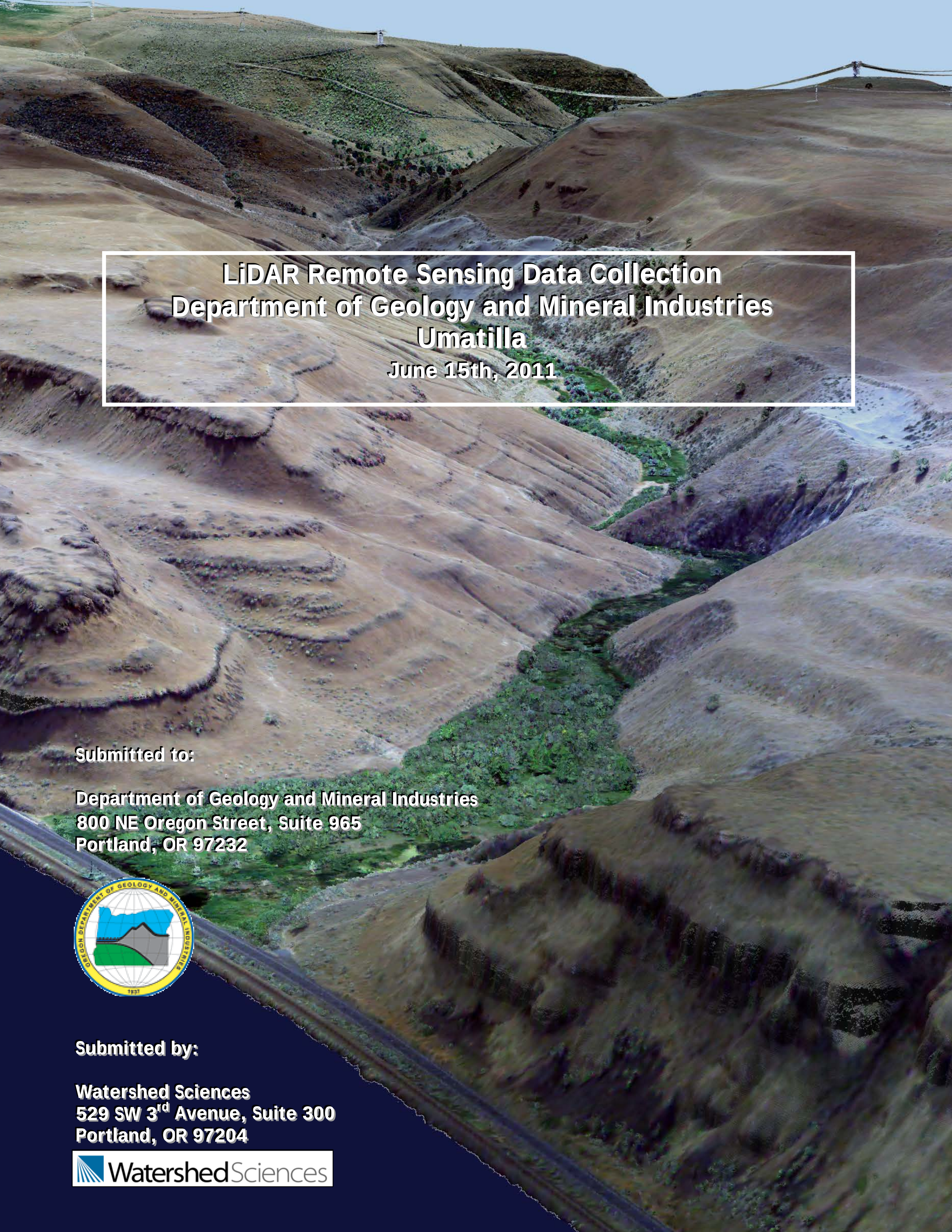

# LiDAR Remote Sensing Data Collection
# Department of Geology and Mineral Industries
# Umatilla

**June 15th, 2011**


**Submitted to:**

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# LiDAR Remote Sensing Data Collection:
## DOGAMI, Umatilla Study Area

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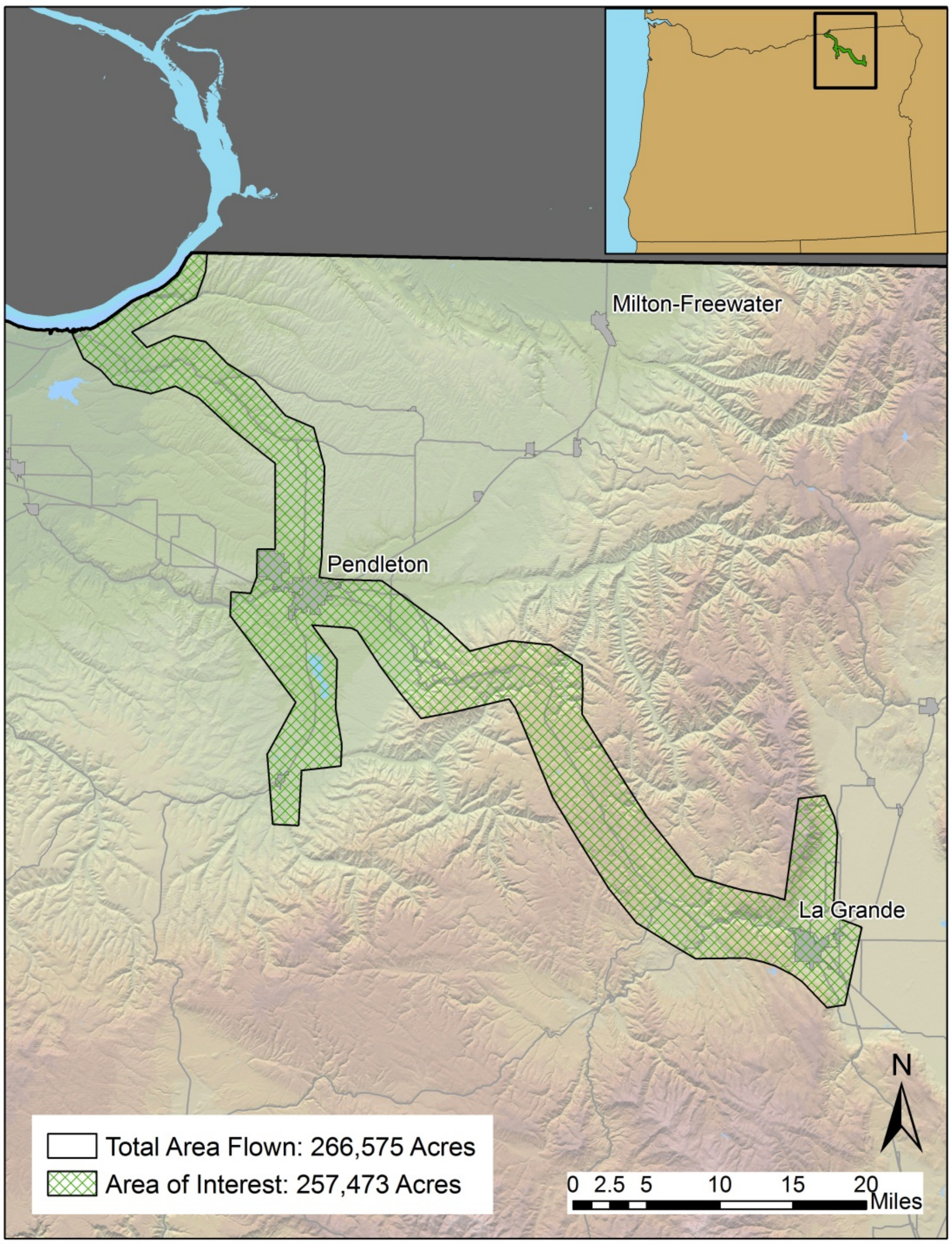
Watershed Sciences

# 1. Overview

## 1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Umatilla study area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 402 square miles (257,473 acres) and the total area flown (TAF) covers 417 square miles (266,575 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. Umatilla data are delivered in Oregon Statewide Lambert Conformal Conic; NAD83(HARN)/ NAVD88(Geoid 03); Units: International Feet.

