2018 OLC Harney 3DEP

NOVEMBER 29, 2018

Data collected for:
Oregon Department of Geology and Mineral Industries

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Project Overview

QSI has completed the acquisition and processing of Light Detection and Ranging (LiDAR) data describing the Oregon LiDAR Consortium's (OLC) Harney 3DEP 2018 Study Area. The Harney TAF (total area flown) shown in Figure 1 encompasses 133,050.8 acres. Terminology used within this report aligns with OLC preferred language; Table 1 includes synonymous USGS 3DEP terminology.

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 occurred between August 3 and 4, 2018. Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter. Final products are listed on pages four and five.

QSI acquires and processes data in the most current, NGS-approved datums and geoid. For OLC Harney, 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 12B) vertical datum, with units in International feet.

For Harney 3DEP products, all final deliverables are projected in Universal Transverse Mercator (UTM) Zone 11 N, using the NAD83 (2011) horizontal datum and the NAVD88 (Geoid 12B) vertical datum, with units in meters.

Table 1: OLC/3DEP synonymous terminology

OLC Terminology	USGS 3DEP Terminology
Area of Interest (AOI)	Defined Project Area (DPA)
Total Area Flown (TAF)	Buffered Project Area (BPA)
Ground Survey Point (GSP)	Check Point
Ground Control Point (GCP)	Control Point

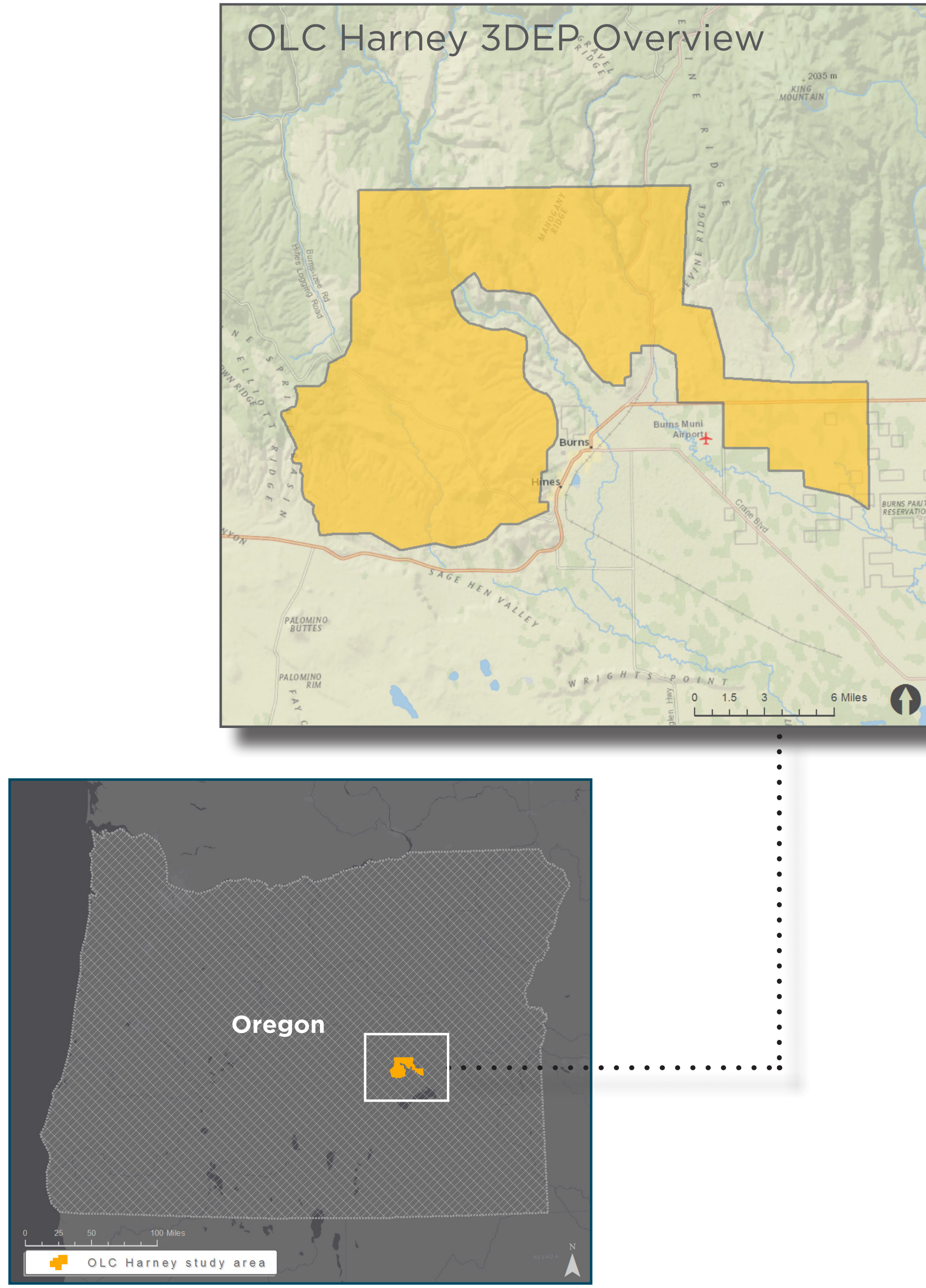

Figure 1: OLC Harney study area location

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

Table 2: OLC Harney delivery details

OLC Harney	
Acquisition Dates	August 3 & 4, 2018
Area of Interest	128,890.9 acres
Total Area Flown	133,050.8 acres
Projection	OGIC Lambert
Datum: horizontal & vertical	NAD83 (2011) NAVD88 (Geoid 12B)
Units	International Feet

