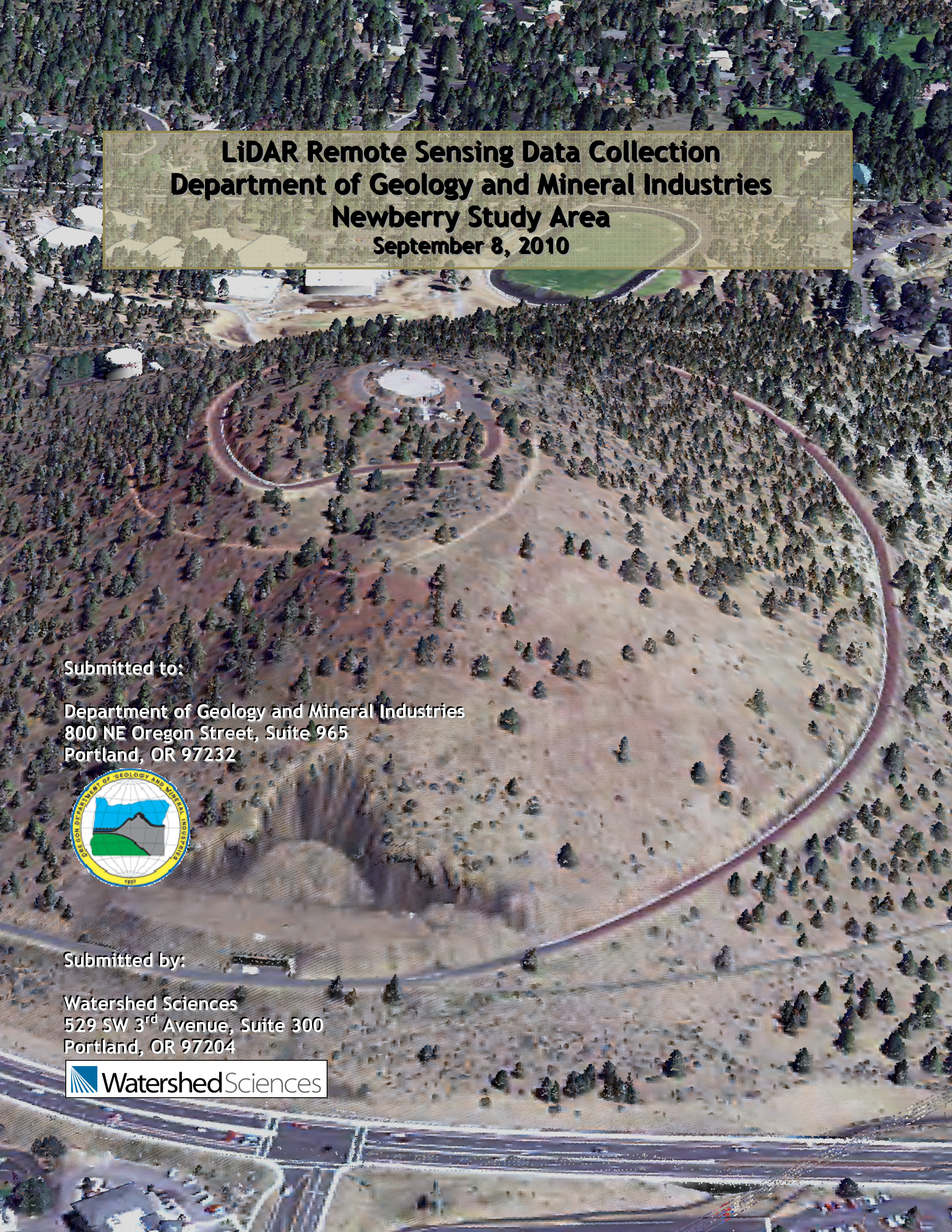


LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
Newberry Study Area
September 8, 2010

Submitted to:

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

Submitted by:

Watershed Sciences
529 SW 3rd Avenue, Suite 300
Portland, OR 97204

Watershed Sciences

LiDAR Remote Sensing Data Collection:
DOGAMI, Newberry Study Area

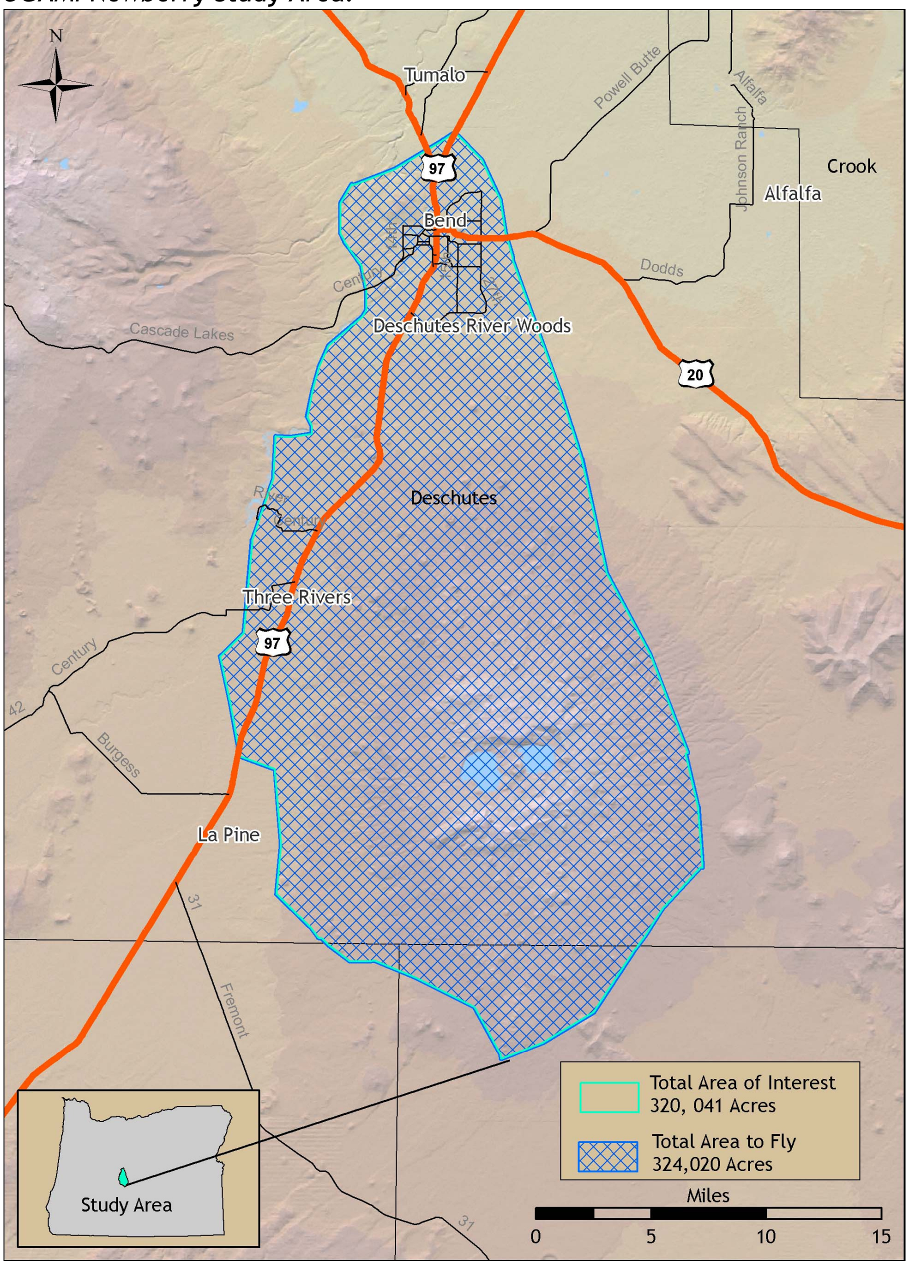
TABLE OF CONTENTS

1. Overview

1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Newberry Study Area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 500 square miles (320,041 acres) and the total area flown (TAF) covers 506 square miles (324,020 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 Newberry Study Area.*



1.2 Area Delivered to Date

Total delivered acreage to date is detailed below.

