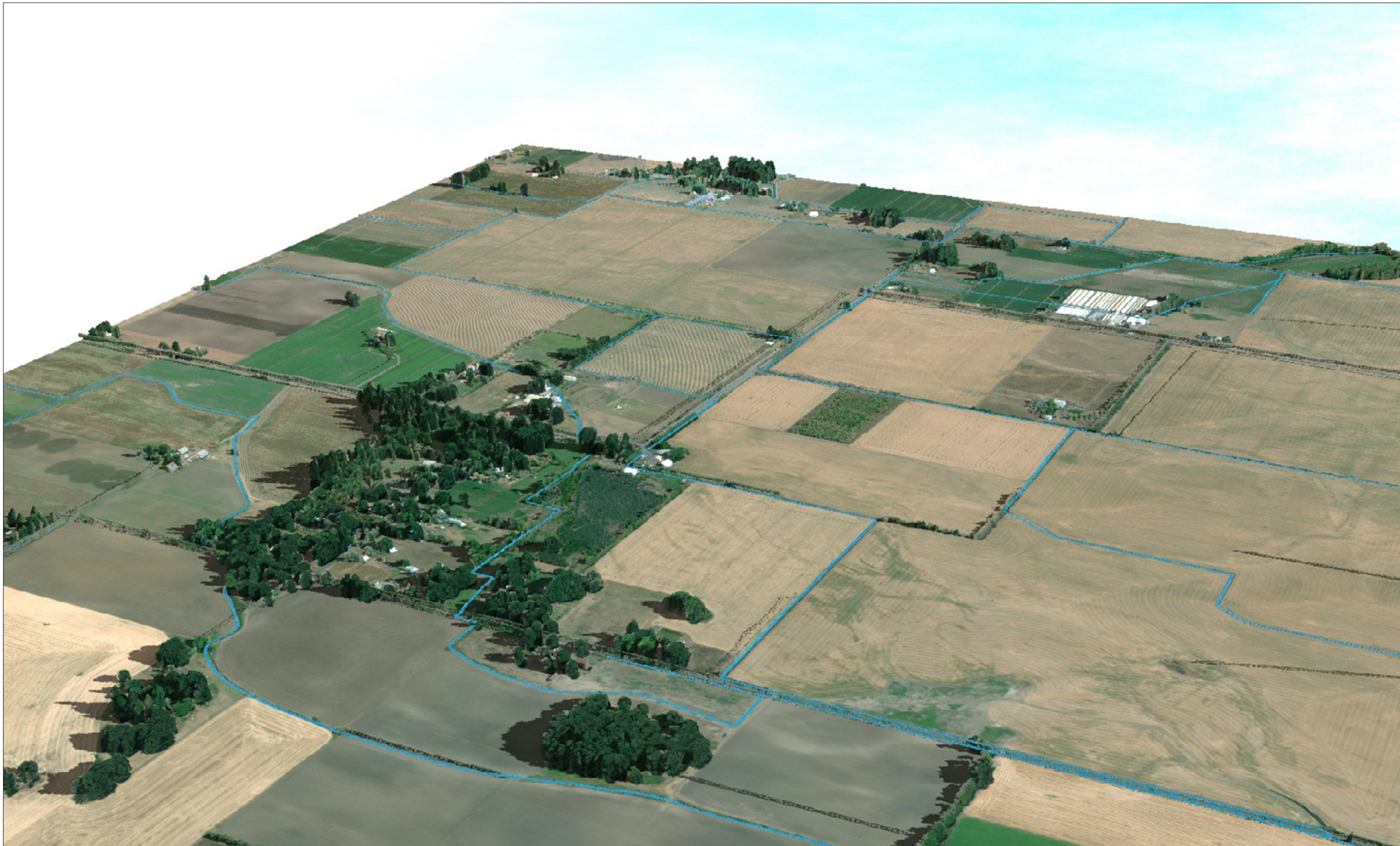
2018 OLC Santiam

March 29, 2019



Data collected for:
Oregon Department of Geology and Mineral Industries

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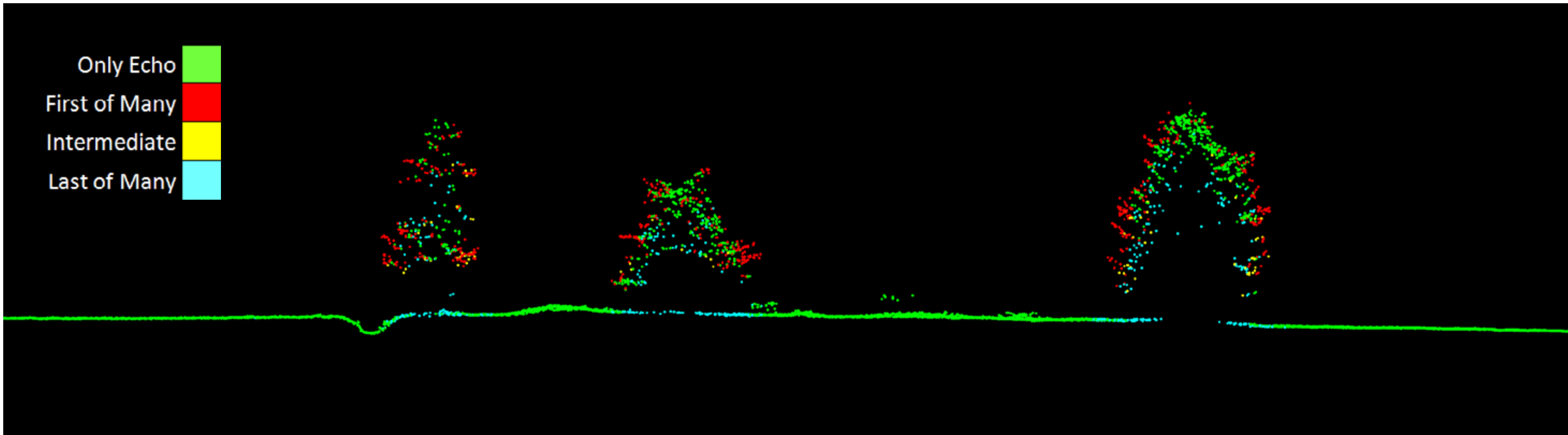

Above: This 6 ft cross section shows a small group of trees within the OLC Santiam project AOI, colored by point laser echo.

