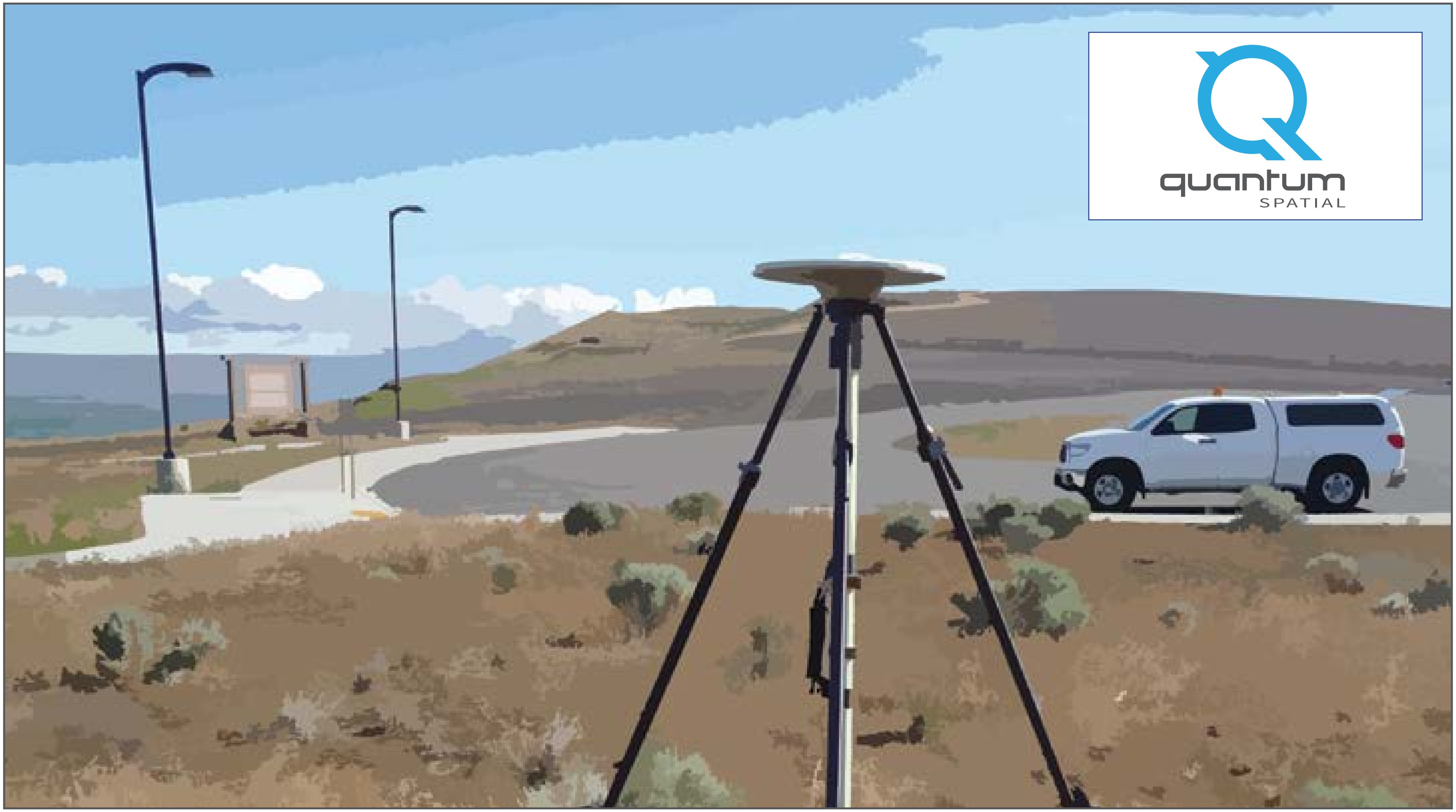
2015 OLC Yakima-Benton



Data collected for:

Department of Geology and Mineral Industries

800 NE Oregon Street
Suite 965
Portland, OR 97232

Prepared by:

