OLC Four Rivers: Delivery 2

November 24, 2015

Trimble R8 (left) positioned over the GPS Monument Cap QB1364 (above).

Data collected for:
Oregon Department of Geology and Mineral Industries

800 NE Oregon Street
Suite 965
Portland, OR 97232

Prepared by:
WSI, A Quantum Spatial Company

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

517 SW 2nd Street
Suite 400
Corvallis, OR 97333
phone: (541) 752-1204
fax: (541) 752-3770

Contents

Snowfall in the project area.

Project Overview

WSI has completed the acquisition and processing of Light Detection and Ranging (LiDAR) data and Four-Band Radiometric Image Enhanced Survey (FRIES) of the Oregon LiDAR Consortiums's (OLC) Four Rivers Delivery Area Two, for the Oregon Department of Geology and Mineral Industries (DoGAMI). The OLC's Four Rivers study area encompasses 470,160 acres; Delivery Area One encompasses 80,071 acres, and Delivery Area Two encompasses 390,089 acres.

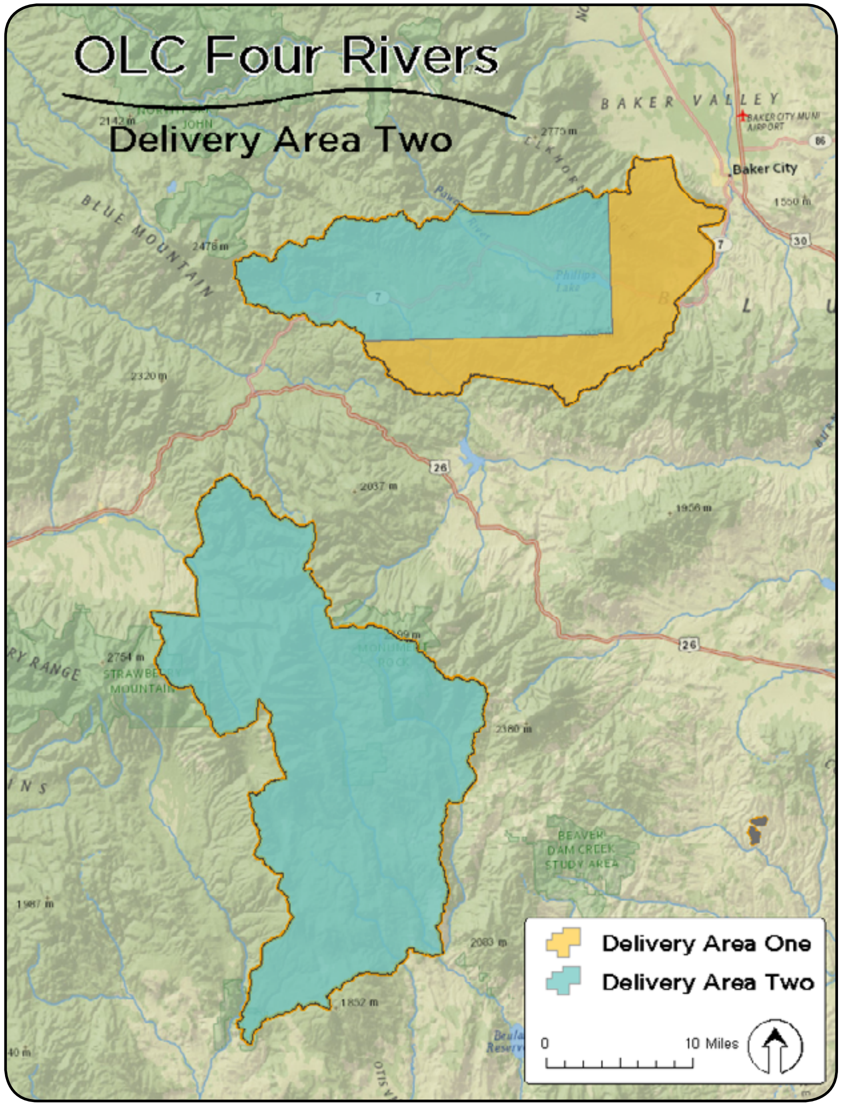
The collection of high resolution geographic data is part of an ongoing pursuit to amass a library of information accessible to government agencies as well as the general public.

LiDAR data collection began on September 10, 2014 and was completed on June 16, 2015. Delivery Area One LiDAR was acquired between September 9, 2014 and October 10, 2014. Delivery Area Two was acquired between October 10, 2014 and October 28, 2014, and the following year between March 17, 2015 and June 16, 2015. Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter. Orthophoto acquisition occurred between August 28, 2014 and September 4, 2014.

Final products created include LiDAR point cloud data, three-foot digital elevation models of bare earth ground model and highest-hit returns, 1.5 foot intensity rasters, 6-inch orthophotos, ground density rasters, study area vector shapes, and corresponding statistical data.

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

OLC Four Rivers Delivery 2 AOI Data Delivered November, 24 2015	
Acquisition Dates	October 10, 2014 - October 28, 2014 & March 17, 2015 - June 16, 2015
Delivery Area Two Area Study Area	390,089 acres
Projection	Oregon Statewide Lambert (OGIC)
Datum: horizontal & vertical	NAD83 (2011) NAVD88 (Geoid 12A)
Units	International Feet



Right: map of Four Rivers Delivery Areas One and Two.