***Figure 1.1.*** *DOGAMI Umatilla Study Area.*

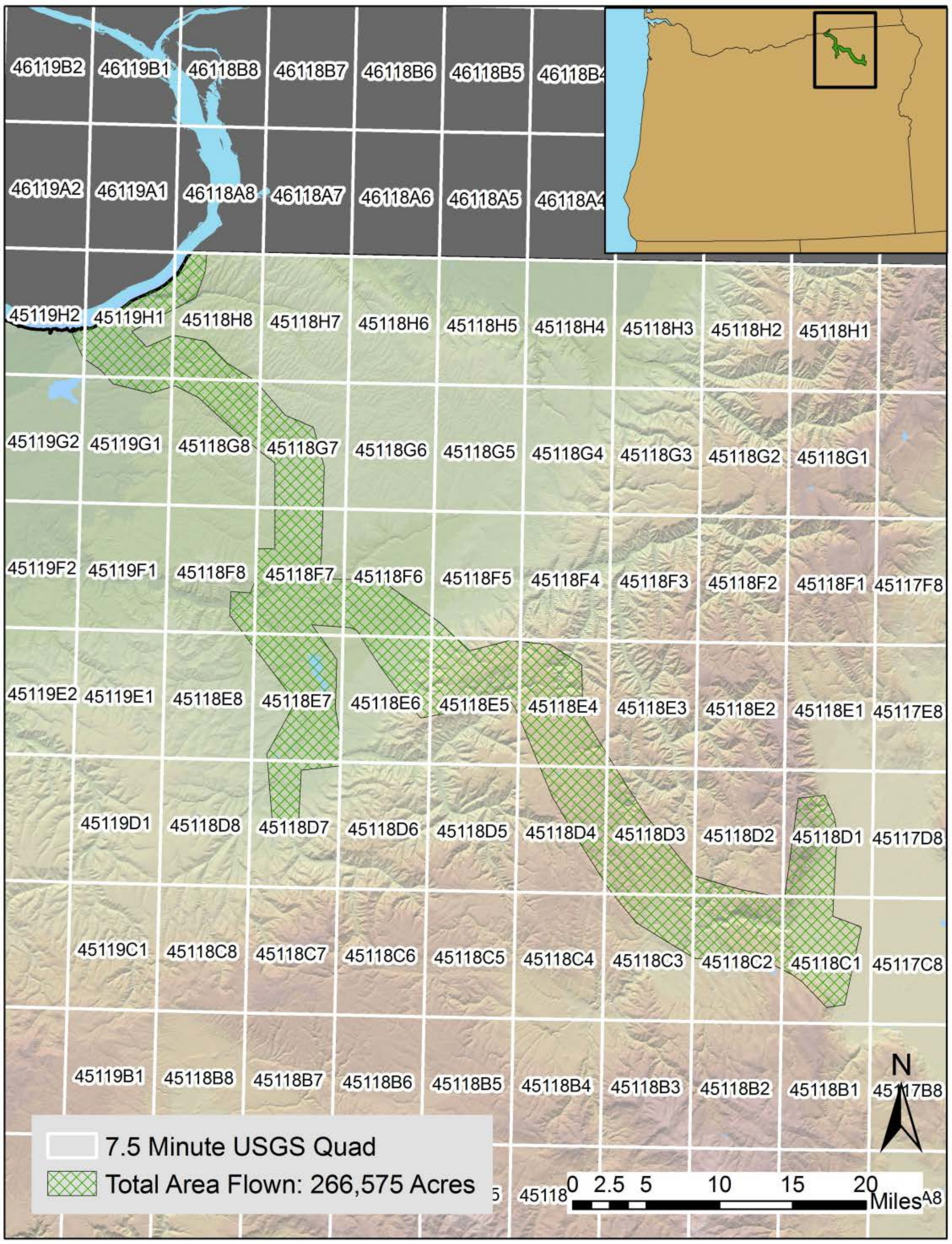


## 1.2 Data Delivered

Total delivered acreage is detailed below.

| DOGAMI Umatilla Study Area | | | |
|---|---|---|---|
| **Delivery Date** | **Acquisition Dates** | **AOI Acres** | **TAF Acres** |
| June 15th, 2011 | March 12th – May 13th, 2011 | 257,473 | 266,575 |

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



# 2. Acquisition

## 2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized Leica ALS50 and ALS60 sensors mounted in a Cessna Caravan 208B. The Leica 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 ±15° from nadir[1]. For select missions, the Leica ALS60 was set to acquire ≥148 kHz and flown at 1500 meters AGL, capturing a scan angle of ±12° from nadir. 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 and ALS60 |
| Survey Altitude (AGL) | 900 m and 1500 m |
| Pulse Rate | ≥105 and ≥148 kHz |
| Pulse Mode | Single and Multiple |
| Mirror Scan Rate | 52 and 63 Hz |
| Field of View | 30° and 24° |
| Roll Compensated | Up to 30° |
| Overlap | 120% (60% Side-lap) |

The study area was surveyed with opposing flight line side-lap of ≥60% (≥120% 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.

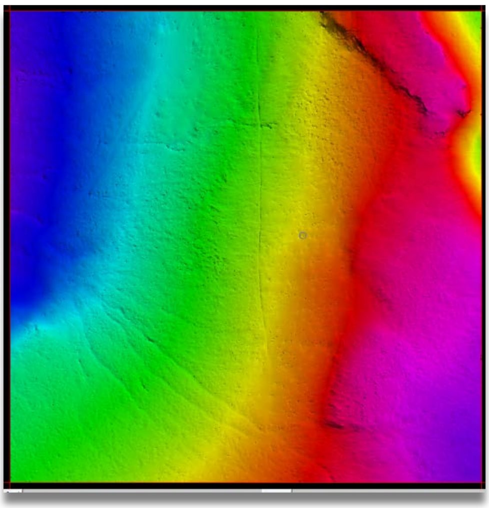
To solve for laser point position, it is vital to have an accurate description of aircraft position and attitude. Aircraft position is described as x, y and z and measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude is measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). **Figure 2.1** shows the flight lines completed for the study area.

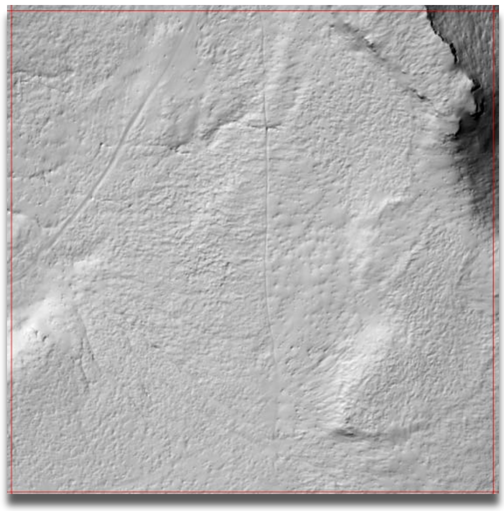
[1] Nadir refers to the perpendicular vector to the ground directly below the aircraft. Nadir is commonly used to measure the angle from the vector and is referred to a "degrees from nadir".

Owing to late seasonal snowpack and contractual deadline restrictions, LiDAR acquisition took place with snow on the ground in upper elevations of the Umatilla 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 10, mean relative accuracy 3 cm; 1$\sigma$ 3 cm). However, the presence of snow will be noticeable in the point data and raster surfaces (see images below).

Bare earth and highest hit raster data represent snow as ‘lobes’ and occasional divots distributed throughout an otherwise smooth surface. Point data that includes multiple days of acquisition may demonstrate minimal layering in flightlines owing to melting or accumulation of snow due to wind redistribution. 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.

