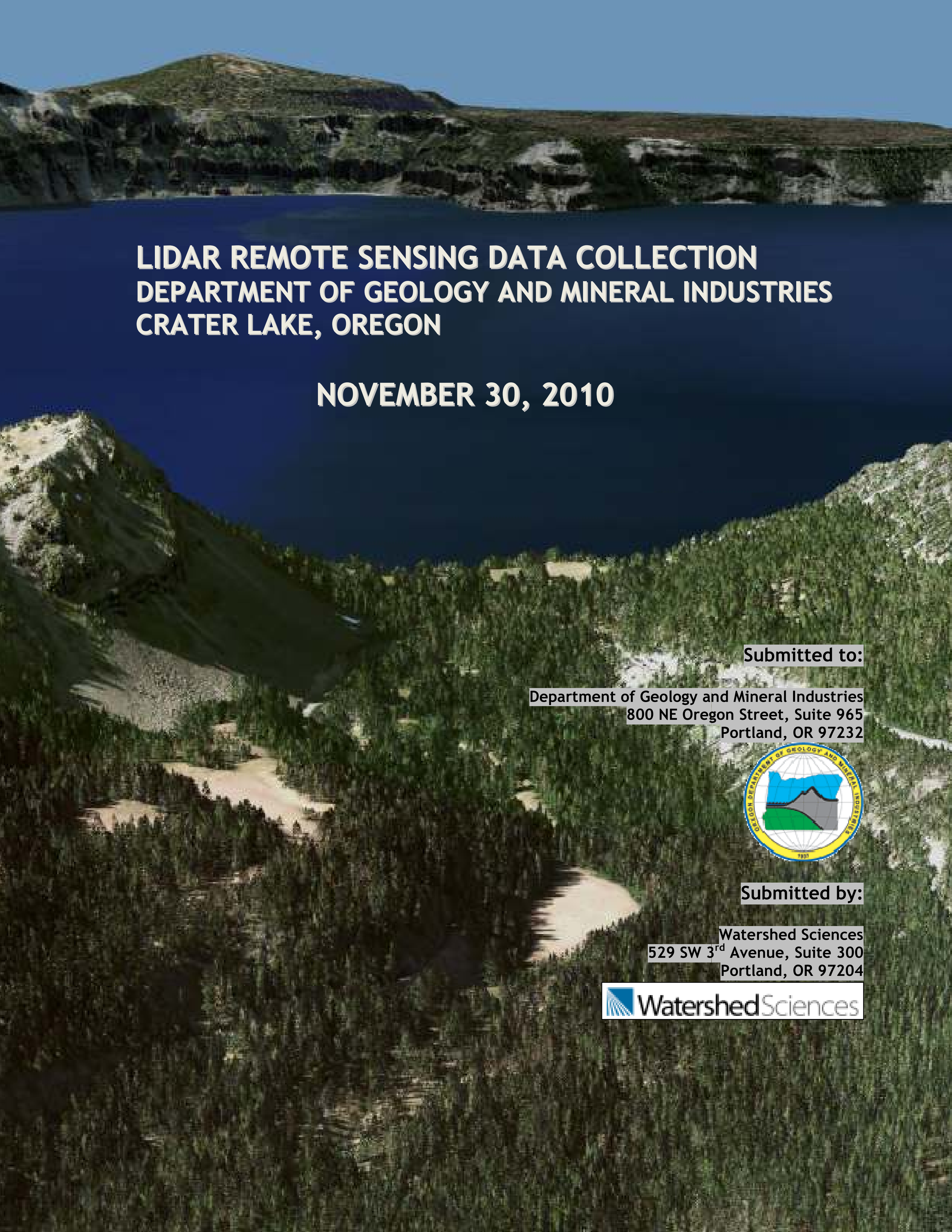

LIDAR REMOTE SENSING DATA COLLECTION
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
CRATER LAKE, OREGON

NOVEMBER 30, 2010

Submitted to:

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LiDAR Remote Sensing Data Collection:
DOGAMI, Crater Lake Study Area

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1. Overview

1.1 Study Area

Watershed Sciences, Inc. collected Light Detection and Ranging (LiDAR) data of the Crater Lake study area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 283 square miles (181,081 acres) and the total area flown (TAF) covers 308 square miles (197,011 acres). The TAF acreage is greater than the original AOI acreage due to buffering and flight planning optimization (**Figure 1.1** below). DOGAMI data are delivered in OGIC(HARN): Projection: Oregon Statewide Lambert Conformal Conic; horizontal and vertical datums: NAD83 (HARN)/NAVD88(Geoid03); Units: International Feet.

