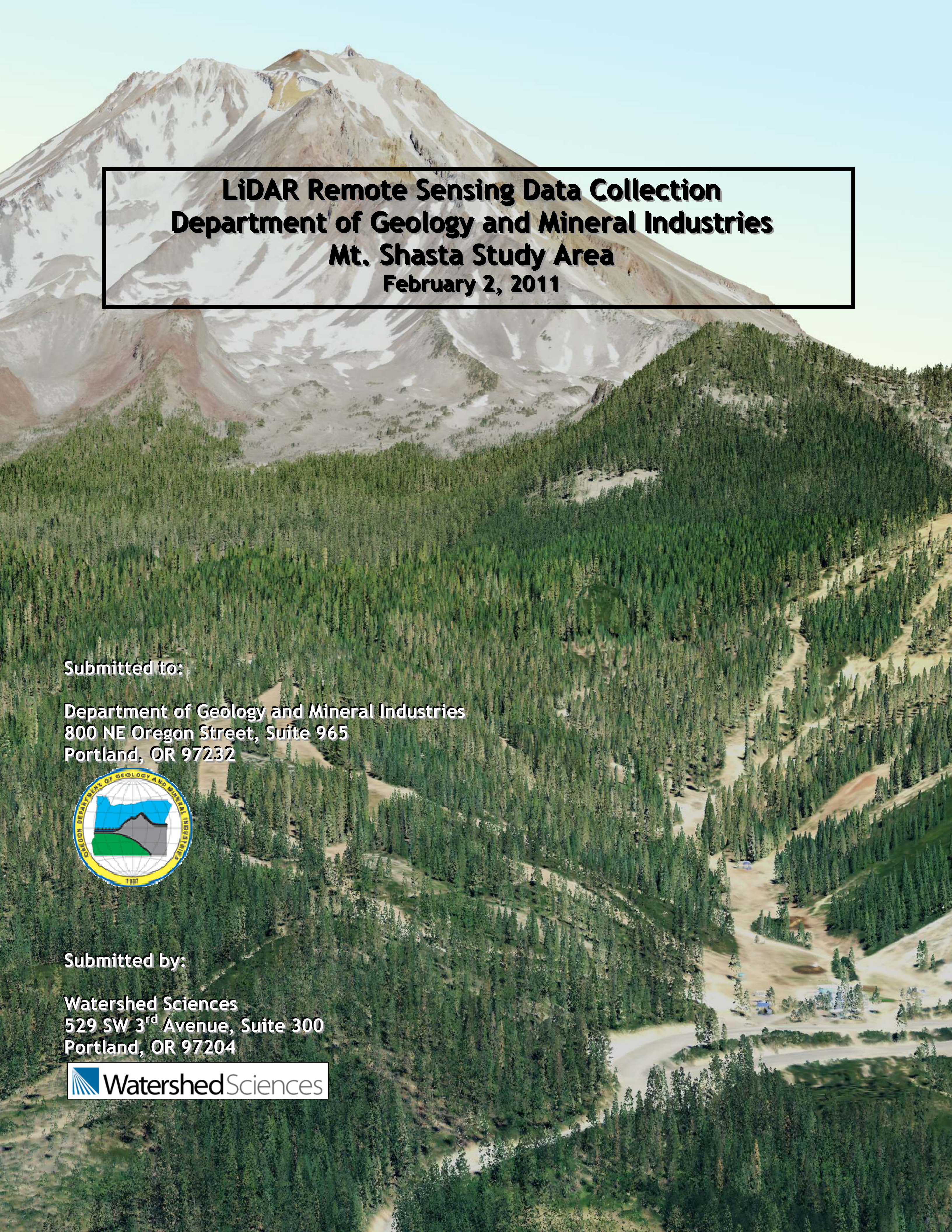

LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
Mt. Shasta Study Area
February 2, 2011

Submitted to:

Department of Geology and Mineral Industries
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Watershed Sciences

LiDAR Remote Sensing Data Collection:
DOGAMI, Mt. Shasta Study Area

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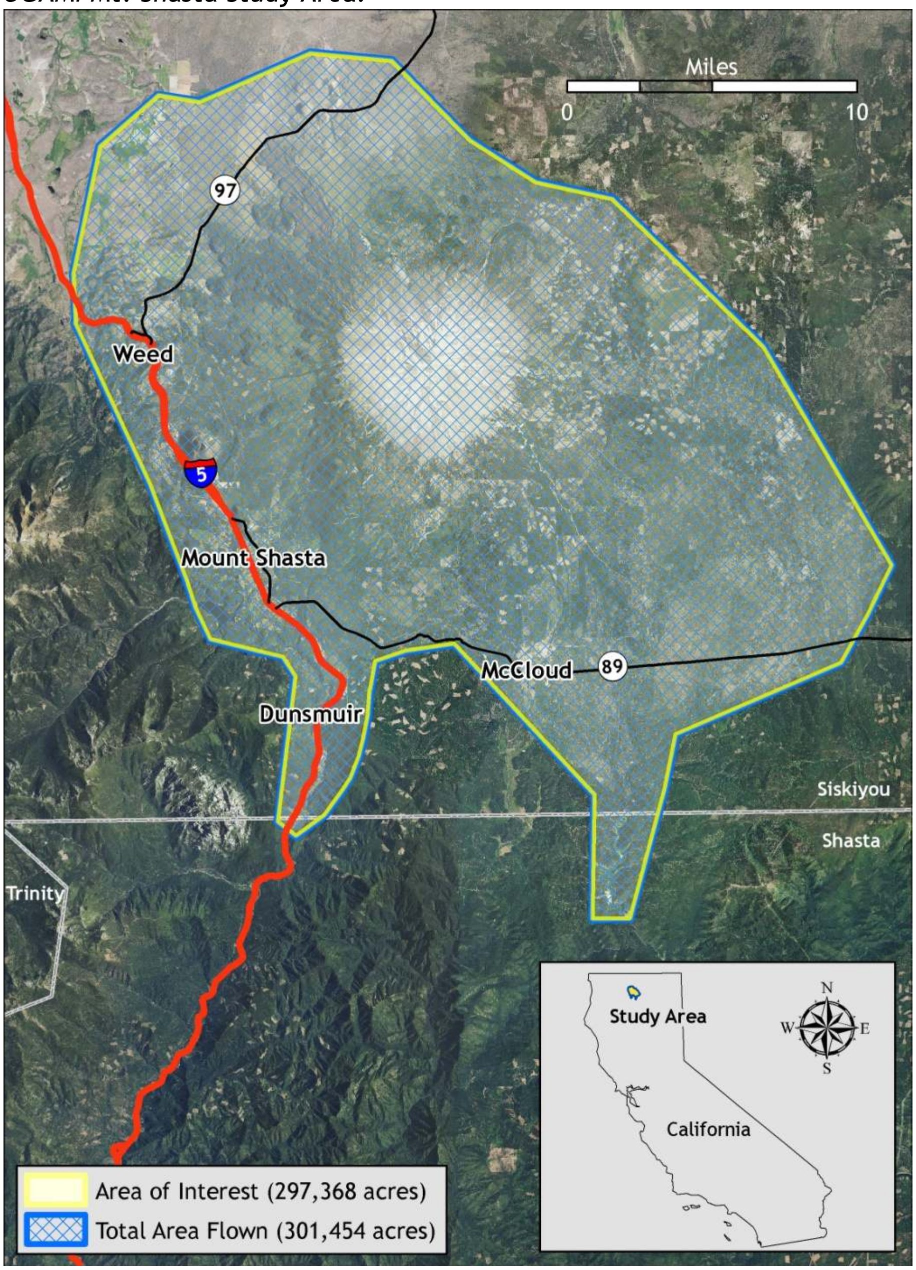
1. Overview

1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Mt. Shasta Study Area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 465 square miles (297,368 acres) and the total area flown (TAF) covers 471 square miles (301,454 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. Mt. Shasta data are delivered in UTM Zone 10; NAD83(CORS96); NAVD88(Geoid 03); Units: meters.