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

Aerial Acquisition

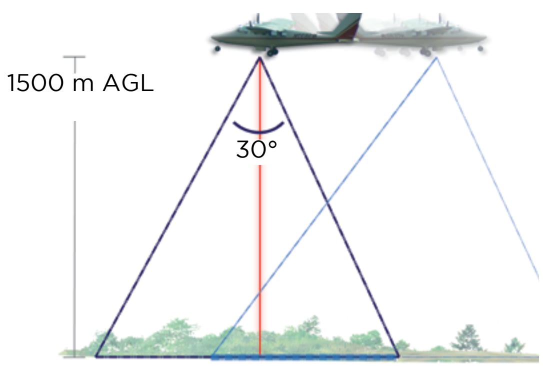
Cessna Caravan

LiDAR Survey

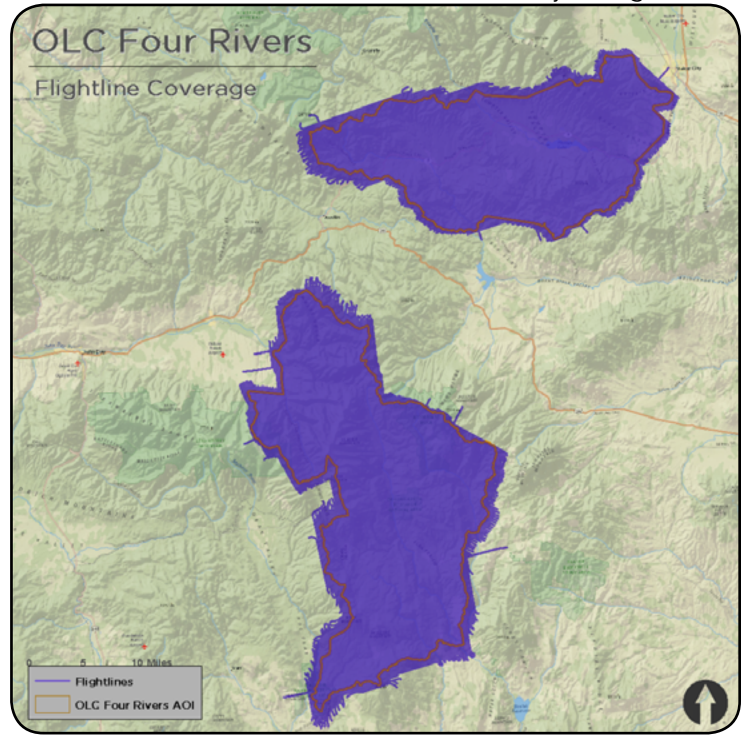
The LiDAR survey utilized a Leica ALS80 sensor mounted in a Cessna Grand Caravan aircraft. The systems were programmed to emit single pulses at a rate of 369 kilohertz and flown at 1500 meters above ground level (AGL), capturing a scan angle of +/-15 degrees from nadir (field of view equal to 30 degrees). 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 65 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, 1,292 full and partial flightlines provide coverage of the study area.



Project Flightlines



Four Rivers Delivery Two Acquisition Specifications	
Sensors Deployed	Leica ALS80
Aircraft	Cessna Grand Caravan
Survey Altitude (AGL)	1500 m
Pulse Rate	369 kHz
Pulse Mode	Single (SPiA)
Field of View (FOV)	30°
Roll Compensated	Yes
Overlap	100% overlap with 65% sidelap
Pulse Emission Density	≥ 8 pulses per square meter

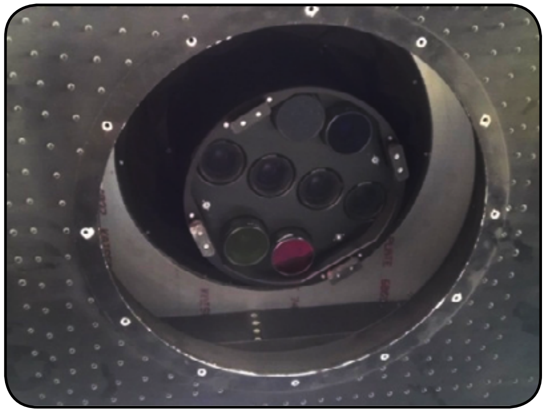
Aerial Acquisition

Photography

The photography or Four-Band Radiometric Image Enhanced Survey (FRIES) utilized an UltraCam Eagle camera mounted in a Cessna 208B Caravan. The UltraCam Eagle is an 80 mm, 260 megapixel large format digital aerial camera manufactured by the Microsoft Corporation. The system is gyro-stabilized and contains a fully integrated UltraNav flight management system with a POS-AV 510 IMU embedded within the body of the camera unit.

The Eagle was designed with high efficiency, high resolution, and high accuracy in mind. With a physical pixel size of 5.2 microns, the Eagle captures a 6.5 cm ground sample distance (GSD) at a flying height of 1,000 meters AGL. This sensor size of the camera is 20,010 x 13,080 pixels in size, which allows for total ground coverage of 1300 x 850 meters within a single captured image frame at 1,000 meters AGL. This large footprint coupled with a fast frame rate (1.8 seconds per frame) allows for highly efficient acquisition. The precise integrated UltraNav system is accurate enough for direct georeferencing in many applications.