DOGAMI Newberry Study Area				
	Delivery Date	**Acquisition Dates**	**AOI Acres**	**TAF Acres**
Delivery Area 1	September 8, 2010	May 28, 2010 – June 1, 2010	**31,380**	**32,225**

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

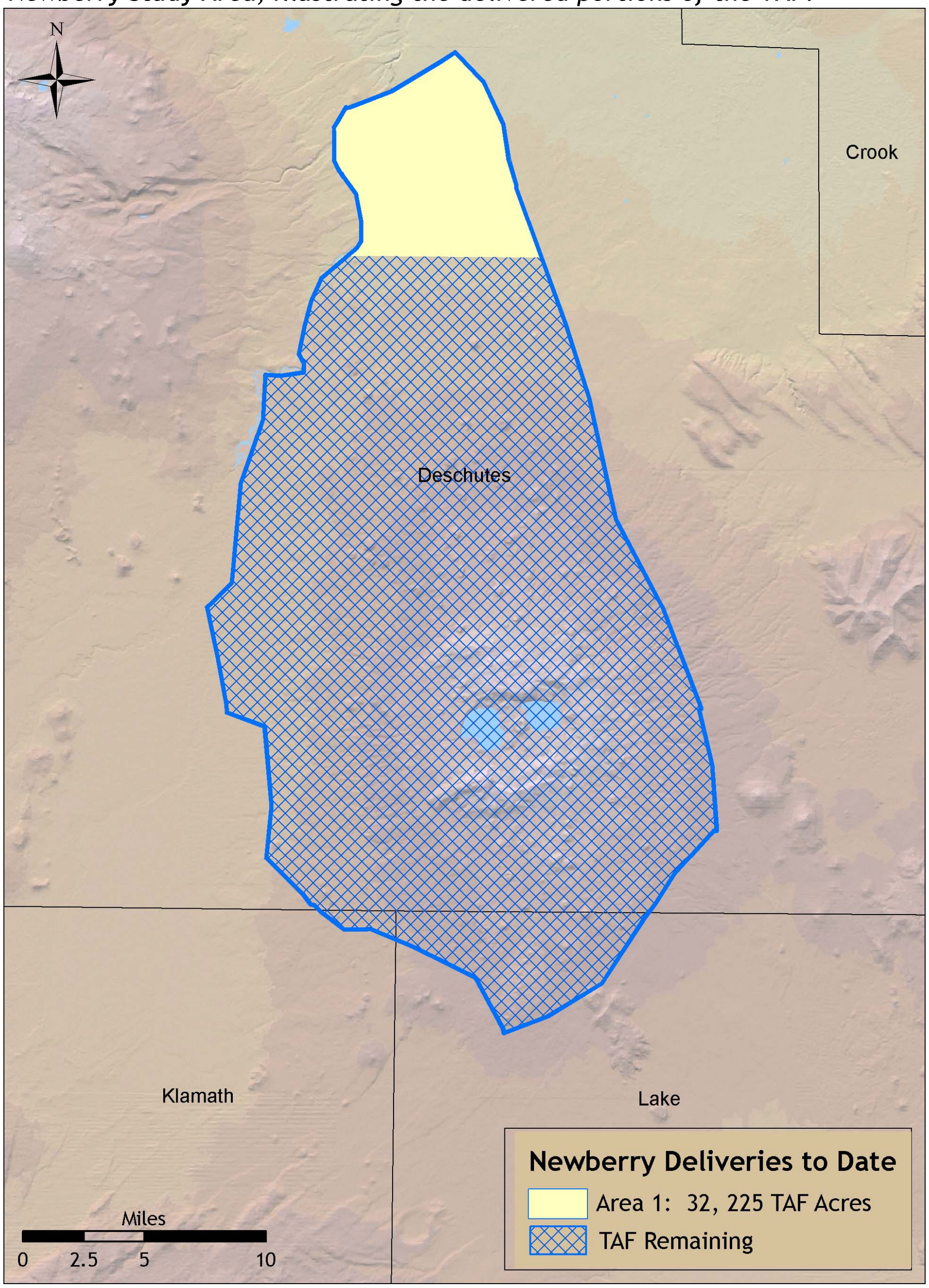
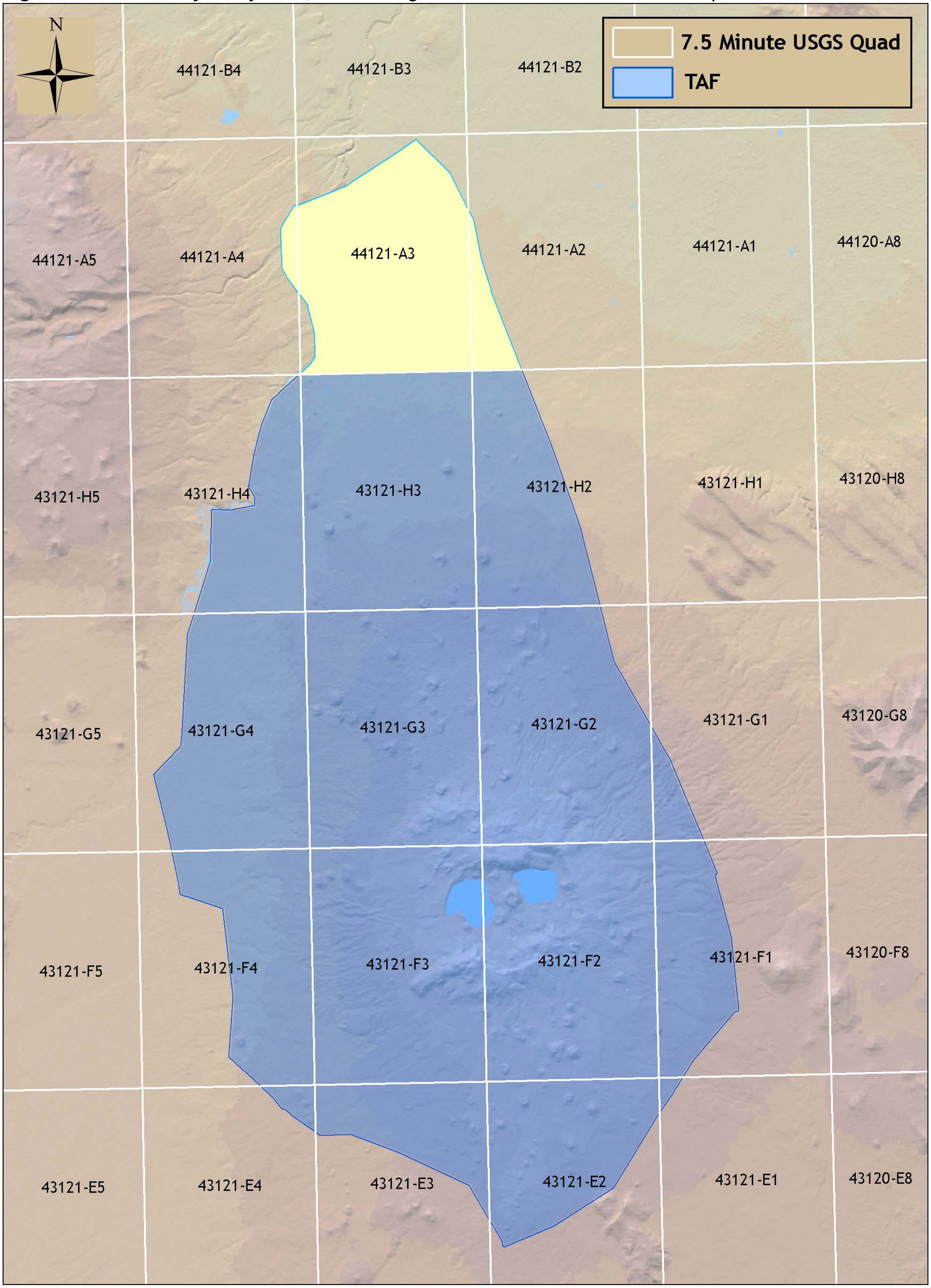


Figure 1.3. *Newberry Study Area, illustrating the delivered 7.5 minute USGS quads.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized a Leica ALS60 sensor mounted in Cessna Caravan 208B. The Leica ALS60 system was set to acquire ≥105,000 laser pulses per second (i.e. 105 kHz pulse rate) and flown at 900 and 1300 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*