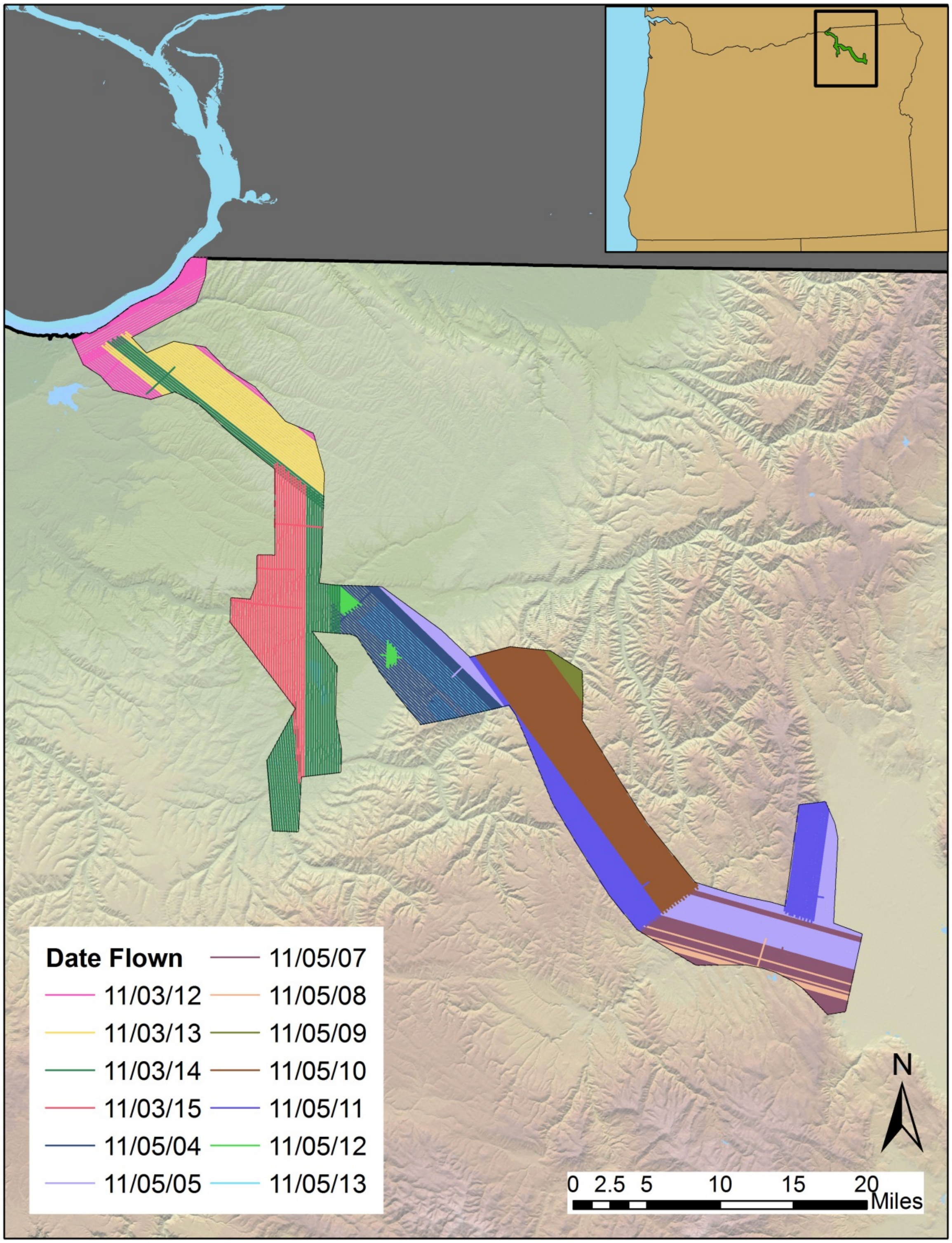
Example of “lobes” and divots resulting from snow distributed throughout the surface area of Mt. Emily in the LiDAR point data (left) and bare earth hillshade (right).





Images taken from the air during Umatilla acquisition.

***Figure 2.1.*** *Actual flightlines for the Umatilla 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 utilized a Trimble GPS receiver model R7 with a Zephyr Geodetic antenna with ground plane (OPUS ID: TRM41249.00) and Trimble GNSS receiver model R7 with a Zephyr Geodetic Model 2 antenna with ground plane (OPUS ID: TRM55971.00) 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 were used for static data acquisition. 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 Oregon Department of Transportation (ODOT) often establish their own benchmarks. NGS benchmarks are preferred for control points on this project NGS point Blue Mountain CBL O (PID: RB1490). In the absence of NGS benchmarks, county surveys, or ODOT monumentation, Watershed Sciences produces its own monuments. These monuments are spaced a minimum of one mile apart 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 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 GNSS 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 GNSS 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). For RTK data, the collector begins recording after remaining stationary for 5 seconds, then calculates the pseudo range position from at least three epochs with the relative error under 1.5 cm horizontal and 2 cm vertical. 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 manholes 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 GNSS 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** shows subsets of these RTK locations.

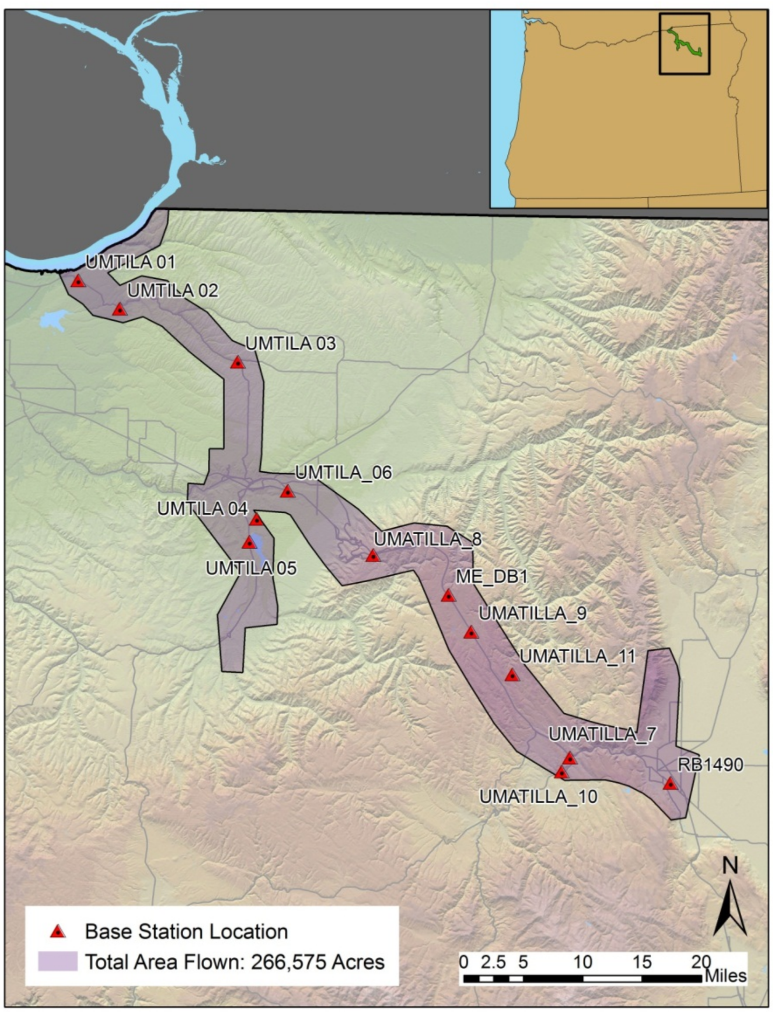
[4] U.S. Army Corps of Engineers , Engineer Research and Development Center Topographic Engineering Center software

[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 Umatilla Study Area.*

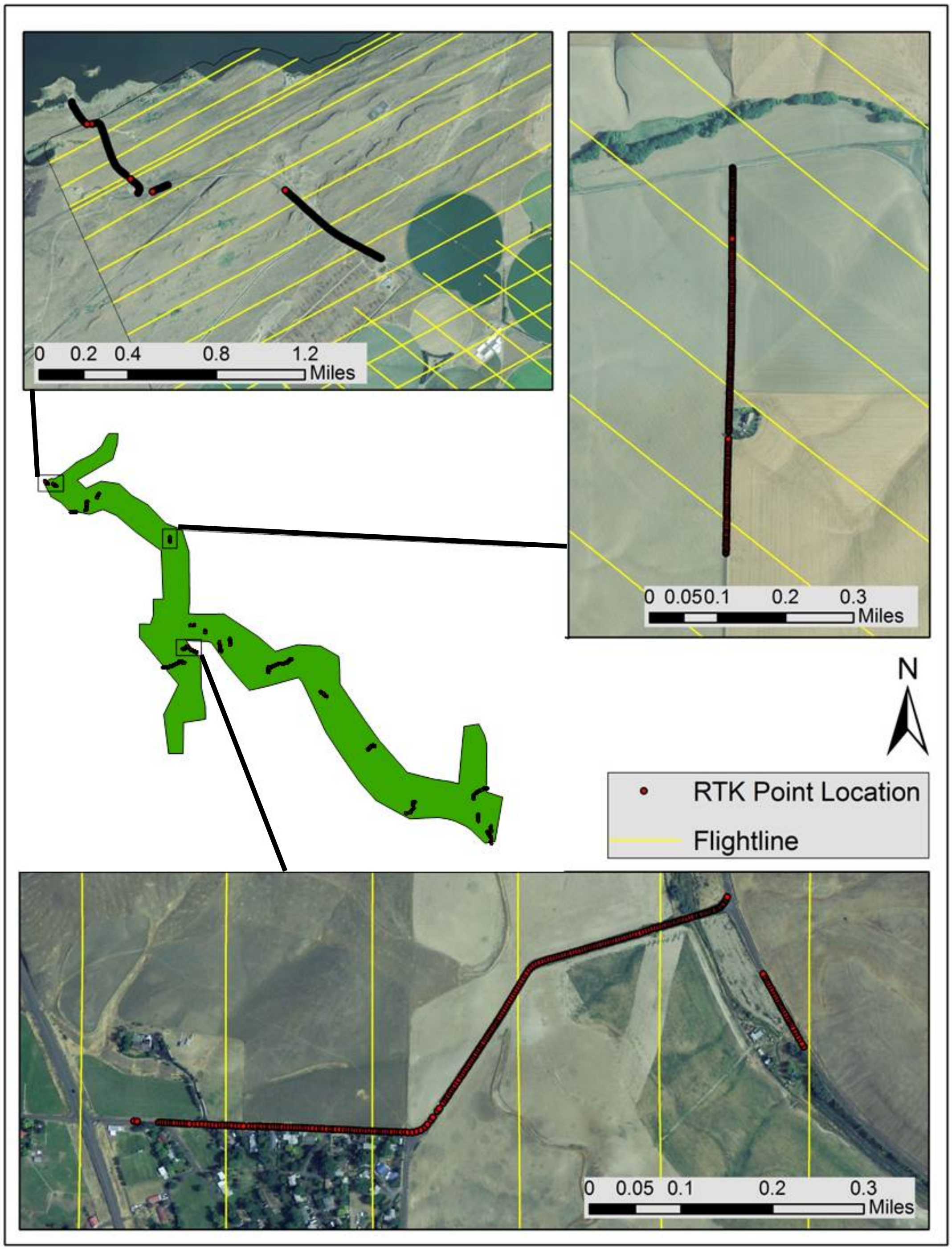
| | Datum NAD83 (HARN) | | GRS80 |
|---|---|---|---|
| **Base Stations ID** | **Latitude (North)** | **Longitude (West)** | **Ellipsoid Height (m)** |
| UMTILA 01 | 45 54 37.42748 | 119 06 40.44241 | 187.547 |
| UMTILA 02 | 45 52 37.00840 | 119 02 13.23425 | 256.274 |
| UMTILA 03 | 45 48 56.90918 | 118 49 44.28748 | 424.397 |
| UMTILA 04 | 45 37 27.78156 | 118 47 22.97323 | 345.370 |
| UMTILA 05 | 45 35 46.40079 | 118 48 05.65319 | 411.839 |
| UMTILA_06 | 45 39 34.53016 | 118 44 13.89421 | 398.271 |
| UMATILLA_7 | 45 20 24.28421 | 118 14 19.60294 | 907.788 |
| UMATILLA_8 | 45 35 00.32808 | 118 35 10.90037 | 1033.373 |
| RB1490 | 45 18 39.41729 | 118 03 52.26088 | 818.690 |
| ME_DB1 | 45 32 11.56540 | 118 27 14.18118 | 1149.374 |
| UMATILLA_9 | 45 29 31.20201 | 118 24 48.43805 | 1142.143 |
| UMATILLA_10 | 45 19 22.32070 | 118 15 10.06304 | 918.771 |
| UMATILLA_11 | 45 26 26.20097 | 118 20 28.29407 | 1250.532 |

