WSI Applied Remote Sensing and Analysis

OLC Wasco County: Delivery One

Trimble R7 Receiver set up over GPS monument WASCO_02.

Data collected for:
Oregon Department of Geology and Mineral Industries

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Suite 965
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Prepared by:
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Contents

Project Overview

WSI has completed the acquisition and processing of Light Detection and Ranging (LiDAR) data for the OLC Wasco County Delivery Area One for the Oregon Department of Geology and Mineral Industries (DOGAMI). The Oregon LiDAR Consortium's Wasco County 2014 project area of interest (AOI) encompasses 1,020,680 acres. Delivery Area One encompasses 176,896.6 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.

WSI LiDAR data acquisition occurred from July 15 - September 19, 2014.

Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter.

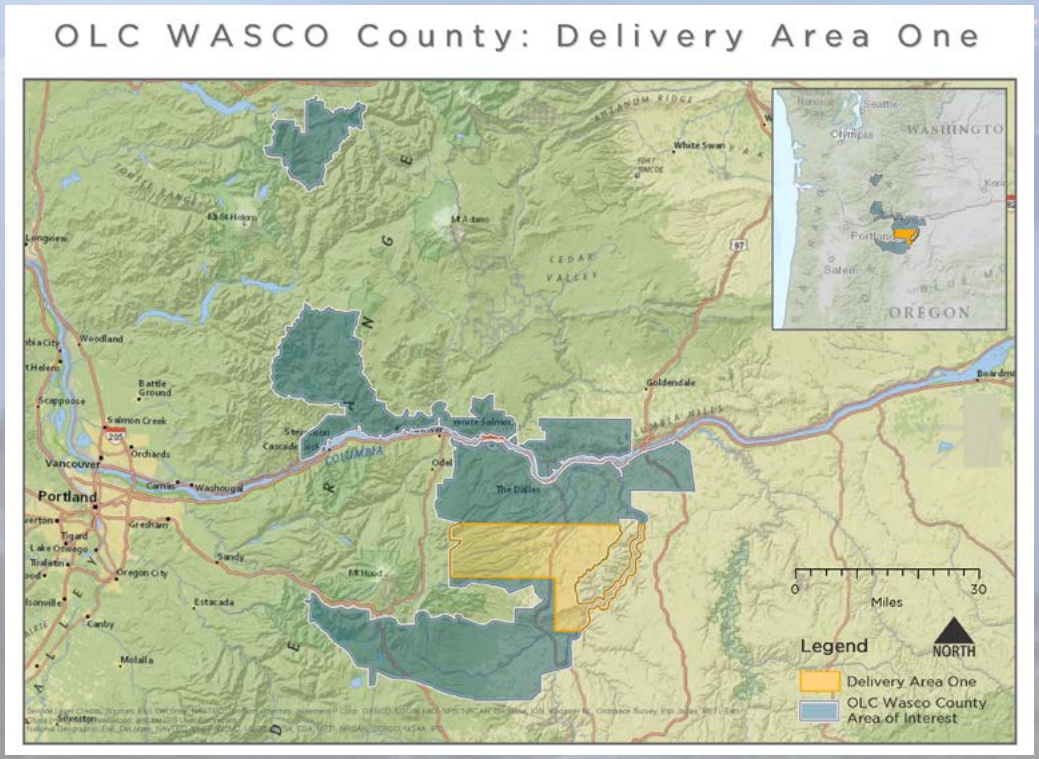
Final products created that are included in Delivery Area One are LiDAR point cloud data, three-foot digital elevation models of bare earth ground models and highest-hit returns, 1.5-foot intensity rasters, three-foot ground density rasters, study area vector shapes, ground survey points and monuments, and corresponding statistical data.

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

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

OLC Wasco County Delivery One Data Delivered: January 2, 2014	
Acquisition Dates	7/15/2014 - 9/19/2014
Delivery Area One Area of Interest	176,896.6 acres
Projection	Oregon Statewide Lambert (OGIC)
Datum: horizontal & vertical	NAD83 (2011) NAVD88 (Geoid 12A)
Units	International Feet

Study Area



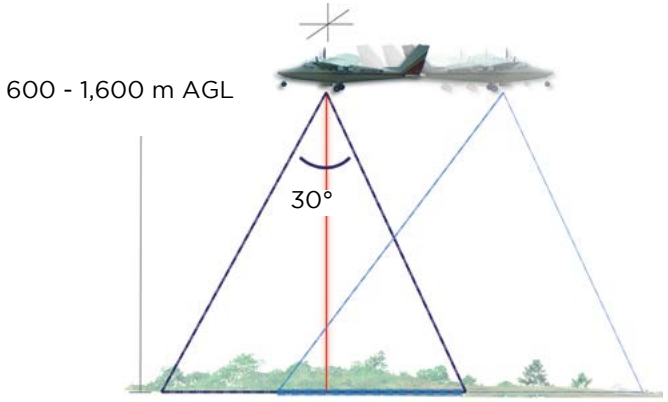
Aerial Acquisition

LiDAR Survey

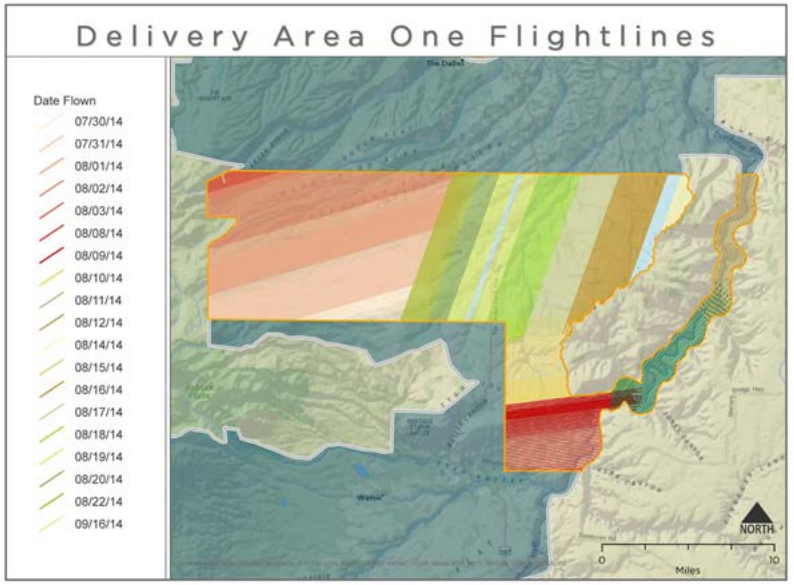
The LiDAR survey used a Leica ALS70 and an Optech Orion H sensor mounted in a Cessna U206G, Partenavia P.68, and Piper Navajo. The systems were programmed to emit single pulses at a rate of 219 kilohertz and flown between 600 and 1,600 meters above ground level (AGL), capturing a scan angle of +/-15 degrees from nadir (field of view equal to 30 degrees). 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 60 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 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 (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). As illustrated in the accompanying map, 413 flightlines provide coverage of the study area.



Project Flightlines



OLC Wasco County LiDAR Acquisition Specifications	
Sensors Deployed	Leica ALS 70 and Orion H
Aircraft	Cessna U206G, Piper Navajo, Partenavia P.68
Survey Altitude (AGL)	600 - 1,600 meters
Pulse Rate	219 kHz
Pulse Mode	Single (SPiA)
Field of View (FOV)	30°
Roll Compensated	Yes
Overlap	100% overlap with 60% sidelap
Pulse Emission Density	≥ 8 pulses per square meter

Ground Survey

Ground control surveys, including monumentation, aerial targets, and ground check points (GCPs) were conducted to support the airborne acquisition. Ground control data are used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data products. See the table to the right for specifications of equipment used.

Instrumentation

All Global Navigation Satellite System (GNSS) static surveys utilized Trimble R7 GNSS receivers with Zephyr Geodetic Model 2 RoHS antennas and Trimble R8 GNSS receivers with internal antennas. Rover surveys for GCP collection were conducted with Trimble R6, Trimble R8, and Trimble R10 GNSS receivers.

Monumentation

Existing and newly established survey benchmarks serve as control points during LiDAR acquisition. Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GCP coverage. NGS benchmarks are preferred for control points; however, in the absence of NGS benchmarks, WSI produces our own monuments, and every effort is made to keep them within the public right of way or on public lands. If monuments are necessary on private property, consent from the owner is required. All monumentation is done with 5/8" x 30" rebar topped with a two-inch diameter aluminum cap stamped "Watershed Sciences, Inc. Control." The table at right provides the list of monuments used in Delivery Area One. See Appendix B for a complete list of monuments placed within the OLC Wasco County 2014 Study Area.

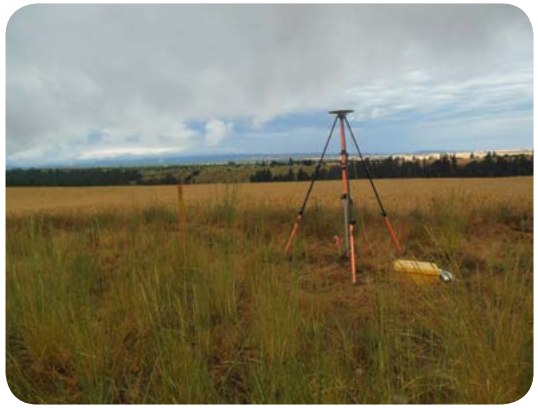
Instrumentation

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_GNSS	Static, Rover
Trimble R10	Integrated Antenna R10	TRMR10	Rover
Trimble R6	Integrated Antenna R10	TRMR10	Rover

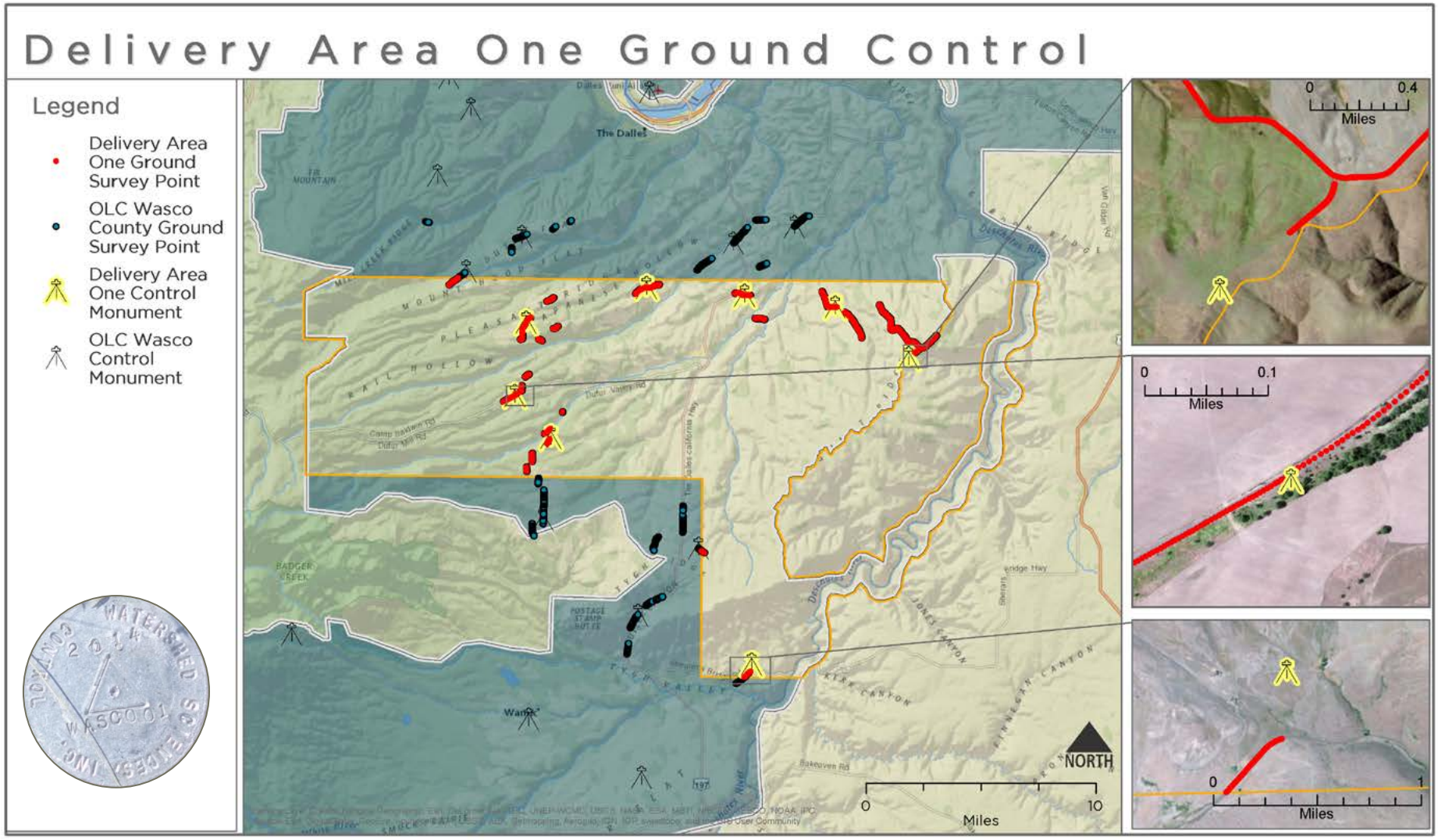
Delivery Area One GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	NAVD88 Height (m)
WASCO_01	45° 25′ 33.92221″	-121° 17′ 35.67224″	694.143	715.200
WASCO_02	45° 24′ 00.14524″	-121° 15′ 38.58602″	668.266	67.992
WASCO_07	45° 28′ 20.67253″	-121° 17′ 01.49189″	652.762	673.886
WASCO_10	45° 29′ 26.20935″	-121° 05′ 18.01985″	348.496	369.761
WASCO_11	45° 29′ 41.84872″	-121° 10′ 33.92138″	352.139	373.376
WASCO_12	45° 29′ 00.75217″	-121° 00′ 25.75182″	459.025	480.243
WASCO_15	45° 27′ 06.62583″	-120° 56′ 27.83190″	839.258	860.373
WASCO_17	45° 15′ 30.16588″	-121° 04′ 46.54399″	366.298	387.695

Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.



GPS receiver set over GPS Monument WASCO_07.


Delivery Area One Ground Control
Legend
Delivery Area One Ground Survey Point
OLC Wasco County Ground Survey Point
Delivery Area One Control Monument
OLC Wasco Control Monument
The Dalles
Warm Springs
NORTH
0
10
Miles
0
0.4
Miles
0
0.1
Miles
0
1
Miles

Methodology

To correct the continuously recorded aircraft position, WSI concurrently conducts multiple static GNSS ground surveys over each monument. All control monuments are observed for a minimum of two survey sessions, each lasting no fewer than two hours. Data are collected at a rate of one hertz, using a 10 degree mask on the antenna. The static GPS data are then triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS) for precise positioning.

Ground Check Points (GCPs) are collected using Real Time Kinematic (RTK), Post-Processed Kinematic (PPK), and Fast-Static (FS) survey techniques. For RTK surveys, a base receiver is positioned at a nearby monument to broadcast a kinematic correction to a roving receiver; for PPK and FS surveys, however, these corrections are post-processed. All GCP measurements are 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. Relative errors for the position must be less than 1.5 centimeters horizontal and 2.0 centimeters vertical in order to be accepted.

In order to facilitate comparisons with high quality LiDAR data, GCP measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. GCPs are taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. GCPs 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.

Monument Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	0.05 m Horizont
St Dev z	0.05 m Vertical

WSI ground professional collecting ground survey points in OLC Wasco County study area.

LiDAR Accuracy

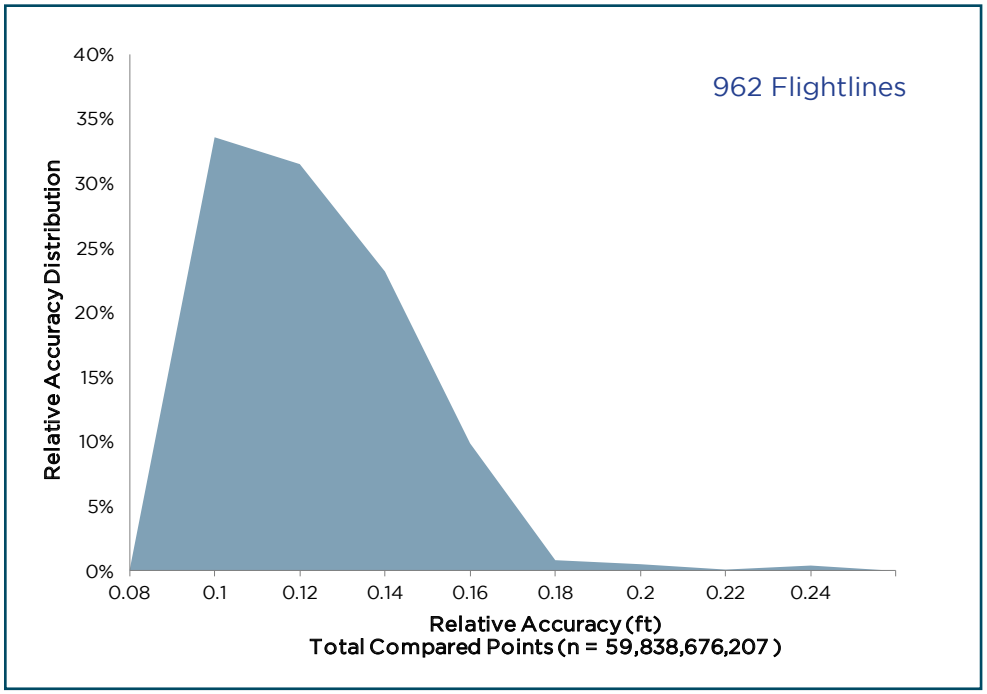
Relative Accuracy

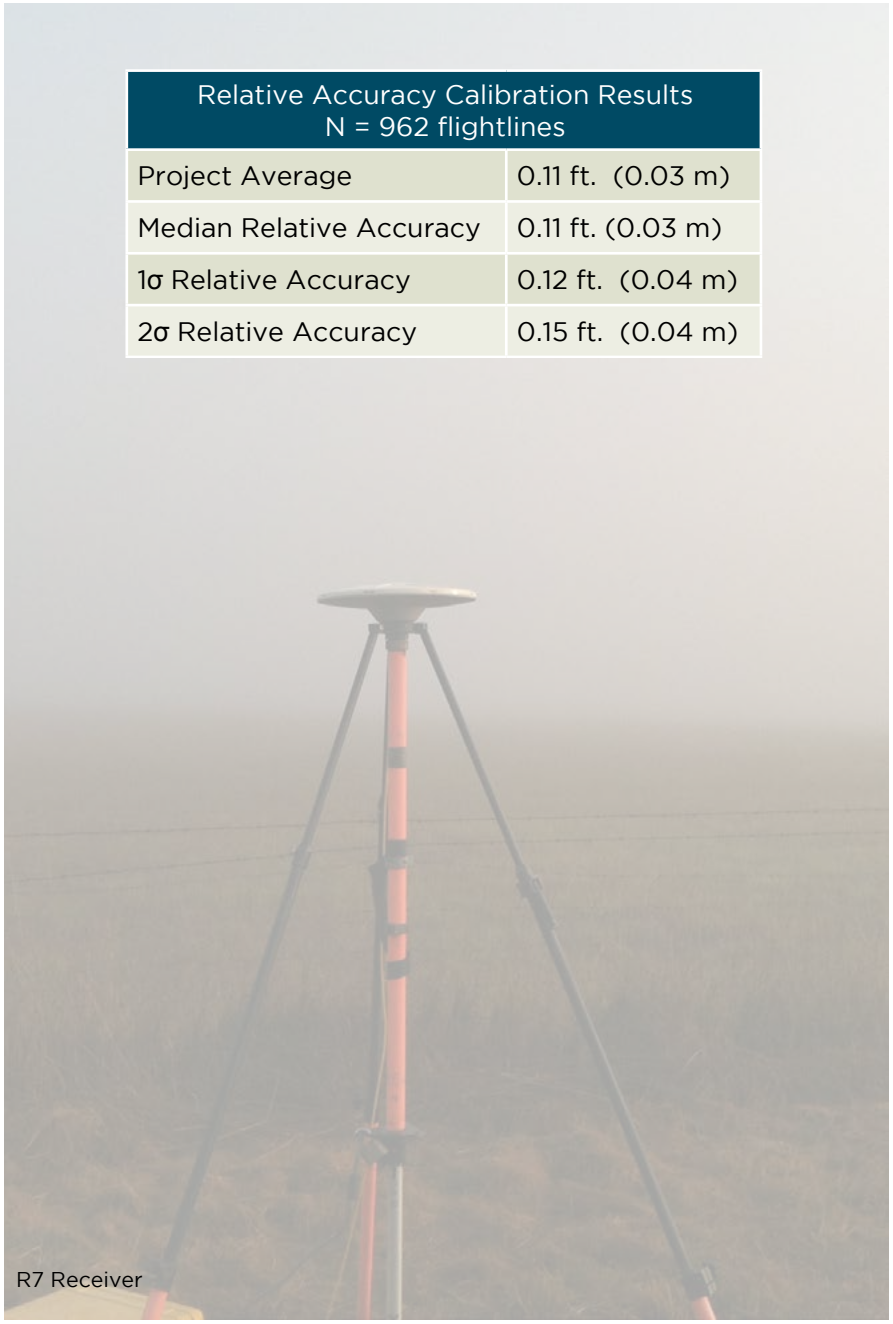
Relative accuracy refers to the internal consistency of the data set and is measured as the divergence between points from different flightlines within an overlapping area. Divergence is most apparent when flightlines are opposing. When the LiDAR system is well calibrated the line to line divergence is low (<10 centimeters). 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 962 full and partial flightlines. Relative accuracy is reported for the cumulative delivered portions of the study area.

Relative Accuracy Calibration Results N = 962 flightlines	
Project Average	0.11 ft. (0.03 m)
Median Relative Accuracy	0.11 ft. (0.03 m)
1σ Relative Accuracy	0.12 ft. (0.04 m)
2σ Relative Accuracy	0.15 ft. (0.04 m)

Relative Accuracy Distribution




R7 Receiver

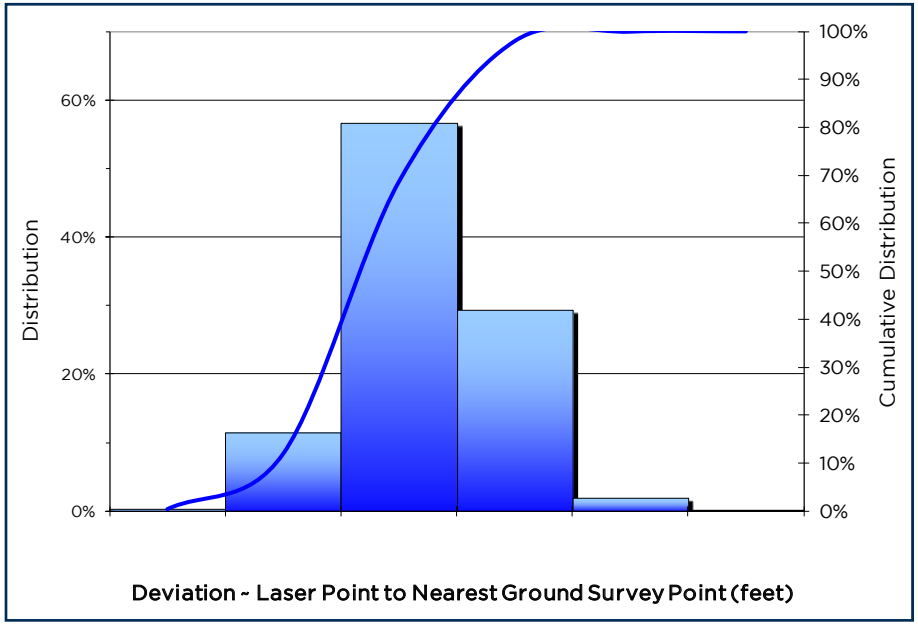
Vertical Accuracy

Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). The statistical model compares known ground check points to the triangulated LiDAR surface. Vertical accuracy statistical analysis 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 95th percentile. For the OLC Wasco County 2014 Delivery Area One, 6,295 GCPs were collected. Statistics are shown for Delivery Area One.

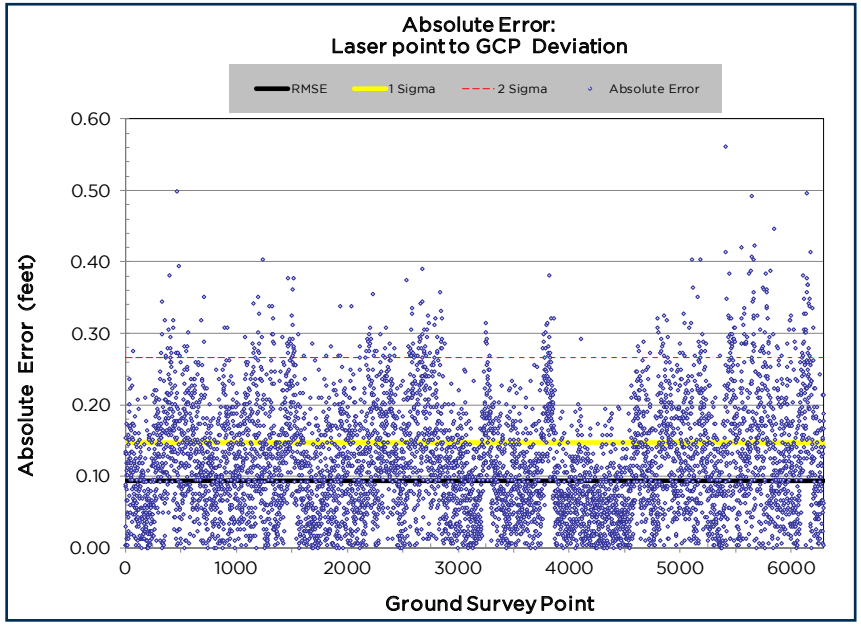
For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet." Vertical Accuracy is reported for the entire study area and reported in the table below. Histogram and absolute deviation statistics displayed below.

Vertical Accuracy Results	
	Delivery Area One
Sample Size (n)	6,295 Ground check points
Root Mean Square Error	0.09 ft. (0.03 m)
1 Standard Deviation	0.15 ft. (0.05 m)
2 Standard Deviation	0.27 ft. (0.08 m)
Average Deviation	0.12 ft. (0.04 m)
Minimum Deviation	-0.30 ft. (-0.09 m)
Maximum Deviation	0.56 ft. (0.17 m)

Vertical Accuracy Distribution



GCP Absolute Error

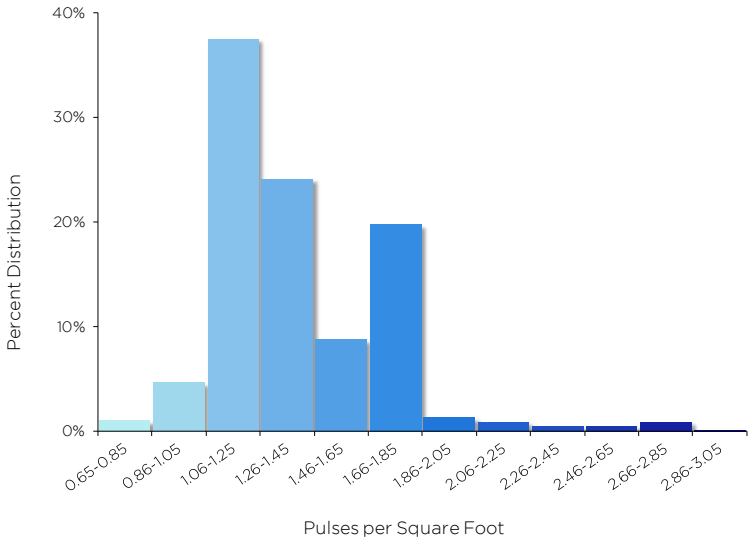


Density

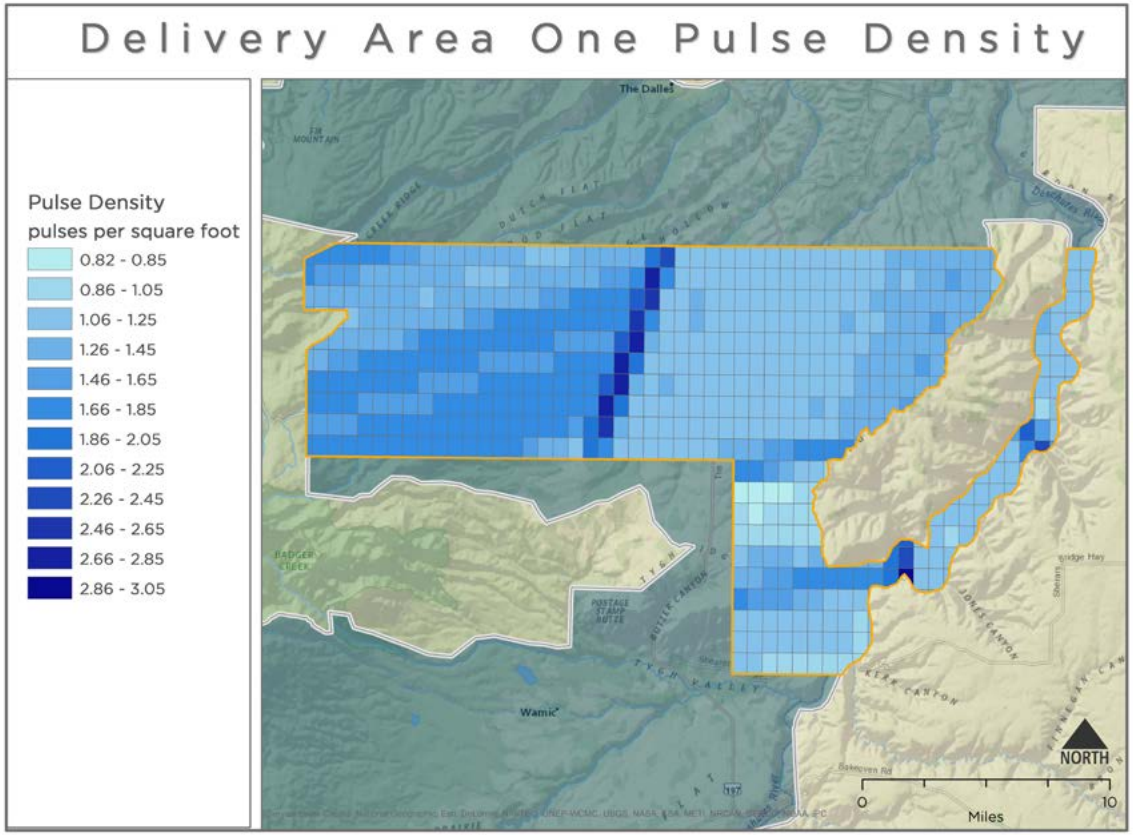
Pulse Density

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 and ground-classified laser point density. Densities are reported for the delivery area.