Cover Photo: A view looking southeast across agricultural landscape in the OLC Santiam project area. The image was created from the LiDAR bare earth model with the above-ground point cloud overlaid and colored by satellite imagery.

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Contents

The above image shows the bare earth hillshade within the OLC Santiam project area.

Project Overview

QSI has completed the acquisition and processing of Light Detection and Ranging (LiDAR) data describing the Oregon LiDAR Consortium's (OLC) Santiam 2018 Study Area. The Santiam TAF (total area flown) shown in Figure 1 encompasses 110,378 acres.

The collection of high resolution geographic data is part of an ongoing pursuit to amass a library of information accessible to government agencies as well as the general public.

LiDAR data acquisition occurred between November 18 and November 20, 2018. Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter. Final products are listed on page 3.

QSI acquires and processes data in the most current, NGS-approved datums and geoid. For OLC Santiam, all final deliverables are projected in Oregon Lambert, endorsed by the Oregon Geographic Information Council (OGIC),[1] using the NAD83 (2011) horizontal datum and the NAVD88 (Geoid 12B) vertical datum, with units in International feet.

Table 1: OLC Santiam delivery details

OLC Santiam	
Acquisition Dates	August 3, 2018
Area of Interest	106.585 acres
Total Area Flown	110,378 acres
Projection	OGIC Lambert
Datum: horizontal & vertical	NAD83 (2011) NAVD88 (Geoid 12B)
Units	International Feet

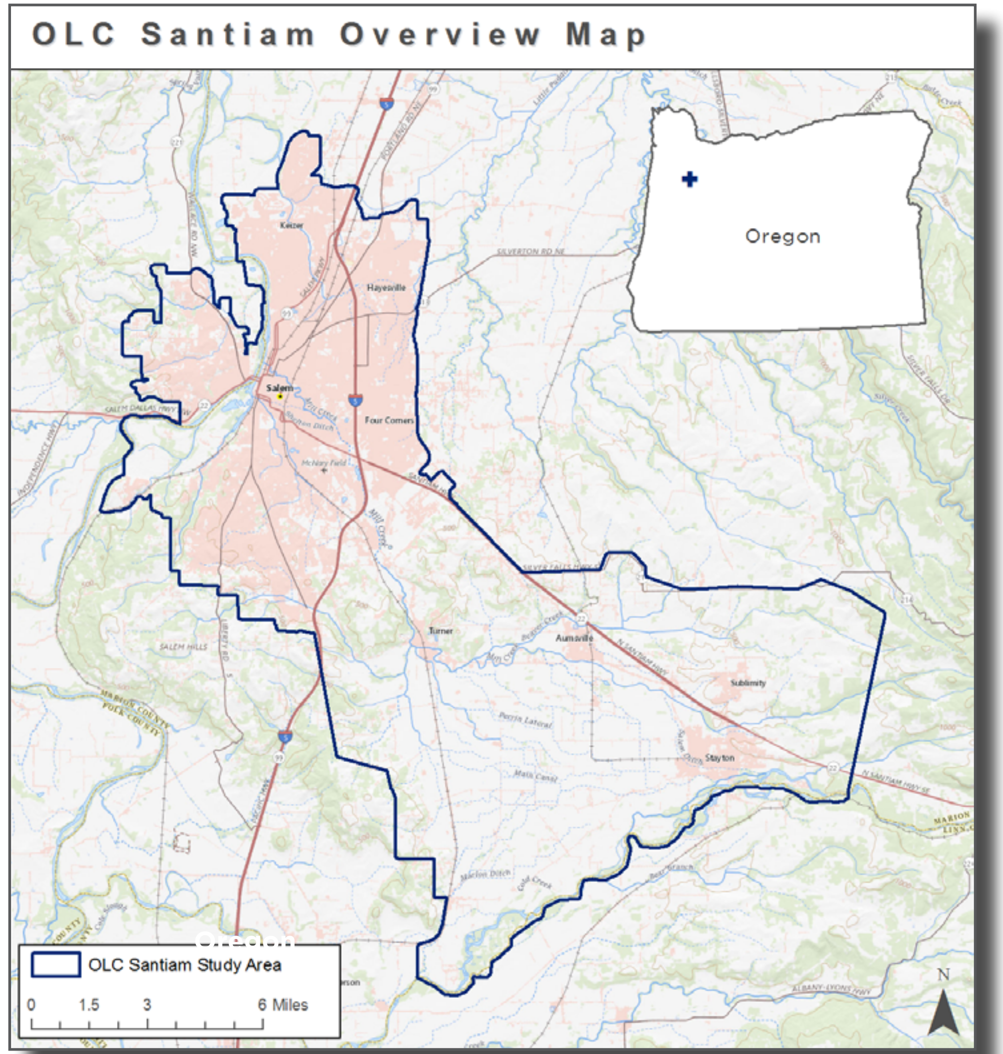


Figure 1: OLC Santiam study area location

1 http://www.oregon.gov/DAS/EISPD/GEO/pages/coordination/projections/projections.aspx

Deliverable OLC Products

Table 2: Products delivered for OLC Santiam study area.

OLC Santiam Projection: OGIC Lambert Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID12B) Units: International Feet	
Points	LAS v 1.2 tiled by 0.075 minute USGS quadrangles • Default (1), ground (2), water (9), and ignored ground (10) classified points • RGB color extracted from NAIP imagery • Intensities
Rasters	3 foot resolution ESRI GRID tiled by 7.5 minute USGS quadrangles • Bare earth (BE) digital elevation model (DEM) • Hydro-flattened BE DEM • Highest hit model 1.5 foot GeoTiffs tiled by 7.5 minute USGS quadrangles • Intensity images
Vectors	Shapefiles (*.shp) • Total area flown (TAF) boundary • TAF tile index of 0.075 minute USGS quadrangles • TAF tile index of 7.5 minute USGS quadrangles • Ground control points • Ground survey points (used to assess accuracy) • Survey monuments • Acquisition flightlines • 0.5 ft resolution contours, tiled • Hydro breaklines - rivers • Hydro breaklines - lakes
Metadata	• FGDC compliant metadata for all data products

Aerial Acquisition

LiDAR Survey

The LiDAR survey utilized a Leica ALS 80 sensor mounted in a Cessna Caravan. For system settings, please see Table 3. These settings are developed to yield points with an average native density of greater than eight pulses per square meter over terrestrial surfaces.

