OLC Harney Basin

Applied
Remote Sensing
and Analysis

Data collected for:

Department of Geology and Mineral Industries

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Project Overview

WSI, a Quantum Spatial company, has collected Light Detection and Ranging (LiDAR) data for the Oregon LiDAR Consortium (OLC) Harney Basin study area. This study area is located in southeastern Oregon.

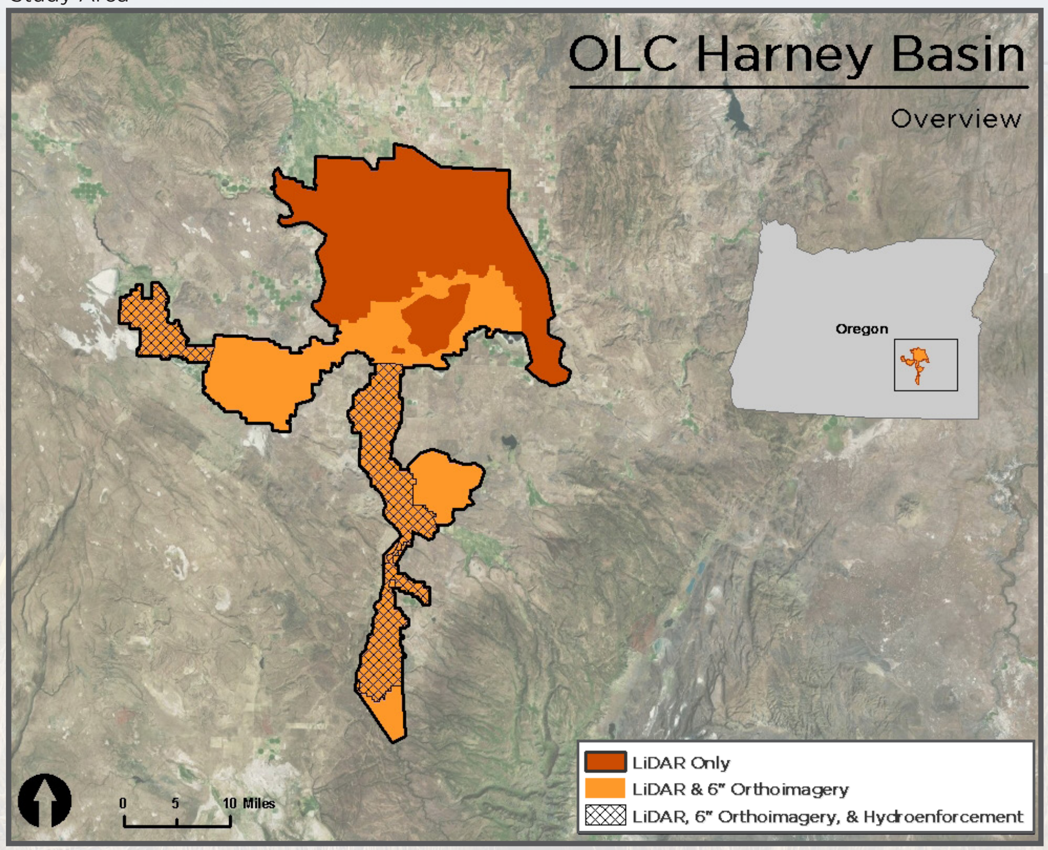
The collection of high resolution geographic data is part of an ongoing pursuit to amass a library of information accessible to government agencies as well as the general public.

In October 2014 WSI employed remote-sensing lasers in order to obtain a total area flown of 405,647 acres. Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter. Six-inch orthophotos were collected in July 2015 and were delivered on October 16, 2015.

Final products created include RGB extracted LiDAR point cloud data, three foot digital elevation models of highest hit and bare earth ground models, hydro-enforced bare earth ground models, and ground density rasters, 1.5 foot intensity rasters, study area vector shapes, stream centerlines, hydro-enforced lake polygons, 6-inch orthoimagery, and corresponding statistical data. Final deliverables are projected in Universal Transverse Mercator (UTM) 11 North.

Harney Basin Data	
LiDAR Acquisition Dates	October 15, 2014 - March 1, 2015
Orthoimagery Acquisition Dates	July 19 - July 23, 2015
Total Area Flown LiDAR Acreage	405,647 acres
LiDAR & 6” Orthoimagery	201,925 acres
LiDAR, 6” Orthoimagery, & Hydroenforced	80,394 acres
Projection	Universal Transverse Mercator (UTM) 11 North
Datum: horizontal & vertical	NAD83 (2011) NAVD88 (Geoid 12A) Epoch 2010.00
Units	Meters

