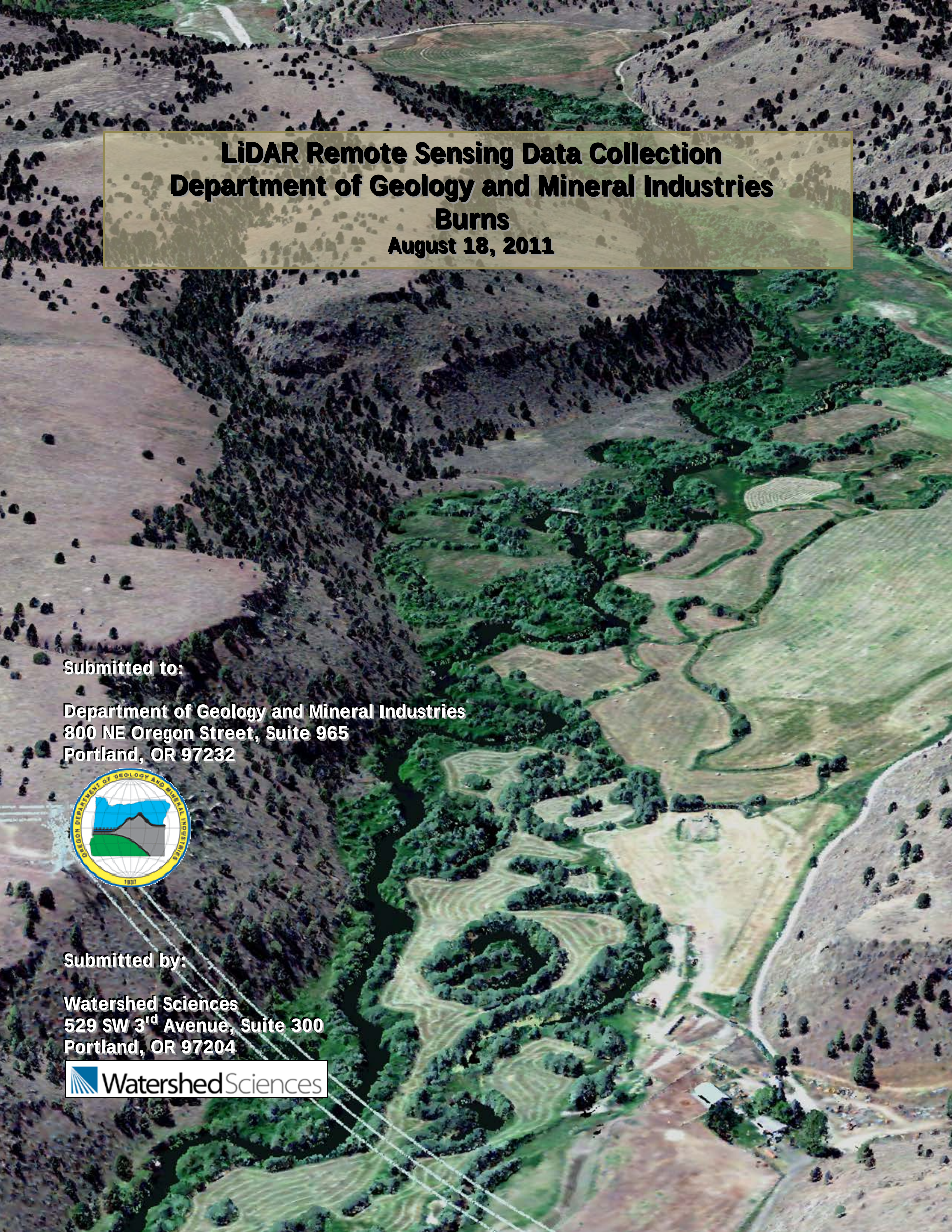

LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
Burns

August 18, 2011

Submitted to:

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

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

LiDAR Remote Sensing Data Collection:
DOGAMI, Burns Study Area

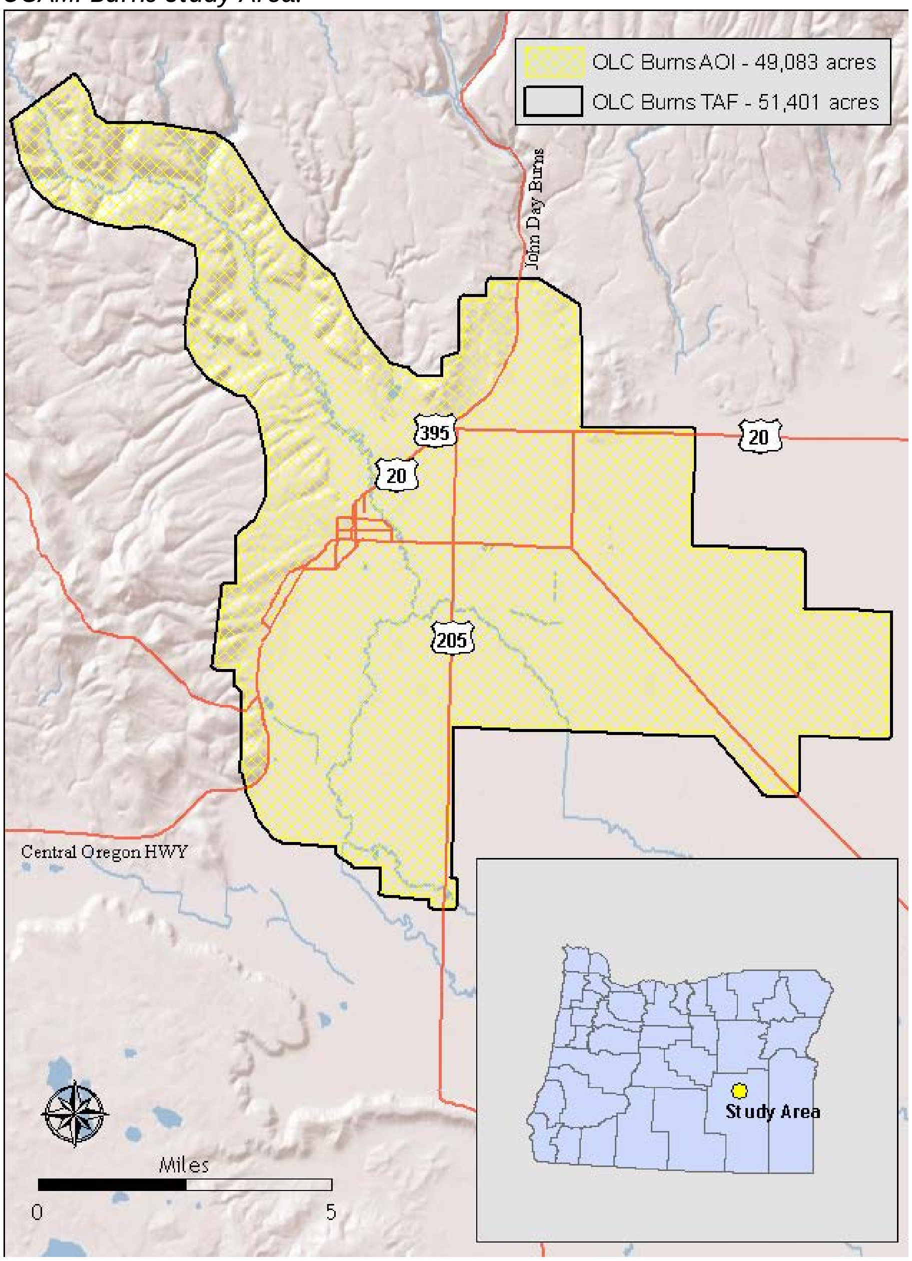
TABLE OF CONTENTS

1. Overview

1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Burns Study Area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 79 square miles (49,083 acres) and the total area flown (TAF) covers 80 square miles (51,401 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. Burns data are delivered in UTM Zone 11; NAD83(CORS96); NAVD88(Geoid 03); Units: meters.