The native pulse density is the number of pulses emitted by the LiDAR system. Some types of surfaces such as 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 vary according to distributions of terrain, land cover, and water bodies. The study area was surveyed with opposing flight line side-lap of greater than 50 percent with at least 100 percent overlap to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per pulse, and all discernible laser returns were processed for the output data set.

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 (two hertz) by an onboard differential GPS unit. Aircraft attitude is measured 200 times per second (200 hertz) as pitch, roll, and yaw (heading) from an onboard inertial measurement unit (IMU).

Table 3: OLC Santiam acquisition specifications

OLC Santiam Acquisition	
Sensors Deployed	Leica ALS 80
Aircraft	Cessna Caravan
Survey Altitude (AGL)	1,400 m
Pulse Rate	348 kHz
Pulse Mode	Multi (MPiA)
Field of View (FOV)	40°
Scan Rate	42 Hz
Overlap	100% overlap with 60% sidelap

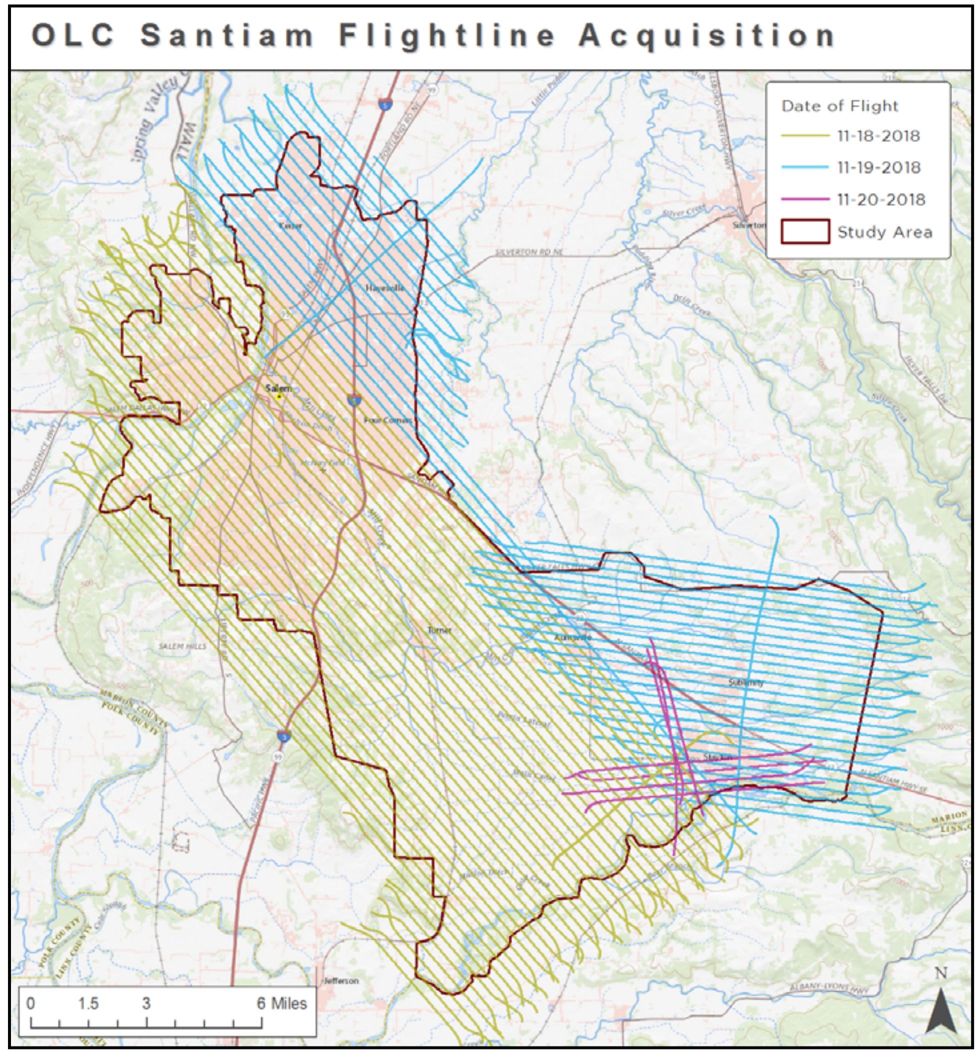


Figure 2: OLC Santiam acquisition flightlines

Ground Survey

Ground control surveys were conducted on November 25, 2018 to support data acquisition, including monumentation, ground control points (GCPs), and ground survey points (GSPs). Bare earth GCPs were collected to correct the final dataset to match the true ground surface and correct any bias from the satellite-based aircraft positional data, sensor installation, or sensor ranging. GSPs, however, were withheld from the calibration process and compared to the final ground surface providing an independent assessment of the Non-vegetated Vertical Accuracy (NVA) of the LiDAR point data. Trimble's VRS Now network was utilized to support collection of GCPs and GSPs. A table of the VRS Now stations used during ground survey are included in Table 4 on the page 7.

Instrumentation

All Global Navigation Satellite System (GNSS) static surveys utilized Trimble's VRS Now network; VRS Now provides real-time kinematic (RTK) corrections utilizing a network of permanent continuously operating reference stations. Rover surveys for GCP and GSP collection were conducted using RTK survey techniques with Trimble R8 GNSS receivers.