Average Pulse Density	pulses per square meter	pulses per square foot
	15.09	1.40



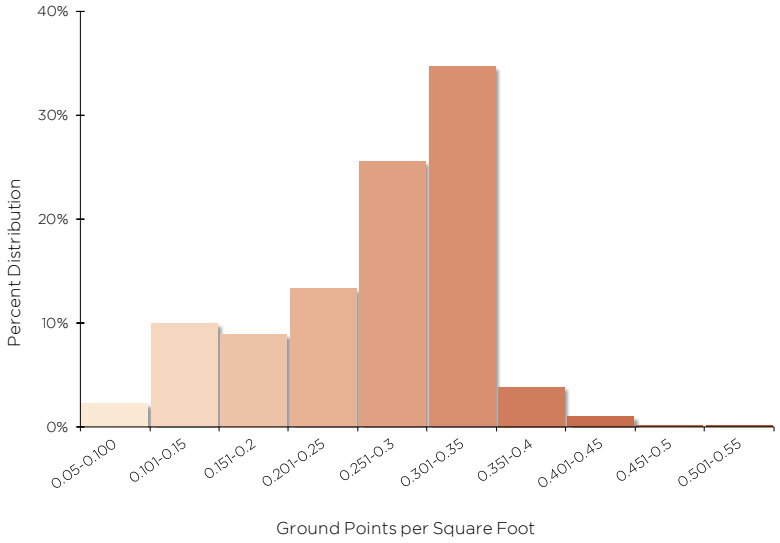
Average Pulse Density per 0.75' USGS Quad (color scheme aligns with density chart).



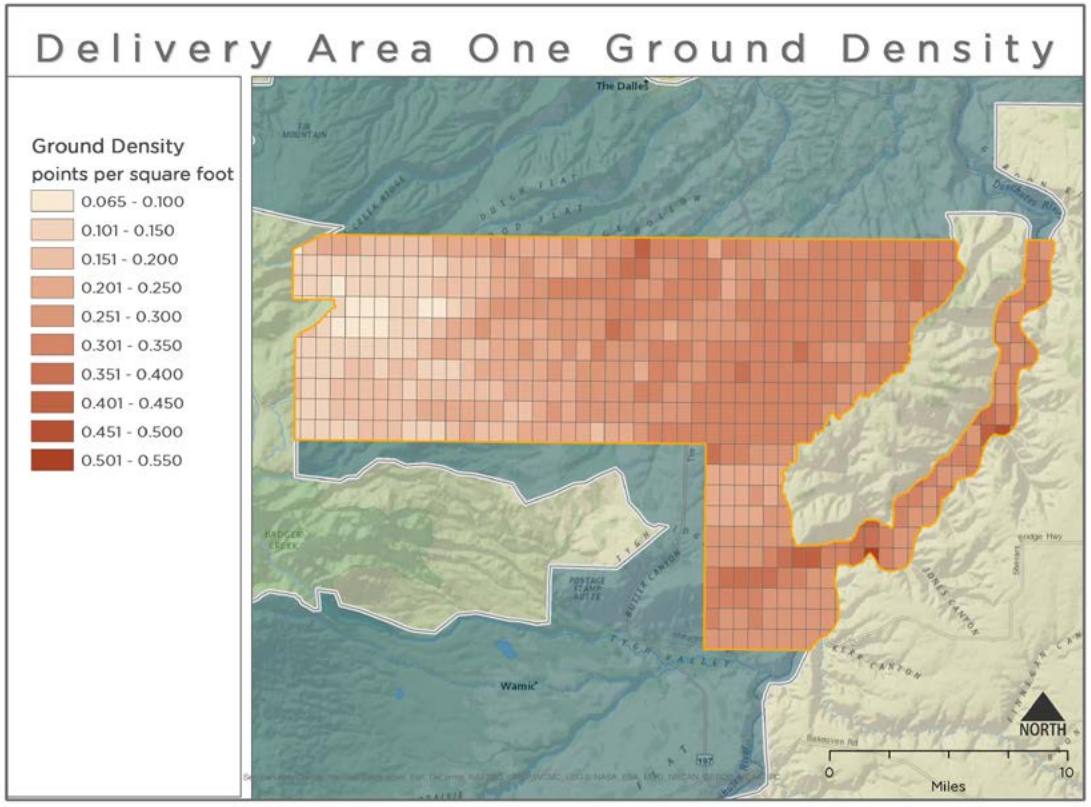
Ground Density

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 is a measure of ground-classified point data for the delivery area.

Ground Density	points per square meter	points per square foot
	2.80	0.26



Average Ground Density per 0.75' USGS Quad (color scheme aligns with density chart).



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Appendix A : PLS Certification

WSI provided LiDAR Services for OLC Wasco County LiDAR Project Delivery 1 as described in this report.

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

12/31/2014

John English
Project Manager
WSI, a Quantum Spatial Company

I, Christopher Glantz, being duly registered as a Professional Land Surveyor in the state of Oregon, say that I hereby certify the methodologies and results of the attached LiDAR project, and that Static GNSS occupations on the Base Stations during airborne flights and RTK survey on hard-surface and GCP's were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between July 15, 2014 and September 19, 2014. Accuracy statistics shown in the Accuracy Section of this Report have been review by me and found to meet the "National Standard for Spatial Data Accuracy".

12/31/2014

Christopher Glantz, PLS
Land Surveyor
WSI, a Quantum Spatial Company
Portland, OR 97204

Appendix B : GPS Monument Table

List of GPS monuments used in OLC Wasco County Survey Area. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

OLC Wasco County GPS Monuments				
PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
RC1228	45° 06′ 49.69688″	-121° 19′ 19.81403″	624.578	646.030
RC2736	45° 37′ 04.04622″	-121° 10′ 30.56142″	46.512	67.992
WASCO_01	45° 25′ 33.92221″	-121° 17′ 35.67224″	694.143	715.200
WASCO_02	45° 24′ 00.14524″	-121° 15′ 38.58602″	668.266	689.337
WASCO_03	45° 30′ 15.15952″	-121° 20′ 16.05414″	706.121	727.237
WASCO_04	45° 31′ 35.06899″	-121° 17′ 17.45080″	659.572	680.767
WASCO_05	45° 40′ 58.30068″	-121° 18′ 03.00268″	194.683	216.110
WASCO_06	45° 39′ 58.42964″	-121° 20′ 07.36657″	328.069	349.483
WASCO_07	45° 28′ 20.67253″	-121° 17′ 01.49189″	652.762	673.886
WASCO_08	45° 37′ 33.53662″	-121° 21′ 18.77199″	485.153	506.493
WASCO_09	45° 36′ 23.21905″	-121° 20′ 06.73995″	618.486	639.790
WASCO_10	45° 29′ 26.20935″	-121° 05′ 18.01985″	348.496	369.761
WASCO_11	45° 29′ 41.84872″	-121° 10′ 33.92138″	352.139	373.376
WASCO_12	45° 29′ 00.75217″	-121° 00′ 25.75182″	459.025	480.243
WASCO_13	45° 20′ 54.35426″	-121° 16′ 00.43344″	731.185	752.265
WASCO_14	45° 33′ 50.86097″	-121° 21′ 51.83958″	628.086	649.267
WASCO_15	45° 27′ 06.62583″	-120° 56′ 27.83190″	839.258	860.373
WASCO_16	45° 19′ 51.53124″	-121° 07′ 39.82528″	771.520	792.637
WASCO_17	45° 15′ 30.16588″	-121° 04′ 46.54399″	366.298	387.695
WASCO_18	45° 17′ 18.80793″	-121° 10′ 52.79618″	490.765	512.026
WASCO_19	45° 32′ 02.50205″	-121° 02′ 38.17485″	323.491	344.841
WASCO_20	45° 31′ 24.81814″	-121° 05′ 55.22316″	226.261	247.595
WASCO_21	45° 34′ 50.63889″	-120° 42′ 20.51709″	406.207	427.542
WASCO_22	45° 36′ 32.32168″	-120° 43′ 27.27584″	322.623	343.983

OLC Wasco County GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
WASCO_23	45° 39′ 25.35061″	-120° 50′ 31.98330″	195.187	216.568
WASCO_25	45° 40′ 26.60543″	-121° 06′ 03.21471″	340.241	361.552
WASCO_26	45° 43′ 42.64888″	-120° 58′ 06.01776″	457.564	478.693
WASCO_27	45° 11′ 11.42881″	-121° 10′ 36.88163″	516.322	537.783
WASCO_28	45° 13′ 21.18185″	-121° 16′ 41.26494″	529.382	550.863
WASCO_29	45° 17′ 13.71773″	-121° 43′ 43.89634″	1148.089	1168.978
WASCO_30	45° 15′ 09.56681″	-121° 45′ 06.60188″	1077.776	1098.738
WASCO_31	45° 11′ 41.00706″	-121° 41′ 34.26892″	1145.538	1166.520
WASCO_32	45° 13′ 23.06365″	-121° 33′ 08.21340″	1268.450	1289.391
WASCO_33	45° 08′ 01.07100″	-121° 37′ 24.78080″	1069.357	1090.435
WASCO_34	45° 16′ 27.80611″	-121° 29′ 24.41946″	1315.774	1336.621
WASCO_35	45° 37′ 57.72073″	-121° 58′ 13.51239″	-5.667	16.201
WASCO_36	45° 41′ 55.00914″	-121° 52′ 30.78102″	23.857	45.572
WASCO_37	45° 46′ 57.14196″	-121° 20′ 34.59729″	711.981	732.985
WASCO_38	45° 45′ 30.26559″	-121° 24′ 17.71854″	589.260	610.392
WASCO_39	45° 42′ 40.65511″	-121° 46′ 39.83483″	12.803	34.339
WASCO_40	45° 43′ 43.90661″	-121° 33′ 54.44150″	315.186	336.630

WSI Applied Remote Sensing and Analysis

OLC Wasco County: Delivery Two

Trimble R7 Receiver set up over GPS monument WASCO_03.

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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.

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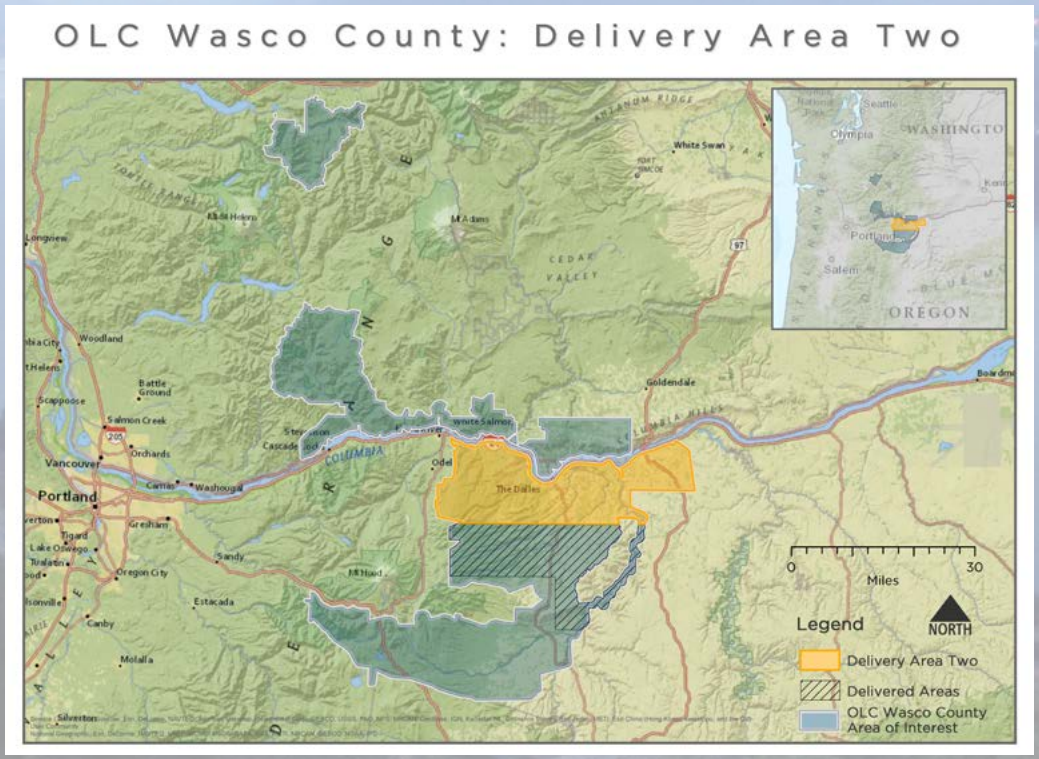
Units	International Feet

Study Area



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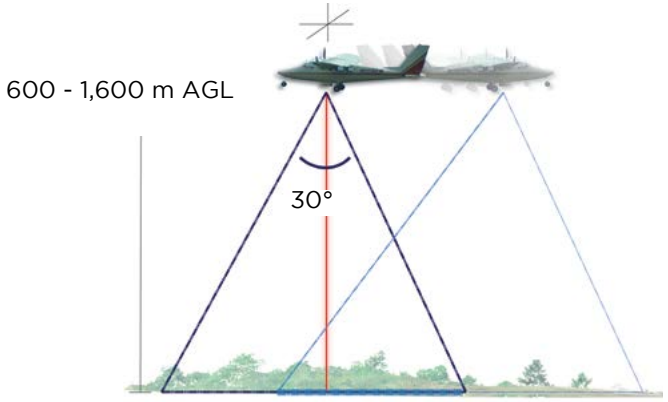
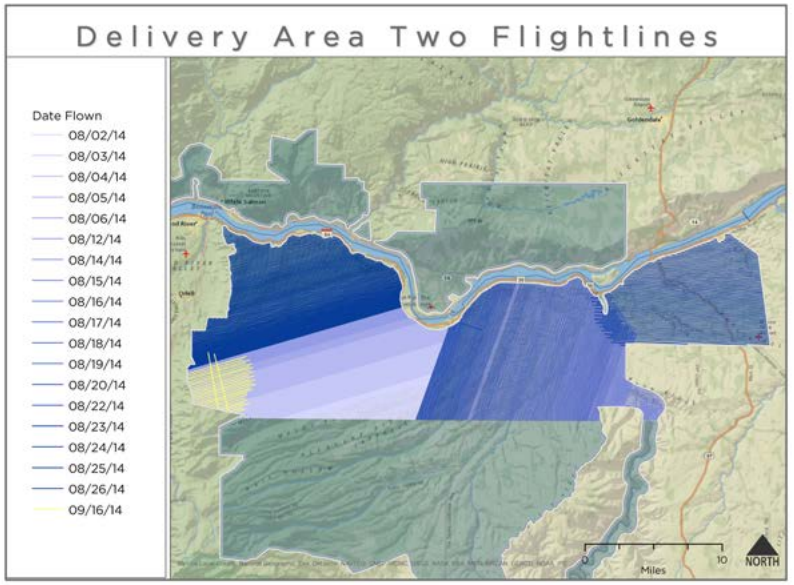
The native pulse density is the number of pulses emitted by the LiDAR system. Some types of surfaces such as dense vegetation or water may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and lightly vary according to distributions of terrain, land cover, and water bodies. The study area was surveyed with opposing flight line side-lap of greater than 60 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 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 (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). As illustrated in the accompanying map, 522 full and partial flightlines provide coverage of the study area.



Project Flightlines



OLC Wasco County LiDAR Acquisition Specification	
Sensors Deployed	Leica ALS 70 and Optech Orion H
Aircraft	Cessna U206G, Piper Navajo, Partenavia P.68
Survey Altitude (AGL)	600 - 1,600 meters
Pulse Rate	219 kHz
Pulse Mode	Single (SPiA)
Field of View (FOV)	30°
Roll Compensated	Yes
Overlap	100% overlap with 60% sidelap
Pulse Emission Density	≥ 8 pulses per square meter

Ground Survey

Ground control surveys, including monumentation, aerial targets, and ground survey points (GSPs) were conducted to support the airborne acquisition. Ground control data are used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data products. See the table to the right for specifications of equipment used.

Instrumentation

All Global Navigation Satellite System (GNSS) static surveys utilized Trimble R7 GNSS receivers with Zephyr Geodetic Model 2 RoHS antennas and Trimble R8 GNSS receivers with internal antennas. Rover surveys for GSP collection were conducted with Trimble R6, Trimble R8, and Trimble R10 GNSS receivers.

Monumentation

Existing and newly established survey benchmarks serve as control points during LiDAR acquisition. Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. NGS benchmarks are preferred for control points; however, in the absence of NGS benchmarks, WSI produces our own monuments, and every effort is made to keep them within the public right of way or on public lands. If monuments are necessary on private property, consent from the owner is required. All monumentation is done with 5/8" x 30" rebar topped with a two-inch diameter aluminum cap stamped "Watershed Sciences, Inc. Control." The table at right provides the list of monuments used in Delivery Area Two. See Appendix B for a complete list of monuments placed within the OLC Wasco County 2014 Study Area.

Instrumentation

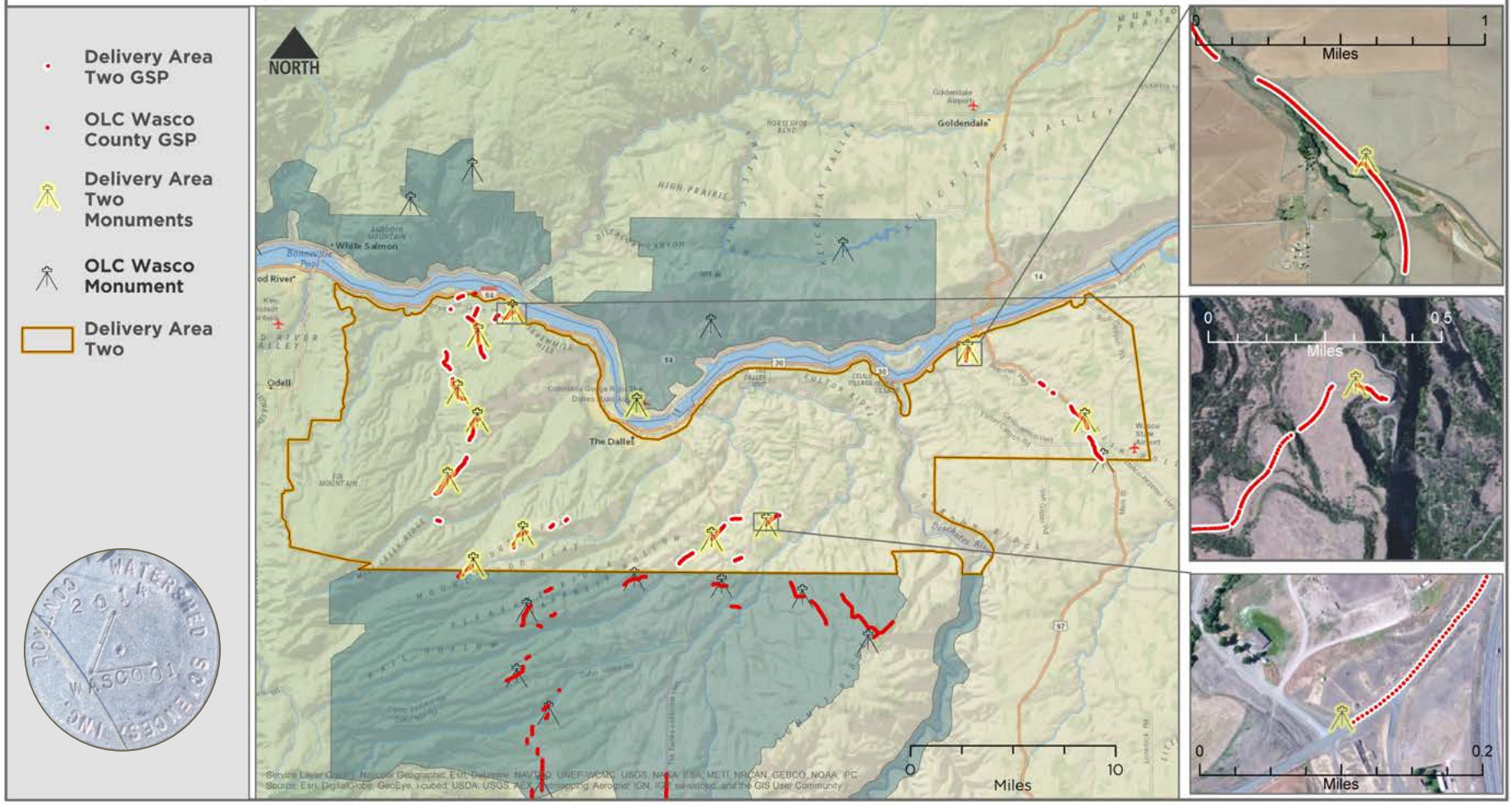
Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_GNSS	Static, Rover
Trimble R10	Integrated Antenna R10	TRMR10	Rover
Trimble R6	Integrated Antenna R6	TRMR6	Rover

Delivery Area Two GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	NAVD88 Height (m)
RC2736	45° 37′ 04.04622″	-121° 10′ 30.56142″	46.512	67.992
WASCO_03	45° 30′ 15.15952″	-121° 20′ 16.05414″	706.121	727.237
WASCO_04	45° 31′ 35.06899″	-121° 17′ 17.45080″	659.572	680.767
WASCO_05	45° 40′ 58.30068″	-121° 18′ 03.00268″	194.683	216.110
WASCO_06	45° 39′ 58.42964″	-121° 20′ 07.36657″	328.069	349.483
WASCO_08	45° 37′ 33.53662″	-121° 21′ 18.77199″	485.153	506.493
WASCO_09	45° 36′ 23.21905″	-121° 20′ 06.73995″	618.486	639.790
WASCO_14	45° 33′ 50.86097″	-121° 21′ 51.83958″	628.086	649.267
WASCO_19	45° 32′ 02.50205″	-121° 02′ 38.17485″	323.491	344.841
WASCO_20	45° 31′ 24.81814″	-121° 05′ 55.22316″	226.261	247.595
WASCO_22	45° 36′ 32.32168″	-120° 43′ 27.27584″	322.623	343.983
WASCO_23	45° 39′ 25.35061″	-120° 50′ 31.98330″	195.187	216.568

Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

Delivery Area Two Ground Control



Methodology

To correct the continuously recorded aircraft position, WSI concurrently conducts multiple static GNSS ground surveys over each monument. All control monuments are observed for a minimum of two survey sessions, each lasting no fewer than two hours. Data are collected at a rate of one hertz, using a 10 degree mask on the antenna. The static GPS data are then triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS) for precise positioning.

Ground Survey Points (GSPs) are collected using Real Time Kinematic (RTK), Post-Processed Kinematic (PPK), and Fast-Static (FS) survey techniques. For RTK surveys, a base receiver is positioned at a nearby monument to broadcast a kinematic correction to a roving receiver; for PPK and FS surveys, however, these corrections are post-processed. All GSP measurements are 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. Relative errors for the position must be less than 1.5 centimeters horizontal and 2.0 centimeters vertical in order to be accepted.

In order to facilitate comparisons with high quality LiDAR data, GSP measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. GSPs are taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. 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.

Monument Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	0.05 m Horiz
St Dev z	0.05 m Vert

WSI ground professional collecting ground survey points in OLC Wasco County study area.

Results

Accuracy Assessment

In some cases statistics were generated for larger areas than the extent represented by delivered areas. Accuracy statistics are a product of calibration and data QA/QC methodology that are spatially coincident with production workflow, which at times exceeds the areal extent of delivery workflow.

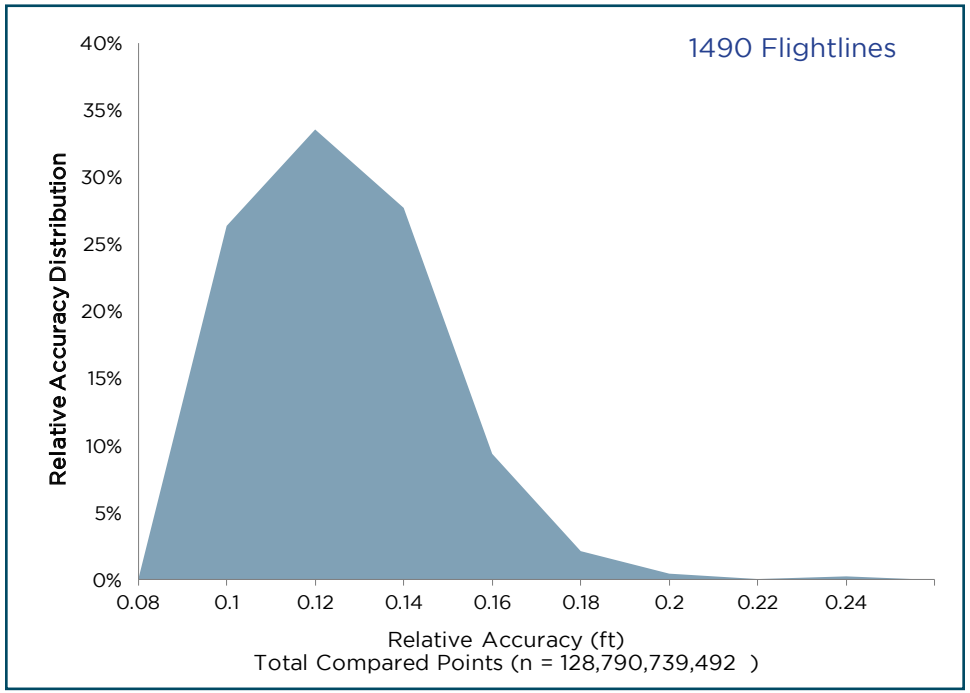
Relative Accuracy

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 centimeters). 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 1490 full and partial flightlines. Relative accuracy is reported for the cumulative delivered portions of the study area.

Relative Accuracy Calibration Results N = 1490 flightlines	
Project Average	0.12 ft. (0.04 m)
Median Relative Accuracy	0.12 ft. (0.04 m)
1σ Relative Accuracy	0.12 ft. (0.04 m)
2σ Relative Accuracy	0.15 ft. (0.05 m)

Relative Accuracy Distribution



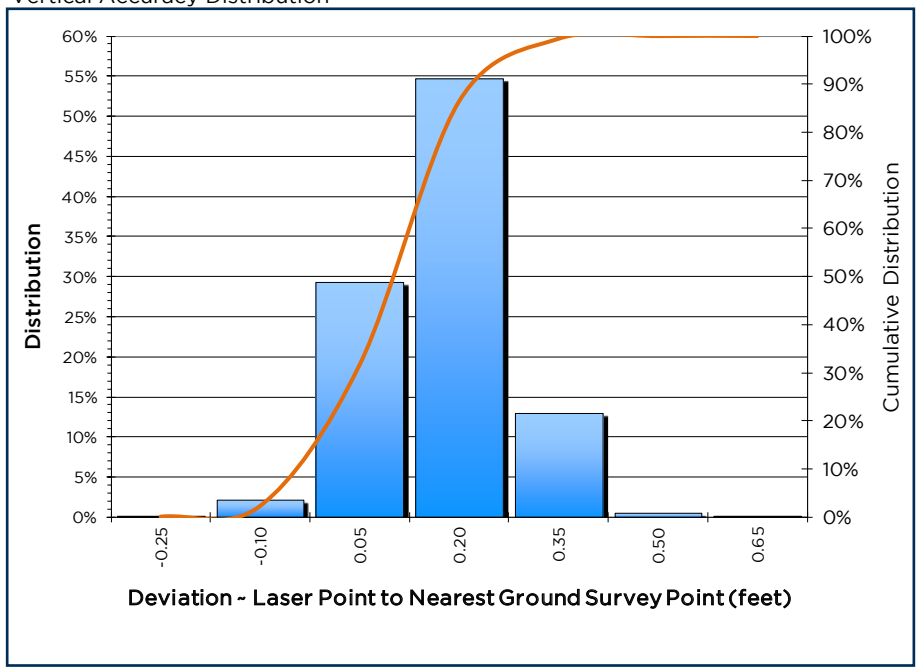
Vertical Accuracy

Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). The statistical model compares known ground survey points to the triangulated LiDAR surface. Vertical accuracy statistical analysis uses 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 Wasco County 2014 Study area, 5,423 GSPs were used to calibrate Delivery Area Two. Statistics are shown for the cumulative delivered areas.

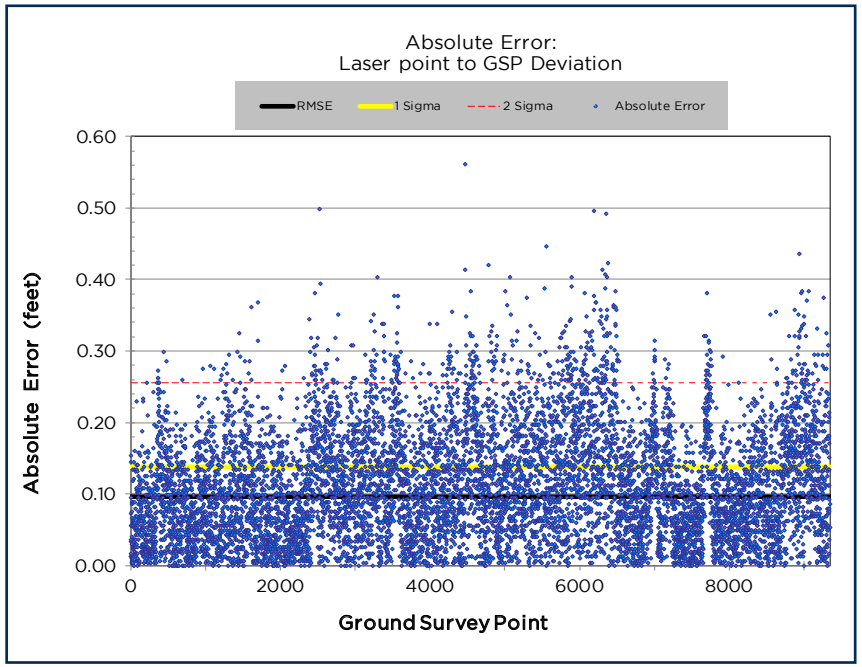
For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet." Vertical Accuracy is reported for the entire delivered study area and reported in the table below. Histogram and absolute deviation statistics displayed below.