QSi, a Quantum Spatial Company

421 SW 6th Avenue
Suite 800
Portland, Oregon 97204
phone: (503) 505-5100
fax: (503) 546-6801

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Project Overview

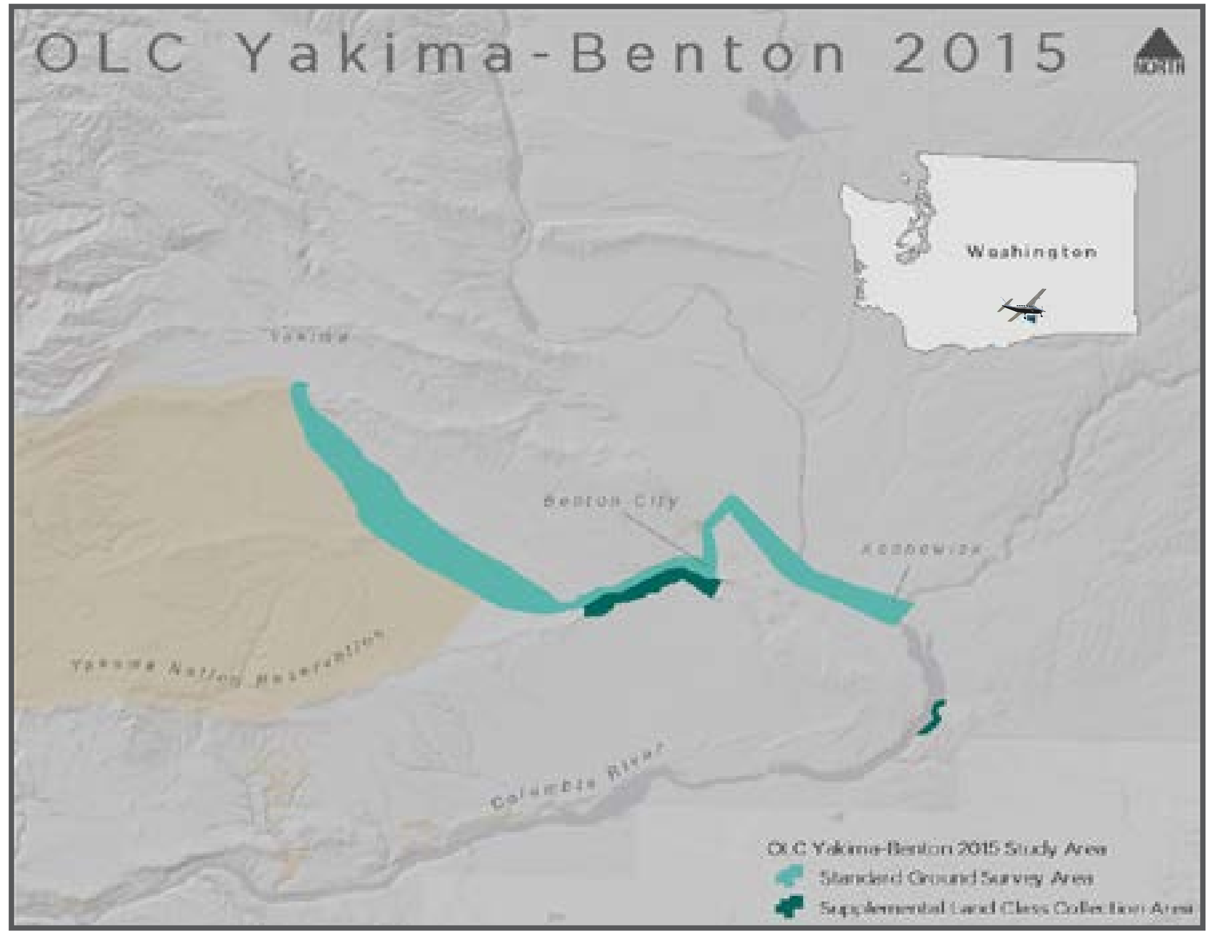
QSi, a Quantum Spatial company, has collected Light Detection and Ranging (LiDAR) data for the Oregon LiDAR Consortium (OLC) Yakima-Benton study area. This study area is located in southern Washington.

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.

In May 2015 QSI employed remote-sensing lasers in order to obtain a total area flown of 194,615 acres. Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter.

Final products created include RGB extracted (from NAIP imagery) LiDAR point cloud data, one-meter digital elevation models of highest hit and bare earth ground models, one-meter density rasters, 0.5-meter intensity rasters, study area vector shapes, and corresponding statistical data. Final deliverables are projected in UTM 11.

OLC Yakima-Benton FEMA Data	
LiDAR Acquisition Dates	5/10/2015 - 6/12/2015
Area of Interest	186,312 acres
Bufered Area of Interest	194,615 acres
Projection	Universal Transverse Mercator (UTM) 11
Horizontal Datum Vertical Datum	NAD83 (2011) NAVD88 (Geoid 12A) Epoch 2010.00
Units	meters