Figure 1.1. *DOGAMI Crater Lake study area.*

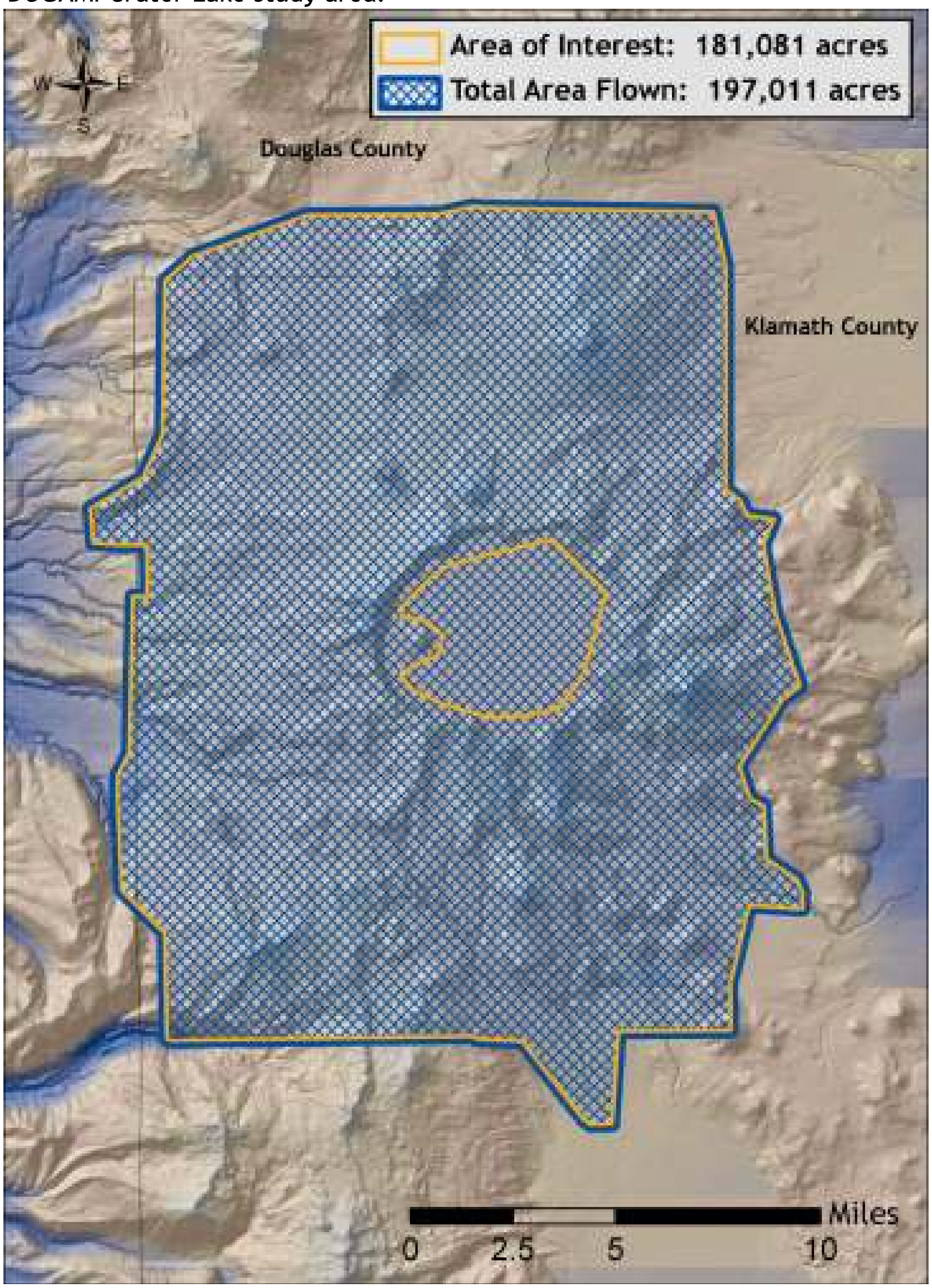
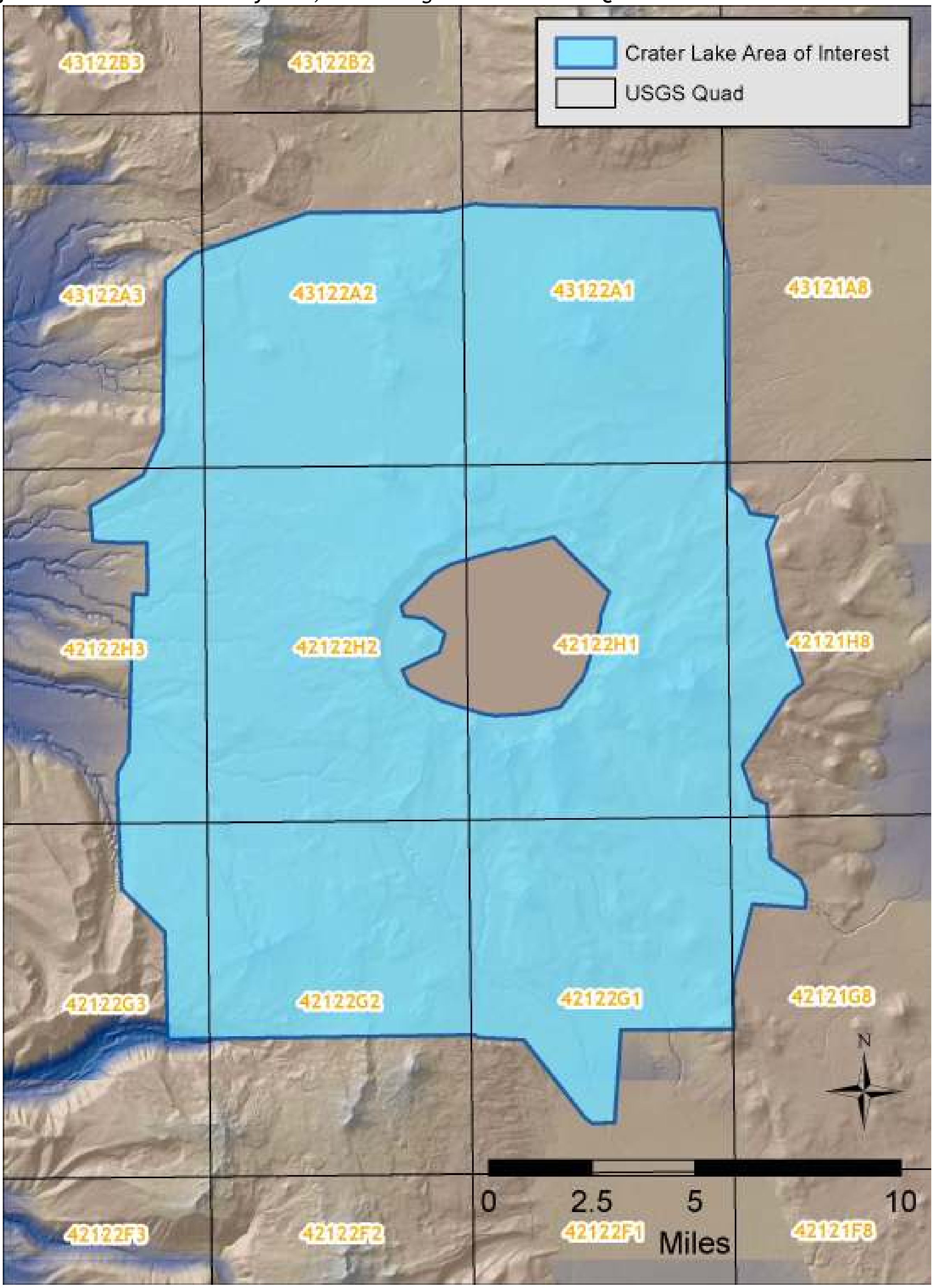


Figure 1.2. *Crater Lake study area, illustrating the AOI in USGS Quad delineation.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized four Leica LiDAR systems and three aircraft. ALS60 sensors were mounted in both a Cessna Caravan 208B and a Partenavia P-68. Two ALS50 Phase II sensors were co-mounted in a separate Cessna Caravan 208B. The Leica systems were set to acquire ≥83,000 laser pulses per second (i.e. 83 kHz pulse rate) and flown at 900 (ALS60) and 1300 (ALS50) meters above ground level (AGL), capturing a scan angle of ±14^{o} and ±13^{o} from nadir[1] respectively. 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*