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



For the Umatilla study area, 5,100 RTK (Real-time kinematic) points were collected. **Figure 2.3** shows detailed views of selected RTK locations.

**Figure 2.3** Selected RTK point locations; 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 464 flightlines and over 16 billion points. Relative accuracy is reported for the entire study area.

- Project Average = 0.09 feet (0.03 m)
- Median Relative Accuracy = 0.09 feet (0.03 m)
- 1σ Relative Accuracy = 0.10 feet (0.03 m)
- 2σ Relative Accuracy = 0.13 feet (0.04 m)

***Figure 3.1*** *Statistical relative accuracies, non-slope adjusted.*

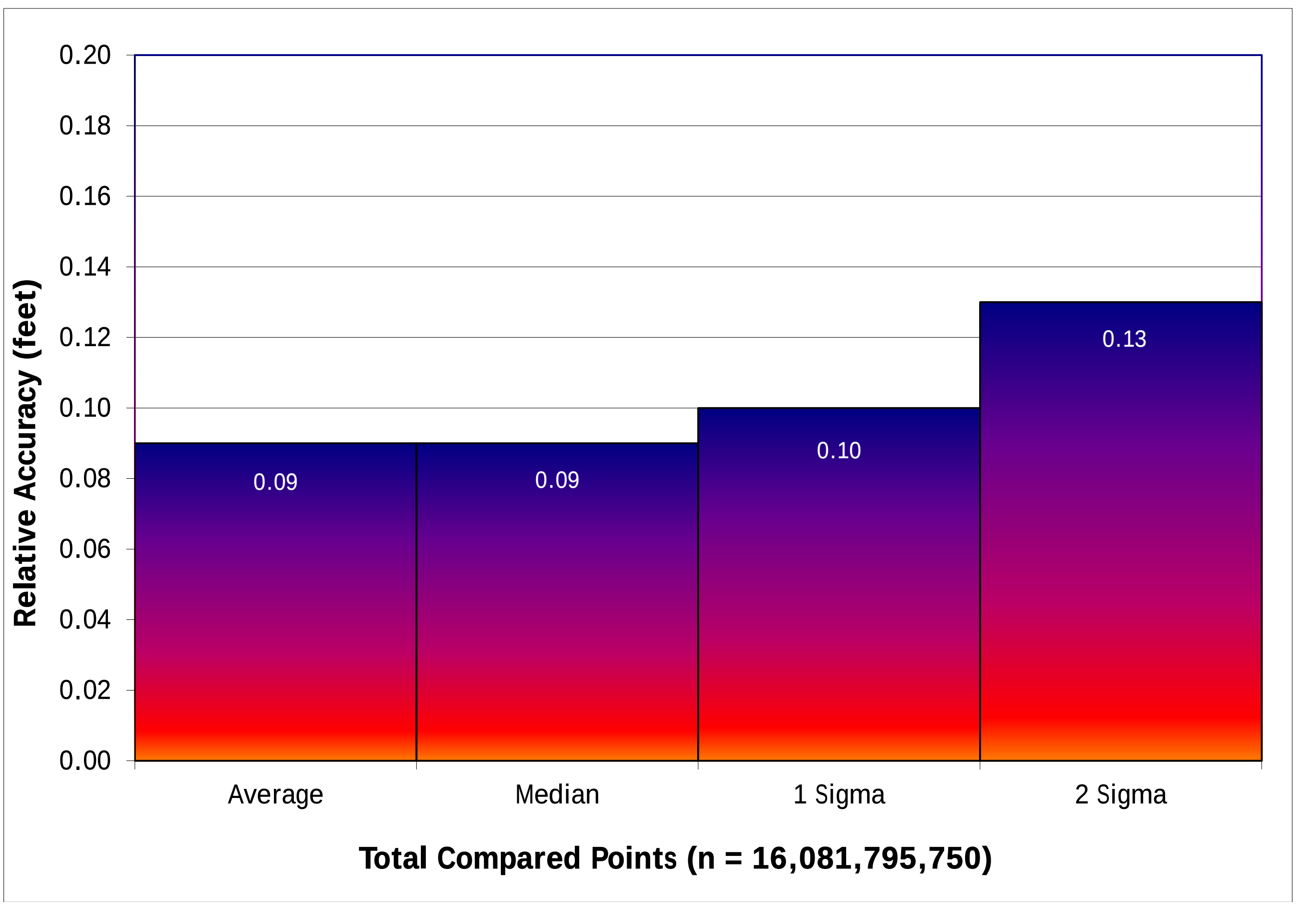
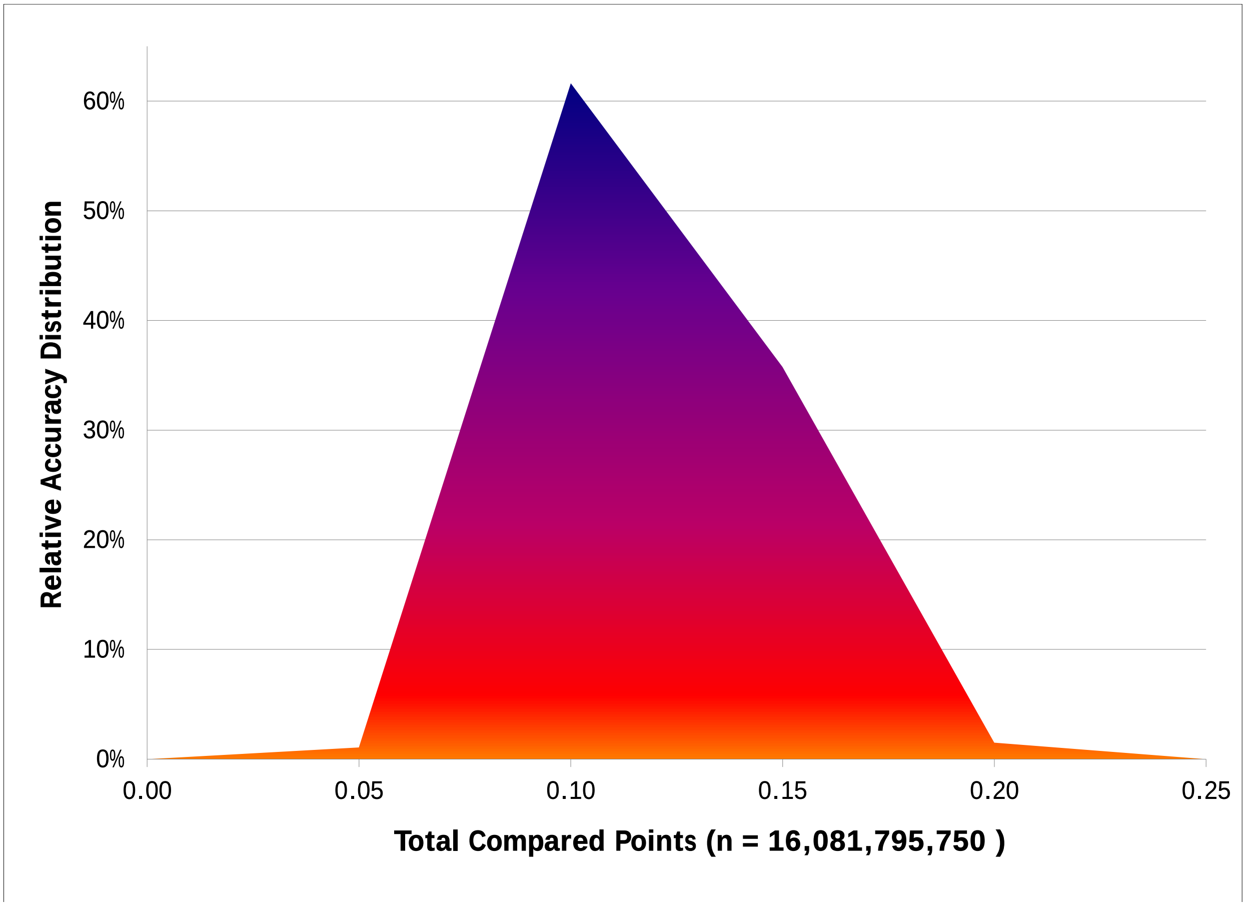