Study Area



Aerial Acquisition

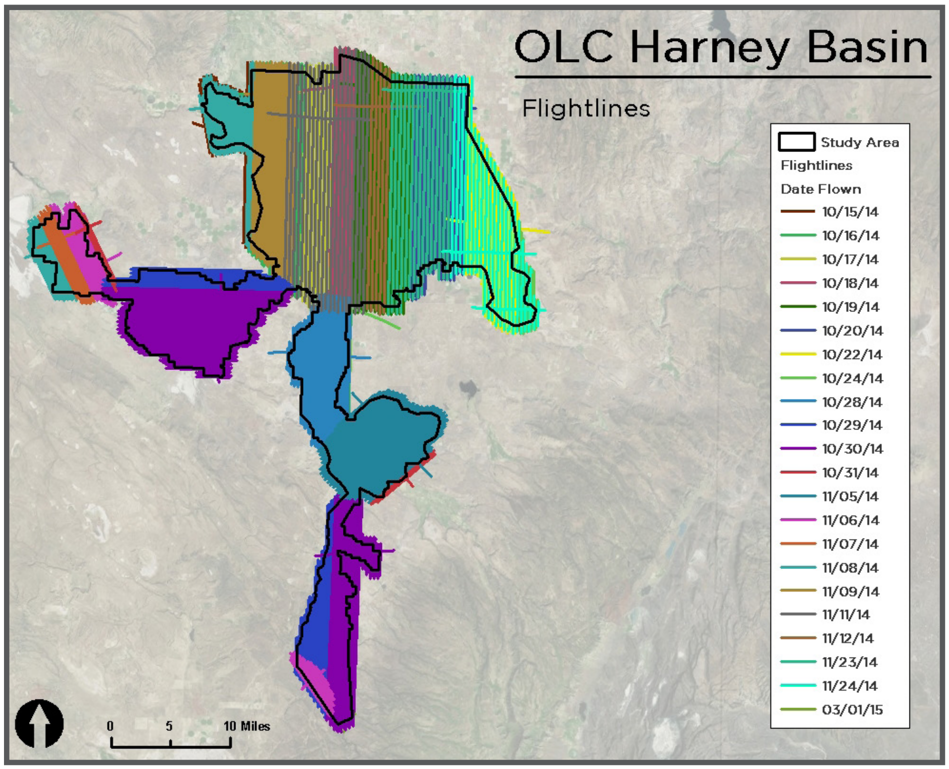
LiDAR Survey

The LiDAR survey occurred between October 15, 2014 and March 1, 2015 utilizing a Leica ALS 50 sensor mounted in a Cessna 208 Grand Caravan. The system was programmed to emit single pulses at around 148.8 kHz and were flown at 1,500 meters above ground level (AGL), capturing a scan angle of 12 degrees from nadir (field of view equal to 24 degrees). 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 WSI LiDAR systems are calibrated per the manufacturer and our own specifications, and tested by WSI for internal consistency for every mission using proprietary methods.

Project Flightlines



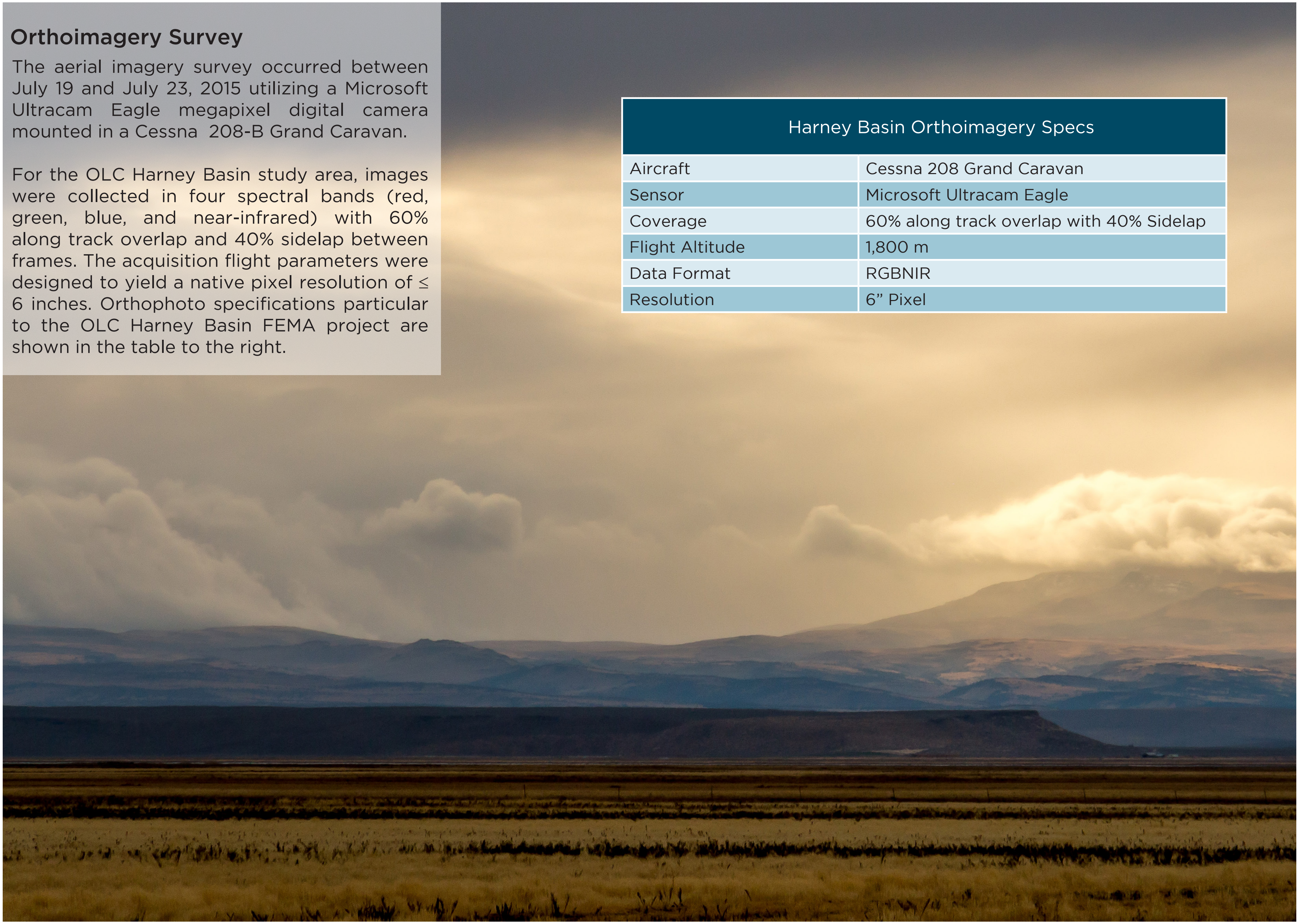
Harney Basin LiDAR Acquisition Specs	
Aircraft	Cessna 208 Grand Caravan
Sensor	Leica ALS 50
Coverage	100% Overlap with 60% Sidelap
Field of View (FOV)	24°
Targeted Pulse Density	≥ 8 pulses per square meter