Table 3: Harney 3DEP delivery details

Harney 3DEP	
Acquisition Dates	August 3 & 4, 2018
Defined Project Area	128,890.9 acres
Buffered Project Area	133,050.8 acres
Projection	UTM 11N
Datum: horizontal & vertical	NAD83 (2011) NAVD88 (Geoid 12B)
Units	Meters

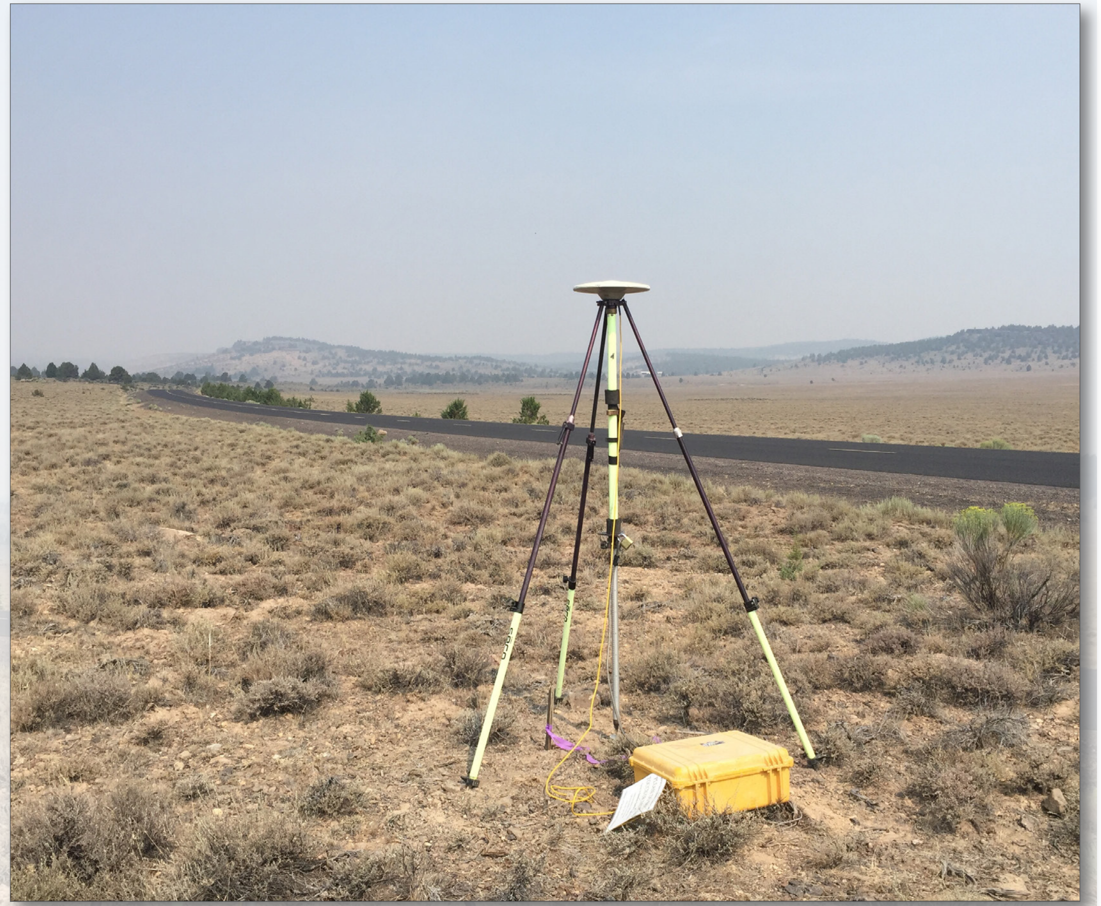

Figure 2: Zephyr GNSS Geodetic Model 2 antenna set up over HARNEY18_01 monument

Deliverable OLC Products

Table 4: Products delivered for OLC Harney study area.

OLC Harney Projection: OGIC Lambert Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID12B) Units: International Feet	
Points	LAS v 1.2 tiled by 0.075 minute USGS quadrangles • Default (1), and ground (2) classified points • RGB color extracted from NAIP imagery • Intensities
Rasters	3 foot resolution ESRI GRID tiled by 7.5 minute USGS quadrangles • Bare earth model • Highest hit model 1.5 foot GeoTiffs tiled by 7.5 minute USGS quadrangles • Intensity images
Vectors	Shapefiles (*.shp) • Total area flown (TAF) boundary • TAF tile index of 0.075 minute USGS quadrangles • TAF tile index of 7.5 minute USGS quadrangles • Ground control points • Ground survey points (used to assess accuracy) • Survey monuments • Acquisition flightlines
Metadata	• FGDC compliant metadata for all data products

Deliverable 3DEP Products

Table 5: Products delivered for Harney 3DEP study area.

Harney 3DEP Projection: UTM 11N Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID12B) Units: meters	
Points	LAS v 1.4 tiled by 750 meter processing tiles • Default (1), ground (2), low noise (7), water (9), bridge decks (17), high noise (18) classified points LAS v 1.4 Swath files • Unclassified points
Rasters	1 meter resolution ESRI GRID tiled to match 750 meter LAS processing tiles • Hydroflattened bare earth model
Vectors	Shapefiles (*.shp) • Defined project area (DPA) • Buffered project area (BPA) • 750 meter LAS tiling scheme, clipped to the DPA • Hydro breaklines in file geodatabase • Check points used for testing Non-Vegetated Vertical Accuracy • Check points used for testing Vegetated Vertical Accuracy • Ground control points used for LiDAR calibration • Project survey monuments
Metadata	• USGS-compliant metadata for all data products, as well as project-level metadata.