The UltraCam Eagle simultaneously collects panchromatic and multispectral (RGB, NIR) imagery in 14-bit format. The spectral sensitivity of the panchromatic charged coupled device (CCD) array ranges from 400-720 nm, with 16,000 grey values per pixel. Four separate 27 mm lenses collect red (590-720 nm), green (490-660 nm), blue (410-590 nm) and near infrared (690-990 nm) light. Panchromatic lenses collect high resolution imagery by illuminating nine CCD arrays, writing nine raw image files. RGB and NIR lenses collect lower resolution imagery, written as four individual raw image files. Level 2 images are created by stitching together raw image data from the nine panchromatic CCDs, and ultimately combined with the multispectral image data to yield Level 3 pan-sharpened TIFFs in either 8-bit format.



Above: UltraCam Eagle lens configuration as viewed from the Cessna Caravan.

Above: A Cessna Grand Caravan 208B was employed in the collection of all orthoimagery.

Below: UltraCam Eagle installed in the aircraft.

Orthophoto of section of the Powder River within the central portion of delivery area one.

Orthophoto Processing

Within the UltraMap software suite, raw acquired images are radiometrically and geometrically corrected using the camera's calibration files and output as Level 2 images. The resulting radiometry is then manually edited to ensure each image has the appropriate tone, no pixels are clipped, and to blend each image with its neighbors. Once radiometry has been edited, separate RGBI and panchromatic images are blended together to form single level 3 pan-sharpened 4 band TIFF images.

The kinematic GPS positional data is post-processed in office, using static monument coordinates from base stations that were occupied for a minimum of 6 hours and were running during the time of acquisition. Photo position and orientation are calculated by linking the time of image capture, the corresponding aircraft position and attitude, and the Smoothed Best Estimate of Trajectory (SBET) data in POSPac MMS, and outputting an initial Exterior Orientations (EO) file.

The EO file is combined with level 3 TIFFs within the Inpho software suite to place the images frames spatially. Aerial triangulation is performed to tie the image frames to each other, and to align them with surveyed ground control coordinates. A point cloud ground model is generated from the image frames by finding matching pixels between images and calculating the coordinates of each extracted point. Triangulated image frames are then draped onto a DEM, derived from the extracted point cloud and orthorectified. Individual orthorectified tiffs are blended together to remove seams and corrected for any remaining radiometric differences between images using Inpho's OrthoVista. The 4-Band image mosaic is tiled to create a usable GeoTIFF raster product.

The 4-band GeoTIFF format allows for flexibility in image analysis and display. By adjusting the image band setup to display the near infrared spectral band as red (this display is known as color-infrared), vegetation stands out extremely vividly in the orthophoto mosaic.

Digital Orthophotography Survey Specifications	
Aircraft	Cessna 208-B Grand Caravan
Sensor	UltraCam Eagle
Altitude	1,846 m AGL
GPS Satellite Constellation	6
GPS PDOP	3.0
GPS Baselines	≤ 13 nm
Image	8-bit GeoTIFF
Along Track Overlap	70%
Spectral Bands	Red, Green, Blue, NIR
Resolution	6 inch pixel size

GPS Monument "OLC_4RVRS_09".

Aerial Targets

Prior to photo acquisition, permanent and temporary aerial photo targets were located and installed throughout the study area. The air targets were set within two miles of a GPS base location and Target Control Points (TCPs) were collected at each corner of the target, as well as the center point, for utilization in the processing and quality control of the orthophoto deliverables.

Because temporary air targets are subject to possible outside influences (e.g., weather, curious public, wildlife), WSI identifies locations adequate for collection of TCPs that are on permanent features. Selected locations include existing aerial targets, turn-arrows, STOP bars, etc. that are visible from the aircraft. WSI also paints permanent targets in appropriate locations when necessary. Additional permanent air targets were identified in the field and used for processing orthophotos.