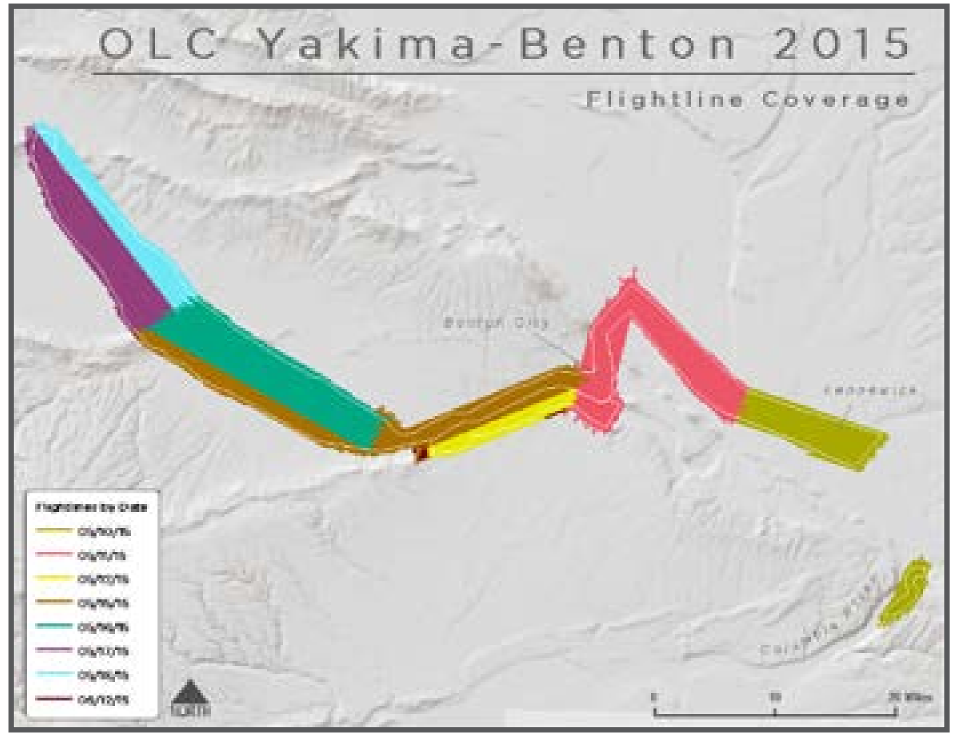
Aerial Acquisition

LiDAR Survey

The LiDAR survey occurred between May 10, 2015 and June 12, 1015 utilizing an Optech Orion H (mounted in a Partenavia P-68) sensor, and a Leica ALS70 (mounted in a Cessna Grand Caravan). The systems were programmed to emit single pulses; the Optech Orion H at around 175 kHz and flown at 1,200 meters above ground level (AGL), capturing a scan angle of 15 degrees from nadir (field of view equal to 30 degrees); the Leica ALS70 at around 198 kHz and flown at 1,400 m AGL, capturing a scan angle of 15 degrees from nadir. These settings were developed to yield points with an average native density of greater than eight pulses per square meter over terrestrial surfaces.

To solve for laser point position, an accurate description of aircraft position and attitude is vital. Aircraft position is described as x, y, and z and was measured twice per second (two hertz) by an onboard differential GPS unit. Aircraft attitude is described as pitch, roll, and yaw (heading) and was measured 200 times per second (200 hertz) from an onboard inertial measurement unit (IMU).

Project Flightlines



The LiDAR sensor operators constantly monitored the data collection settings during acquisition of the data, including pulse rate, power setting, scan rate, gain, field of view, and pulse mode. For each flight, the crew performed airborne calibration maneuvers designed to improve the calibration results during the data processing stage. They were also in constant communication with the ground crew to ensure proper ground GPS coverage for data quality. The LiDAR coverage was completed with no data gaps or voids, barring non-reflective surfaces (e.g., open water, wet asphalt). All necessary measures were taken to acquire data under good conditions (e.g., minimum cloud decks) and in a manner (e.g., adherence to flight plans) that prevented the possibility of data gaps. All QSi LiDAR systems are calibrated per the manufacturer and our own specifications, and tested by QSi for internal consistency for every mission using proprietary methods.

OLC Yakima - Benton LiDAR Acquisition Specs		
Sensor	Optech Orion H	Leica ALS70
Aircraft	Partenavia P-68	Cessna Grand Caravan
Acquisition Dates	5/10 - 5/12/2015 5/15 - 5/18/2015	6/12/2015
Coverage	100% Overlap with 60% Sidelap	100% Overlap with 60% Sidelap
Field of View (FOV)	30 degrees	30 degrees
Targeted Pulse Density	≥8 PPSM	≥8 PPSM
Scan Rate	66 Hz	58.1 Hz
Speed	100 kts	110 kts
Active Days on Project	7	1

