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LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
Union Baker Study Area
August 31, 2012

LiDAR Remote Sensing Data Collection:
DOGAMI, Union Baker Study Area

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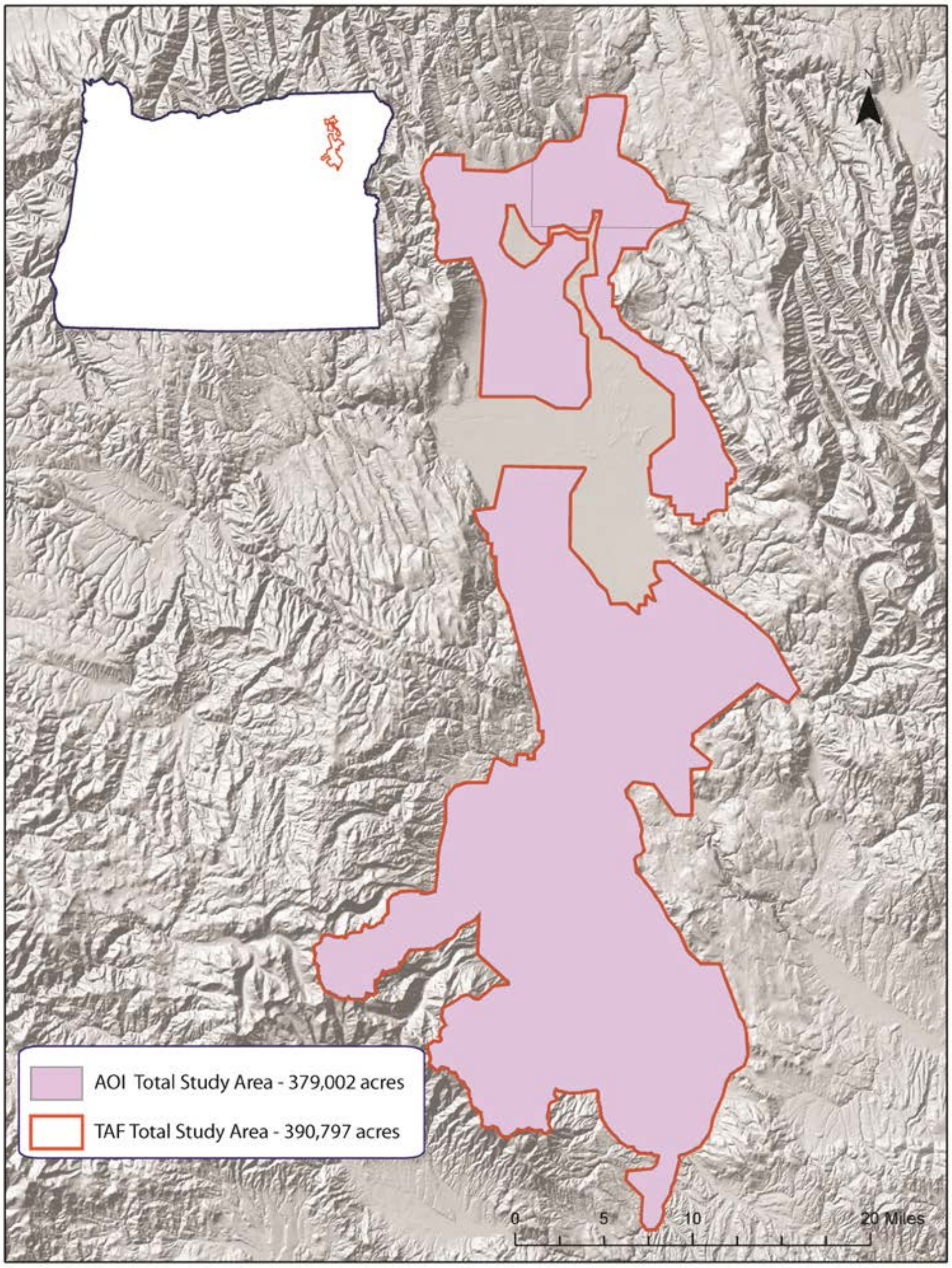
1. Overview

1.1 Study Area

WSI has collected Light Detection and Ranging (LiDAR) data of the Union Baker Study Area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The total Area of Interest (AOI) and the total area flown (TAF) covers 379,002 acres and 390,797 acres respectively. The TAF acreage is greater than the original AOI acreage due to buffering and flight planning optimization (**Figure 1.1** below). Union Baker 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 Union Baker Study Area.*

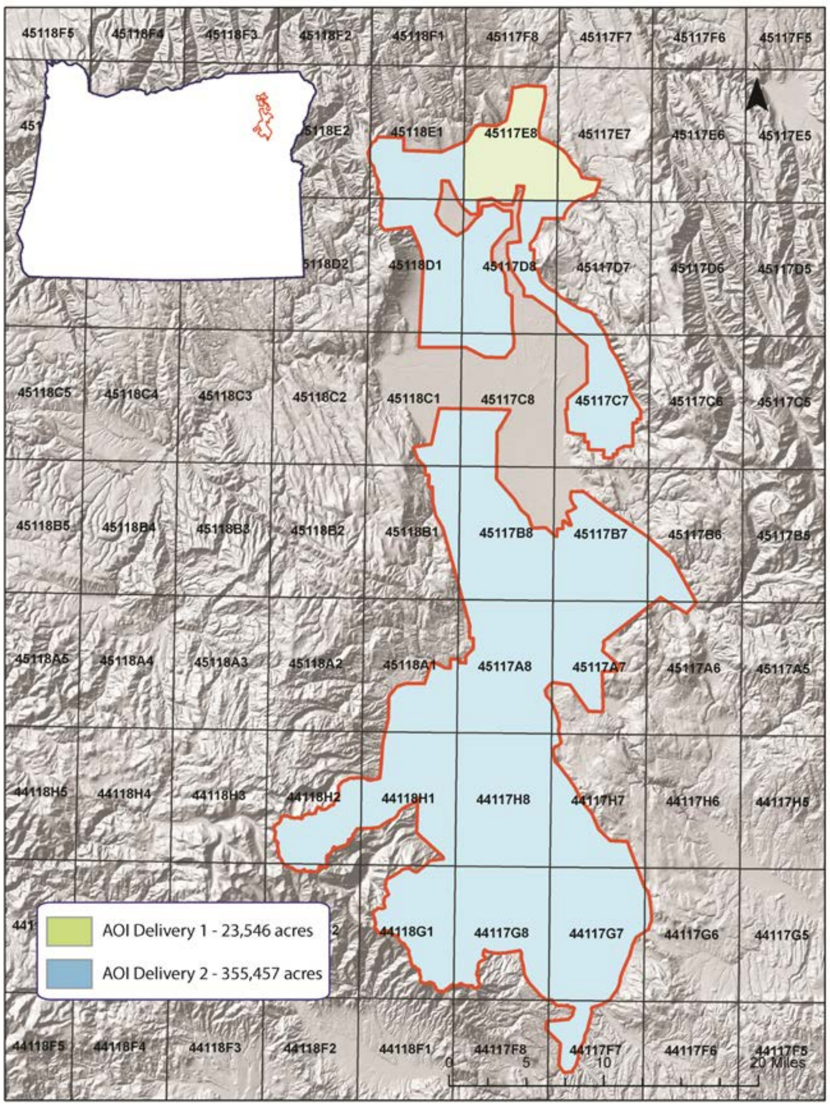


1.2 Area Delivered to Date

Table 1.1. *Total delivered acreage to date is detailed below.*

DOGAMI Union Baker Study Area				
	Delivery Date	Acquisition Dates	AOI Acres	TAF Acres
Delivery Area 1	January, 31, 2012	December 8, 2011 - December 12, 2011	23,546	24,420
Delivery Area 2	August 31, 2012	May 14, 2012 - July 2, 2012	355,457	366,376

Figure 1.2. *Union Baker Delivery Areas.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized Leica ALS50, ALS60 and ALS70 sensors mounted in Cessna Caravan 208B and Partenavia P.38 aircrafts. The systems were set to acquire ≥105,000 laser pulses per second (i.e. 105 kHz pulse rate) and flown at 900 and 1400 meters above ground level (AGL), capturing a scan angle of 314° 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*