***Figure 3.2.*** *Percentage distribution of relative accuracies, non-slope adjusted.*




## 3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Umatilla study area, 5,100 RTK points were collected for data in the study area. Absolute accuracy is reported for the entire study area and shown in **Table 3.1** below**.**

***Table 3.1*** *Absolute Accuracy – Deviation between laser points and RTK survey points.*

| **Sample Size (n):** 5,100 | |
|---|---|
| **Root Mean Square Error (RMSE):** 0.11 feet (0.03m) | |
| **Standard Deviations** | **Deviations** |
| **1 sigma (σ):** 0.10 feet (0.03 m) | **Minimum Δz:** -0.40 feet (-0.12 m) |
| **2 sigma (σ):** 0.20 feet (0.06 m) | **Maximum Δz:** 0.71 feet (0.22 m) |
| | **Average Δz:** -0.03 feet (-0.01 m) |

***Figure 3.3*** *Umatilla Study Area histogram statistics*

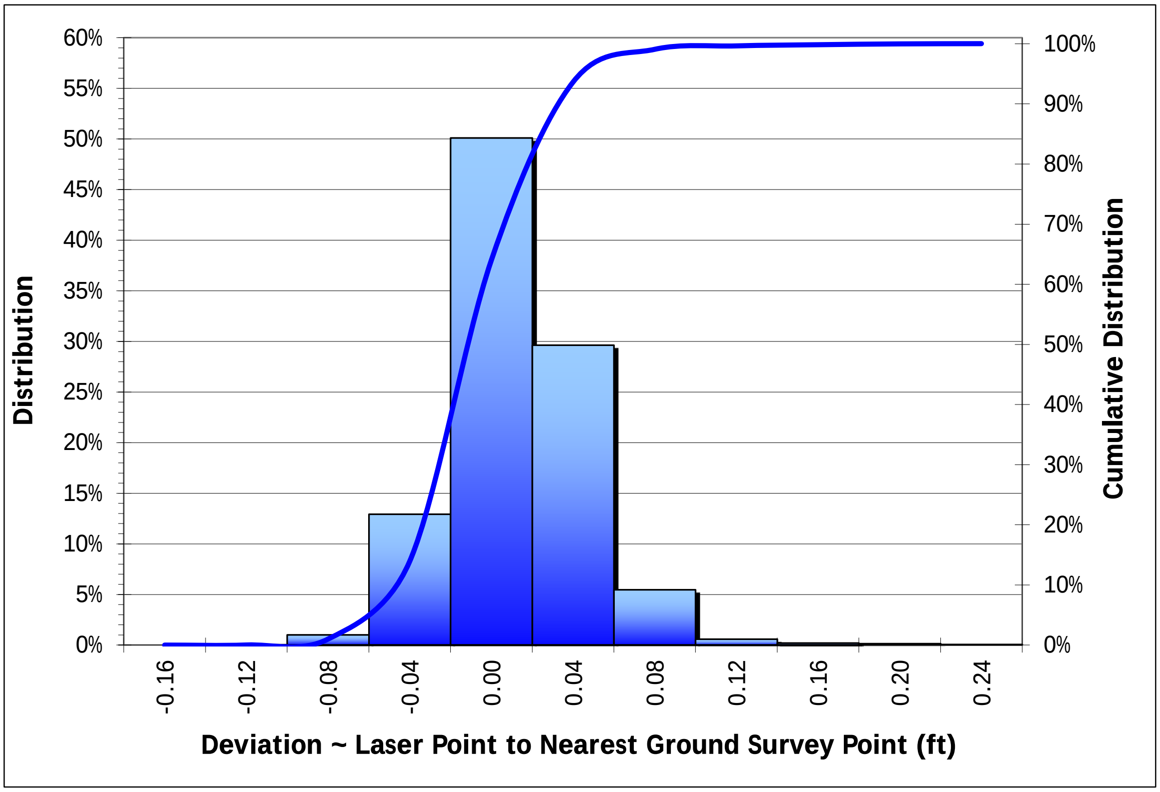
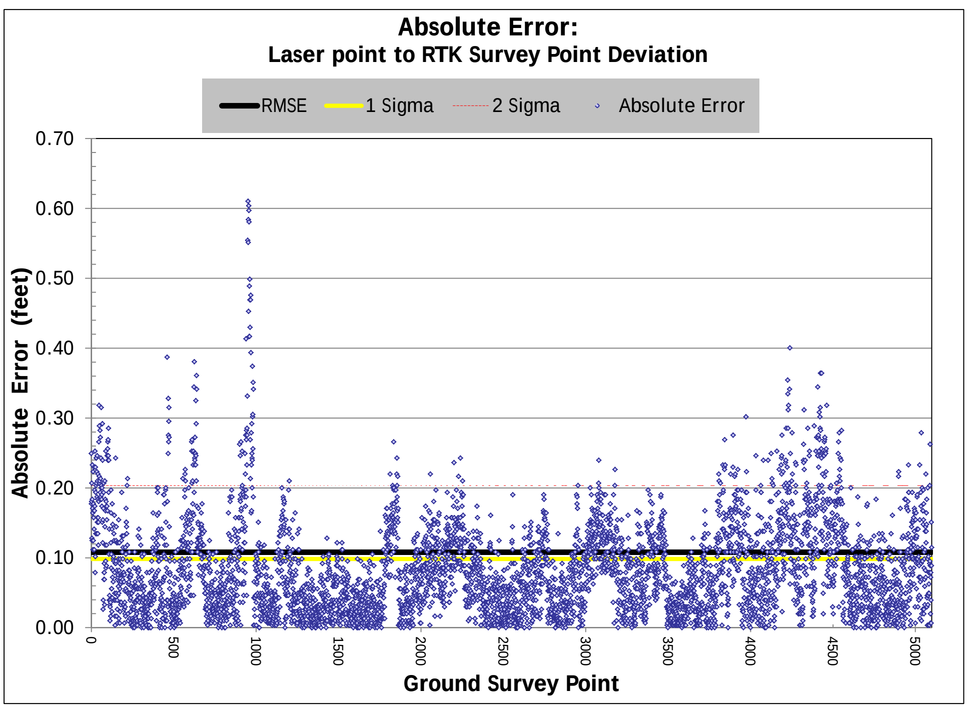



***Figure 3.4*** *Umatilla Study Area point absolute deviation statistics.*



# 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 have been calculated based on first return laser point density and ground-classified laser pulse density.