Aerial Acquisition

LiDAR Survey

The LiDAR survey utilized a Galaxy Optech Prime sensor mounted in a Cessna Caravan. Data were acquired beginning on August 3, 2018 and ending the following morning of August 4, 2018 . For system settings, please see Table 6. 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 50 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 data set.

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).

Table 6: OLC Harney acquisition specifications

OLC Harney Acquisition	
Sensors Deployed	Optech Galaxy Prime
Aircraft	Cessna Caravan
Survey Altitude (AGL)	1,600 m
Pulse Rate	650 kHz
Pulse Mode	Multi (MPiA)
Field of View (FOV)	57.25°
Scan Rate	69.87 Hz
Overlap	100% overlap with 50% sidelap

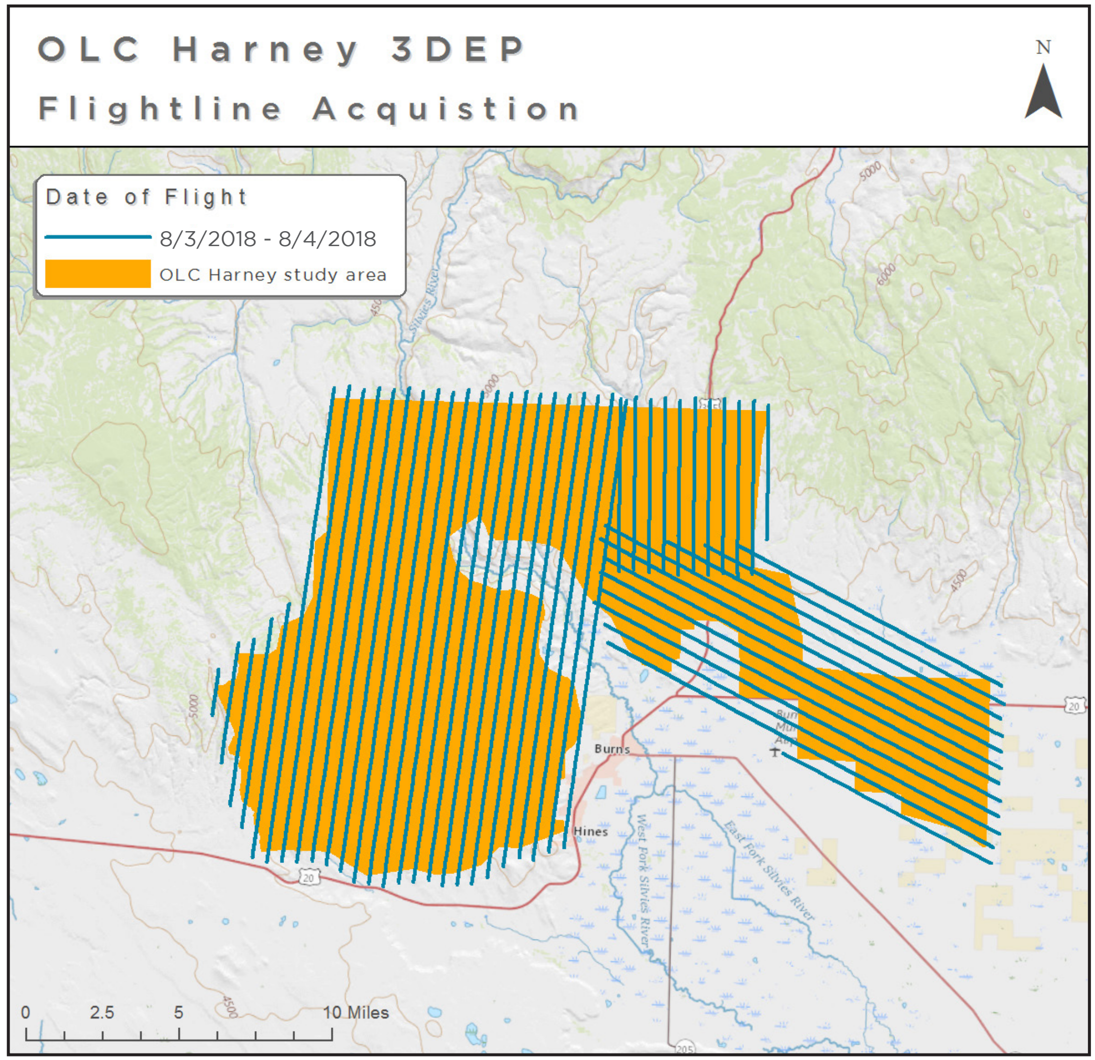

Figure 3: OLC Harney acquisition flightlines

Ground Survey

Ground control surveys were conducted to support data acquisition, including monumentation, ground control points (GCPs), and ground survey points (GSPs). Bare earth GCPs were collected to correct the final dataset to match the true ground surface and correct any bias from the satellite-based aircraft positional data, sensor installation, or sensor ranging. GSPs, however, were withheld from the calibration process and compared to the final ground surface (within vegetated and non-vegetated land cover) providing an independent assessment of the non-vegetated and Vegetated Vertical Accuracy of the LiDAR point data. Survey monuments were utilized to support collection of GCPs and GSPs. A table of the monuments used during ground survey are included in Table 7 on the page 9.

Instrumentation

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

Monumentation

Monuments were used for collection of ground control points and ground survey points using real time kinematic (RTK), post processed kinematic (PPK), and fast static (FS) survey techniques. Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GCP/GSP coverage. 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.