Figure 1.1. *DOGAMI Mt. Shasta Study Area.*

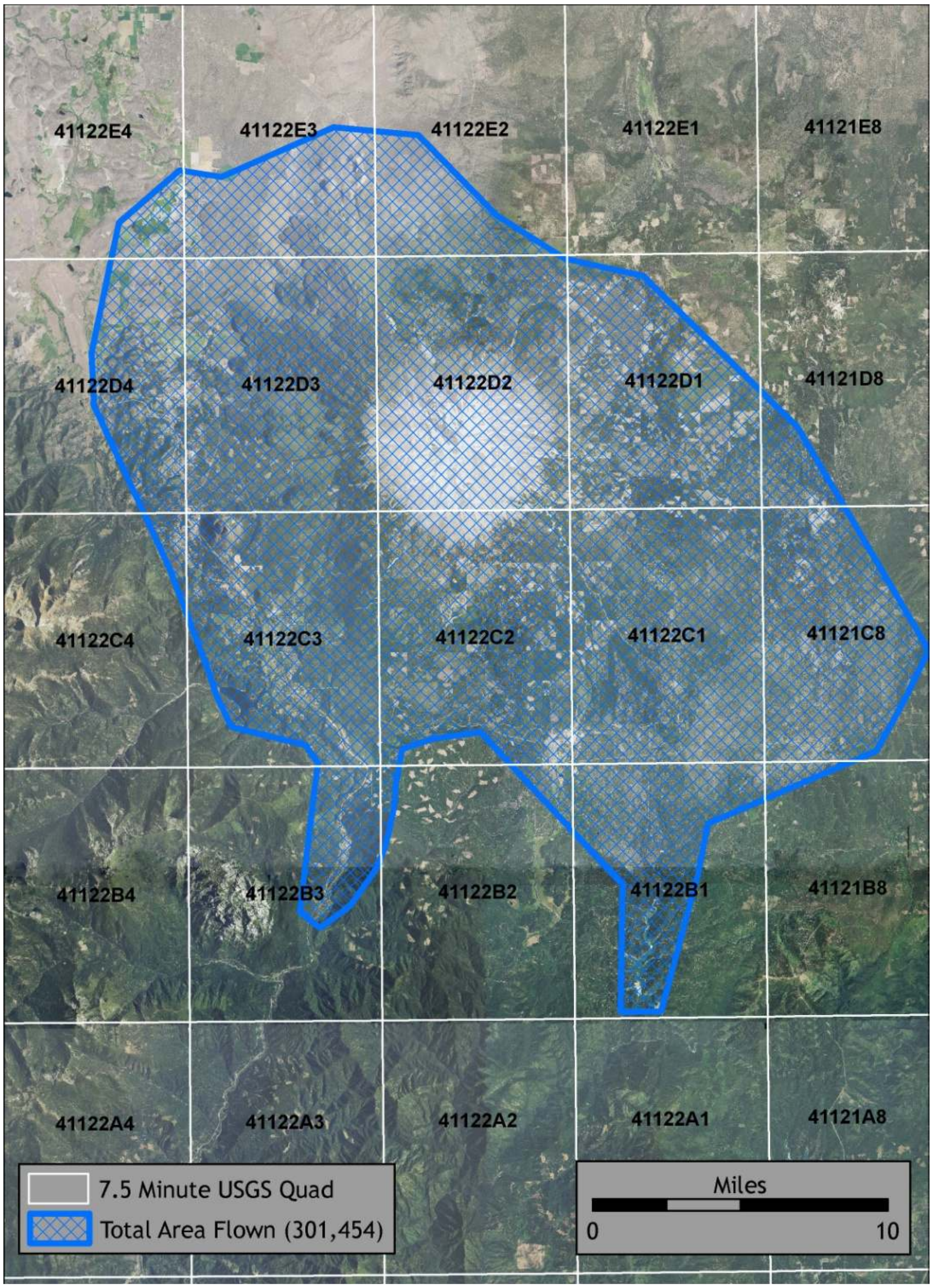


1.2 Area Delivered to Date

Total delivered acreage to date is detailed below.

DOGAMI Mt. Shasta Study Area				
	Delivery Date	Acquisition Dates	AOI Acres	TAF Acres
Delivery Area 1	February 2, 2011	July 5, 2010 – September 2, 2010	297,368	301,454

Figure 1.2. *Mt. Shasta Study Area, illustrating the delivered 7.5 minute USGS quads.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized 2 Leica ALS50 Phase II sensors co-mounted in a 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 1300 meters above ground level (AGL), capturing a scan angle of $\pm 14^{o}$ 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*

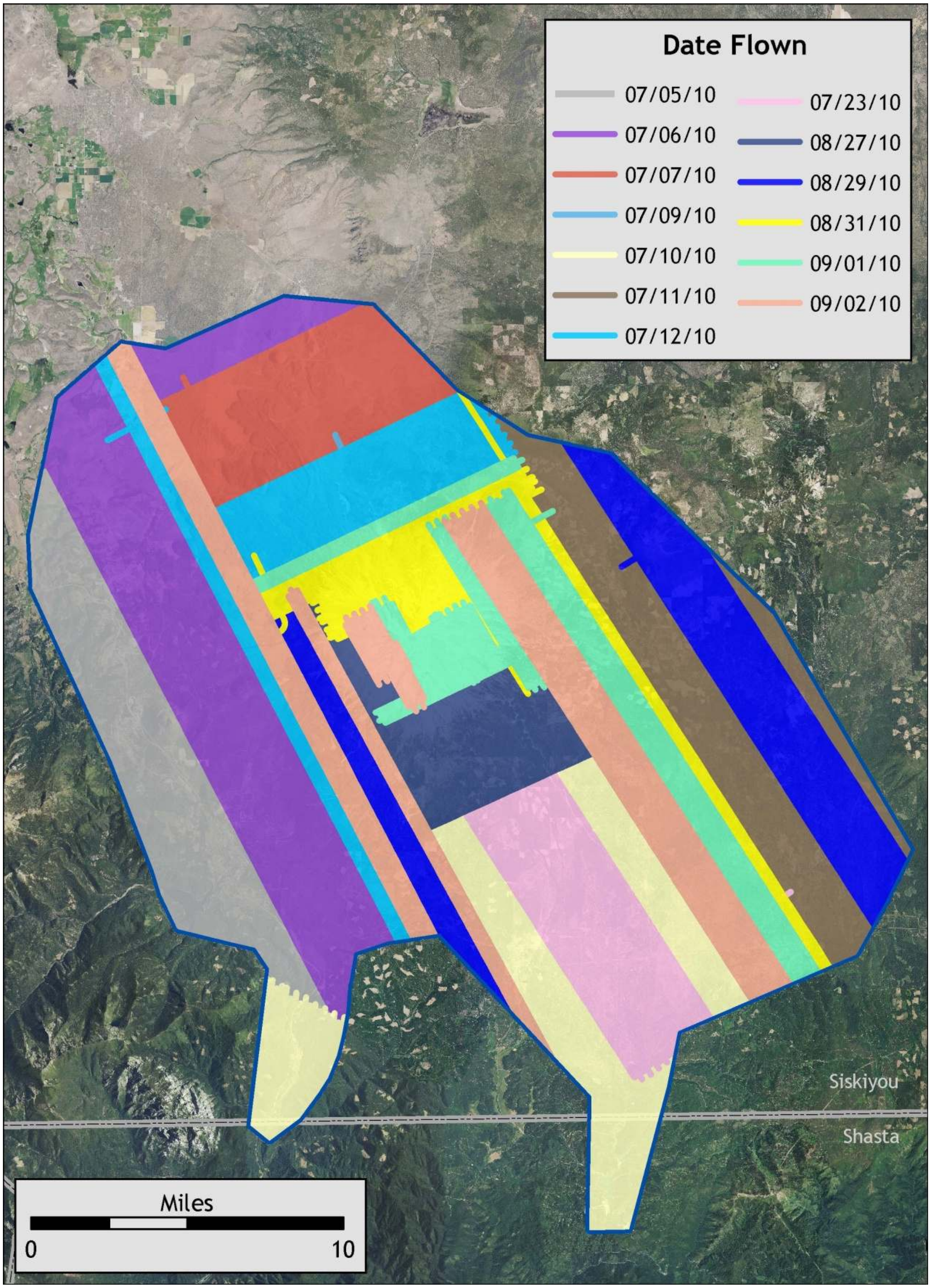
Sensors	Leica ALS50 Phase II
Survey Altitude (AGL)	1300 m
Pulse Rate	>83 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	28^{o} ($\pm 14^{o}$ from nadir)
Roll Compensated	Up to 15^{o}
Overlap	100% (50% Side-lap)

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 Mt. Shasta 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 utilizes a Trimble GPS receiver model R7 with a Zephyr Geodetic antenna with ground plane 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 where used for static data acquisition. 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. 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 California Department of Transportation (CALTRANS) 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 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 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.