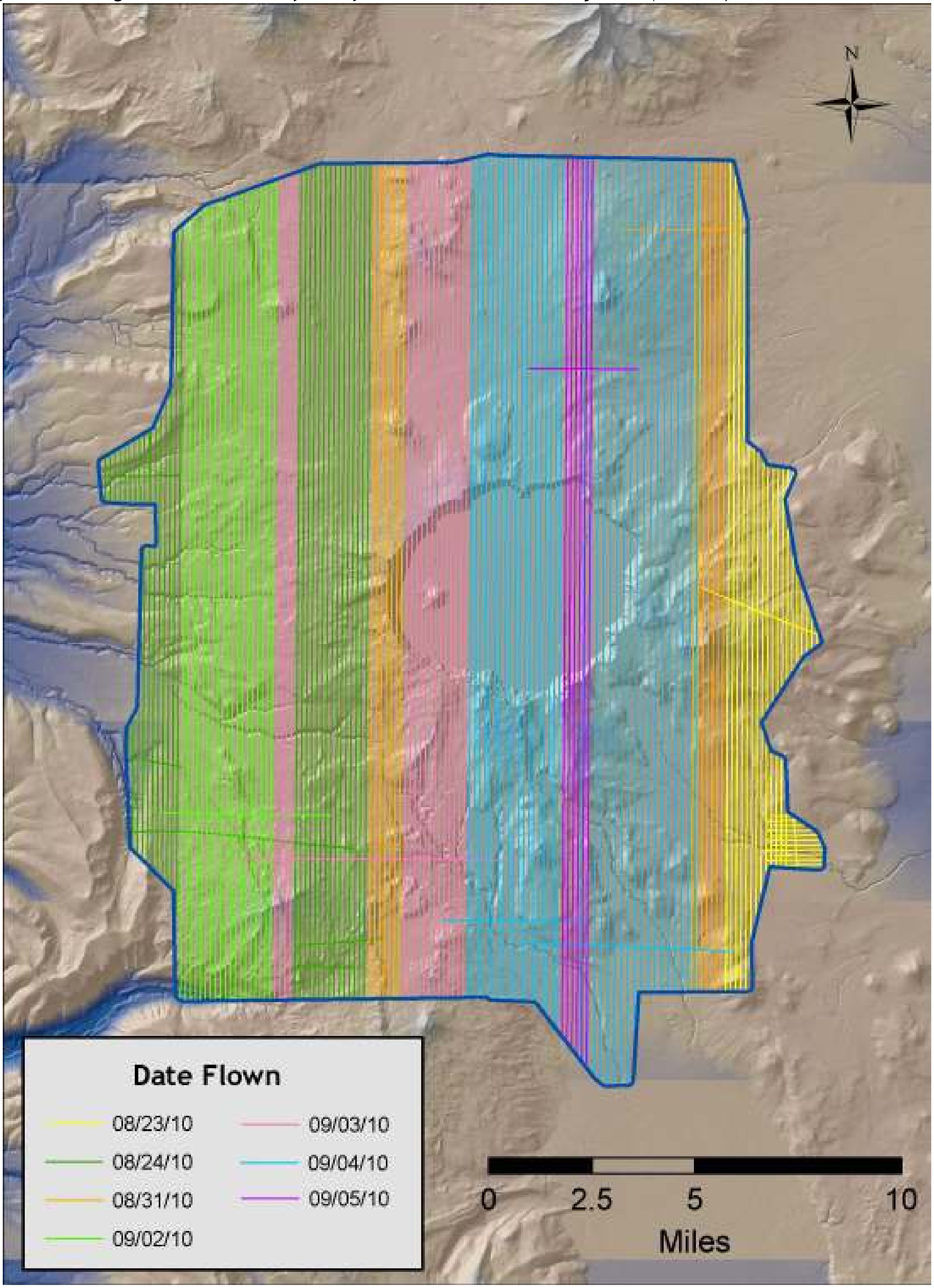
Sensors	Leica ALS60 and ALS50 Phase II
Survey Altitude (AGL)	900 m and 1300 m
Pulse Rate	>83 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	30^{o}(900m AGL) and 28^{o}(1300m AGL)
Roll Compensated	Up to 15^{o}
Overlap	100% (50% Side-lap)

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 study area.

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 study area.

[1] Nadir refers to the vector perpendicular 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. *Flightlines and dates flown for the Crater Lake study area (n = 220).*



2.2 Ground Survey – Instrumentation and Methods

During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over either previously established or newly set monuments. 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 positional 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 all points within the survey area(s).

2.2.1 Instrumentation

For this study area all Global Navigation Satellite System (GNSS[3]) survey work utilizes a Trimble GPS receiver model R7 with a Zephyr Geodetic antenna with ground plane for static control points. The Trimble GPS R8 unit is used primarily for Real Time Kinematic (RTK) work but can also be used as a static receiver. For RTK data, the collector begins recording after remaining stationary for five seconds then calculating the pseudo range position from at least three epochs with the relative error under 1.5 cm horizontal and 2.0 cm vertical. 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

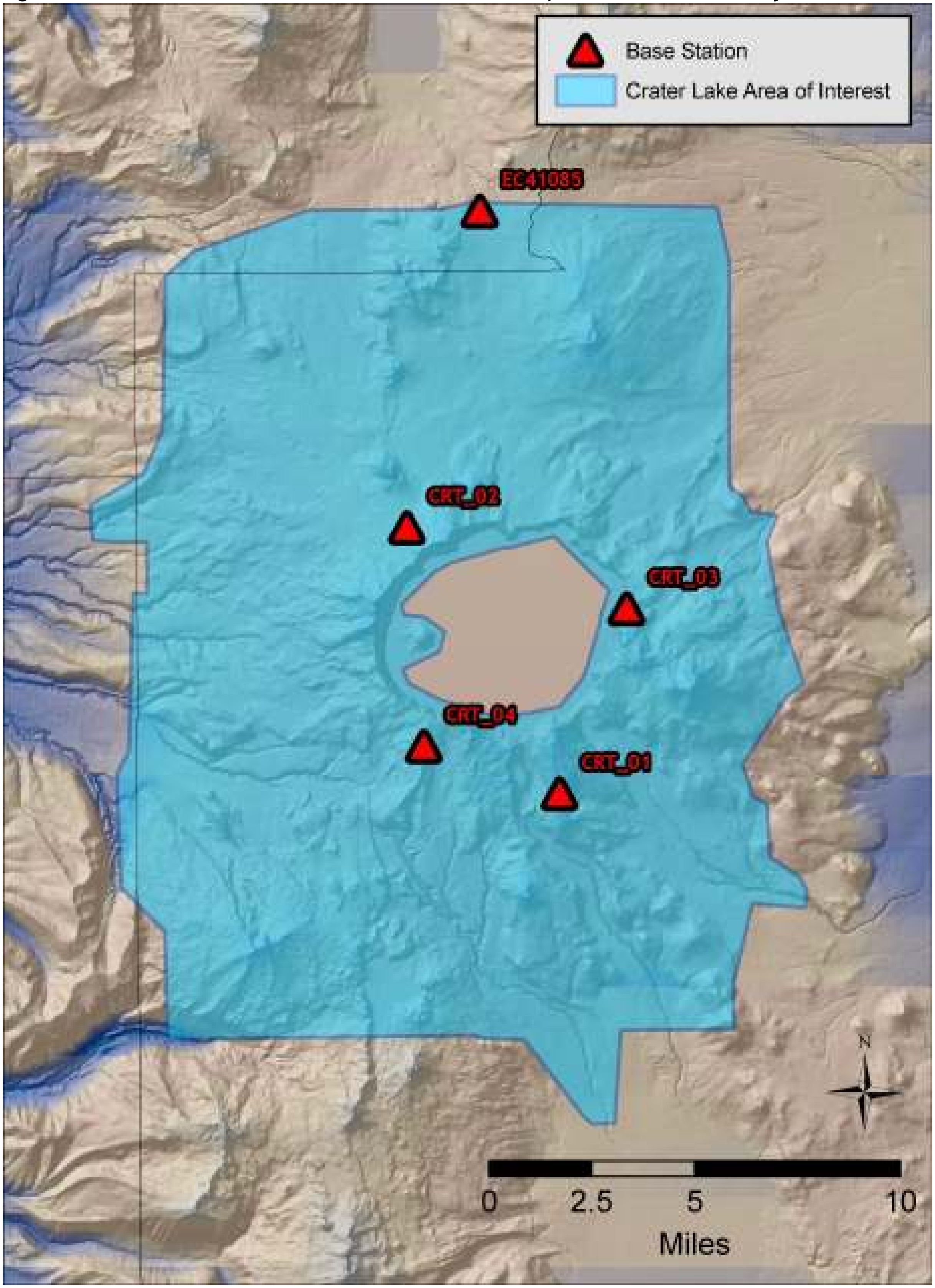
2.2.2 Monumentation

Whenever possible, existing and established survey benchmarks 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" rebar topped with an aluminum cap stamped "WATERSHED SCIENCES INC," the year, and point name, as in the photo below. Monument coordinates are provided in **Table 2.2** and shown in **Figure 2.2** for the AOI.