Figure 1.1. *DOGAMI Burns Study Area.*

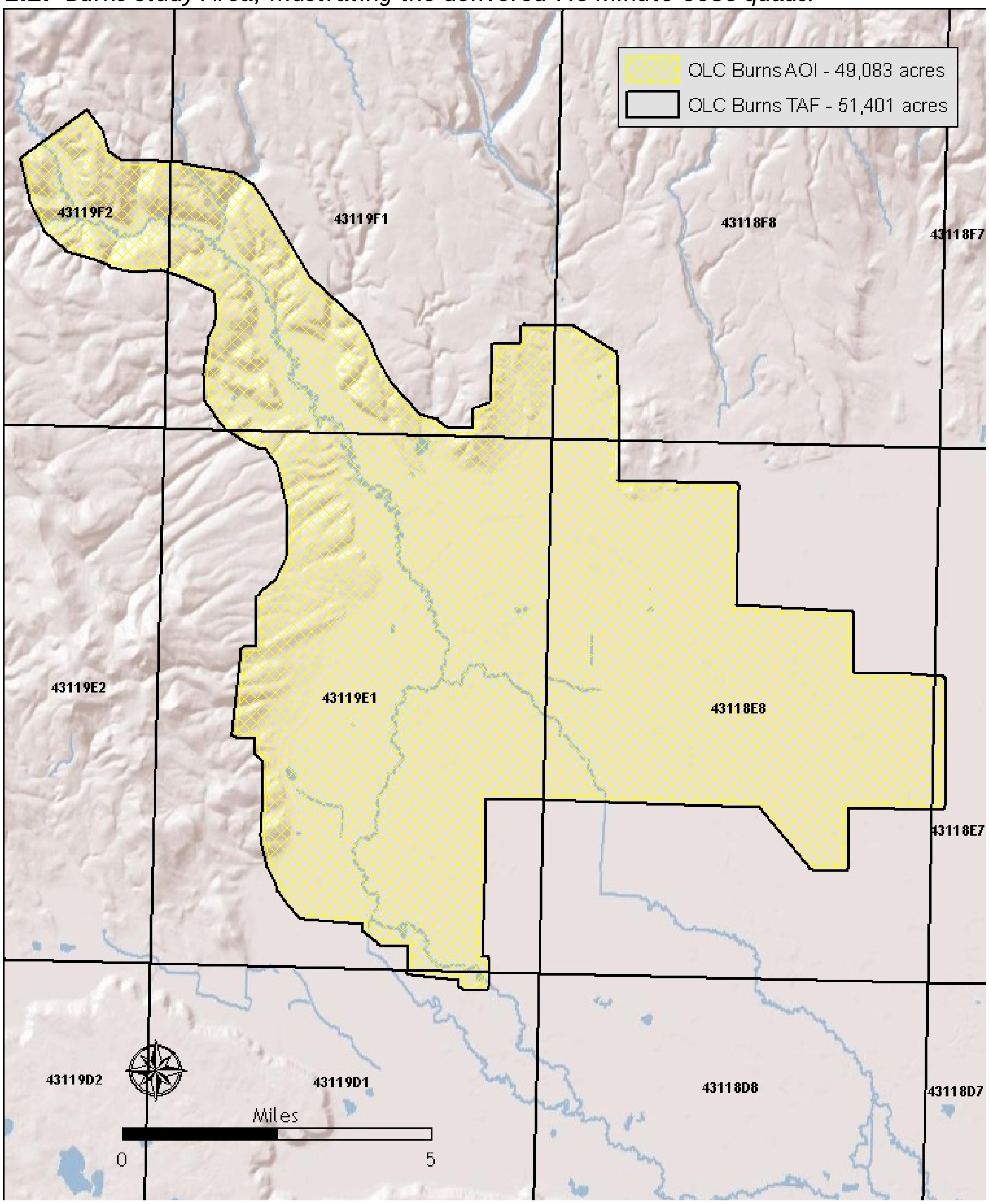


1.2 Area Delivered to Date

Total delivered acreage to date is detailed below.

DOGAMI Burns Study Area				
	Delivery Date	**Acquisition Dates**	**AOI Acres**	**TAF Acres**
Delivery Area	August 18, 2011	June 19. 2011- June 2011	**49,083**	**51,401**

Figure 1.2. *Burns 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 SN094 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 meters above ground level (AGL), capturing a scan angle of ±14^{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*

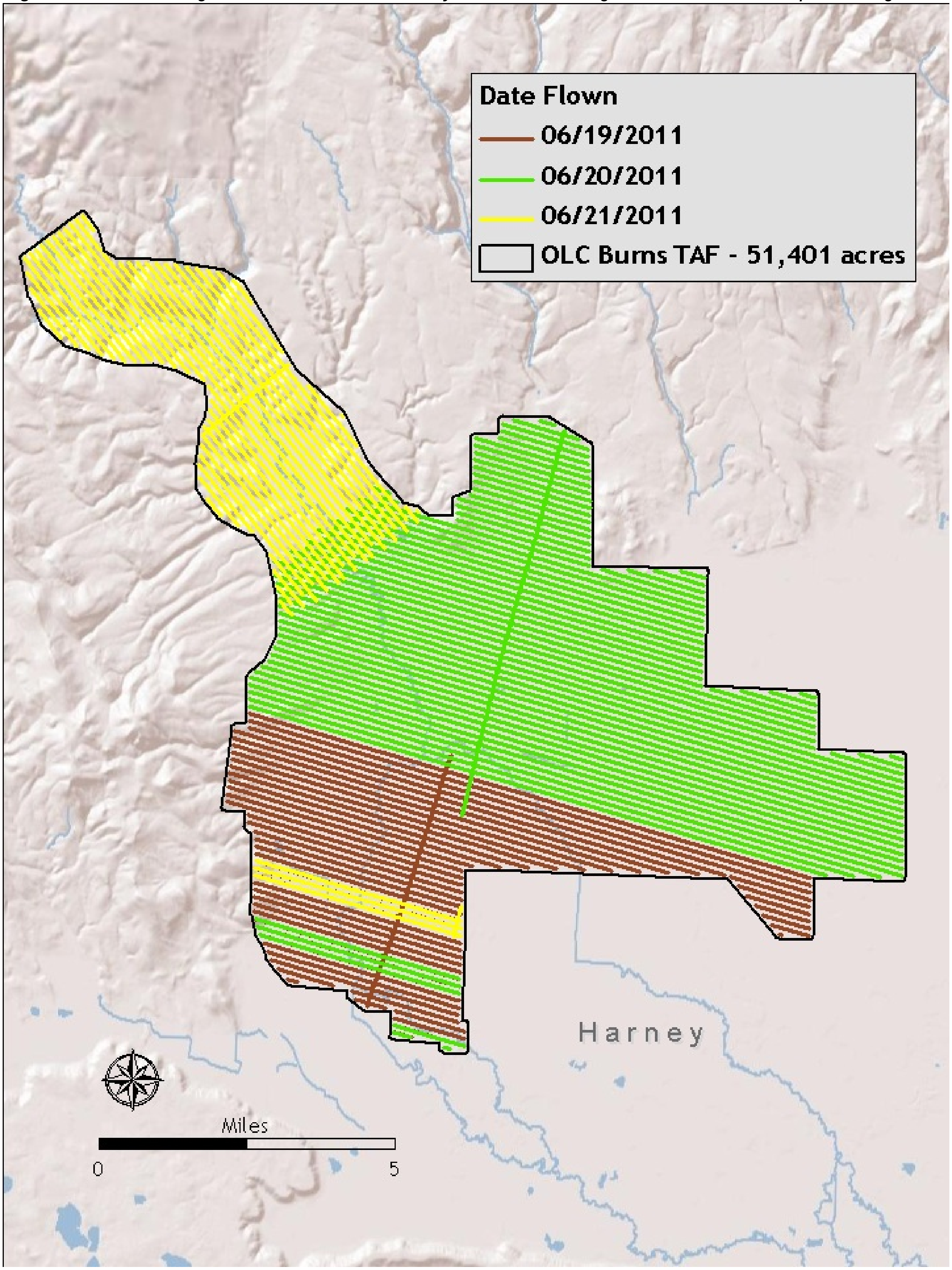
Sensor	Leica SN094
Survey Altitude (AGL)	900 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	30^{o} (±14^{o} from nadir)
Roll Compensated	Up to 15^{o}
Overlap	100% (50% Side-lap)

