2016 McKenzie River

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

Contents

Project Overview

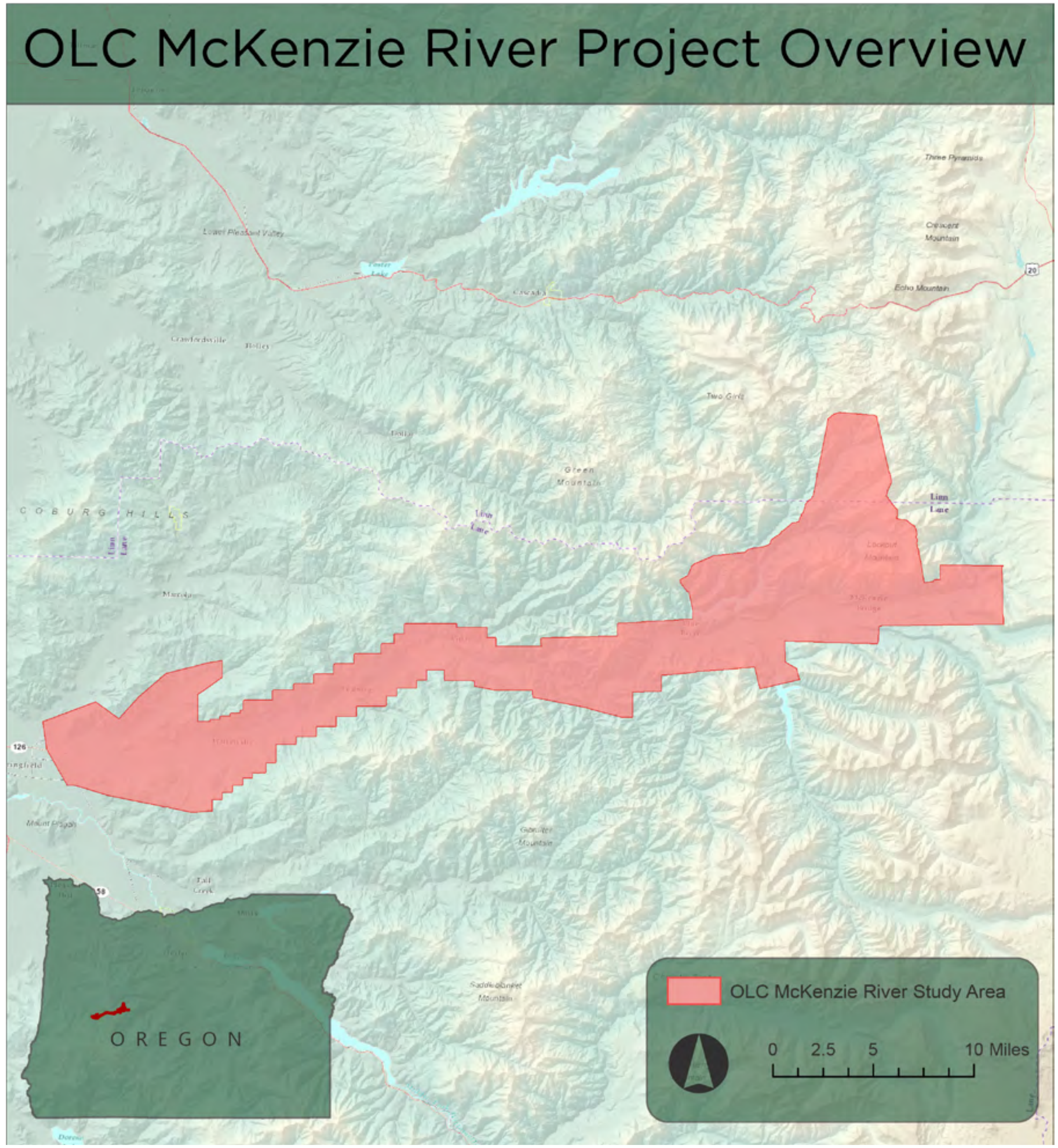
Quantum Spatial has collected Light Detection and Ranging (LiDAR) data for the Oregon Lidar Consortium (OLC) McKenzie River study area. This study area is located near Eugene, Oregon.

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 and June 2016 QSI employed remote-sensing lasers in order to obtain a total area flown of 141,508 acres. Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter.

Final products created include 6-inch orthophotos, RGB extracted (from NAIP imagery) LiDAR point cloud data, three foot digital elevation models of highest hit and bare earth ground models, 1.5 foot intensity rasters, 1.5 foot ground density, study area vector shapes, and corresponding statistical data. Final deliverables are projected in Oregon Statewide Lambert Conformal Conic.

OLC McKenzie River Data	
Project Acquisition Dates	5/28/2016 - 6/21/2016
Area of Interest	135,783 acres
Bufered Area of Interest	141,508 acres
Projection	OGIC
Horizontal Datum Vertical Datum	NAD83 (2011) Epoch 2010.00 NAVD88 (Geoid 12B)
Units	International Feet



Study area overview map.