Table 2.2. *Base Station Surveyed Coordinates, (NAD83/NAVD88, OPUS corrected) used for kinematic post-processing of the aircraft GPS data for the Crater Lake study area.*

	Datum NAD83(HARN)		GRS80
Base Station ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
EC41085	43 05 19.75697	122 07 00.30649	1744.463
CRT_02	42 58 39.93048	122 09 11.91472	2108.462
CRT_03	42 56 54.40424	122 02 54.67769	2153.677
CRT_04	42 54 02.88942	122 08 46.55752	2114.885
CRT_01	42 53 01.02373	122 04 53.61398	2233.5085

Figure 2.2. Base station and real time kinematic locations for the Crater Lake study area.



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 six hours. At the beginning of every session the tripod and antenna are reset, resulting in two independent instrument heights and data files. Data is collected at a rate of 1Hz using a ten degree mask on the antenna.

The ground crew uploads the GPS data to our 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 three CORS stations resulting in a fully adjusted position. After multiple days of data have been collected at each monument, accuracy and error ellipses are calculated from the OPUS reports. This information leads to a rating of the monument based on FGDC-STD-007.2-1998[4] Part 2, table 2.1 at the 95% confidence level. When a statistically stable position is found, CORPSCON[5] 6.0.1 software is used to convert the UTM positions to geodetic positions. This geodetic position is used for processing the LiDAR data.

RTK and aircraft mounted GPS measurements are made during periods with PDOP[6] less than or equal to 3.0 and with at least six satellites in view of both a stationary reference receiver and the roving receiver. Static GPS data are collected in a continuous sesion averaging the high PDOP into the final solution, the same way CORS stations operate. RTK positions are 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).

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 are collected 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 include manholes and other flat utility structures that have clearly indicated center points. In the absence of utility structures, a PK nail can be driven into asphalt or concrete and marked with paint.

Multiple differential GPS units are used in the ground-based RTK portion of the survey. To collect accurate ground surveyed points, a GPS base unit is set up over monuments to broadcast a kinematic correction to a roving GPS unit. The ground crew uses a roving unit to receive radio-relayed kinematic corrected positions from the base unit. This RTK survey allows precise location measurements ($\sigma \leq 1.5$ cm).

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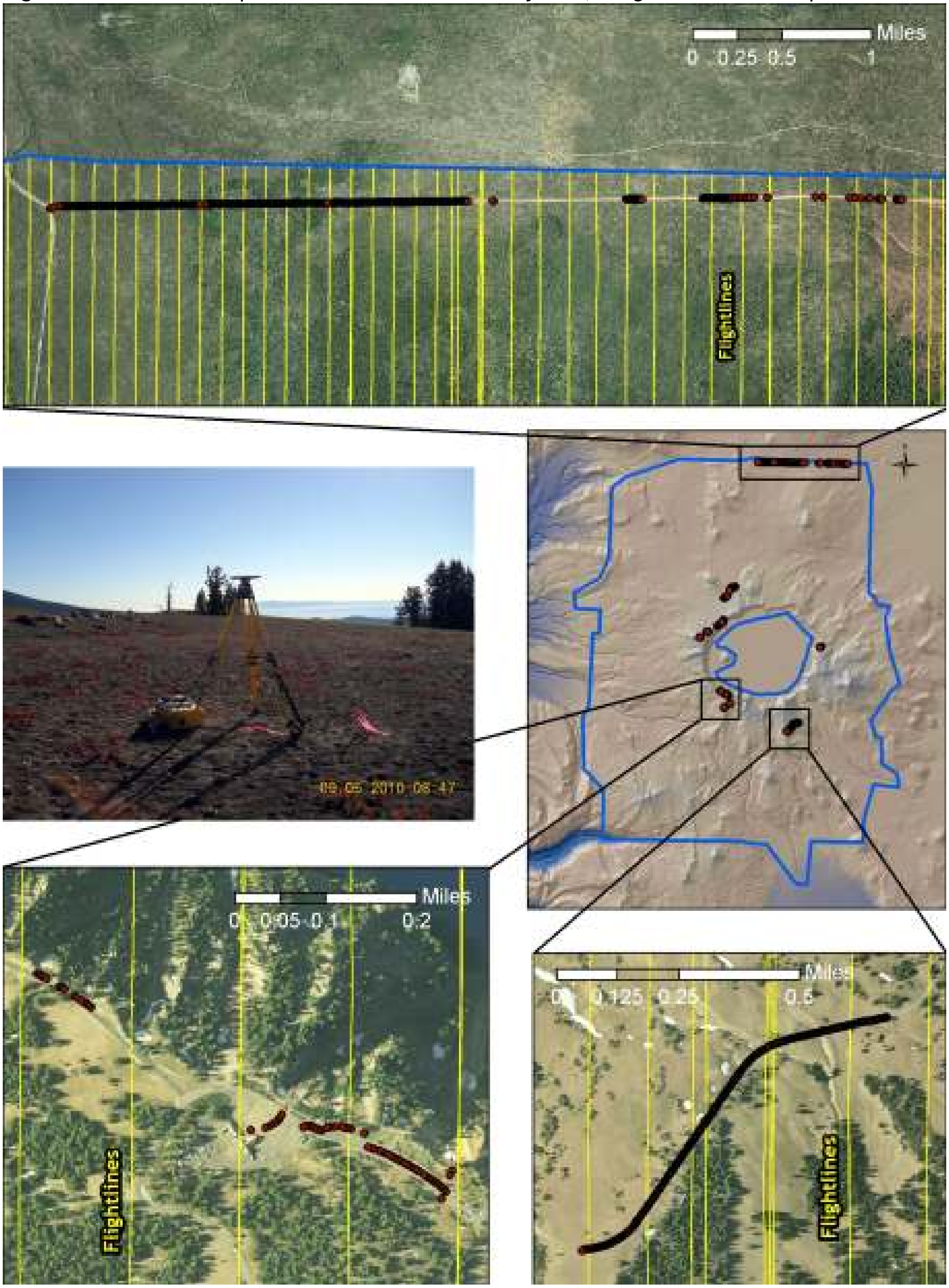
4 Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards
5 U.S. Army Corps of Engineers , Engineer Research and Development Center Topographic Engineering Center software
6 PDOP: Point Dilution of Precision is a measure of satellite geometry, with smaller numbers indicating better geometry between a point and satellites