Orthoimagery Survey

The aerial imagery survey occurred between July 19 and July 23, 2015 utilizing a Microsoft Ultracam Eagle megapixel digital camera mounted in a Cessna 208-B Grand Caravan.

For the OLC Harney Basin study area, images were collected in four spectral bands (red, green, blue, and near-infrared) with 60% along track overlap and 40% sidelap between frames. The acquisition flight parameters were designed to yield a native pixel resolution of ≤ 6 inches. Orthophoto specifications particular to the OLC Harney Basin FEMA project are shown in the table to the right.

Harney Basin Orthoimagery Specs	
Aircraft	Cessna 208 Grand Caravan
Sensor	Microsoft Ultracam Eagle
Coverage	60% along track overlap with 40% Sidelap
Flight Altitude	1,800 m
Data Format	RGBNIR
Resolution	6” Pixel



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.

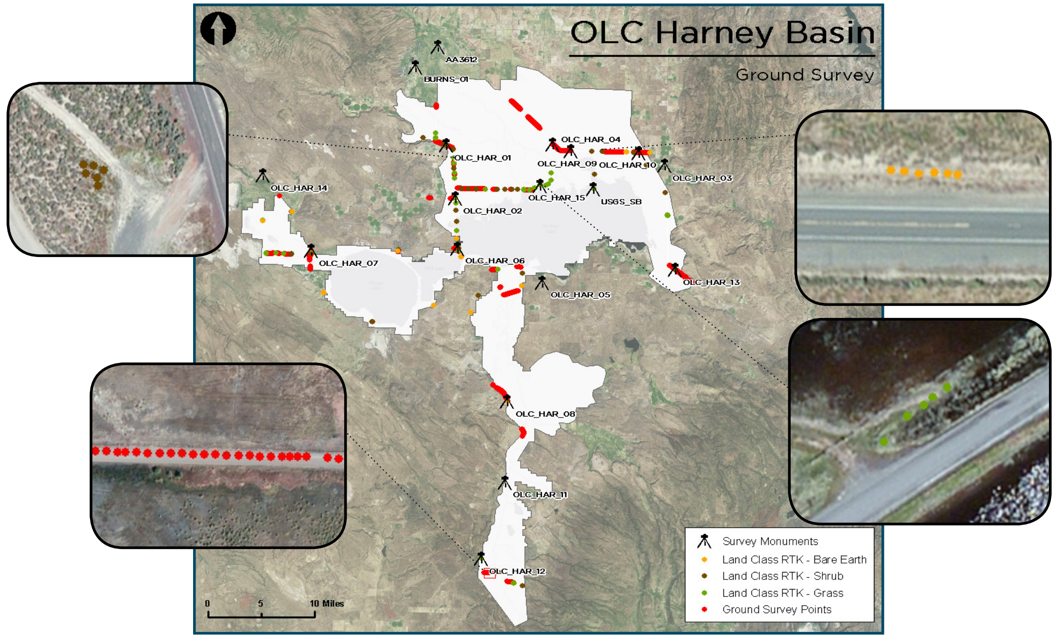
Instrumentation

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, 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 the OLC Harney Basin study area.

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



PID	Latitude	Longitude	Ellipsoid (m)	NAVD88 Height (m)
AA3612	43° 35' 12.75421"	-119° 01' 12.92687"	1246.862	1265.939
BURNS_01	43° 33' 24.84714"	-119° 03' 39.28528"	1244.709	1263.846
OLC_HAR_01	43° 26' 38.17970"	-119° 00' 00.59290"	1315.073	1334.400
OLC_HAR_02	43° 22' 02.87026"	-118° 58' 50.13588"	1235.986	1255.340
OLC_HAR_03	43° 25' 15.73915"	-118° 35' 28.35984"	1240.283	1259.158
OLC_HAR_04	43° 26' 55.42365"	-118° 48' 03.23293"	1232.331	1251.530
OLC_HAR_05	43° 14' 51.28831"	-118° 48' 52.39015"	1240.150	1259.305
OLC_HAR_06	43° 17' 40.03914"	-118° 58' 28.33935"	1232.415	1251.791
OLC_HAR_07	43° 17' 10.37884"	-119° 14' 49.25461"	1235.275	1254.854
OLC_HAR_08	43° 04' 24.68599"	-118° 52' 27.62120"	1244.395	1263.706
OLC_HAR_09	43° 26' 22.17204"	-118° 46' 00.73490"	1233.833	1253.003
OLC_HAR_10	43° 26' 20.58303"	-118° 38' 24.82591"	1237.414	1256.378
OLC_HAR_11	42° 57' 21.67392"	-118° 52' 31.79275"	1250.624	1269.775
OLC_HAR_12	42° 50' 40.38553"	-118° 54' 57.74254"	1261.321	1280.605
OLC_HAR_13	43° 16' 11.97387"	-118° 34' 05.57282"	1233.850	1252.721
OLC_HAR_14	43° 23' 37.80584"	-119° 20' 26.75632"	1301.975	1301.976
OLC_HAR_15	43° 23' 18.83931"	-118° 49' 23.60840"	1230.459	1249.698
USGS_SB	43° 23' 05.38408"	-118° 43' 23.99386"	1229.829	1248.953

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

Methodology

To correct the continuously recorded onboard measurement of the aircraft position, WSI 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), 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.