***Table 4.1**. Average density statistics for the Umatilla Study Area.*

| Average Pulse Density | Average Ground Density |
|---|---|
| 0.83 sq. feet (8.91 sq. meters) | 0.3 sq. feet (3.25 sq. meters) |

***Figure 4.1.** Histogram of first return laser pulse density.*

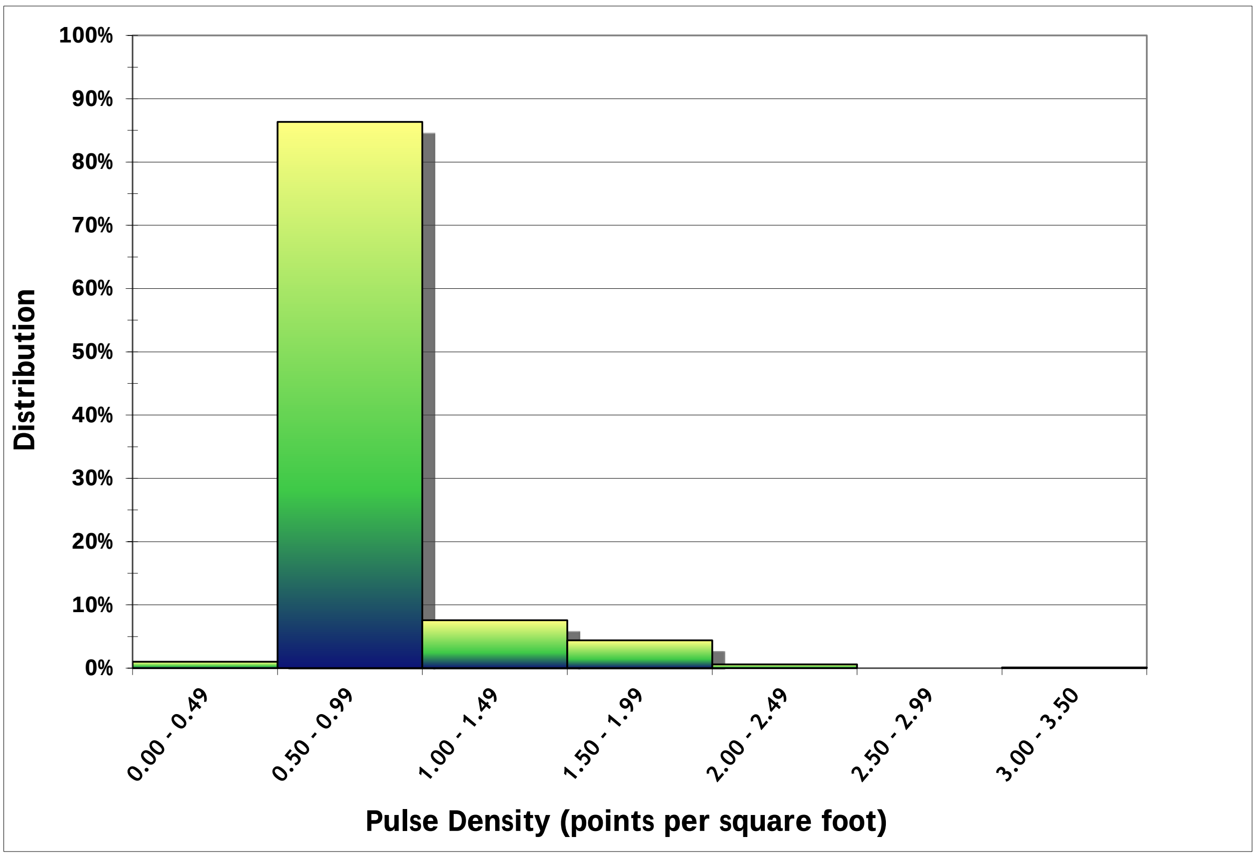


***Figure 4.2.*** *First return laser pulse densities per 0.75' USGS Quad.*

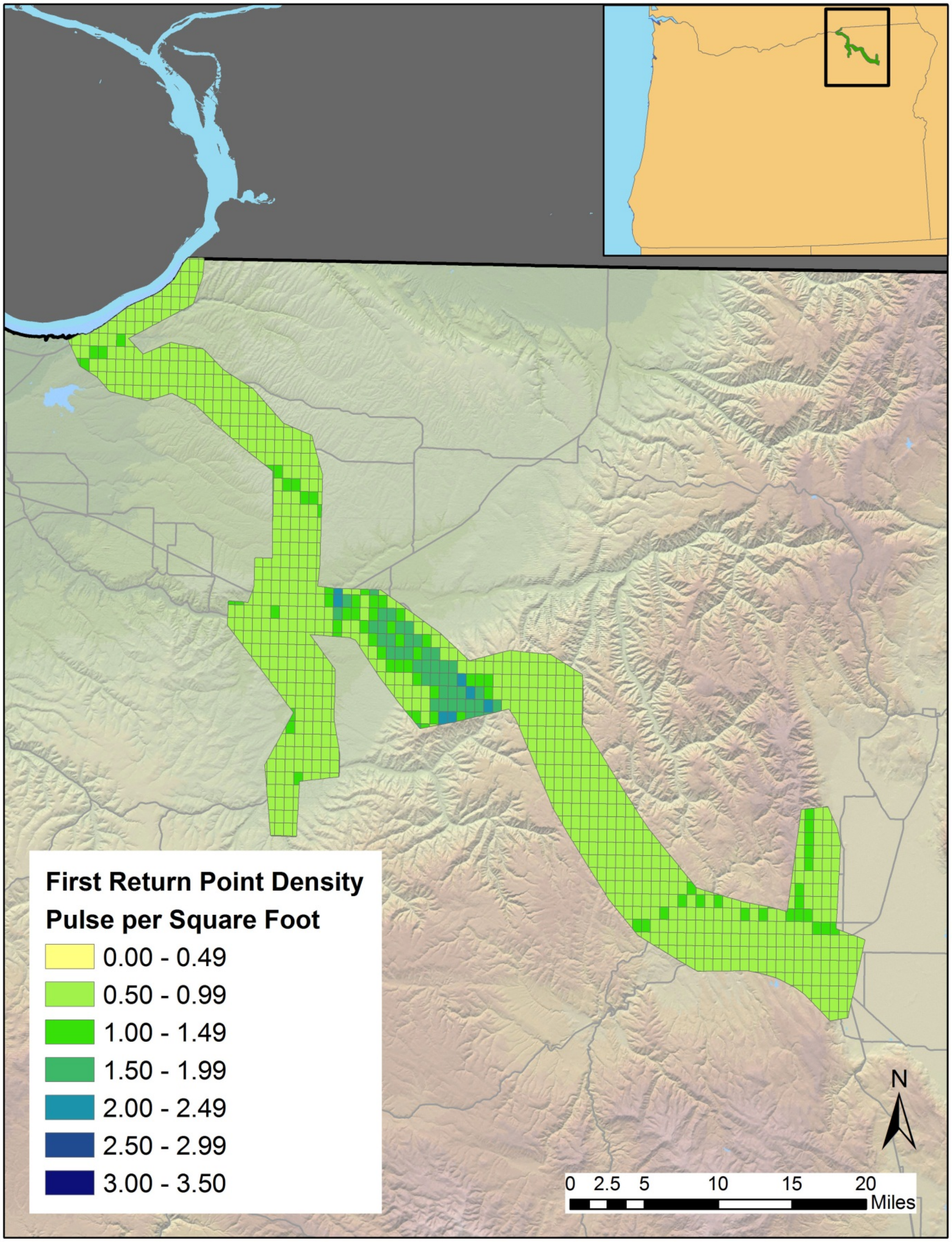
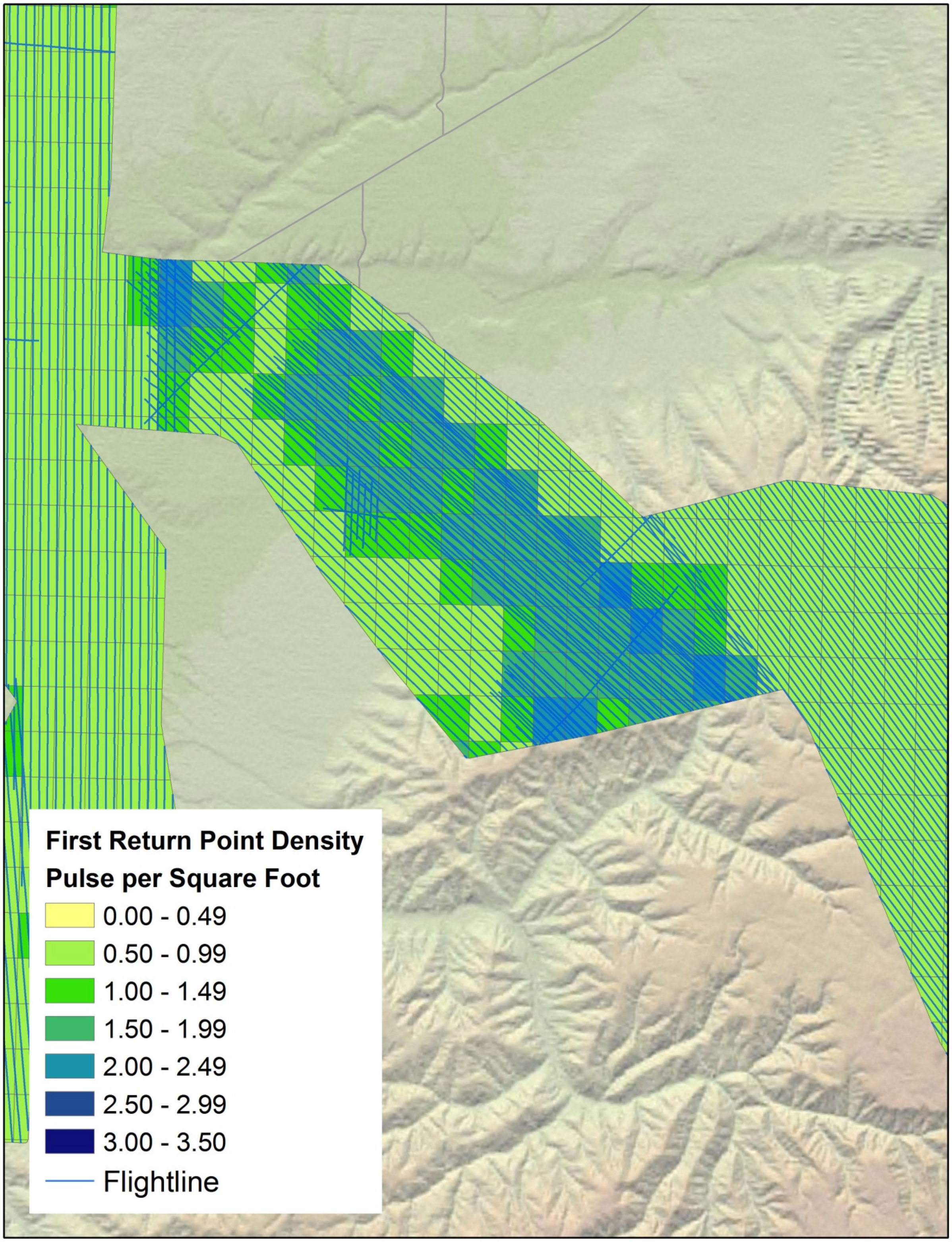