Figure 2.3 *Selected RTK points in the Crater Lake study area; images are NAIP orthophotos.*



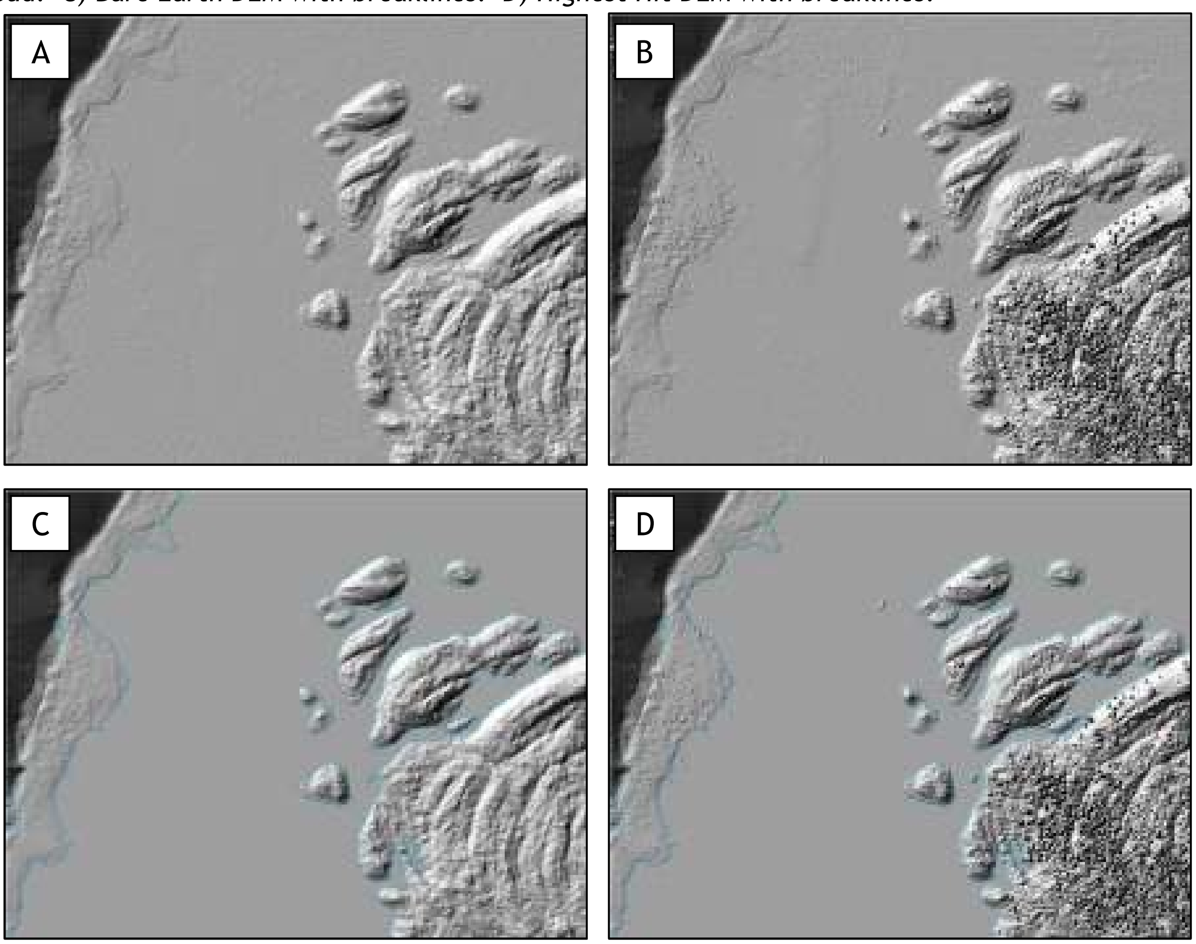
3. Breaklines

3.1 Methodology (Crater Lake)

Breaklines were utilized in the creation of the Bare-Earth and Highest-Hit DEMs in an effort to make these data sets USGS compliant (USGS NGP Base LiDAR Specification Version 13 Appendix 2). LiDAR points known to be water were classified as such (ASPRS code=9) and their elevations were sampled to arrive at an upper threshold defining the water surface elevation at the time of acquisition. Areas where there were no laser returns were assumed to be part of the water surface due to signal absorption and reflection known to occur on wetted surfaces. Generalized 3d polylines were then generated to encompass all areas considered to be water and were assigned the water surface elevation value determined previously (6174.86 feet). Only "flat" water bodies greater than 2 acres were considered for hydro-enforcement. "Islands" were retained in the Bare-Earth DEMS if greater than 1000 square feet.

Bare-Earth DEMS were created by triangulating all "ground" classified points including the inserted 3d breaklines utilizing TerraSolid's TerraScan and TerraModeler software. The Highest-Hit DEMS were generated from "ground" and "default" classified points. In instances where "Water" classified points had the highest elevation value, the water surface elevation of 6174.86 feet was used.

Figure 3.1. *A) Bare Earth DEM derived from point cloud. B) Highest Hit DEM derived from point cloud. C) Bare Earth DEM with breaklines. D) Highest Hit DEM with breaklines.*



4. Accuracy

4.1 Relative Accuracy Calibration Results

Relative accuracy statistics are based on the comparison of 220 flightlines and over 5 billion points for the entire study area.

- Project Average = 0.15ft (0.05m)
- Median Relative Accuracy = 0.15ft (0.05m)
- 1σ Relative Accuracy = 0.16ft (0.05m)
- 2σ Relative Accuracy = 0.18ft (0.06m)