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.

Below: Ground professional collecting ground survey points.

Land cover descriptions of check points taken for the OLC Harney Basin study area.

Land Cover Type	Land Cover Code	Description
Bare Earth	BARE	Bare Earth, Concrete
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
Trimble R10	Integrated Antenna R10	TRMR10	Rover

Accuracy

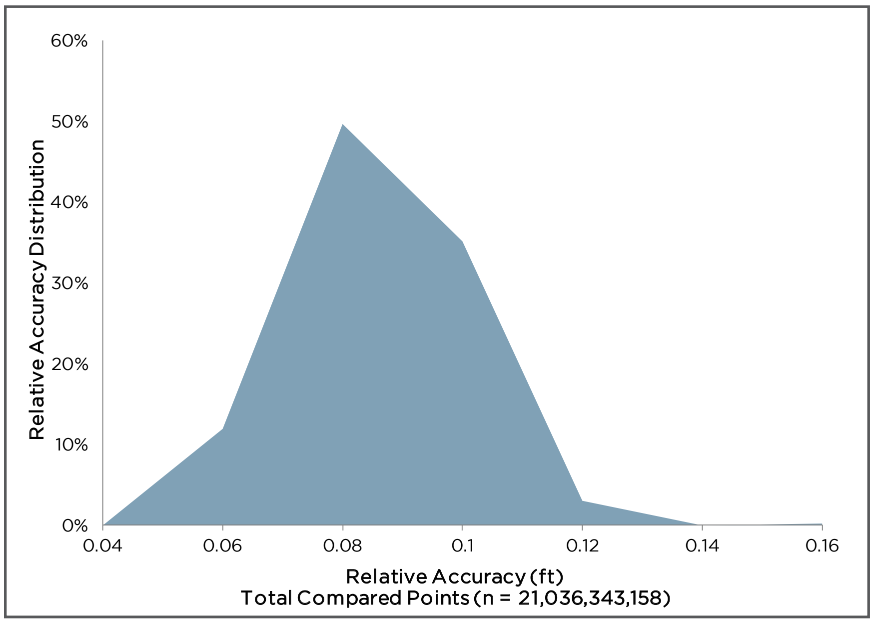
Relative Accuracy

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 427 flightlines and over 21 billion LiDAR points. Relative accuracy is reported for the entire study area.

Relative Accuracy Calibration Results	
Project Average	0.08 ft. (0.02 m)
Median Relative Accuracy	0.08 ft. (0.02 m)
1σ Relative Accuracy	0.08 ft. (0.02 m)
2σ Relative Accuracy	0.10 ft. (0.03 m)

Relative Accuracy Distribution.



Below: Trimble R8 receiver set up over survey monument OLC HAR_04 (**left**).

Vertical Accuracy

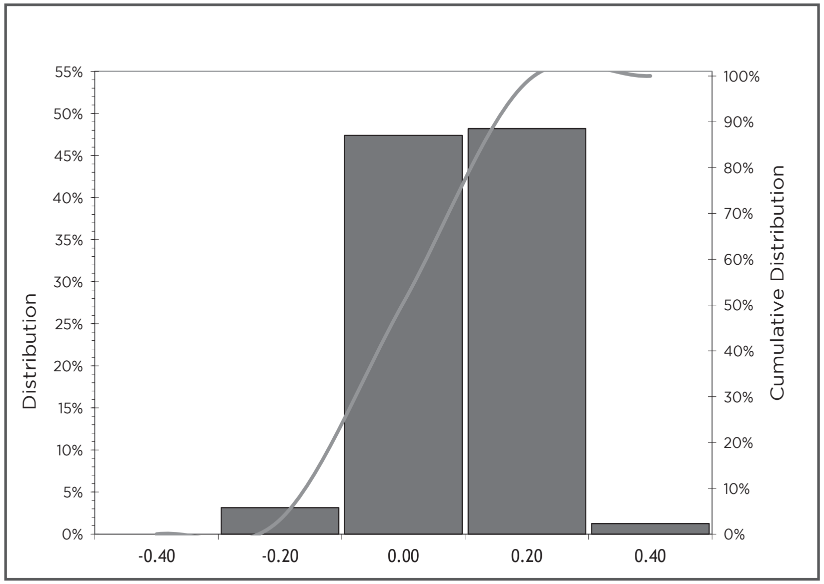
Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). The statistical model compares known Ground Survey Points (GSPs) to 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 Harney Basin study area, 7,697 GSPs were collected.