Vertical Accuracy Results		
	Delivery Area Two	Cumulative
Sample Size (n) (ground survey points)	5,423	9,345
Root Mean Square Error	0.09 ft. (0.03 m)	0.10 ft. (0.03 m)
1 Standard Deviation	0.13 ft. (0.04 m)	0.14 ft. (0.04 m)
2 Standard Deviation	0.25 ft. (0.08 m)	0.26 ft. (0.08 m)
Average Deviation	0.10 ft. (0.03 m)	0.11 ft. (0.03 m)
Minimum Deviation	-0.35 ft. (-0.11 m)	-0.35 ft. (-0.11 m)
Maximum Deviation	0.50 ft. (0.15 m)	0.56 ft. (0.17 m)

Vertical Accuracy Distribution



GSP Absolute Error

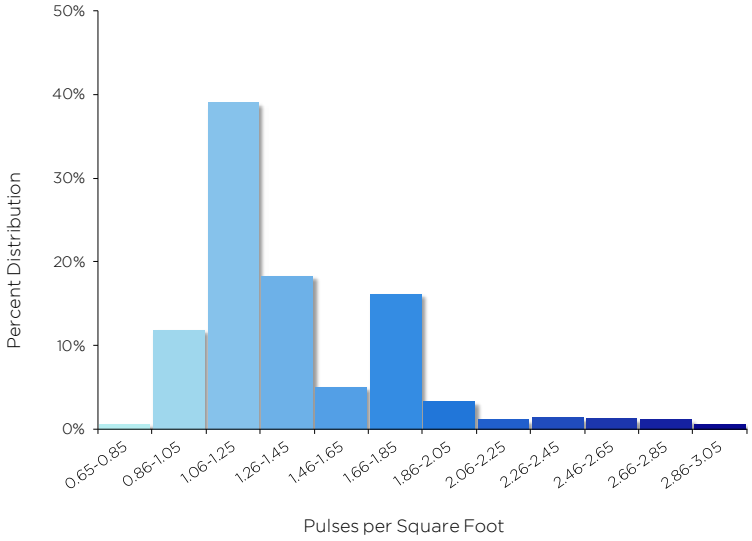


Density

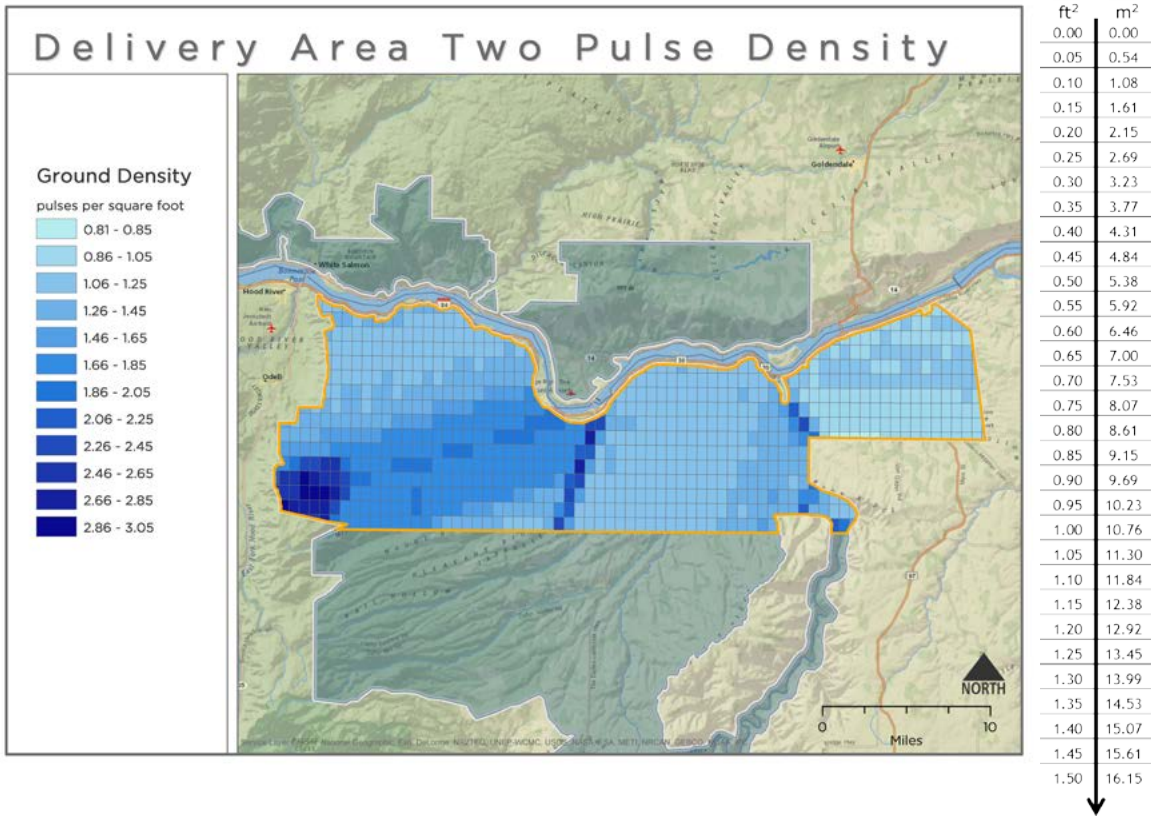
Pulse Density

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 and ground-classified laser point density. Densities are reported for the delivery area.

Average Pulse Density	pulses per square meter	pulses per square foot
	15.08	1.40



Average Pulse Density per 0.75' USGS Quad (color scheme aligns with density chart).

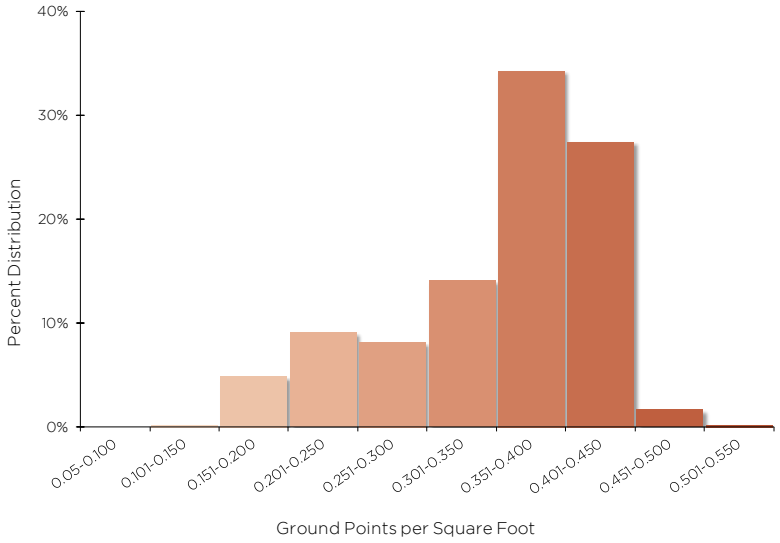


Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

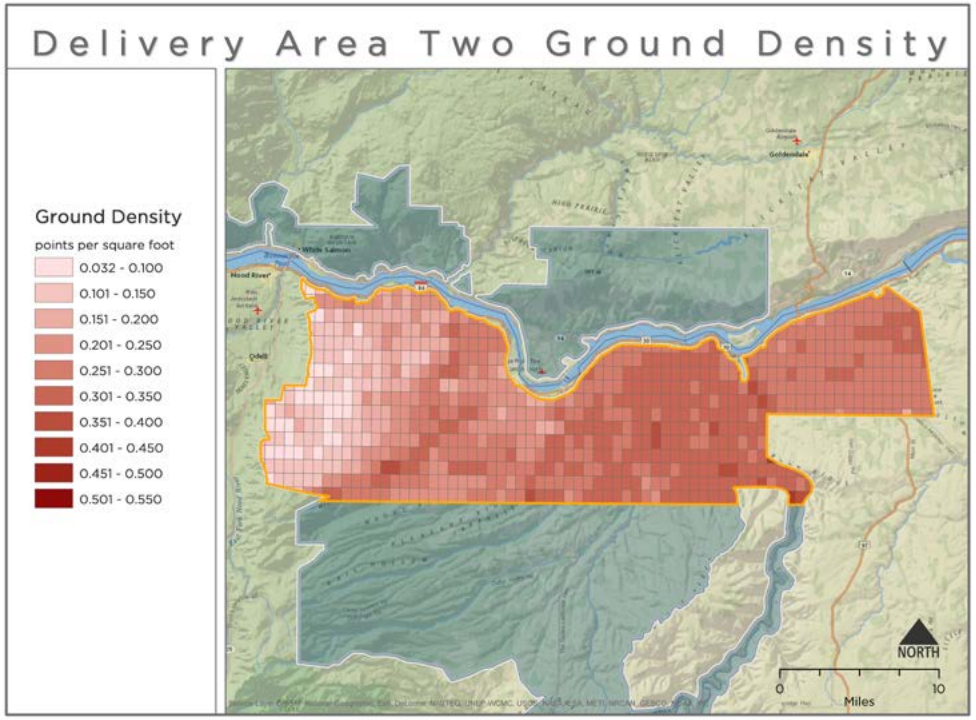
Ground Density

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 is a measure of ground-classified point data for the delivery area.

Ground Density	points per square meter	points per square foot
	2.73	0.25



Average Ground Density per 0.75' USGS Quad (color scheme aligns with density chart).



Pts ft²	Pts m²
0.00	0.00
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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
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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

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Appendix A : PLS Certification

WSI provided LiDAR Services for OLC Wasco County Survey project, Delivery Two, as described in this report.

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

1/20/2015

John English
Project Manager
WSI, a Quantum Spatial Company

I, Christopher Glantz, being duly registered as a Professional Land Surveyor in the state of Oregon, say that I hereby certify the methodologies and results of the attached LiDAR project, and that Static GNSS occupations on the Base Stations during airborne flights and RTK survey on hard-surface and GSP's were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between August 2, 2014 and September 16, 2014. Accuracy statistics shown in the Accuracy Section of this Report have been review by me and found to meet the "National Standard for Spatial Data Accuracy".

1/20/2015

Christopher Glantz, PLS
Land Surveyor
WSI, a Quantum Spatial Company
Portland, OR 97204

Appendix B : GPS Monument Table

List of GPS monuments used in OLC Wasco County Survey Area. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

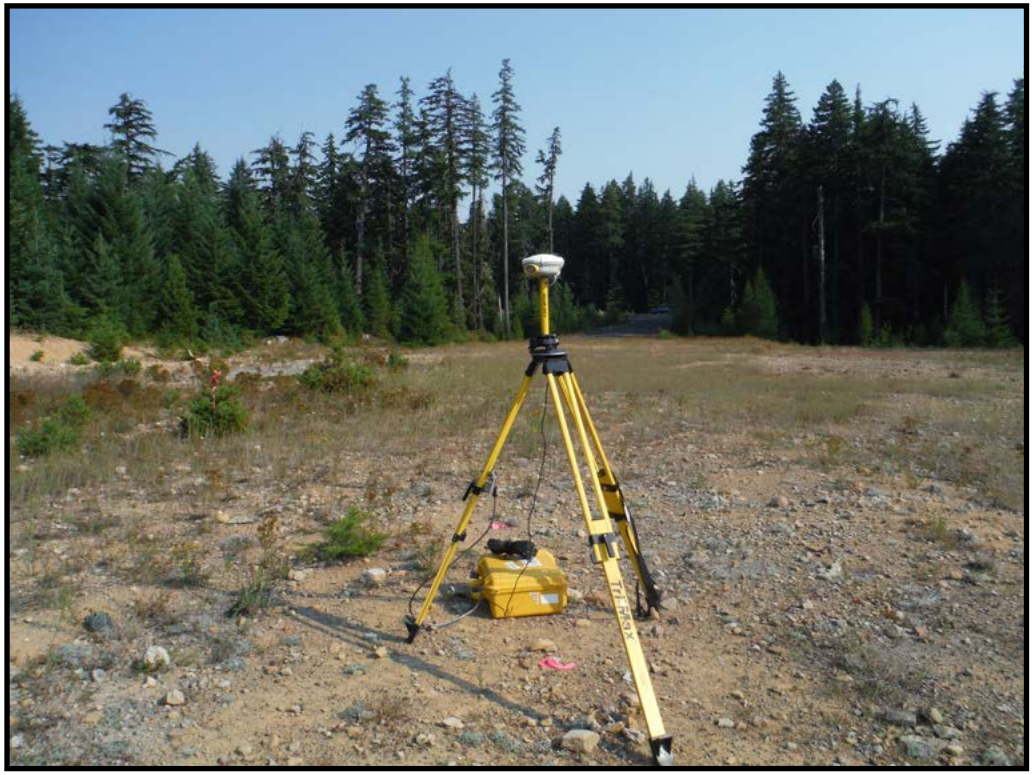
OLC Wasco County GPS Monuments				
PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
RC1228	45° 06′ 49.69688″	-121° 19′ 19.81403″	624.578	646.030
RC2736	45° 37′ 04.04622″	-121° 10′ 30.56142″	46.512	67.992
WASCO_01	45° 25′ 33.92221″	-121° 17′ 35.67224″	694.143	715.200
WASCO_02	45° 24′ 00.14524″	-121° 15′ 38.58602″	668.266	689.337
WASCO_03	45° 30′ 15.15952″	-121° 20′ 16.05414″	706.121	727.237
WASCO_04	45° 31′ 35.06899″	-121° 17′ 17.45080″	659.572	680.767
WASCO_05	45° 40′ 58.30068″	-121° 18′ 03.00268″	194.683	216.110
WASCO_06	45° 39′ 58.42964″	-121° 20′ 07.36657″	328.069	349.483
WASCO_07	45° 28′ 20.67253″	-121° 17′ 01.49189″	652.762	673.886
WASCO_08	45° 37′ 33.53662″	-121° 21′ 18.77199″	485.153	506.493
WASCO_09	45° 36′ 23.21905″	-121° 20′ 06.73995″	618.486	639.790
WASCO_10	45° 29′ 26.20935″	-121° 05′ 18.01985″	348.496	369.761
WASCO_11	45° 29′ 41.84872″	-121° 10′ 33.92138″	352.139	373.376
WASCO_12	45° 29′ 00.75217″	-121° 00′ 25.75182″	459.025	480.243
WASCO_13	45° 20′ 54.35426″	-121° 16′ 00.43344″	731.185	752.265
WASCO_14	45° 33′ 50.86097″	-121° 21′ 51.83958″	628.086	649.267
WASCO_15	45° 27′ 06.62583″	-120° 56′ 27.83190″	839.258	860.373
WASCO_16	45° 19′ 51.53124″	-121° 07′ 39.82528″	771.520	792.637
WASCO_17	45° 15′ 30.16588″	-121° 04′ 46.54399″	366.298	387.695
WASCO_18	45° 17′ 18.80793″	-121° 10′ 52.79618″	490.765	512.026
WASCO_19	45° 32′ 02.50205″	-121° 02′ 38.17485″	323.491	344.841
WASCO_20	45° 31′ 24.81814″	-121° 05′ 55.22316″	226.261	247.595
WASCO_21	45° 34′ 50.63889″	-120° 42′ 20.51709″	406.207	427.542
WASCO_22	45° 36′ 32.32168″	-120° 43′ 27.27584″	322.623	343.983

OLC Wasco County GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
WASCO_23	45° 39′ 25.35061″	-120° 50′ 31.98330″	195.187	216.568
WASCO_25	45° 40′ 26.60543″	-121° 06′ 03.21471″	340.241	361.552
WASCO_26	45° 43′ 42.64888″	-120° 58′ 06.01776″	457.564	478.693
WASCO_27	45° 11′ 11.42881″	-121° 10′ 36.88163″	516.322	537.783
WASCO_28	45° 13′ 21.18185″	-121° 16′ 41.26494″	529.382	550.863
WASCO_29	45° 17′ 13.71773″	-121° 43′ 43.89634″	1148.089	1168.978
WASCO_30	45° 15′ 09.56681″	-121° 45′ 06.60188″	1077.776	1098.738
WASCO_31	45° 11′ 41.00706″	-121° 41′ 34.26892″	1145.538	1166.520
WASCO_32	45° 13′ 23.06365″	-121° 33′ 08.21340″	1268.450	1289.391
WASCO_33	45° 08′ 01.07100″	-121° 37′ 24.78080″	1069.357	1090.435
WASCO_34	45° 16′ 27.80611″	-121° 29′ 24.41946″	1315.774	1336.621
WASCO_35	45° 37′ 57.72073″	-121° 58′ 13.51239″	-5.667	16.201
WASCO_36	45° 41′ 55.00914″	-121° 52′ 30.78102″	23.857	45.572
WASCO_37	45° 46′ 57.14196″	-121° 20′ 34.59729″	711.981	732.985
WASCO_38	45° 45′ 30.26559″	-121° 24′ 17.71854″	589.260	610.392
WASCO_39	45° 42′ 40.65511″	-121° 46′ 39.83483″	12.803	34.339
WASCO_40	45° 43′ 43.90661″	-121° 33′ 54.44150″	315.186	336.630

WSI Applied Remote Sensing and Analysis

OLC Wasco County: Delivery Three



Trimble R7 Receiver set up over GPS monument WASCO_31.

Data collected for:
Oregon Department of Geology and Mineral Industries

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fax: (541) 752-3770

Contents

Project Overview

WSI has completed the acquisition and processing of Light Detection and Ranging (LiDAR) data for the OLC Wasco County Delivery Area Three for the Oregon Department of Geology and Mineral Industries (DOGAMI). The Oregon LiDAR Consortium's Wasco County 2014 project area of interest (AOI) encompasses 1,020,680 acres. Delivery Area Three encompasses 117,128 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.

WSI LiDAR data acquisition for delivery areas one through three occurred from July 15 - September 19, 2014. Delivery area three was acquired from September 4 - 14, 2014.

Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter.

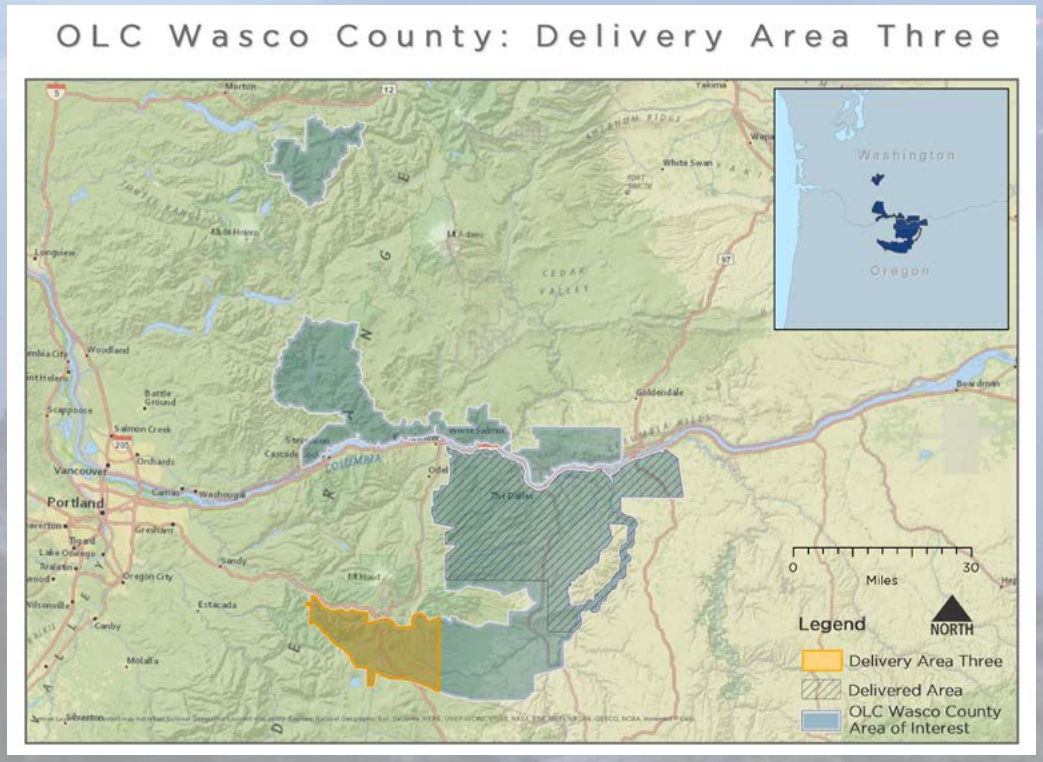
Final products created that are included in Delivery Area Three are LiDAR point cloud data, three-foot resolution digital elevation models of bare earth ground models and highest-hit returns, 1.5-foot intensity rasters, three-foot ground density rasters, study area vector shapes, ground survey points and monuments, and corresponding statistical data.

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

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

OLC Wasco County Delivery Three Data Delivered: March 26, 2014	
Acquisition Dates	9/4/2014 - 9/14/2014
Delivery Area Three Area of Interest	117,128 acres
Projection	Oregon Statewide Lambert (OGIC)
Datum: horizontal & vertical	NAD83 (2011) NAVD88 (Geoid 12A)
Units	International Feet

Study Area



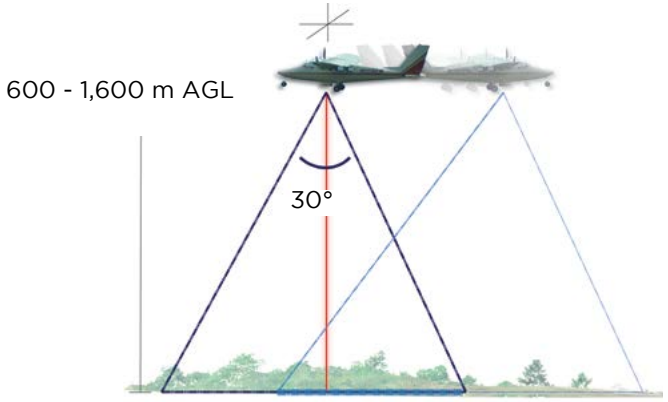
Aerial Acquisition

LiDAR Survey

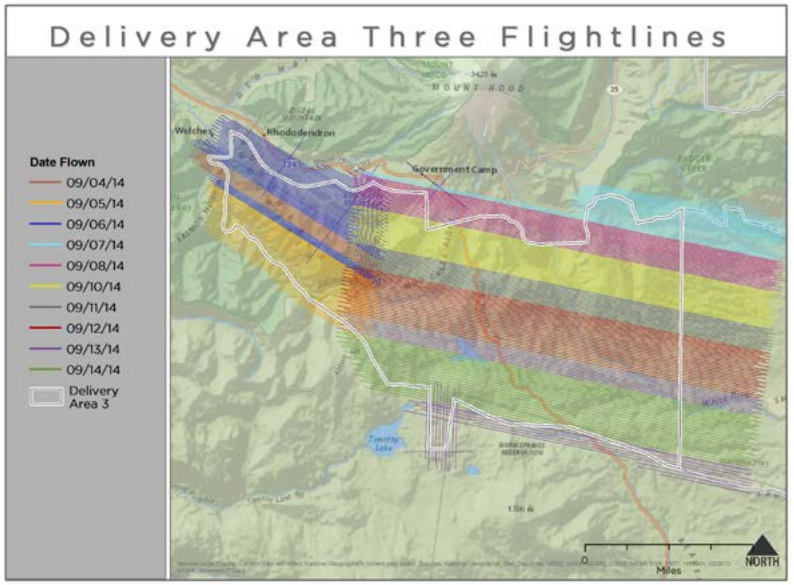
The LiDAR survey used a Leica ALS70 and an Optech Orion H sensor mounted in a Cessna U206G, Partenavia P.68, and Piper Navajo. The systems were programmed to emit single pulses at a rate of 219 kilohertz and flown between 600 and 1,600 meters above ground level (AGL), capturing a scan angle of +/-15 degrees from nadir (field of view equal to 30 degrees). 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 60 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 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 (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). As illustrated in the accompanying map, 500 full and partial flightlines provide coverage of the delivery area three study area.



Project Flightlines



OLC Wasco County LiDAR Acquisition Specification	
Sensors Deployed	Leica ALS 70 and Optech Orion H
Aircraft	Cessna U206G, Piper Navajo, Partenavia P.68
Survey Altitude (AGL)	600 - 1,600 meters
Pulse Rate	219 kHz
Pulse Mode	Single (SPiA)
Field of View (FOV)	30°
Roll Compensated	Yes
Overlap	100% overlap with 60% sidelap
Pulse Emission Density	≥ 8 pulses per square meter

Ground Survey

Ground control surveys, including monumentation, aerial targets, and ground survey points (GSPs) were conducted to support the airborne acquisition. Ground control data are used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data products. See the table to the right for specifications of equipment used.

Instrumentation

All Global Navigation Satellite System (GNSS) static surveys utilized Trimble R7 GNSS receivers with Zephyr Geodetic Model 2 RoHS antennas and Trimble R8 GNSS receivers with internal antennas. Rover surveys for GSP collection were conducted with Trimble R6, Trimble R8, and Trimble R10 GNSS receivers.

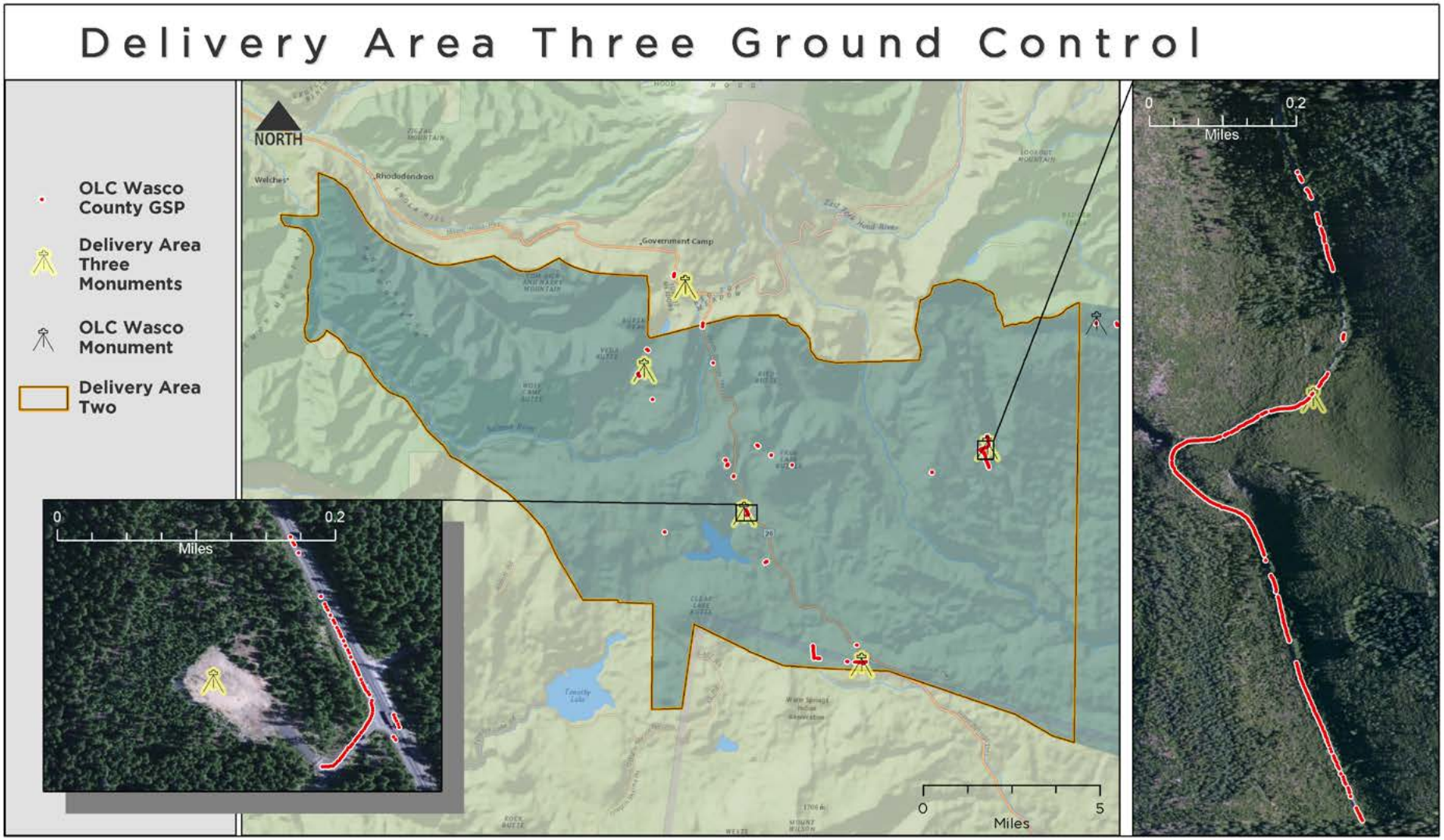
Monumentation

Existing and newly established survey benchmarks serve as control points during LiDAR acquisition. Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. NGS benchmarks are preferred for control points; however, in the absence of NGS benchmarks, WSI produces our own monuments, and every effort is made to keep them within the public right of way or on public lands. If monuments are necessary on private property, consent from the owner is required. All monumentation is done with 5/8" x 30" rebar topped with a two-inch diameter aluminum cap stamped "Watershed Sciences, Inc. Control." The table at right provides the list of monuments used in Delivery Area Three. See Appendix B for a complete list of monuments placed within the OLC Wasco County 2014 Study Area.

Instrumentation			
Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_GNSS	Static, Rover
Trimble R10	Integrated Antenna R10	TRMR10	Rover
Trimble R6	Integrated Antenna R6	TRMR6	Rover

Delivery Area Three GPS Monuments				
PID	Latitude	Longitude	Ellipsoid Height (m)	NAVD88 Height (m)
WASCO_29	45° 17' 13.71773"	-121° 43' 43.89634"	1148.089	1168.978
WASCO_30	45° 15' 09.56681"	-121° 45' 06.60188"	1077.776	1098.738
WASCO_31	45° 11' 41.00706"	-121° 41' 34.26892"	1145.538	1166.520
WASCO_32	45° 13' 23.06365"	-121° 33' 08.21340"	1268.450	1289.391
WASCO_33	45° 08' 01.07100"	-121° 37' 24.78080"	1069.357	1090.435

Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.


Delivery Area Three Ground Control
NORTH
OLC Wasco County GSP
Delivery Area Three Monuments
OLC Wasco Monument
Delivery Area Two
Government Camp
Rhododendron
0
0.2
Miles
0
5
Miles

Methodology

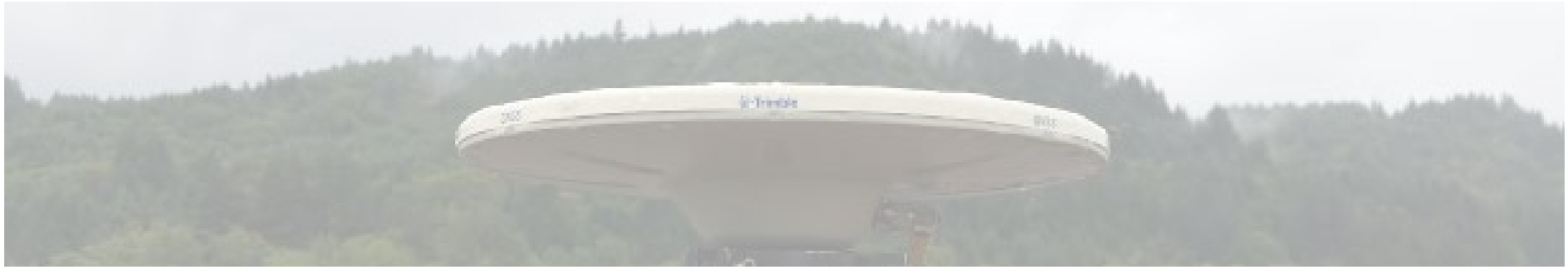
To correct the continuously recorded aircraft position, WSI concurrently conducts multiple static GNSS ground surveys over each monument. All control monuments are observed for a minimum of two survey sessions, each lasting no fewer than two hours. Data are collected at a rate of one hertz, using a 10 degree mask on the antenna. The static GPS data are then triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS) for precise positioning.

Ground Survey Points (GSPs) are collected using Real Time Kinematic (RTK), Post-Processed Kinematic (PPK), and Fast-Static (FS) survey techniques. For RTK surveys, a base receiver is positioned at a nearby monument to broadcast a kinematic correction to a roving receiver; for PPK and FS surveys, however, these corrections are post-processed. All GSP measurements are 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. Relative errors for the position must be less than 1.5 centimeters horizontal and 2.0 centimeters vertical in order to be accepted.

In order to facilitate comparisons with high quality LiDAR data, GSP measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. GSPs are taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. 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.

Monument Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	0.05 m Horiz
St Dev z	0.05 m Vert

WSI ground professional collecting ground survey points in OLC Wasco County study area.