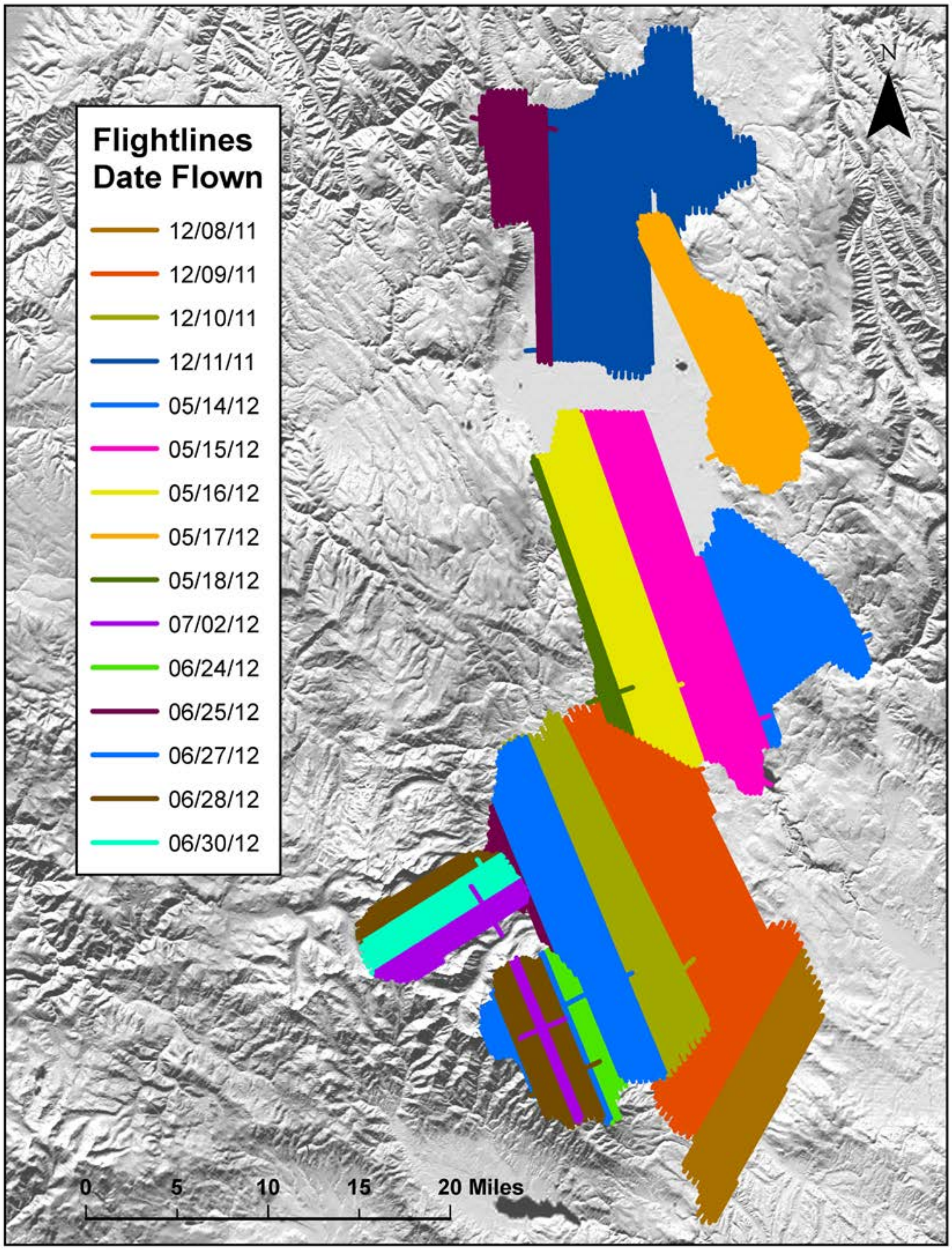
Sensors	Leica ALS50, ALS60, ALS70
Survey Altitude (AGL)	900 m and 1400 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	30° (315° from nadir)
Roll Compensated	Up to 15°
Overlap	100% (60% Side-lap)

The study area was surveyed with opposing flight line side-lap of ≥60% (≥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 *Flightlines for the Union Baker Study Area illustrating the dates flown*



Owing to late seasonal snowpack and contractual deadline restrictions, LiDAR acquisition took place with snow on the ground in upper elevations of the Union Baker survey area, with the approval of DoGAMI. While the presence of an impermanent surface (e.g. snow, water, dunes) can influence data calibration and relative accuracy, the overall calibration statistics for the present data are excellent (see page 13, mean relative accuracy 4 cm; 1σ 5 cm). WSI's overall assessment of the data is that it is robust and sufficient for analytical applications as long as the user is aware of the presence of snow in isolated areas.

2.2 Union Baker Intensity

The Union Baker LiDAR survey was conducted with four separate laser systems (one Leica ALS50 system, two Leica ALS60 systems, and one Leica ALS70). The ALS70 system emits laser pulses in a fundamentally different manner from the ALS50 and ALS60, splitting individual pulses into two channels, halving the emitted energy. The ALS70 system gain setting requires greater sensitivity to accommodate low energy returns, amplifying the majority of intensity values for a given dataset. That is, the distribution of intensity values for ALS70 data is skewed high, towards the upper (255) limit of data values. The imagery derived from this intensity data has greater contrast than other sensor models. When data from separate models are adjacent or mixed, there is a pronounced artifact in intensity imagery at the data boundary, as illustrated in Figure 2.2. To date, there is no methodology for resolving or normalizing these data values in order to eliminate this artifact.

Figure 2.2 *Union Baker intensity image*

2.3 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 2.3**. 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.

2.3.1 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 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.

2.3.2 Monumentation

Whenever possible, existing and established survey benchmarks shall serve as control points during LiDAR acquisition including those previously set by WSI. 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, WSI 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 30" rebar topped with a 2" diameter aluminum cap stamped "Watershed Sciences, Inc.".

[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

2.3.3 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 control points are observed for a minimum of two survey sessions lasting no fewer than 2 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 Dropbox website 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 2.3)** at the 95% confidence level.

All RTK measurements are made during periods with a Position Dilution of Precision (PDOP) of $\leq$ 3.0 and in view of at least six satellites by the stationary reference and 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 are 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 are used in the ground based real-time kinematic (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 measurement ($\sigma \leq$ 1.5 cm). **Figure 2.4** shows a subset of these RTK locations.