Methodology

Ground control points and ground survey points were collected using real time kinematic (RTK) survey techniques. For RTK surveys, a roving receiver receives corrections from a Real-Time Network (RTN) via radio or cellular network, enabling rapid collection of points with relative errors less than 1.5 cm horizontal and 2.0 cm vertical. RTK surveys recorded observations for a minimum of five seconds on each GCP/GSP. All GCP and GSP measurements were made during periods with a Position Dilution of Precision (PDOP) no greater than 3.0 and in view of at least six satellites for both receivers.

In order to facilitate comparisons with high quality LiDAR data, GCP and GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads. GCPs and GSPs were taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. GCPs and GSPs were collected within as many flight lines as possible; however, the distribution depended on ground access constraints and may not be equitably distributed throughout the study area.

Figure 3: BE DEM hillshade with the study area; Turner Quarry is visible in the lower left-hand corner of the image.

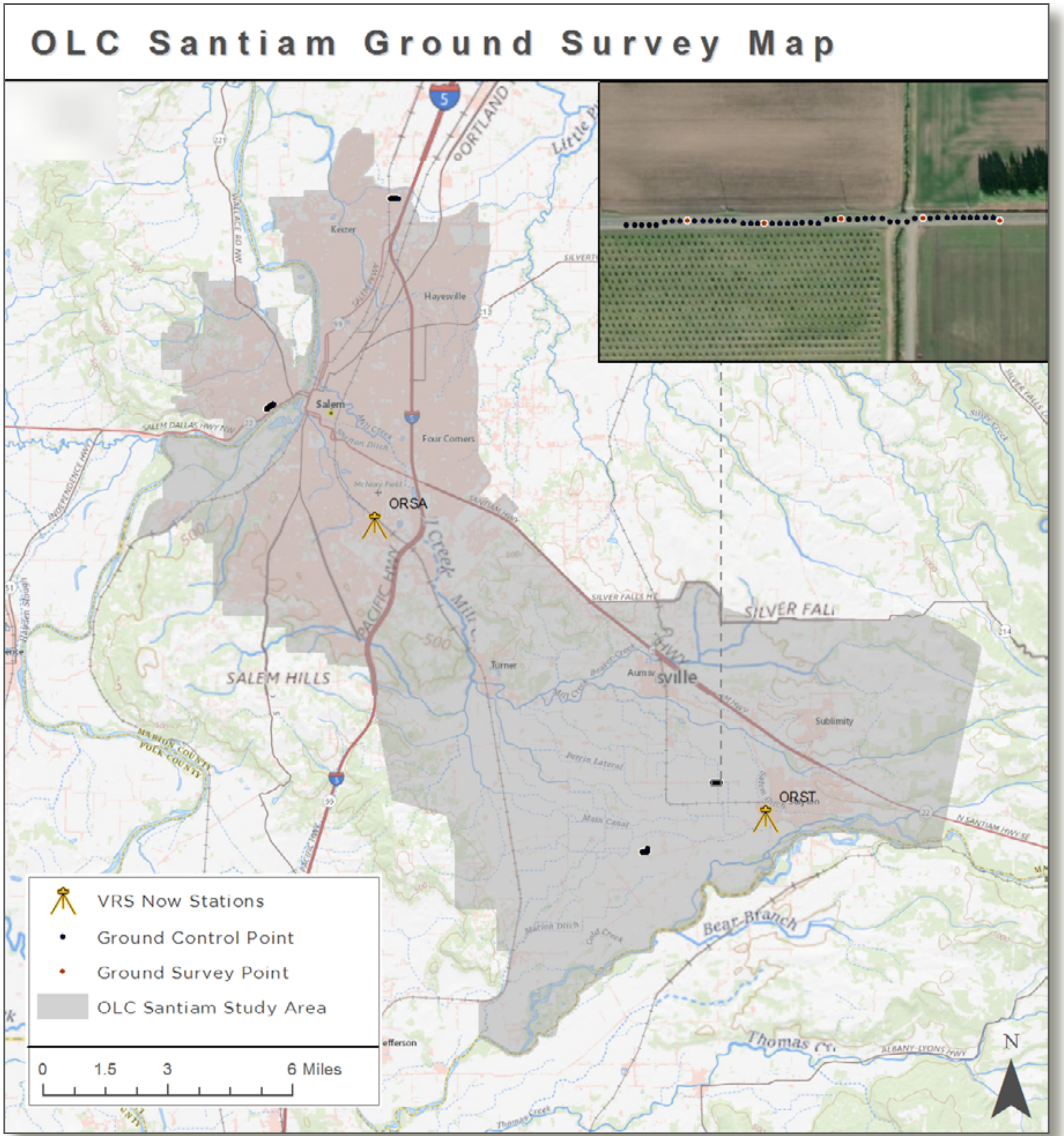


Figure 4: Santiam study area ground survey map

Table 4: OLC Santiam VRS Now stations. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12B

PID		Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
VRS Now Station	ORST	44° 47’ 50.12988”	-122° 49’ 02.18606”	116.806	140.046
	ORSA	44° 53’ 59.23909”	-123° 00’ 30.84151”	55.270	78.213

Table 5: Ground survey instrumentation

Instrumentation			
Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R8 GNSS	Integrated Antenna	TRMR8_GNSS	Rover

Geospatial Corrections of Aircraft Positional Data

Precise Point Positioning

To improve precision and accuracy of the aircraft trajectory, the latest generation of Global Navigation Satellite System (GNSS) satellites and recent advances in GNSS post-processing technology have made possible trajectory processing methods that do not require conventional base support: specifically, TerraPos® Precise Point Positioning (PPP).

PPP using TerraPos software utilizes advanced atmospheric and tectonic models to produce highly accurate trajectories without differential GNSS from base stations. Although other PPP options exist on the market, internal testing at QSI has determined that TerraPos produces the most reliably accurate result.

When utilized properly and sufficiently controlled by a ground survey during post-processing, PPP has the following advantages over conventional collection methods:

- Agility: The airborne acquisition is untethered by access constraints of the ground survey team at the time of acquisition, particularly in remote areas that lack permanent base stations.
- Flexibility: The airborne acquisition team can instantly shift collection priorities based on weather and client needs without waiting for a ground survey team to relocate.
- Accuracy: If properly controlled with a ground survey and datum adjustment during post-processing, PPP produces results at least as accurate as conventional methods utilizing base stations.