Ground Survey

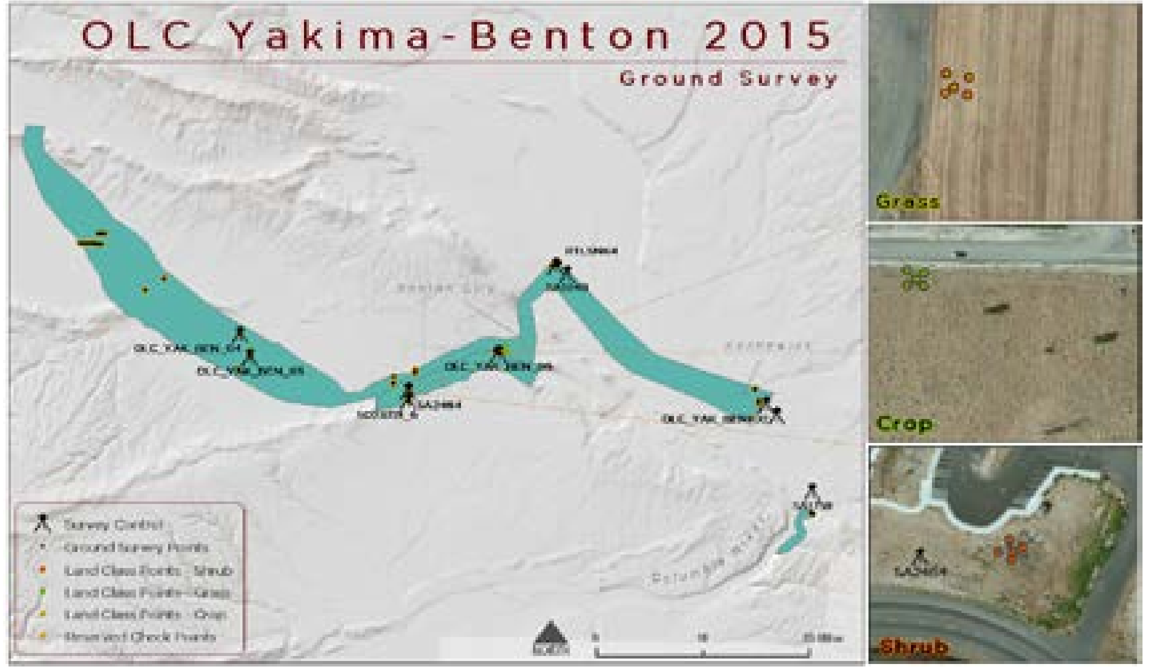
Ground control surveys, including monumentation and ground survey points (GSPs) were conducted to support the airborne acquisition. Ground control data are used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data.

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 R8 and Trimble R10 GNSS receivers. See the table on the following page for specifications of equipment used.

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, QSi 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 the OLC Yakima-Benton study area.



Ground survey map of the 2015 OLC Yakima - Benton study area.

PID	Latitude	Longitude	Ellipsoid (m)	NAVD88 Height (m)
OLC_YAK_BEN_01	46° 11' 15.71878"	-118° 58' 58.44381"	102.111	123.845
OLC_YAK_BEN_02	46° 12' 03.03595"	-119° 00' 12.93707"	87.802	109.551
OLC_YAK_BEN_03	46° 14' 35.88751"	-120° 01' 13.35015"	181.176	202.601
OLC_YAK_BEN_04	46° 16' 27.50413"	-120° 02' 28.04077"	192.722	214.167
OLC_YAK_BEN_05	46° 23' 22.68656"	-120° 21' 26.90432"	217.219	238.851
OLC_YAK_BEN_06	46° 15' 41.32661"	-119° 31' 57.89712"	242.794	264.150
OLC_YAK_BEN_07	46° 20' 48.95525"	-120° 11' 50.38942"	202.718	224.307
RTLSNK4	46° 22' 58.32941"	-119° 25' 31.06706"	127.457	149.056
SA1046	46° 22' 21.46038"	-119° 24' 10.15768"	111.989	133.621
SA1759	46° 05' 04.14324"	-118° 54' 34.51824"	90.576	112.202
SA2464	46° 12' 19.62432"	-119° 42' 26.18348"	428.316	449.572
SB0330	46° 23' 21.86286"	-120° 19' 41.26623"	214.424	236.040
SC03221-6	46° 11' 31.95084"	-119° 42' 21.76881"	410.116	431.359

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

Monument Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	0.02 m
St Dev z	0.05 m

Methodology

To correct the continuously recorded onboard measurement of the aircraft position, QSi concurrently conducts 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.

Ground Survey Points (GSPs)

Ground Survey Points (GSPs) are collected using Real Time Kinematic (RTK) survey techniques. For RTK surveys, a base receiver is positioned at a nearby monument to broadcast a kinematic correction to a roving receiver. 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.

Land Cover Class

In addition to ground survey points, land cover class control points were collected throughout the study area. Individual accuracies were calculated for each land cover type to assess confidence in the LiDAR derived ground models across land cover classes. Land cover types and descriptions are shown in the table below.

Land cover descriptions of check points taken for the OLC Yakima-Benton study area.

Land Cover Type	Land Cover Code	Description
Crop	CROP	Areas dominated by crops
Shrub	SHRUB	Areas dominated by shrubs
Grass	SH_GRASS	Areas dominated by short grass

Ground survey instrumentation

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


Ground professional collecting land class RTK points.