Aerial Acquisition

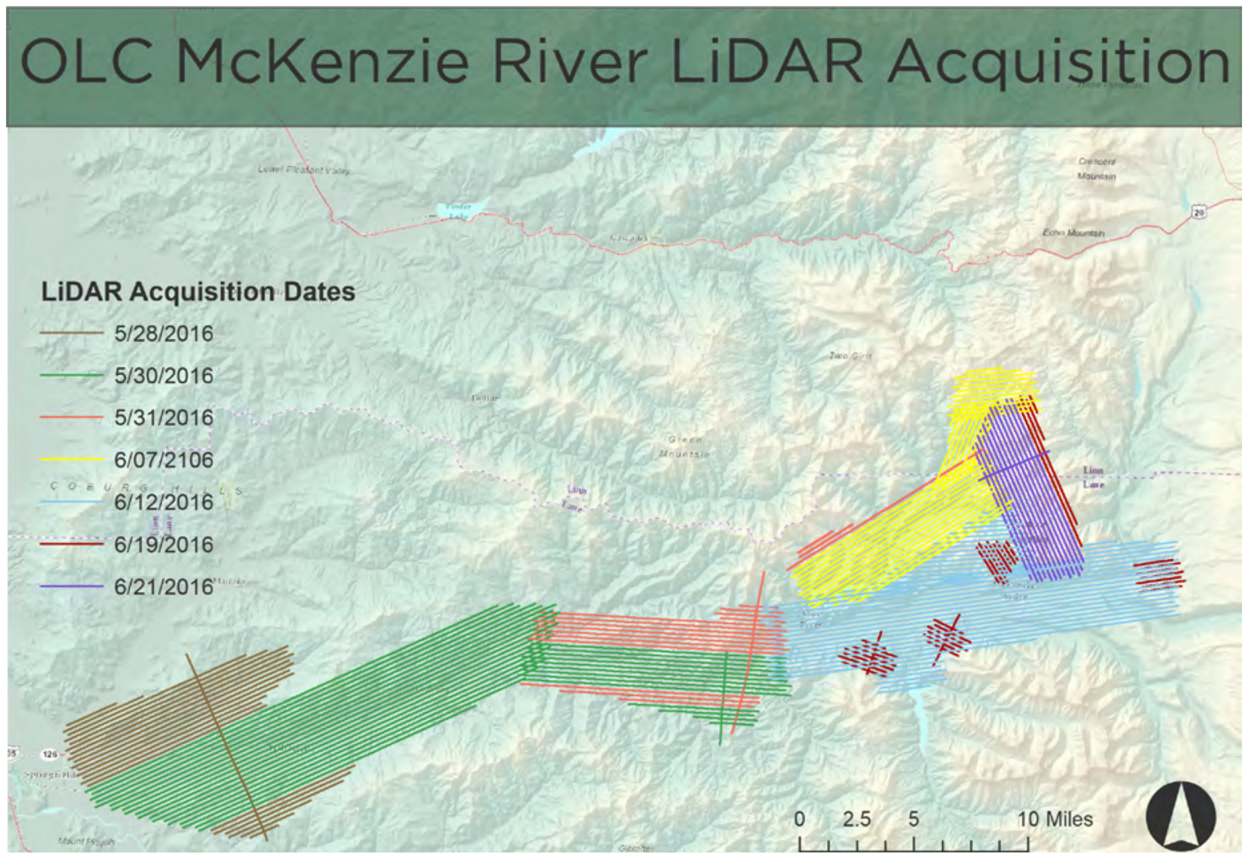
LiDAR Survey

The LiDAR survey occurred between May 28, 2016 and June 21, 2016 utilizing a Leica ALS80 mounted in a Cessna Grand Caravan. The systems were programmed to emit single pulses at around 189 kHz and flown at 1,500 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).

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 McKenzie River LiDAR Acquisition Specs	
Sensor	Leica ALS80
Aircraft	Cessna Grand Caravan
LiDARAcquisition Dates	5/28/2016 - 6/21/2016
Coverage	60% Overlap with 55% Sidelap
Field of View (FOV)	30 degrees
Targeted Pulse Density	≥8 PPSM
Pulse Rate	369 kHz
Speed	105 kts
Target Above Ground Level (AGL)	1,500 meters



