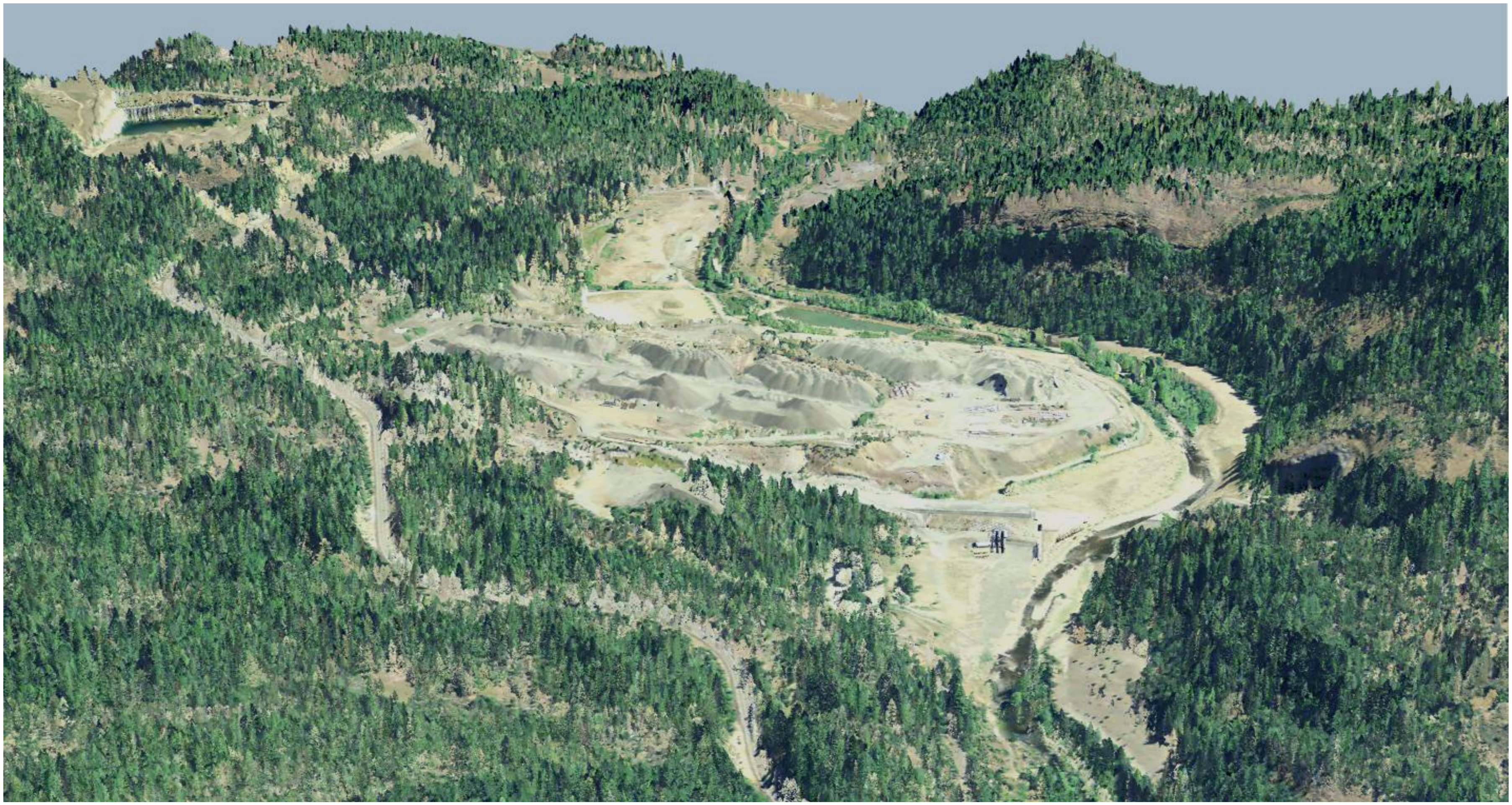

Figure 6.2. View of the Lost Creek Lake Reservoir, Oregon. Image is a LiDAR point cloud colored with RGB values from NAIP imagery.

Figure 6.3. View overlooking the Crater Lake Highway Bridge (Hwy 62) through Shady Cove, Oregon. Image is a LiDAR point cloud colored with RGB values from NAIP imagery.

7. Citations

U.S. Geological Survey Land Cover Institute. "NLCD Land Cover Class Definitions." 17 March, 2011. http://landcover.usgs.gov/classes.php