Processing

This section describes the processing methodologies for all data acquired by QSI for the 2018 OLC Santiam LiDAR project.

LiDAR Processing

Once the LiDAR data arrived in the laboratory, QSI employed a suite of automated and manual techniques for processing tasks. Processing tasks included: GPS kinematic corrections, calculation of laser point position, relative accuracy testing and calibrations, classification of ground and non-ground points, and assessments of statistical absolute accuracy. The general workflow for calibration of the LiDAR data was as follows:

LiDAR Processing Step	Software Used
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GNSS (collected at 2 Hz) and IMU (collected at 200 Hz) with TerraPos® Precise Point Positioning methodologies.	Inertial Explorer TerraPos® PPP
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude are calculated throughout the survey.	Inertial Explorer
Calculate laser point position by associating SBET information to each laser point return time, with offsets relative to scan angle, intensity, etc. included. This process creates the raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.4) format, in which each point maintains the corresponding scan angle, return number (echo), intensity, and x, y, z information. These data are converted to orthometric elevation (NAVD88) by applying a Geoid 12B correction.	Leica CloudPro
Import raw laser points into subset bins. Filter for noise and perform manual relative accuracy calibration.	LASTools TerraScan Custom QSI software
Classify ground points and test relative accuracy using ground classified points per each flight line. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale), and GPS/IMU drift. Calibrations are performed on ground classified points from paired flight lines. Every flight line is used for relative accuracy calibration.	TerraMatch TerraScan Custom QSI software
Assess Non-Vegetated Vertical Accuracy and Vegetated Vertical Accuracy via direct comparisons of ground classified points to reserved non-vegetated and vegetated checkpoint survey data.	TerraScan
Assign headers (e.g., projection information, variable length record, project name) to *.las files.	Las Monkey

LAS Classification Scheme

The classification classes are determined by the USGS LiDAR Base Specification, version 1.3 specifications and are an industry standard for the classification of LiDAR point clouds. The classes used in the dataset are as follows and have the following descriptions:

- **Class 1 – Processed, but unclassified.** This class covers features such as vegetation, cars, utility poles, or any other point that does not fit into another deliverable class.
- **Class 2 – Bare earth ground**. Points used to create bare earth surfaces.
- **Class 9 – Water.** Point returned off water surfaces.
- **Class 10 – Ignored Ground**. Points within 0.7 meters of river and lake breaklines.

Hydro-Flattened Breaklines

Class 2 LiDAR was used to create a bare earth surface model. The surface model was then used to heads-up digitize 2D breaklines of inland streams and rivers with a 100 foot nominal width and inland ponds and lakes of two acres or greater surface area.

Elevation values were assigned to all inland ponds and lakes, inland pond and lake islands, inland streams and rivers and inland stream and river islands using Quantum Spatial proprietary software

All ground (ASPRS Class 2) LiDAR data inside of the collected inland breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. The breakline files were then translated to Esri file geodatabase format using Esri conversion tools.

Hydro-Flattened Raster DEM Creation

Hydro flattening breaklines are merged with Class 2 LAS and set to enforce elevations within closed areas identified as water while retaining near shore LiDAR elevations. This process is used to ensure a downstream gradient along streams and waterbodies are level.

LiDAR Accuracy Assessments

Relative Accuracy

Relative vertical 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 centimeters). Internal consistency is affected by system attitude offsets (pitch, roll, and heading), mirror flex (scale), and GPS/IMU drift.

Relative accuracy statistics, reported in Table 7 are based on the comparison of 96 full and partial flightlines and over 7 billion sample points.

Table 6: Relative accuracy

Relative Accuracy Calibration Results		
Project Average	0.020 m	0.065 ft
Median Relative Accuracy	0.020 m	0.064 ft
1σ Relative Accuracy	0.021 m	0.067 ft
2σ Relative Accuracy	0.024 m	0.077 ft
Flightlines	n = 96	
Sample points	7,559,647,359	

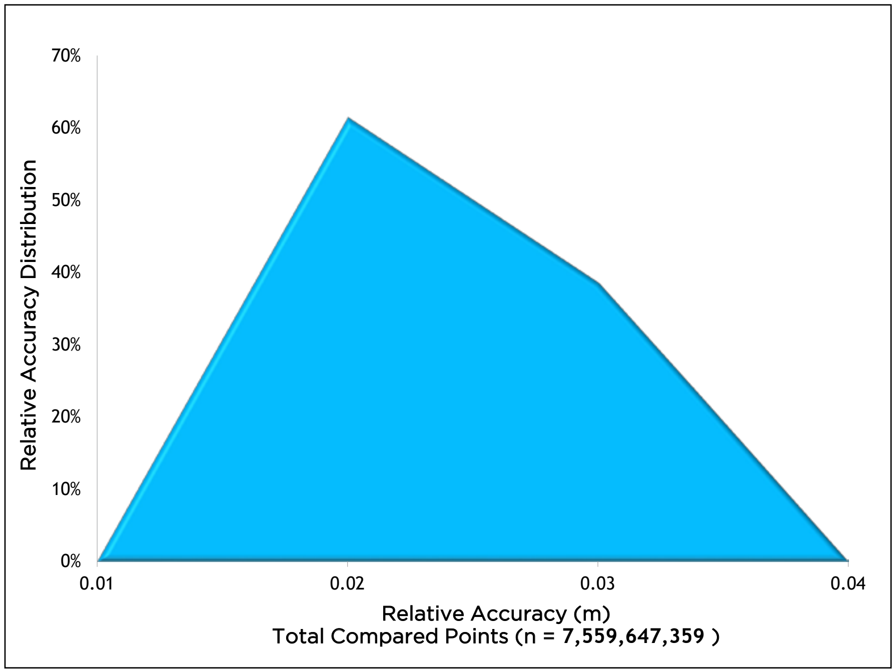


Figure 5: Relative accuracy based on 96 flightlines.