Accuracy

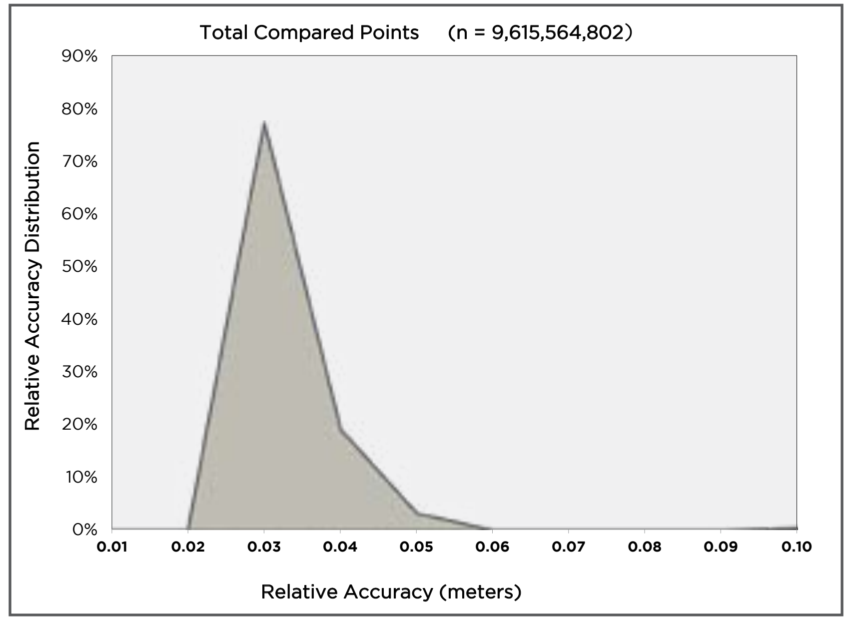
Relative Accuracy

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 220 flightlines and over nine billion LiDAR points. Relative accuracy is reported for the entire study area.

Relative Accuracy Calibration Results	
Project Average	0.028 m (0.093 ft)
Median Relative Accuracy	0.027 m (0.088 ft)
1σ Relative Accuracy	0.029 m (0.095 ft)
2σ Relative Accuracy	0.037 m (0.123 ft)

Relative Accuracy Distribution.



Below: Trimble R8 receiver set up over survey monument YAK_BEN_05 (**left**).