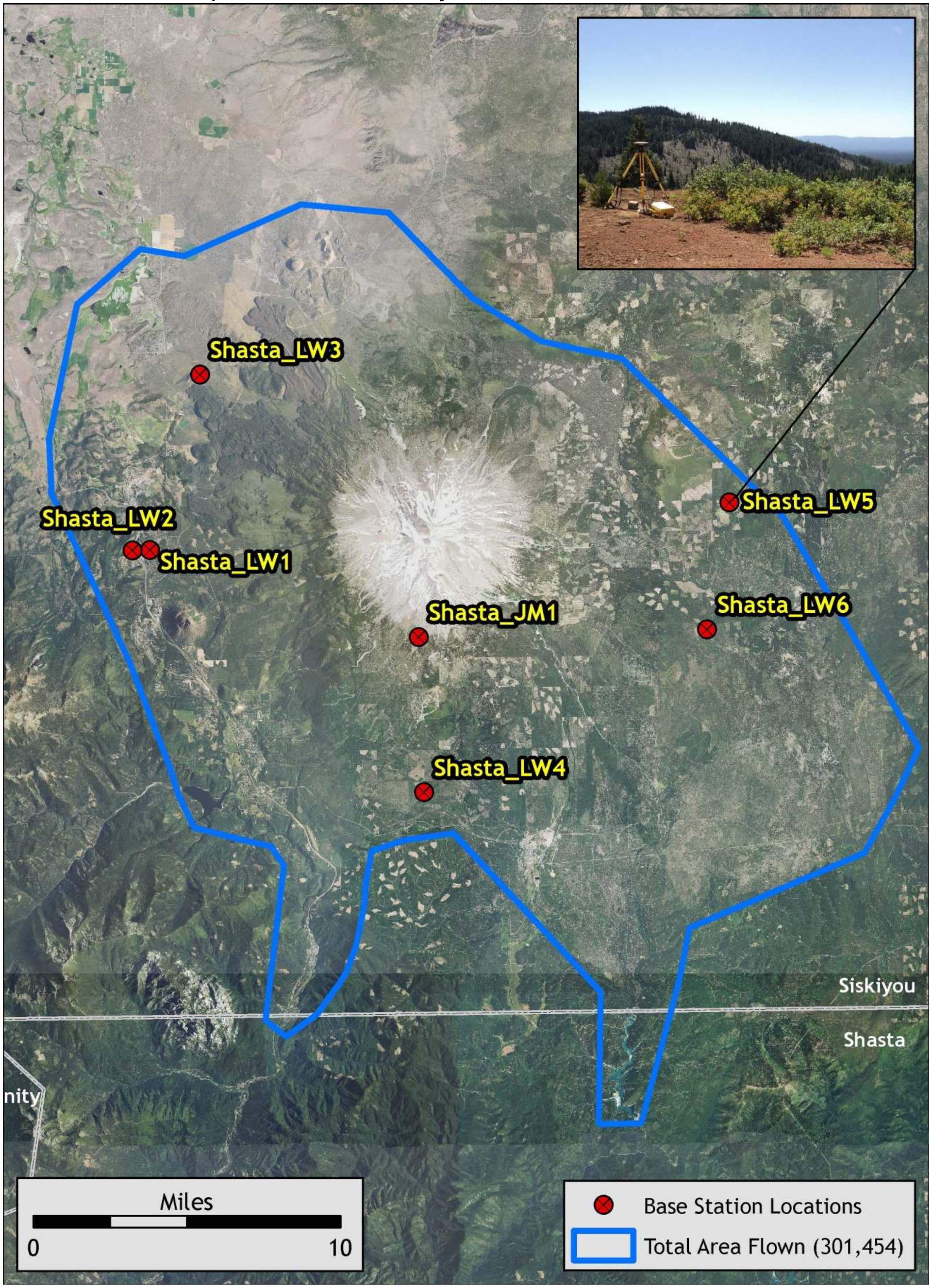
Multiple differential GPS units were used in the ground based real-time kinematic (RTK) portion of the survey. To collect accurate ground surveyed points, a GPS base unit was set up over monuments to broadcast a kinematic correction to a roving GPS unit. The ground crew used a roving unit to receive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

[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

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

	Datum NAD83 (HARN)		GRS80
Base Stations ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
Shasta_LW1	41 24 03.45538	122 22 22.65715	1116.07
Shasta_LW2	41 24 02.81084	122 23 02.56508	1104.6585
Shasta_LW3	41 29 01.20001	122 20 27.27812	1078.7325
Shasta_LW4	41 17 07.43160	122 12 09.90782	1471.1675
Shasta_LW6	41 21 39.73849	122 01 27.22312	1319.687
Shasta_LW5	41 25 15.35243	122 00 33.79785	1558.674
Shasta_JM1	41 21 31.67560	122 12 18.33616	2302.615

Figure 2.2. *Base stations for the Mt. Shasta Study Area.*



For the Mt. Shasta study area, 3,236 RTK (Real-time kinematic) points were. **Figures 2.3 – 2.4** show detailed views of selected RTK locations.

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

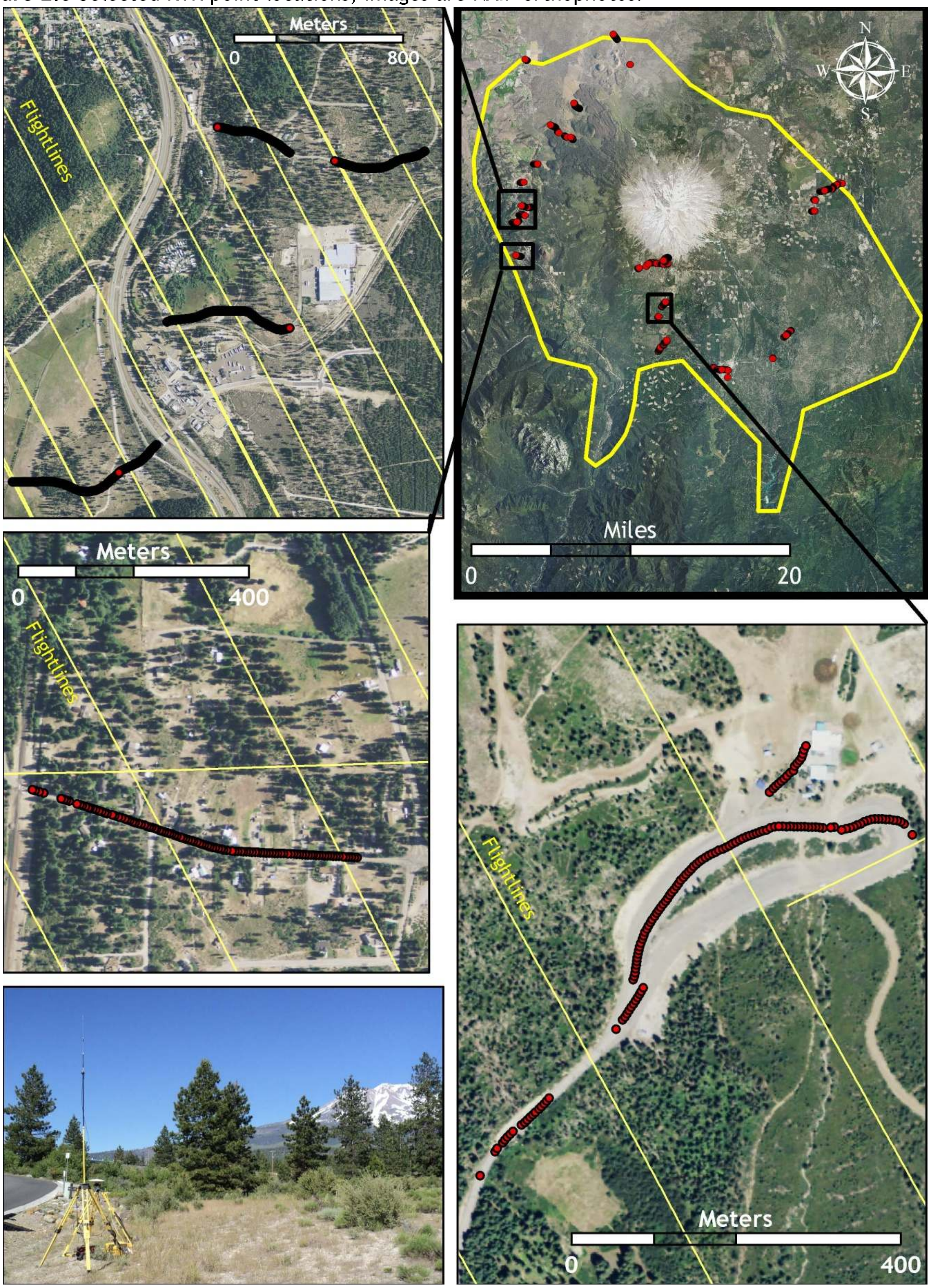
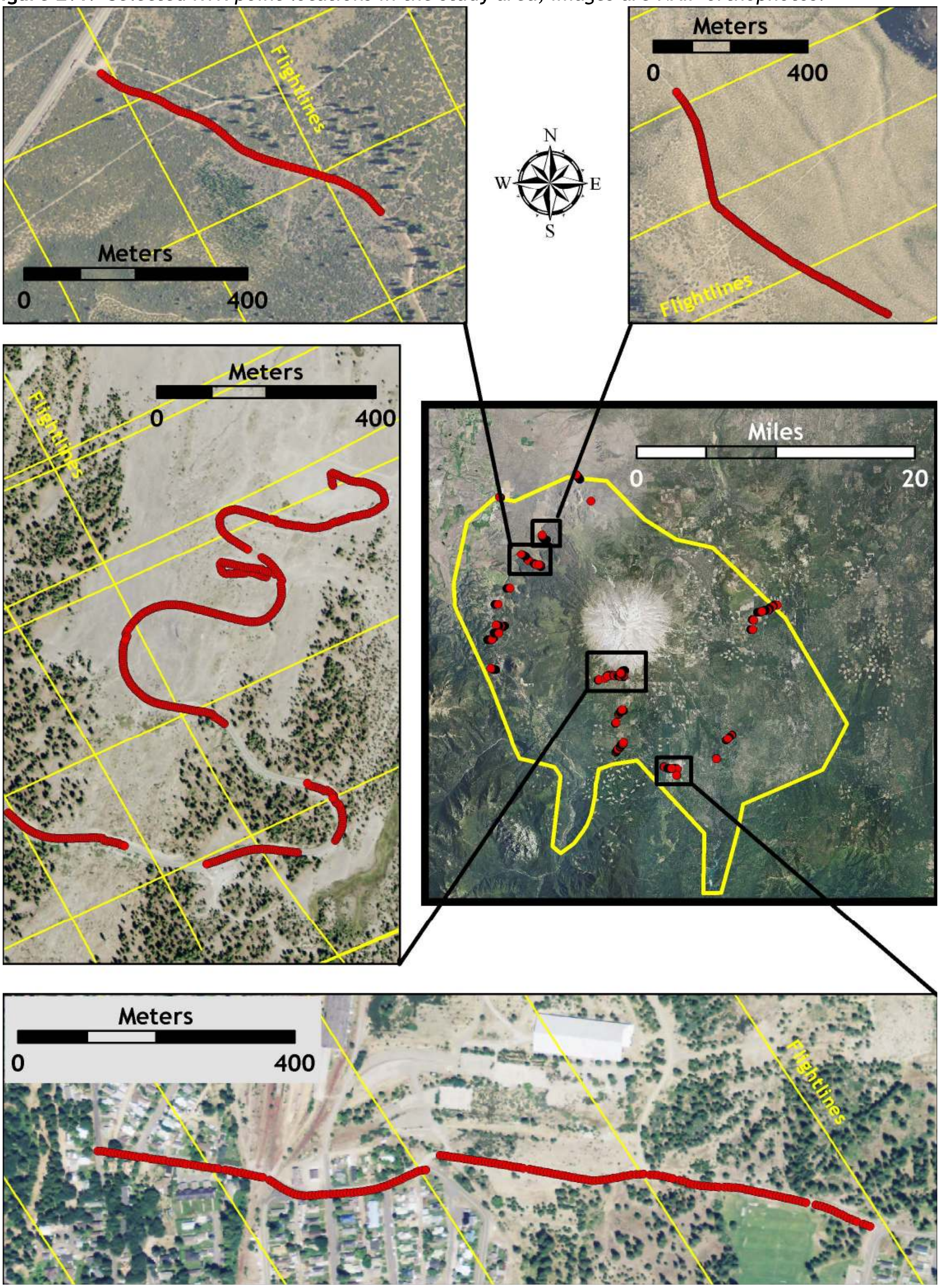