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 Burns Study Area illustrating the dates flown for processing.*



2.2 Ground Survey – Instrumentation and Methods

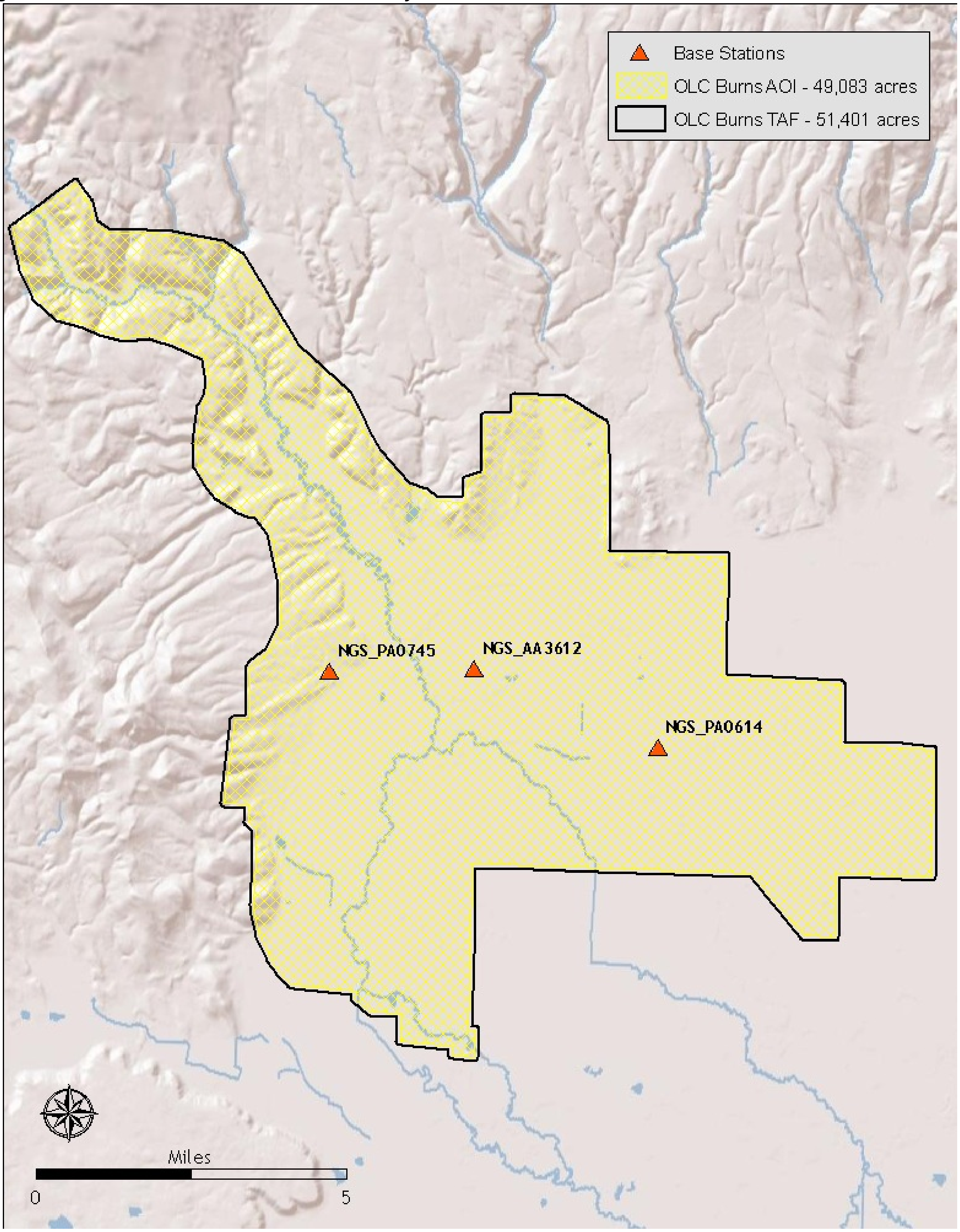
During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over monuments with known coordinates. Monument coordinates are provided in **Table 2.2** and shown in **Figure 2.2**. After the airborne survey, the static GPS data were processed using triangulation with CORS stations 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 Burns Study Area.*

	Datum NAD83 (HARN)		GRS80
Base Stations ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
NGS_PAO614	43 34 10.12819	118 57 37.54758	1242.786
NGS_AA3612	43 35 12.75382	119 01 12.92721	1246.877
NGS_PAO745	43 35 07.64020	119 03 59.11205	1256.039