Results

Accuracy Assessment

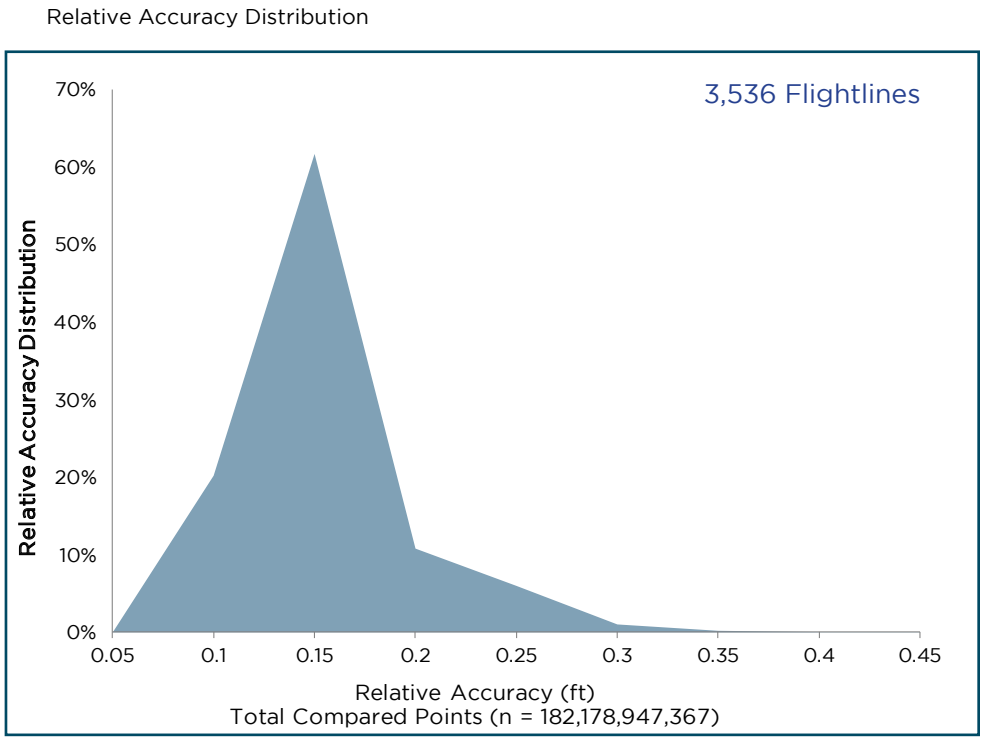
In some cases statistics were generated for larger areas than the extent represented by delivered areas. Accuracy statistics are a product of calibration and data QA/QC methodology that are spatially coincident with production workflow, which at times exceeds the areal extent of delivery workflow.

Relative Accuracy

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 centimeters). 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 3,536 full and partial flightlines. Relative accuracy is reported for the cumulative delivered portions of the study area.

Relative Accuracy Calibration Results N = 3,536 flightlines	
Project Average	0.13 ft. (0.04 m)
Median Relative Accuracy	0.12 ft. (0.04 m)
1σ Relative Accuracy	0.13 ft. (0.04 m)
2σ Relative Accuracy	0.22 ft. (0.07 m)



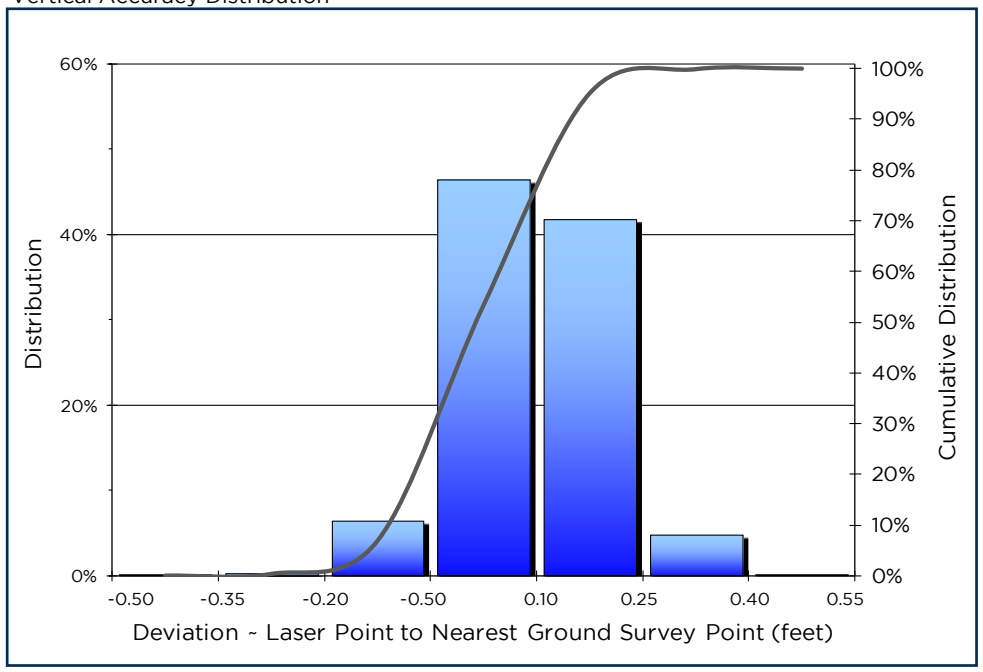
Vertical Accuracy

Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). The statistical model compares known ground survey points to the triangulated LiDAR surface. Vertical accuracy statistical analysis uses 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 Wasco County 2014 Study area, 1,052 GSPs were used to calibrate Delivery Area Three. Statistics are shown for the cumulative delivered areas.

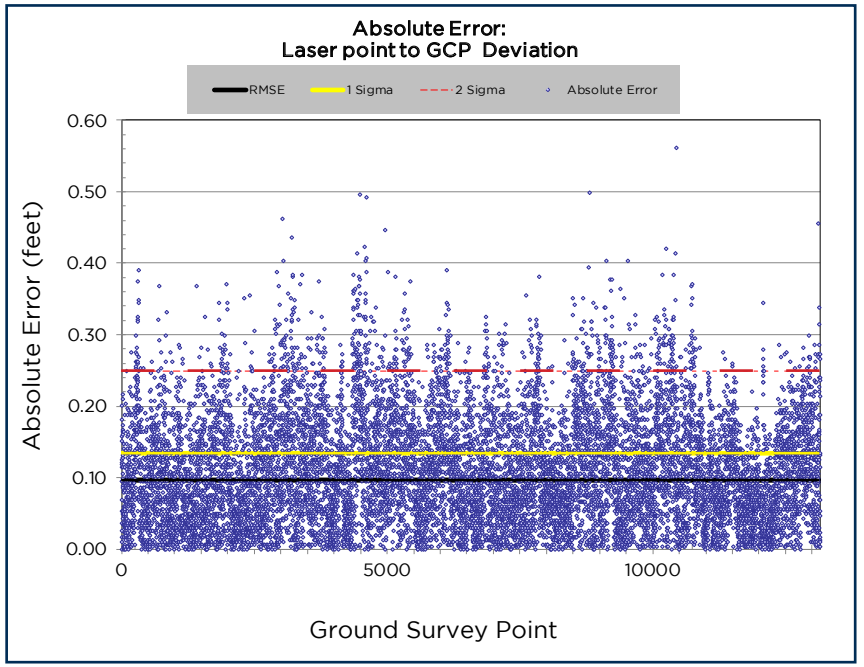
For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet." Vertical Accuracy is reported for the entire delivered study area and reported in the table below. Histogram and absolute deviation statistics displayed below.

Vertical Accuracy Results		
	Delivery Area Three	Cumulative
Sample Size (n) (ground survey points)	1,052	13,161
Root Mean Square Error	0.09 ft. (0.03 m)	0.10 ft. (0.03 m)
1 Standard Deviation	0.13 ft. (0.04 m)	0.14 ft. (0.04 m)
2 Standard Deviation	0.23 ft. (0.07 m)	0.25 ft. (0.08 m)
Average Deviation	0.06 ft. (0.02 m)	0.09 ft. (0.03 m)
Minimum Deviation	-0.25 ft. (-0.08 m)	-0.46 ft. (-0.14 m)
Maximum Deviation	0.34 ft. (0.11 m)	0.56 ft. (0.17 m)

Vertical Accuracy Distribution



GSP Absolute Error

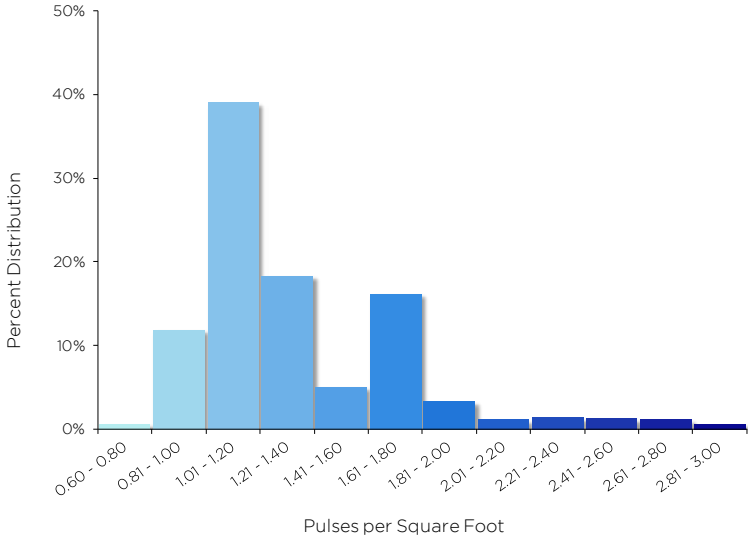


Density

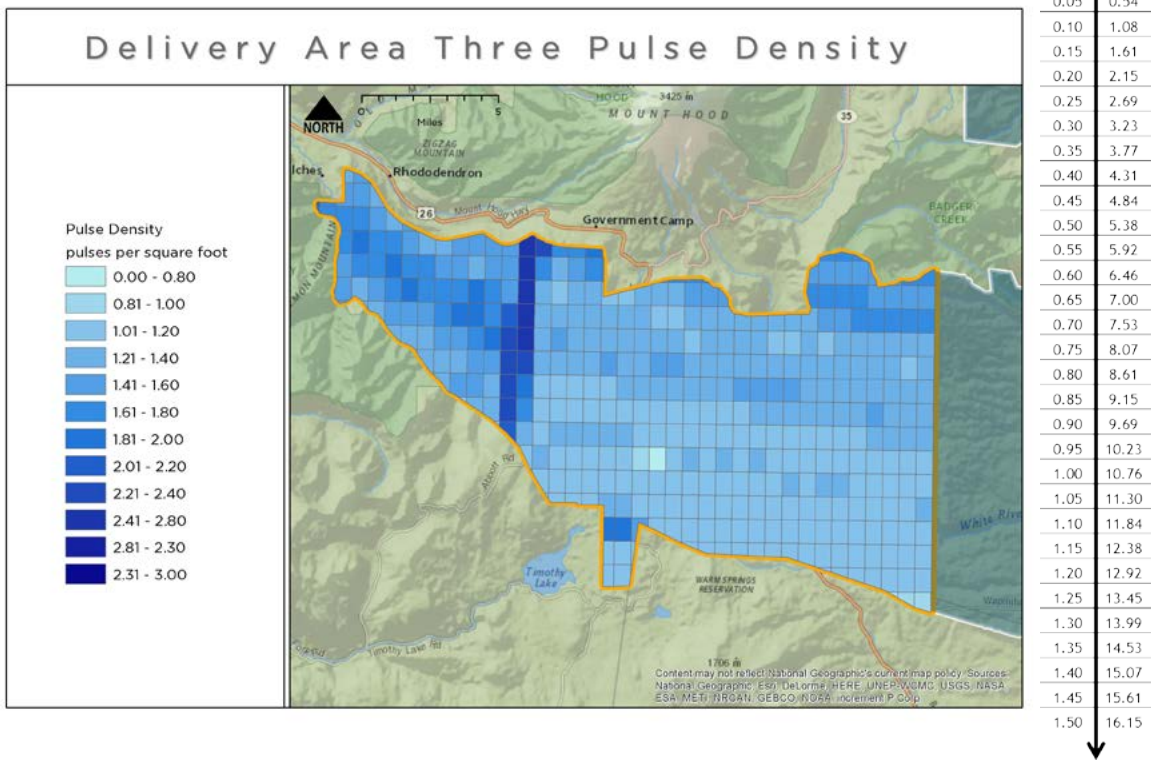
Pulse Density

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 and ground-classified laser point density. Densities are reported for the delivery area.

	pulses per square meter	pulses per square foot
Average Pulse Density	14.47	1.34



Average Pulse Density per 0.75' USGS Quad.

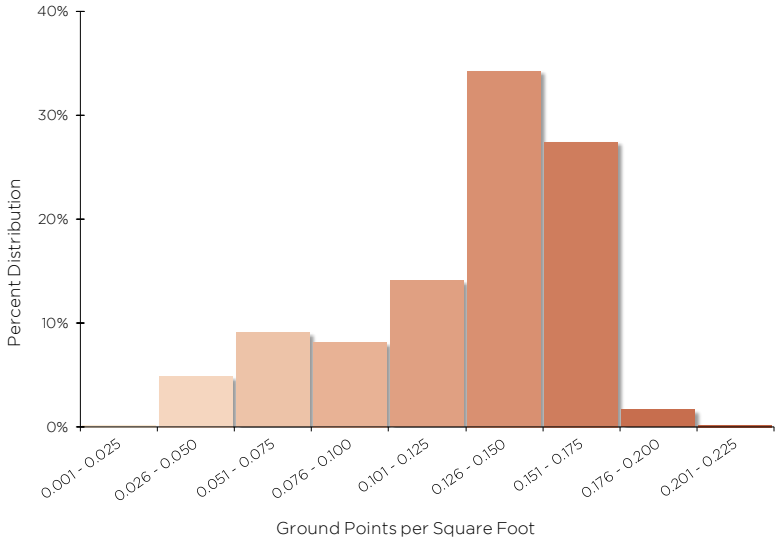


Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

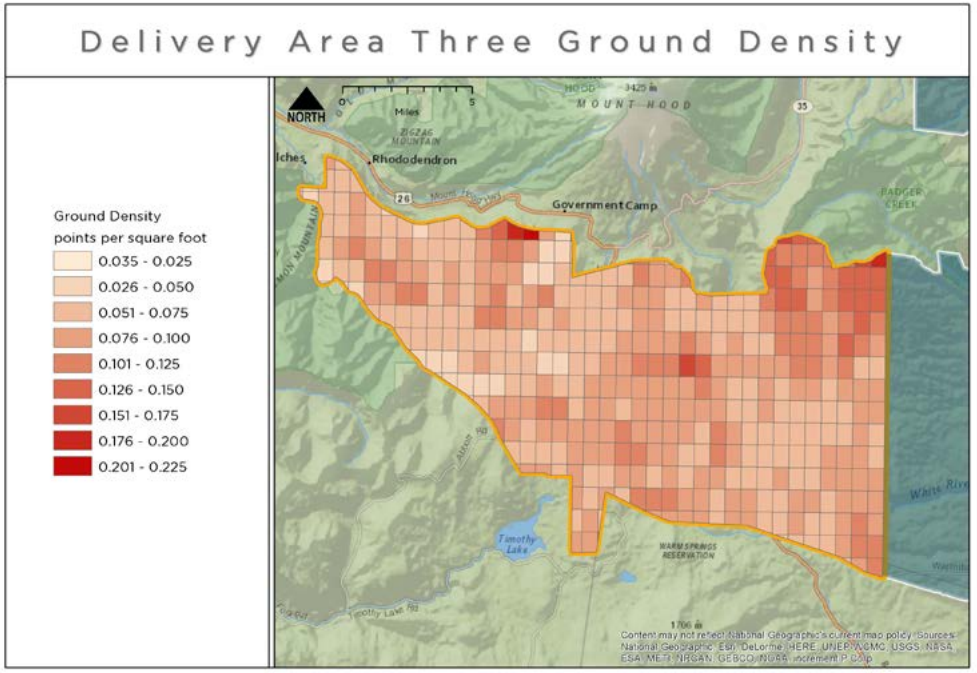
Ground Density

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 is a measure of ground-classified point data for the delivery area.

Ground Density	points per square meter	points per square foot
	0.88	0.08



Average ground density per 0.75' USGS Quad.



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
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0.20	2.15
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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

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Appendix A : PLS Certification

WSI provided LiDAR Services for OLC Wasco County Survey project, Delivery Three, as described in this report.

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

John T. English 3/26/2015

John English
Project Manager
WSI, a Quantum Spatial Company

I, Christopher Glantz, being duly registered as a Professional Land Surveyor in the state of Oregon, say that I hereby certify the methodologies and results of the attached LiDAR project, and that Static GNSS occupations on the Base Stations during airborne flights and RTK survey on hard-surface and GSP's were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between September 3, 2014 and September 21, 2014. Accuracy statistics shown in the Accuracy Section of this Report have been review by me and found to meet the "National Standard for Spatial Data Accuracy".

3/26/2015

Christopher Glantz, PLS
Land Surveyor
WSI, a Quantum Spatial Company

REGISTERED
PROFESSIONAL
LAND SURVEYOR

OREGON
JUNE 2, 2010
CHRISTOPHER A. GLANTZ
83648

RENEWS 6/30/2015

Appendix B : GPS Monument Table

List of GPS monuments used in OLC Wasco County Survey Area. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

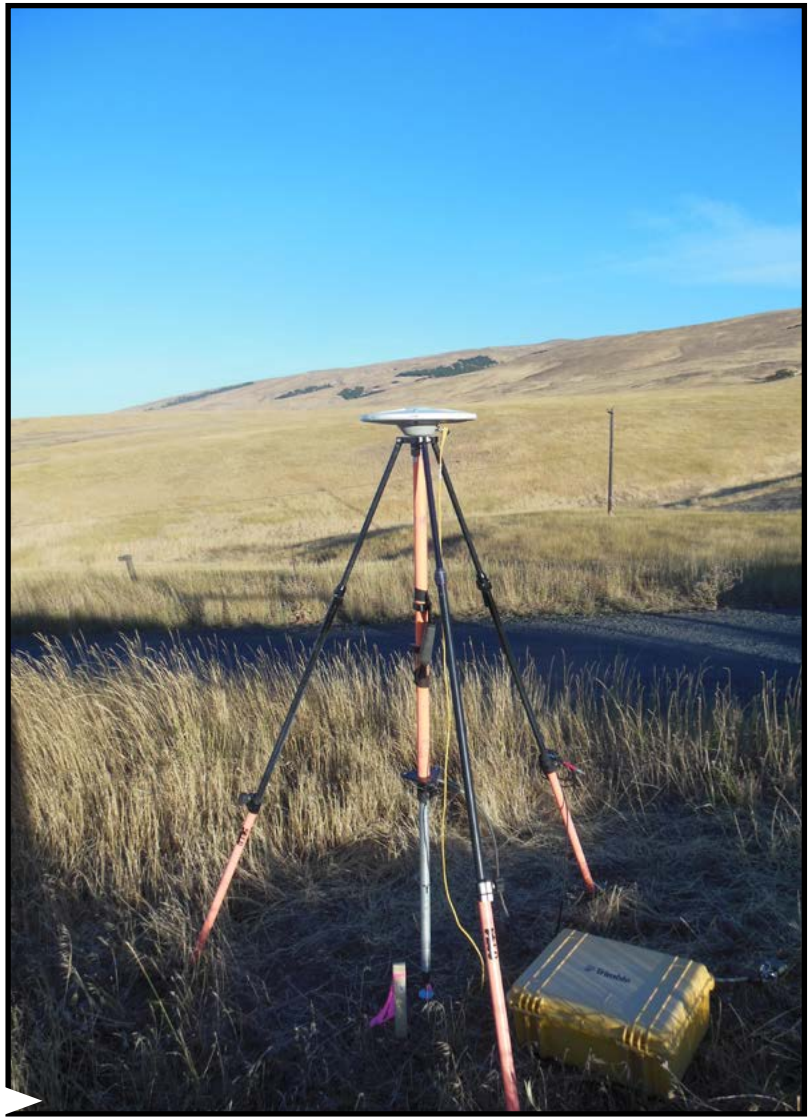
OLC Wasco County GPS Monuments				
PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
RC1228	45° 06′ 49.69688″	-121° 19′ 19.81403″	624.578	646.030
RC2736	45° 37′ 04.04622″	-121° 10′ 30.56142″	46.512	67.992
WASCO_01	45° 25′ 33.92221″	-121° 17′ 35.67224″	694.143	715.200
WASCO_02	45° 24′ 00.14524″	-121° 15′ 38.58602″	668.266	689.337
WASCO_03	45° 30′ 15.15952″	-121° 20′ 16.05414″	706.121	727.237
WASCO_04	45° 31′ 35.06899″	-121° 17′ 17.45080″	659.572	680.767
WASCO_05	45° 40′ 58.30068″	-121° 18′ 03.00268″	194.683	216.110
WASCO_06	45° 39′ 58.42964″	-121° 20′ 07.36657″	328.069	349.483
WASCO_07	45° 28′ 20.67253″	-121° 17′ 01.49189″	652.762	673.886
WASCO_08	45° 37′ 33.53662″	-121° 21′ 18.77199″	485.153	506.493
WASCO_09	45° 36′ 23.21905″	-121° 20′ 06.73995″	618.486	639.790
WASCO_10	45° 29′ 26.20935″	-121° 05′ 18.01985″	348.496	369.761
WASCO_11	45° 29′ 41.84872″	-121° 10′ 33.92138″	352.139	373.376
WASCO_12	45° 29′ 00.75217″	-121° 00′ 25.75182″	459.025	480.243
WASCO_13	45° 20′ 54.35426″	-121° 16′ 00.43344″	731.185	752.265
WASCO_14	45° 33′ 50.86097″	-121° 21′ 51.83958″	628.086	649.267
WASCO_15	45° 27′ 06.62583″	-120° 56′ 27.83190″	839.258	860.373
WASCO_16	45° 19′ 51.53124″	-121° 07′ 39.82528″	771.520	792.637
WASCO_17	45° 15′ 30.16588″	-121° 04′ 46.54399″	366.298	387.695
WASCO_18	45° 17′ 18.80793″	-121° 10′ 52.79618″	490.765	512.026
WASCO_19	45° 32′ 02.50205″	-121° 02′ 38.17485″	323.491	344.841
WASCO_20	45° 31′ 24.81814″	-121° 05′ 55.22316″	226.261	247.595
WASCO_21	45° 34′ 50.63889″	-120° 42′ 20.51709″	406.207	427.542
WASCO_22	45° 36′ 32.32168″	-120° 43′ 27.27584″	322.623	343.983

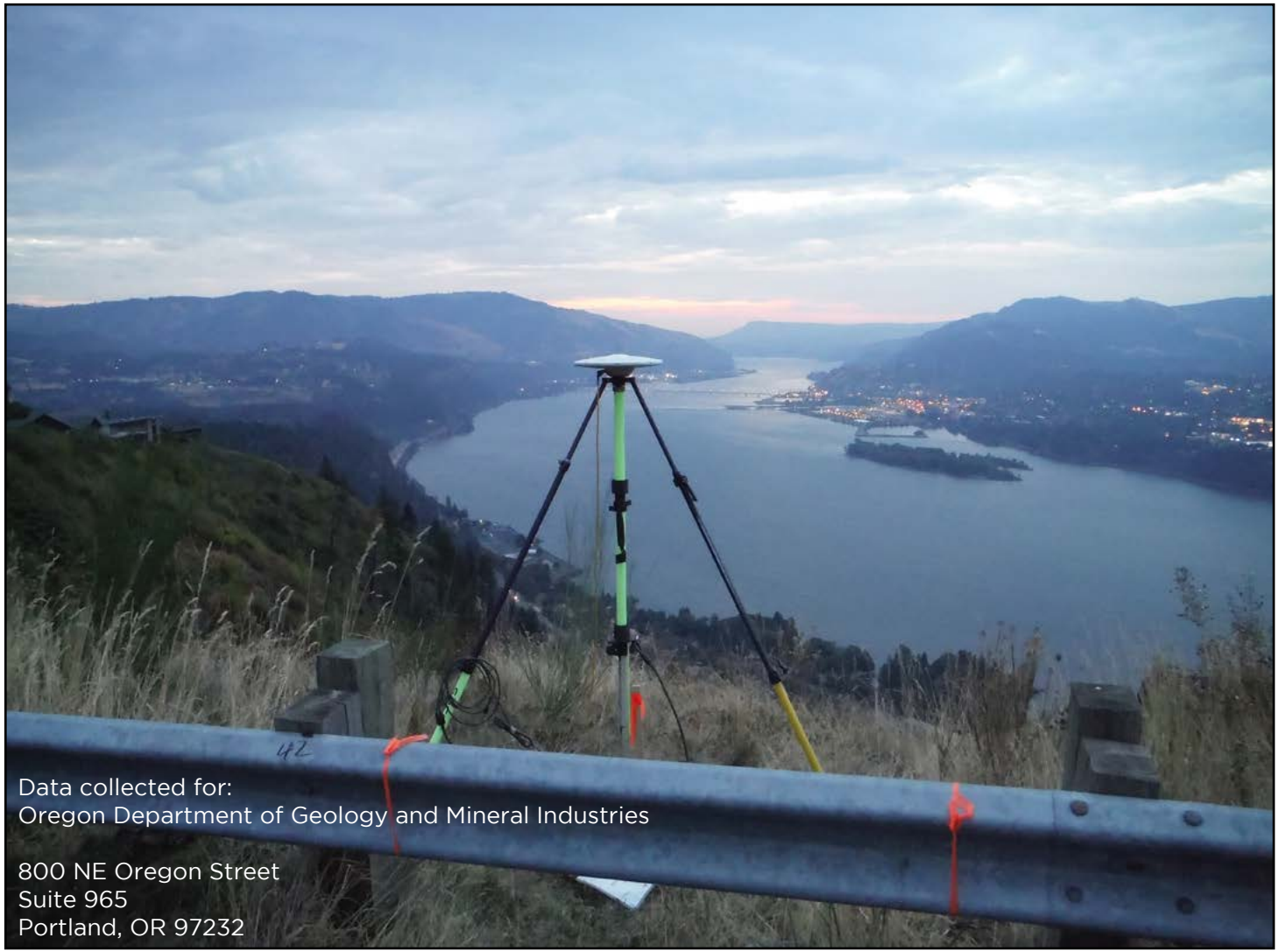
OLC Wasco County GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
WASCO_23	45° 39′ 25.35061″	-120° 50′ 31.98330″	195.187	216.568
WASCO_25	45° 40′ 26.60543″	-121° 06′ 03.21471″	340.241	361.552
WASCO_26	45° 43′ 42.64888″	-120° 58′ 06.01776″	457.564	478.693
WASCO_27	45° 11′ 11.42881″	-121° 10′ 36.88163″	516.322	537.783
WASCO_28	45° 13′ 21.18185″	-121° 16′ 41.26494″	529.382	550.863
WASCO_29	45° 17′ 13.71773″	-121° 43′ 43.89634″	1148.089	1168.978
WASCO_30	45° 15′ 09.56681″	-121° 45′ 06.60188″	1077.776	1098.738
WASCO_31	45° 11′ 41.00706″	-121° 41′ 34.26892″	1145.538	1166.520
WASCO_32	45° 13′ 23.06365″	-121° 33′ 08.21340″	1268.450	1289.391
WASCO_33	45° 08′ 01.07100″	-121° 37′ 24.78080″	1069.357	1090.435
WASCO_34	45° 16′ 27.80611″	-121° 29′ 24.41946″	1315.774	1336.621
WASCO_35	45° 37′ 57.72073″	-121° 58′ 13.51239″	-5.667	16.201
WASCO_36	45° 41′ 55.00914″	-121° 52′ 30.78102″	23.857	45.572
WASCO_37	45° 46′ 57.14196″	-121° 20′ 34.59729″	711.981	732.985
WASCO_38	45° 45′ 30.26559″	-121° 24′ 17.71854″	589.260	610.392
WASCO_39	45° 42′ 40.65511″	-121° 46′ 39.83483″	12.803	34.339
WASCO_40	45° 43′ 43.90661″	-121° 33′ 54.44150″	315.186	336.630

WSI Applied Remote Sensing and Analysis

OLC Wasco County: Delivery Four





Left: Trimble R7 Receiver set up over GPS monument WASCO_40
Cover: Views of monument WASCO_25.

Data collected for:
Oregon Department of Geology and Mineral Industries

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Contents

Project Overview

WSI has completed the acquisition and processing of Light Detection and Ranging (LiDAR) data for the OLC Wasco County Delivery Area Four for the Oregon Department of Geology and Mineral Industries (DOGAMI). The Oregon LiDAR Consortium's Wasco County 2014 project area of interest (AOI) encompasses 1,020,680 acres. Delivery Area Four encompasses 67,682 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.

WSI LiDAR data acquisition for delivery areas one through four occurred from July 15 - September 19, 2014. Delivery area four was acquired from August 27 - 29, 2014.

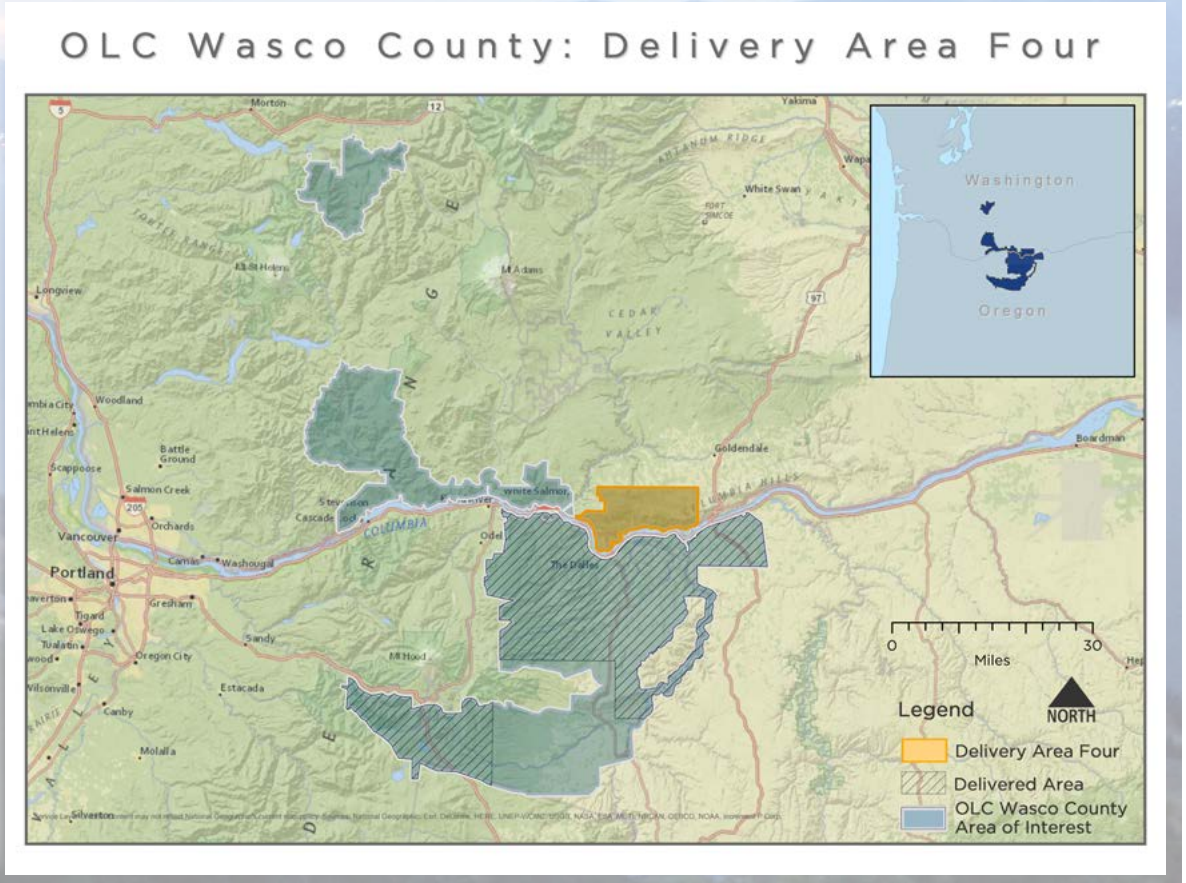
Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter.

Final products created that are included in Delivery Area Four are LiDAR point cloud data, three-foot resolution digital elevation models of bare earth ground models and highest-hit returns, 1.5-foot intensity rasters, three-foot ground density rasters, study area vector shapes, ground survey points and monuments, and corresponding statistical data.

WSI acquires and processes data in the most current, NGS-approved datums and geoid. For OLC Wasco County Delivery 4, all final deliverables are projected in Washington State Plane South, using the NAD83(2011) horizontal datum and the NAVD88 (Geoid 12A) vertical datum, with units in US Survey Feet.