Figure 4.1. *Statistical relative accuracies, non slope-adjusted.*

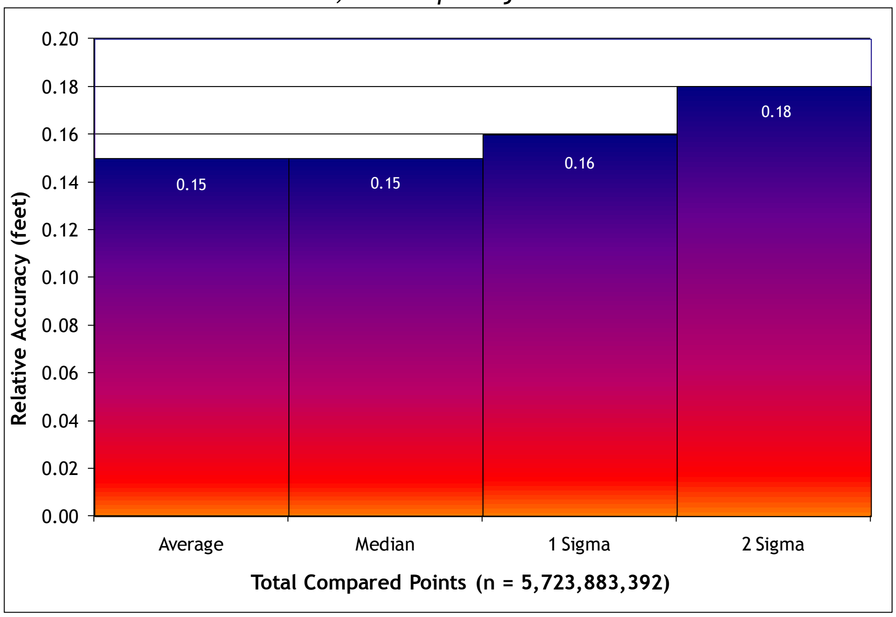
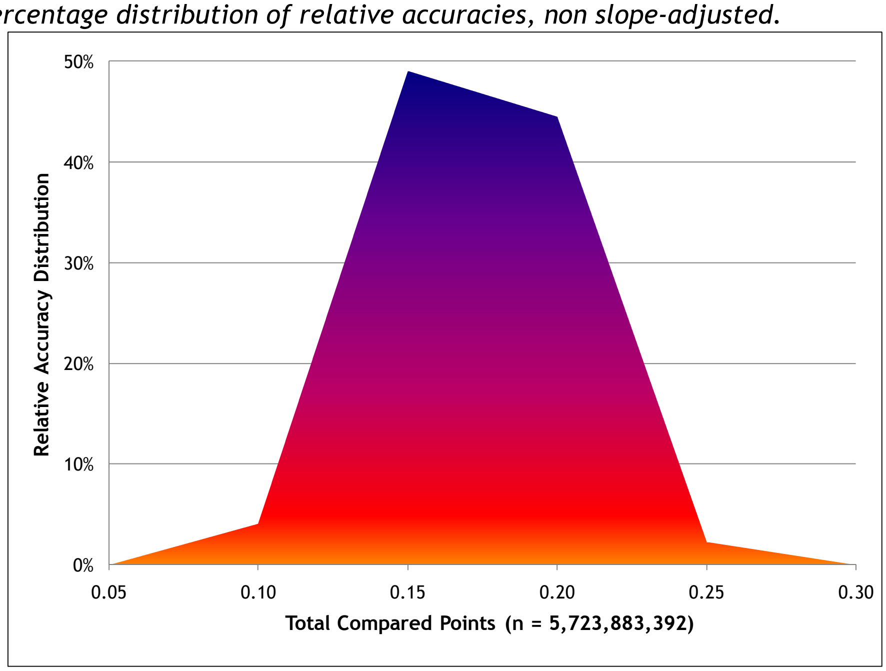


Figure 4.2. *Percentage distribution of relative accuracies, non slope-adjusted.*



4.2 Absolute Accuracy

Absolute accuracy compares known Real Time Kinematic (RTK) ground survey points to the closest laser point. For the Crater Lake study area, 1,512 RTK points were collected. Accuracy statistics are reported in **Table 3.1** and shown in **Figures 3.3-3.4.**

Table 4.1. *Absolute Accuracy – Deviation between laser points and RTK survey points.*

Sample Size (n): 1,512	
Root Mean Square Error (RMSE): 0.15 feet (0.05 m)	
Standard Deviations	**Deviations**
1 sigma (σ): 0.15 feet (.05m)	**Minimum Δz:** -0.55 feet (-.17m)
2 sigma (σ): 0.30 feet (.09m)	**Maximum Δz:** 0.44 feet (0.13m)
	Average Δz: 0.12 feet (.04m)

Figure 4.3. *Crater Lake Study area histogram statistics*

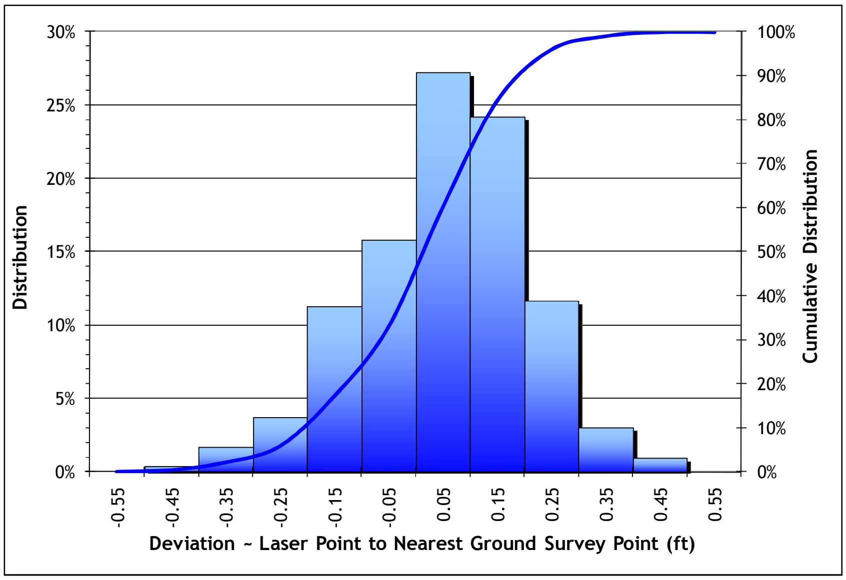
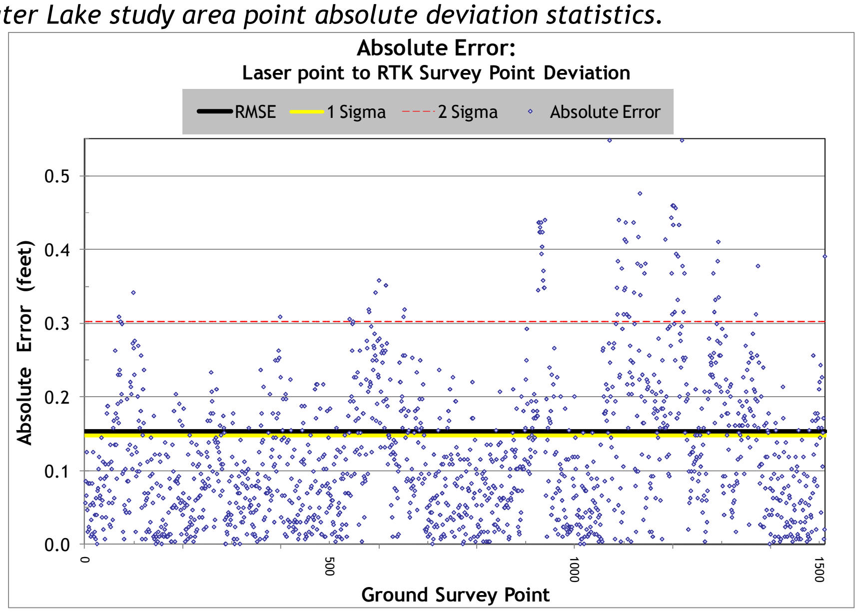