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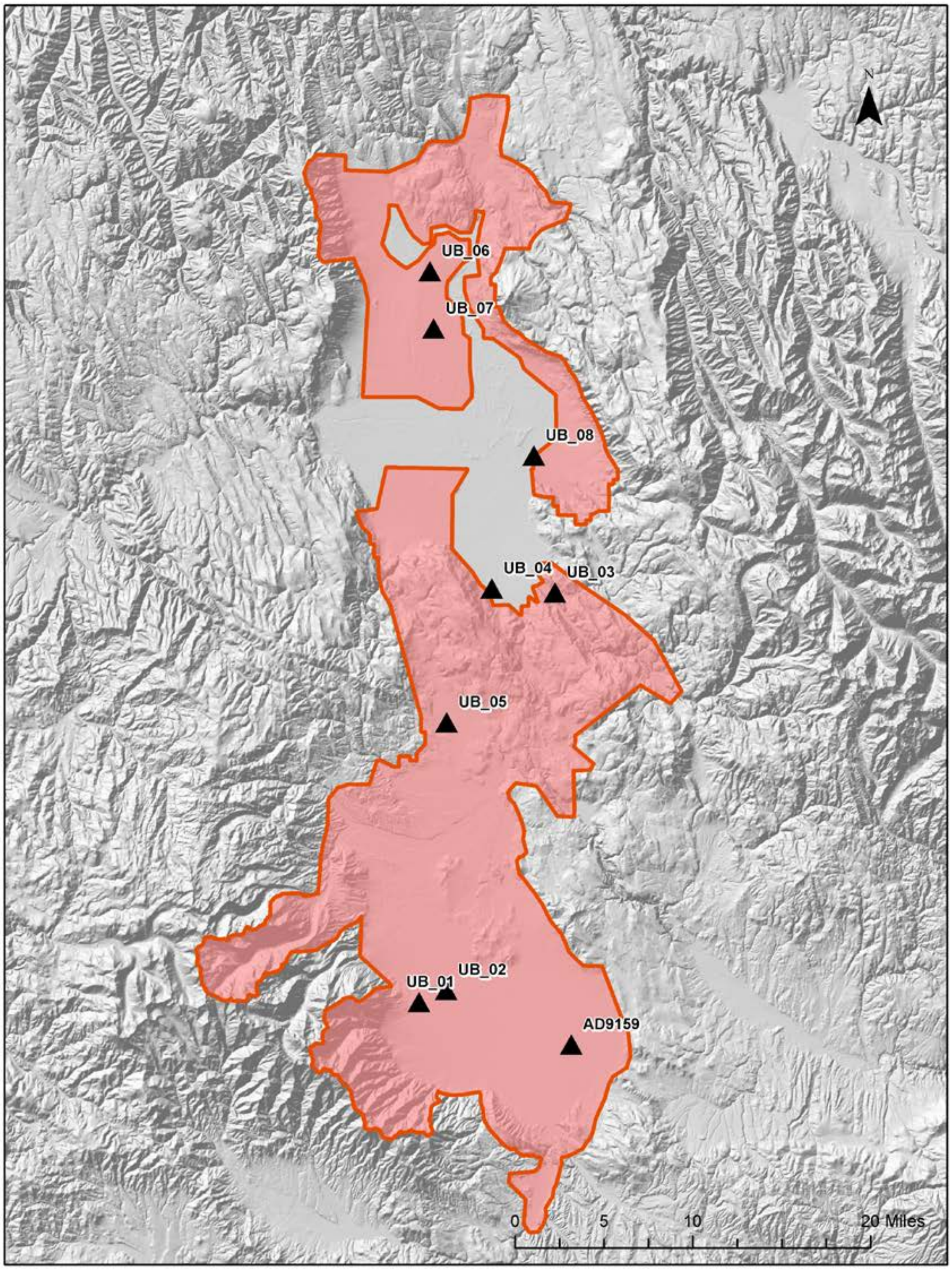
[4] U.S. Army Corps of Engineers , Engineer Research and Development Center Topographic Engineering Center software

[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 Union Baker Study Area.*

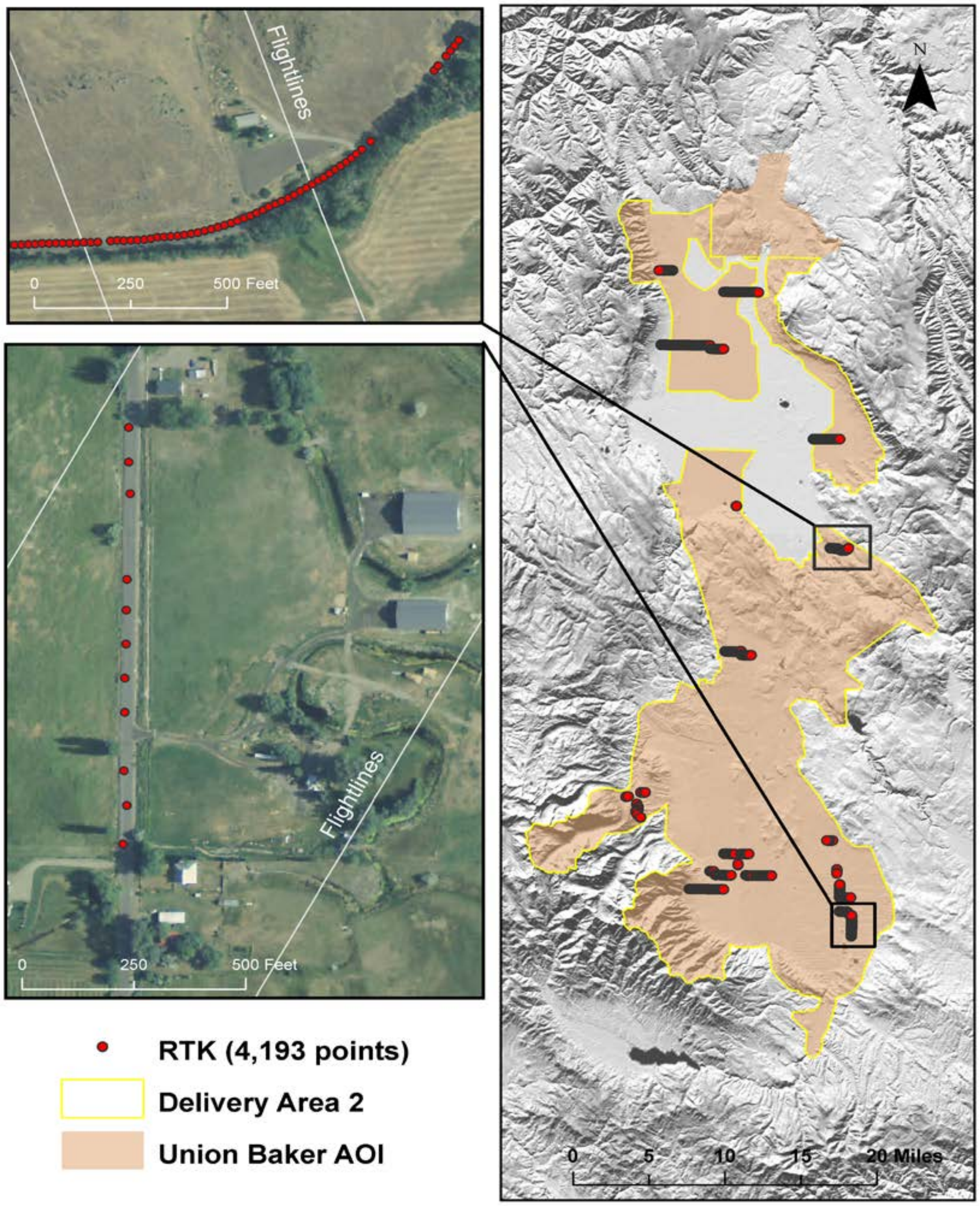
	DATUM NAD83 (HARN)		GRS80
Base Station ID	Latitude (North)	Longitude (West)	Ellipsoid Height (m)
UB_01	44 52 08.78621	-117 58 59.55526	1064.525
UB_02	44 52 44.96607	-117 57 07.99989	1020.506
AD9159	44 50 08.88212	-117 48 30.06107	1009.617
UB_06	45 27 50.61921	-117 58 51.85649	822.055
UB_07	45 25 03.10649	-117 58 32.52314	821.41
UB_08	45 18 53.60318	-117 51 29.65085	803.496
UB_03	45 12 13.10466	-117 49 56.47174	859.632
UB_04	45 12 23.52838	-117 54 18.54380	813.749
UB_05	45 05 49.21878	-117 57 19.25957	1013.809
CATH_CK_01	45 12 44.91643	-117 45 21.13705	1099.933
CRITFC_TS1	45 11 43.15785	-117 45 41.27188	1025.702

Figure 2.3. *Base stations for the Union Baker Study Area*.



For total delivery area, 4,193 RTK (Real-time kinematic) points were collected in the study area.

Figure 2.4. *Selected RTK point locations in the study area for delivery area 2. Images are NAIP orthophotos.*



2.3.4 Monument Accuracy

Table 2.3. *FGDC-STD-007.2-1998[6] at the 95% confidence level for the Quinault USGS survey area*

St Dev $_{NE}$	0.050 m
St Dev $_{z}$	0.100 m

[6] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards (Part 2 table 2.1)

3. Hydro-Flattening Methodology

All bare-earth hydro-flattened digital elevation models (DEMs) have been hydro-flattened according to the U.S. Geological Survey's National Geospatial Program's "LiDAR Guidelines and Base Specification" Version 13 (USGS NGP). For all water bodies perceived to be "flat," LiDAR points were sampled to arrive at an elevation threshold defining the water surface at a uniform elevation where the water edge meets the surrounding terrain. Three dimensional breaklines were then created to encompass all areas considered to be water and were assigned the water surface elevation value determined previously. All "flat" water bodies greater than 2 acres were considered for hydro-flattening. All "islands" greater than 100 m^2 were retained in the DEMs.