Methodology

Ground control points and ground survey points were collected using real time kinematic (RTK), post-processed kinematic (PPK), and fast static (FS) survey techniques. For RTK surveys, a base receiver was positioned at a nearby monument to broadcast a kinematic correction to a roving receiver; for PPK and FS surveys, however, these corrections were post-processed. RTK and PPK surveys recorded observations for a minimum of five seconds, while FS surveys recorded observations for up to fifteen minutes on each GCP/GSP in order to support longer baselines for post-processing. All GCP and GSP measurements were 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 were requred to 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 and GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads. GCPs and GSPs were taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. GCPs and 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.

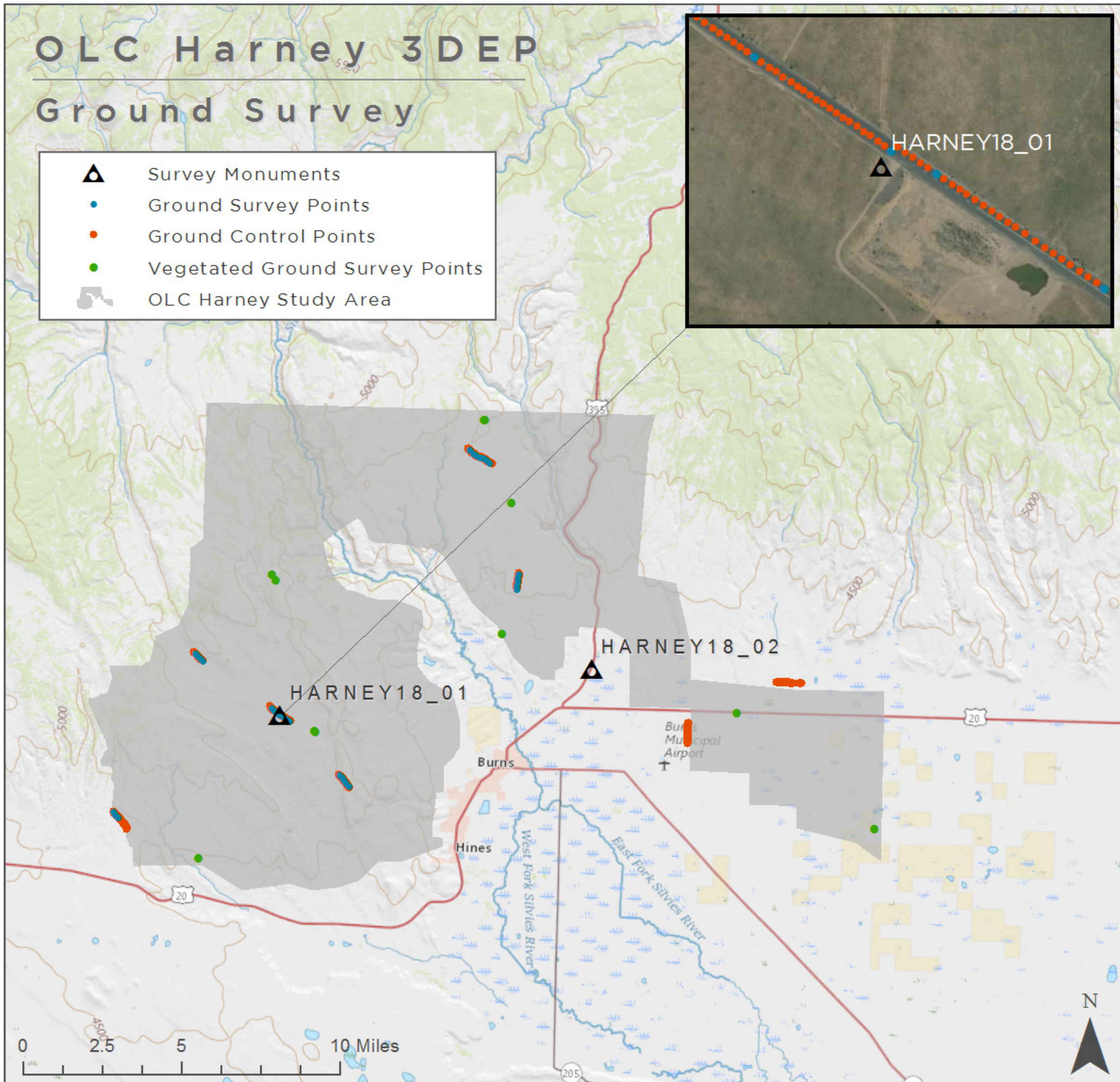

Figure 4: Harney study area ground survey map

Figure 5: OLC Harney Bare Earth GSP

Figure 6: HARNEY18_01 monument cap

Table 7: OLC Harney monuments. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12B

PID		Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
QSI Monuments	HARNEY18_01	43° 36' 27.63887"	-119° 11' 53.06752"	1415.567	1434.589
	HARNEY18_02	43° 37' 56.84197"	-119° 00' 08.90518"	1255.817	1274.785

Table 8: 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 GNSS	Integrated Antenna	TRMR8_GNSS	Rover

Table 9: Monument accuracy

Network Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	2 cm
St Dev Z	2 cm

Geospatial Corrections of Aircraft Positional Data

PP-RTX

To improve precision and accuracy of the aircraft trajectory, the latest generation of Global Navigation Satellite System (GNSS) satellites and recent advances in GNSS post-processing technology have made possible trajectory processing methods that do not require conventional base support: specifically, Trimble® CenterPoint™ Post-Processed Real-Time Extended (PP-RTX).

PP-RTX using Applanix POSPac MMS software leverages near real-time atmospheric models from Trimble's extensive worldwide network of continuously operating base stations to produce highly accurate trajectories.