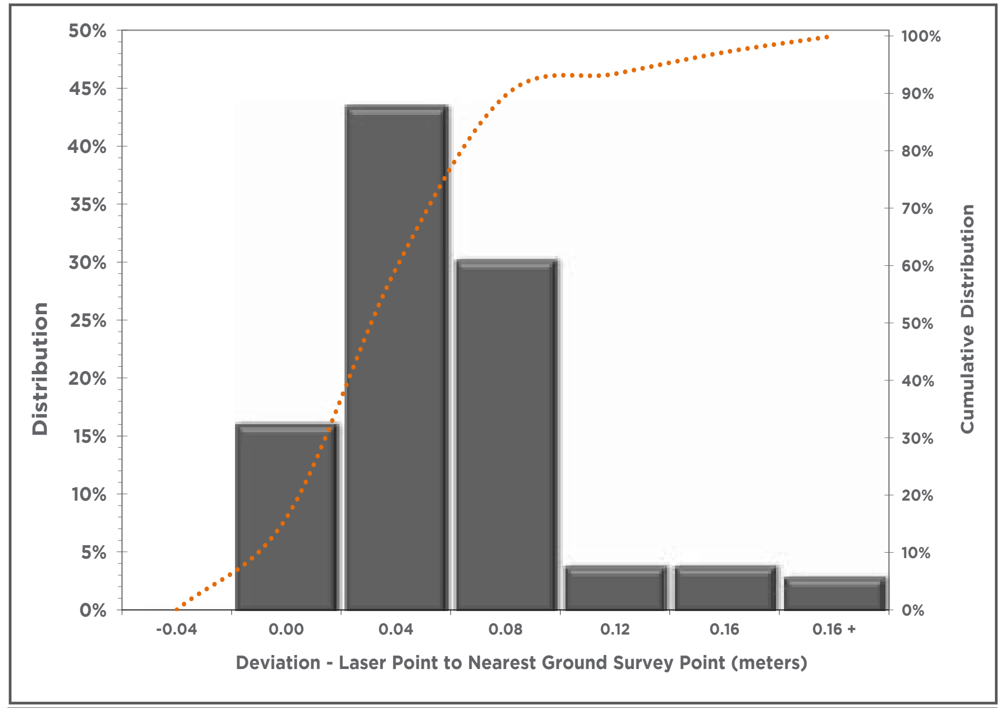
Vertical Accuracy

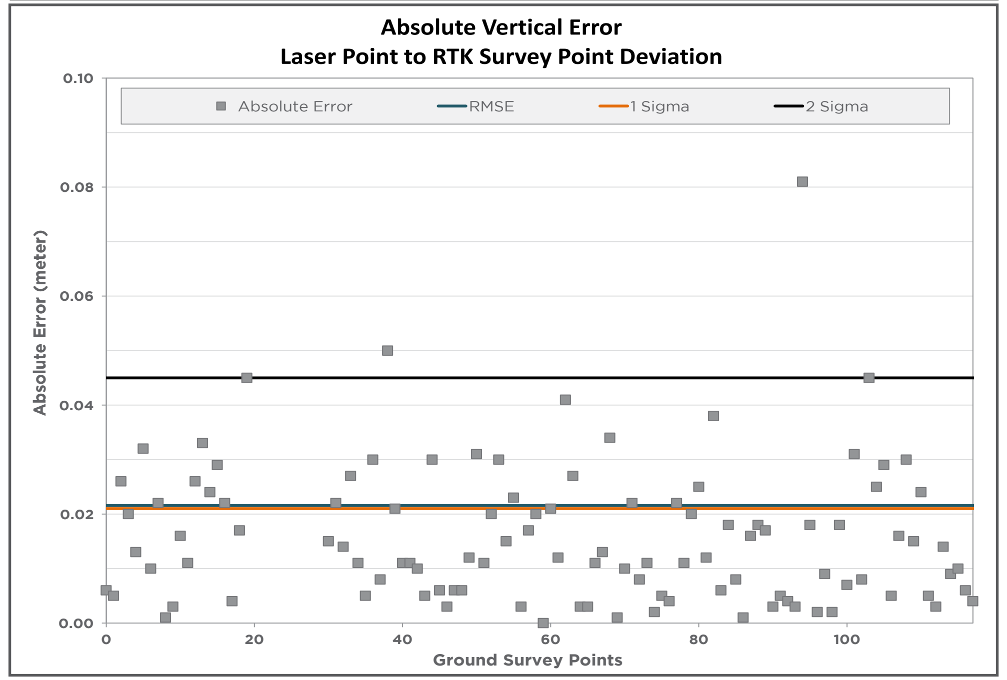
Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). The statistical model compares known ground survey points (GSPs) to the closest laser point. 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 Yakima-Benton study area, a total of 2,220 GSPs were collected. An additional 118 reserved ground survey points were collected for independent verification, resulting in an average accuracy of 0.017 meters and a fundamental vertical accuracy (FVA) of 0.042 meters.

Vertical Accuracy Results	Hard Surface
Sample Size (n)	n = 118 GSPs
FVA (RMSE*1.96)	0.042 m (0.139 ft)
Root Mean Square Error	0.022 m (0.071 ft)
1 Standard Deviation	0.021 m (0.069 ft)
2 Standard Deviations	0.045 m (0.148 ft)
Average Deviation	0.017 m (0.056 ft)
Minimum Deviation	-0.081 m (-0.266 ft)
Maximum Deviation	0.050 m (0.164 ft)