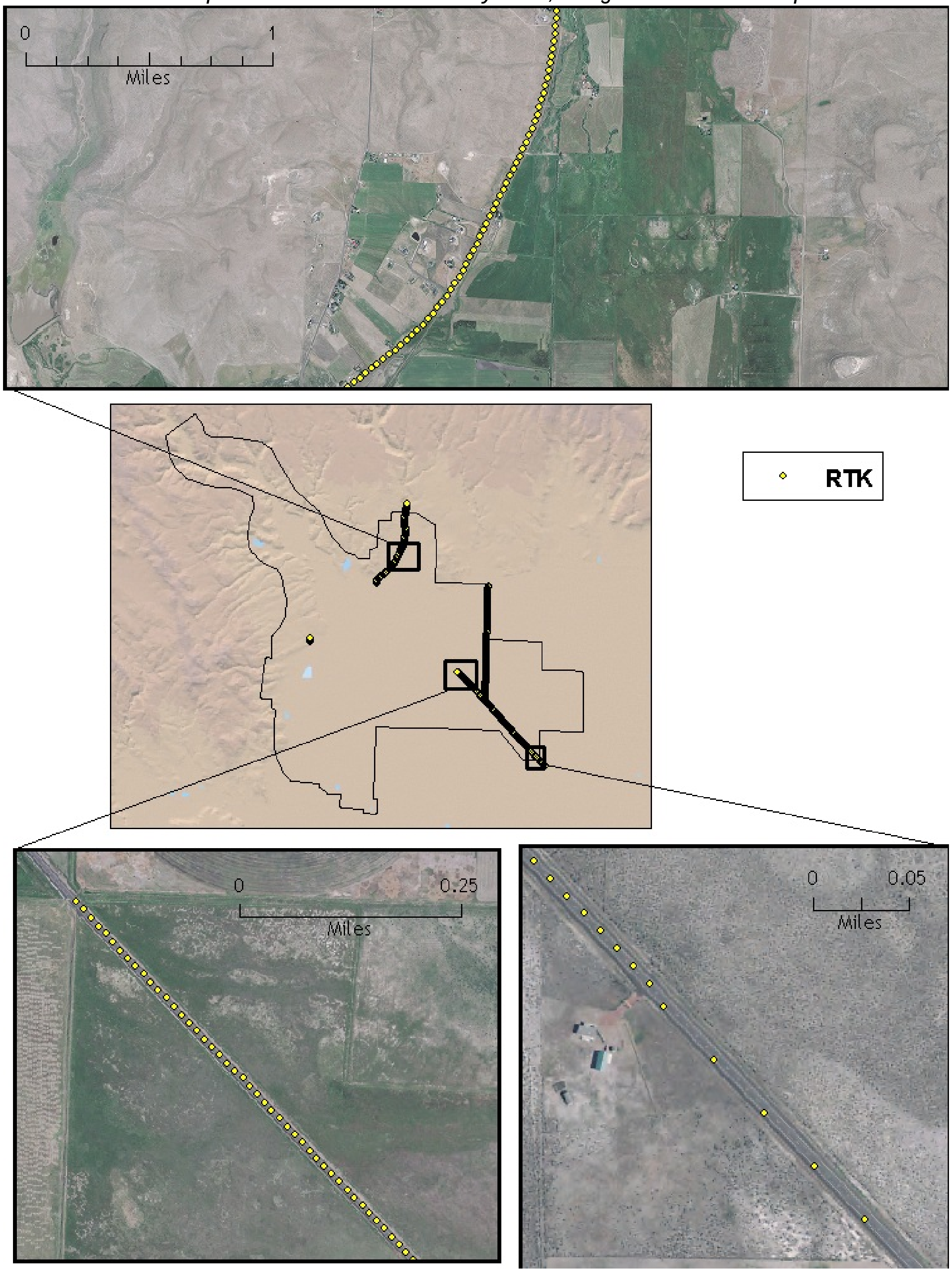
[2] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.

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



For data delivered, 594 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; 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 137 flightlines and over 2 billion points. Relative accuracy is reported for the portion of the study area shown in **Figure 3.1** below.