***Figure 2.4**. Selected RTK point locations in the study area; images are NAIP orthophotos.*



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 821 flightlines and over 17 billion points. Relative accuracy is reported for the entire of the study area, shown in **Figure 3.1** below.

- Project Average = 0.05 m
- Median Relative Accuracy = 0.04 m
- 1σ Relative Accuracy = 0.05m
- 2σ Relative Accuracy = 0.04 m

Figure 3.1. *Relative Accuracy Covered Area.*

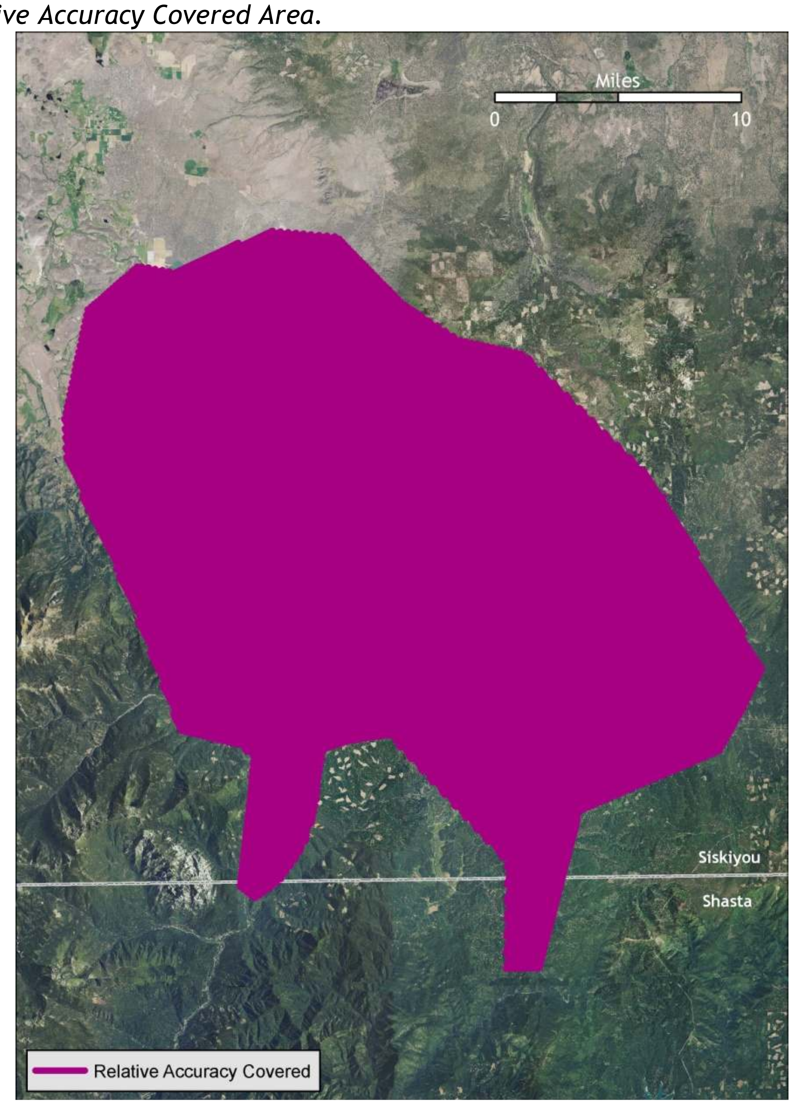


Figure 3.2. Statistical relative accuracies, non slope-adjusted.