***Figure 4.3.*** *The central portion of the study area includes data from many overlapping flight lines resulting in locally higher pulse density.*



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 4.4.*** *Histogram of ground-classified laser point density.*

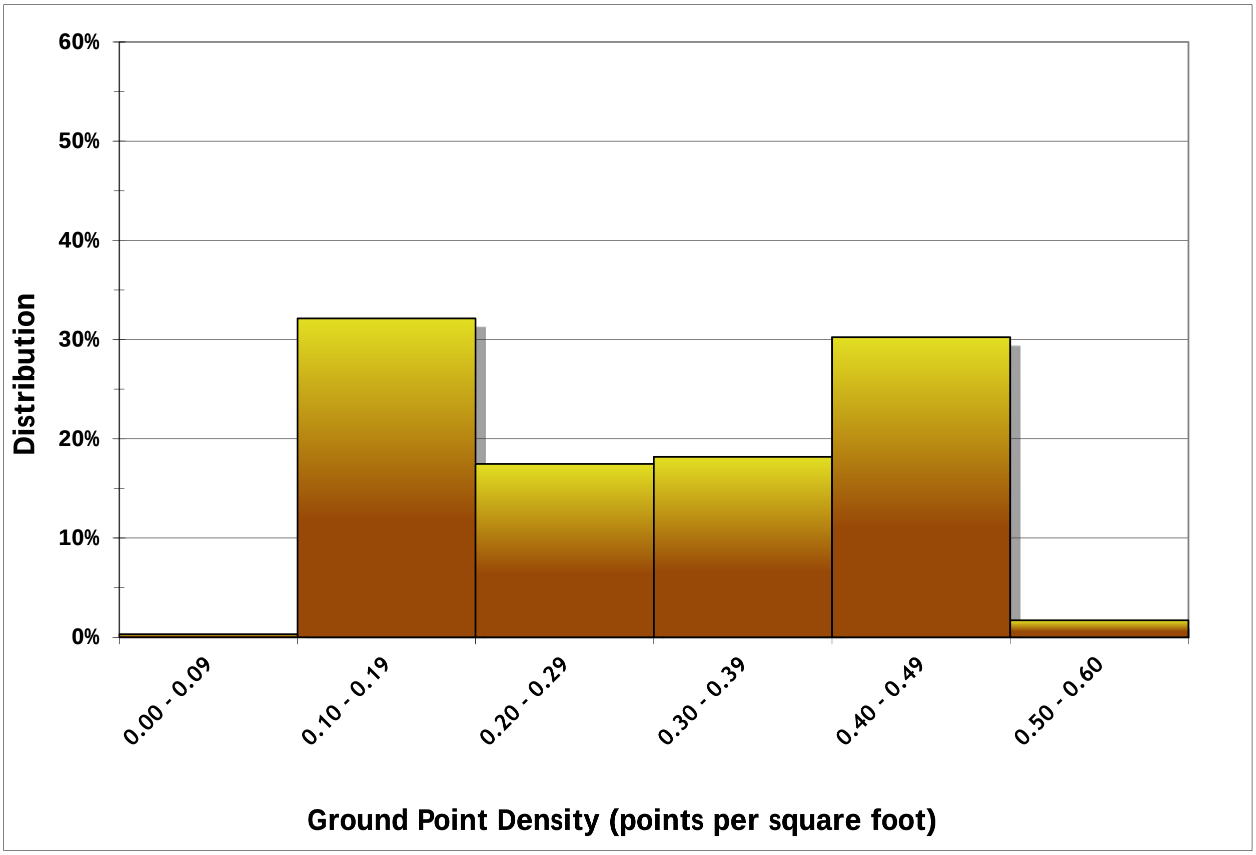


***Figure 4.5.*** *Ground-classified laser point density per 0.75' USGS Quad for data delivered to date.*

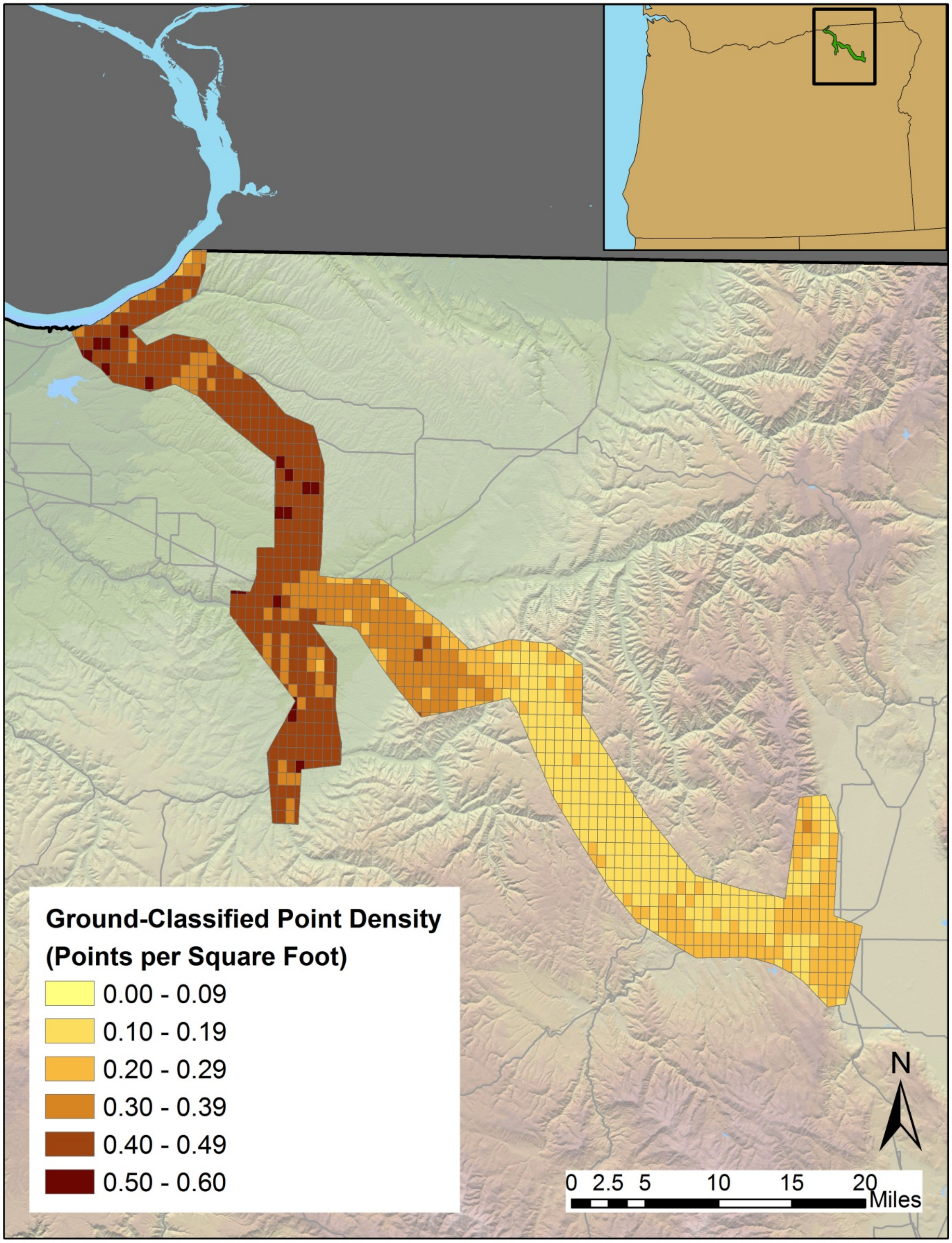
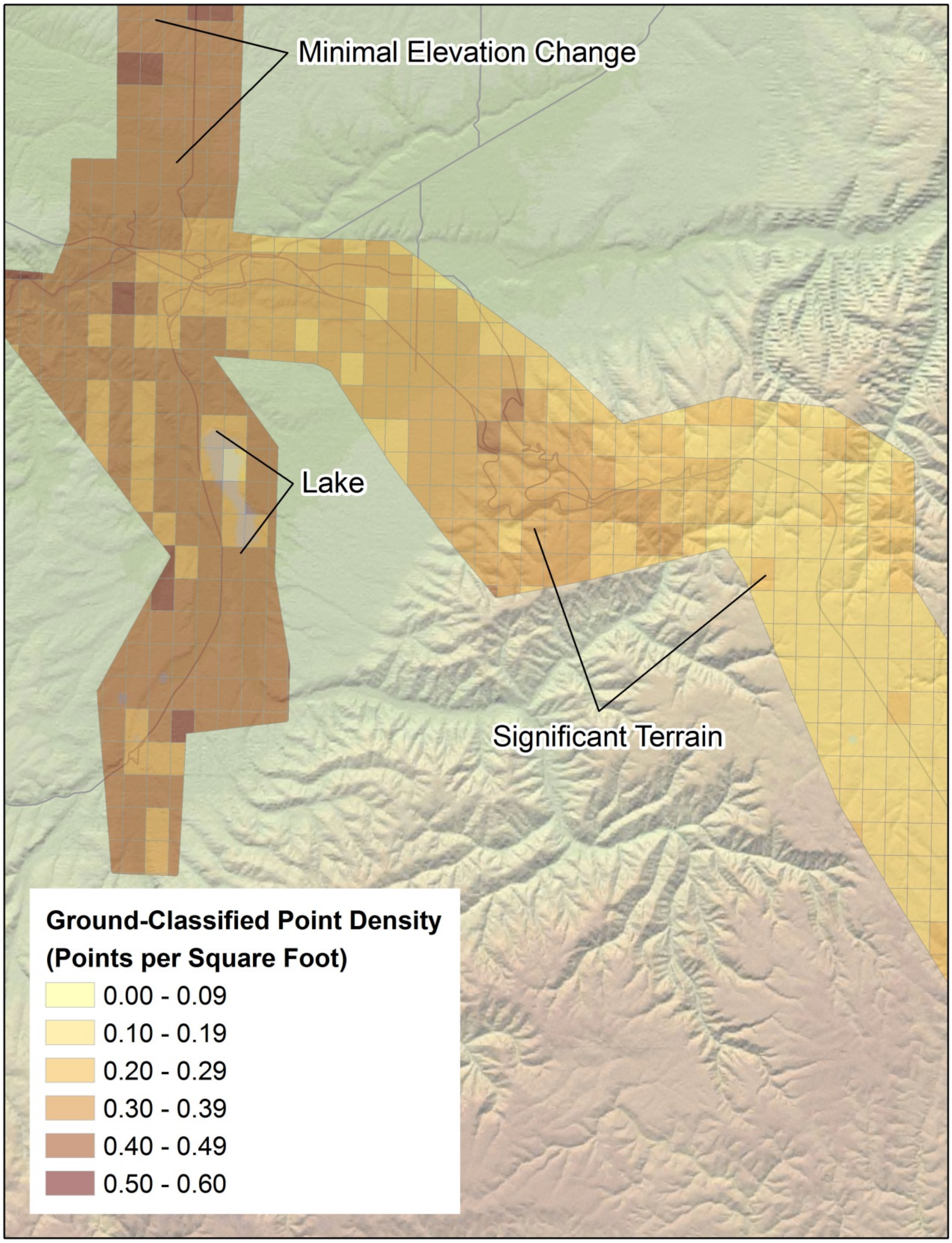


***Figure 4.6.*** *Variations in ground point density can be attributed to the topography and surface type of the study area.*



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## 5. Certifications