When utilized properly and sufficiently controlled by a ground survey during post-processing, PP-RTX has the following advantages over conventional collection methods:

- Agility: The airborne acquisition is untethered by access constraints of the ground survey team at the time of acquisition, particularly in remote areas that lack permanent base stations.
- Flexibility: The airborne acquisition team can instantly shift collection priorities based on weather and client needs without waiting for a ground survey team to relocate.
- Accuracy: If properly controlled with a ground survey and datum adjustment during post-processing, PP-RTX produces results at least as accurate as conventional methods utilizing base stations.

Processing

This section describes the processing methodologies for all data acquired by QSI for the 2018 OLC Harney 3DEP LiDAR project.

LiDAR Processing

Once the LiDAR data arrived in the laboratory, QSI employed a suite of automated and manual techniques for processing tasks. Processing tasks included: GPS, kinematic corrections, calculation of laser point position, relative accuracy testing and calibrations, classification of ground and non-ground points, and assessments of statistical absolute accuracy. The general workflow for calibration of the LiDAR data was as follows:

LiDAR Processing Step	Software Used
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GNSS (collected at 2 Hz) and IMU (collected at 200 Hz) with Trimble CenterPoint PP-RTX methodologies.	POSGNSS Trimble CenterPoint PosPac MMS
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude are calculated throughout the survey.	POSGNSS POSPac MMS
Calculate laser point position by associating SBET information to each laser point return time, with offsets relative to scan angle, intensity, etc. included. This process creates the raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.4) format, in which each point maintains the corresponding scan angle, return number (echo), intensity, and x, y, z information. These data are converted to orthometric elevation (NAVD88) by applying a Geoid 12B correction.	Optech LMS Pro
Import raw laser points into subset bins. Filter for noise and perform manual relative accuracy calibration.	LASTools TerraScan Custom QSI software
Classify ground points and test relative accuracy using ground classified points per each flight line. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale), and GPS/IMU drift. Calibrations are performed on ground classified points from paired flight lines. Every flight line is used for relative accuracy calibration.	TerraMatch TerraScan Custom QSI software
Assess Non-Vegetated Vertical Accuracy and Vegetated Vertical Accuracy via direct comparisons of ground classified points to reserved non-vegetated and vegetated checkpoint survey data.	TerraScan
Assign headers (e.g., projection information, variable length record, project name) to *.las files.	Las Monkey

LAS Classification Scheme

The classification classes are determined by the USGS LiDAR Base Specification, version 1.3 specifications and are an industry standard for the classification of LiDAR point clouds. The classes used in the dataset are as follows and have the following descriptions:

- **Class 1 – Processed, but unclassified.** This class covers features such as vegetation, cars, utility poles, or any other point that does not fit into another deliverable class.
- **Class 2 – Bare earth ground**. Points used to create bare earth surfaces.
- **Class 7 – Low noise.** Erroneous points not meant for use below the identified ground surface.
- **Class 9 – Water.** Point returned off water surfaces.
- **Class 17 – Bridge decks.** Points falling on bridge decks.
- **Class 18 – High noise.** Erroneous points above ground surface not attributed to real features.

Hydro-Flattened Breaklines

Class 2 LiDAR was used to create a bare earth surface model. The surface model was then used to heads-up digitize 2D breaklines of inland streams and rivers with a 100 foot nominal width and inland ponds and lakes of two acres or greater surface area.

Elevation values were assigned to all inland ponds and lakes, inland pond and lake islands, inland streams and rivers and inland stream and river islands using Quantum Spatial proprietary software

All ground (ASPRS Class 2) LiDAR data inside of the collected inland breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. The breakline files were then translated to Esri file geodatabase format using Esri conversion tools.

Hydro-Flattened Raster DEM Creation

Hydro flattening breaklines are merged with Class 2 LAS and set to enforce elevations within closed areas identified as water while retaining near shore LiDAR elevations. This process is used to ensure a downstream gradient along streams and waterbodies are level.

LiDAR Accuracy Assessments

Relative Accuracy

Relative vertical 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, reported in Table 10 are based on the comparison of 50 full and partial flightlines and over 11 billion sample points.

Table 10: Relative accuracy

Relative Accuracy Calibration Results		
Project Average	0.028 m	0.092 ft
Median Relative Accuracy	0.028 m	0.092 ft
1σ Relative Accuracy	0.029 m	0.097 ft
2σ Relative Accuracy	0.033 m	0.108 ft
Flightlines	n = 50	
Sample points	11,464,132,706	