Figure 4.4. *Crater Lake study area point absolute deviation statistics.*



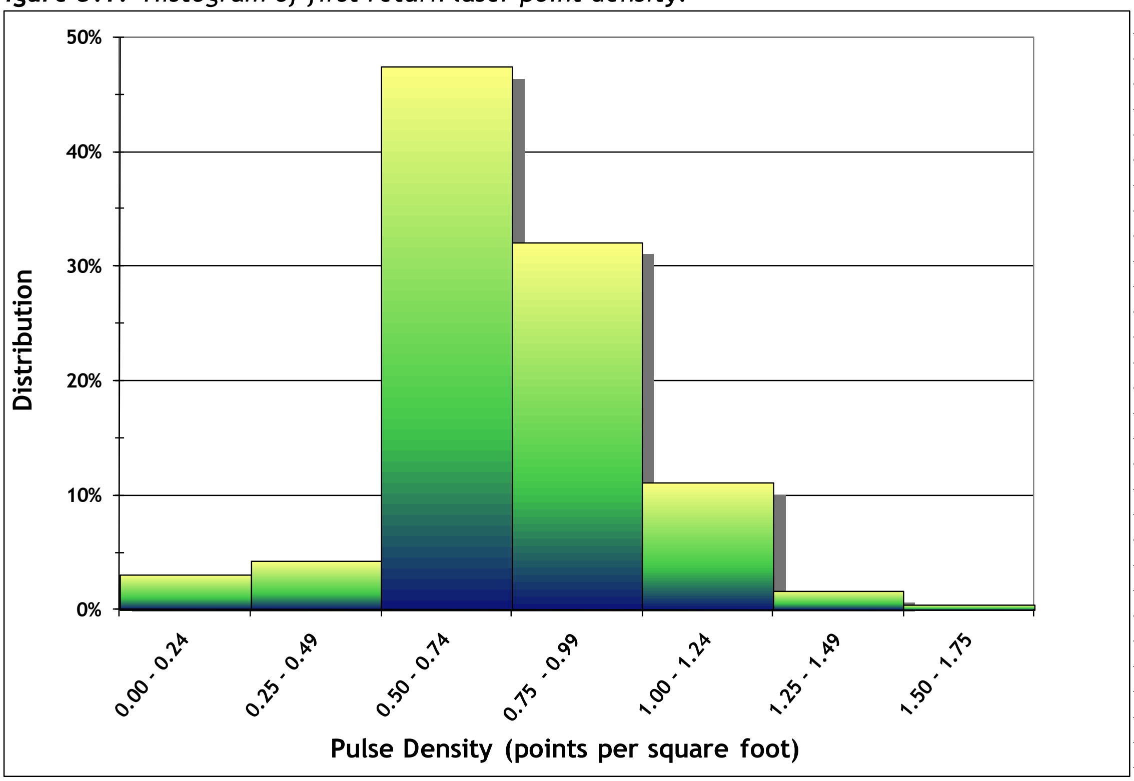
5. Data Density/Resolution

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 distributions of 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 5.1. *Average density statistics for Crater Lake data.*

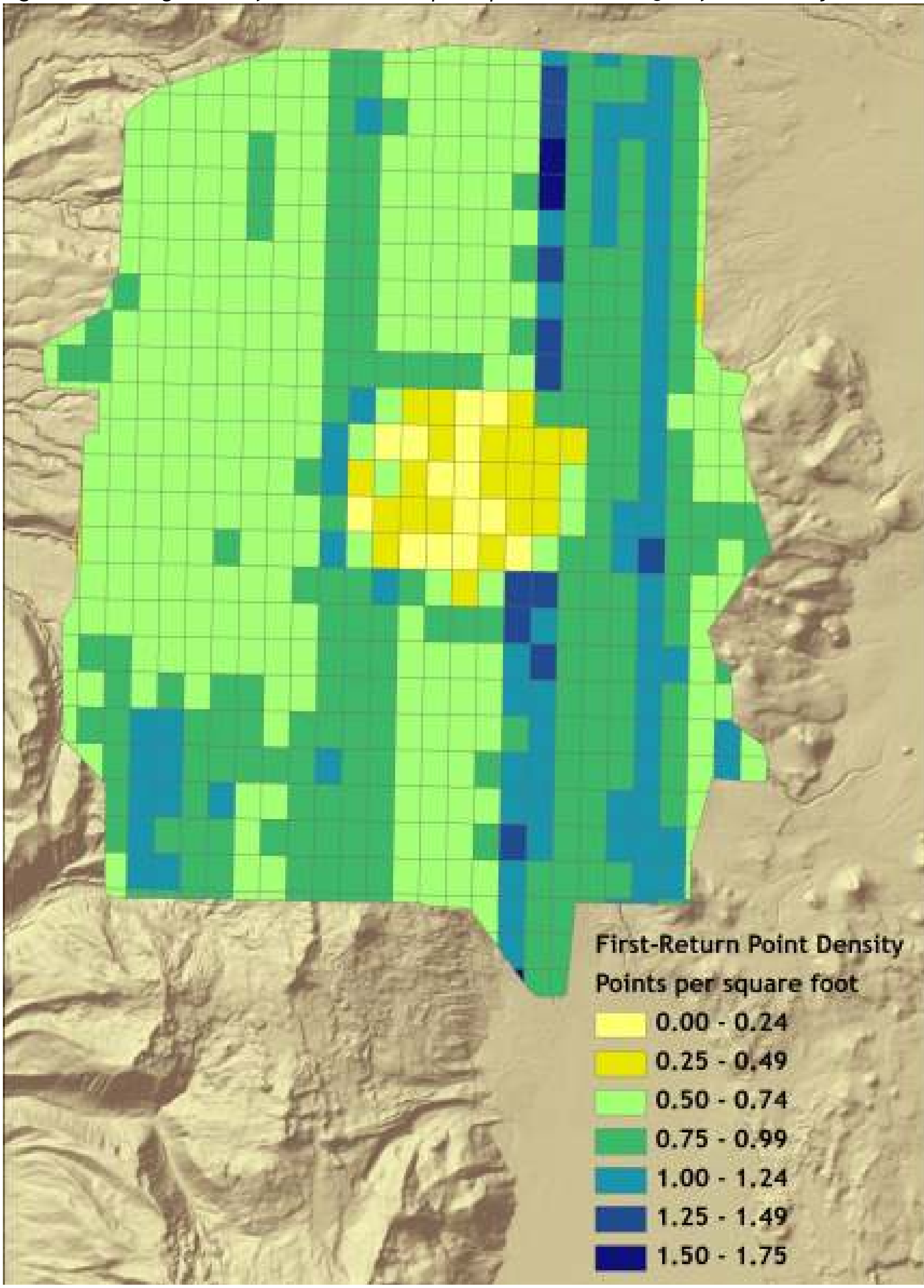
Average Pulse Density (per square ft)	Average Pulse Density (per square m)	Average Ground Density (per square ft)	Average Ground Density (per square m)
0.78	8.39	0.15	1.63