Aerial Acquisition

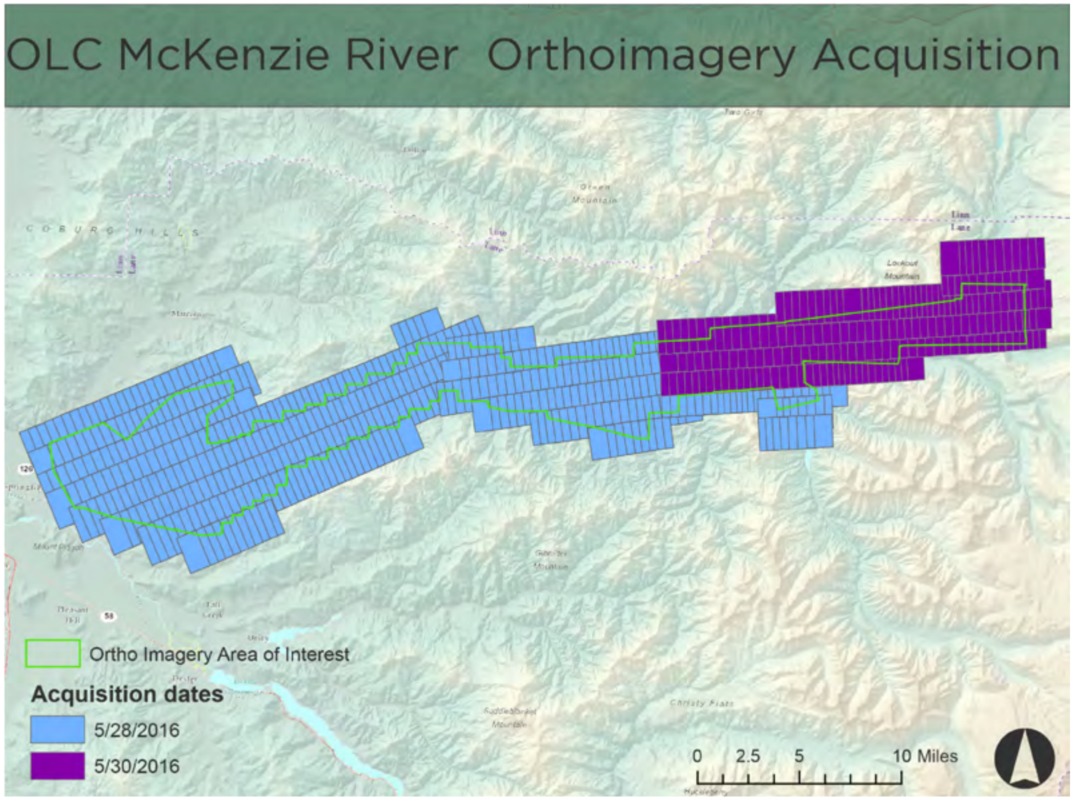
Photography

The photography or Four-Band Radiometric Image Enhanced Survey (FRIES) utilized an UltraCam Eagle 260 megapixel camera mounted in a Piper Navajo. 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.

Digital Orthophotography Survey Specifications	
Aircraft	Piper Navajo
Sensor	UltraCam Eagle
Altitude	1,200 m AGL
GPS Satellite Constellation	6
GPS PDOP	3.0
GPS Baselines	≤ 13 nm
Image	8-bit GeoTIFF
Along Track Overlap	60%
Spectral Bands	Red, Green, Blue, NIR
Resolution	6 in. pixel size



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.

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), post processed kinematic (PPK), and fast static (FS) survey techninques. Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. QSI utilized seven existing monuments and established two new monuments for the OLC McKenzie River LiDAR project. New monumentation was set using 5/8” x 30” rebar topped with stamped 2-1/2” aluminum caps. QSI’s professional land surveyor, Evon Silvia (OR PLS #81104) 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 on the previous page provides the list of monuments used.

PID	Lat	Long	Ellipse Height (m	NAVD88 Height (m)
HJAN	44° 12’ 46.43913”	-122° 15’ 18.89177”	417.000	439.305
LANE_62	44° 09’ 36.54184”	-122° 09’ 57.92458”	418.342	440.547
LANE_63	44° 15’ 13.30087”	-122° 07’ 55.02809”	1377.917	1399.838
LANE_64	44° 13’ 05.95643”	-122° 06’ 13.58380”	1482.927	1504.828
LANE_75	44° 09’ 14.03758”	-122° 21’ 22.49449”	302.432	324.986
MCK16_01	44° 04’ 07.44732”	-122° 48’ 13.32199”	161.560	184.819
MCK16_02	44° 03’ 27.07744”	-122° 56’ 27.74950”	127.310	150.741
QE2666	44° 08’ 44.29897”	-122° 34’ 13.99783”	221.076	243.931
WC1413	44° 10’ 26.56512”	-122° 17’ 02.44061”	393.112	415.576

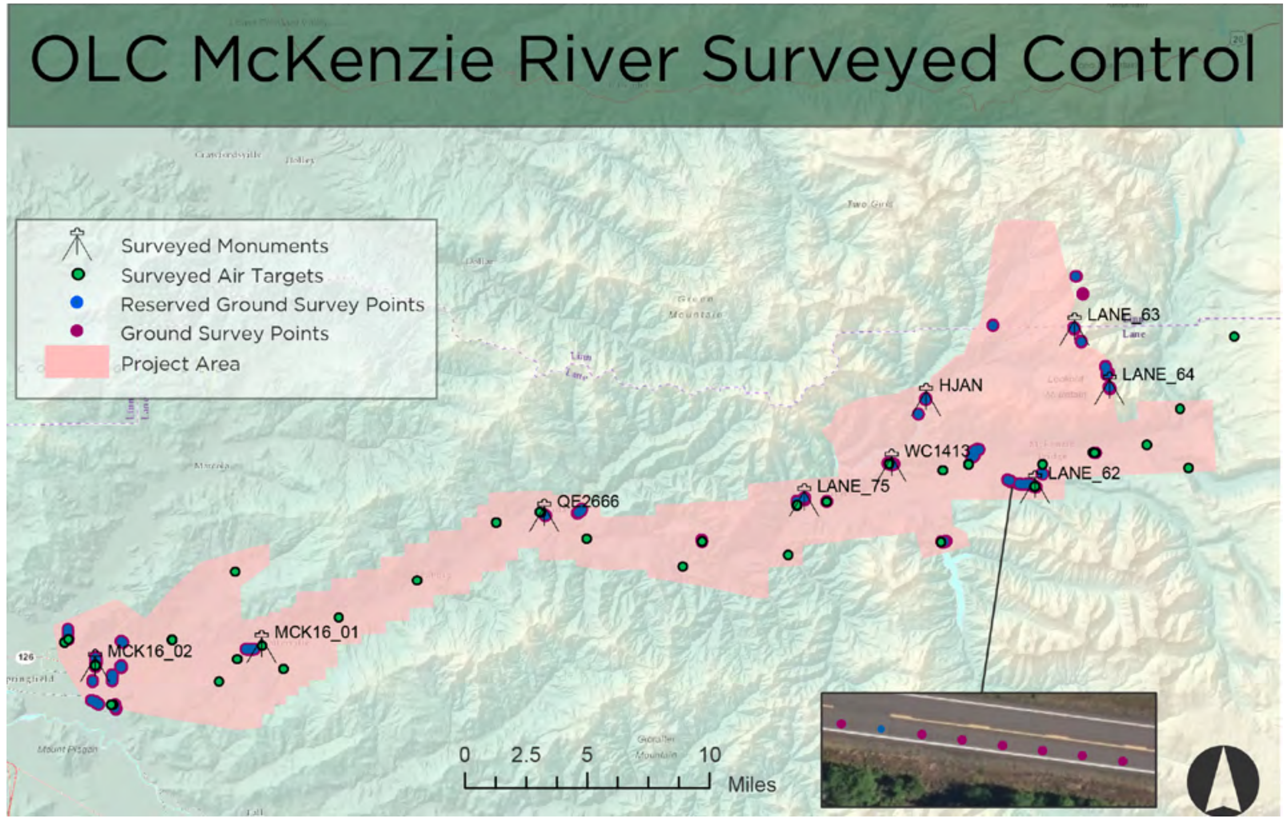
Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12A.