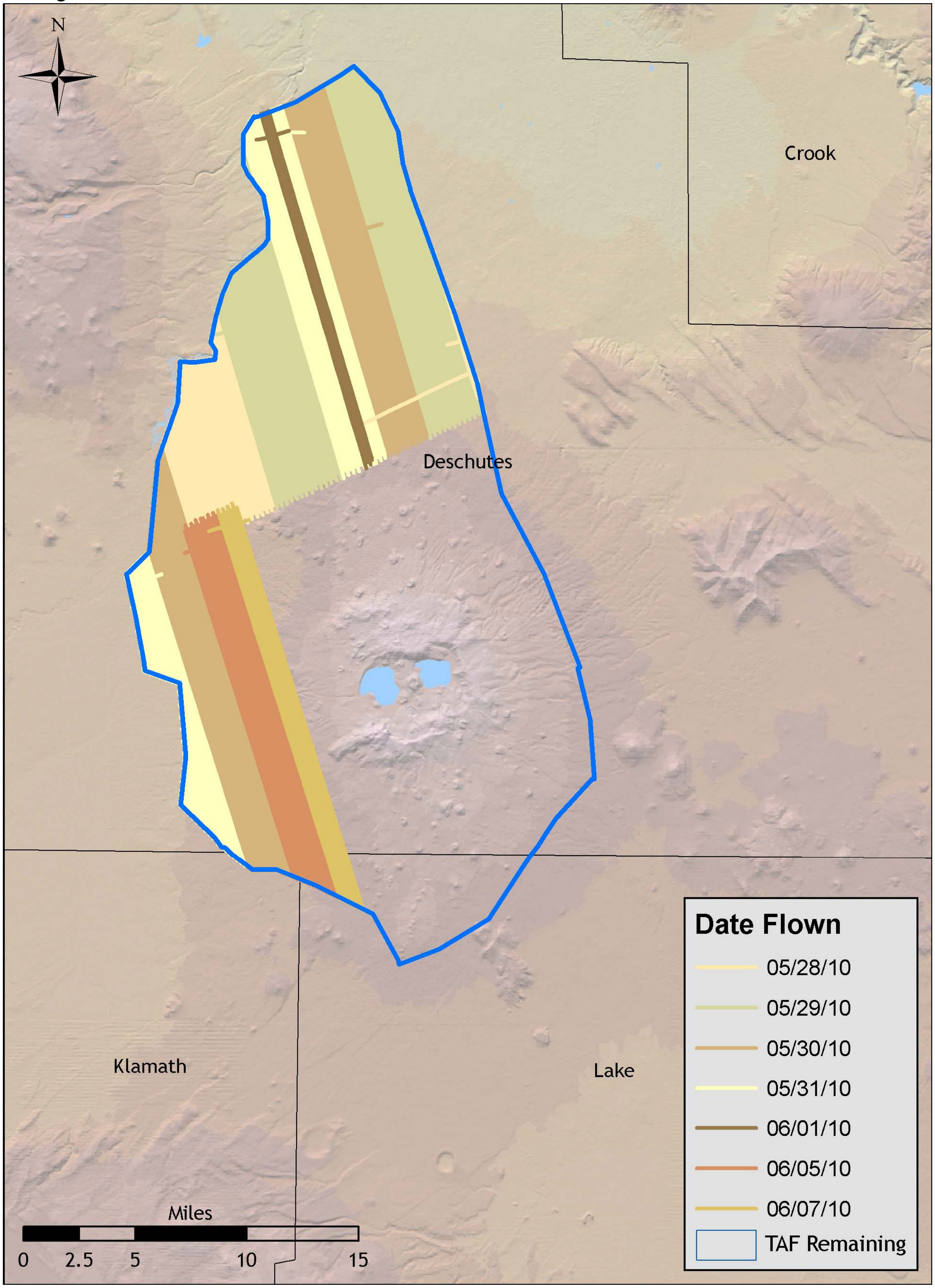
Sensor	Leica ALS60
Survey Altitude (AGL)	900 m and 1300 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	28° (±14° from nadir)
Roll Compensated	Up to 15°
Overlap	100% (50% Side-lap)

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

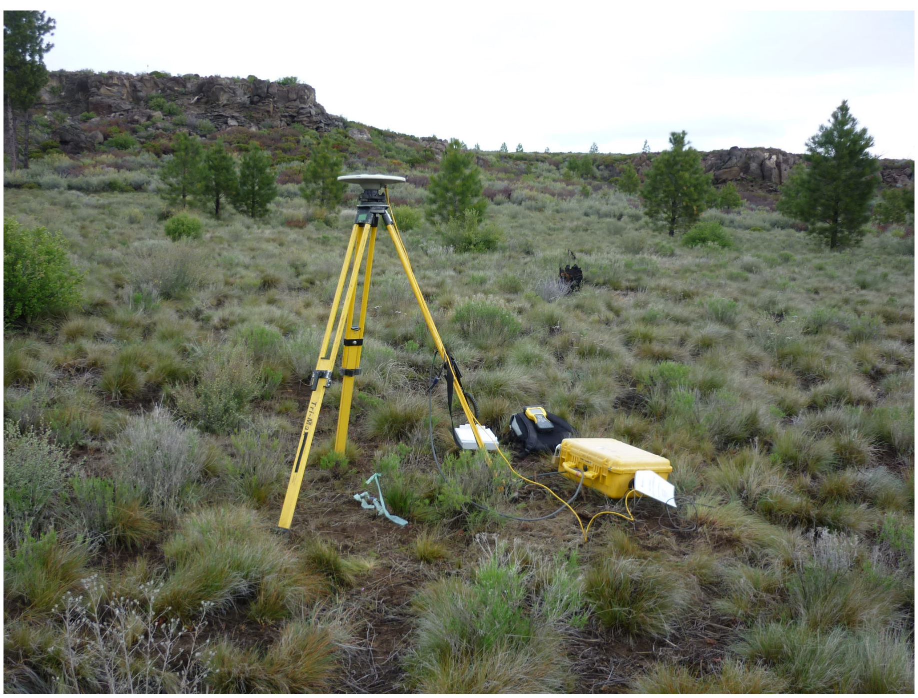


2.2 Ground Survey – Instrumentation and Methods

During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over 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.

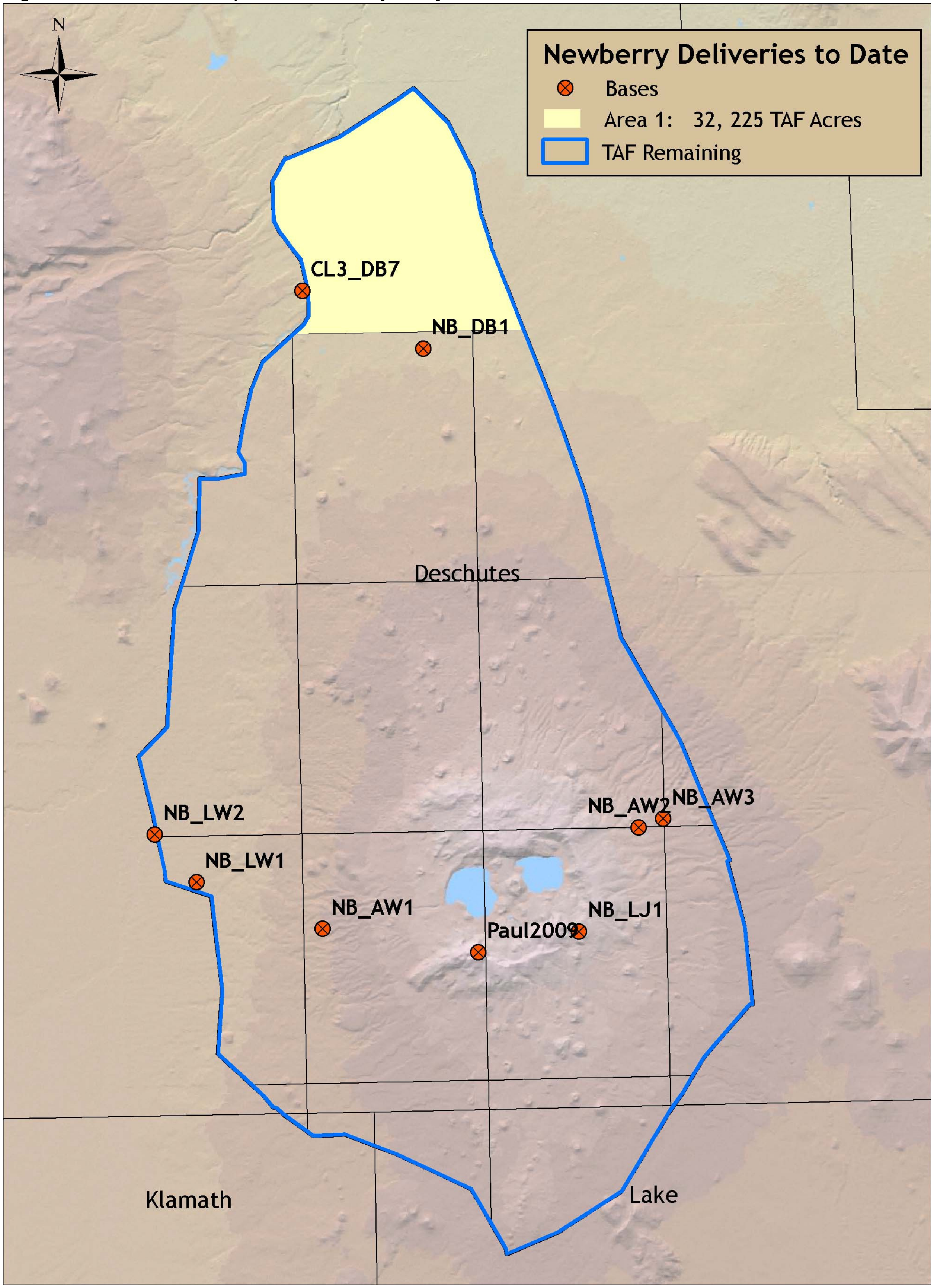
***Table 2.2**. Base Station Surveyed Coordinates, (NAD83/NAVD88, OPUS corrected) used for kinematic post-processing of the aircraft GPS data for the Newberry Study Area.*