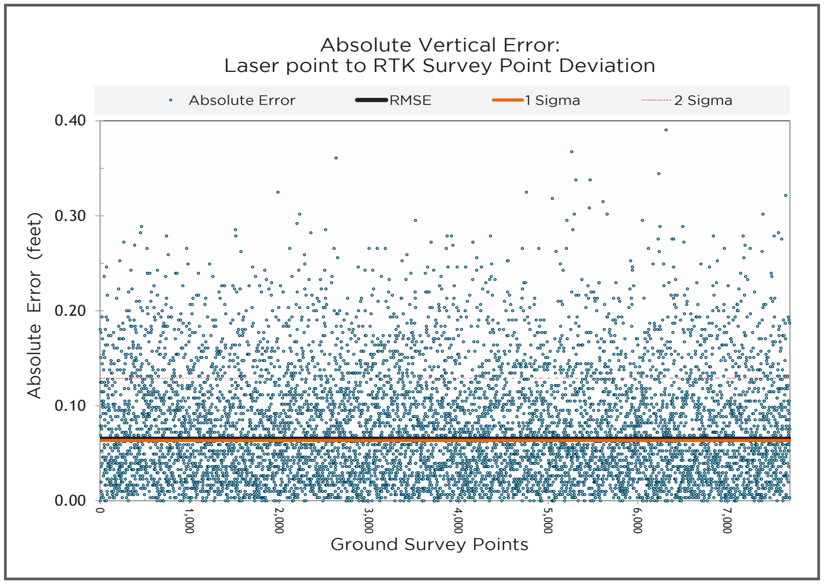
For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet." Vertical Accuracy is reported for the entire study area and reported in the table below. Histogram and absolute deviation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

Vertical Accuracy Results	Hard Surface
Sample Size (n)	7,697 GSPs
FVA (RMSE*1.96)	0.19 ft. (0.06 m)
Root Mean Square Error	0.10 ft. (0.03 m)
1 Standard Deviation	0.10 ft. (0.03 m)
2 Standard Deviations	0.19 ft. (0.06 m)
Average Deviation	0.08 ft. (0.02 m)
Minimum Deviation	-0.39 ft. (-0.12 m)
Maximum Deviation	0.34 ft. (0.11 m)

Vertical Accuracy Distribution



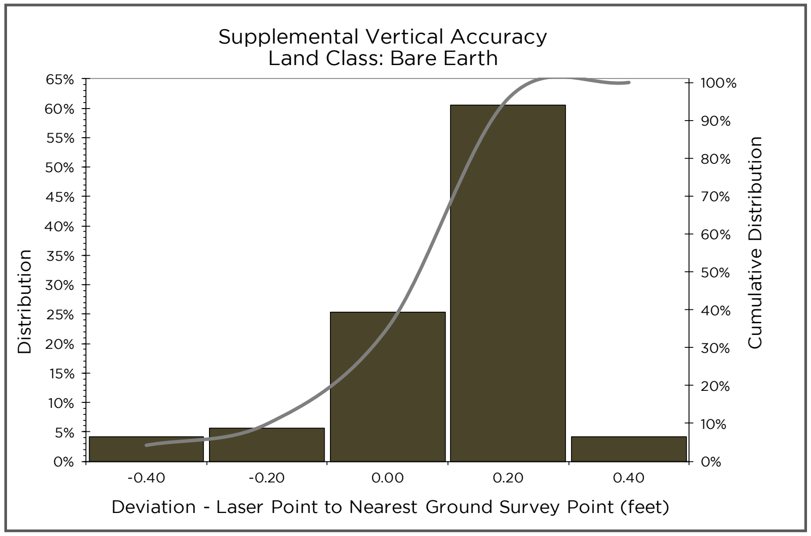
Absolute Vertical Error

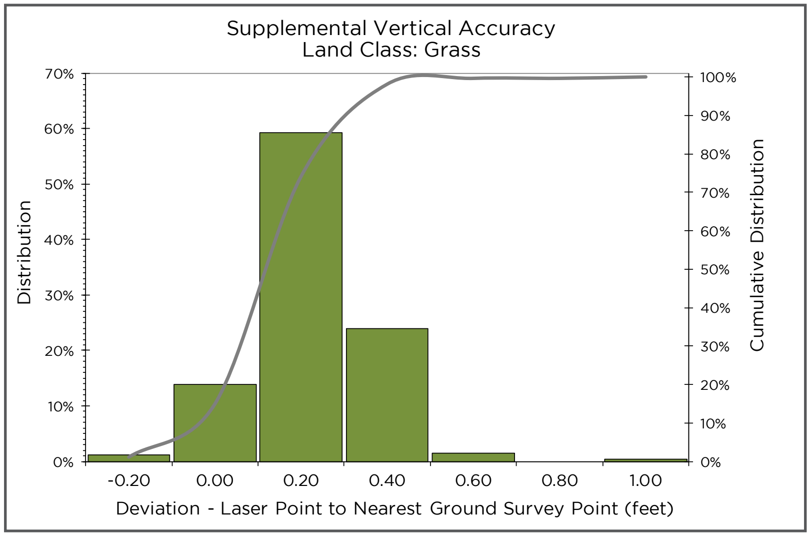


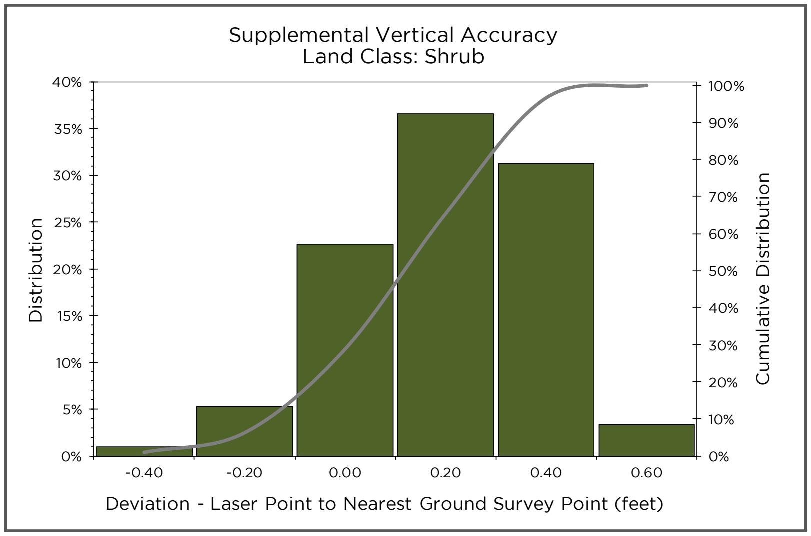
Supplemental and Consolidated Vertical Accuracies