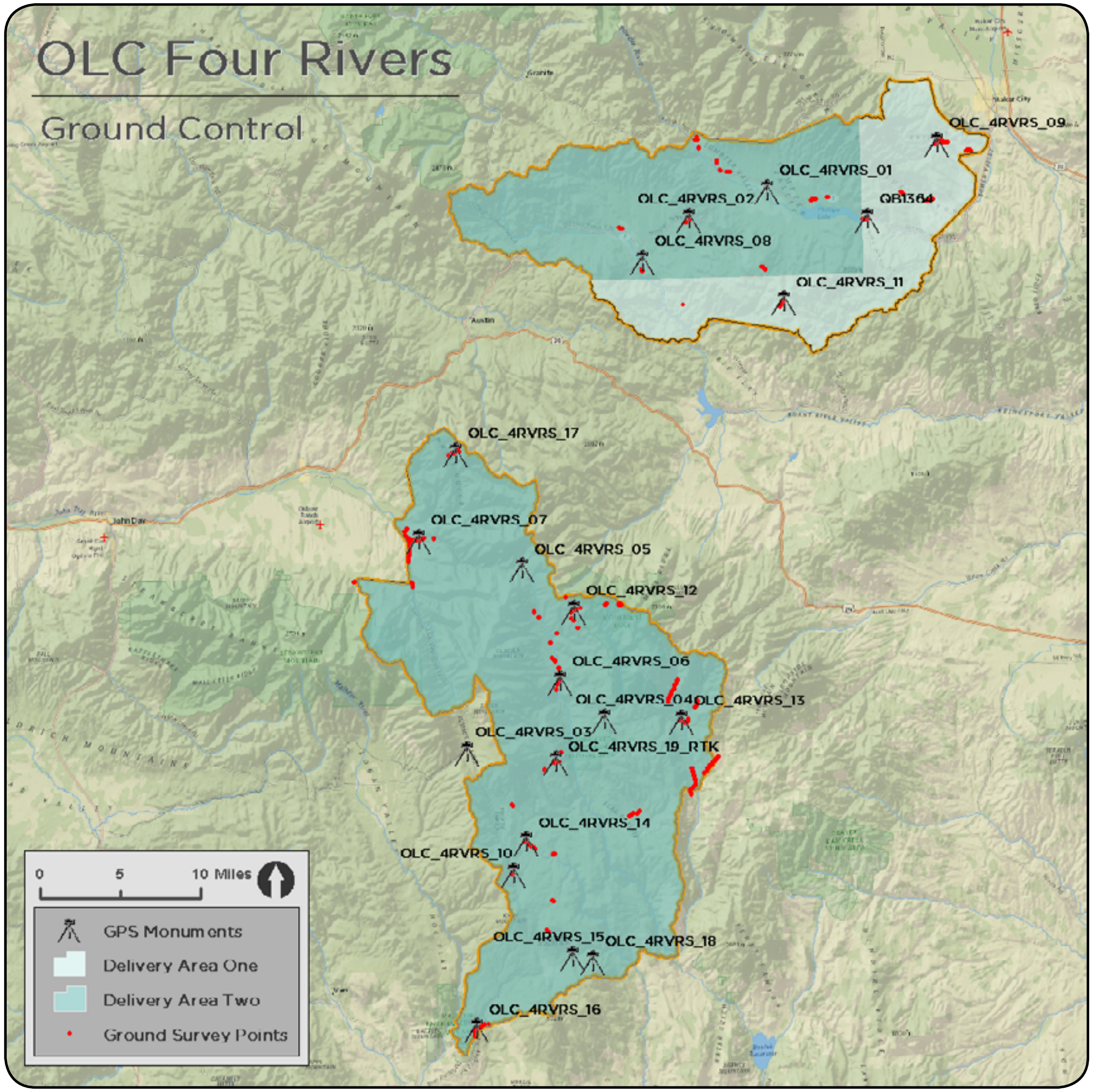
All TCPs were acquired using one of two methods. The air targets that were set within two miles of a GPS base location had TCPs collected at each corner of the target as well as the center point. In order to increase TCP sample size for data quality, WSI also used a Fast-Static (FS) survey technique by baseline post-processing. For the air targets that were set this way, WSI collected a single static session with the R8 rover set over the center point of the target. The FS sessions lasted 15-30 minutes, depending on the distance of the air target to the base station. The static sessions and the concurrent R7 base session data were later processed in Trimble Business Center software. The use of post processing eliminates the need to deal with radio link issues, and fast static methodology generally results in precision equal to or better than full RTK collection on each target.

Examples of permanent air targets.




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 and orthoimagery products.



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 19 new monuments for the OLC Four Rivers LiDAR project (Monument Table on following page). 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 (OR PLS #83648) oversaw and certified the establishment of all monuments.

Ground professional setting up an R7 unit over a base station.

Monuments Table

OLC Four Rivers Monuments				
PID	Latitude	Longitude	Ellipsoid Height (m)	NAVD 88 Height (m)
OLC_4RVRS_01	44° 42' 05.21049"	-118° 07' 10.55806"	1243.446	1260.423
OLC_4RVRS_02	44° 40' 40.86017"	-118° 13' 07.50897"	1405.010	1422.061
OLC_4RVRS_03	44° 12' 15.24681"	-118° 30' 51.25222"	1596.494	1614.134
OLC_4RVRS_04	44° 13' 50.23144"	-118° 20' 29.66052"	1678.079	1695.550
OLC_4RVRS_05	44° 22' 04.04811"	-118° 26' 26.27744"	1673.490	1690.853
OLC_4RVRS_06	44° 15' 56.25740"	-118° 23' 48.26503"	1523.051	1540.504
OLC_4RVRS_07	44° 23' 45.44675"	-118° 34' 08.18962"	1215.771	1233.466
OLC_4RVRS_08	44° 38' 27.91126"	-118° 16' 46.23027"	1239.037	1256.224
OLC_4RVRS_09	44° 44' 24.07335"	-117° 54' 13.74862"	1311.965	1328.990
OLC_4RVRS_10	44° 05' 37.98923"	-118° 27' 37.51011"	1734.292	1752.061
OLC_4RVRS_11	44° 36' 04.44639"	-118° 06' 10.24269"	1618.117	1635.069
OLC_4RVRS_12	44° 19' 45.23278"	-118° 22' 38.73499"	1966.112	1983.404
OLC_4RVRS_13	44° 13' 39.69461"	-118° 14' 45.54583"	1435.453	1452.865
OLC_4RVRS_14	44° 07' 18.11222"	-118° 26' 35.38120"	1606.261	1624.014
OLC_4RVRS_15	44° 01' 04.73466"	-118° 23' 21.89923"	1633.668	1651.513
OLC_4RVRS_16	43° 57' 17.57039"	-118° 30' 40.00011"	1454.187	1472.287
OLC_4RVRS_17	44° 28' 22.11837"	-118° 31' 14.39092"	1718.217	1735.658
OLC_4RVRS_18	44° 00' 47.98231"	-118° 21' 50.95986"	1690.748	1708.595
OLC_4RVRS_19_RTK	44° 11' 35.72109"	-118° 24' 14.64106"	1667.069	1684.669
QB1364	44° 40' 24.70948"	-117° 59' 40.96849"	1235.861	1252.818