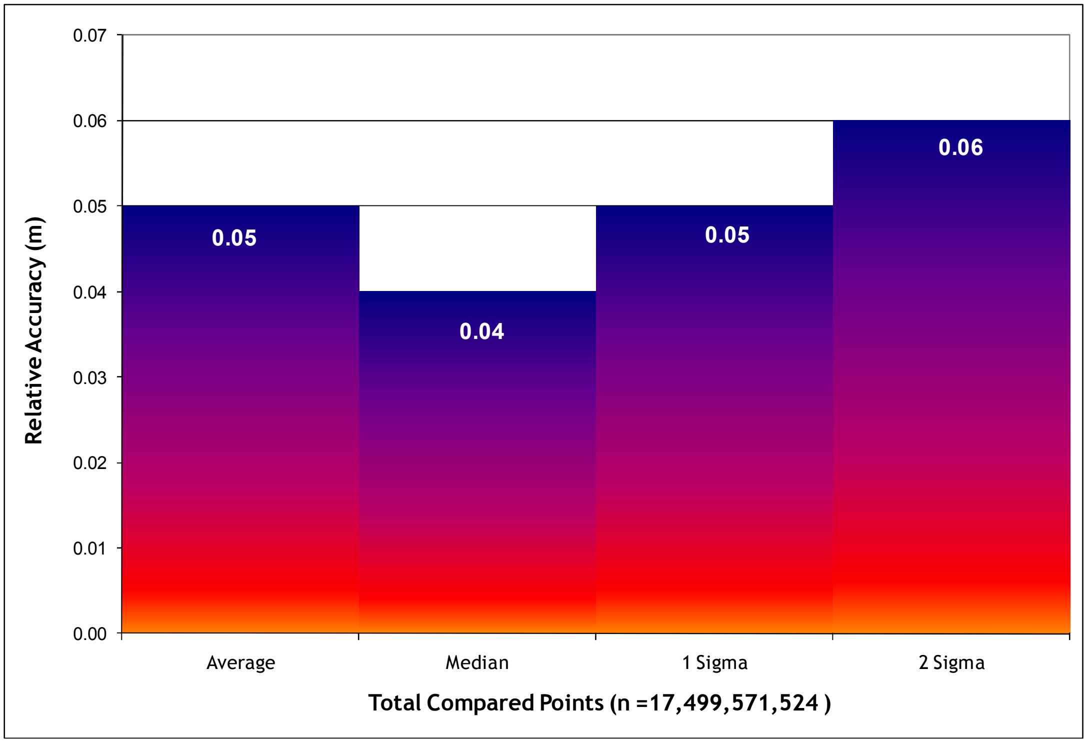
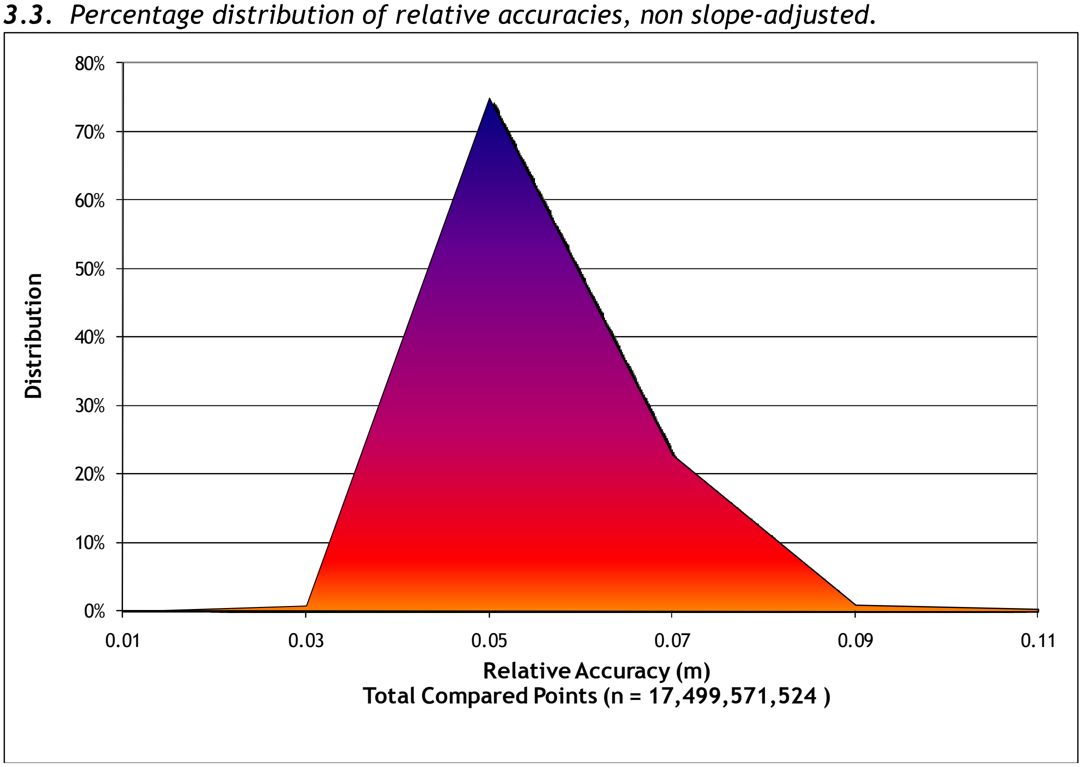


Figure 3.3. Percentage distribution of relative accuracies, non slope-adjusted.



3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Mt. Shasta study area, 3,236 RTK points were collected for data in the study area. Absolute accuracy is reported for the entire 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): 3,236	
Root Mean Square Error (RMSE): 0.04m	
Standard Deviations	**Deviations**
1 sigma (σ): 0.04 m	**Minimum Δz:** -0.19 m
2 sigma (σ): 0.09 m	**Maximum Δz:** 0.15 m
	Average Δz: 0.03 m