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

Figure 3.1. *Relative Accuracy Covered Area.*

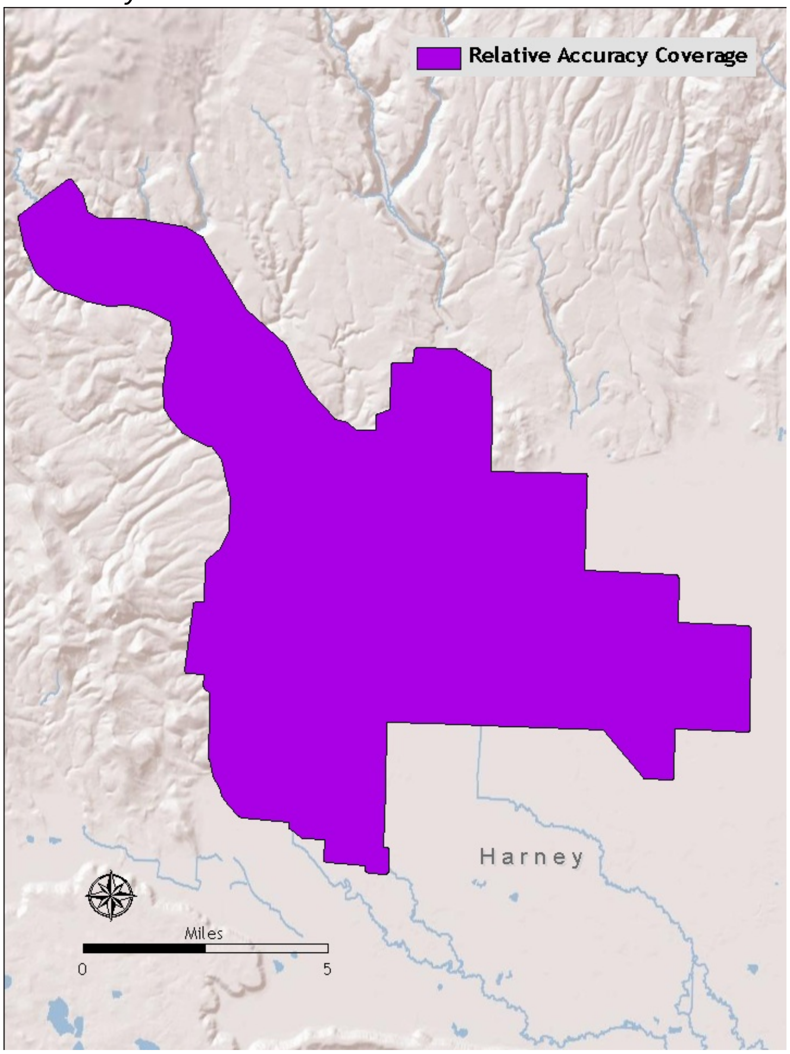


Figure 3.2. *Statistical relative accuracies, non slope-adjusted.*

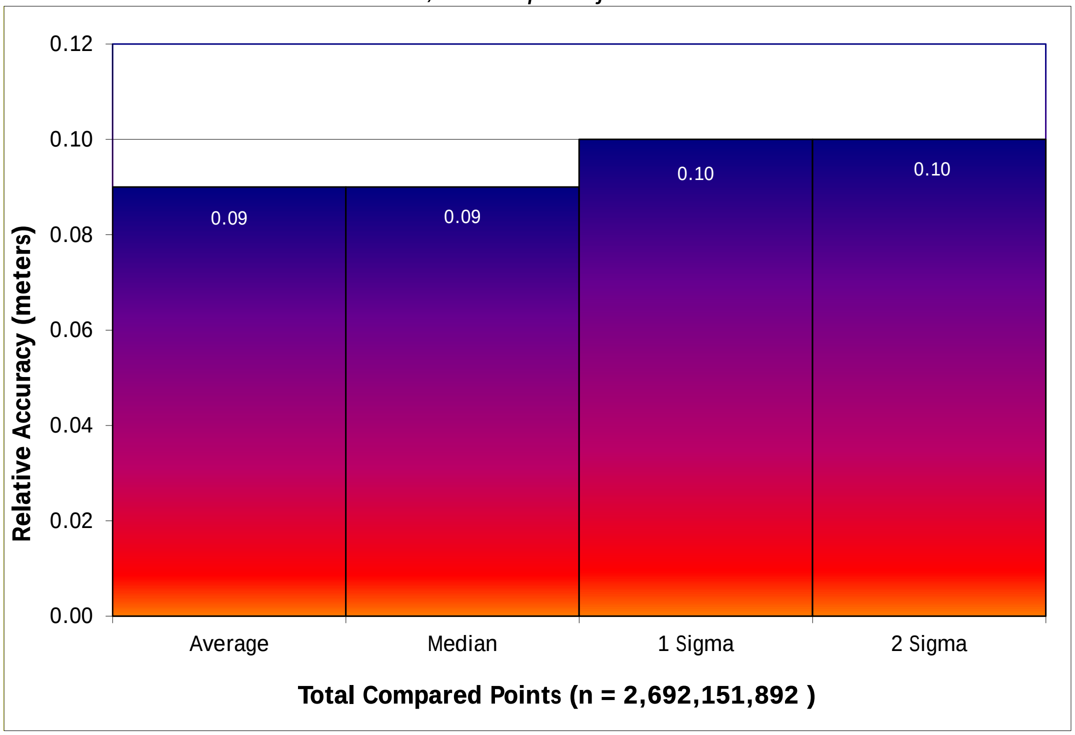
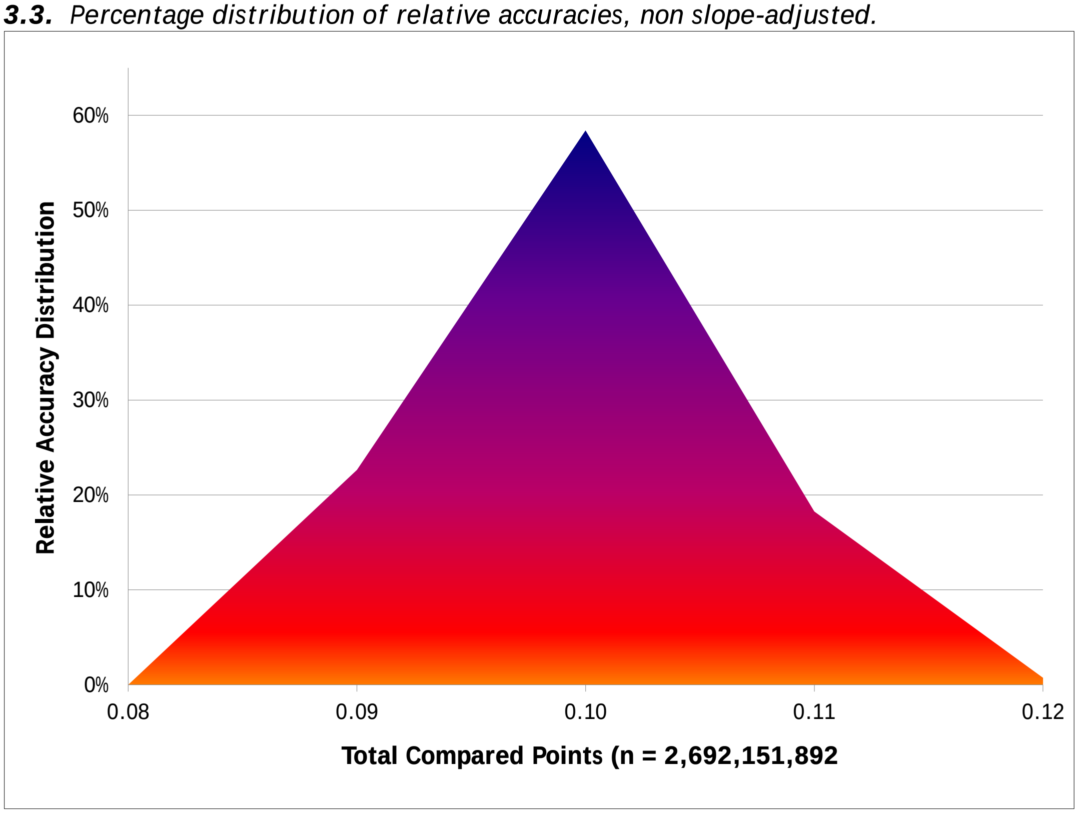


Figure 3.3. *Percentage distribution of relative accuracies, non slope-adjusted.*



3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Burns Study Area, 594 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): 594	
Root Mean Square Error (RMSE): 0.03m	
Standard Deviations	**Deviations**
1 sigma (σ): 0.04 m	**Minimum Δz:** -0.08 m
2 sigma (σ): 0.06 m	**Maximum Δz:** 0.10 m
	Average Δz: 0.01m

Figure 3.4. *Absolute Accuracy Covered Area.*

Figure 3.5. *Burns Study Area histogram statistics*

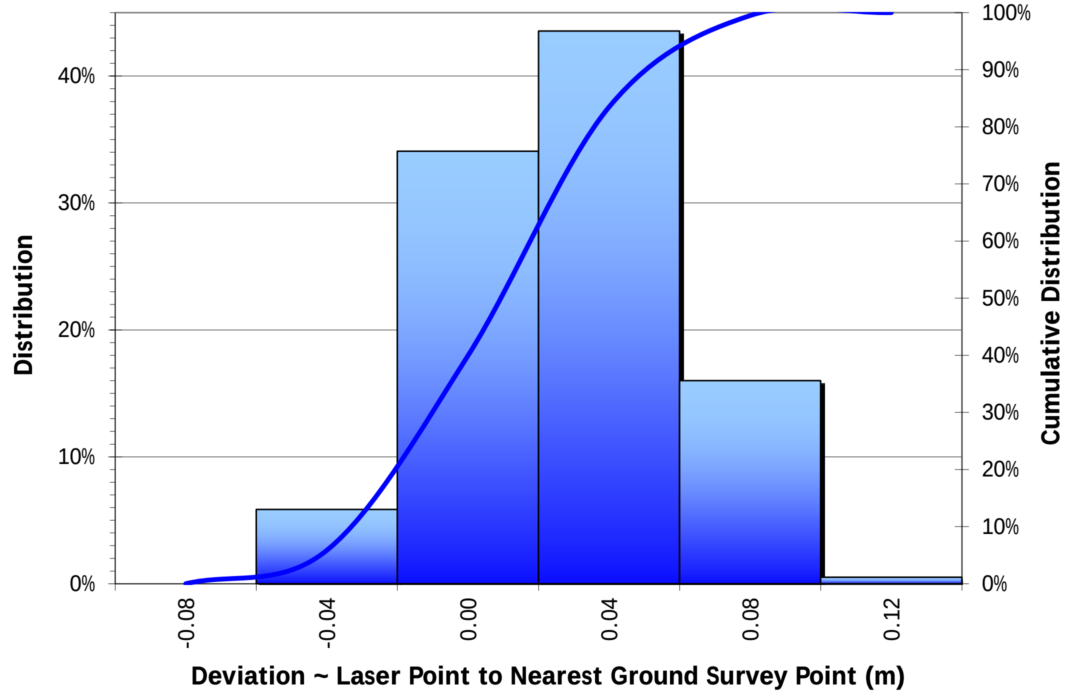
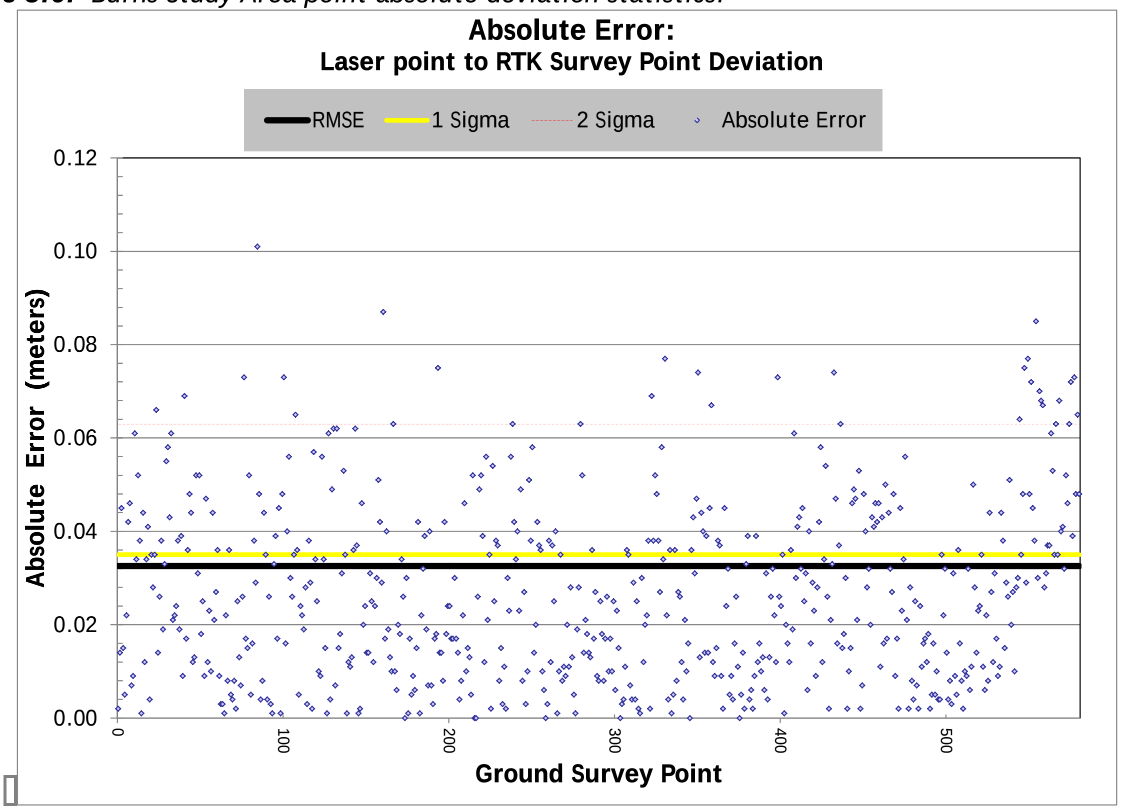