Centerlines were digitized for all water surfaces not perceived as "flat." Thousands of points were sampled along the stream and channel centerlines to generate three-dimensional z values. A smoothing algorithm was then applied to ensure the centerlines consistently run downstream. LiDAR points were classified as water using the z threshold values of the appropriate centerlines. A breakline polygon was created around the water points with all discontinuities (e.g., bridges, overhanging vegetation, etc.) removed. Z values were applied to the breakline polygon based on the elevation values of the closest associated centerline vertex. Again, "islands" were retained in the bare-earth DEMs if greater than 100 m^2.

The bare-earth DEMs were created by triangulating all "ground" classified points and inserting 3-D breaklines utilizing TerraSolid's TerraScan and TerraModeler software. Any ground points within 1 m of the breaklines were reclassified to "ignored-ground" (ASPRS code: 10) before triangulation. 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 from the bare-earth raster was used.

Figure 3.1. *Hillshade comparison of (A) Non-hydro-flattened raster and (B) Hydro-flattened raster*

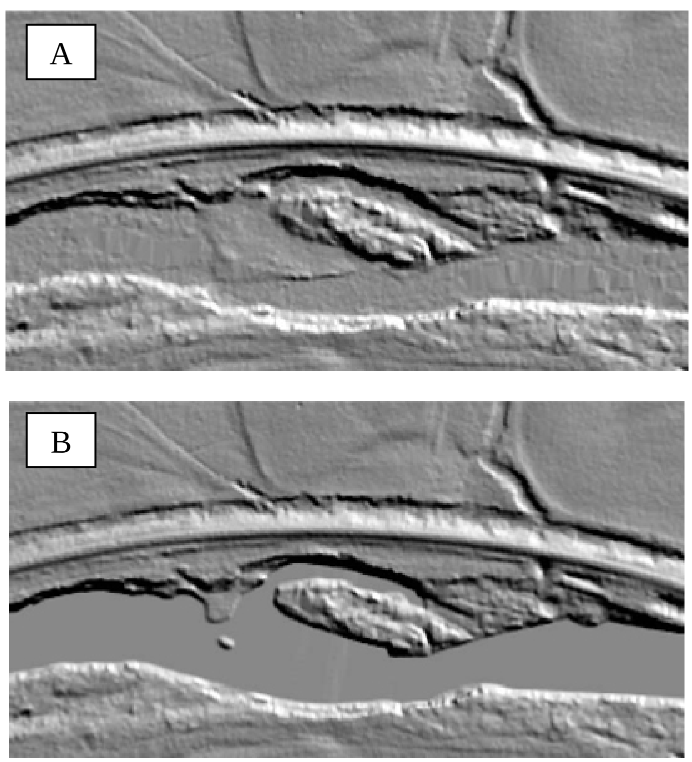
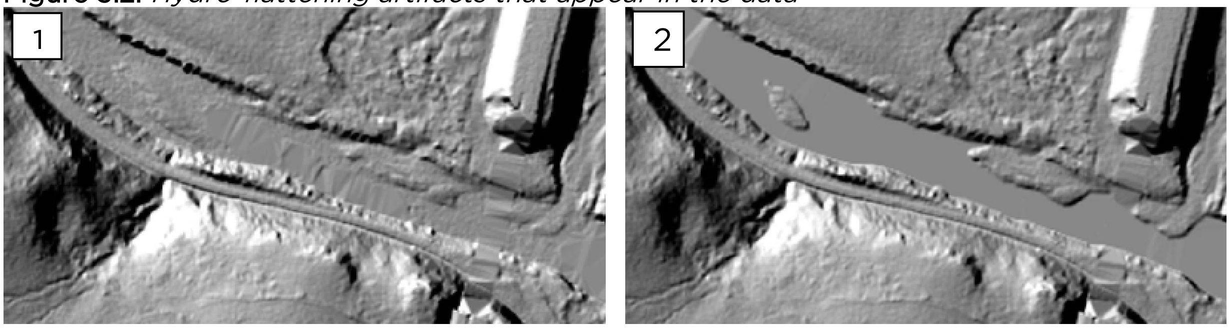
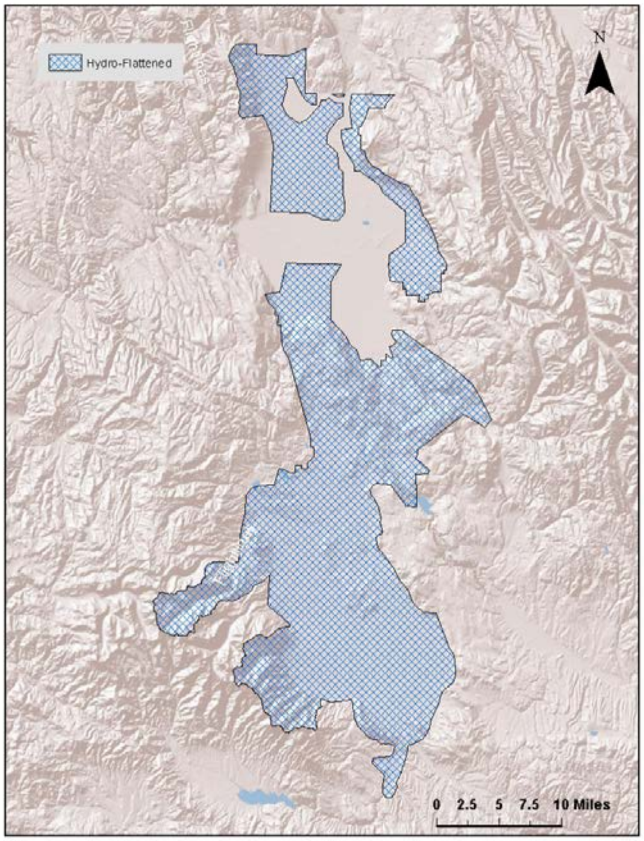


Figure 3.2. *Hydro-flattening artifacts that appear in the data*



Hydro-Flattening of the Union Baker study area was conducted in adherence to the USGS LiDAR Guidelines and Base Specifications Version 13 (USGS Spec). There were several processing challenges due to the complex nature of this fluvial system. In particular, high gradient streams with plentiful sediment flows tend to have cross current waterfalls not occurring perpendicular to the stream bank (Figure 3.2, Image 1). On page 8, guideline 3, section 2, bullet point 2, the USGS Spec states that river breaklines should be "level bank-to-bank (perpendicular to the apparent flow centerline)" and that "the water surface edge (is) at or below the immediately surrounding terrain". WSI adhered to these guidelines (Figure 3.2, Image 2), recognizing that the methodology would introduce artifacts markedly different from the true topography of the stream corridor (Figure 3.2, Image 1).

Figure 3.3. *Hydro-flattened USGS portion of OLC Union Baker study area.*


Hydro-Flattened
N
0 2.5 5 7.5 10 Miles

4. Accuracy

4.1 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 shown in **Figures 4.2 and 4.3** are based on the comparison of 804 flightlines and over 35 billion points. Relative accuracy is reported for the entire study area, shown in **Figure 4.1** below.