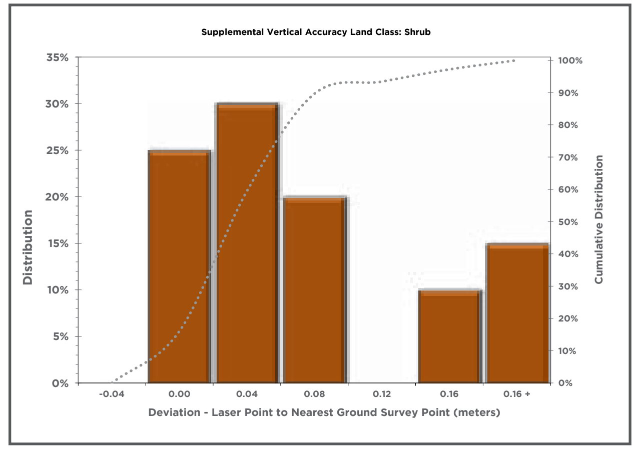
Vertical Accuracy Distribution

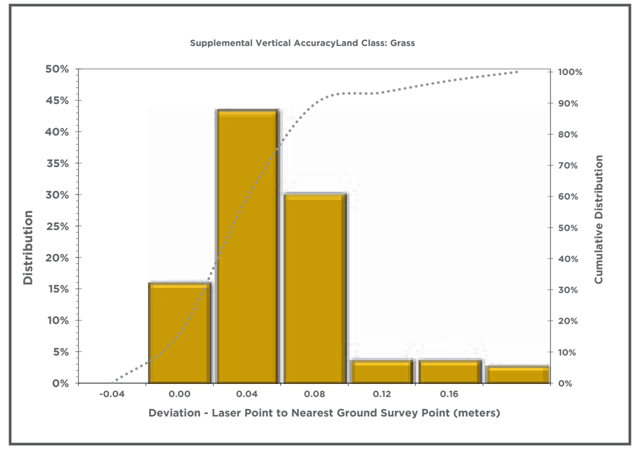


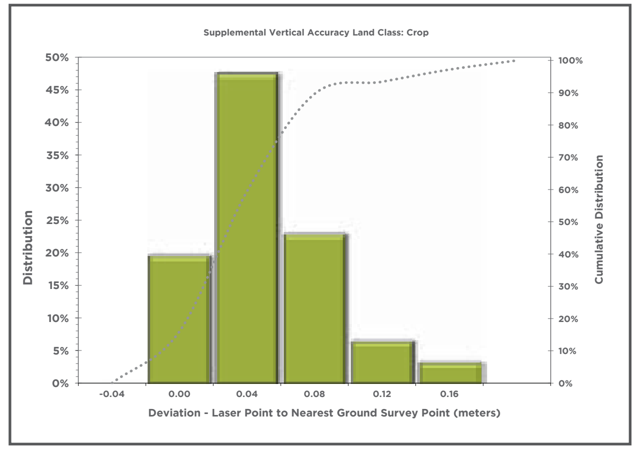


Supplemental and Consolidated Vertical Accuracies

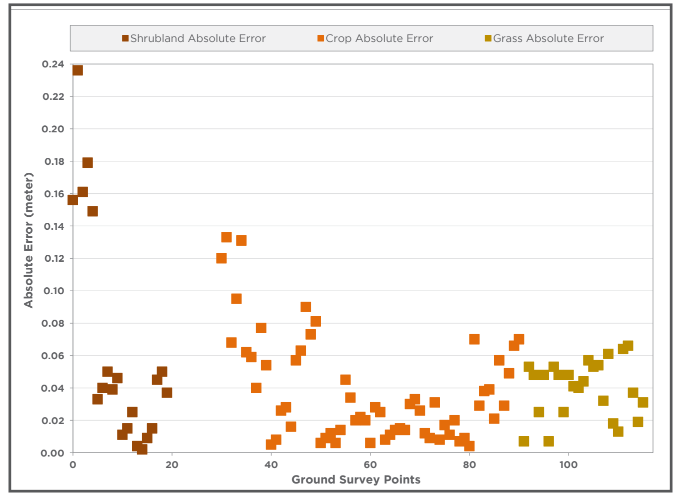
QSi also assessed absolute vertical accuracy for the OLC Yakima-Benton study area, using Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA) reporting. SVA compares known ground survey point data within individual land cover class categories to the triangulated ground surface generated by the LiDAR points. CVA, rather, compares known ground survey points within all land cover classes to the triangulated ground surface generated by LiDAR points. SVA and CVA are measures of the accuracy of LiDAR point data in various land cover classes where the LiDAR system has a high probability of measuring the ground surface and is evaluated at the 95th percentile, as shown in the table below.







Vertical Accuracy Results	SVA			CVA
	Shrub	Grass	Crop	All Land Cover Classes
Sample Size	n = 20	n = 25	n = 61	n = 106
1 Standard Deviation	0.049 m 0.160 ft	0.048 m 0.159 ft	0.041 m 0.135 ft	0.048 m 0.157 ft
2 Standard Deviations	0.182 m 0.597 ft	0.063 m 0.208 ft	0.095 m 0.312 ft	0.133 m 0.435 ft
Average Deviation	0.065 m 0.214 ft	0.040 m 0.130 ft	0.037 m 0.123 ft	0.043 m 0.142 ft
Minimum Deviation	-0.037 m -0.121 ft	0.007 m 0.023 ft	-0.033 m -0.108 ft	-0.037 m -0.121 ft
Maximum Deviation	0.236 m 0.774 ft	0.066 m 0.217 ft	0.133 m 0.436 ft	0.236 m 0.774 ft



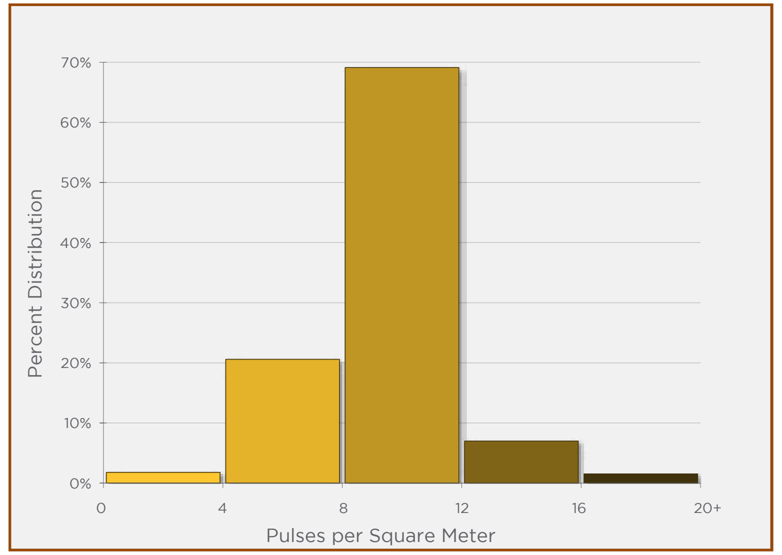
Density

Pulse Density

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.

Average Point Densities			
Pulses per square meter	Pulses per square foot	Ground points per square meter	Ground points per square foot
8.89	0.83	2.63	0.24