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

Methodology

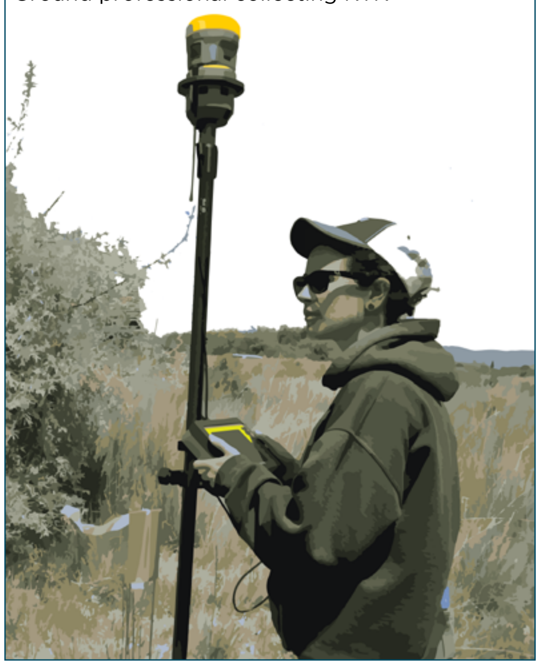
Monument Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	0.020 m
St Dev z	0.050 m

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.

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 R8 or R10 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.

Ground professional collecting RTK



Instrumentation			
Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2	TRM57972.00	Static
Trimble R8 GNSS	Integrated Antenna R8 Model 2	TRM_R8_Model_2	Static & RTK
Trimble R10 GNSS	Integrated Antenna R10	TRM_R10	RTK

LiDAR Accuracy

Relative Accuracy

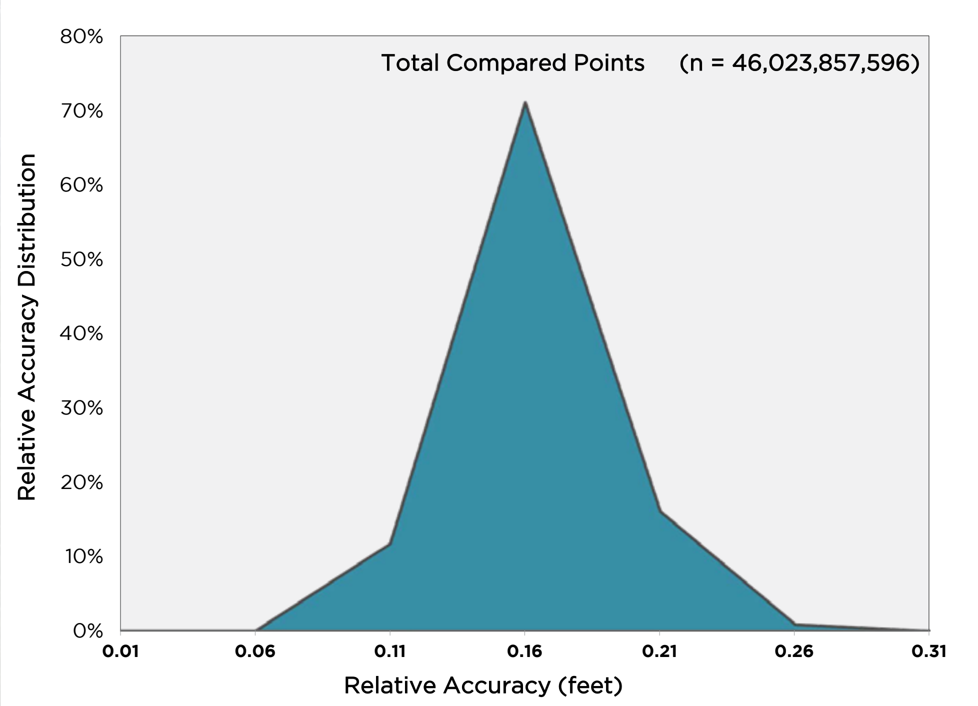
Relative accuracy refers to the internal consistency of the data set and is measured as the divergence between points from different flightlines within an overlapping area. Divergence is most apparent when flightlines are opposing. When the LiDAR system is well calibrated the line to line divergence is low (<10 centimeters). Internal consistency is affected by system attitude offsets (pitch, roll, and heading), mirror flex (scale), and GPS/IMU drift.

Cumulative relative accuracy statistics are based on the comparison of 1,135 full and partial flightlines and over 52 billion points. Relative accuracy is reported for the cumulative delivered portions of the study area.

Relative Accuracy Calibration Results

	Delivery 1	Delivery 2	Cumulative
Number of flightlines	n = 256	n = 879	n = 1,135
Total compared points	n = 6,565,309,427	n = 46,023,857,596	n = 52,888,506,496
Project Average	0.12 ft. (0.04 m)	0.14 ft. (0.04 m)	0.13 ft. (0.04 m)
Median Relative Accuracy	0.11 ft. (0.03 m)	0.14 ft. (0.04 m)	0.13 ft. (0.04 m)
1σ Relative Accuracy	0.12 ft. (0.04 m)	0.15 ft. (0.05 m)	0.14 ft. (0.04 m)
2σ Relative Accuracy	0.15 ft. (0.05 m)	0.18 ft. (0.06 m)	0.18 ft. (0.05 m)