	Datum NAD83 (HARN)		GRS80
Base Stations ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
CL3_DB7	44 01 17.70633	121 22 01.03065	1160.174
NB_DB1	43 59 29.39875	121 17 02.85375	1155.739
NB_LW1	43 43 37.01802	121 26 52.42743	1271.890
NB_LW2	43 45 04.81800	121 28 33.09215	1261.725
NB_AW1	43 42 08.45361	121 21 41.57000	1505.226
NB_AW2	43 44 59.60983	121 08 33.02702	1845.624
NB_AW3	43 45 14.14298	121 07 31.60507	1790.6125
NB_LJ1	43 41 54.43972	121 11 06.24045	2109.5155
Paul2009	43 41 21.10786	121 15 17.60226	2414.443



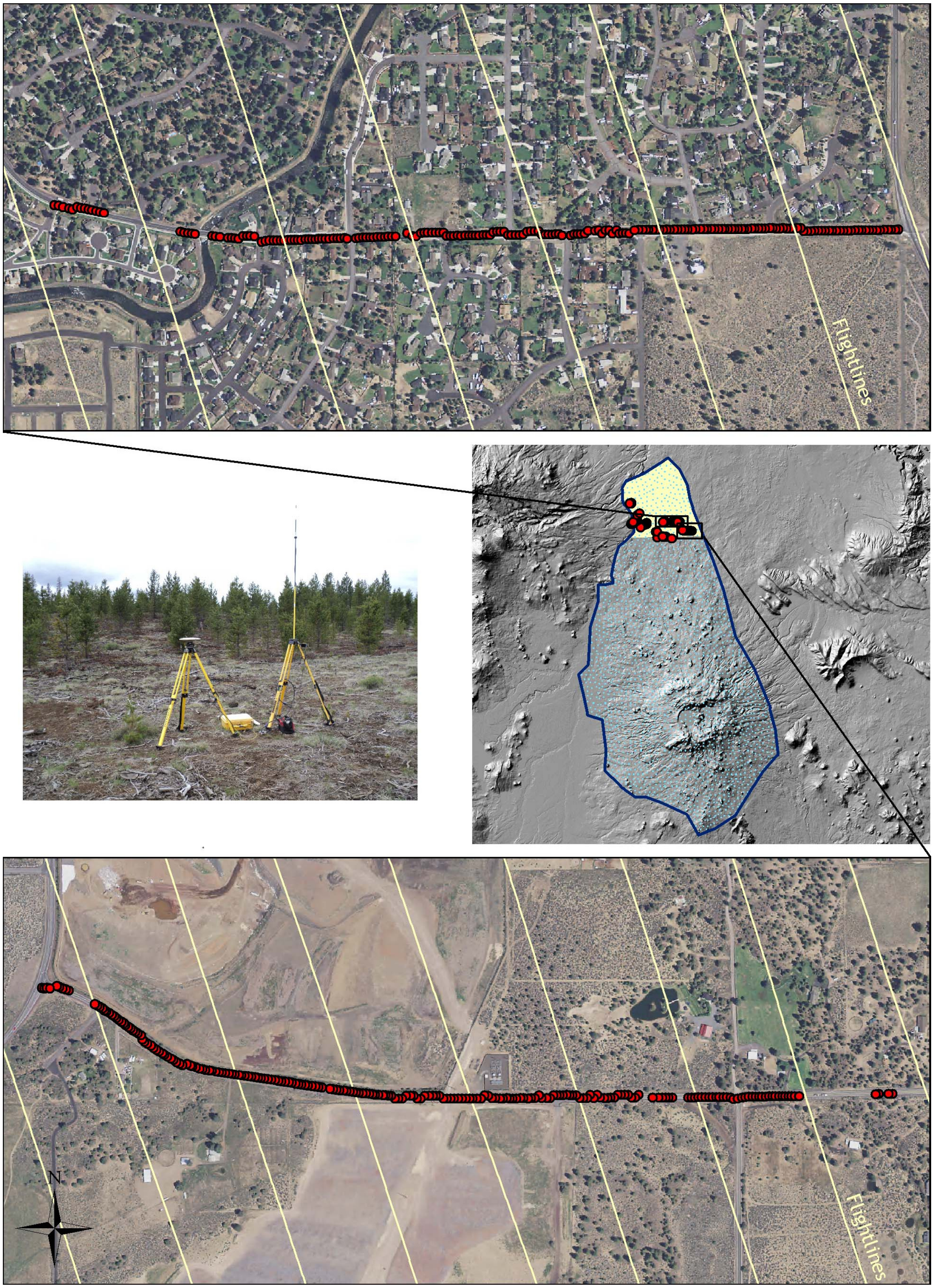
[2] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.

Figure 2.2. Base stations for the Newberry Study Area.



For data delivered to date, 1,209 RTK (Real-time kinematic) points were collected in the study area. **Figures 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 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 201 flightlines and over 4 billion points. Relative accuracy is reported for the portion of the study area 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 = 0.13 ft (0.04m)
- 2σ Relative Accuracy = 0.17 ft (0.05 m)