Figure 5.1. *Histogram of first return laser point density.*



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

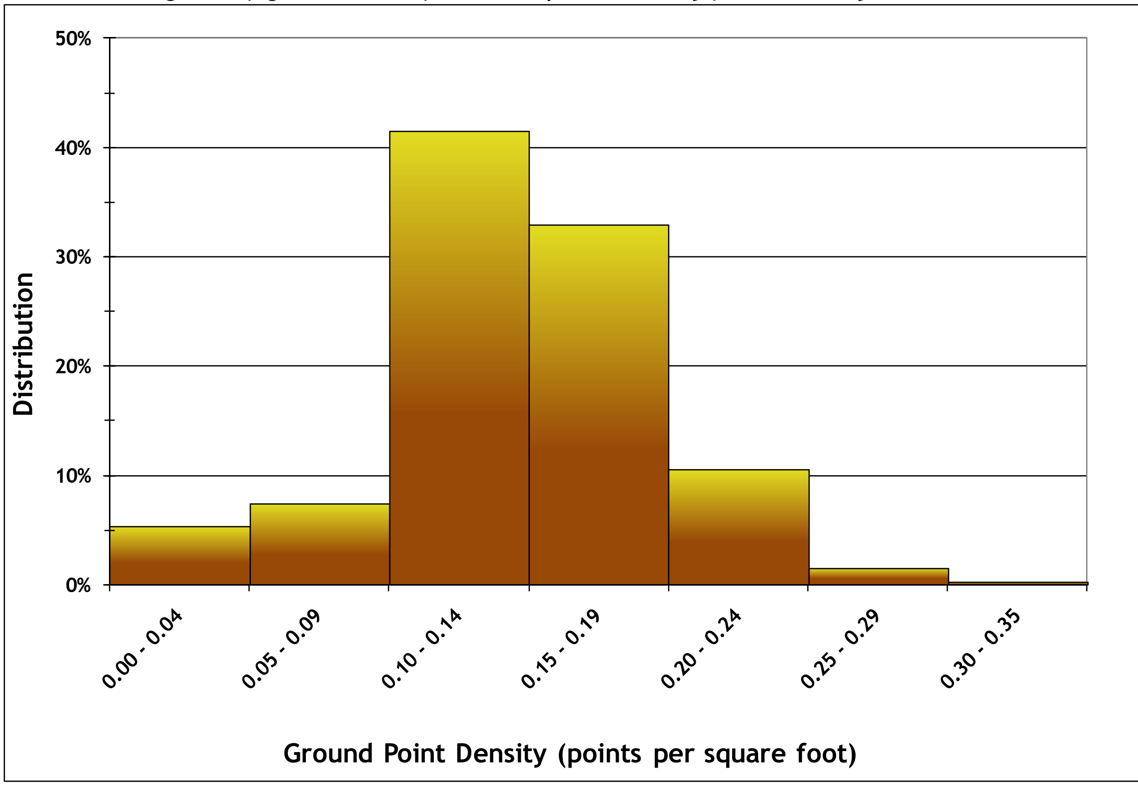
Figure 5.2. Image shows first return laser point per 0.75' USGS Quad for the study area.



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

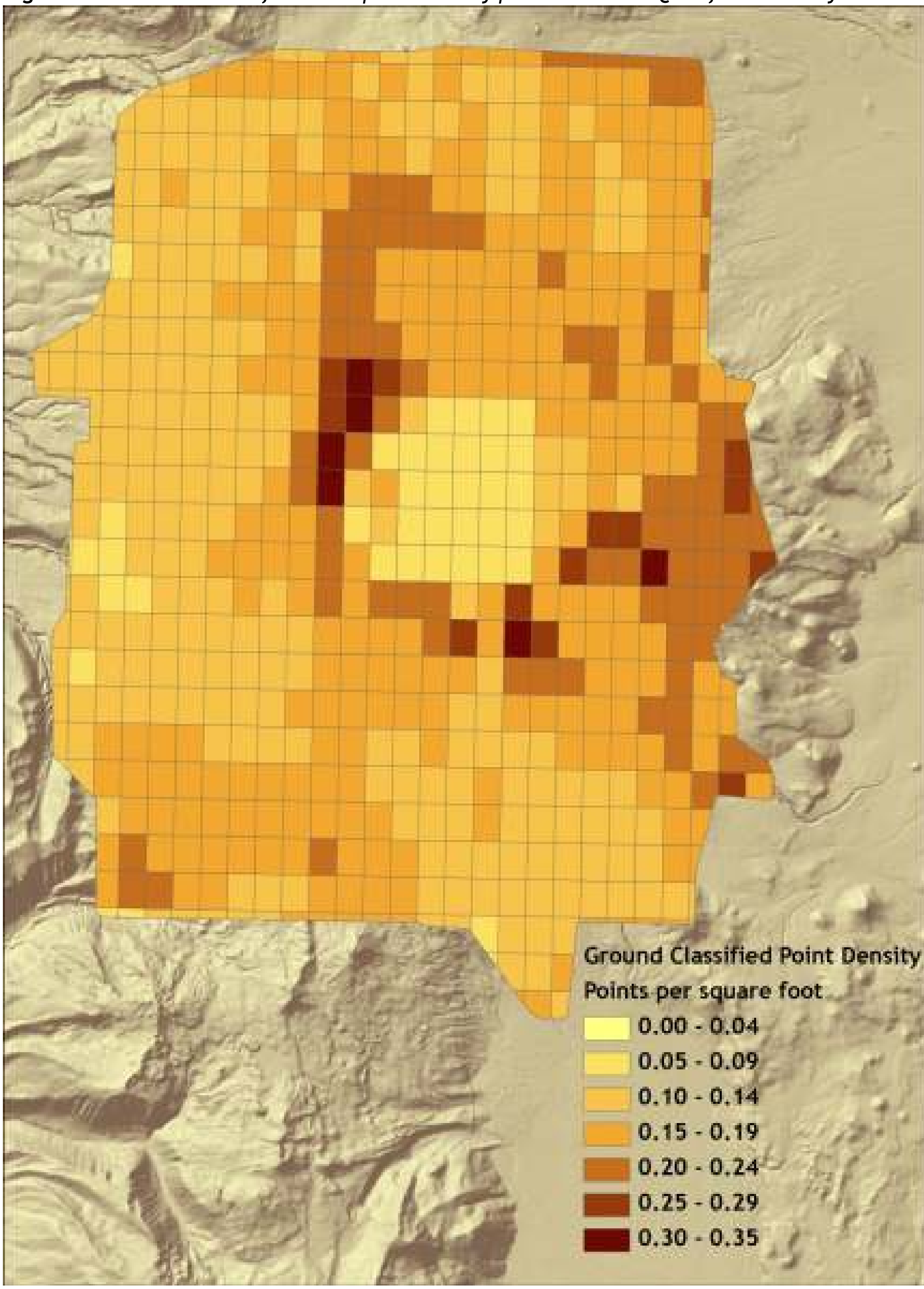
Ground classifications were derived from ground surface modeling. Supervised classifications were performed by reseeding of the ground model where it was determined that the ground model failed, usually under dense vegetation and/or at breaks in terrain, steep slopes and at bin boundaries.

***Figure 5.3**. Histogram of ground-classified laser point density for the study area.*



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 5.4**. Ground-classified laser point density per 0.75' USGS Quad for the study area.*



Pts ft^2	Pts m^2
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

6. Selected Imagery

***Figure 6.1**. Image of the Crater Lake showing view facing east. Image is derived from LiDAR data points with RGB values extracted from NAIP imagery.*

***Figure 6.2**. Image of the Wizard Island, facing Southeast. Image derived from LiDAR data points with RGB values extracted from NAIP imagery.*

Figure 5.3 *Image of the Crater Lake showing view facing North. Image is derived from LiDAR data points with RGB values extracted from NAIP imagery.*