Relative Accuracy Distribution Delivery Two



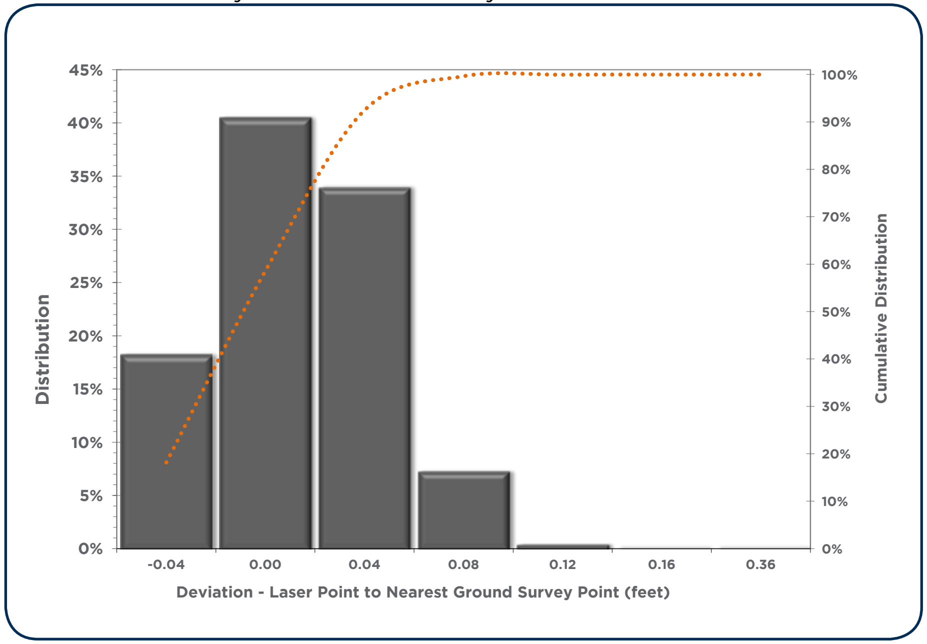
Vertical Accuracy

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 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 Four Rivers Delivery Area Two study area, 4,763 GSPs were collected; a total of 5,452 GSPs were collected for the entire Four River study area.

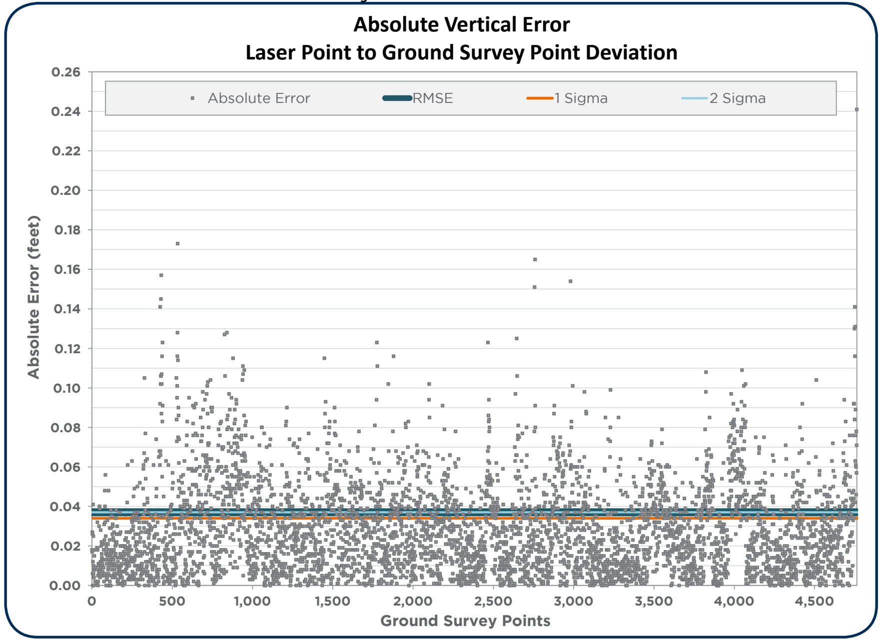
For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet." Vertical Accuracy is reported for the entire study area and reported in the table below. Histogram and absolute deviation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

Vertical Accuracy Results			
	Delivery Area One	Delivery Area Two	Cumulative
Sample Size (n)	689 Ground survey points	4,763 Ground survey points	5,452 Ground survey point
Root Mean Square Error	0.09 ft. (0.03 m)	0.04 ft. (0.01 m)	0.05 ft. (0.02 m)
1 Standard Deviation	0.07 ft. (0.02 m)	0.03 ft. (0.01 m)	0.04 ft. (0.01 m)
2 Standard Deviation	0.16 ft. (0.05 m)	0.07 ft. (0.02 m)	0.09 ft. (0.03 m)
Average Deviation	-0.01 ft. (0.00 m)	0.03 ft. (0.01 m)	0.03 ft. (0.01 m)
Minimum Deviation	-0.24 ft. (-0.07 m)	-0.26 ft. (-0.08 m)	-0.26 ft. (-0.08 m)
Maximum Deviation	0.56 ft. (0.17 m)	0.36 ft. (0.11 m)	0.56 ft. (0.17 m)