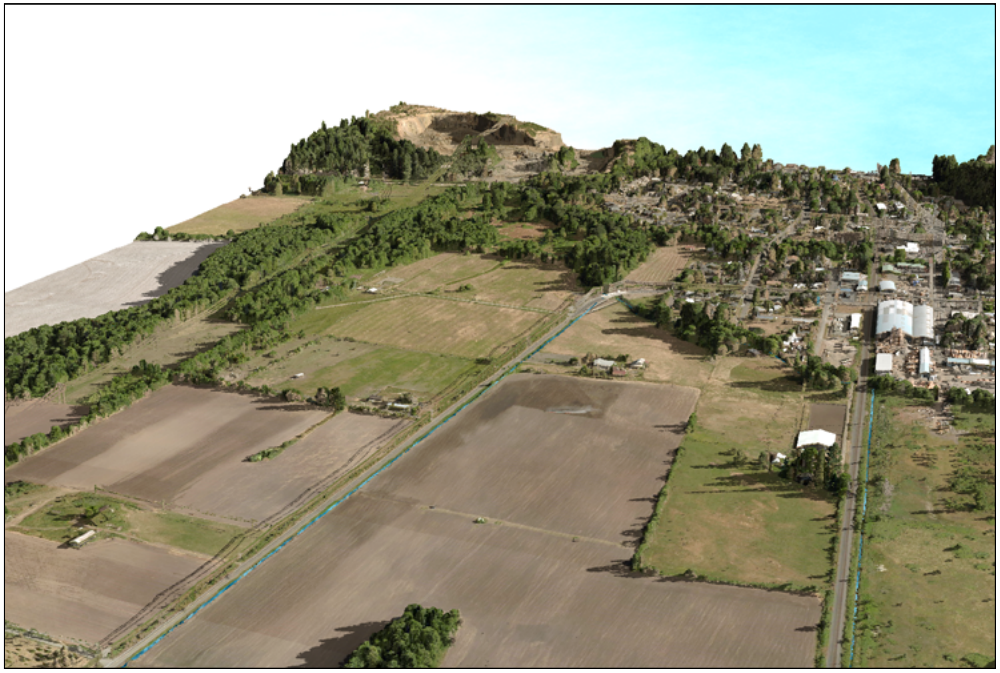


Figure 6: View looking northwest towards Turner, Oregon in the OLC Santiam project area. The image was created from the LiDAR bare earth model colored with satellite imagery.

Vertical Accuracy

Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Positional Accuracy Standards for Digital Geospatial Data V1.0 (ASPRS, 2014). The statistical model compares known reserved ground survey points (GSPs) to the ground model, triangulated from the neighboring laser points. Vertical accuracy statistical analysis uses reserved ground survey 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 95th percentile.

For the OLC Santiam study area, a total of 180 ground control points were collected and used for calibration of the LiDAR data. An additional 20 ground survey points were collected and reserved for independent verification, resulting in a non-vegetated vertical accuracy (NVA) of 0.044 meters, or 0.143 feet.

Table 7: Non-Vegetated Vertical Accuracy results

Non-vegetated Vertical Accuracy	Tested against TIN	
Sample Size (n)	20 Reserved Ground Survey Points	
Vertical Accuracy at 95% confidence level (RMSE*1.96)	**0.044 m**	0.143 ft
Root Mean Square Error	0.022 m	0.073 ft
Standard Deviation	0.016 m	0.052 ft
Minimum Deviation	-0.063 m	-0.207 ft
Maximum Deviation	0.025 m	0.082 ft

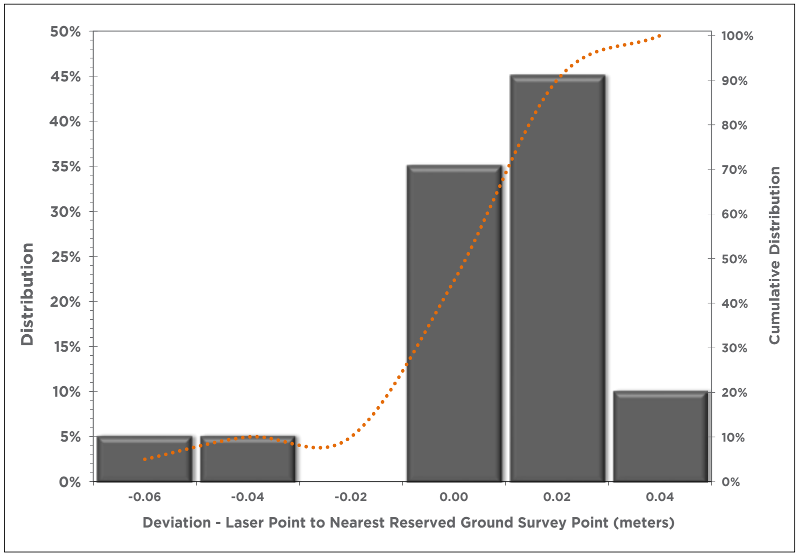


Figure 7: Non-Vegetated Vertical Accuracy distribution; points tested against the unclassified TIN.

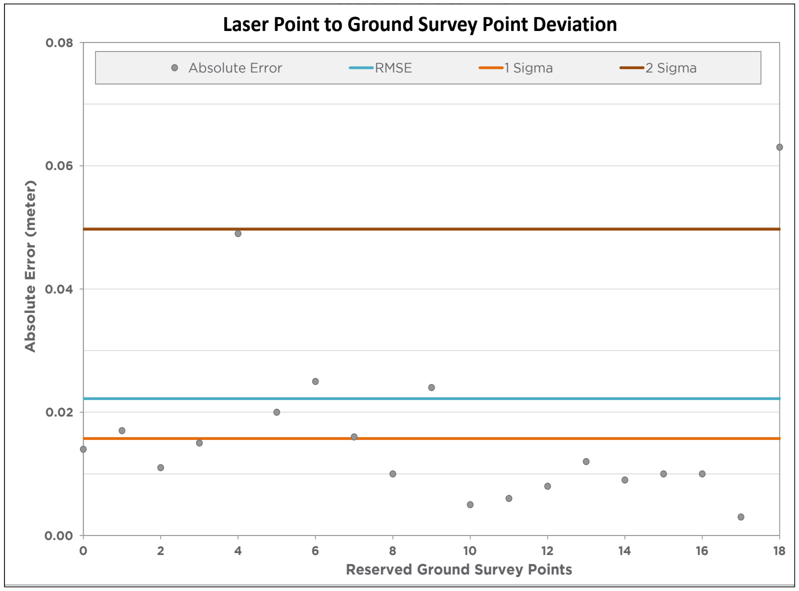


Figure 8: Reserved ground survey point absolute error; points tested against the unclassified TIN.