- Project Average = 0.15 ft (0.04 m)
- Median Relative Accuracy = 0.12 ft (0.04 m)
- 1σ Relative Accuracy = 0.16 ft (0.05 m)
- 2σ Relative Accuracy = 0.25 ft (0.08 m)

Figure 4.1. *Relative Accuracy Covered Area.*

Figure 4.2. *Statistical relative accuracies, non slope-adjusted.*

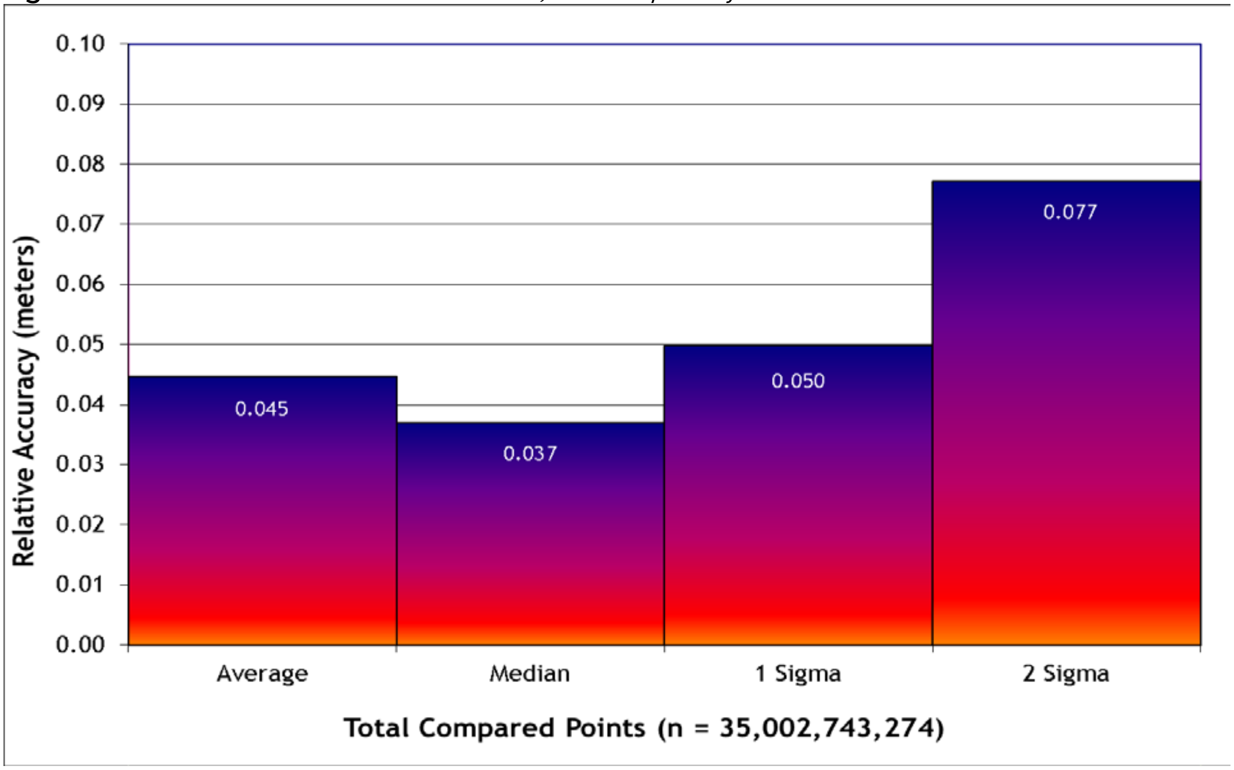
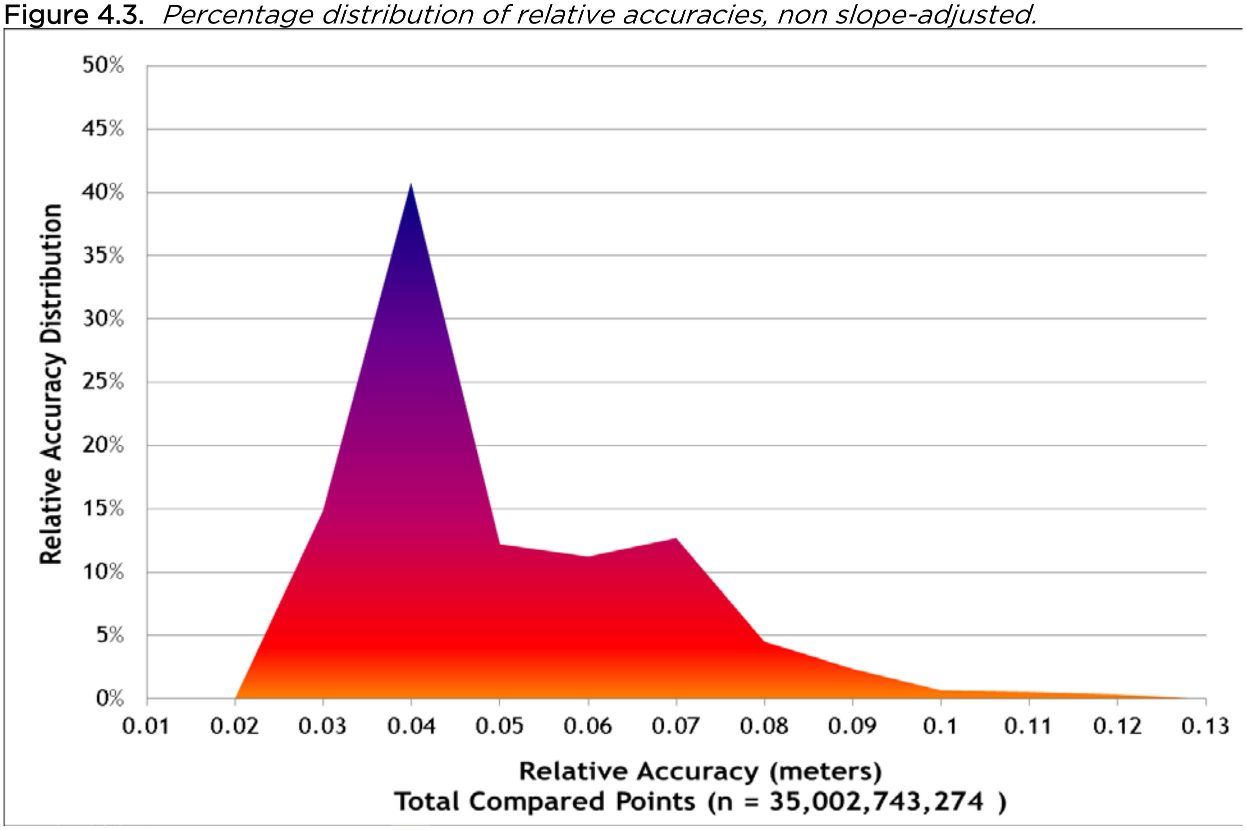


Figure 4.3. *Percentage distribution of relative accuracies, non slope-adjusted.*



4.2 Fundamental Vertical Accuracy

FVA accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998). FVA compares known RTK ground survey points to the closest laser point. FVA uses ground control points in open areas where the LiDAR system has a "very high probability" that the sensor will measure the ground surface and is evaluated at the 95% percentile of $RMSE_{Z.}$ For the Union Baker Study Area, 4,193 RTK points were collected.

For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet," in accordance with the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). Fundamental Vertical accuracy is reported for the entire study area shown, in **Figure 4.4**, and reported in **Table 4.1** below. Histogram and absolute deviation statistics are reported in **Figures 4.5 and 4.6**.