WSI also assessed absolute vertical accuracy for the OLC Harney Basin 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
	Hard Surface	Grass	Shrub	Bare Earth	All Land Cover Classes
Sample Size (n)	7,697 GSPs	267 GSPs	208 GSPs	71 GSPs	8,243 GSPs
FVA (RMSE*1.96)	0.19 ft. 0.06 m	0.25 ft. 0.08 m	0.37 ft. 0.11 m	0.30 ft. 0.09 m	0.21 ft. 0.06 m
Root Mean Square Error	0.10 ft. 0.03 m	0.13 ft. 0.04 m	0.19 ft. 0.06 m	0.15 ft. 0.05 m	0.11 ft. 0.03 m
1 Standard Deviation	0.10 ft. 0.03 m	0.18 ft. 0.06 m	0.23 ft. 0.07 m	0.13 ft. 0.04 m	0.10 ft. 0.03 m
2 Standard Deviations	0.19 ft. 0.06 m	0.34 ft. 0.10 m	0.40 ft. 0.12 m	0.27 ft. 0.08 m	0.21 ft. 0.06 m
Average Deviation	0.08 ft. 0.02 m	0.15 ft. 0.04 m	0.18 ft. 0.05 m	0.12 ft. 0.04 m	0.00 ft. 0.00 m
Minimum Deviation	-0.39 ft. -0.12 m	-0.24 ft. -0.07 m	-0.48 ft. -0.15 m	-0.44 ft. -0.13 m	-0.48 ft. -0.15 m
Maximum Deviation	0.34 ft. 0.11 m	0.81 ft. 0.25 m	0.52 ft. 0.16 m	0.26 ft. 0.08 m	0.81 ft. 0.25 m







Digital Imagery Accuracy Assessment

Image accuracy was measured by air target locations and independent ground survey points. Air target GPS points were measured against the placement of the air target in the imagery. In addition, ground survey points were identified on the LiDAR intensity images in areas of clear visibility. Once the ground survey points were identified in the intensity images, the exact spot was identified in the orthophotography, and the displacement was recorded for further statistical analysis.

The circular standard error (CSE) at 95% confidence for the OLC Harney Basin study area was 0.095 meters, measured by ground survey points and air targets. The CSE at 39.35% confidence was 0.039 meters. Circular standard error was approximated based on the FGDC National Standard for Spatial Data Accuracy for horizontal accuracy.[1]

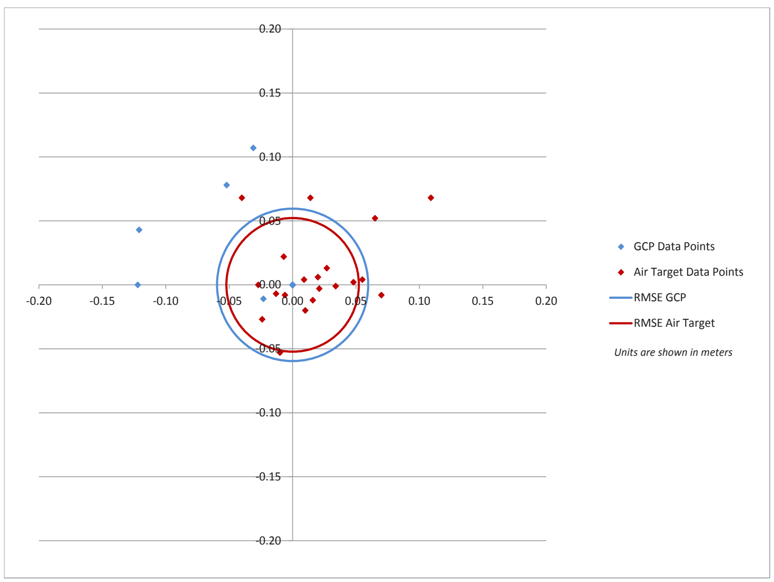
Circular Standard Error	
39.35% Confidence	95% Confidence
0.039 m	0.095 m

The CSE (at 95% conficence) was computed as follows:

where $RMSE_x \neq RMSE_y$: $CSE \sim 2.4477*0.5*(RMSE_x+RMSE_y)$

The CSE (at 39.35% confidence) was computed as follows:

where $RMSE_x \neq RMSE_y$: $CSE \sim 0.5*(RMSE_x+RMSE_y)$



Ground Check Points			
Sample Size: n=5			
	Check Points$_x$	Check Points$_y$	Check Points$_{xy}$
Mean	-0.023	0.014	0.027
Average Magnitude	0.023	0.016	0.028
RMSE	0.047	0.036	0.060
1σ	0.043	0.034	0.055
1.96σ	0.084	0.067	0.107

Air Targets			
Sample Size: n=20			
	Check Points$_x$	Check Points$_y$	Check Points$_{xy}$
Mean	0.019	0.008	0.020
Average Magnitude	0.031	0.022	0.038
RMSE	0.041	0.033	0.052
1σ	0.037	0.033	0.049
1.96σ	0.073	0.064	0.097