Figure 3.4. *Absolute Accuracy Covered Area.*

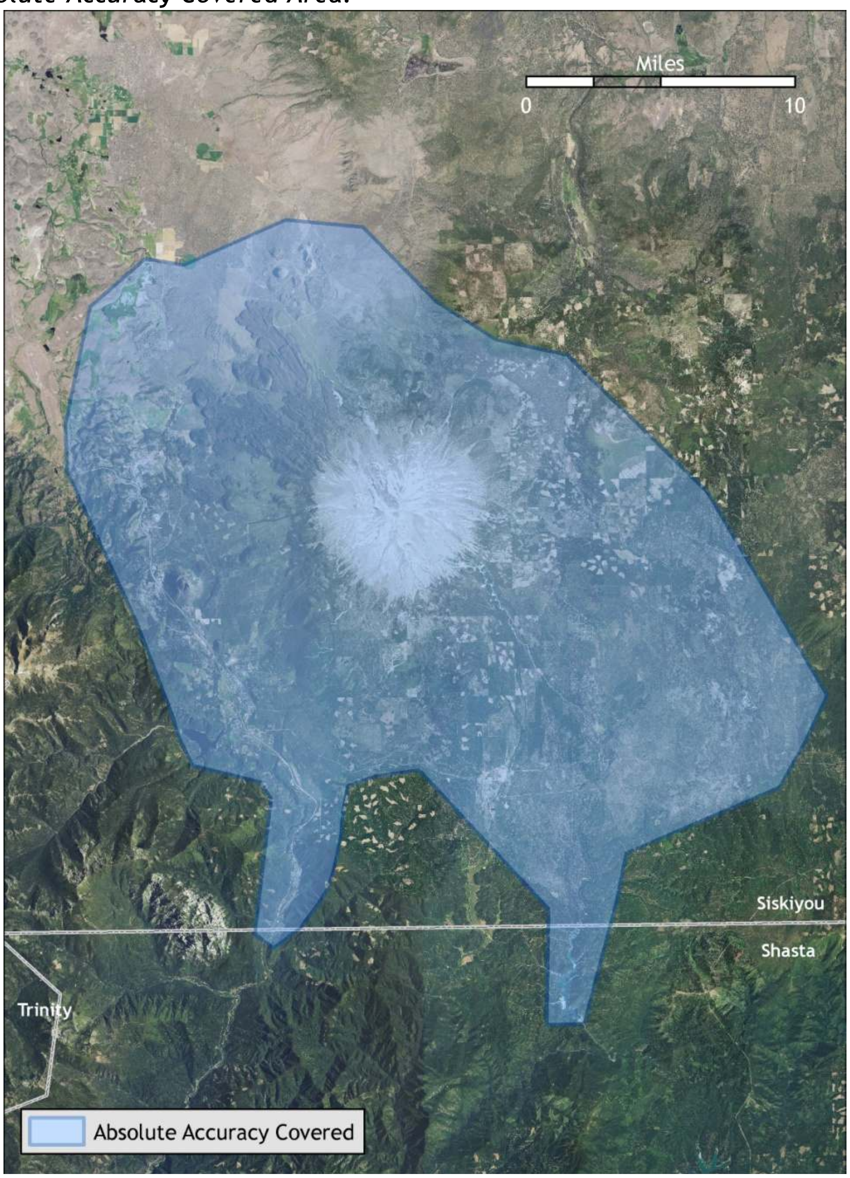


Figure 3.5. *Mt. Shasta Study Area histogram statistics*

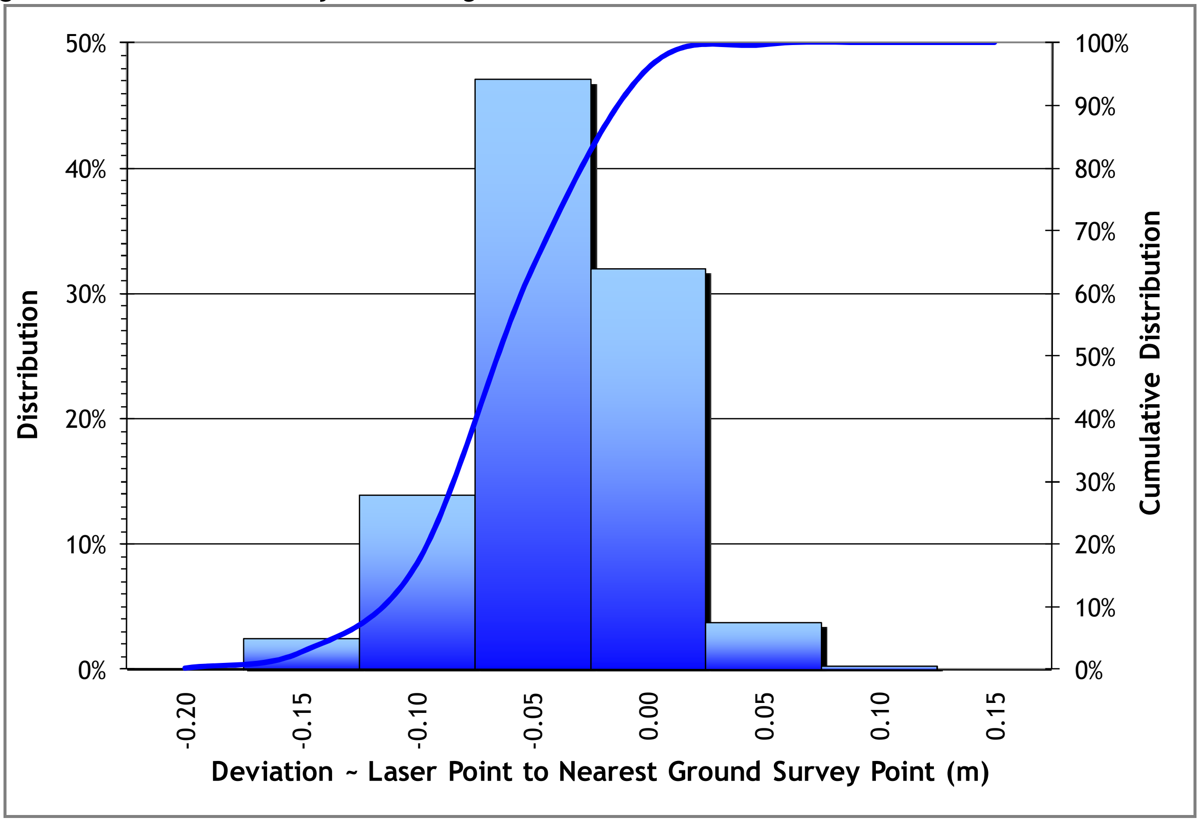
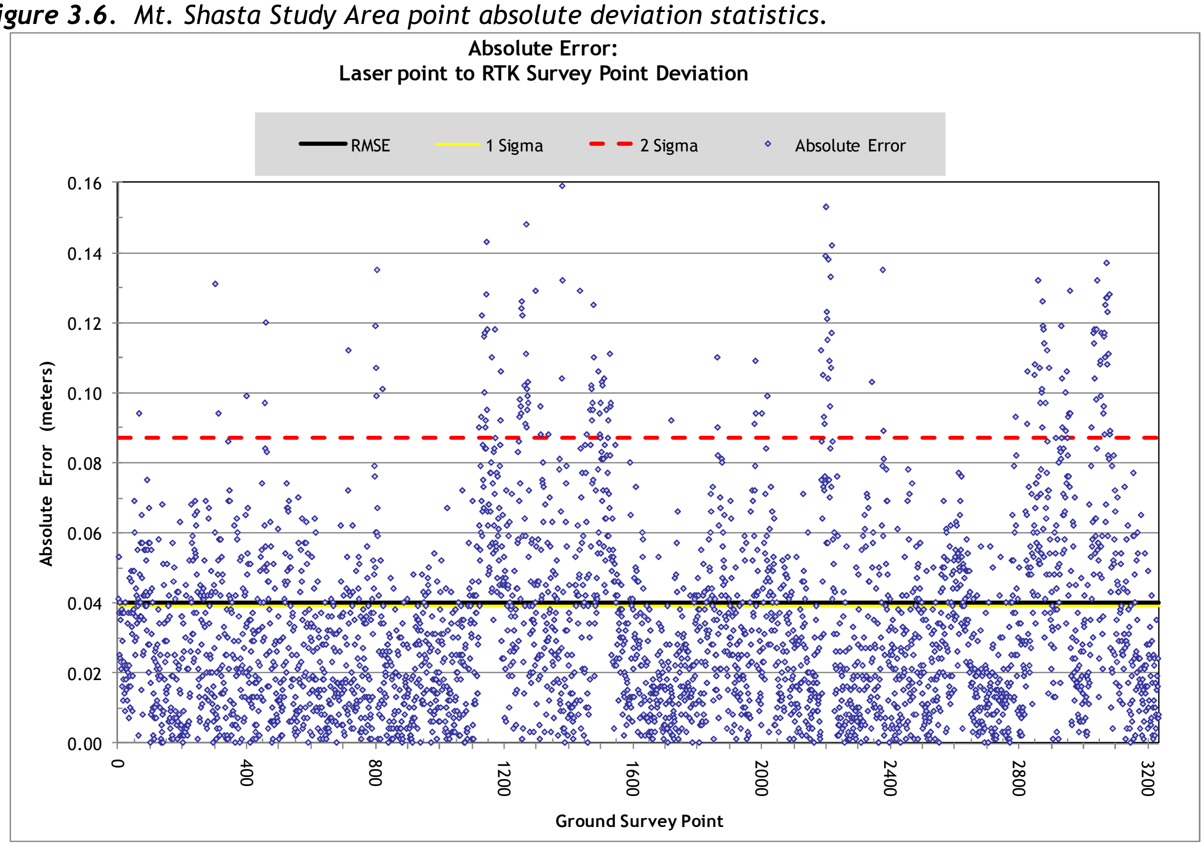


Figure 3.6. *Mt. Shasta Study Area point absolute deviation statistics.*



4. Data Density/Resolution

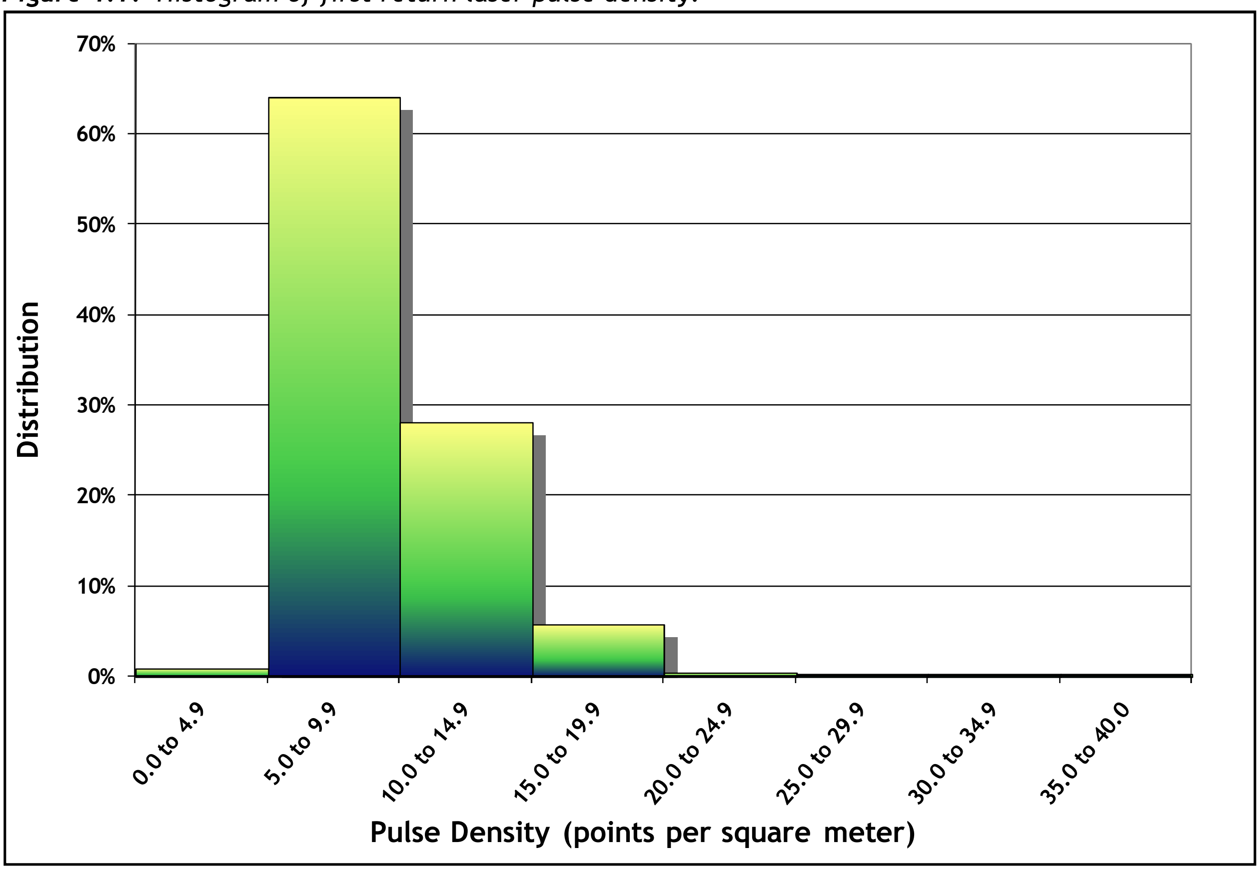
4.1 Density Statistics

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 pulse density.