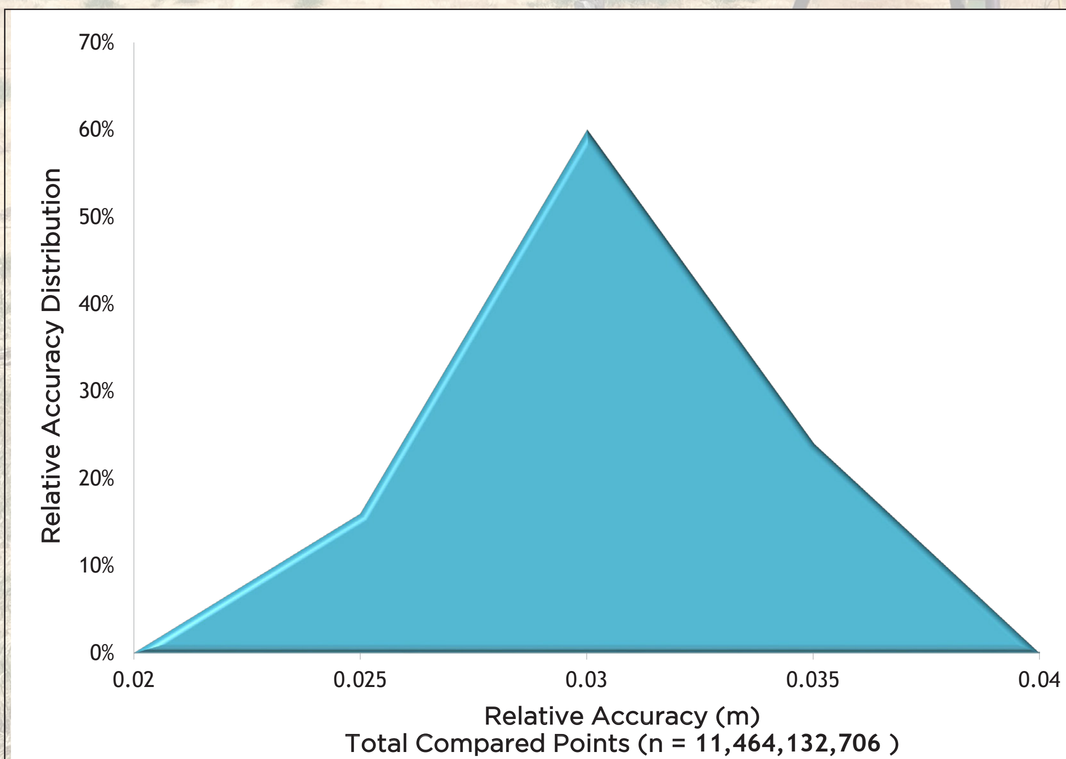

Figure 7: Relative accuracy based on 50 flightlines.

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 Positional Accuracy Standards for Digital Geospatial Data V1.0 (ASPRS, 2014). The statistical model compares known ground survey points (GSPs) to the ground model, triangulated from the neighboring laser points. 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 study area, a total of 760 ground control points were collected and used for calibration of the LiDAR data. An additional 46 reserved ground survey points were collected for independent verification. LAS data from the OLC Harney 2018 project was compared to the reserved ground survey points to determine the Non-Vegetated Vertical Accuracy (NVA) of the LAS and of the Bare Earth DEM; see table 11 for results.

QSI collected 10 additional ground survey points in areas of vegetated land cover. These vegetated ground survey points were tested against the bare earth DEM to determine the Vegetated Vertical Accuracy (VVA) of the DEM; results are included in table 12 on the following page.

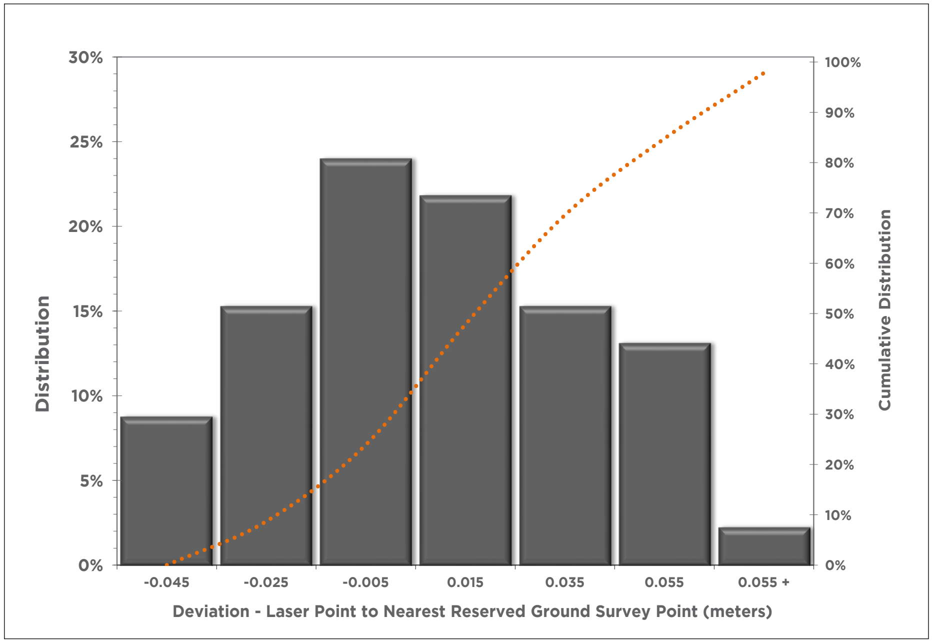

Figure 8: Non-Vegetated Vertical Accuracy distribution; points tested against the unclassified TIN.

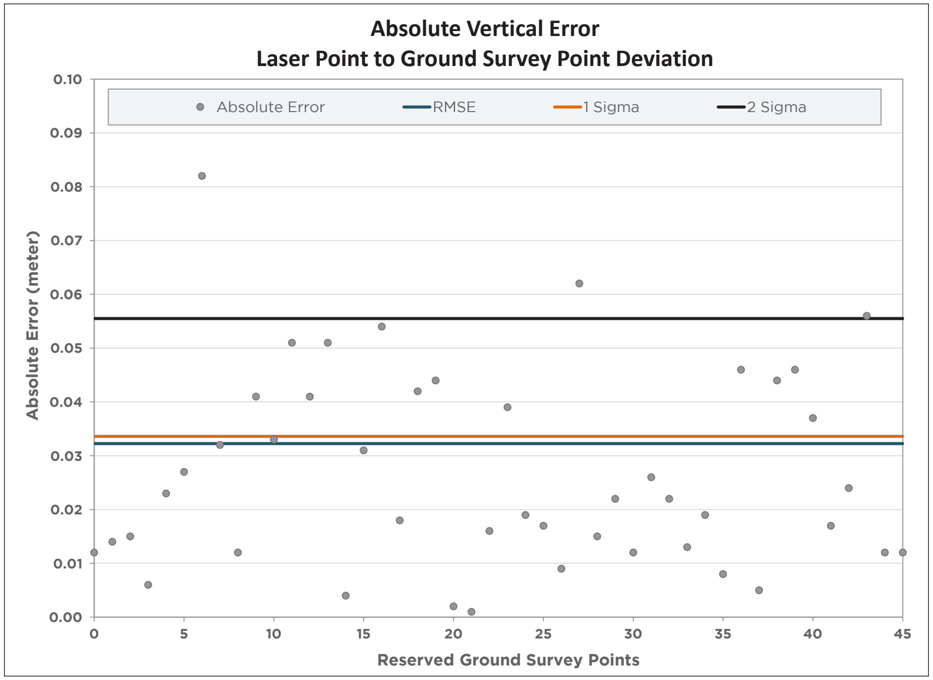

Figure 9: Reserved ground survey point absolute error; points tested against the unclassified TIN.