Figure 3.6. *Burns Study Area point absolute deviation statistics.*



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 three different land cover types in compliance with FEMA LiDAR Specifications for Flood Hazard Mapping, Section A4B-7. 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 Burns study area are listed below. FEMA guidlines allow for a minimum of three (3) land cover types for assessment. Owing to the relative homogeneity of land cover in the Burns study area, the three land cover types detailed below were determined to be representative of the study area. 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 (RMSE ≤ 15 cm).

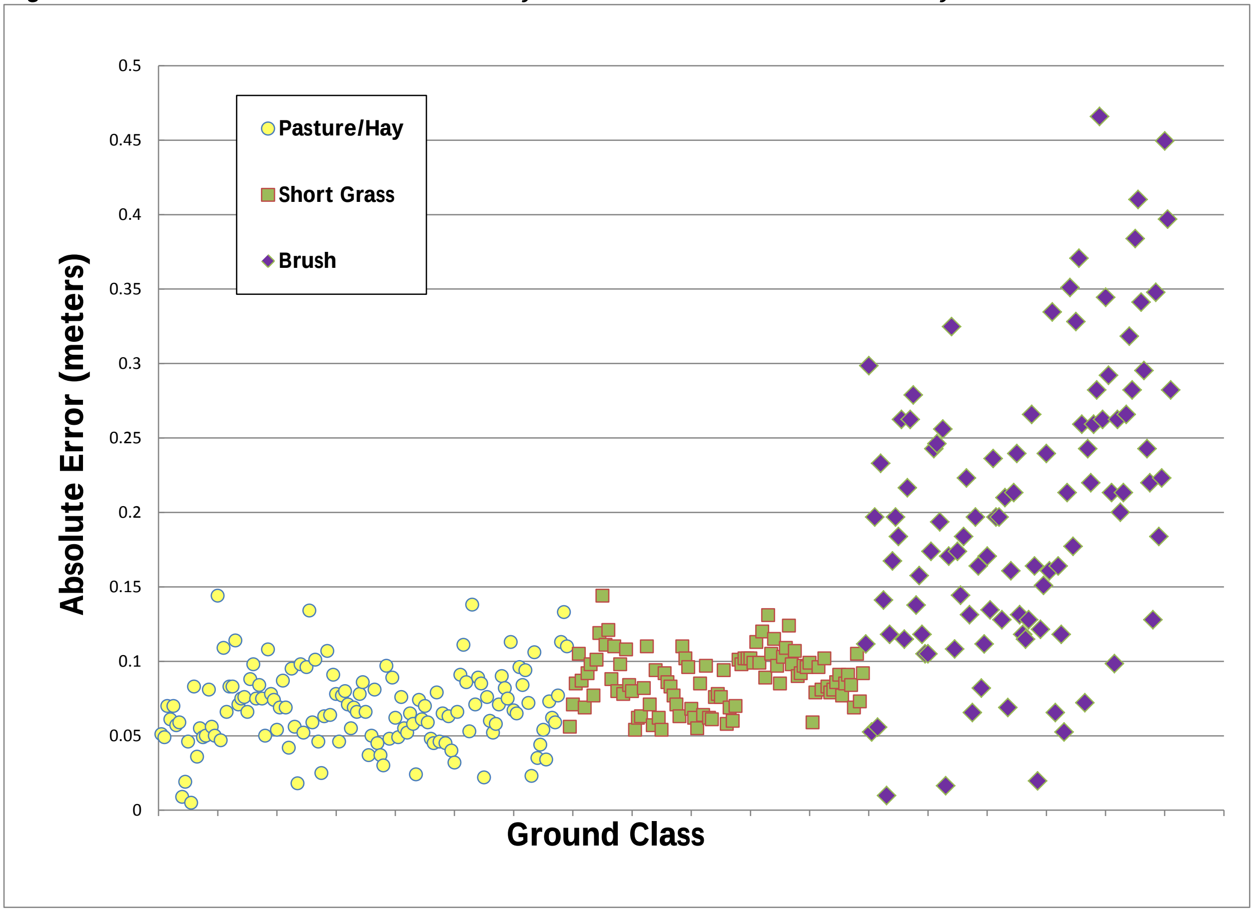
Pasture/Hay:	Areas of grass mixture planted for livestock grazing or production of seed.
Grass - short:	Grasses <2 feet in height
Brush:	Woody vegetation under 6 feet in height

Table 3.1 *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):
Pasture/Hay	138	0.07 m 0.24 ft	0.07 m 0.22 ft	0.08 m 0.25 ft	0.11 m 0.37 ft
Grass - short (<2.0 ft)	100	0.09 m 0.29 ft	0.09 m 0.29 ft	0.10 m 0.32 ft	0.12 m 0.39 ft
Brush	104	0.07 m 0.22 ft	0.06 m 0.20 ft	0.07 m 0.24 ft	0.11 m 0.37 ft

Pasture/Hay landcover class.