OLC Wasco County Delivery Four Data Delivered: April 24, 2015	
Acquisition Dates	8/27/2014 - 8/29/2014
Delivery Area Four Area of Interest	67,682 acres
Projection	Washington State Plane South
Horizontal Datum Vertical Datum	NAD83 (2011) NAVD88 (Geoid 12A)
Units	US Survey Feet

Study Area



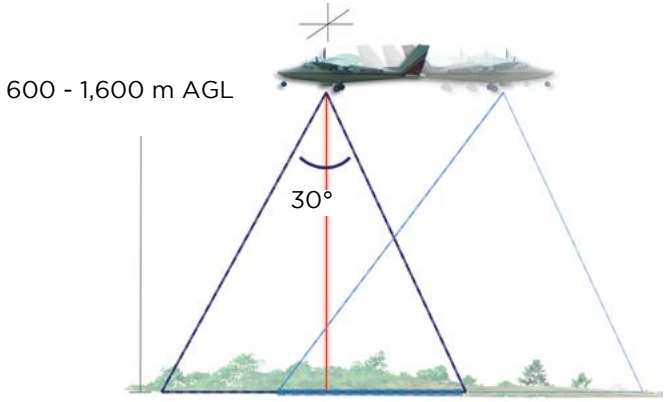
Aerial Acquisition

LiDAR Survey

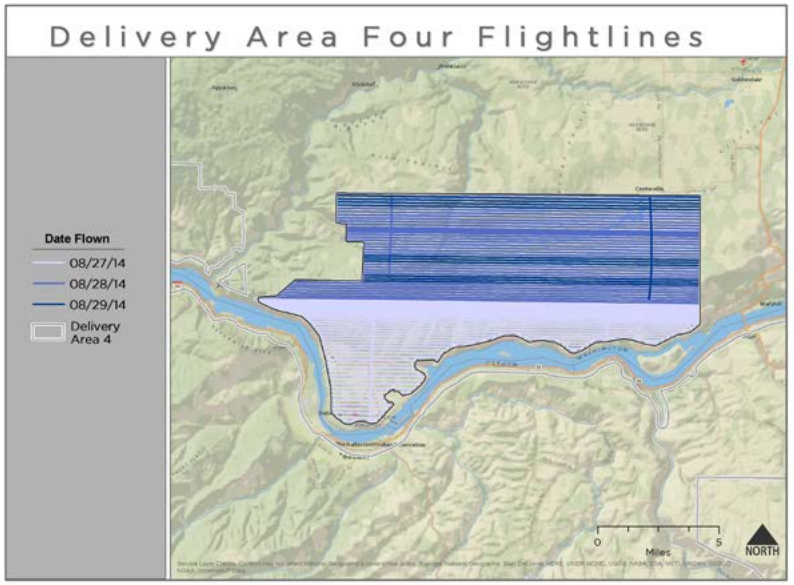
The LiDAR survey used a Leica ALS70 and an Optech Orion H sensor mounted in a Cessna U206G, Partenavia P.68, and Piper Navajo. The systems were programmed to emit single pulses at a rate of 219 kilohertz and flown between 600 and 1,600 meters above ground level (AGL), capturing a scan angle of +/-15 degrees from nadir (field of view equal to 30 degrees). 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 60 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 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 (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). As illustrated in the accompanying map, 88 full and partial flightlines provide coverage of the delivery area four study area.



Project Flightlines



OLC Wasco County LiDAR Acquisition Specification	
Sensors Deployed	Leica ALS 70 and Optech Orion H
Aircraft	Cessna U206G, Piper Navajo, Partenavia P.68
Survey Altitude (AGL)	600 - 1,600 meters
Pulse Rate	219 kHz
Pulse Mode	Single (SPiA)
Field of View (FOV)	30°
Roll Compensated	Yes
Overlap	100% overlap with 60% sidelap
Pulse Emission Density	≥ 8 pulses per square meter

Ground Survey

Ground control surveys, including monumentation, aerial targets, and ground survey points (GSPs) were conducted to support the airborne acquisition. Ground control data are used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data products. See the table to the right for specifications of equipment used.

Instrumentation

All Global Navigation Satellite System (GNSS) static surveys utilized Trimble R7 GNSS receivers with Zephyr Geodetic Model 2 RoHS antennas and Trimble R8 GNSS receivers with internal antennas. Rover surveys for GSP collection were conducted with Trimble R6, Trimble R8, and Trimble R10 GNSS receivers.

Monumentation

Existing and newly established survey benchmarks serve as control points during LiDAR acquisition. Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. NGS benchmarks are preferred for control points; however, in the absence of NGS benchmarks, WSI produces our own monuments, and every effort is made to keep them within the public right of way or on public lands. If monuments are necessary on private property, consent from the owner is required. All monumentation is done with 5/8" x 30" rebar topped with a two-inch diameter aluminum cap stamped "Watershed Sciences, Inc. Control." The table at right provides the list of monuments used in Delivery Area Four. See Appendix B for a complete list of monuments placed within the OLC Wasco County 2014 Study Area.

Instrumentation

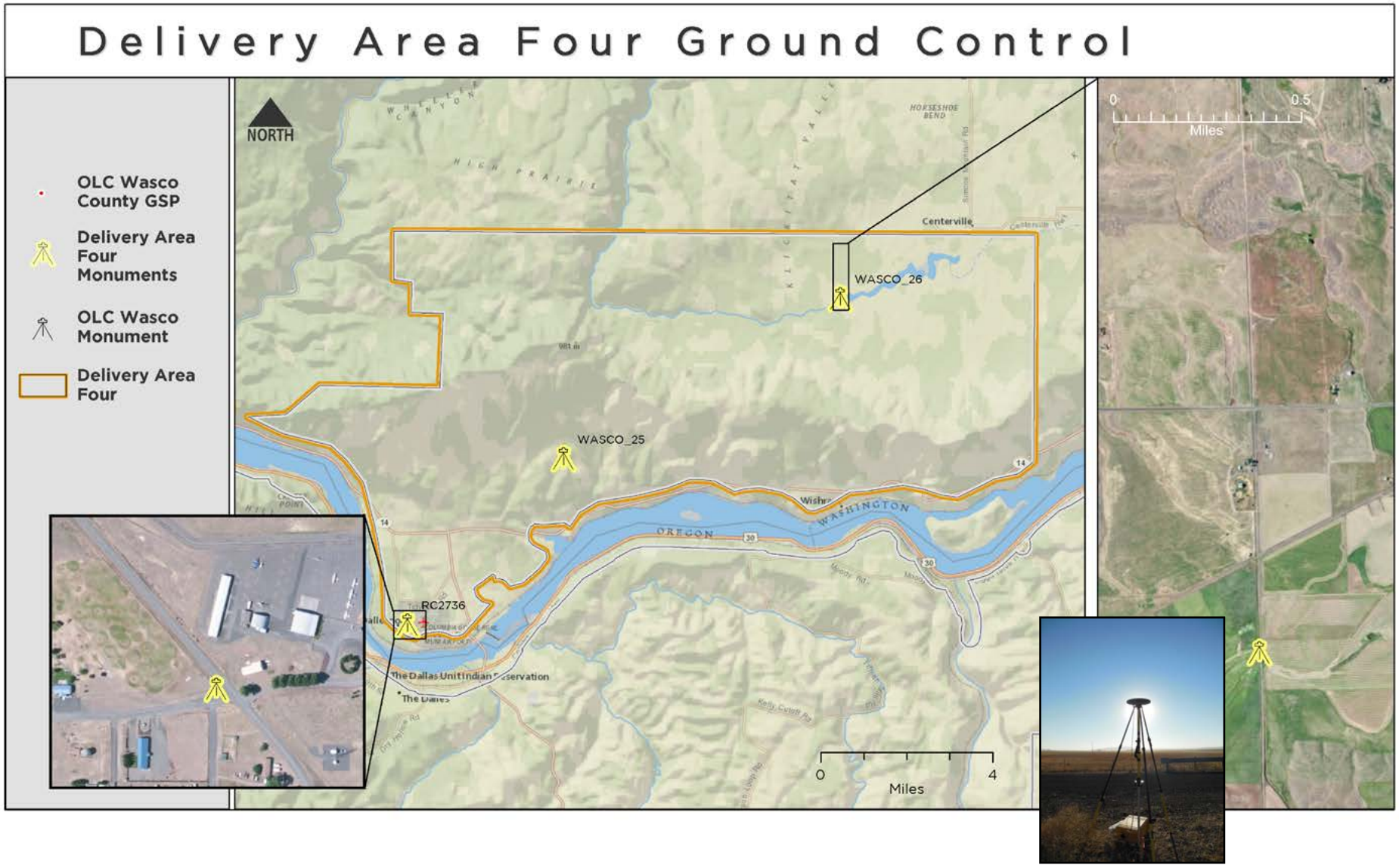
Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R6	Integrated Antenna R6	TRMR6	Rover
Trimble R7	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_GNSS	Static, Rover
Trimble R10	Integrated Antenna R10	TRMR10	Rover

Delivery Area Four GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	NAVD88 Height (m)
RC2736	45° 37' 04.04622"	-121° 10' 30.56142"	46.512	67.992
WASCO_25	45° 40' 26.60543"	-121° 06' 03.21471"	340.241	361.552
WASCO_26	45° 43' 42.64888"	-120° 58' 06.01776"	457.564	478.694

Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

Delivery Area Four Ground Control



Methodology

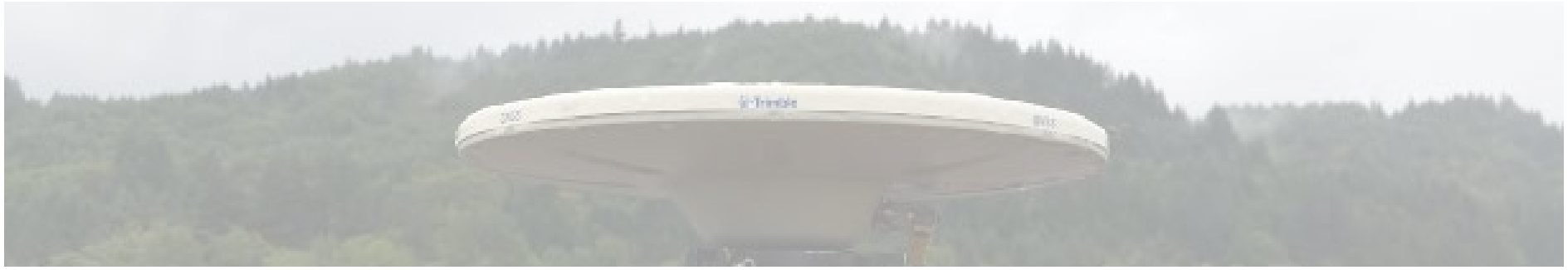
To correct the continuously recorded aircraft position, WSI concurrently conducts multiple static GNSS ground surveys over each monument. All control monuments are observed for a minimum of two survey sessions, each lasting no fewer than two hours. Data are collected at a rate of one hertz, using a 10 degree mask on the antenna. The static GPS data are then triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS) for precise positioning.

Ground Survey Points (GSPs) are collected using Real Time Kinematic (RTK), Post-Processed Kinematic (PPK), and Fast-Static (FS) survey techniques. For RTK surveys, a base receiver is positioned at a nearby monument to broadcast a kinematic correction to a roving receiver; for PPK and FS surveys, however, these corrections are post-processed. All GSP measurements are 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. Relative errors for the position must be less than 1.5 centimeters horizontal and 2.0 centimeters vertical in order to be accepted.

In order to facilitate comparisons with high quality LiDAR data, GSP measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. GSPs are taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. 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.

Monument Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	0.05 m Horiz
St Dev z	0.05 m Vert

WSI ground professional collecting ground survey points in OLC Wasco County study area.



Results

Accuracy Assessment

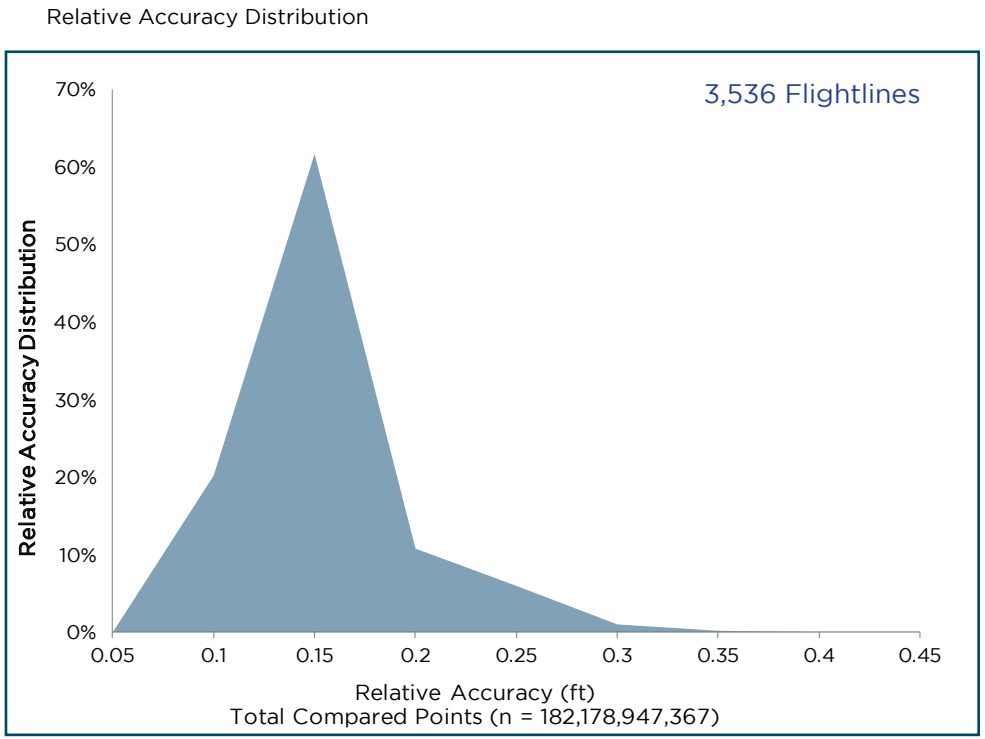
In some cases statistics were generated for larger areas than the extent represented by delivered areas. Accuracy statistics are a product of calibration and data QA/QC methodology that are spatially coincident with production workflow, which at times exceeds the areal extent of delivery workflow.

Relative Accuracy

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 centimeters). 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 3,536 full and partial flightlines. Relative accuracy is reported for the cumulative delivered portions of the study area.

Relative Accuracy Calibration Results N = 3,536 flightlines	
Project Average	0.13 ft. (0.04 m)
Median Relative Accuracy	0.12 ft. (0.04 m)
1σ Relative Accuracy	0.13 ft. (0.04 m)
2σ Relative Accuracy	0.22 ft. (0.07 m)



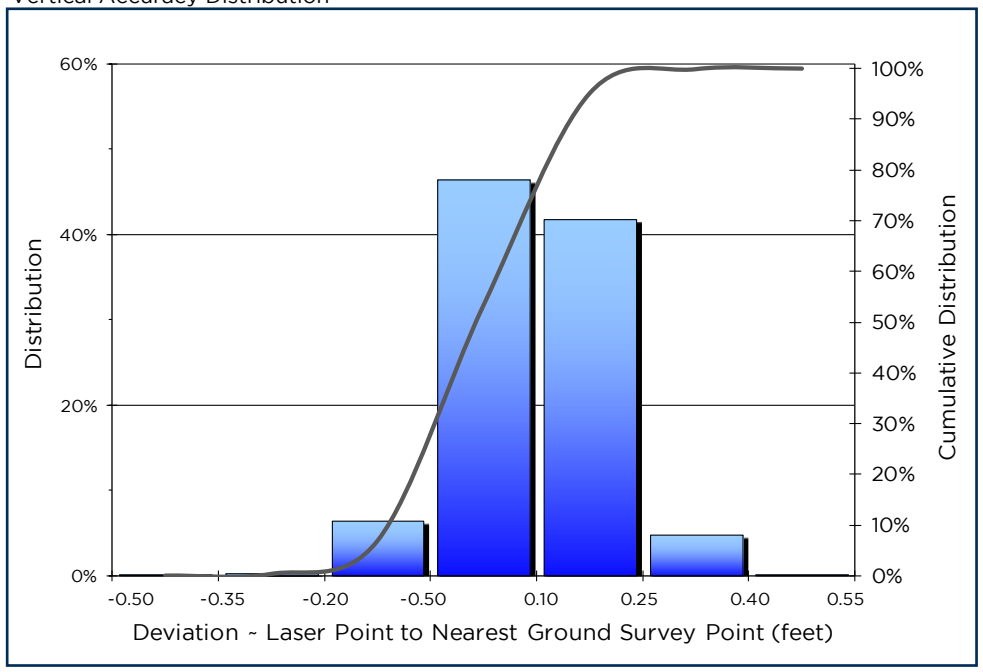
Vertical Accuracy

Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). The statistical model compares known ground survey points to the triangulated LiDAR surface. Vertical accuracy statistical analysis uses 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 Wasco County 2014 Study area, 1,287 GSPs were used to calibrate Delivery Area Four. Vertical Accuracy is reported for the entire delivered study area and reported in the table below.

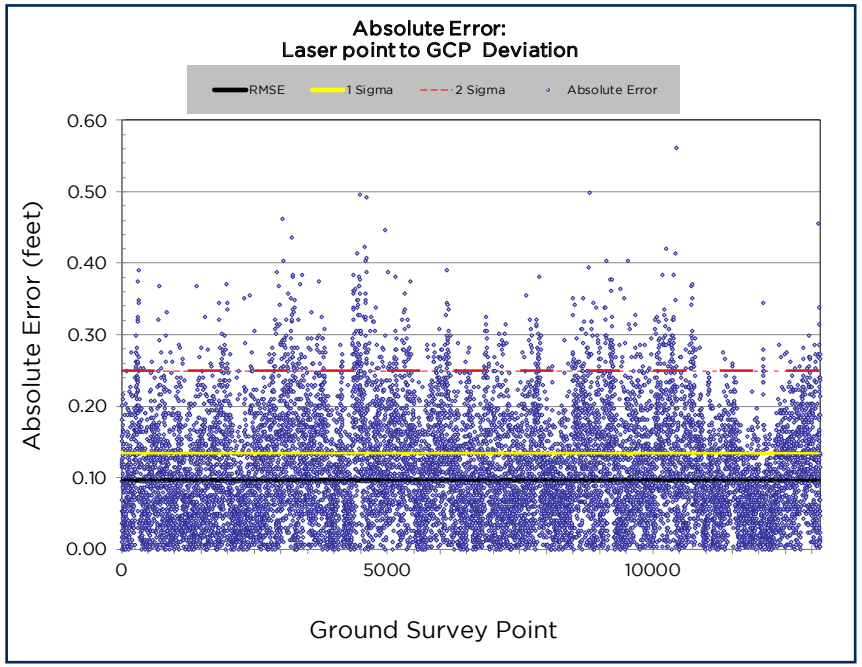
For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet."

Vertical Accuracy Results		
	Delivery Area Four	Cumulative
Sample Size (n) (ground survey points)	1,287	13,161
Root Mean Square Error	0.09 ft. (0.03 m)	0.10 ft. (0.03 m)
1 Standard Deviation	0.14 ft. (0.04 m)	0.13 ft. (0.04 m)
2 Standard Deviation	0.26 ft. (0.08 m)	0.25 ft. (0.08 m)
Average Deviation	0.10 ft. (0.03 m)	0.09 ft. (0.03 m)
Minimum Deviation	-0.40 ft. (-0.12 m)	-0.46 ft. (-0.14 m)
Maximum Deviation	0.46ft. (0.14 m)	0.56 ft. (0.17 m)

Vertical Accuracy Distribution



GSP Absolute Error

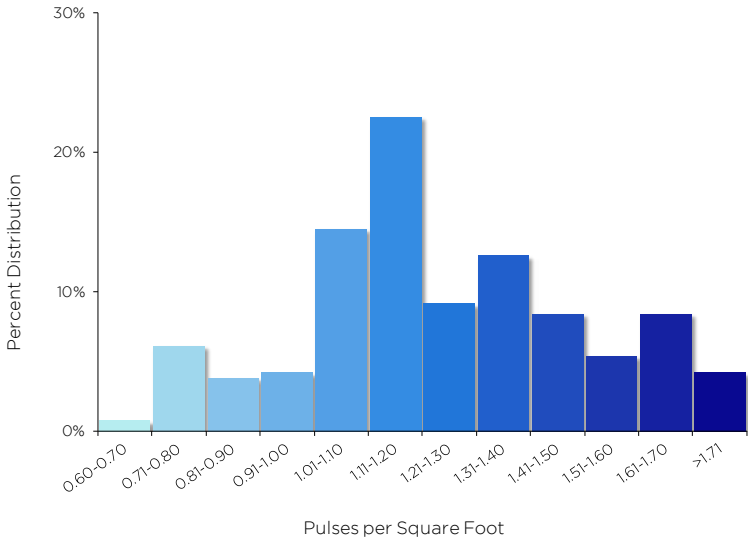


Density

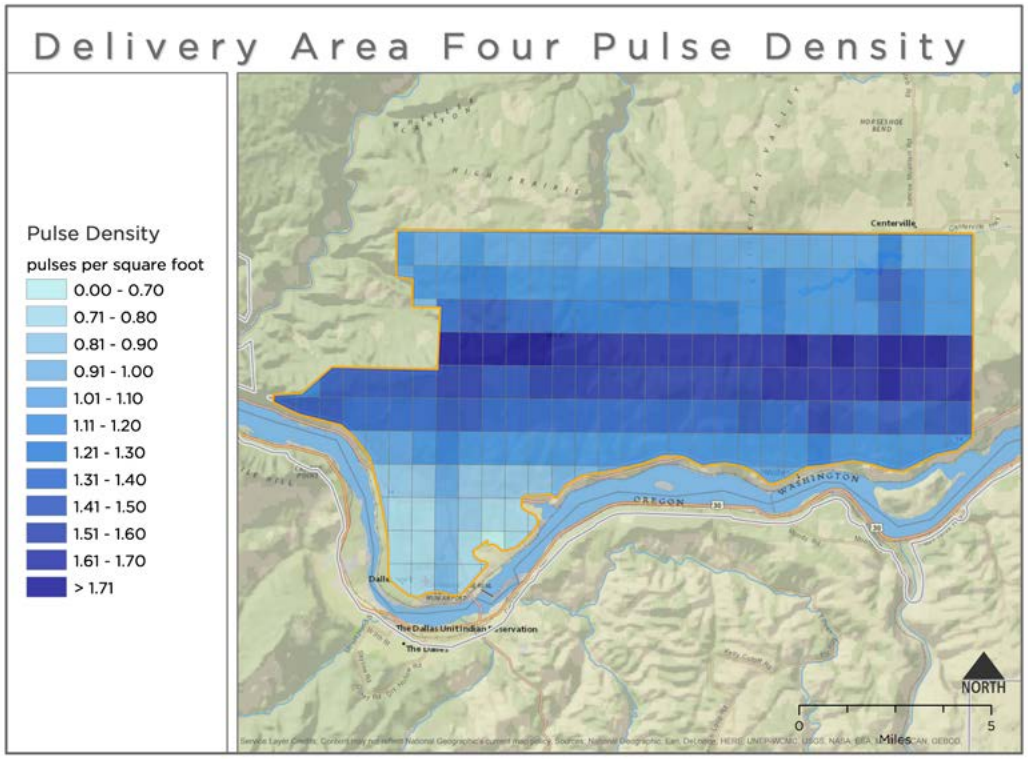
Pulse Density

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 and ground-classified laser point density. Densities are reported for the delivery area.

	pulses per square meter	pulses per square foot
Average Pulse Density	13.77	1.28



Average Pulse Density per 0.75' USGS Quad.

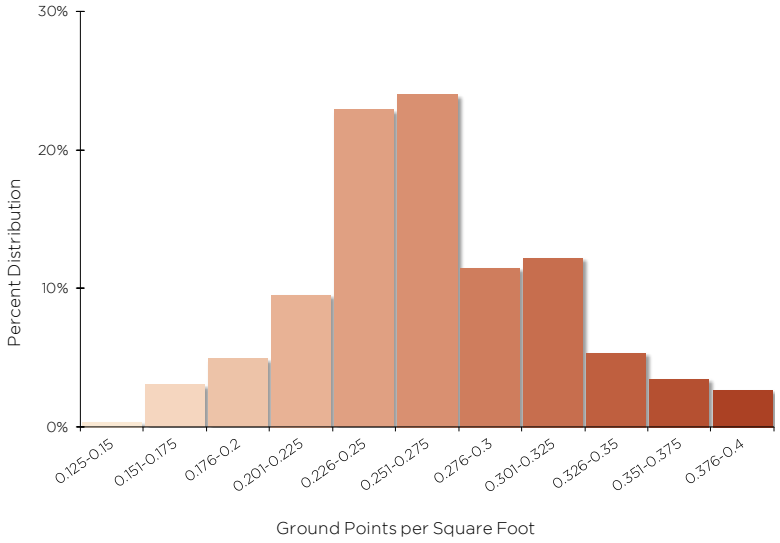


Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

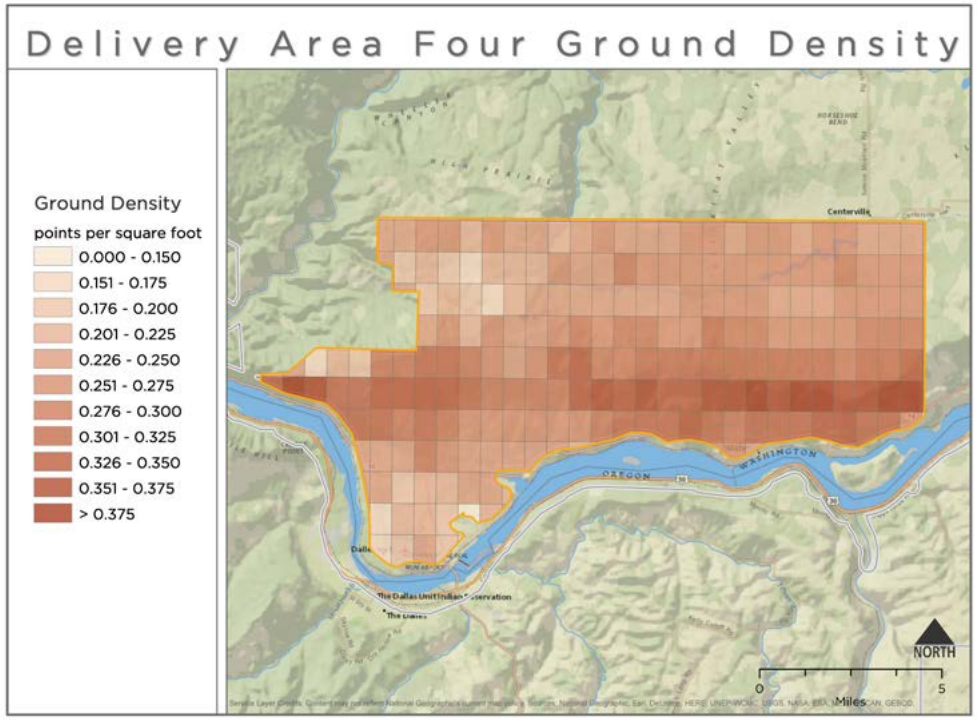
Ground Density

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 is a measure of ground-classified point data for the delivery area.

Ground Density	points per square meter	points per square foot
	2.91	0.27



Average ground 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
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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

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Appendix A : PLS Certification

WSI provided LiDAR services for the OLC Wasco County Delivery 4 project as described in this report.

I, Evon P. Silvia, 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 July 19, 2014, and between August 27, 2014, and August 29, 2014.