Vertical Accuracy

LAS Swath NVA:
Required NVA of the LiDAR-swath data is 19.6 centimeters according to specification. Harney NVA at a 95 percent confidence level (derived according to NSSDA, in open terrain using 0.032 m (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA)) is **0.063 m**; assessed and reported using National Digital Elevation Program (NDEP)/ ASPRS Guidelines.

Bare Earth DEM NVA:
Required NVA of the bare earth DEM is 19.6 centimeters according to specification. OLC Harney NVA at a 95 percent confidence level (derived according to NSSDA, in open terrain using 0.036 m (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA)) is **0.070 m**; assessed and reported using National Digital Elevation Program (NDEP)/ ASPRS Guidelines.

Bare Earth DEM VVA:
The required VVA at the 95th percentile according to specification is 29.4 centimeters. The VVA tested **0.092 m** at the 95th percentile using National Digital Elevation Program (NDEP)/ASPRS Guidelines against the DEM using 10 VVA points.

Table 11: Non-Vegetated Vertical Accuracy

Non-vegetated Vertical Accuracy	Tested against Unclassified TIN		Tested against BE DEM	
Sample Size (n)	46 Reserved Ground Survey Points		46 Reserved Ground Survey Points	
Vertical Accuracy at 95% confidence level (RMSE*1.96)	**0.063 m**	0.207 ft	**0.070 m**	0.230 ft
Root Mean Square Error	0.032 m	0.106 ft	0.036 m	0.117 ft
Standard Deviation	0.034 m	0.110 ft	0.041 m	0.134 ft
Minimum Deviation	-0.082 m	-0.269 ft	-0.096 m	-0.315 ft
Maximum Deviation	0.056 m	0.184 ft	0.062 m	0.204 ft

Table 12: Vegetated Vertical Accuracy results

Vegetated Vertical Accuracy	Tested against BE DEM	
Sample Size (n)	10 Reserved Ground Survey Points	
Vertical Accuracy at 95th percentile	**0.092 m**	0.302 ft
Root Mean Square Error	0.050 m	0.164 ft
Standard Deviation	0.070 m	0.230 ft
Minimum Deviation	-0.091 m	-0.298 ft
Maximum Deviation	0.093 m	0.305 ft

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. Densities are reported for the entire study area.