Density

Pulse Density

Final pulse density is calculated after processing and is a measure of first returns per sampled area. Some types of surfaces (e.g., dense vegetation, 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 pulse density. Densities are reported for the entire study area.

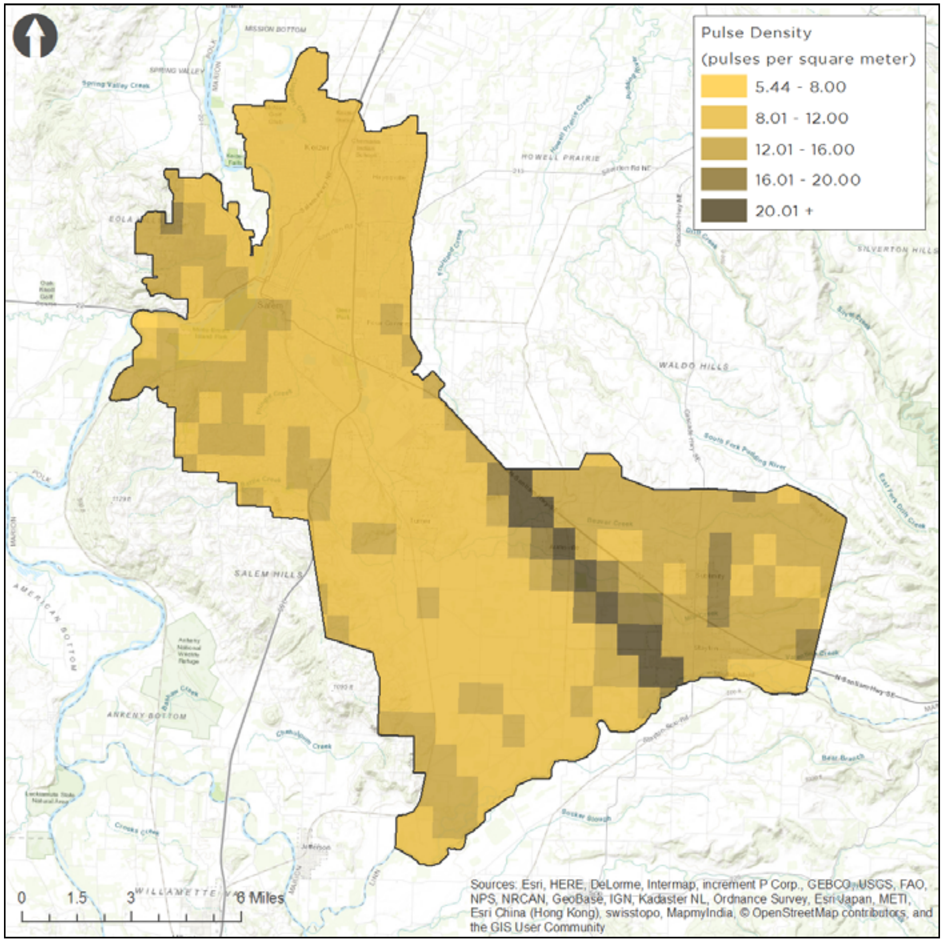
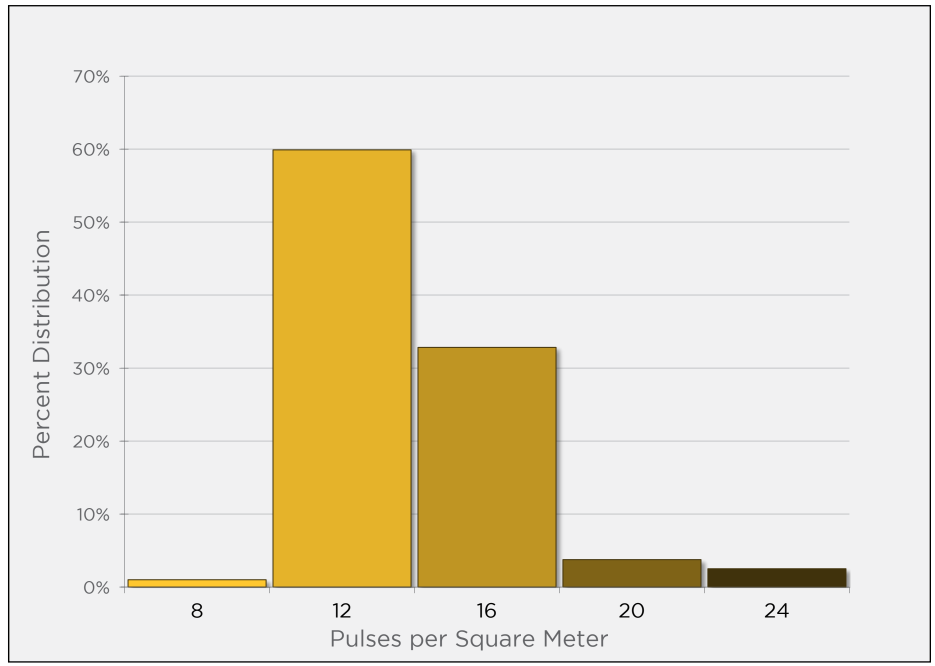


Figure 9: Average pulse density per 0.75 USGS Quad (color scheme aligns with density

Table 8: Average pulse density

Average Pulse Density	pulses per square meter	pulses per square foot
	12.25	1.14



Ground Density

Ground classifications were derived from ground surface modeling. Further 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 tile boundaries. The classifications are influenced by terrain and grounding parameters that are adjusted for the dataset. The reported ground density in Table 9 is a measure of ground-classified point data for the entire study area.