Figure 3.1. *Relative Accuracy Covered Area.*

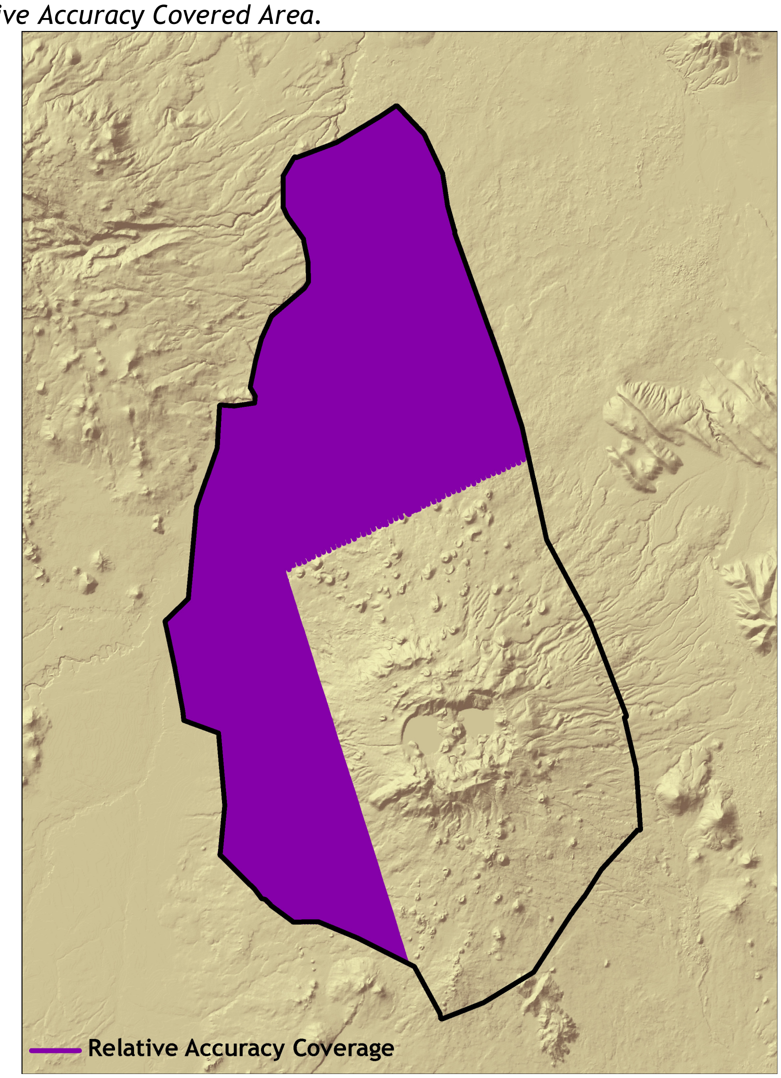


Figure 3.2. *Statistical relative accuracies, non slope-adjusted.*

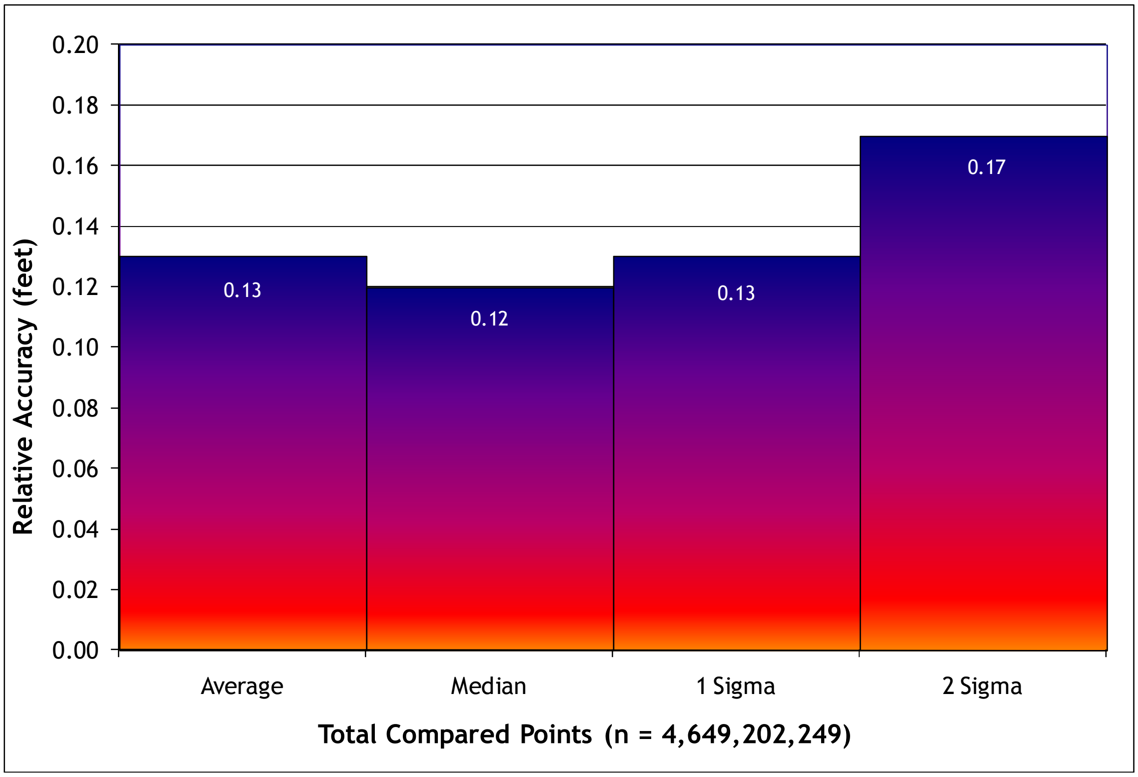
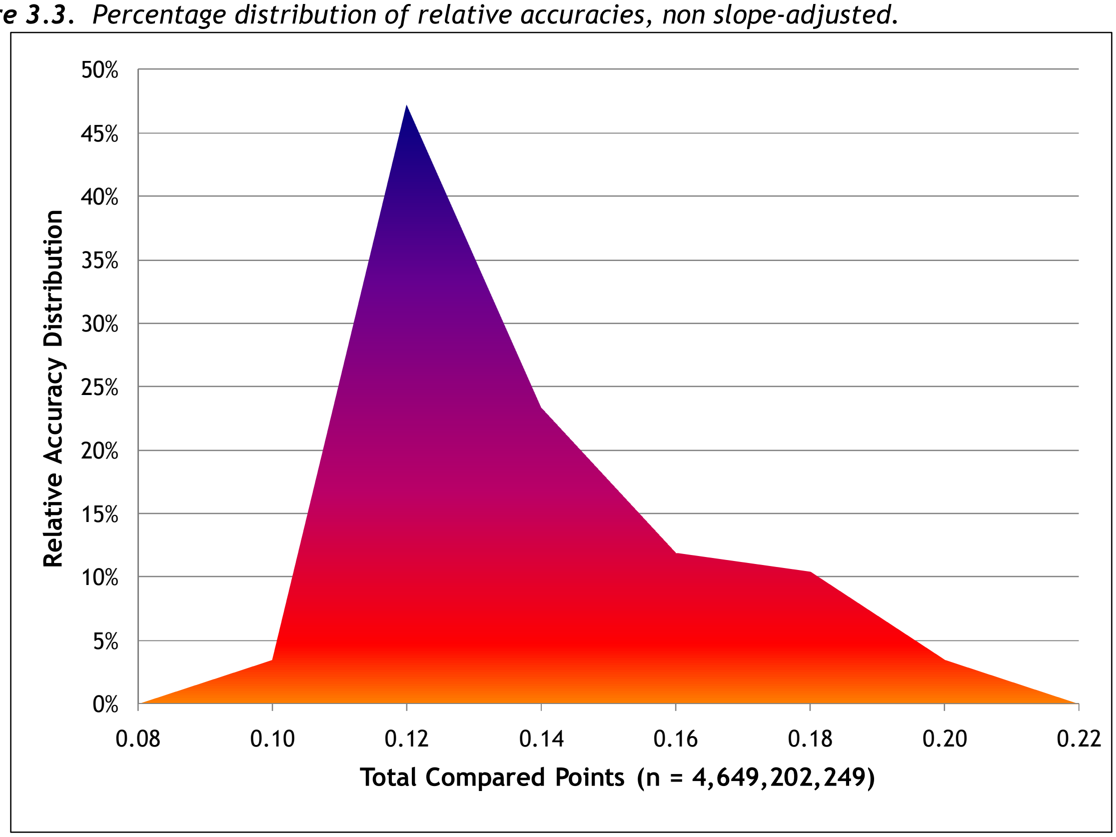


Figure 3.3. *Percentage distribution of relative accuracies, non slope-adjusted.*



3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Newberry Study Area, 1,209 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): 1,209	
Root Mean Square Error (RMSE): 0.12 ft (0.04m)	
Standard Deviations	**Deviations**
1 sigma (σ): 0.12 ft (0.04 m)	**Minimum Δz:** -0.35 ft (-0.11 m)
2 sigma (σ): 0.23 ft (0.07 m)	**Maximum Δz:** 0.18 ft (0.06 m)
	Average Δz: 0.10 ft (0.03 m)