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 4/23/2015

Evon P. Silvia, PLS Oregon
WSI, a Quantum Spatial Company
Corvallis, OR 97333

REGISTERED
PROFESSIONAL
LAND SURVEYOR

Evon P. Silvia

OREGON
JUNE 10, 2014
EVON P. SILVIA
81104LS

EXPIRES: 6/30/2016

John English
Project Manager
WSI, a Quantum Spatial Company

Appendix B : GPS Monument Table

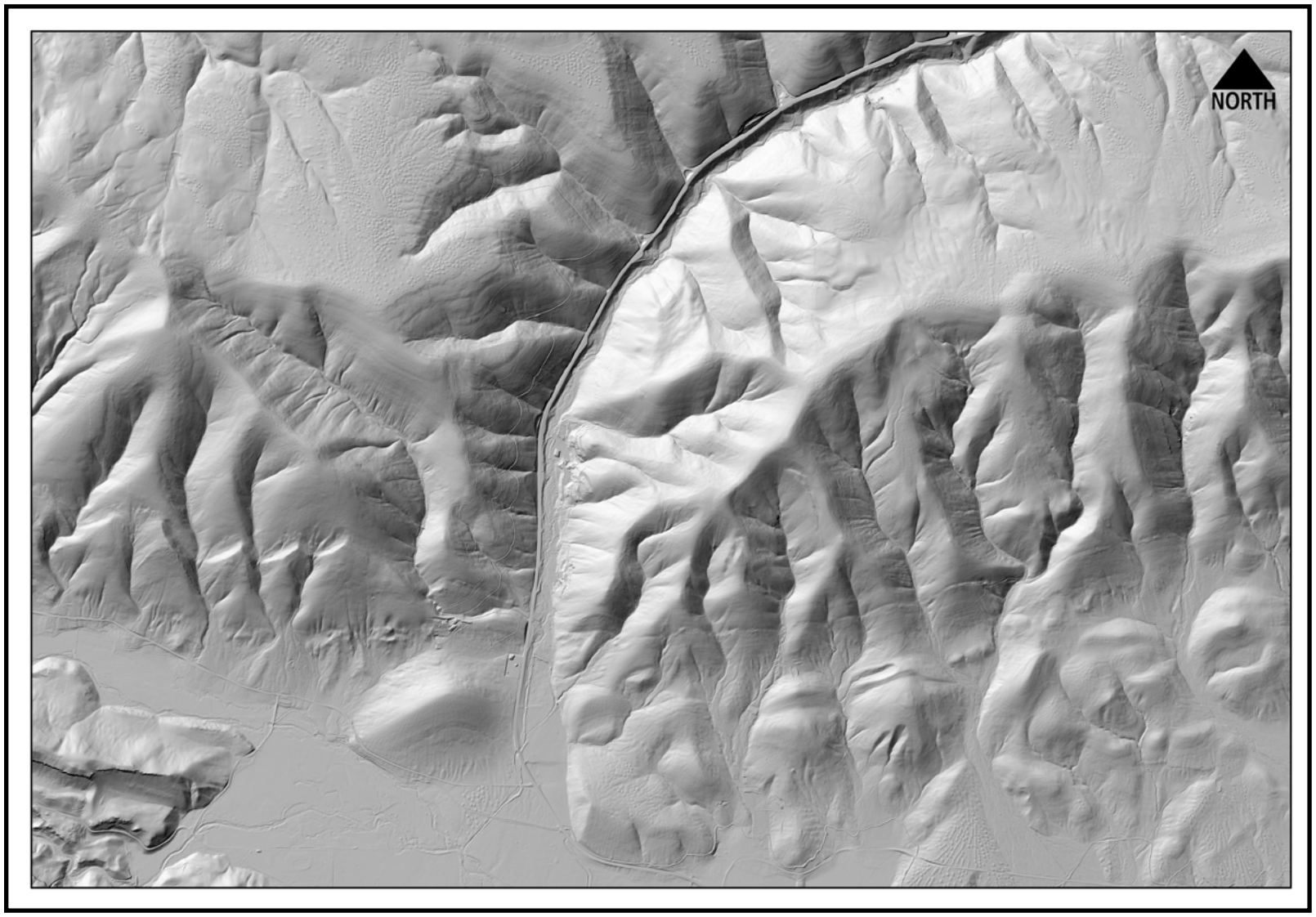
List of GPS monuments used in OLC Wasco County Survey Area. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

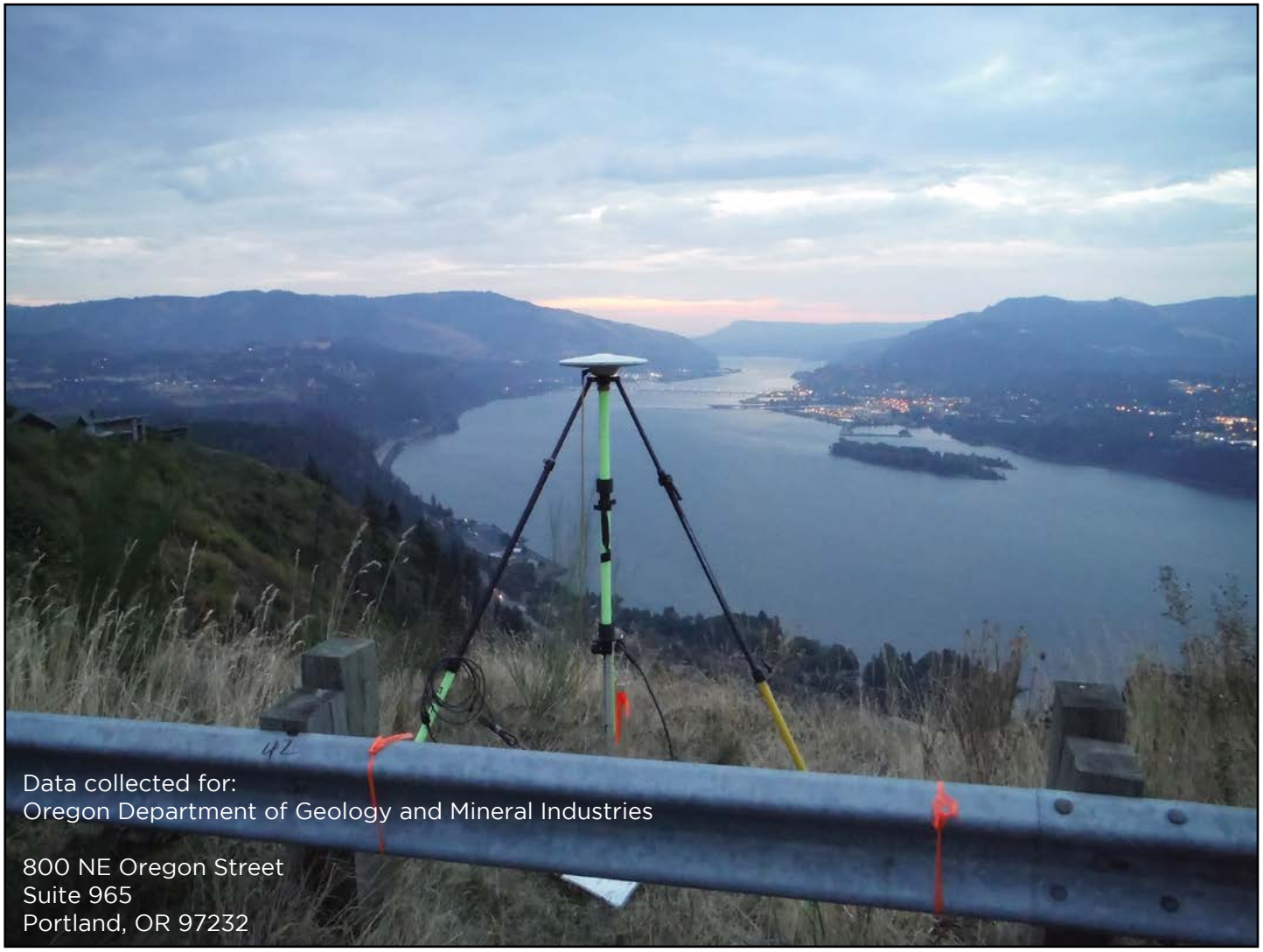
OLC Wasco County GPS Monuments				
PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
CISPUS_WSDOT	46° 26’ 36.97104”	-121° 52’ 43.74268”	351.067	371.315
RC1228	45° 06’ 49.69688”	-121° 19’ 19.81403”	624.578	646.030
RC2736	45° 37’ 04.04622”	-121° 10’ 30.56142	46.512	67.992
WASCO_01	45° 25’ 33.92221”	-121° 17’ 35.67224	694.143	715.201
WASCO_02	45° 24’ 00.14524”	-121° 15’ 38.58602	668.266	689.337
WASCO_03	45° 30’ 15.15952”	-121° 20’ 16.05414	706.121	727.237
WASCO_04	45° 31’ 35.06899”	-121° 17’ 17.45080	659.572	680.767
WASCO_05	45° 40’ 58.30068”	-121° 18’ 03.00268	194.683	216.110
WASCO_06	45° 39’ 58.42964”	-121° 20’ 07.36657	328.069	349.483
WASCO_07	45° 28’ 20.67253”	-121° 17’ 01.49189	652.762	673.887
WASCO_08	45° 37’ 33.53662”	-121° 21’ 18.77199	485.153	506.493
WASCO_09	45° 36’ 23.21905”	-121° 20’ 06.73995	618.486	639.790
WASCO_10	45° 29’ 26.20935”	-121° 05’ 18.01985	348.496	369.761
WASCO_11	45° 29’ 41.84872”	-121° 10’ 33.92138	352.139	373.376
WASCO_12	45° 29’ 00.75217”	-121° 00’ 25.75182	459.026	480.244
WASCO_13	45° 20’ 54.35426”	-121° 16’ 00.43344	731.185	752.266
WASCO_14	45° 33’ 50.86097”	-121° 21’ 51.83958	628.086	649.268
WASCO_15	45° 27’ 06.62583”	-120° 56’ 27.83190	839.259	860.374
WASCO_16	45° 19’ 51.53124”	-121° 07’ 39.82528	771.520	792.637
WASCO_17	45° 15’ 30.16588”	-121° 04’ 46.54399	366.298	387.695
WASCO_18	45° 17’ 18.80793”	-121° 10’ 52.79618	490.765	512.026
WASCO_19	45° 32’ 02.50205”	-121° 02’ 38.17485”	323.491	344.842
WASCO_20	45° 31’ 24.81814”	-121° 05’ 55.22316”	226.261	247.595
WASCO_21	45° 34’ 50.63889”	-120° 42’ 20.51709”	406.207	427.542

OLC Wasco County GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
WASCO_22	45° 36′ 32.32168”	-120° 43’ 27.27584”	322.623	343.983
WASCO_23	45° 39′ 25.35061”	-120° 50’ 31.98330”	195.187	216.568
WASCO_25	45° 40’ 26.60543”	-121° 06’ 03.21471”	340.241	361.552
WASCO_26	45° 43’ 42.64888”	-120° 58’ 06.01776”	457.564	478.694
WASCO_27	45° 11’ 11.42881”	-121° 10’ 36.88163”	516.322	537.783
WASCO_28	45° 13’ 21.18185”	-121° 16’ 41.26494”	529.382	550.863
WASCO_29	45° 17’ 13.71773”	-121° 43’ 43.89634”	1148.089	1168.979
WASCO_30	45° 15’ 09.56681”	-121° 45’ 06.60188”	1077.776	1098.738
WASCO_31	45° 11’ 41.00706”	-121° 41’ 34.26892”	1145.538	1166.520
WASCO_32	45° 13’ 23.06365”	-121° 33’ 08.21340”	1268.450	1289.391
WASCO_33	45° 08’ 01.07100”	-121° 37’ 24.78080”	1069.357	1090.435
WASCO_34	45° 16’ 27.80611”	-121° 29’ 24.41946”	1315.774	1336.621
WASCO_35	45° 37’ 57.72073”	-121° 58’ 13.51239”	-5.667	16.202
WASCO_36	45° 41’ 55.00914”	-121° 52’ 30.78102”	23.857	45.572
WASCO_37	45° 46′ 57.14196”	-121° 20’ 34.59729”	711.982	732.986
WASCO_38	45° 45′ 30.26559”	-121° 24’ 17.71854”	589.261	610.393
WASCO_39	45° 42′ 40.65511”	-121° 46′ 39.83483”	12.803	34.339
WASCO_40	45° 43’ 43.90661”	-121° 33’ 54.44150”	315.186	336.630
WASCO_42	45° 54’ 07.67264”	-121° 50’ 17.85716”	834.320	854.972
WASCO_43	45° 55’ 54.71561”	-121° 53’ 11.33665”	758.641	779.276
WASCO_44	45° 48’ 16.86853”	-121° 55’ 47.53866”	312.848	334.157
WASCO_45	45° 52’ 16.95001”	-122° 01’ 36.37869”	858.400	879.346
WASCO_46	45° 54’ 42.15120”	-122° 04’ 08.39043”	1230.996	1251.737
WASCO_47	46° 26’ 41.33207”	-121° 50’ 25.02618”	374.530	394.683
WASCO_49	45° 50’ 36.52992”	-122° 05’ 15.77825”	1028.699	1049.682

OLC Wasco County: Delivery Five





Left: Trimble R7 Receiver set up over GPS monument WASCO_40
Cover: bare earth raster image created from LiDAR point of Butter Canyon.

Data collected for:
Oregon Department of Geology and Mineral Industries

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Contents

Project Overview

WSI has completed the acquisition and processing of Light Detection and Ranging (LiDAR) data for the OLC Wasco County Delivery Area Five for the Oregon Department of Geology and Mineral Industries (DOGAMI). The Oregon LiDAR Consortium's Wasco County 2014 project area of interest (AOI) encompasses 1,020,680 acres. Delivery Area Five encompasses 184,798 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.

WSI LiDAR data acquisition for delivery areas one through five occurred from July 15, 2014 - February 11, 2015.

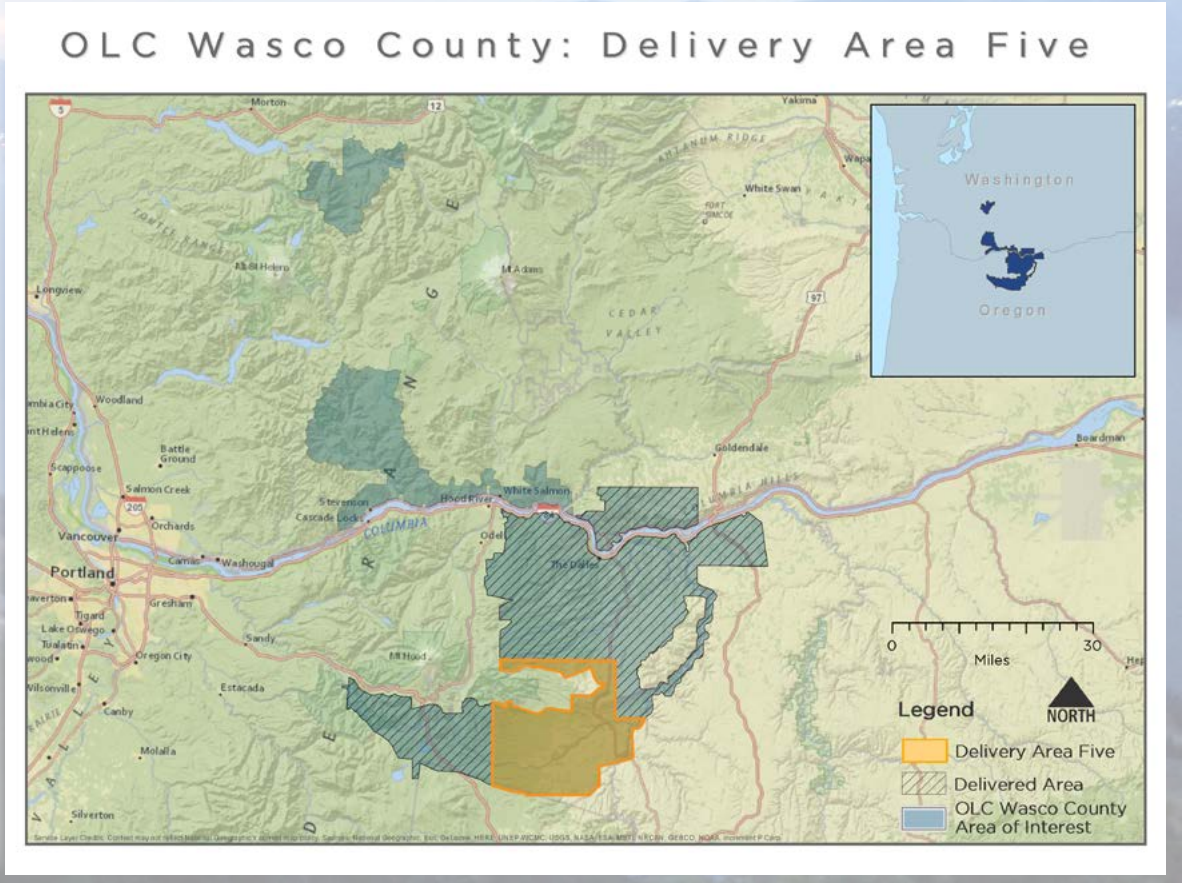
Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter.

Final products created that are included in Delivery Area Five are LiDAR point cloud data, three-foot resolution digital elevation models of bare earth ground models and highest-hit returns, 1.5-foot intensity rasters, three-foot ground density rasters, study area vector shapes, ground survey points and monuments, and corresponding statistical data.

WSI acquires and processes data in the most current, NGS-approved datums and geoid. For OLC Wasco County delivery area five, all final deliverables are projected in Oregon Statewide Lambert (OGIC), using the NAD83(2011) horizontal datum and the NAVD88 (Geoid 12A) vertical datum, with units in International Feet.

OLC Wasco County Delivery Five Data Delivered: April 24, 2015	
Acquisition Dates	7/30/2014 - 2/11/2015
Delivery Area Five Area of Interest	184,798 acres
Projection	OREGON STATEWIDE LAMBERT (OGIC)
Horizontal datum	NAD83 (2011) Epoch 2010.00
Vertical datum	NAVD88 (Geoid 12A)
Units	International Feet

Study Area



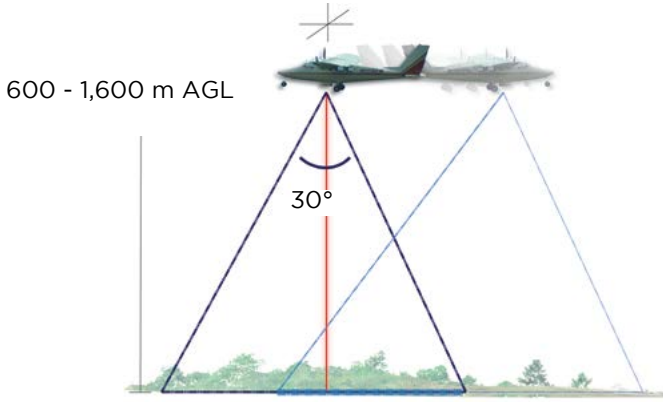
Aerial Acquisition

LiDAR Survey

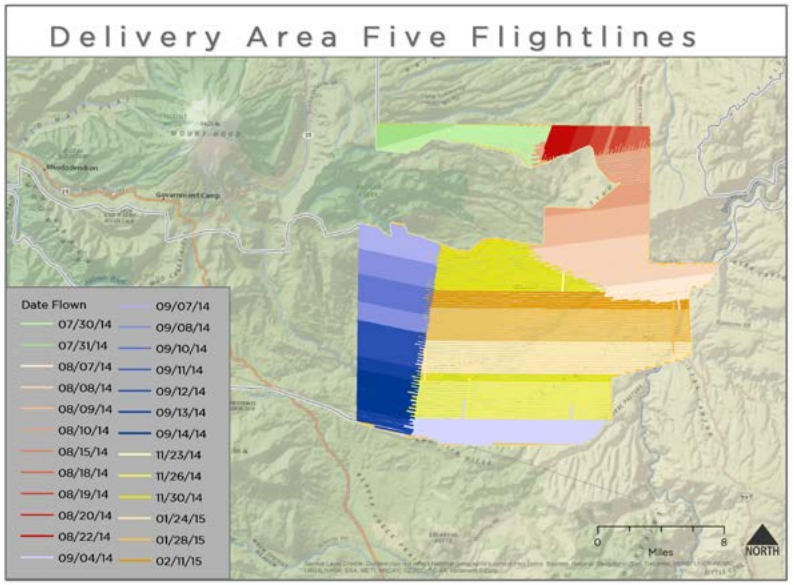
The LiDAR survey used a Leica ALS70 and an Optech Orion H sensor mounted in a Cessna U206G, Partenavia P.68, and Piper Navajo. The systems were programmed to emit single pulses at a rate of 219 kilohertz and flown between 600 and 1,600 meters above ground level (AGL), capturing a scan angle of +/-15 degrees from nadir (field of view equal to 30 degrees). 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 60 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 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 (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). As illustrated in the accompanying map, 653 full and partial flightlines provide coverage of the delivery area five study area.



Project Flightlines



OLC Wasco County LiDAR Acquisition Specifications	
Sensors Deployed	Leica ALS 70 and Optech Orion H
Aircraft	Cessna U206G, Piper Navajo, Partenavia P.68
Survey Altitude (AGL)	600 - 1,600 meters
Pulse Rate	219 kHz
Pulse Mode	Single (SPiA)
Field of View (FOV)	30°
Roll Compensated	Yes
Overlap	100% overlap with 60% sidelap
Pulse Emission Density	≥ 8 pulses per square meter

Ground Survey

Ground control surveys, including monumentation, aerial targets, and ground survey points (GSPs) were conducted to support the airborne acquisition. Ground control data are used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data products. See the table to the right for specifications of equipment used.

Instrumentation

All Global Navigation Satellite System (GNSS) static surveys utilized Trimble R7 GNSS receivers with Zephyr Geodetic Model 2 RoHS antennas and Trimble R8 GNSS receivers with internal antennas. Rover surveys for GSP collection were conducted with Trimble R6, Trimble R8, and Trimble R10 GNSS receivers.

Monumentation

Existing and newly established survey benchmarks serve as control points during LiDAR acquisition. Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. NGS benchmarks are preferred for control points; however, in the absence of NGS benchmarks, WSI produces our own monuments, and every effort is made to keep them within the public right of way or on public lands. If monuments are necessary on private property, consent from the owner is required. All monumentation is done with 5/8" x 30" rebar topped with a two-inch diameter aluminum cap stamped "Watershed Sciences, Inc. Control." The table at right provides the list of monuments used in Delivery Area Five. See Appendix B for a complete list of monuments placed within the OLC Wasco County 2014 Study Area.

Instrumentation

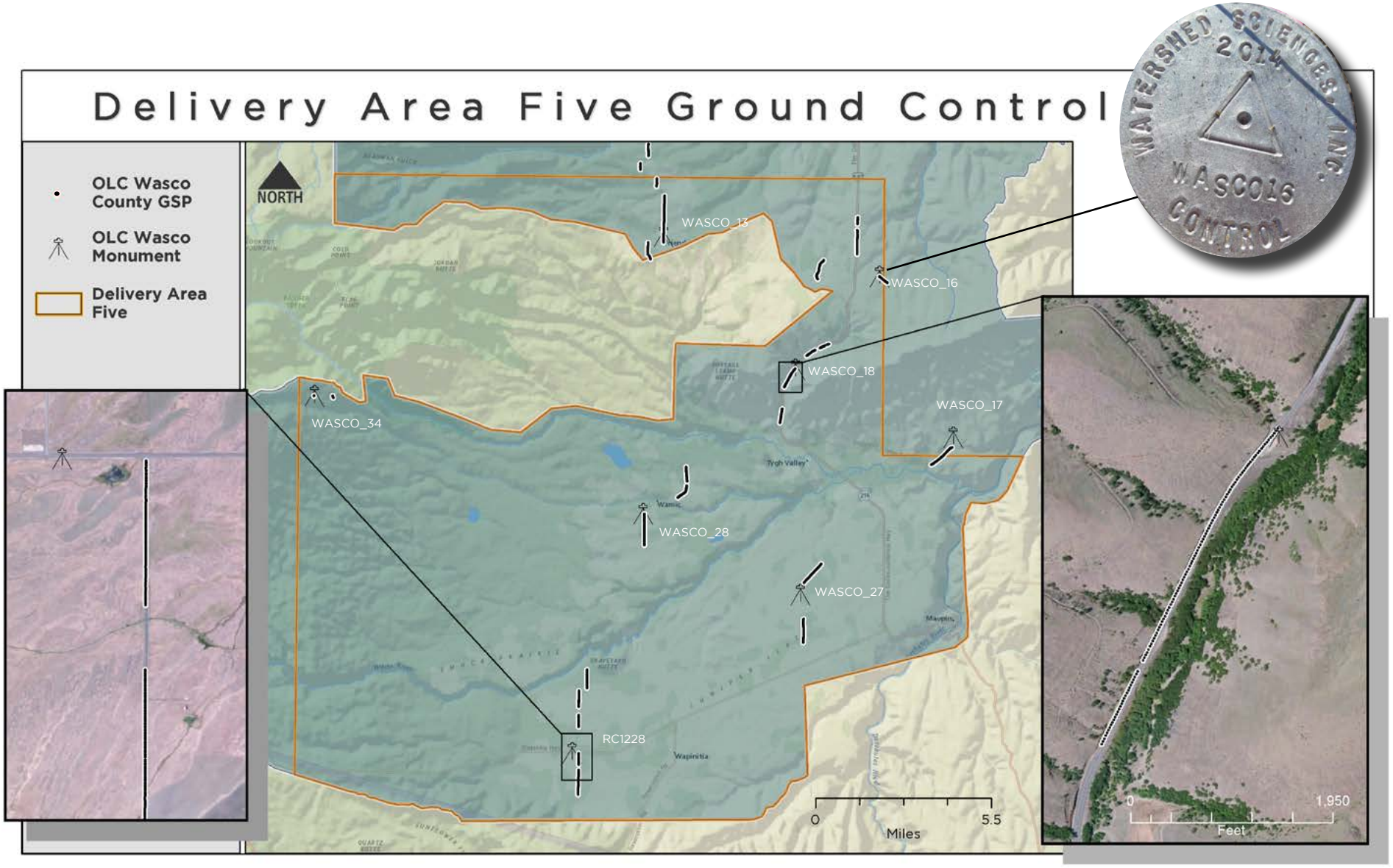
Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R6	Integrated Antenna R6	TRMR6	Rover
Trimble R7	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_GNSS	Static, Rover
Trimble R10	Integrated Antenna R10	TRMR10	Rover

Delivery Area Five GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	NAVD88 Height (m)
RC1228	45° 06' 49.69688"	-121° 19' 19.81403"	624.578	646.030
WASCO_13	45° 20' 54.35426"	-121° 16' 00.43344"	731.185	752.265
WASCO_16	45° 19' 51.53124"	-121° 07' 39.82528"	771.520	792.637
WASCO_17	45° 15 30.16588"	-121° 04' 46.54399"	366.298	387.695
WASCO_18	45° 17' 18.80793"	-121° 10' 52.79618"	490.765	512.026
WASCO_27	45° 11' 11.42881"	-121° 10' 36.88163"	516.322	537.783
WASCO_28	45° 13' 21.18185"	-121° 16' 41.26494"	529.382	550.863
WASCO_34	45° 16' 27.80611"	-121° 29' 24.41946"	1315.774	1336.621

Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

Trimble R7 set up over GPS monument Wasco_16.


Delivery Area Five Ground Control
OLC Wasco County GSP
OLC Wasco Monument
Delivery Area Five
NORTH
WASCO_13
WASCO_16
WASCO_18
WASCO_17
WASCO_34
WASCO_28
WASCO_27
RC1228
Tygh Valley
Wapinitia
0
5.5
Miles
WATERSHED SCIENCES, INC.
2014
WASCO16
CONTROL
0
1,950
Feet

Methodology

To correct the continuously recorded aircraft position, WSI concurrently conducts multiple static GNSS ground surveys over each monument. All control monuments are observed for a minimum of two survey sessions, each lasting no fewer than two hours. Data are collected at a rate of one hertz, using a 10 degree mask on the antenna. The static GPS data are then triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS) for precise positioning.

Ground Survey Points (GSPs) are collected using Real Time Kinematic (RTK), Post-Processed Kinematic (PPK), and Fast-Static (FS) survey techniques. For RTK surveys, a base receiver is positioned at a nearby monument to broadcast a kinematic correction to a roving receiver; for PPK and FS surveys, however, these corrections are post-processed. All GSP measurements are 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. Relative errors for the position must be less than 1.5 centimeters horizontal and 2.0 centimeters vertical in order to be accepted.

In order to facilitate comparisons with high quality LiDAR data, GSP measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. GSPs are taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. 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.

Monument Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	0.05 m Horiz
St Dev z	0.05 m Vert

WSI ground professional collecting ground survey points in OLC Wasco County study area.

Results

Accuracy Assessment

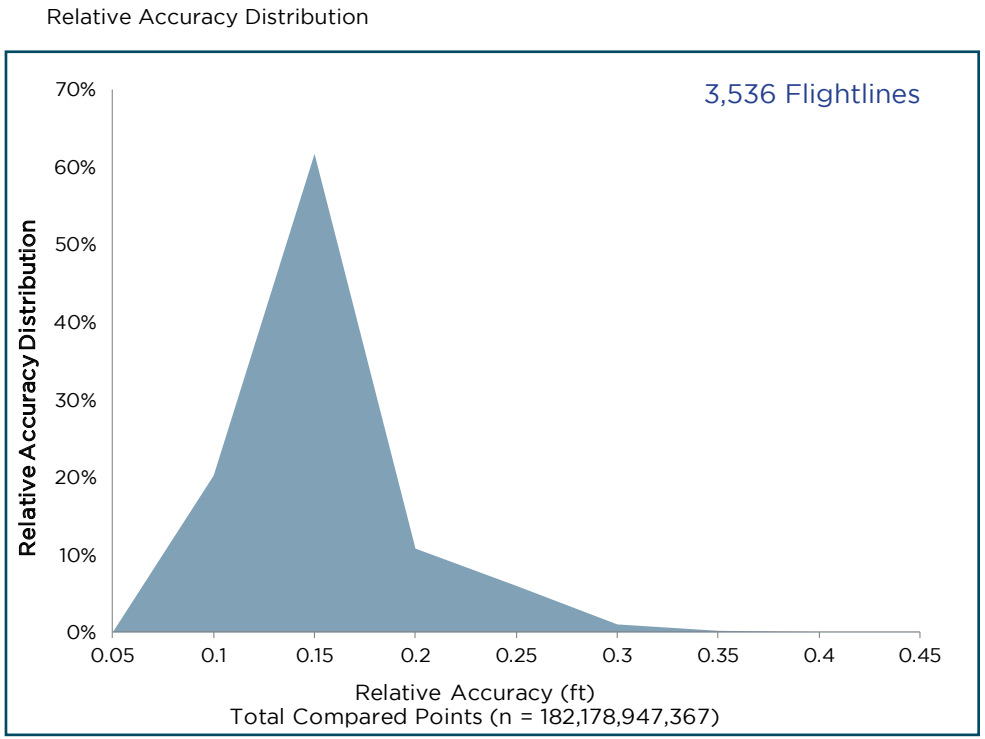
In some cases statistics were generated for larger areas than the extent represented by delivered areas. Accuracy statistics are a product of calibration and data QA/QC methodology that are spatially coincident with production workflow, which at times exceeds the areal extent of delivery workflow.

Relative Accuracy

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 centimeters). 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 3,536 full and partial flightlines. Relative accuracy is reported for the cumulative delivered portions of the study area.

Relative Accuracy Calibration Results N = 3,536 flightlines	
Project Average	0.13 ft. (0.04 m)
Median Relative Accuracy	0.12 ft. (0.04 m)
1σ Relative Accuracy	0.13 ft. (0.04 m)
2σ Relative Accuracy	0.22 ft. (0.07 m)



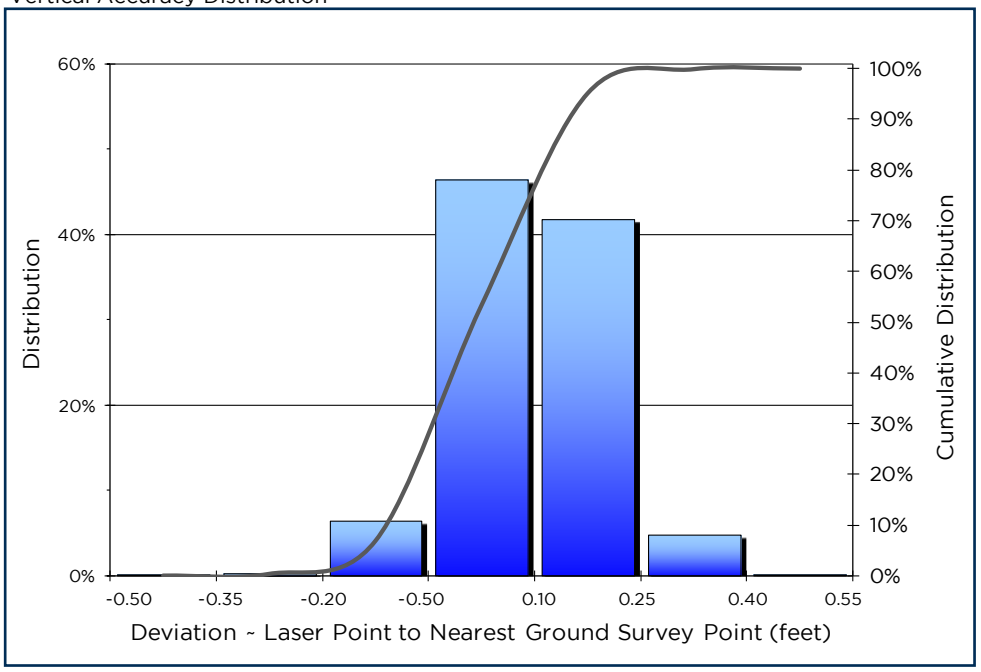
Vertical Accuracy

Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). The statistical model compares known ground survey points to the triangulated LiDAR surface. Vertical accuracy statistical analysis uses 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 Wasco County 2014 Study area, 1,287 GSPs were used to calibrate Delivery Area Five. Vertical Accuracy is reported for the entire delivered study area and reported in the table below.

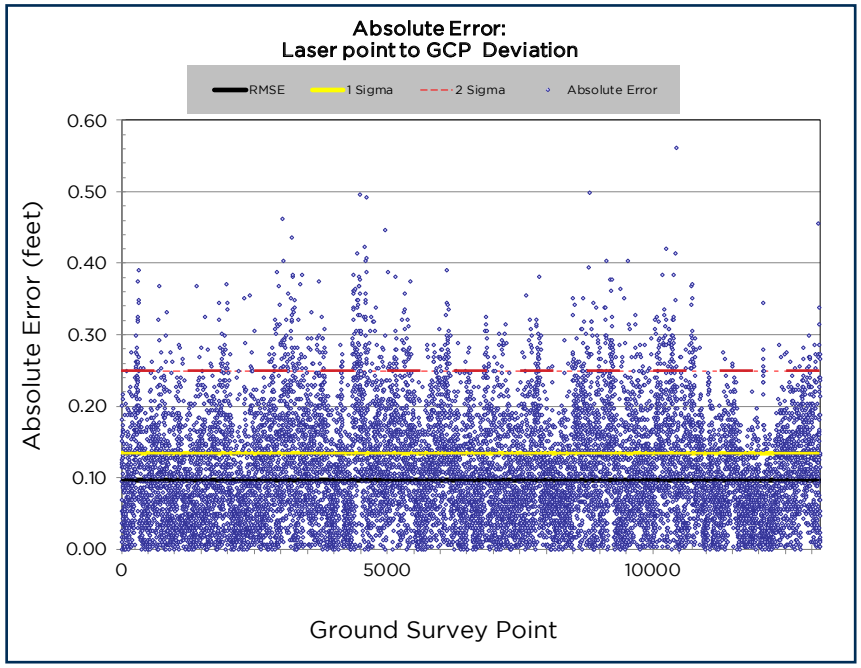
For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet."