Table 4.1. *Average density statistics for the Mt. Shasta Study Area.*

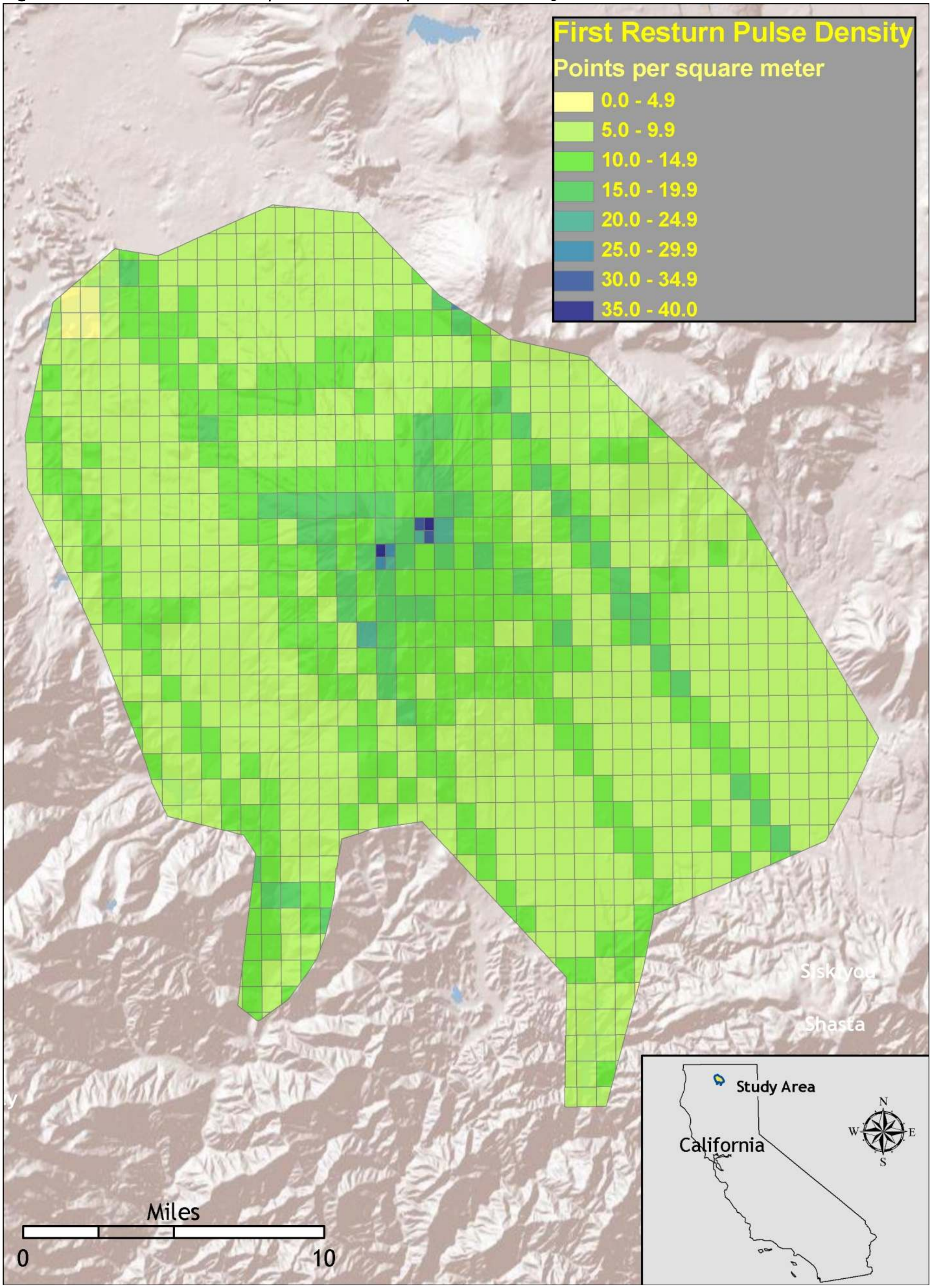
Average Pulse Density (per square m)	Average Ground Density (per square m)
10.18	1.82

Figure 4.1. *Histogram of first return laser pulse 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

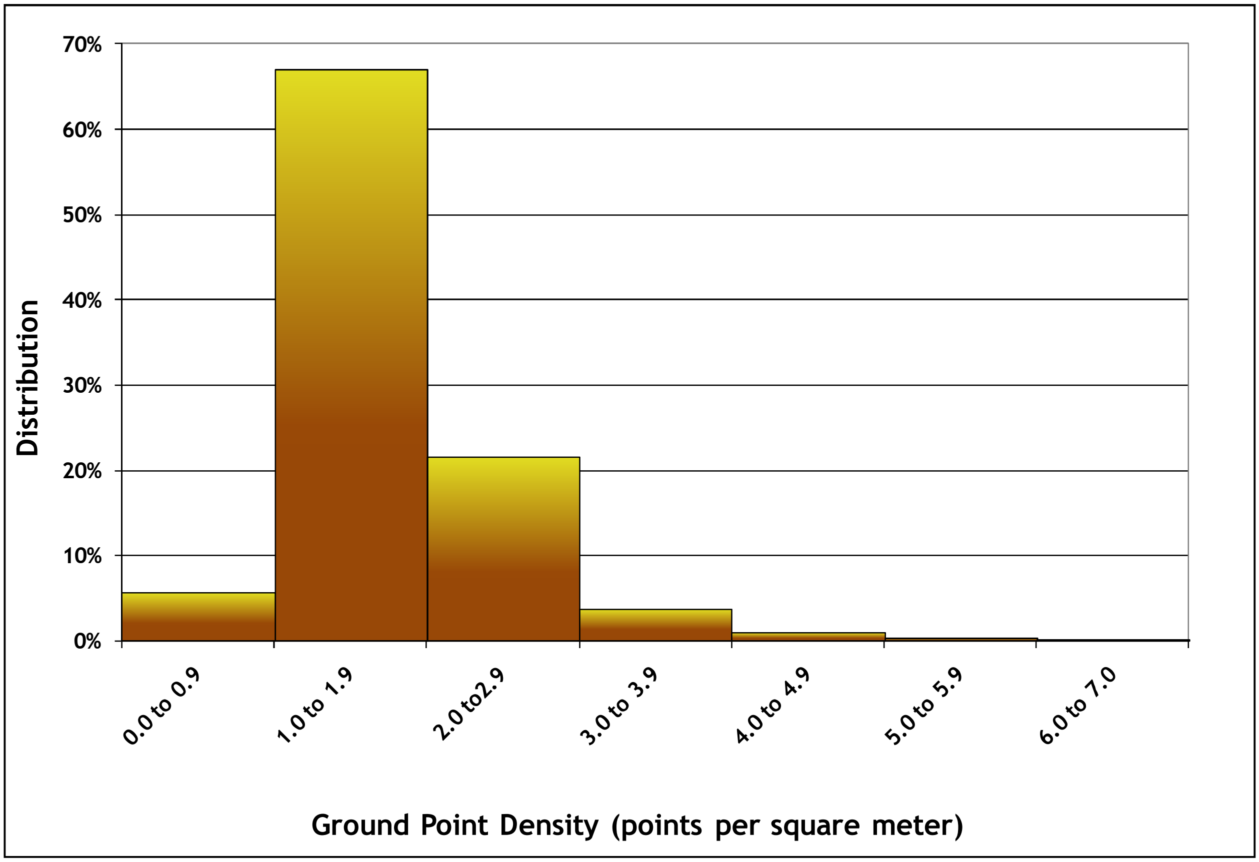
Figure 4.2. *First return laser pulse densities per 0.75' USGS Quad.*