Monument Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	0.020
St Dev Z	0.020

Ground Survey Points (GSPs)

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 surveys, however, these corrections are post-processed. FS surveys record observations for up to fifteen minutes on each GSP in order to support longer baselines for post-processing. 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.



Ground survey instrumentation

Instrumentation			
Receiver Model	Antenna	OPUS Antenna ID	Use
Timble R10 GNSS	Integrated GNSS Antenna R10	TRM_R10	Static & Rover
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static
Trimble R6 GNSS	Integrated GNSS Antenna R6	TRM_R6	Static & Rover

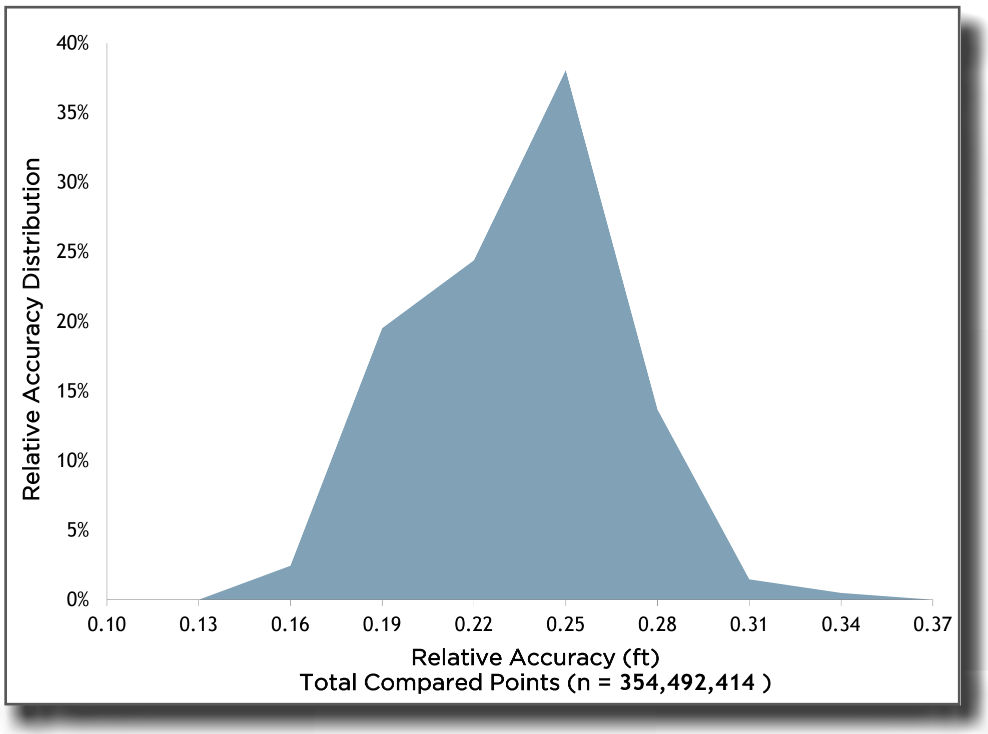
Accuracy

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 90 flightlines and over 354,492,414 sample LiDAR points. Relative accuracy is reported for the entire study area.

Relative Accuracy Distribution.



Relative Accuracy Calibration Results	
Number of Flightlines	90
Number of Sample LiDAR Points	352,154,741
Project Average	0.0392 m 0.1287 ft.
Median Relative Accuracy	0.0323 m 0.1060 ft.
1σ Relative Accuracy	0.0479 m 0.1572 ft.
2σ Relative Accuracy	0.0816 m 0.2678 ft.