Vertical Accuracy Results	
	Cumulative
Sample Size (n) (ground survey points)	13,161
Root Mean Square Error	0.10 ft. (0.03 m)
1 Standard Deviation	0.13 ft. (0.04 m)
2 Standard Deviation	0.25 ft. (0.08 m)
Average Deviation	0.09 ft. (0.03 m)
Minimum Deviation	-0.46 ft. (-0.14 m)
Maximum Deviation	0.56 ft. (0.17 m)

Vertical Accuracy Distribution



GSP Absolute Error

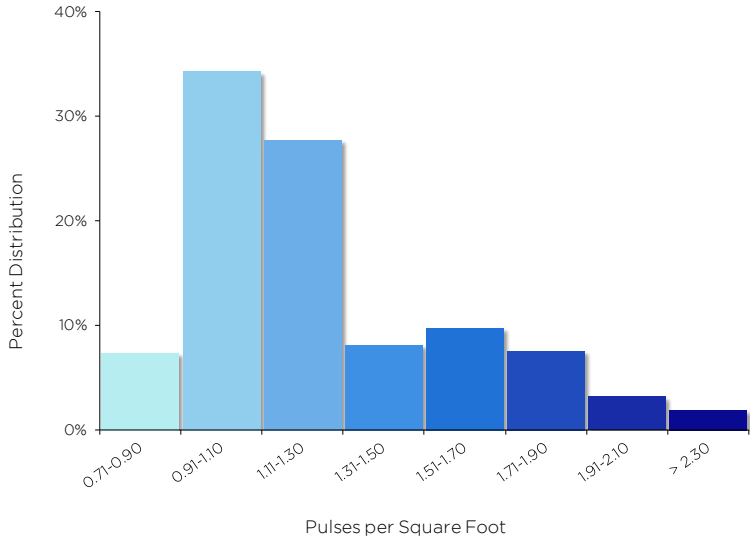


Density

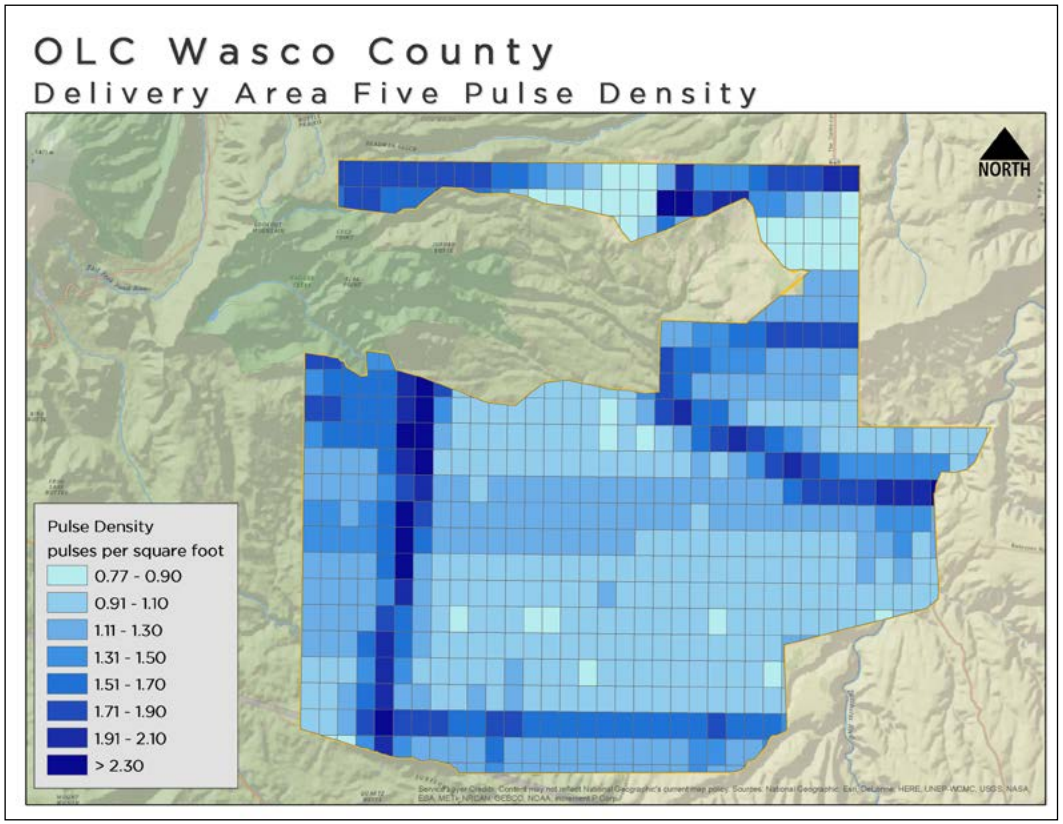
Pulse Density

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 and ground-classified laser point density. Densities are reported for the delivery area.

Average Pulse Density	pulses per square meter	pulses per square foot
	13.48	1.25



Average Pulse Density per 0.75' USGS Quad.

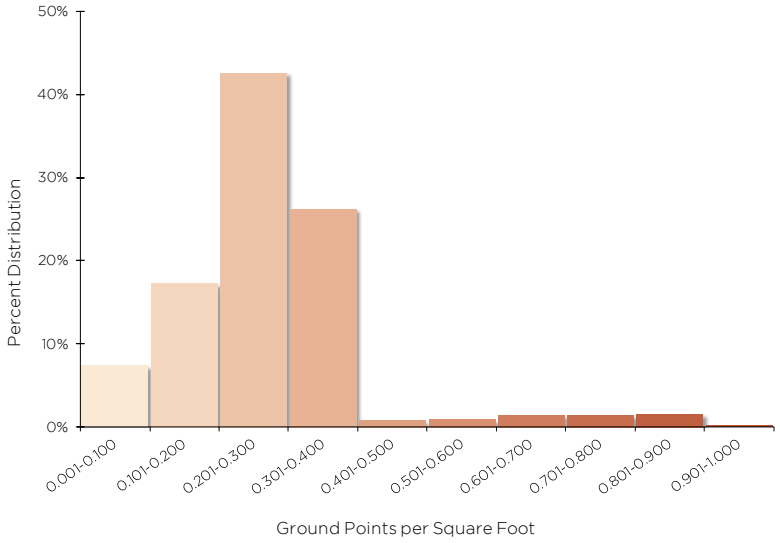


Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

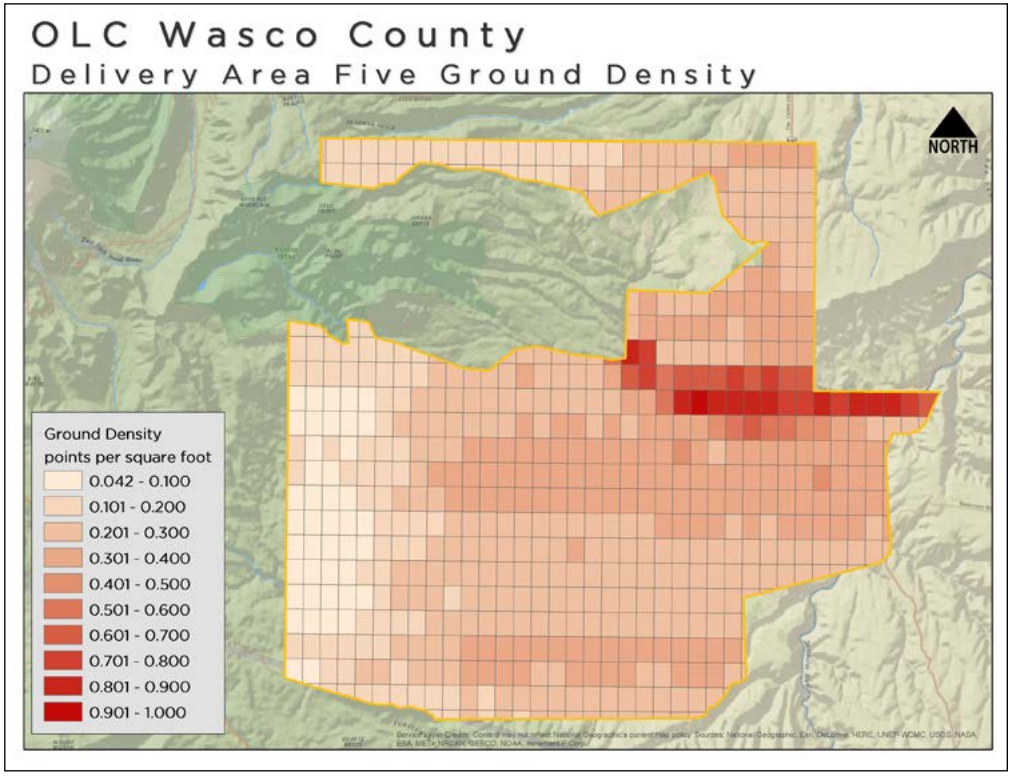
Ground Density

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 is a measure of ground-classified point data for the delivery area.

Ground Density	points per square meter	points per square foot
	2.98	0.28



Average ground 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

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Appendix A : PLS Certification

WSI provided LiDAR Services for OLC Wasco County Survey project, Delivery Five, as described in this report.

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

6/17/2015

John English
Project Manager
WSI, a Quantum Spatial Company

I, Christopher Glantz, being duly registered as a Professional Land Surveyor in the state of Oregon, say that I hereby certify the methodologies and results of the attached LiDAR project, and that Static GNSS occupations on the Base Stations during airborne flights and RTK survey on hard-surface and GSP's were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between July 30, 2014 and February 11, 2014. Accuracy statistics shown in the Accuracy Section of this Report have been review by me and found to meet the "National Standard for Spatial Data Accuracy".

6/17/2015

Christopher Glantz, PLS
Land Surveyor
WSI, a Quantum Spatial Company

Appendix B : GPS Monument Table

List of GPS monuments used in OLC Wasco County Survey Area. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

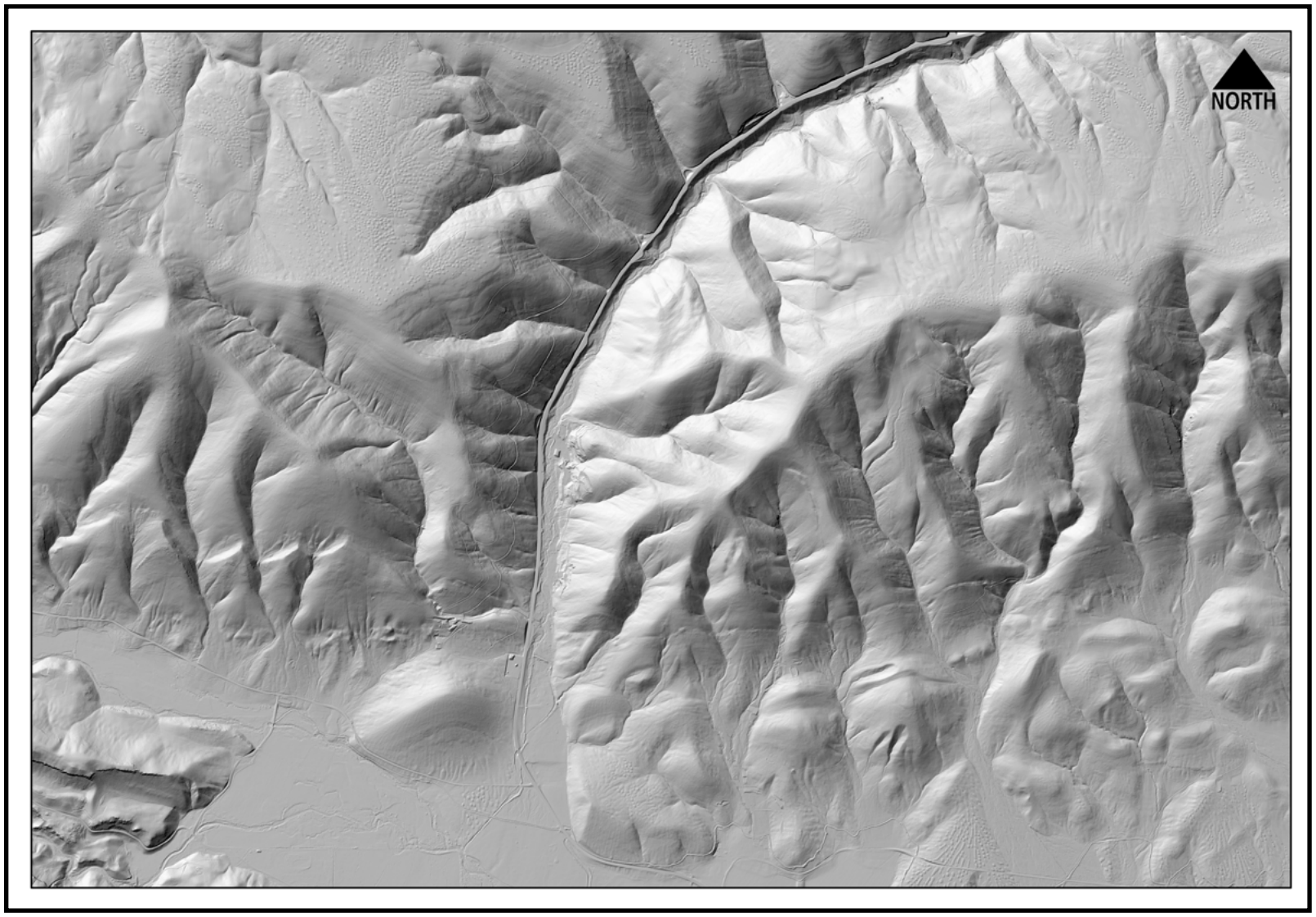
OLC Wasco County GPS Monuments

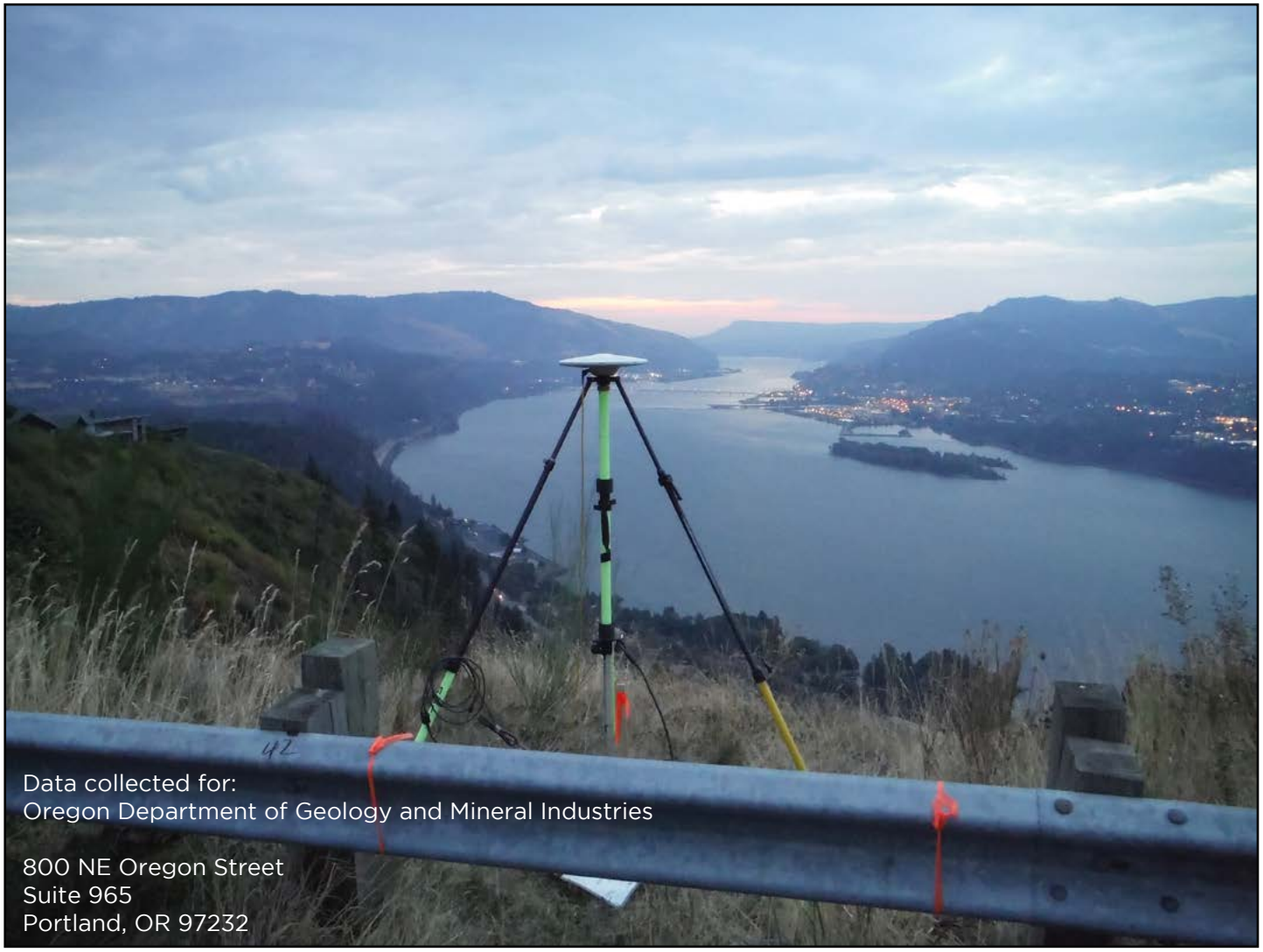
PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
CISPUS_WSDOT	46° 26’ 36.97104”	-121° 52’ 43.74268”	351.067	371.315
RC1228	45° 06’ 49.69688”	-121° 19’ 19.81403”	624.578	646.030
RC2736	45° 37’ 04.04622”	-121° 10’ 30.56142	46.512	67.992
WASCO_01	45° 25’ 33.92221”	-121° 17’ 35.67224	694.143	715.201
WASCO_02	45° 24’ 00.14524”	-121° 15’ 38.58602	668.266	689.337
WASCO_03	45° 30’ 15.15952”	-121° 20’ 16.05414	706.121	727.237
WASCO_04	45° 31’ 35.06899”	-121° 17’ 17.45080	659.572	680.767
WASCO_05	45° 40’ 58.30068”	-121° 18’ 03.00268	194.683	216.110
WASCO_06	45° 39’ 58.42964”	-121° 20’ 07.36657	328.069	349.483
WASCO_07	45° 28’ 20.67253”	-121° 17’ 01.49189	652.762	673.887
WASCO_08	45° 37’ 33.53662”	-121° 21’ 18.77199	485.153	506.493
WASCO_09	45° 36’ 23.21905”	-121° 20’ 06.73995	618.486	639.790
WASCO_10	45° 29’ 26.20935”	-121° 05’ 18.01985	348.496	369.761
WASCO_11	45° 29’ 41.84872”	-121° 10’ 33.92138	352.139	373.376
WASCO_12	45° 29’ 00.75217”	-121° 00’ 25.75182	459.026	480.244
WASCO_13	45° 20’ 54.35426”	-121° 16’ 00.43344	731.185	752.266
WASCO_14	45° 33’ 50.86097”	-121° 21’ 51.83958	628.086	649.268
WASCO_15	45° 27’ 06.62583”	-120° 56’ 27.83190	839.259	860.374
WASCO_16	45° 19’ 51.53124”	-121° 07’ 39.82528	771.520	792.637
WASCO_17	45° 15’ 30.16588”	-121° 04’ 46.54399	366.298	387.695
WASCO_18	45° 17’ 18.80793”	-121° 10’ 52.79618	490.765	512.026
WASCO_19	45° 32’ 02.50205”	-121° 02’ 38.17485”	323.491	344.842
WASCO_20	45° 31’ 24.81814”	-121° 05’ 55.22316”	226.261	247.595
WASCO_21	45° 34’ 50.63889”	-120° 42’ 20.51709”	406.207	427.542
WASCO_22	45° 36’ 32.32168”	-120° 43’ 27.27584”	322.623	343.983
WASCO_23	45° 39’ 25.35061”	-120° 50’ 31.98330”	195.187	216.568

OLC Wasco County GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
WASCO_25	45° 40’ 26.60543”	-121° 06’ 03.21471”	340.241	361.552
WASCO_26	45° 43’ 42.64888”	-120° 58’ 06.01776”	457.564	478.694
WASCO_27	45° 11’ 11.42881”	-121° 10’ 36.88163”	516.322	537.783
WASCO_28	45° 13’ 21.18185”	-121° 16’ 41.26494”	529.382	550.863
WASCO_29	45° 17’ 13.71773”	-121° 43’ 43.89634”	1148.089	1168.979
WASCO_30	45° 15’ 09.56681”	-121° 45’ 06.60188”	1077.776	1098.738
WASCO_31	45° 11’ 41.00706”	-121° 41’ 34.26892”	1145.538	1166.520
WASCO_32	45° 13’ 23.06365”	-121° 33’ 08.21340”	1268.450	1289.391
WASCO_33	45° 08’ 01.07100”	-121° 37’ 24.78080”	1069.357	1090.435
WASCO_34	45° 16’ 27.80611”	-121° 29’ 24.41946”	1315.774	1336.621
WASCO_35	45° 37’ 57.72073”	-121° 58’ 13.51239”	-5.667	16.202
WASCO_36	45° 41’ 55.00914”	-121° 52’ 30.78102”	23.857	45.572
WASCO_37	45° 46’ 57.14196”	-121° 20’ 34.59729”	711.982	732.986
WASCO_38	45° 45’ 30.26559”	-121° 24’ 17.71854”	589.261	610.393
WASCO_39	45° 42’ 40.65511”	-121° 46’ 39.83483”	12.803	34.339
WASCO_40	45° 43’ 43.90661”	-121° 33’ 54.44150”	315.186	336.630
WASCO_42	45° 54’ 07.67264”	-121° 50’ 17.85716”	834.320	854.972
WASCO_43	45° 55’ 54.71561”	-121° 53’ 11.33665”	758.641	779.276
WASCO_44	45° 48’ 16.86853”	-121° 55’ 47.53866”	312.848	334.157
WASCO_45	45° 52’ 16.95001”	-122° 01’ 36.37869”	858.400	879.346
WASCO_46	45° 54’ 42.15120”	-122° 04’ 08.39043”	1230.996	1251.737
WASCO_47	46° 26’ 41.33207”	-121° 50’ 25.02618”	374.530	394.683
WASCO_49	45° 50’ 36.52992”	-122° 05’ 15.77825”	1028.699	1049.682
WASCO_50	46° 31’ 29.10701”	-121° 57’ 18.86098”	251.394	271.883
WASCO_51	46° 26’ 26.26180”	-121° 59’ 53.98877”	304.189	324.596
WASCO_52	46° 21’ 37.68176”	-122° 00’ 20.12964”	1269.233	1289.292
WASCO_53	46° 19’ 30.68852”	-121° 58’ 30.50980”	852.127	872.153

OLC Wasco County: Delivery Six





Left: Trimble R7 Receiver set up over GPS monument WASCO_40
Cover: bare earth raster image created from LiDAR point of Butter Canyon.

Data collected for:
Oregon Department of Geology and Mineral Industries

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Contents

Project Overview

WSI has completed the acquisition and processing of Light Detection and Ranging (LiDAR) data for the OLC Wasco County Delivery Area Six for the Oregon Department of Geology and Mineral Industries (DOGAMI). The Oregon LiDAR Consortium's Wasco County 2014-2015 project area of interest (AOI) encompasses 1,020,680 acres. Delivery Area Six encompasses 317,371 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 for delivery areas one through six occurred from July 15, 2014 - August 5, 2015.

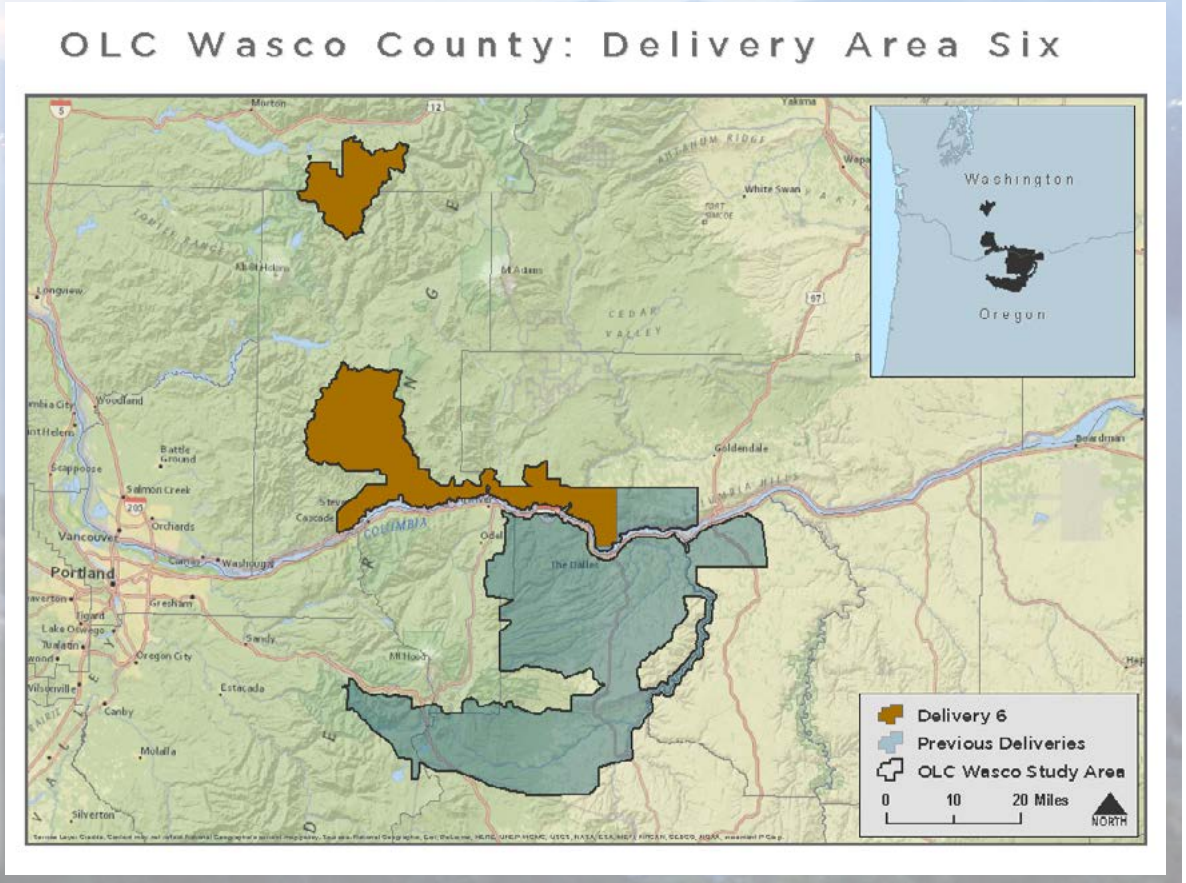
Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter.

Final products created that are included in Delivery Area Five are LiDAR point cloud data, three-foot resolution digital elevation models of bare earth ground models and highest-hit returns, 1.5-foot intensity rasters, three-foot ground density rasters, study area vector shapes, ground survey points and monuments, and corresponding statistical data.

WSI acquires and processes data in the most current, NGS-approved datums and geoid. For OLC Wasco County delivery area six, all final deliverables are projected in Washington State Plane South, using the NAD83(2011) horizontal datum and the NAVD88 (Geoid 12A) vertical datum, with units in US Survey Feet.

OLC Wasco County Delivery Six Data Delivered: December 18, 2015	
Acquisition Dates	8/27/2014 - 8/5/2015
Delivery Area Six Data Extent	317,371 acres
Projection	Washington State Plane South
Horizontal datum	NAD83 (2011) Epoch 2010.00
Vertical datum	NAVD88 (Geoid 12A)
Units	US Survey Feet

Study Area



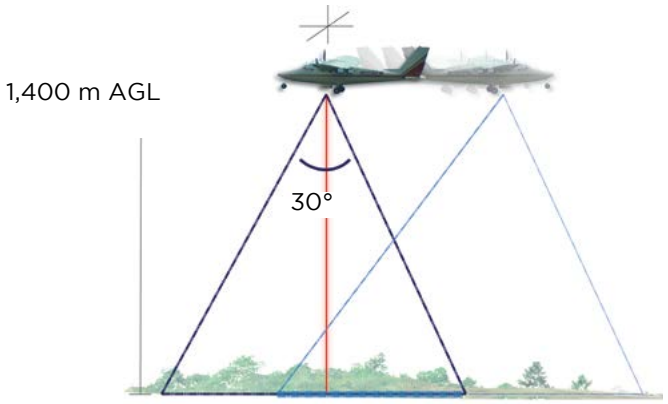
Aerial Acquisition

LiDAR Survey

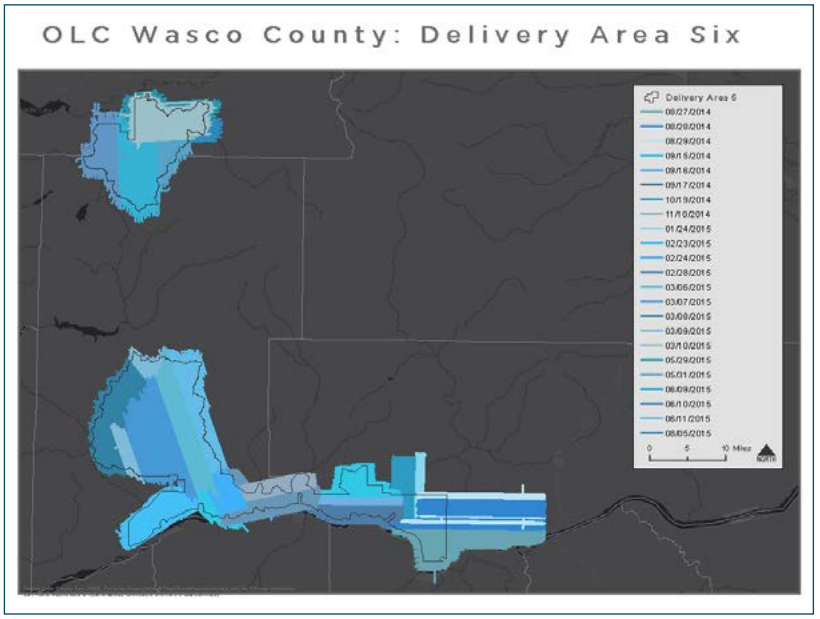
The LiDAR survey used a Leica ALS70 sensor mounted in a Cessna Grand Caravan. The system was programmed to emit single pulses at a rate of 198 kilohertz and flown around 1,400 meters above ground level (AGL), capturing a scan angle of +/-15 degrees from nadir (field of view equal to 30 degrees). These 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 60 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 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 (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). As illustrated in the accompanying map, 809 full and partial flightlines provide coverage of the delivery area six study area.