Figure 3.4. *Absolute Accuracy Covered Area.*

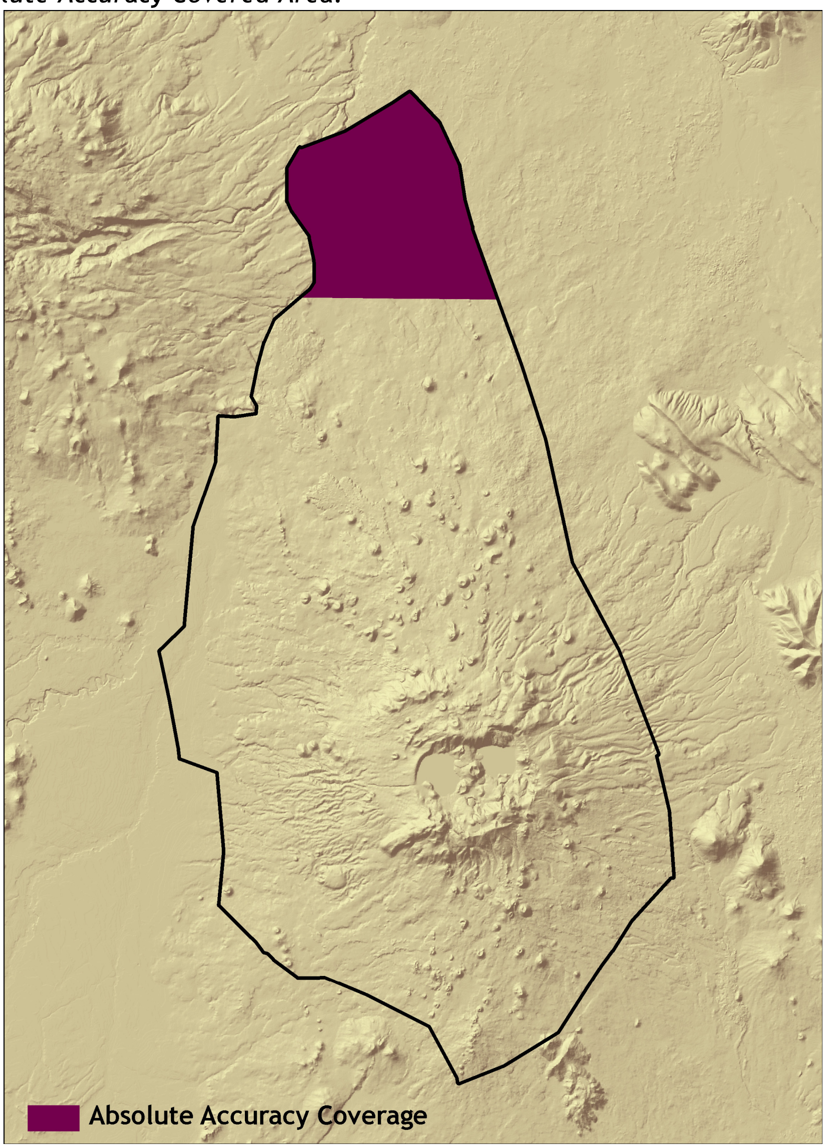


Figure 3.5. Newberry Study Area histogram statistics

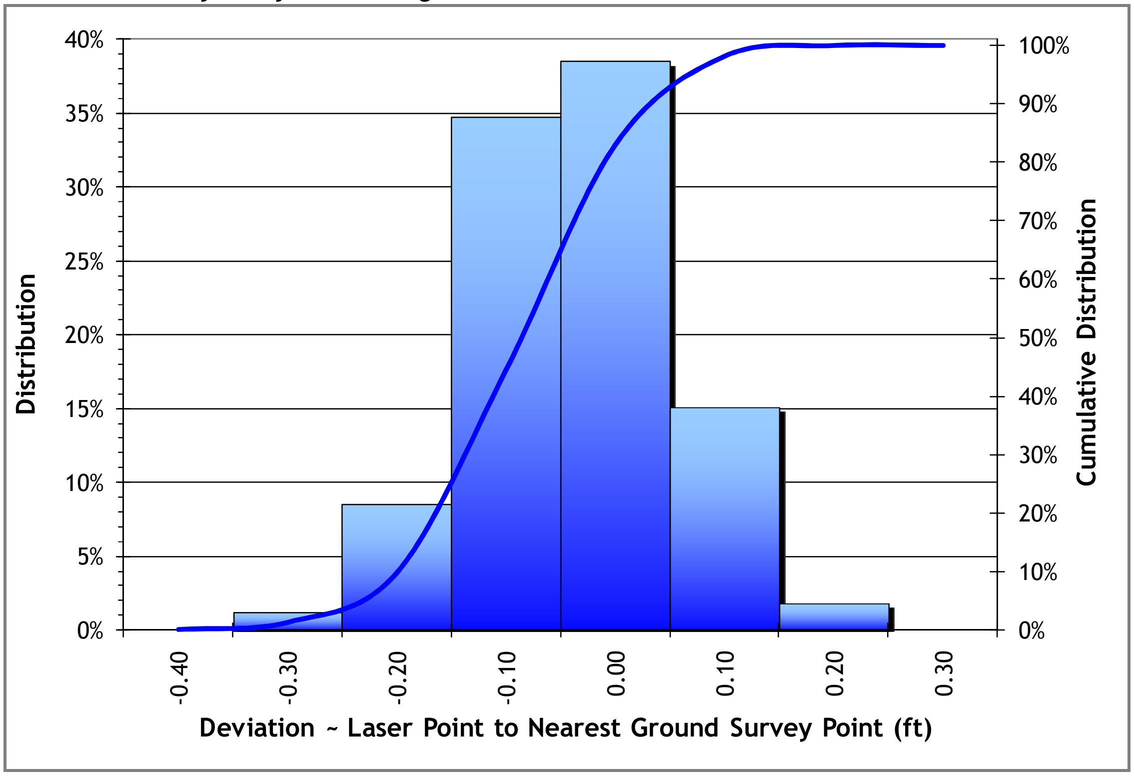
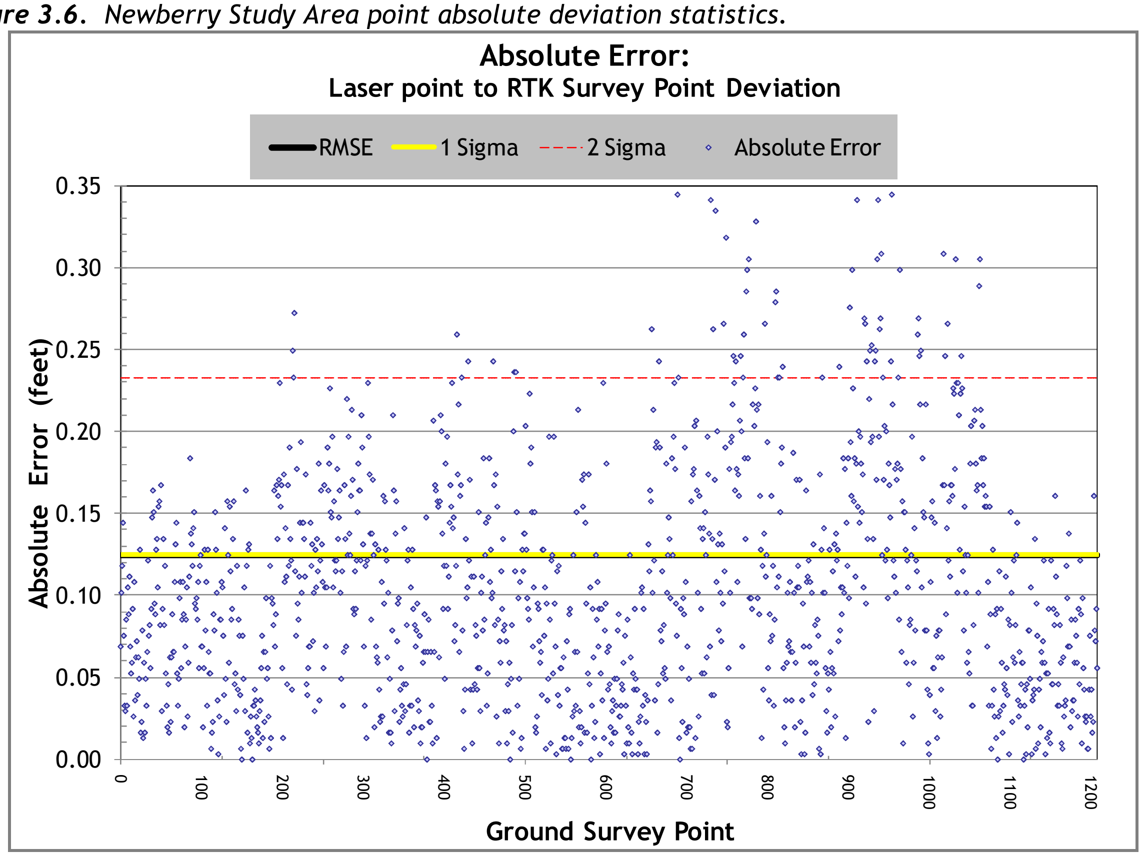


Figure 3.6. Newberry Study Area point absolute deviation statistics.