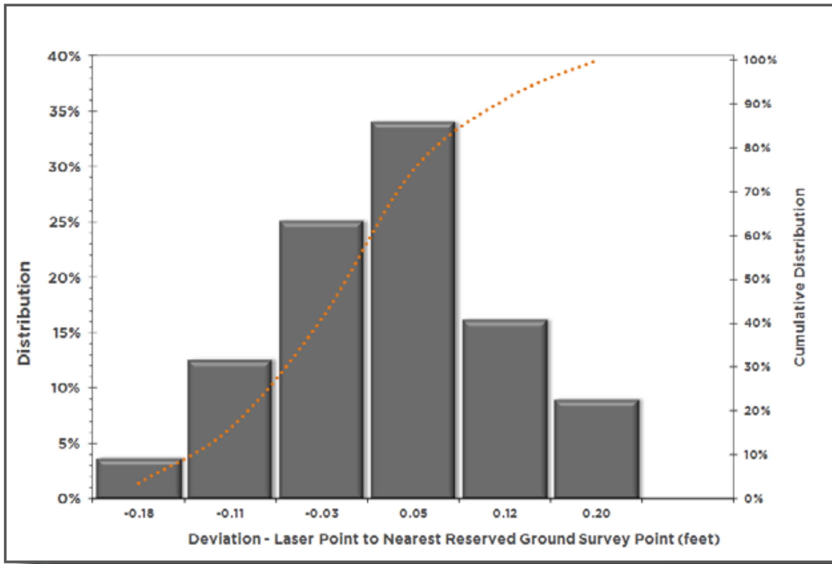
Vertical Accuracy

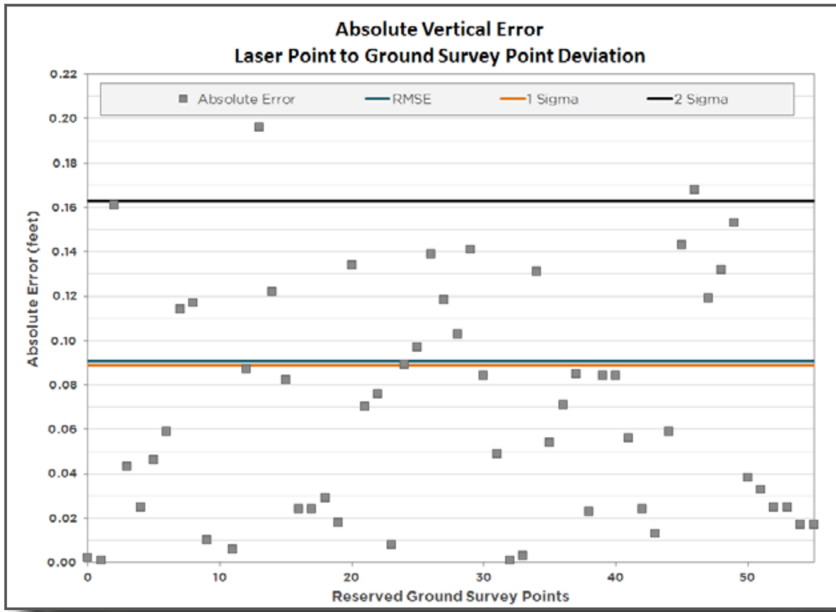
Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2014). The statistical model compares known ground survey points (GSPs) to 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 McKenzie River study area, a total of 1,723 GSPs were collected. An additional 56 reserved ground survey points were collected for independent verification, resulting in a non-vegetated vertical accuracy (NVA) of 0.054 meters.

Vertical Accuracy Results	Hard Surface
Sample Size (n)	n = 56 GSPs
NVA (RMSE*1.96)	0.054 m (0.178 ft.)
Root Mean Square Error	0.028 m (0.091 ft.)
1 Standard Deviation	0.027 m (0.089 ft.)
2 Standard Deviations	0.050 m (0.163 ft.)
Average Magnitude of Deviation	0.022 m (0.073 ft.)
Minimum Deviation	-0.076 m (-0.248 ft.)
Maximum Deviation	0.049 m (0.161 ft.)