Vertical Accuracy Distribution Delivery Two



GSP Absolute Error Delivery Two

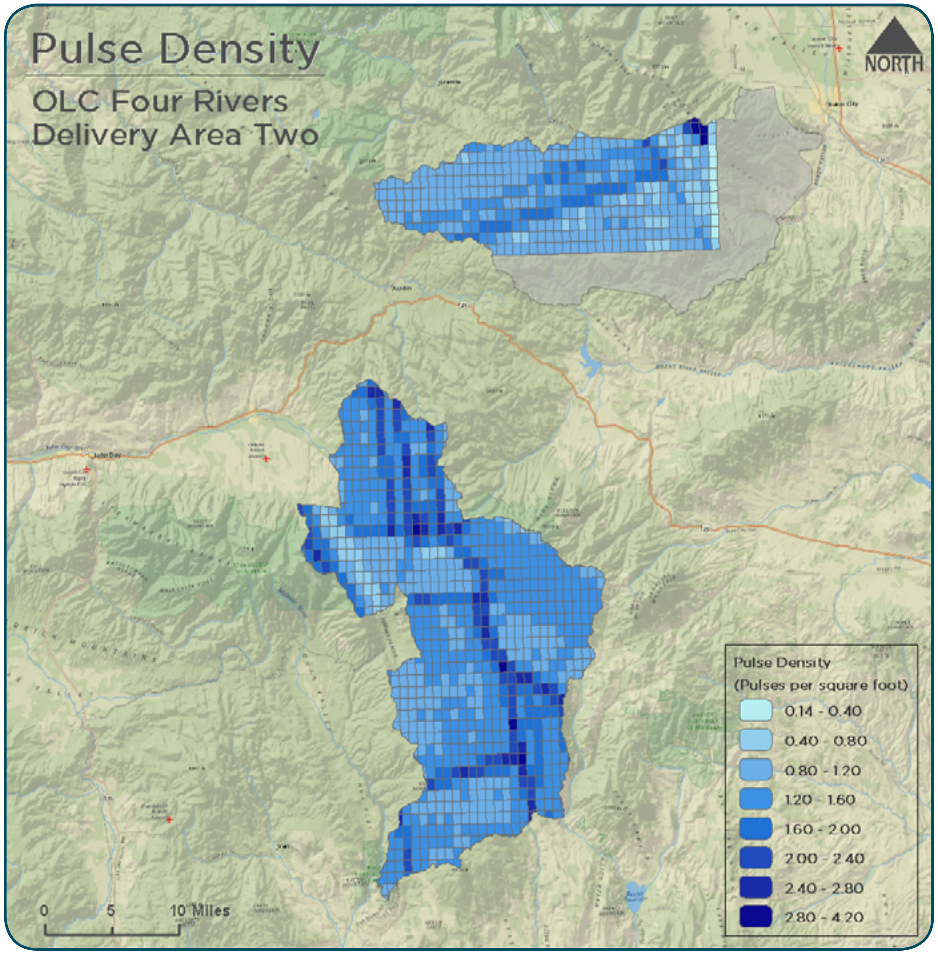


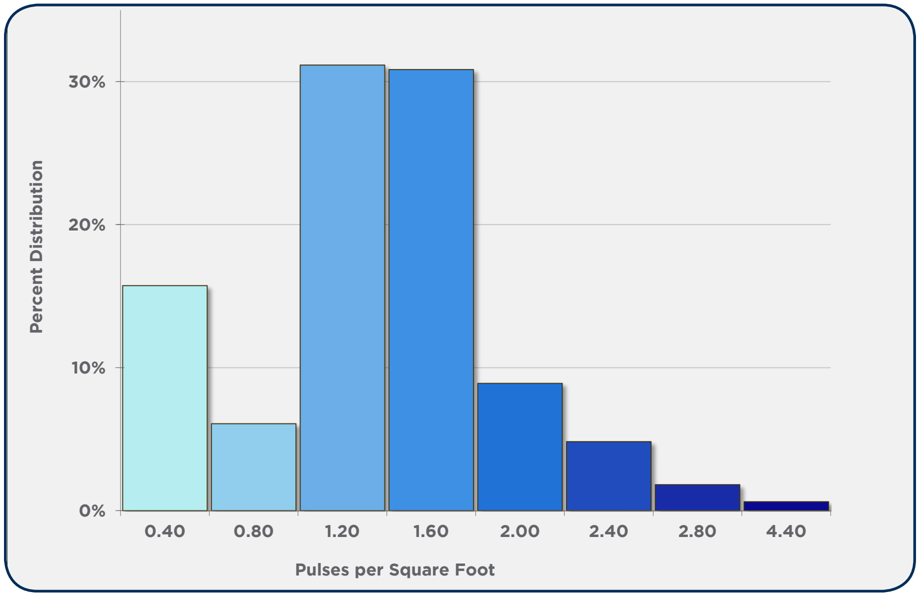
Density

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.

Pulse Density	Pulses per square meter	Pulses per square foot
Delivery 1	9.28	0.86
Delivery 2	11.97	1.11
Cumulative Results	11.54	1.07