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

Sample Size (n): 4,193	
Root Mean Square Error (RMSE): 0.14 ft (0.04 m)	
Fundamental Vertical Accuracy: Compiled to Meet 0.29 ft. (0.09m) accuracy at 95% confidence level in open terrain	
Standard Deviations	Deviations
1 sigma (σ): 0.14 ft (0.04 m)	Minimum Δz: -0.68 ft (-0.21 m)
2 sigma (σ): 0.29 ft (0.09 m)	Maximum Δz: 0.39 ft (0.12 m)
	Average Δz: 0.12 ft (0.04m)

Figure 4.4. *Absolute Accuracy Covered Area.*

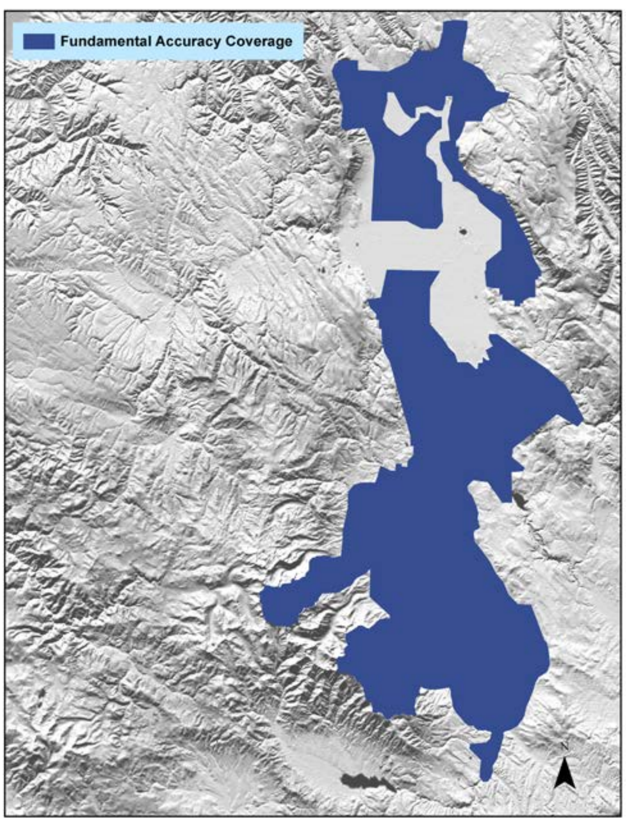


Figure 4.5. *Union Baker Study Area vertical accuracy histogram statistics*

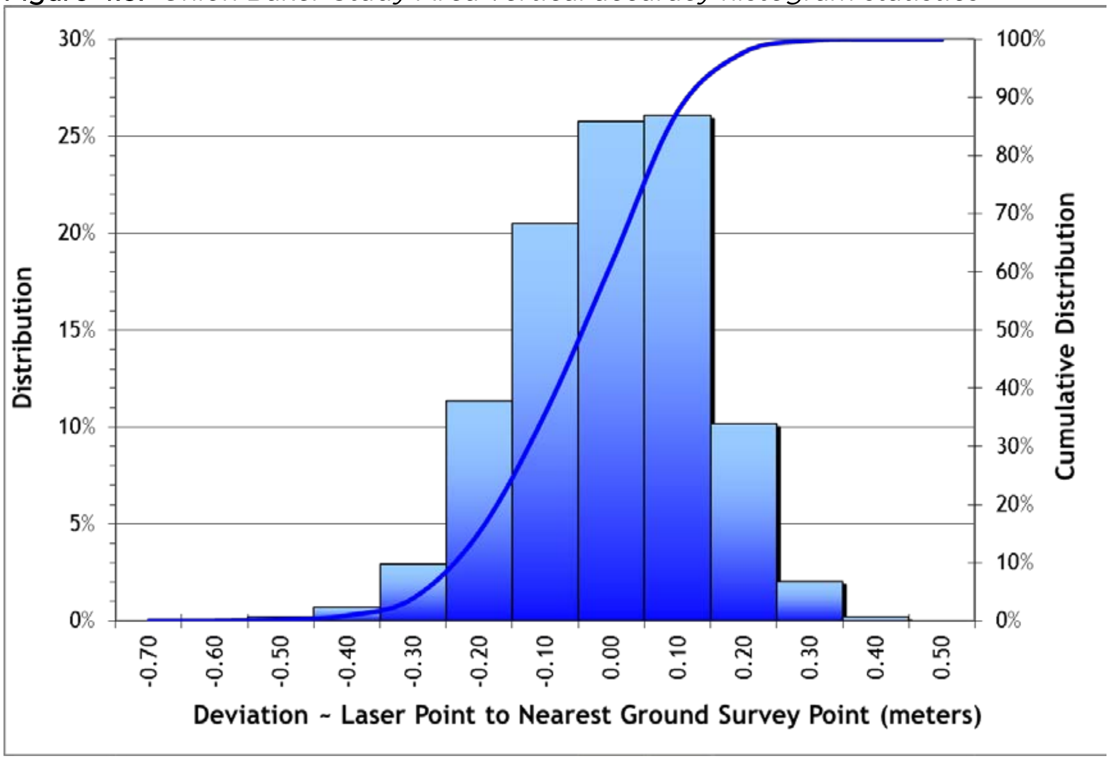
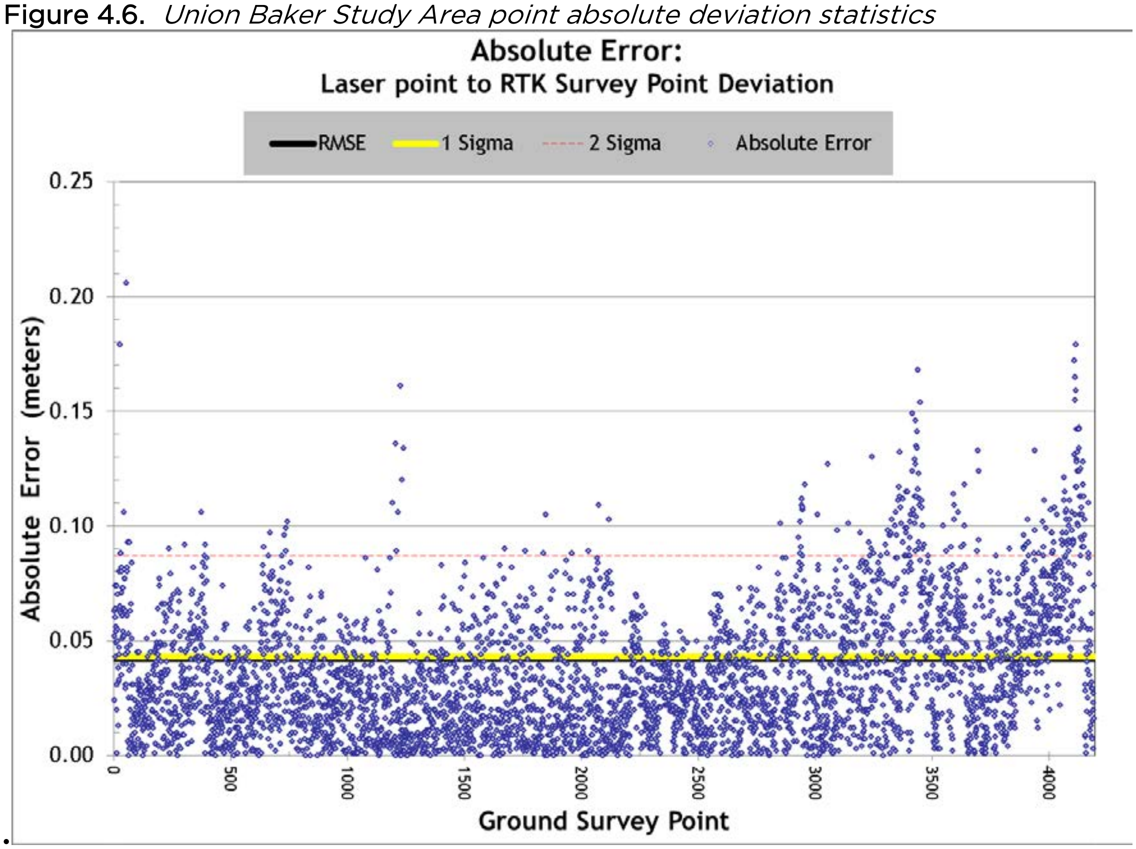


Figure 4.6. *Union Baker Study Area point absolute deviation statistics*



4.3 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 terrain, land cover and water bodies. Density histograms and maps (**Figures 4.7 – 4.10**) have been calculated based on first return laser point density and ground-classified laser point density.