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

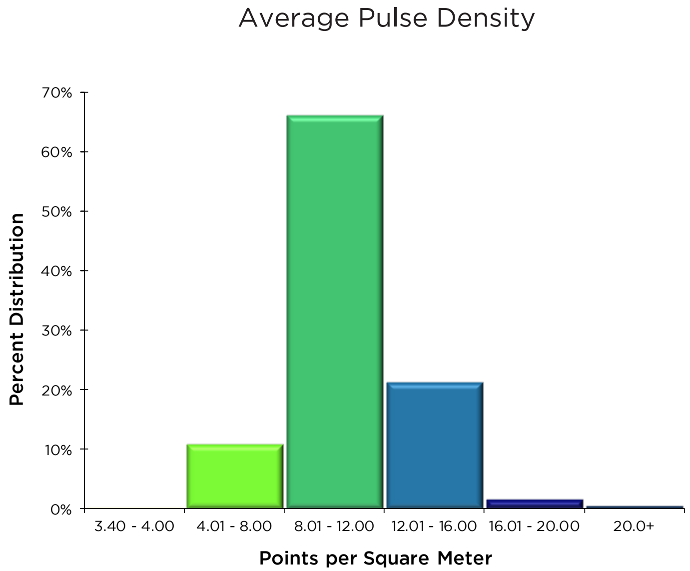
Density

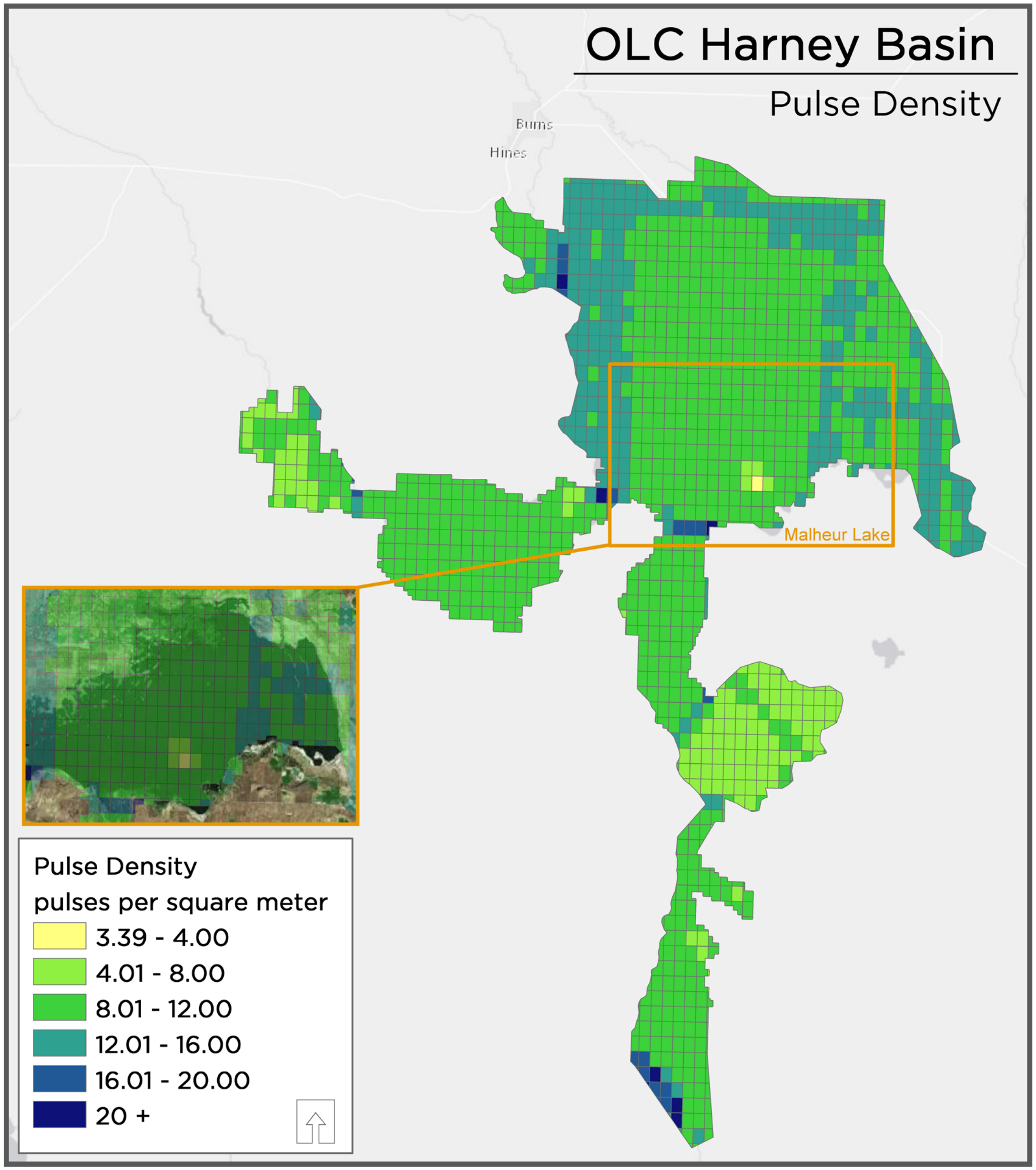
Pulse Density

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 foot	Pulses per square meter	Ground points per square foot	Ground points per square meter
1.00	10.81	0.35	3.73