Watershed Sciences provided LiDAR services for the Umatilla 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 6/15/2011

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

RENEWAL DATE: 6/30/2012

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# 6. Selected Imagery

***Figure 6.1***. Southeast view of Juniper Canyon with the Columbia River in the foreground. Image is a LiDAR point cloud with RGB values RGB values extracted from NAIP imagery

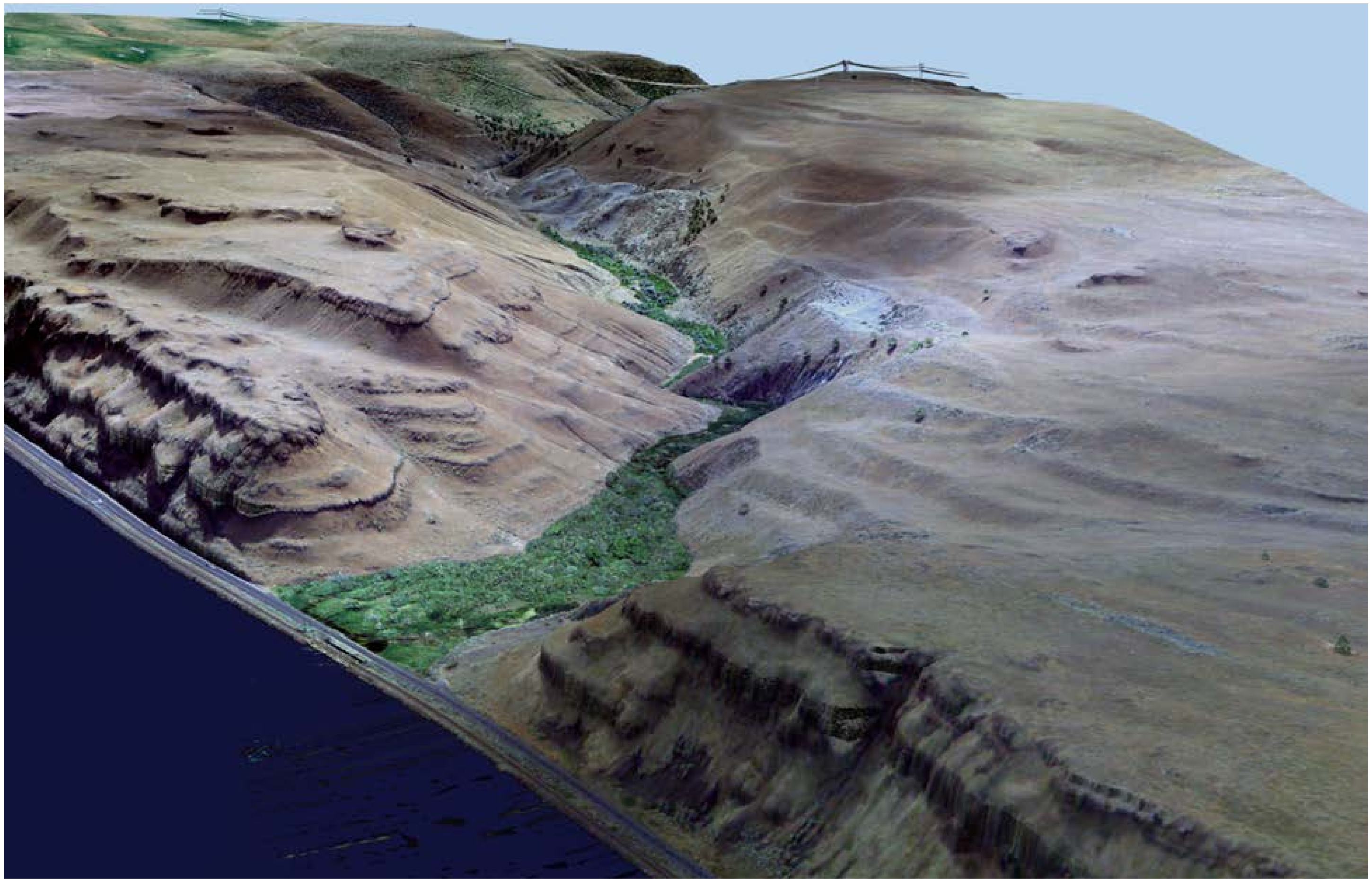

***Figure 6.2.*** East view of Pendleton-John Day Highway and McKay Reservoir. Image is a LiDAR point cloud with RGB values extracted from NAIP imagery.

***Figure 6.3.*** North view of Pendleton-John Day Highway through Pilot Rock, Oregon. Image is a LiDAR point cloud with RGB values extracted from NAIP imagery.