4. Data Density/Resolution

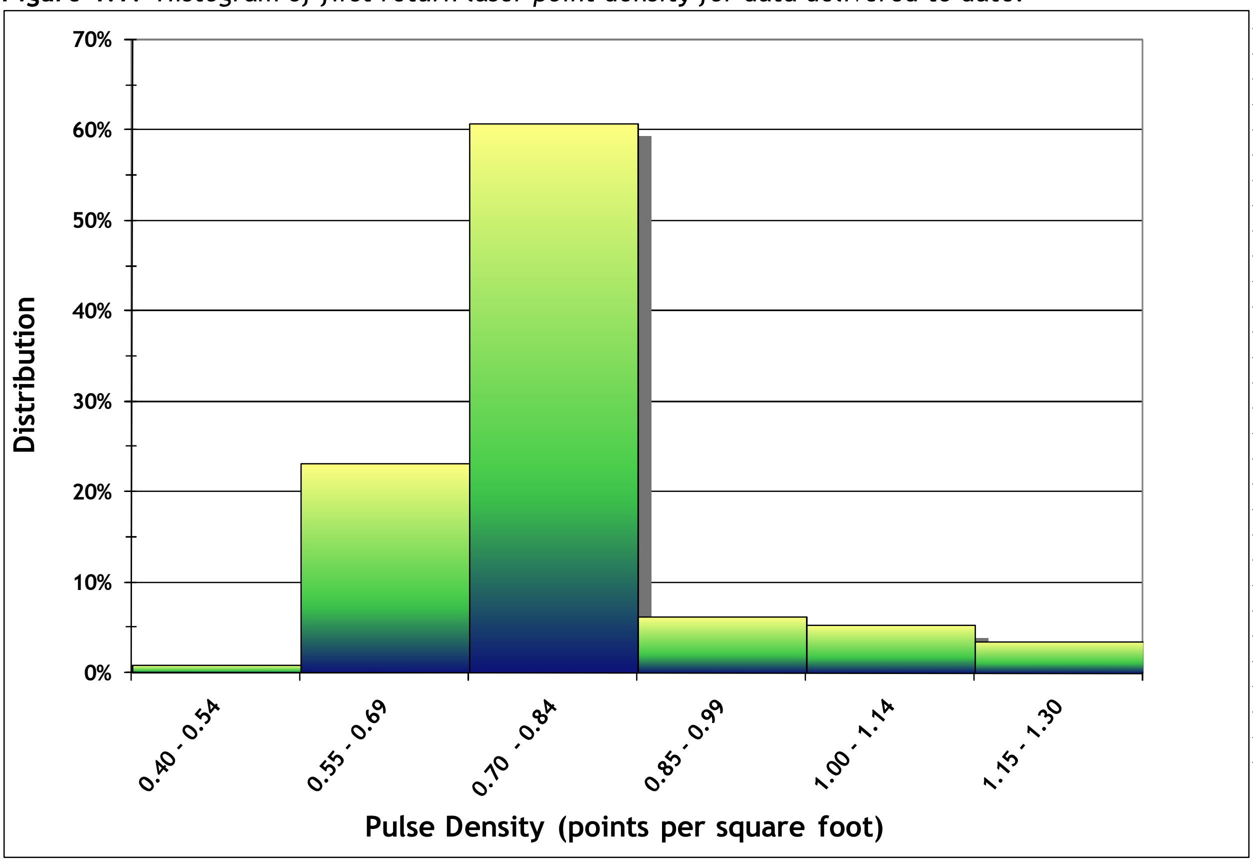
4.1 Density Statistics

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 Newberry Study Area data delivered to date.*

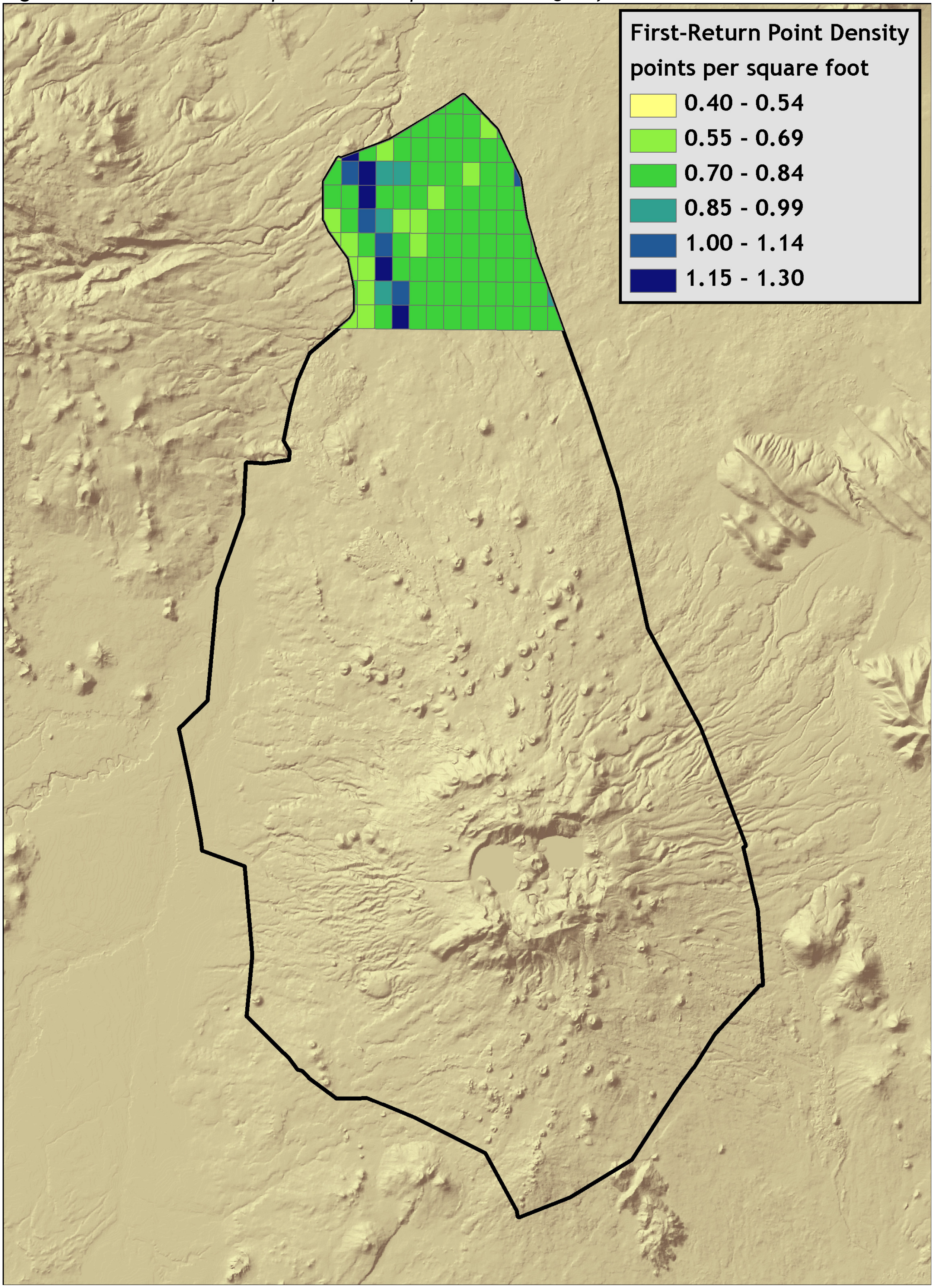
Average Pulse Density (per square ft)	Average Pulse Density (per square m)	Average Ground Density (per square ft)	Average Ground Density (per square m)
0.78	8.3	.24	2.6