Figure 3.7. *Absolute deviation statistics by cover class within the Burns study area.*



4. Data Density/Resolution

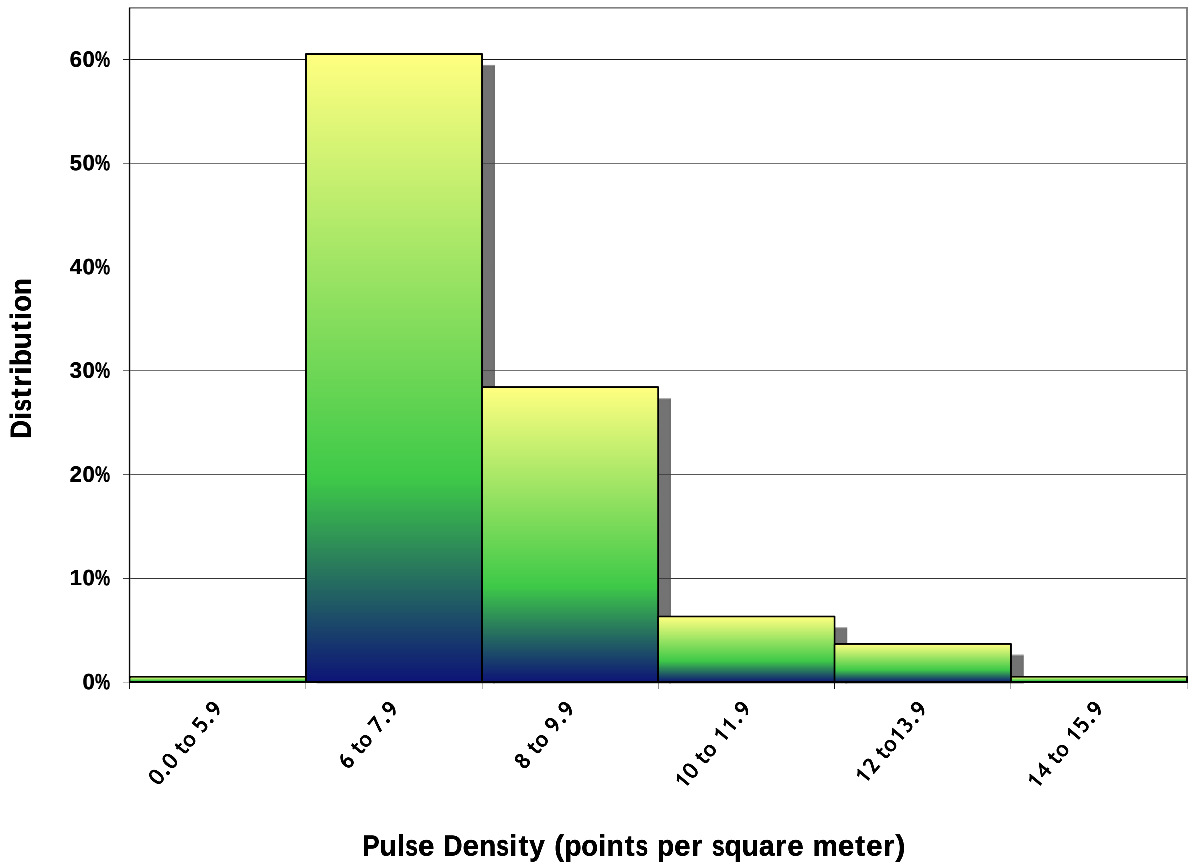
4.1 Density Statistics

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 (**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 Burns Study Area data delivered to date.*

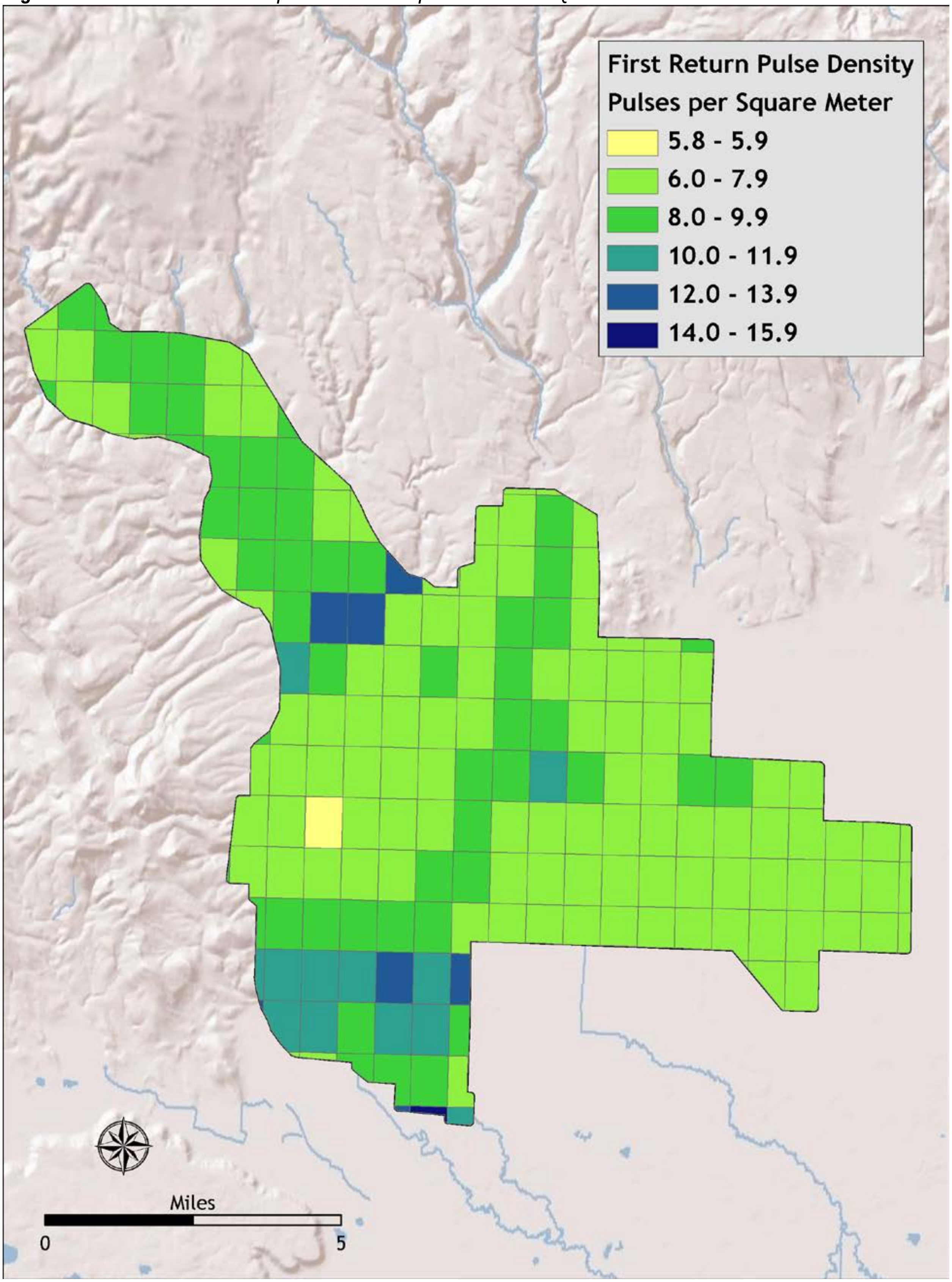
Average Pulse Density (per square m)	Average Ground Density (per square m)
8.25	2.19

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 for data delivered to date*