Vertical Accuracy Distribution

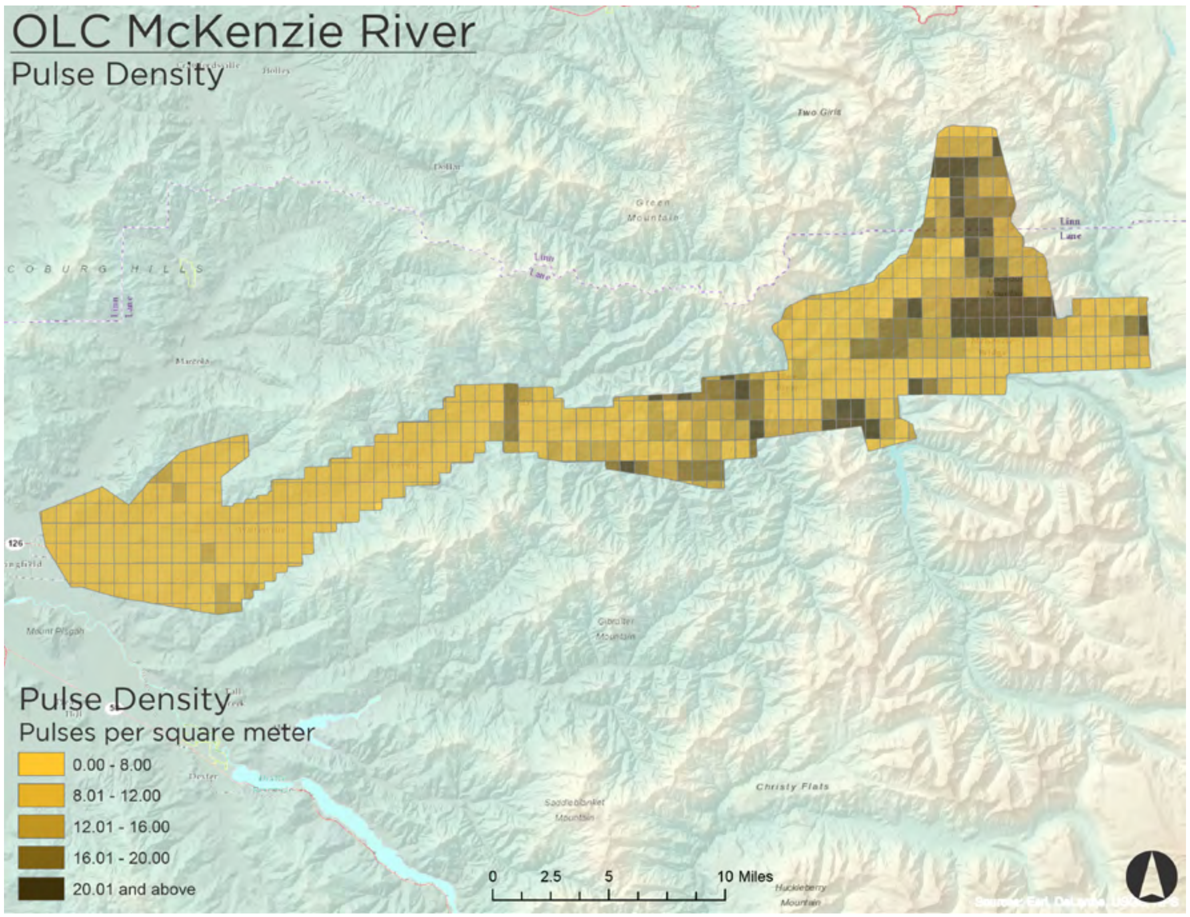




Density

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.

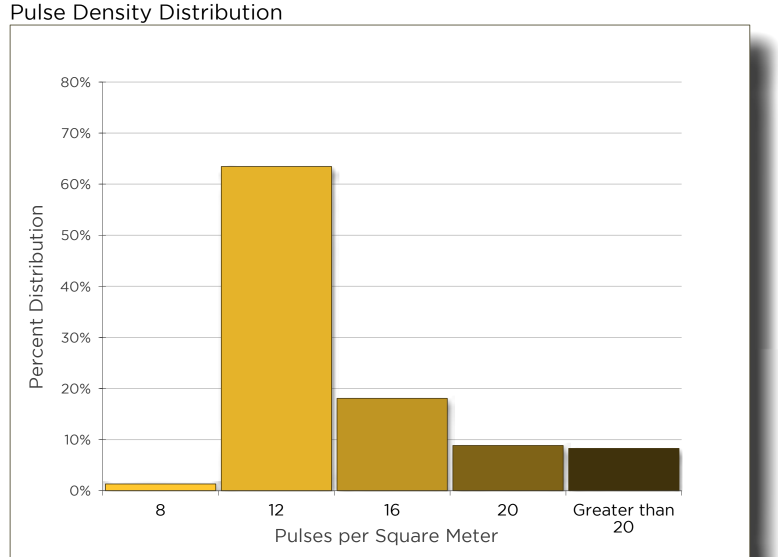


Average Pulse Density per 0.75' USGS Quad (color scheme aligns with density chart).

Pulse Density Distribution

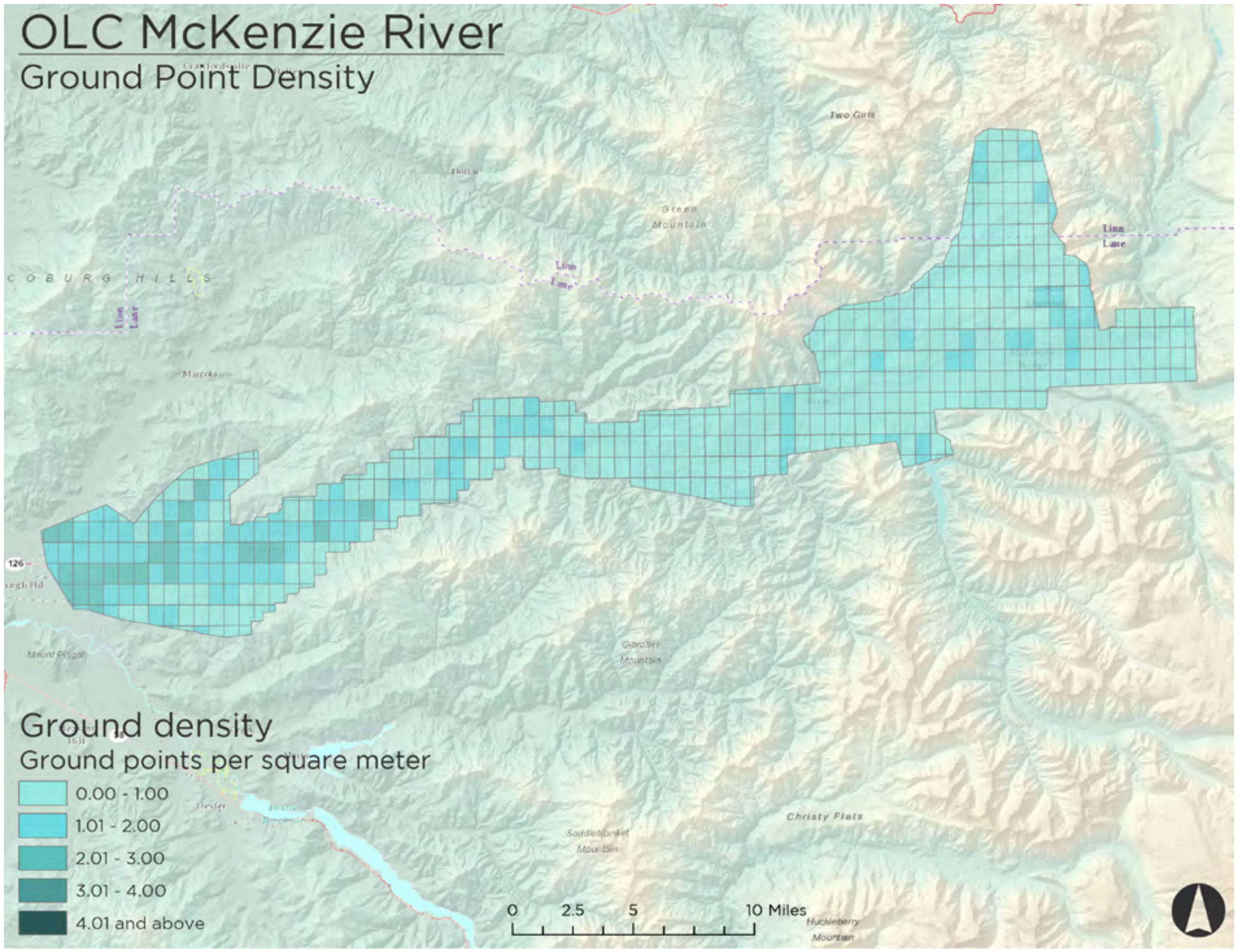
Average Point Densities			
Pulses per square meter	Pulses per square foot	Ground points per square meter	Ground points per square foot
12.49	1.16	0.89	0.08