Pulse Density Distribution

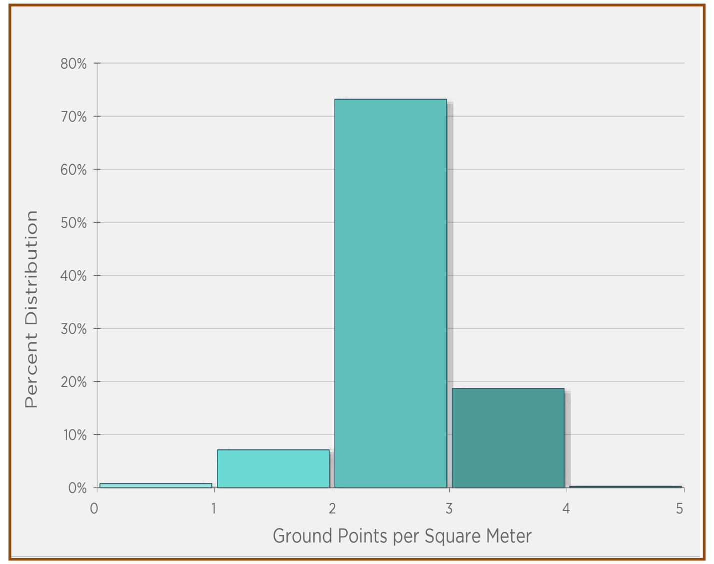


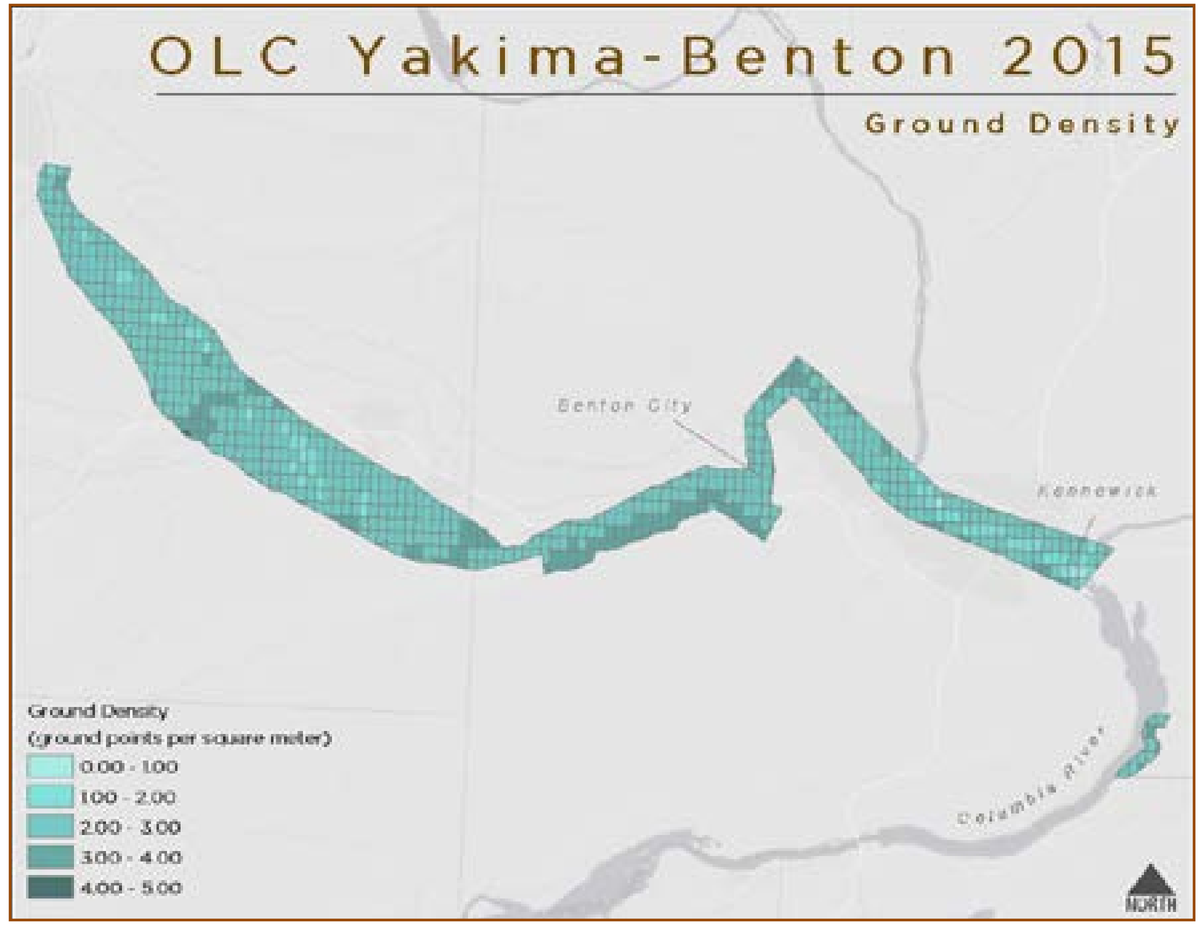
Average Pulse Density per 0.75' USGS Quad (color scheme aligns with density chart).

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.

Ground Density Distribution





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

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Appendix
PLS Certification

WSI provided LiDAR Services for OLC Yakima-Benton LiDAR survey project 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.

10/23/2015

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 during airborne flights and RTK surveys were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between May 9, 2015 and May 20, 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".

10/23/15

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

REGISTERED
PROFESSIONAL
LAND SURVEYOR

OREGON
JUNE 2, 2010
CHRISTOPHER A. GLANTZ
83648

RENEWS 6/30/2017