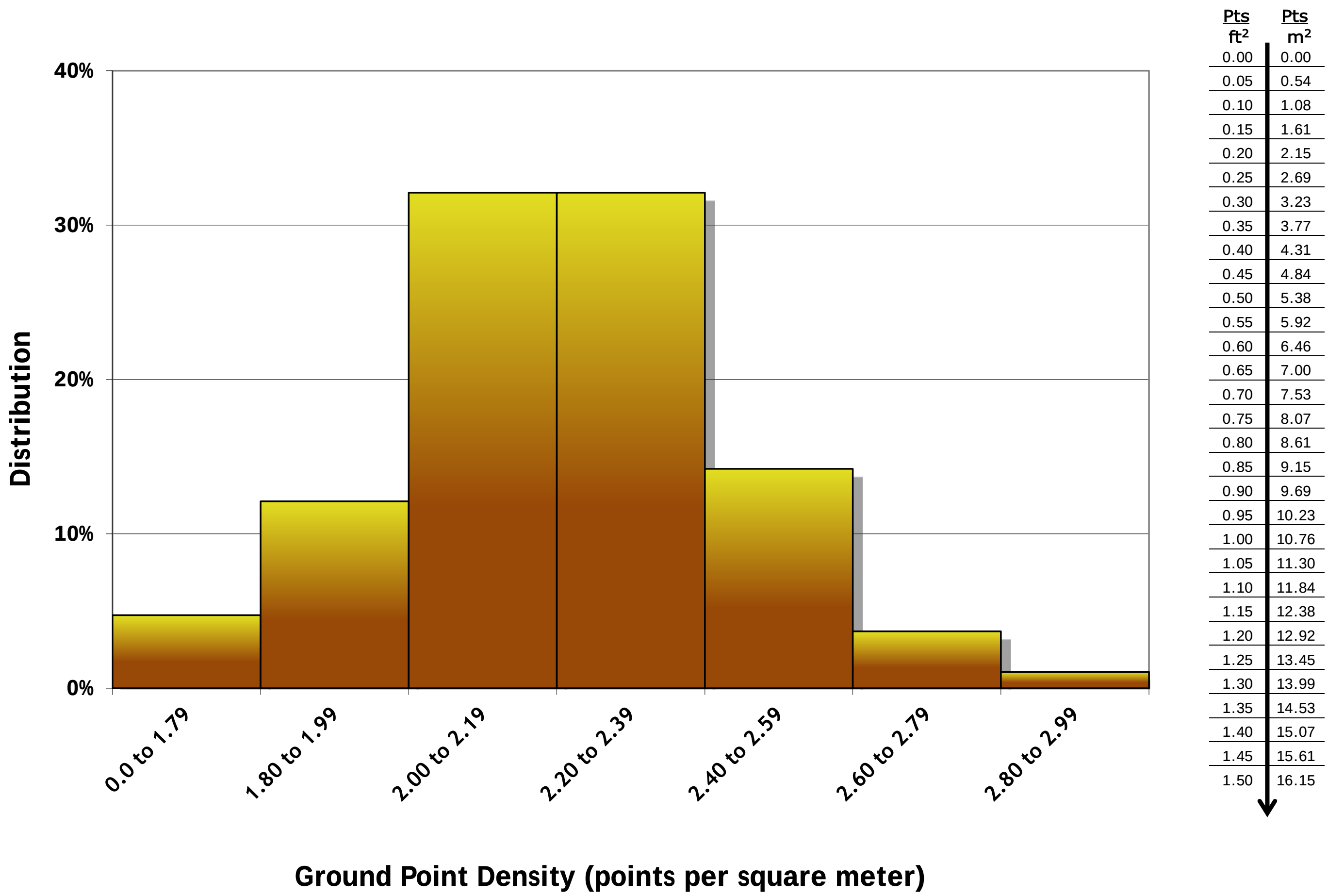
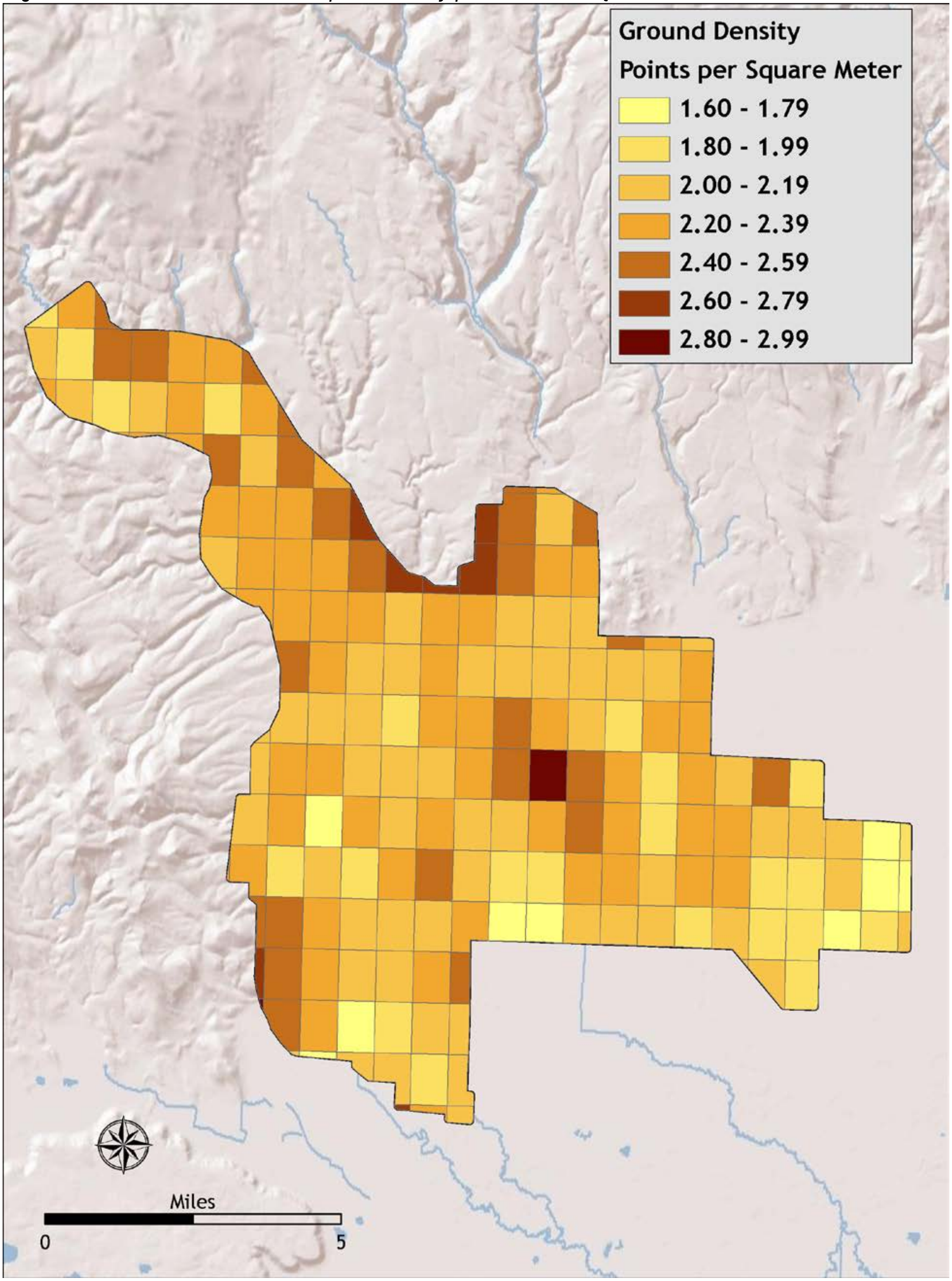


Figure 4.4. *Ground-classified laser point density per 0.75' USGS Quad for data delivered to date.*



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 Burns 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 8/17/2011

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 Eastern view of Silvies River and Central Oregon Highway just North of Burns, Oregon. Image is a LiDAR point could coloted with RGB values from NAIP imagery.

Figure 5.2. Northern view of Silvies River just Northeast of Burns, Oregon. Image is a LiDAR point cloud colored with RGB values from NAIP imagery.