Pulse Density Distribution

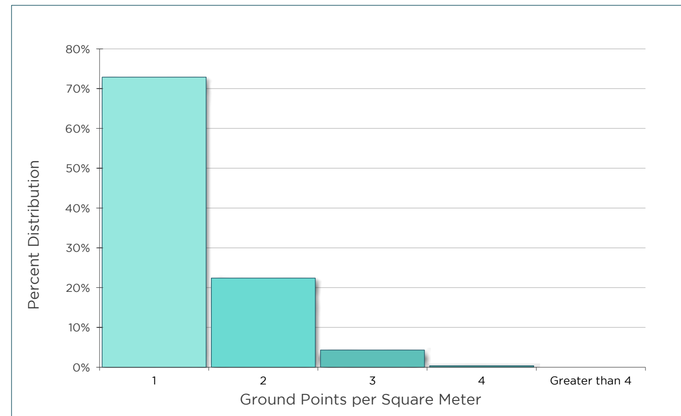


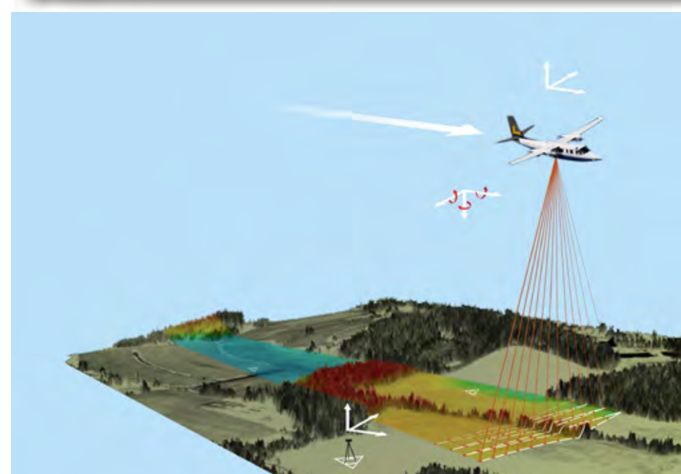
Ground Density

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).

Orthoimagery

Digital orthoimagery were collected using a 260 megapixel ultra large format digital aerial camera. Within the UltraMap software suite, raw acquired images are radiometrically and geometrically corrected using the camera's calibration files and output as Level Two images. The resulting radiometry is then manually edited to ensure that each image has the appropriate tone, no pixels are clipped, and each image is blended with its neighbors. Once radiometry has been edited, separate RGB and Panchromatic images are blended together to form single level three pansharpened four-band image and saved in a TIFF format for input to subsequent processes.

Photo position and orientation were 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. Within the Inpho software suite, automated aerial triangulation was performed to tie images together and align with ground control.

Autocorrelated digital elevation models were created for areas where publicly-available DEMs were not deemed sufficiently accurate. This was performed through Inpho's Match-T DSM extension, which utilizes dense image matching algorithms to derive a point cloud from acquired image frames and orientations. Bare-earth elevation models were generated through classification of the resulting point clouds. Adjusted images were then draped upon an auto-correlated ground model and orthorectified.

Individual orthorectified tiffs were blended together to remove seams and corrected for any remaining radiometric differences between images using Inpho's OrthoVista.

The processing workflow for orthoimagery is as follows:

Orthoimagery Processing Step	Software Used
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GPS (collected at two hertz) and static ground GPS (one hertz) data collected over geodetic controls.	Pos Pac MMS v. 7.1
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude will be calculated throughout the survey.	Pos Pac MMS v. 7.1
Create an exterior orientation (EO) files for each photo image with omega, phi, and kappa.	POS-EO and Pos Pac MMS v. 7.1
Convert "Level 00" raw imagery into geometrically corrected "Level 02" image files.	UltraMap Raw Data Center v. 3.9.1
Apply radiometric adjustments to "Level 02" image files to create "Level 03" Pan-sharpened tiffs.	UltraMap Radiometry v. 3.9.1
Apply EO to photos, measure ground control points, and perform aerial triangulation.	Inpho Match-AT v. 6.1
Import DEM, orthorectify, and clip triangulated photos to specified area of interest.	Inpho OrthoMaster v. 6.1
Mosaic orthorectified imagery, blending seams between individual photos and correcting for radiometric differences between photos.	Inpho Orthovista v. 6.1

Final Clipped Imagery

Orthophoto Accuracy

Orthophoto Accuracy Assessment

Image accuracy was measured using field surveyed air target locations, and if (due to acquisition constraints) the desired quantity of air targets was not able to be field surveyed, LiDAR-derived Ground Control Points (GCPs) are also used for accuracy assessment. Air target GPS points were measured against the placement of the air target in the imagery. In addition, GCPs were identified on the LiDAR intensity images in areas of clear visibility. Once the GCPs were identified in the intensity images, the exact spot was identified in the orthophotography, and the displacement was recorded for further statistical analysis. In order to support any and all desired user goals, Horizontal accuracy is reported based on 1) Field Surveyed Air Targets alone, 2) LiDAR-derived GCPs alone, and 3) The combination of Air Targets and GCPs that yields a statistically significant sample size.