Table 4.2. *Average density statistics for entire Union Baker Study Area.*

Average Pulse Density (per square ft)	Average Pulse Density (per square m)	Average Ground Density (per square ft)	Average Ground Density (per square m)
0.86	9.28	0.20	4.18

Figure 4.7. *Histogram of first return laser point density for data delivered to date.*

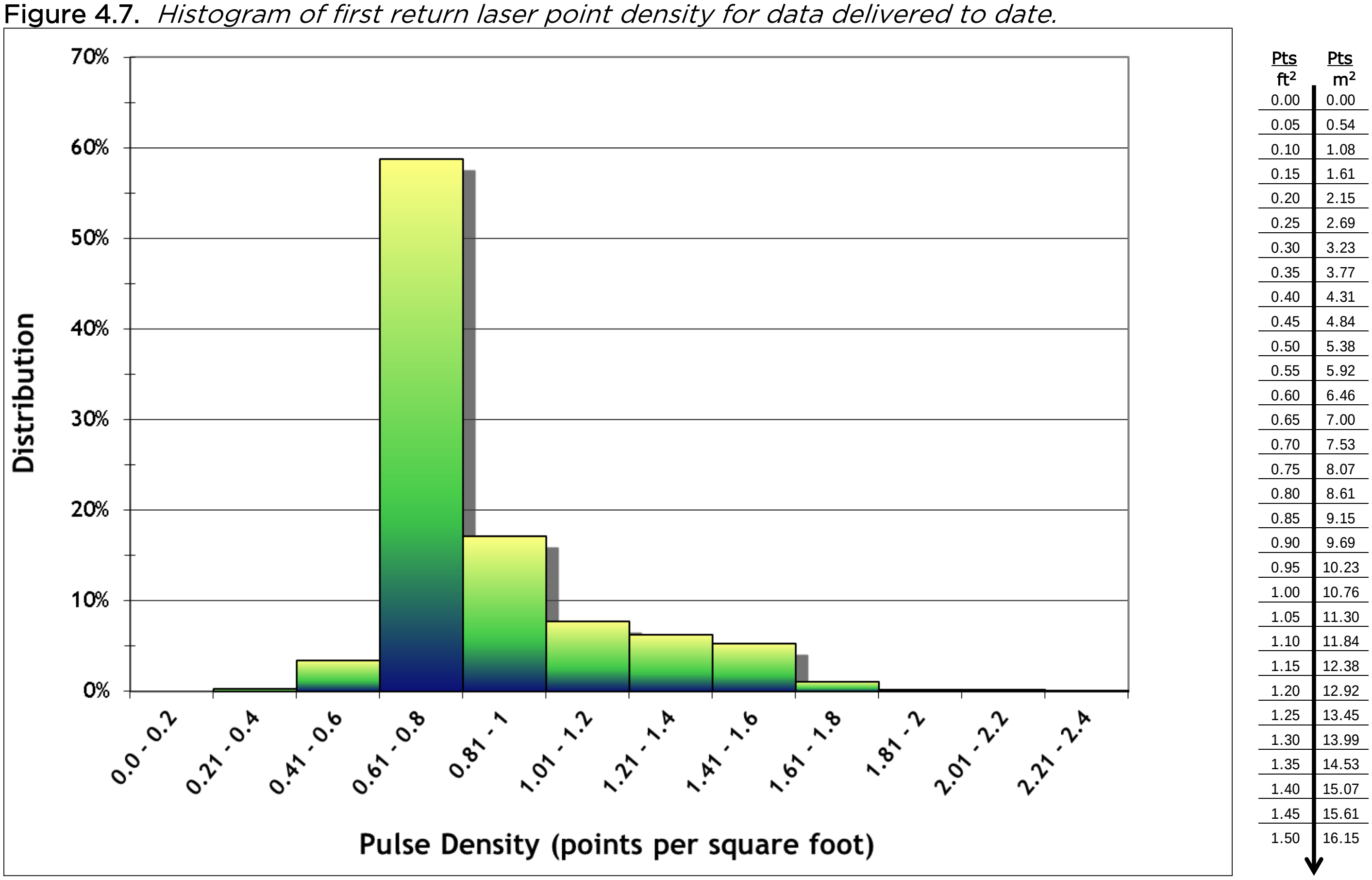
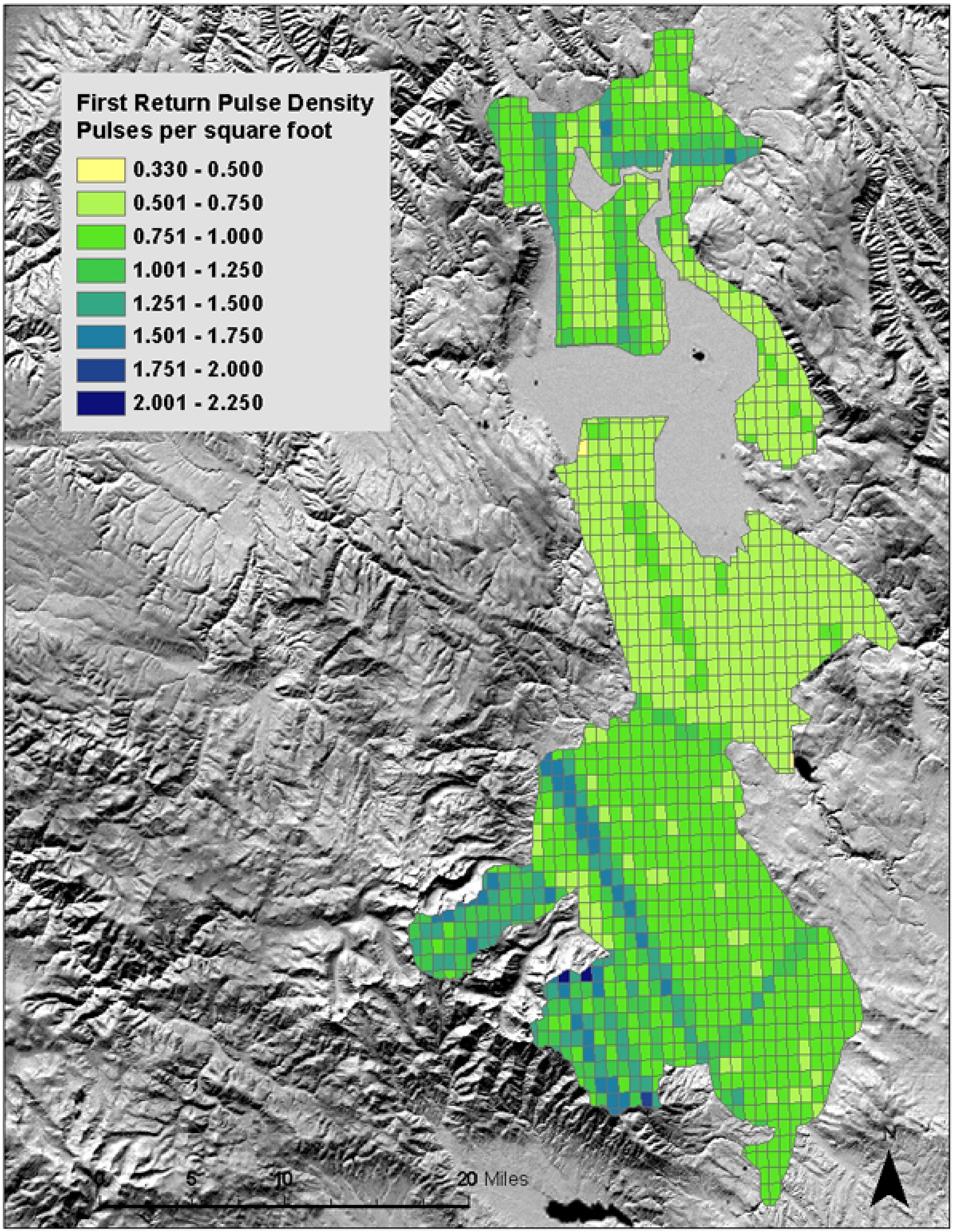