Project Flightlines



OLC Wasco County LiDAR Acquisition Specifications	
Sensors Deployed	Leica ALS 70
Aircraft	Cessna Grand Caravan
Survey Altitude (AGL)	1,400 meters
Pulse Rate	198 kHz
Pulse Mode	Single (SPiA)
Field of View (FOV)	30°
Roll Compensated	Yes
Overlap	100% overlap with 60% sidelap
Pulse Emission Density	≥ 8 pulses per square meter

Ground Survey

Ground control surveys, including monumentation, aerial targets, and ground survey points (GSPs) were conducted to support the airborne acquisition. Ground control data are used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data products. See the table to the right for specifications of equipment used.

Instrumentation

All Global Navigation Satellite System (GNSS) static surveys utilized Trimble R7 GNSS receivers with Zephyr Geodetic Model 2 RoHS antennas and Trimble R8 GNSS receivers with internal antennas. Rover surveys for GSP collection were conducted with Trimble R6, Trimble R8, and Trimble R10 GNSS receivers.

Monumentation

Ground control surveys, including monumentation, and ground survey points (GSPs), were conducted to support the airborne acquisition. Ground control data were used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data.

The spatial configuration of ground survey monuments provided redundant control within 13 nautical miles of the mission areas for LiDAR flights. Monuments were also used for collection of ground survey points using real time kinematic (RTK).

Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. QSI established two new monuments for the PGE Tucannon Wind Farm LiDAR project (Table on Page 6). New monumentation was set using 5/8" x 30" rebar topped with stamped 2-1/2" aluminum caps. QSI's professional land surveyor, Christopher Glantz (WA PLS #48755) oversaw and certified the establishment of all monuments.

To correct the continuously recorded onboard measurements of the aircraft position, QSI concurrently conducted multiple static Global Navigation Satellite System (GNSS) ground surveys (1 Hz recording frequency) over each monument. During post-processing, the static GPS data were triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

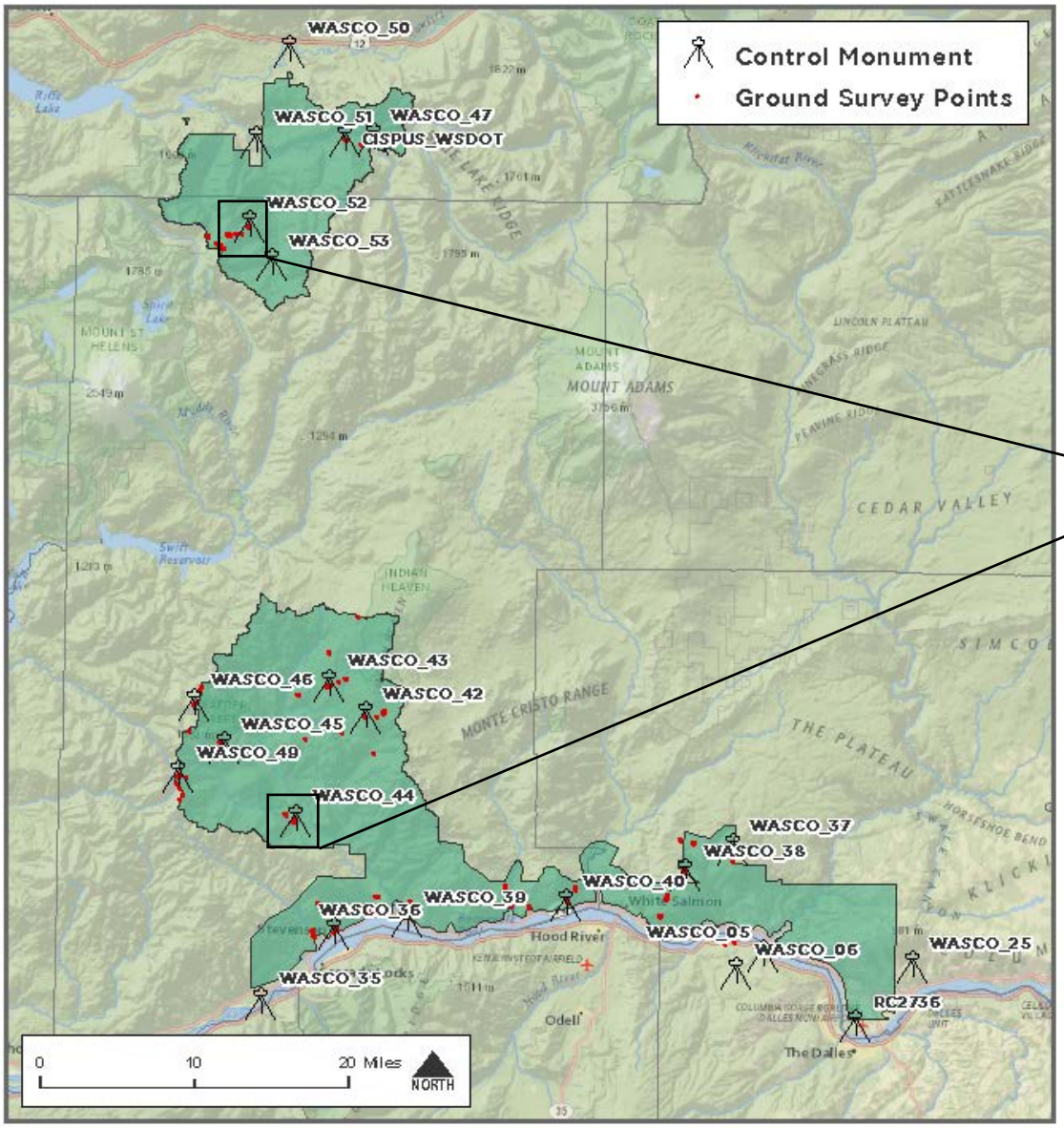
The table at right provides the list of monuments used in Delivery Area Six. See Appendix B for a complete list of monuments placed within the OLC Wasco County 2014-2015 Study Area.

Instrumentation			
Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R6	Integrated Antenna R6	TRMR6	Rover
Trimble R7	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_GNSS	Static, Rover
Trimble R10	Integrated Antenna R10	TRMR10	Rover

PID	Latitude	Longitude	Ellipsoid Height (m)	NAVD88 Height (m)
CISPUS_ WSDOT	46° 26' 36.97104"	-121° 52' 43.74268"	351.067	371.315
RC1228	45° 06' 49.69688"	-121° 19' 19.81403"	624.578	646.030
RC2736	45° 37' 04.04622"	-121° 10' 30.56142"	46.512	67.992
WASCO_05	45° 40' 58.30068"	-121° 18' 03.00268"	194.683	216.110
WASCO_06	45° 39' 58.42964"	-121° 20' 07.36657"	328.069	349.483
WASCO_25	45° 40' 26.60543"	-121° 06' 03.21471"	340.241	361.552
WASCO_35	45° 37' 57.72073"	-121° 58' 13.51239"	-5.667	16.202
WASCO_36	45° 41' 55.00914"	-121° 52' 30.78102"	23.857	45.572
WASCO_37	45° 46' 57.14196"	-121° 20' 34.59729"	711.982	732.986
WASCO_38	45° 45' 30.26559"	-121° 24' 17.71854"	589.261	610.393
WASCO_39	45° 42' 40.65511"	-121° 46' 39.83483"	12.803	34.339
WASCO_40	45° 43' 43.90661"	-121° 33' 54.44150"	315.186	336.630
WASCO_42	45° 54' 07.67264"	-121° 50' 17.85716"	834.320	854.972
WASCO_43	45° 55' 54.71561"	-121° 53' 11.33665"	758.641	779.276
WASCO_44	45° 48' 16.86853"	-121° 55' 47.53866"	312.848	334.157
WASCO_45	45° 52' 16.95001"	-122° 01' 36.37869"	858.400	879.346
WASCO_46	45° 54' 42.15120"	-122° 04' 08.39043"	1230.996	1251.737
WASCO_47	46° 26' 41.33207"	-121° 50' 25.02618"	374.530	394.683
WASCO_49	45° 50' 36.52992"	-122° 05' 15.77825"	1028.699	1049.682
WASCO_50	46° 31' 29.10701"	-121° 57' 18.86098"	251.394	271.883
WASCO_51	46° 26' 26.26180"	-121° 59' 53.98877"	304.189	324.596
WASCO_52	46° 21' 37.68176"	-122° 00' 20.12964"	1269.233	1289.292
WASCO_53	46° 19' 30.68852"	-121° 58' 30.50980"	852.127	872.153

Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

OLC Wasco County: Delivery Area Six Ground Control



Methodology

Ground survey points (GSPs) are collected using Real Time Kinematic (RTK) and Post Processed Kinematic (PPK) survey techniques. For RTK surveys, a Trimble R7 base unit was set up over an appropriate monument to broadcast a real-time correction to a roving R6 unit. This RTK rover survey allows for precise location measurement (2.0 centimeter). All RTK measurements were made during periods with a Position Dilution of Precision (PDOP) of less than 3.0 and in view of at least six satellites by the stationary reference and roving receiver. For RTK data, the collector recorded at least a five-second stationary observation, and then calculated the pseudorange position from three one-second epochs with relative error less than 1.5 centimeter horizontal and 2.0 centimeter vertical.

GSP positions were collected on bare earth locations such as paved, gravel or stable dirt roads, and other locations where the ground was clearly visible (and was likely to remain visible) from the sky during the data acquisition and GSP measurement periods. In order to facilitate comparisons with LiDAR data, GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads. The planned locations for control points were determined prior to field deployment, and the suitability of these locations was verified on site. The distribution of ground survey points depended on ground access constraints, and may not be equitably distributed throughout the study area.

Monument Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	0.05 m Horiz
St Dev z	0.05 m Vert

WSI ground professional collecting ground survey points in OLC Wasco County study area.

Results

Accuracy Assessment

In some cases statistics were generated for larger areas than the extent represented by delivered areas. Accuracy statistics are a product of calibration and data QA/QC methodology that are spatially coincident with production workflow, which at times exceeds the areal extent of delivery workflow.

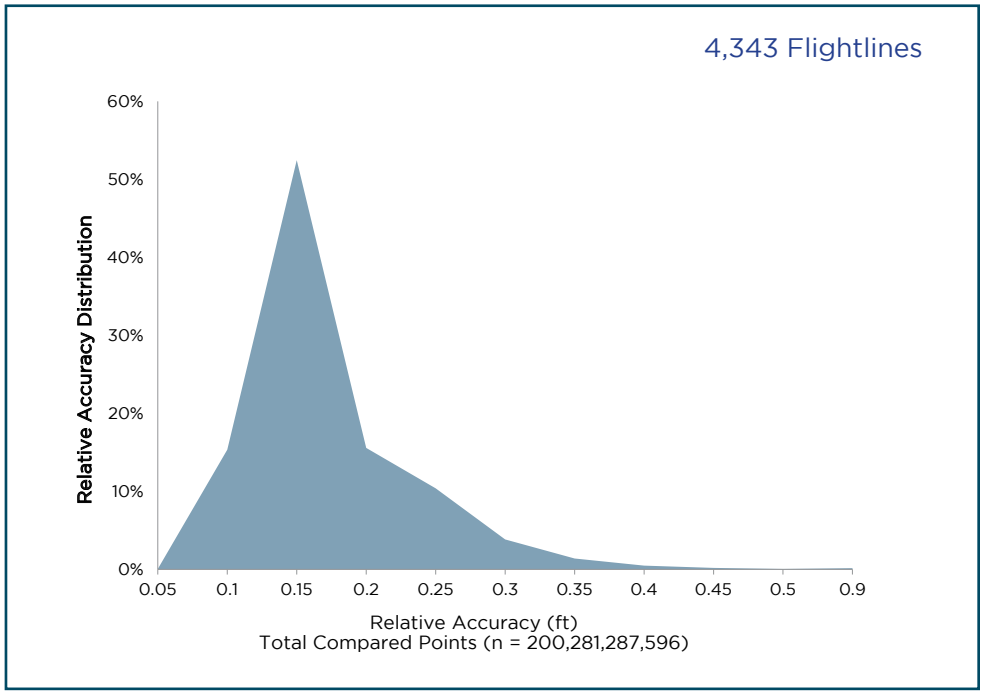
Relative Accuracy

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 centimeters). 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 4,343 full and partial flightlines. Relative accuracy is reported for the cumulative delivered portions of the study area.

Relative Accuracy Calibration Results N = 4,343 flightlines	
Project Average	0.148 ft. (0.045 m)
Median Relative Accuracy	0.129 ft. (0.039 m)
1σ Relative Accuracy	0.148 ft. (0.045 m)
2σ Relative Accuracy	0.259 ft. (0.079 m)

Relative Accuracy Distribution



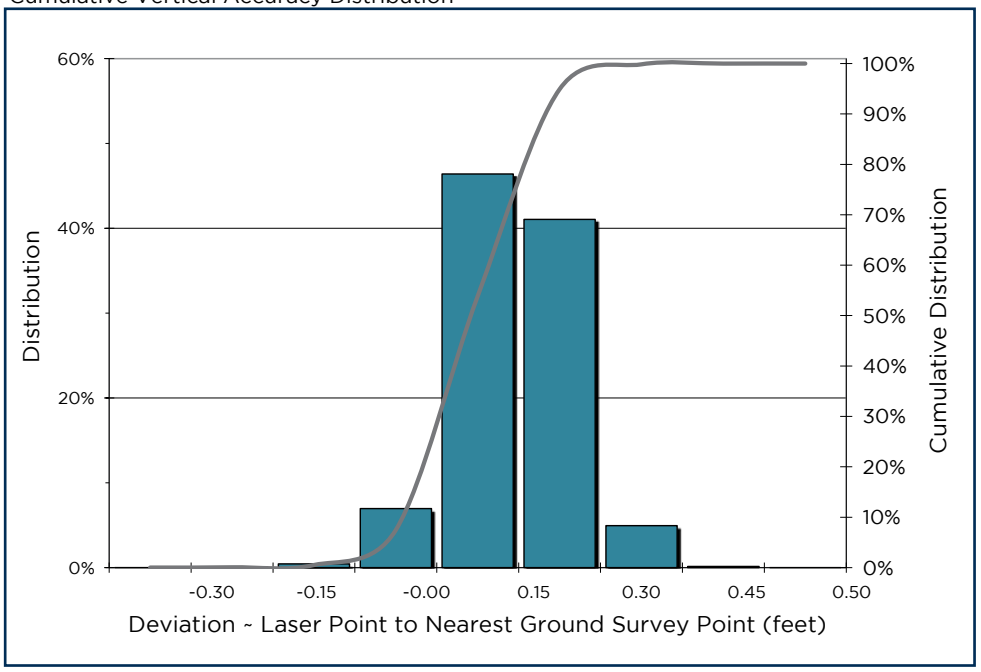
Vertical Accuracy

Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). The statistical model compares known ground survey points to the triangulated LiDAR surface. Vertical accuracy statistical analysis uses 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 Wasco County 2014-2015 Study area, 2,269 GSPs were used to calibrate Delivery Area Six. Vertical Accuracy is reported for the entire delivered study area and reported in the table below.

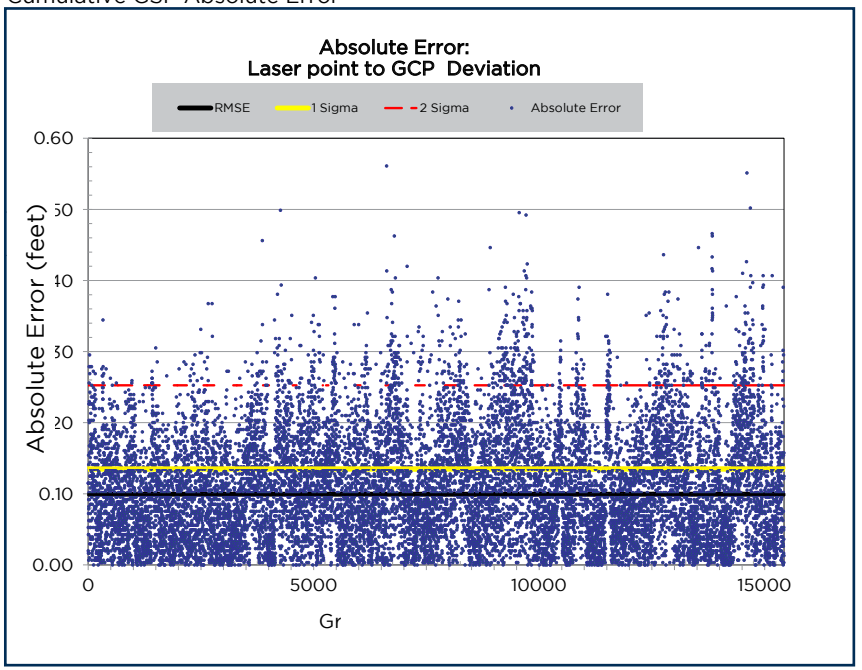
For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet."

Vertical Accuracy Results		
	Delivery 6	Cumulative
Sample Size (n) (ground survey points)	2,269	15,430
Root Mean Square Error	0.115 ft. (0.035 m)	0.099 ft. (0.030 m)
1 Standard Deviation	0.138 ft. (0.042 m)	0.135 ft. (0.041 m)
2 Standard Deviation	0.269 ft. (0.082 m)	0.253 ft. (0.077 m)
Average Deviation	0.111 ft. (0.034 m)	0.110 ft. (0.033 m)
Minimum Deviation	-0.551 ft. (-0.168 m)	-0.551 ft. (-0.168 m)
Maximum Deviation	0.466 ft. (0.142 m)	0.561 ft. (0.171 m)

Cumulative Vertical Accuracy Distribution



Cumulative GSP Absolute Error

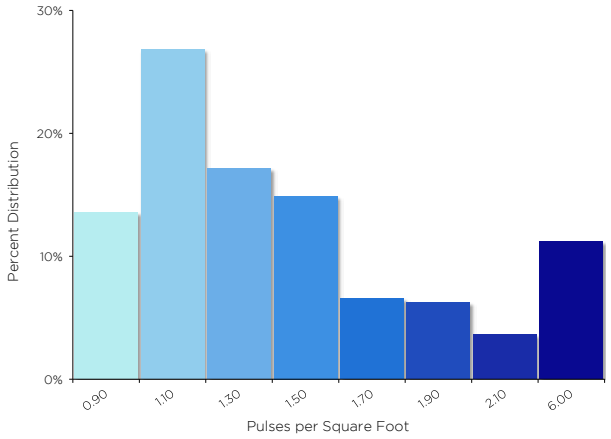


Density

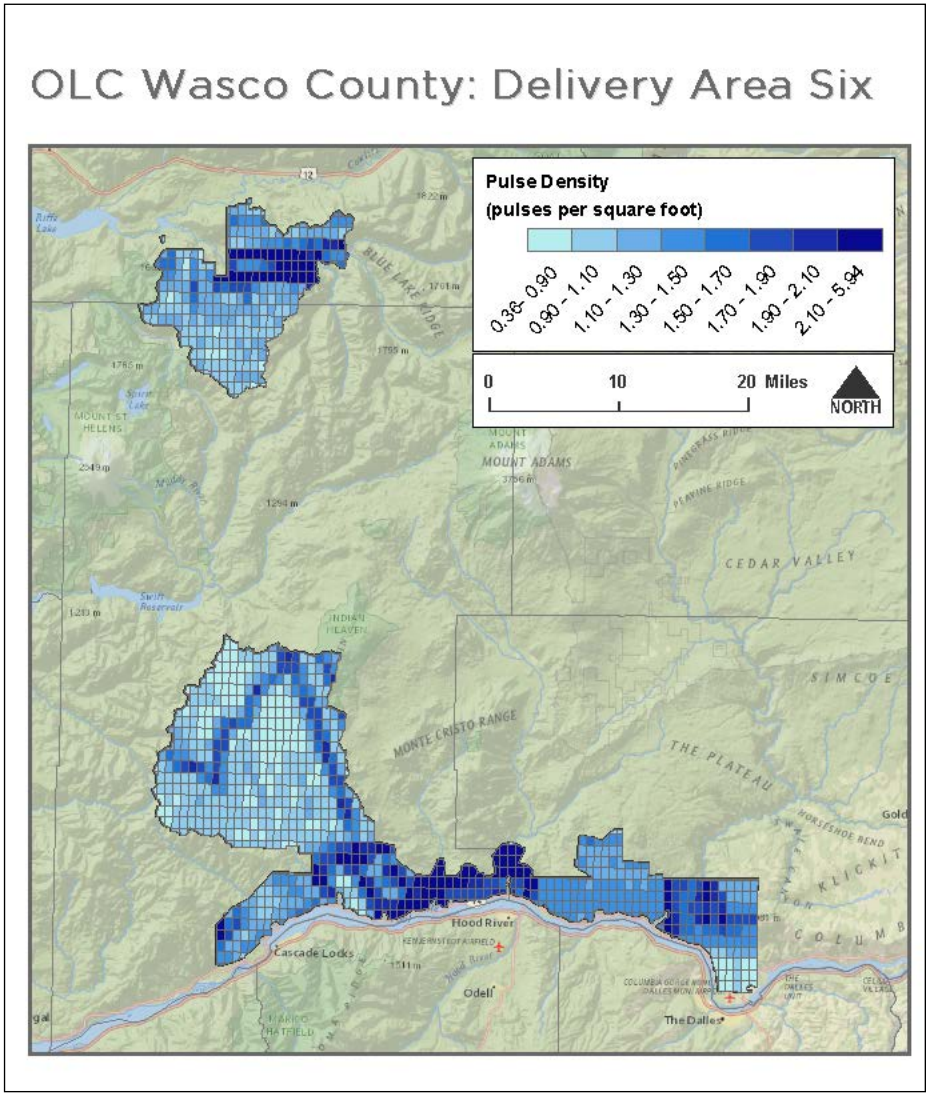
Pulse Density

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 and ground-classified laser point density. Densities are reported for the delivery area.

	pulses per square meter	pulses per square foot
Delivery 6 Pulse Density	14.83	1.38
Cumulative Pulse Density	14.54	1.35



Average Pulse Density per 0.75' USGS Quad.



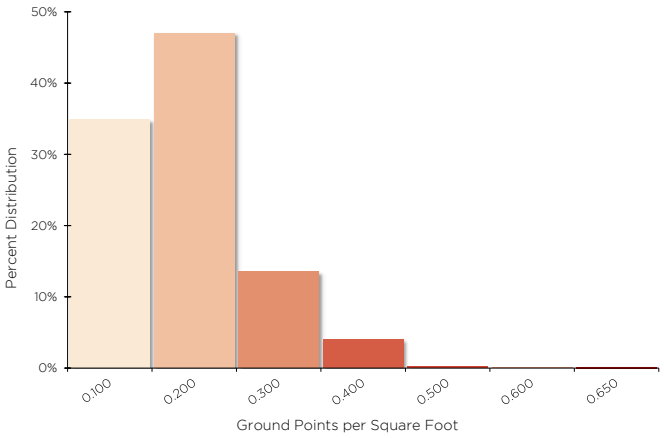
Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

Ground Density

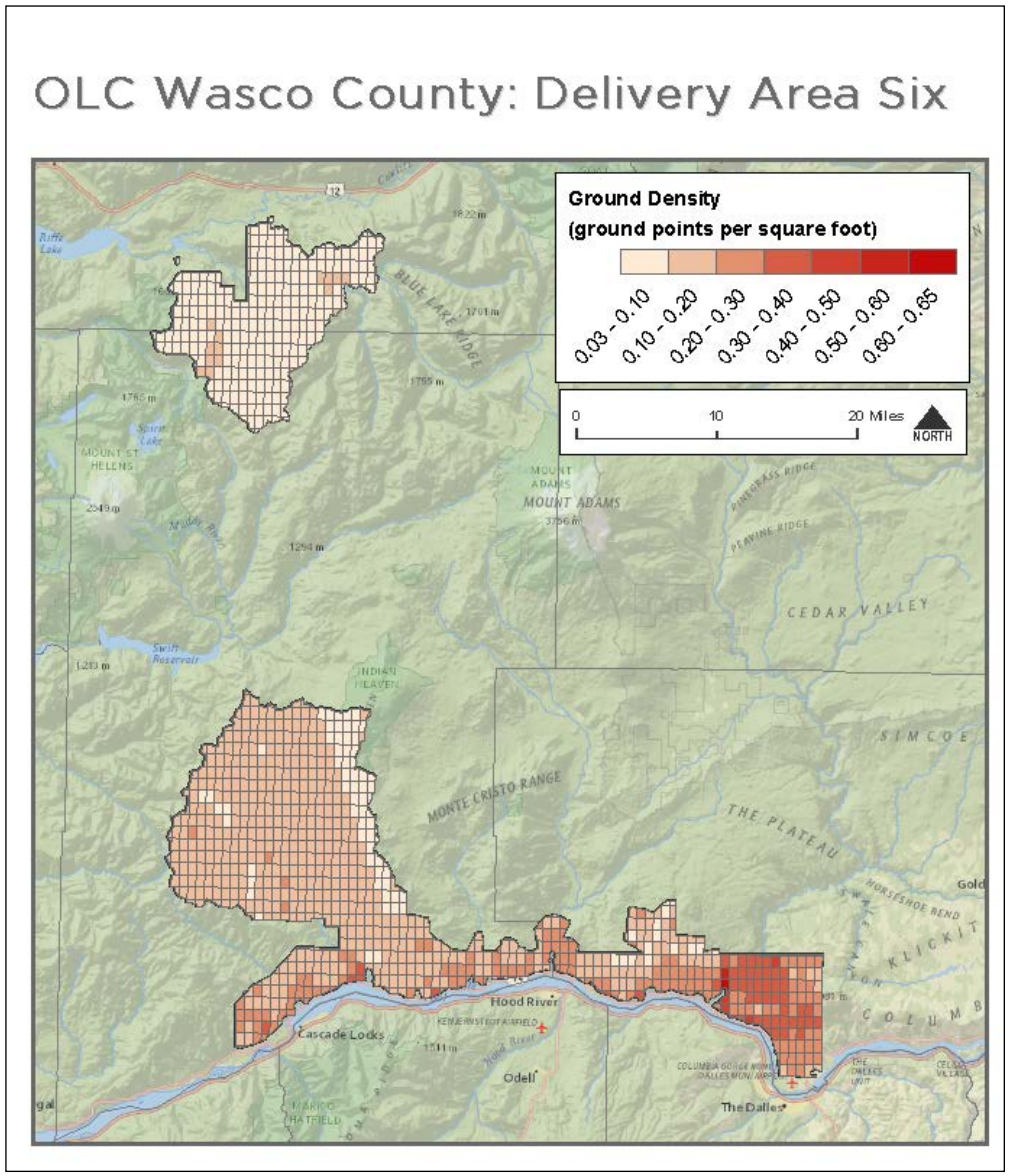
Ground classifications were derived from ground surface modeling. Further classifications were performed by reseeding of the ground model where it was determined that the ground model failed, usually under dense vegetation and/or at breaks in terrain, steep slopes, and at tile boundaries. The classifications are influenced by terrain and grounding parameters that are adjusted for the dataset. The reported ground density is a measure

	points per square meter	points per square foot
Delivery 6 Ground Density	1.50	0.14

	points per square meter	points per square foot
Cumulative Ground Density	2.22	0.21



Average ground density per 0.75' USGS Quad.



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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
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1.25	13.45
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1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

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Appendix A : PLS Certification

WSI provided LiDAR Services for OLC Wasco County Survey project, Delivery Six, as described in this report.

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

John T English 12/21/2015

John English
Project Manager
WSI, a Quantum Spatial Company

I, Christopher Glantz, being duly registered as a Professional Land Surveyor in the state of Oregon, say that I hereby certify the methodologies and results of the attached LiDAR project, and that Static GNSS occupations on the Base Stations during airborne flights and RTK survey on hard-surface and GSP's were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between July 19, 2014 and March 5, 2015. Accuracy statistics shown in the Accuracy Section of this Report have been review by me and found to meet the "National Standard for Spatial Data Accuracy".

12/18/2015

Christopher Glantz, PLS
Land Survey Manager
WSI, a Quantum Spatial Company

Appendix B : GPS Monument Table

List of GPS monuments used in OLC Wasco County Survey Area. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

OLC Wasco County GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
CISPUS_WSDOT	46° 26’ 36.97104”	-121° 52’ 43.74268”	351.067	371.315
RC1228	45° 06’ 49.69688”	-121° 19’ 19.81403”	624.578	646.030
RC2736	45° 37’ 04.04622”	-121° 10’ 30.56142	46.512	67.992
WASCO_01	45° 25’ 33.92221”	-121° 17’ 35.67224	694.143	715.201
WASCO_02	45° 24’ 00.14524”	-121° 15’ 38.58602	668.266	689.337
WASCO_03	45° 30’ 15.15952”	-121° 20’ 16.05414	706.121	727.237
WASCO_04	45° 31’ 35.06899”	-121° 17’ 17.45080	659.572	680.767
WASCO_05	45° 40’ 58.30068”	-121° 18’ 03.00268	194.683	216.110
WASCO_06	45° 39’ 58.42964”	-121° 20’ 07.36657	328.069	349.483
WASCO_07	45° 28’ 20.67253”	-121° 17’ 01.49189	652.762	673.887
WASCO_08	45° 37’ 33.53662”	-121° 21’ 18.77199	485.153	506.493
WASCO_09	45° 36’ 23.21905”	-121° 20’ 06.73995	618.486	639.790
WASCO_10	45° 29’ 26.20935”	-121° 05’ 18.01985	348.496	369.761
WASCO_11	45° 29’ 41.84872”	-121° 10’ 33.92138	352.139	373.376
WASCO_12	45° 29’ 00.75217”	-121° 00’ 25.75182	459.026	480.244
WASCO_13	45° 20’ 54.35426”	-121° 16’ 00.43344	731.185	752.266
WASCO_14	45° 33’ 50.86097”	-121° 21’ 51.83958	628.086	649.268
WASCO_15	45° 27’ 06.62583”	-120° 56’ 27.83190	839.259	860.374
WASCO_16	45° 19’ 51.53124”	-121° 07’ 39.82528	771.520	792.637
WASCO_17	45° 15’ 30.16588”	-121° 04’ 46.54399	366.298	387.695
WASCO_18	45° 17’ 18.80793”	-121° 10’ 52.79618	490.765	512.026
WASCO_19	45° 32’ 02.50205”	-121° 02’ 38.17485”	323.491	344.842
WASCO_20	45° 31’ 24.81814”	-121° 05’ 55.22316”	226.261	247.595
WASCO_21	45° 34’ 50.63889”	-120° 42’ 20.51709”	406.207	427.542
WASCO_22	45° 36’ 32.32168”	-120° 43’ 27.27584”	322.623	343.983
WASCO_23	45° 39’ 25.35061”	-120° 50’ 31.98330”	195.187	216.568

OLC Wasco County GPS Monuments

PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
WASCO_25	45° 40’ 26.60543”	-121° 06’ 03.21471”	340.241	361.552
WASCO_26	45° 43’ 42.64888”	-120° 58’ 06.01776”	457.564	478.694
WASCO_27	45° 11’ 11.42881”	-121° 10’ 36.88163”	516.322	537.783
WASCO_28	45° 13’ 21.18185”	-121° 16’ 41.26494”	529.382	550.863
WASCO_29	45° 17’ 13.71773”	-121° 43’ 43.89634”	1148.089	1168.979
WASCO_30	45° 15’ 09.56681”	-121° 45’ 06.60188”	1077.776	1098.738
WASCO_31	45° 11’ 41.00706”	-121° 41’ 34.26892”	1145.538	1166.520
WASCO_32	45° 13’ 23.06365”	-121° 33’ 08.21340”	1268.450	1289.391
WASCO_33	45° 08’ 01.07100”	-121° 37’ 24.78080”	1069.357	1090.435
WASCO_34	45° 16’ 27.80611”	-121° 29’ 24.41946”	1315.774	1336.621
WASCO_35	45° 37’ 57.72073”	-121° 58’ 13.51239”	-5.667	16.202
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