Figure 4.1*. Histogram of first return 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

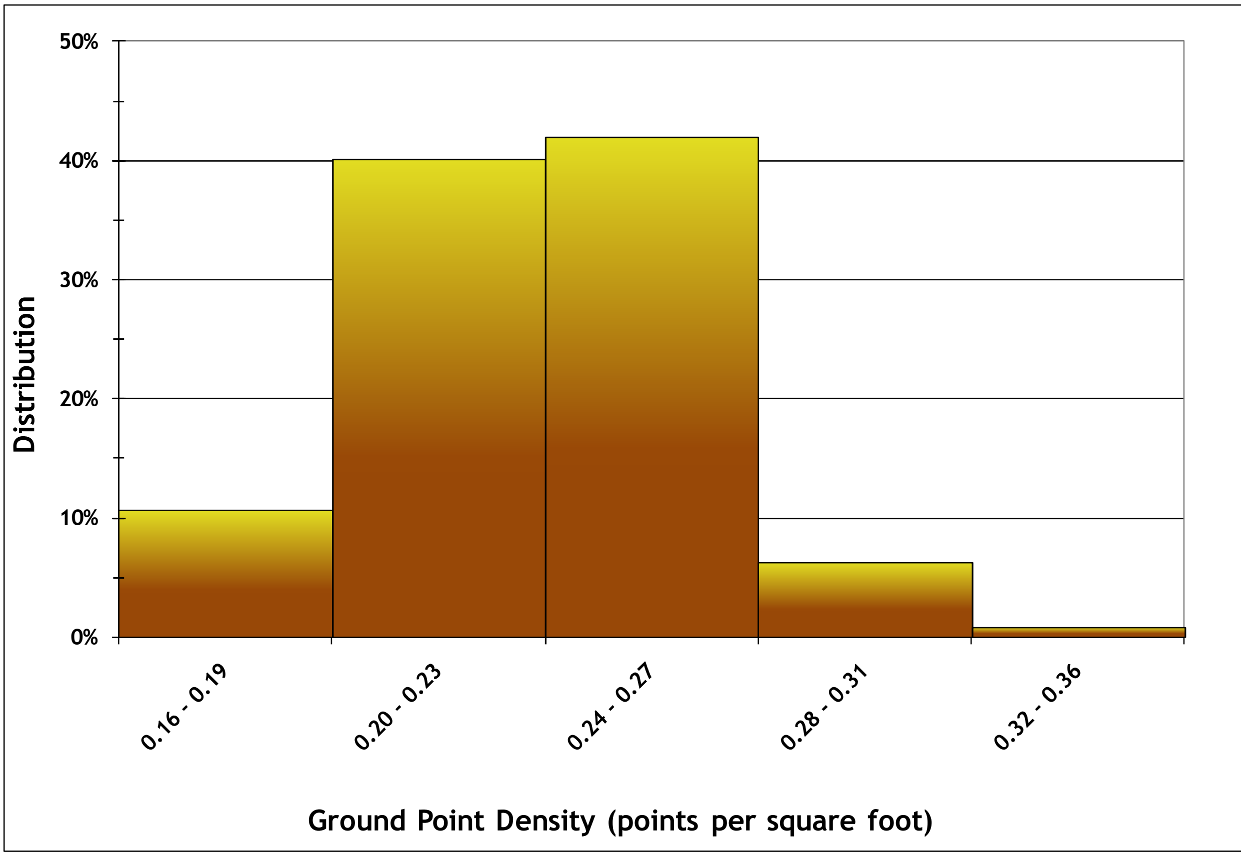
Figure 4.2. *First return laser point densities per 0.75' USGS Quad for data delivered to date.*



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

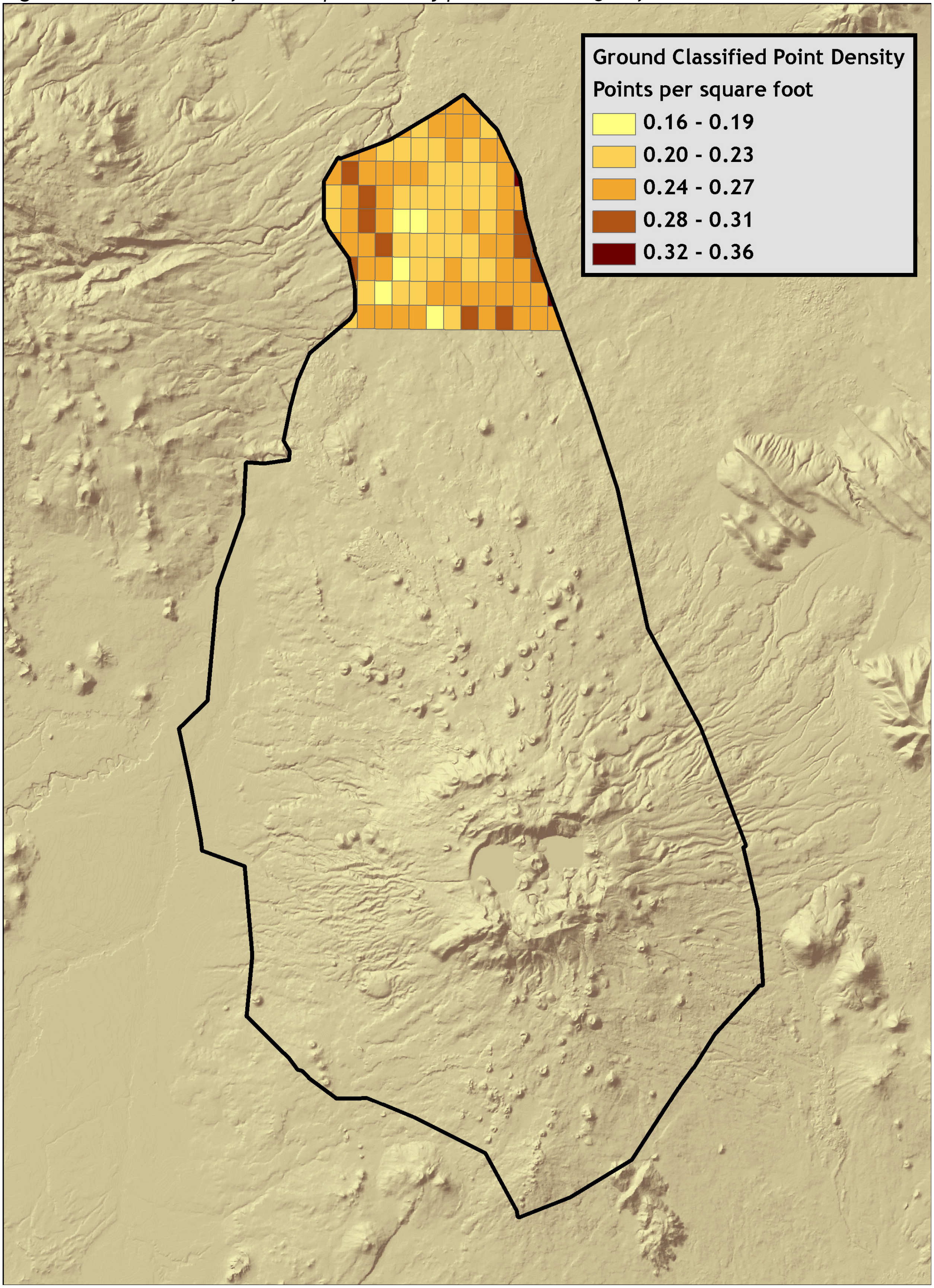
Ground classifications were derived from ground surface modeling. Classifications were performed by reseeding of the ground model where it was determined that the ground model failed, usually under dense vegetation and/or at breaks in terrain, steep slopes and at bin boundaries.

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

Figure 5.1. *3-d oblique view of the Deschutes River in Bend, OR. Image is a three dimensional LiDAR point cloud with RGB values extracted from a NAIP orthophoto.*

Figure 5.2. *View from the Northwest of Pilot Butte near Bend, Oregon. Image is a three dimensional LiDAR point cloud with RGB values extracted from a NAIP orthophoto.*

Figure 5.3. *View from the east of an area north of Bend, OR along the Deschutes River. Image is a three dimensional LiDAR point cloud with RGB values extracted from a NAIP orthophoto.*