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.*



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
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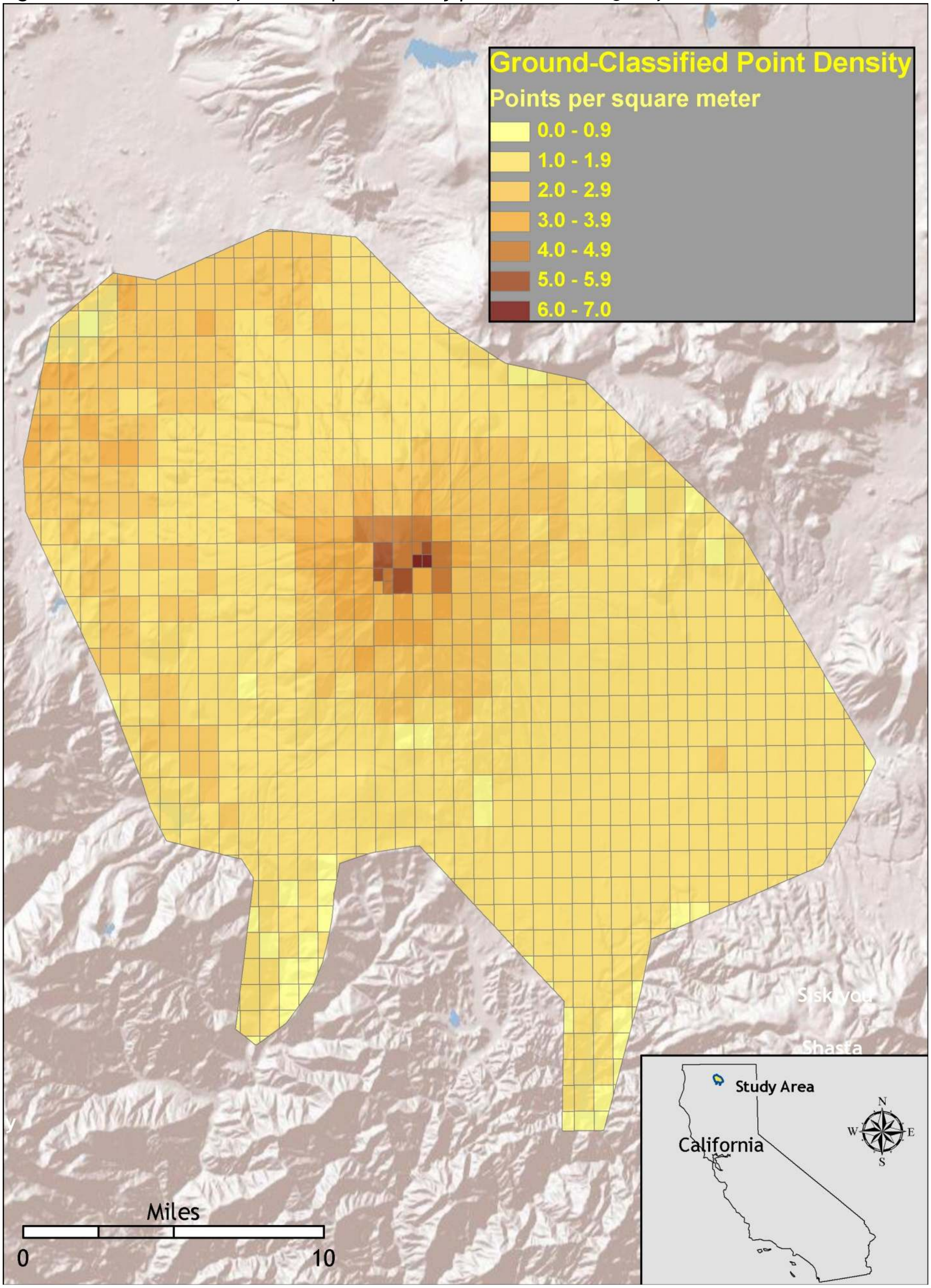
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

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. Lava flow on northern slope of Mount Shasta, view to the west. Image is a three dimensional point cloud with RGB values extracted from a NAIP orthophoto.

Figure 5.2. Lava flow on northern slope of Mount Shasta, view to the east. Image is a three dimensional point cloud with RGB values extracted from a NAIP orthophoto.

Figure 5.3. Northeast face of Mount Shasta, view looking southeast. *Image is a three dimensional point cloud with RGB values extracted from a NAIP orthophoto.*

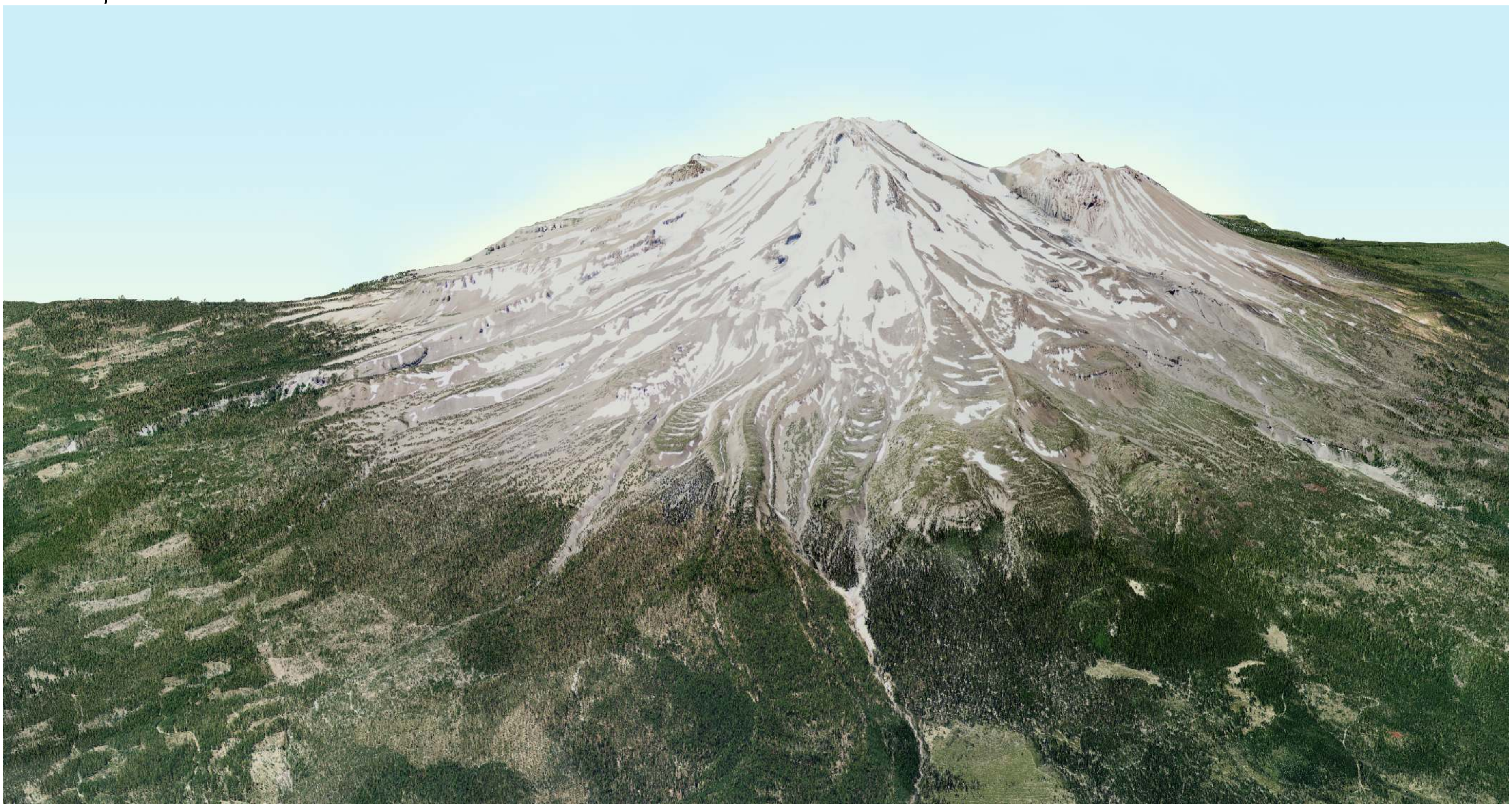


Figure 5.4 Mount Shasta Ski Park located on southern face of the mountain, view looking north. *Image is a three dimensional point cloud with RGB values extracted from a NAIP orthophoto.*

Figure 5.5. Black Butte located along I-5 near the city of Mount Shasta, view looking northeast. Image is a three dimensional point cloud with RGB values extracted from a NAIP orthophoto.

Figure 5.6. Peak and western face of Mount Shasta, view looking southwest. Image is a three dimensional point cloud with RGB values extracted from a NAIP orthophoto.