Pulse Density Distribution



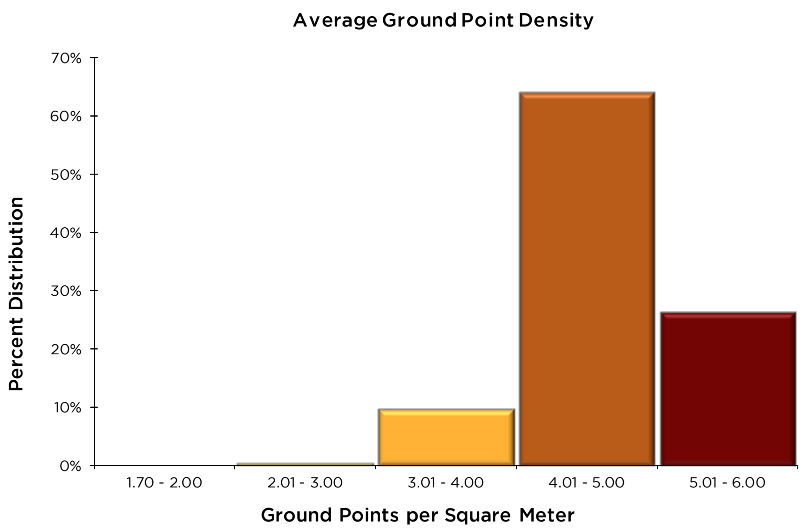


Average Pulse Density per 0.75' USGS Quad (color scheme aligns with density chart). Note area of lower pulse density within the Malheur Lake area, and other areas comprised of predominantly water.

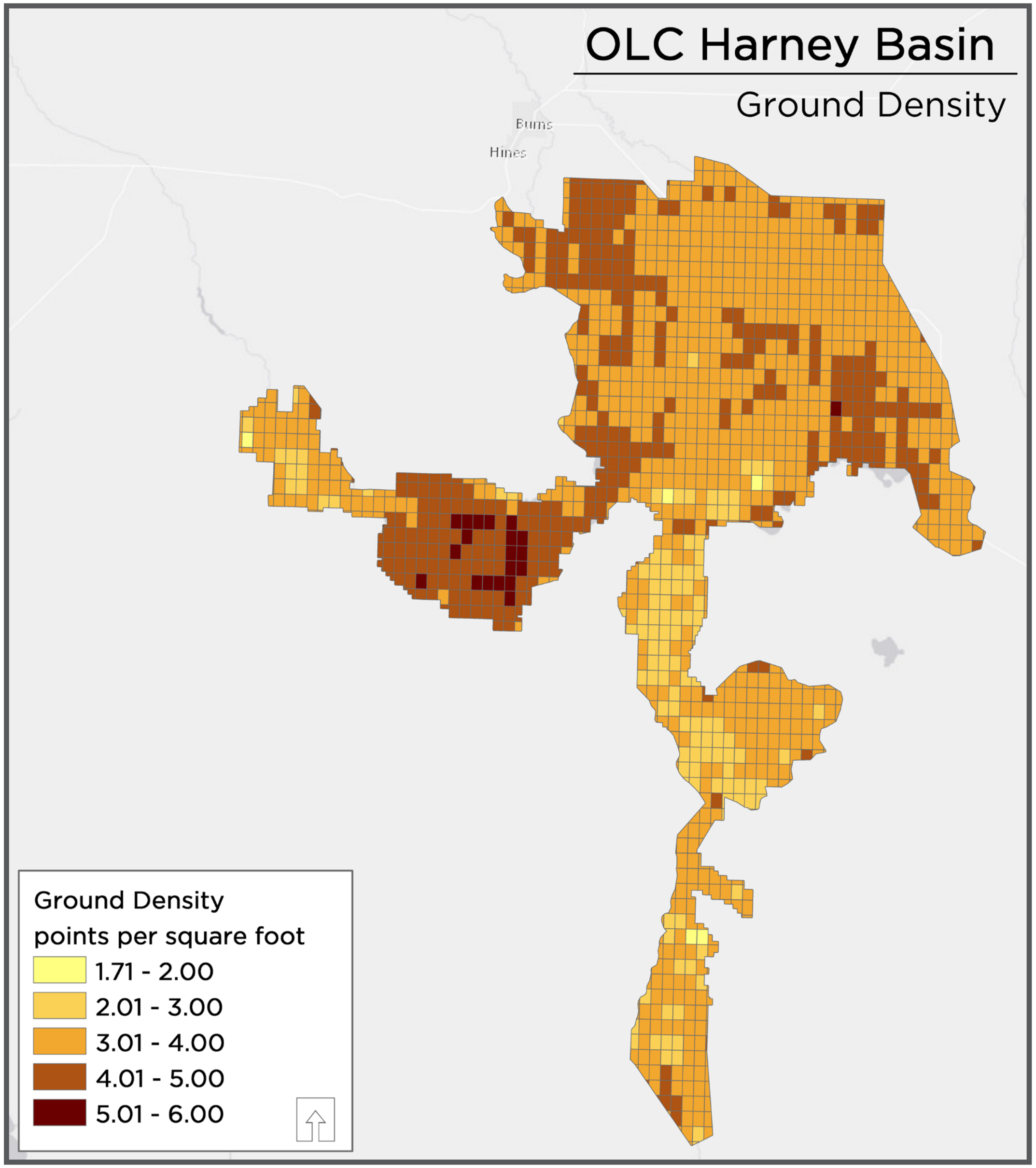
Ground Density

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 Harney Basin 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.

5/21/2015

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 October 14, 2014 and March 1, 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".

5/21/2015

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

REGISTERED
PROFESSIONAL
LAND SURVEYOR

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JUNE 2, 2010
CHRISTOPHER A. GLANTZ
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RENEWS 6/30/2015