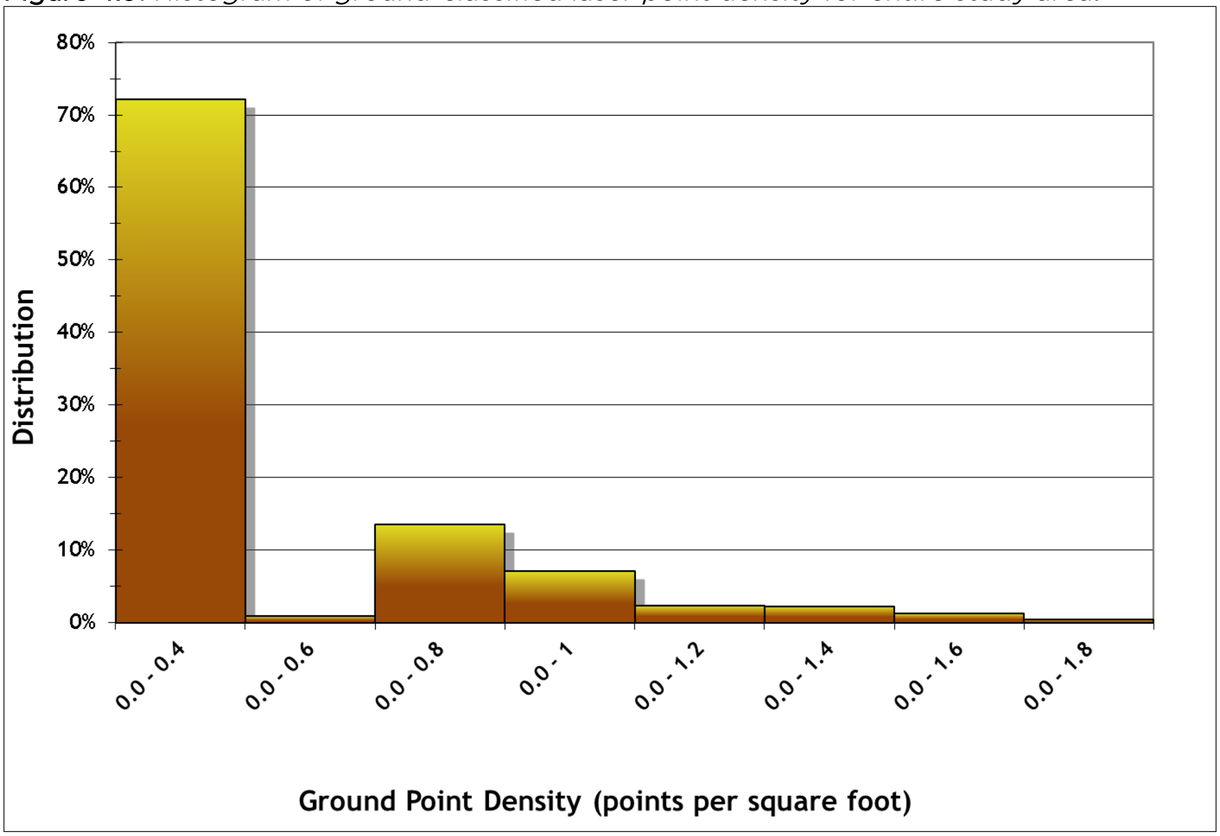
Figure 4.8. *First return laser point densities per 0.75' USGS Quad.*



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

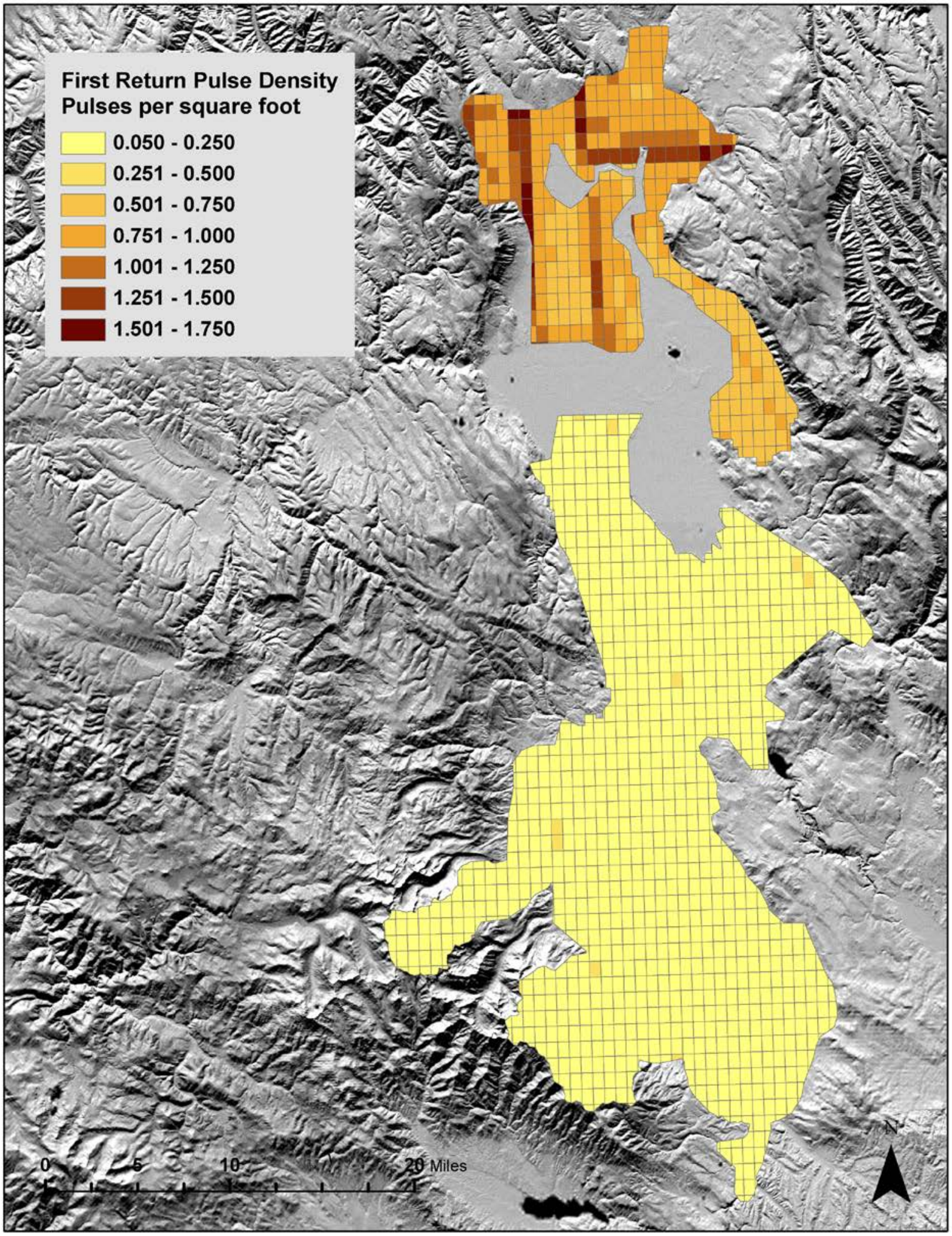
Ground classifications were derived from ground surface modeling. Classifications were performed by reseeding of the ground model where it was determined that the ground model failed, usually under dense vegetation and/or at breaks in terrain, steep slopes and at bin boundaries.

Figure 4.9. *Histogram of ground-classified laser point density for entire 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

Figure 4.10. *Ground-classified laser point density 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

5. Certifications

WSI provided LiDAR services for the Union Baker 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
WSI

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.

REGISTERED
PROFESSIONAL
LAND SURVEYOR
8/30/2012

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

RENEWAL DATE: 6/30/2014

Christopher W. Yotter-Brown, PLS Oregon & Washington
WSI
Portland, OR 97204

6. Citations

Federal Geographic Data Committee, 1998. Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy. Subcommittee for Base Cartographic Data, 25p.

Flood, M, (Ed.), 2004. ASPRS Guidelines-Vertical Accuracy Reporting for Lidar Data, V1.0. American Society for Photogrammetry and Remote Sensing (ASPRS) Lidar Committee, 20p.

7. Selected Imagery

Figure 7.1. *Baker City. Image is a three-dimensional LiDAR point cloud with RGB values extracted from a 2010 NAIP orthophoto.*

Figure 7.2. *Thief Valley Reservoir. Image is a three-dimensional LiDAR point cloud with RGB values extracted from a 2010 NAIP orthophoto.*

Figure 7.3. *Union Baker Area wind farm. Image is a three-dimensional LiDAR point cloud with RGB values extracted from a 2010 NAIP orthophoto.*