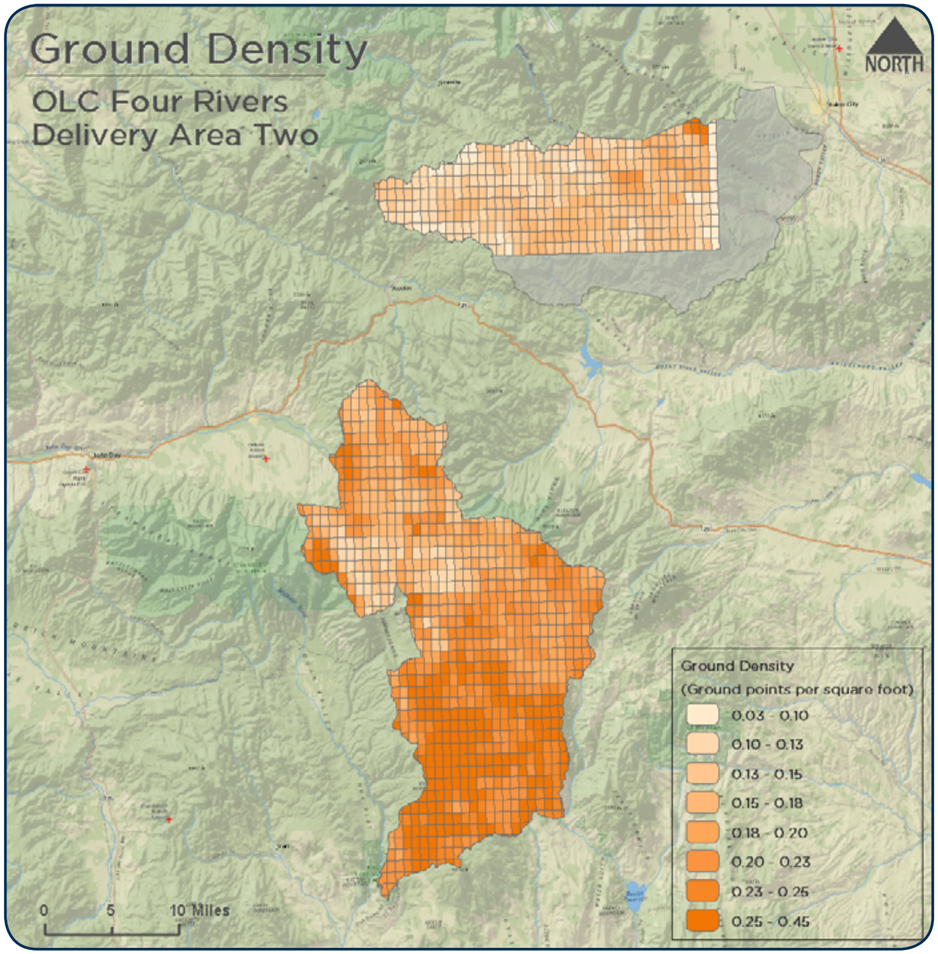


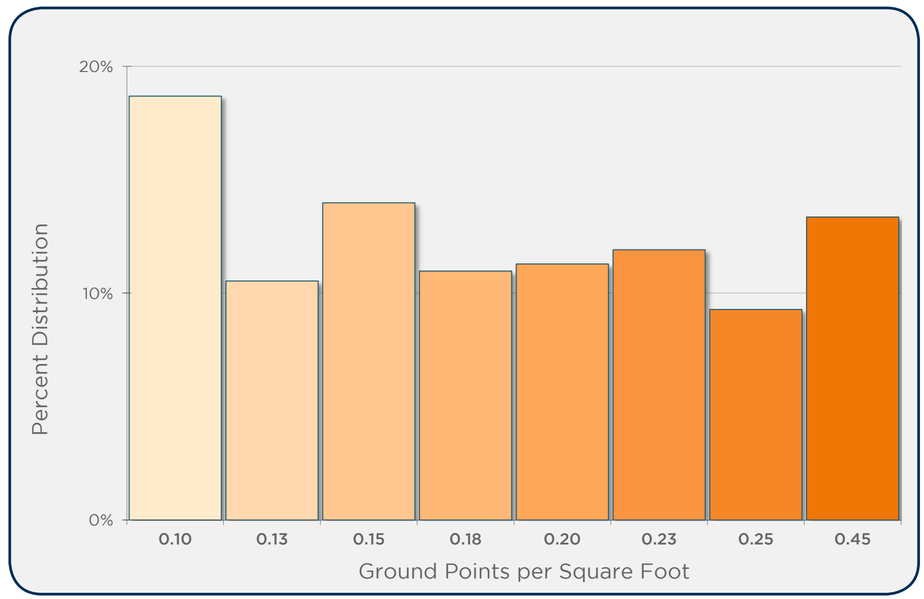
Average Pulse Density per 0.75' USGS Quad (color scheme aligns with density chart).

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	Ground points per square meter	Ground points per square foot
Delivery 1	1.54	0.14
Delivery 2	1.69	0.16
Cumulative Results	1.67	0.15





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

Orthophoto Accuracy

Orthophoto Accuracy Assessment

To assess the spatial accuracy of the orthophotographs, artificial check points were established. Twenty-three target control points, distributed evenly across the total acquired area, were generated on permanent air target surface features, such as painted road lines and fixed high-contrast objects or on temporary air targets. They were then compared against check points identified from the LiDAR intensity images. The accuracy of the final mosaic was calculated in relation to the LiDAR-derived check points and is listed below. Accuracy statistics are reported for the entire Four Rivers Orthophoto AOI.

Above: Example of co-registration of color images with LiDAR intensity images. Below: Examples of permanent air targets.

Orthophoto horizontal accuracy results.

Orthophoto Horizontal Accuracy (n=23)	WSI Achieved (ft.)
RMSE	0.83
1 Sigma	0.95
2 Sigma	1.25

[Page Intentionally Blank]

Appendix A : PLS Certification

WSI, a Quantum Spatial company, provided LiDAR Services for OLC Four Rivers LiDAR project Delivery 2 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 11/24/2015

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 15, 2014 and June 16, 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".

11/24/2015

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

REGISTERED
PROFESSIONAL
LAND SURVEYOR

OREGON
JUNE 2, 2010
CHRISTOPHER A. GLANTZ
83648

RENEWS 6/30/2017

[Page Intentionally Blank]