The RMSEr for the OLC McKenzie River site was 1.185 ft. measured by ground survey points and air targets. RMSEr was computed based on the FGDC National Standard for Spatial Data Accuracy for horizontal accuracy where[1] RMSEr = ffl(RMSEx2+RMSEy2),

The Circular standard error for the OLC McKenzie River site was 0.827 ft. measured by ground survey points and air targets. Circular standard error (at 39.35% standard) was approximated based on the FGDC National Standard for Spatial Data Accuracy for horizontal accuracy[1] where RMSEx ≠ RMSEy: CSE= 0.5*(RMSEx+RMSEy).

The Horizontal Accuracy (ACCr) for the OLC McKenzie Rive site was 2.023 ft. measured by ground survey points and air targets. ACCr was computed based on the FGDC National Standard for Spatial Data Accuracy for horizontal accuracy[1] where RMSEx ≠ RMSEy: ACCr= 2.4477*0.5*(RMSEx+RMSEy).

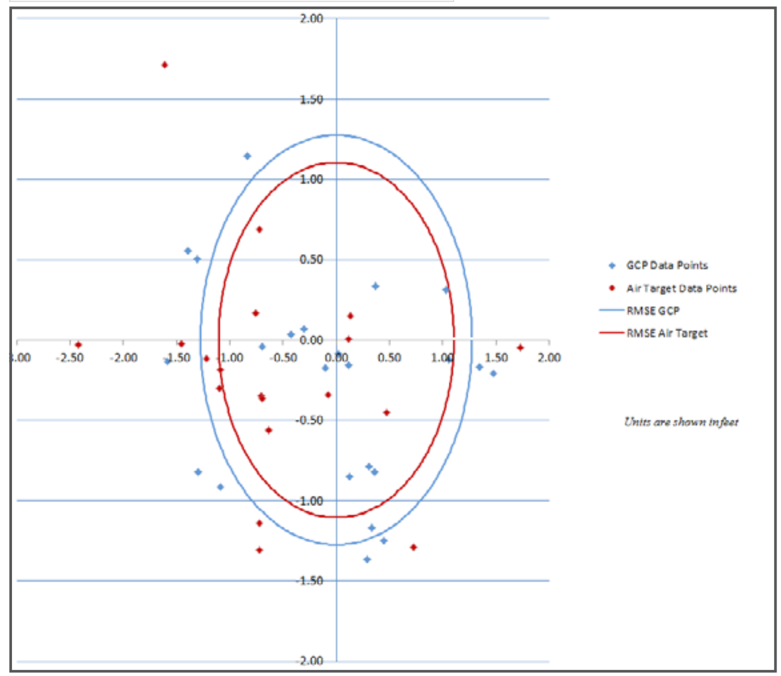
[1] Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards (FGDC-STD-007.3-1998). Part 3: National Standard for Spatial Data Accuracy, Appendix 3-A, page 3-10.

http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3

Orthophoto horizontal accuracy results calculated in feet.

	Air targets Only	derived GCP only	Air Target + GCP
Number of check points	23	19	42
RMSE			
RMSEx	0.873	1.069	0.967
RMSEy	0.678	0.695	0.686
RMSEr* -*defined as: √(RMSE$_x$^{2}+RMSE$_y$^{2})*	1.105	1.275	1.185
NSSDA Accuracy Reporting Standards			
IF RMSEx ≠ RMSEy			
Circular standard error at 39.35% confidence level	0.776	0.882	0.827
Horiz Accuracy (ACCr) at 95% Confidence Level**	1.898	2.159	2.023
IF RMSEx = RMSEy			
Horiz Accuracy (ACCr) at 95% Confidence Level**	N/A	N/A	N/A

NSSDA horizontal accuracy definitions:
*$RMSE_r$ is defined as: $\sqrt{(RMSE_x^2+RMSE_y^2)}$
** Horizontal Accuracy (ACCr) at 95% Confidence Level:
If $RMSE_x \neq RMSE_y$: $2.4477*0.5*(RMSE_x+RMSE_y)$ If $RMSE_x = RMSE_y$: $1.7308*RMSE_r$



Scatterplot displaying the XY deviation of aerial targets and LiDAR derived GCPs when compared to the orthophoto imagery.

[Page Intentionally Blank]

Appendix
PLS Certification

Quantum Spatial, Inc. provided LiDAR services for the 2016 McKenzie River 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 between May 26, 2016 and June 21, 2016.

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".

REGISTERED
PROFESSIONAL
LAND SURVEYOR

OREGON
JUNE 10, 2014
EVON P. SILVIA
81104LS

EXPIRES: 06/30/2018

Evon P. Silvia, PLS
Quantum Spatial, Inc.
Corvallis, OR 97333