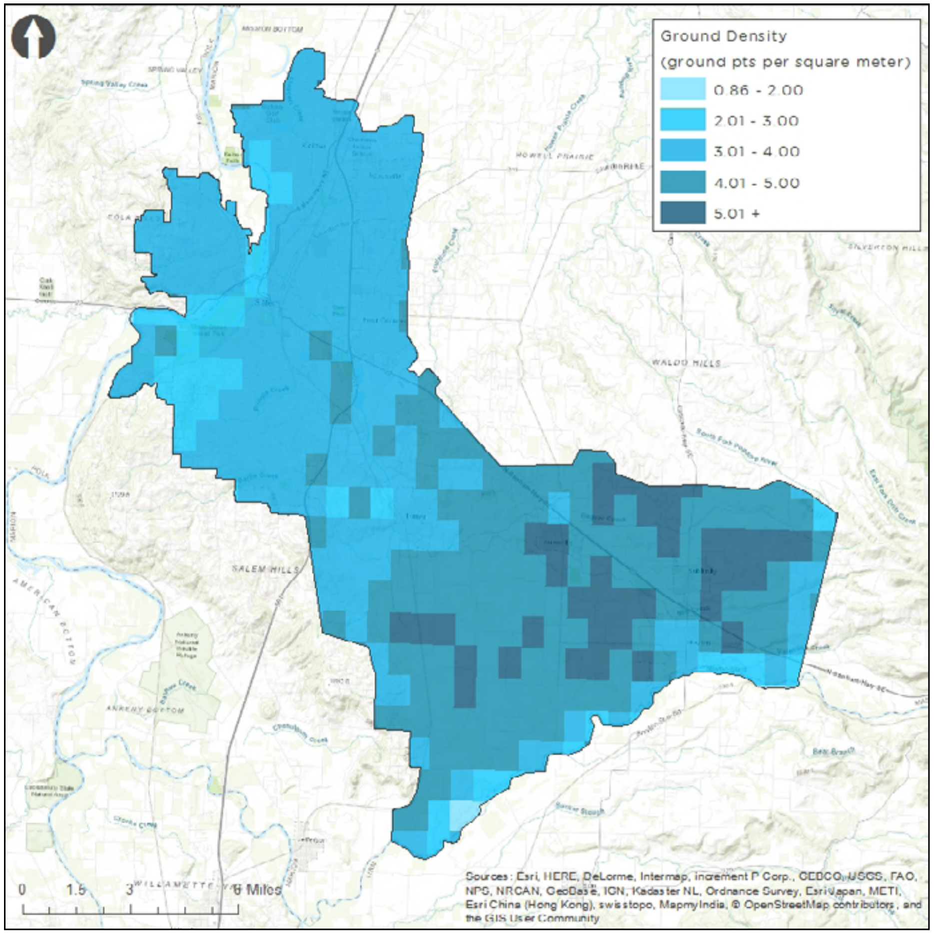


Table 9: Average ground density

Average Ground Density	points per square meter	points per square foot
	3.87	0.36

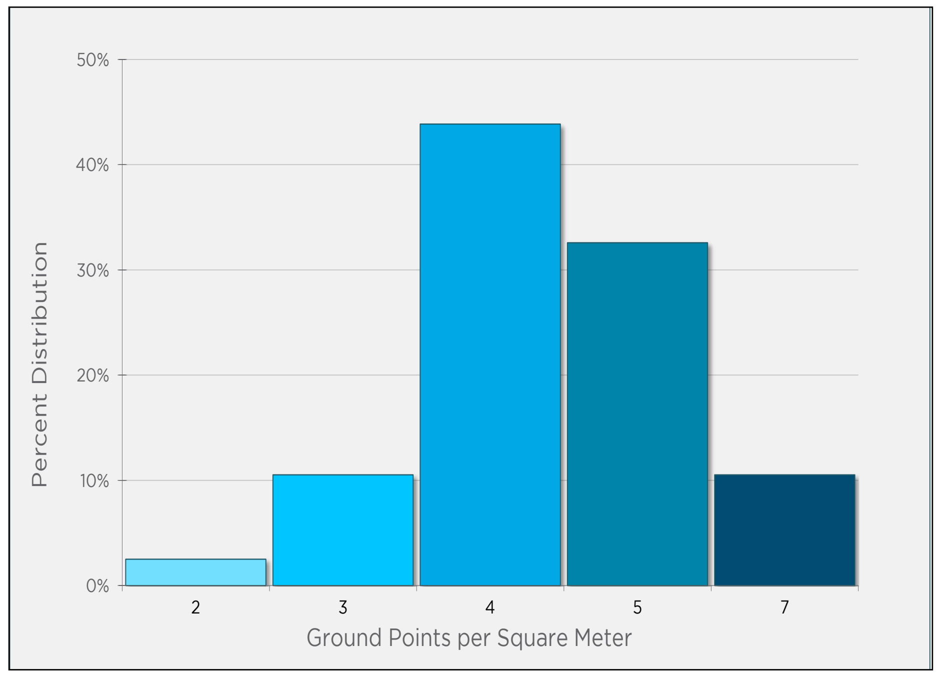


Figure 10: Average ground density per 0.75' USGS Quad (color scheme aligns with density chart).

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Appendix A : PLS Certification

Quantum Spatial, Inc. provided LiDAR services for the OLC Santiam project as described in this report.

I, John English, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

John T English
John T English (Apr 1, 2019)

Apr 1, 2019

John English
Project Manager
Quantum Spatial, Inc.

I, Evon P. Silvia, PLS, being duly registered as a Professional Land Surveyor in and by the state of Oregon, hereby certify that the methodologies, static GNSS occupations used during airborne flights, and ground survey point collection were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted on November 18-20, 2018, for the airborne survey and November 25, 2018, for the ground survey.

Accuracy statistics shown in the Accuracy Section of this Report have been reviewed by me and found to meet the “National Standard for Spatial Data Accuracy”.

Evon P. Silvia

Mar 29, 2019

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