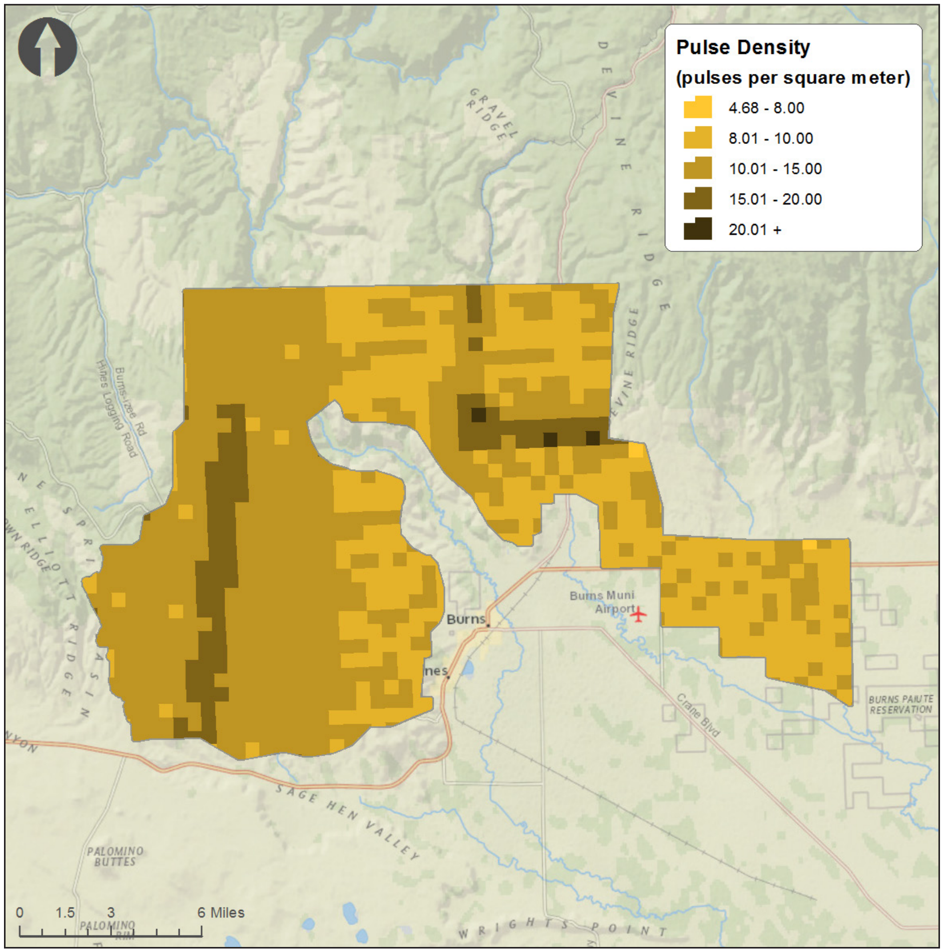

Table 13: Average pulse density

Average Pulse Density	pulses per square meter	pulses per square foot
	11.25	1.05

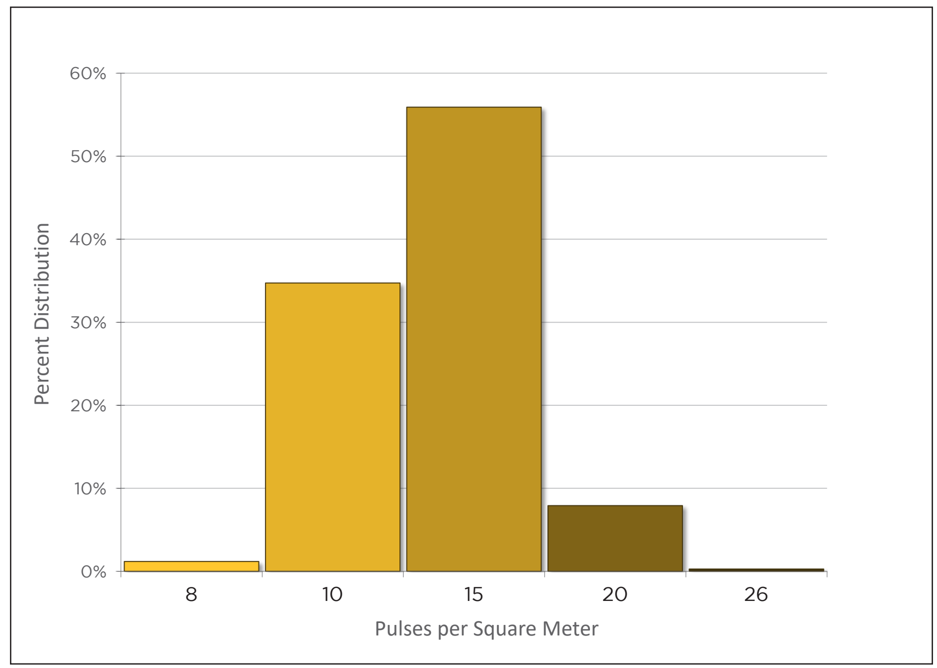

Figure 10: Average pulse density per 0.75' USGS Quad (color scheme aligns with density chart).

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 in Table 14 is a measure of ground-classified point data for the entire study area.

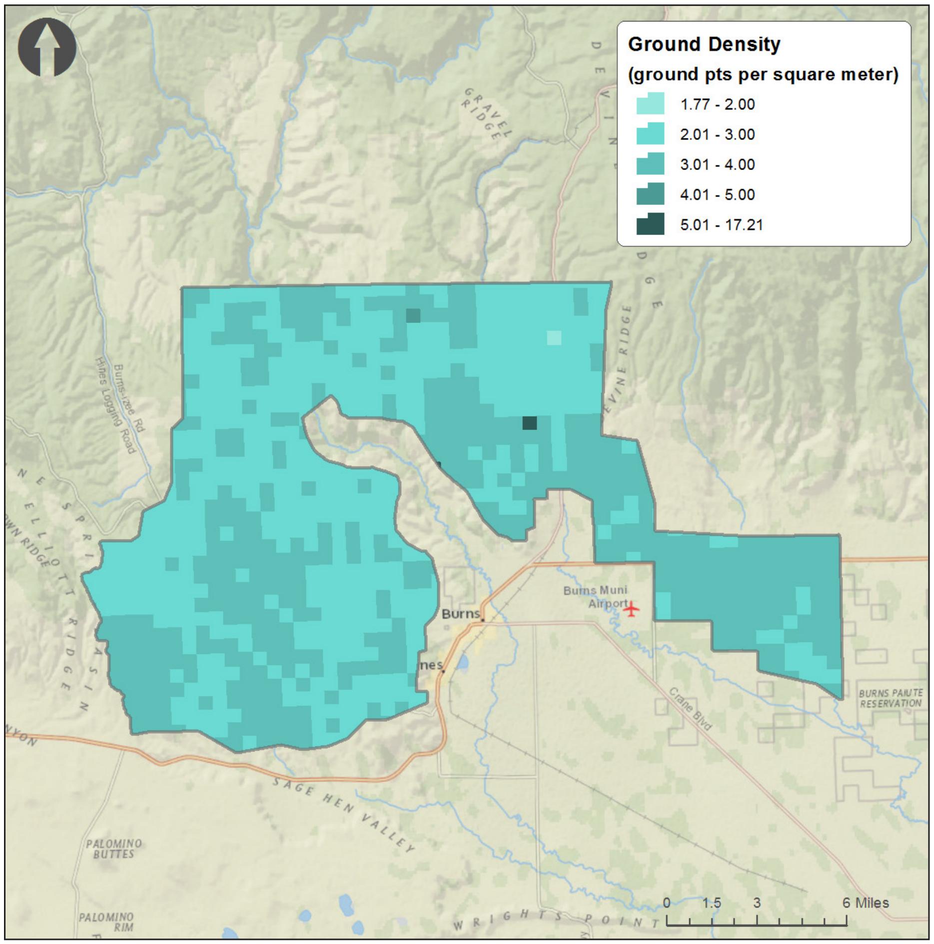

Table 14: Average ground density

	points per square meter	points per square foot
Average Ground Density	3.03	0.28

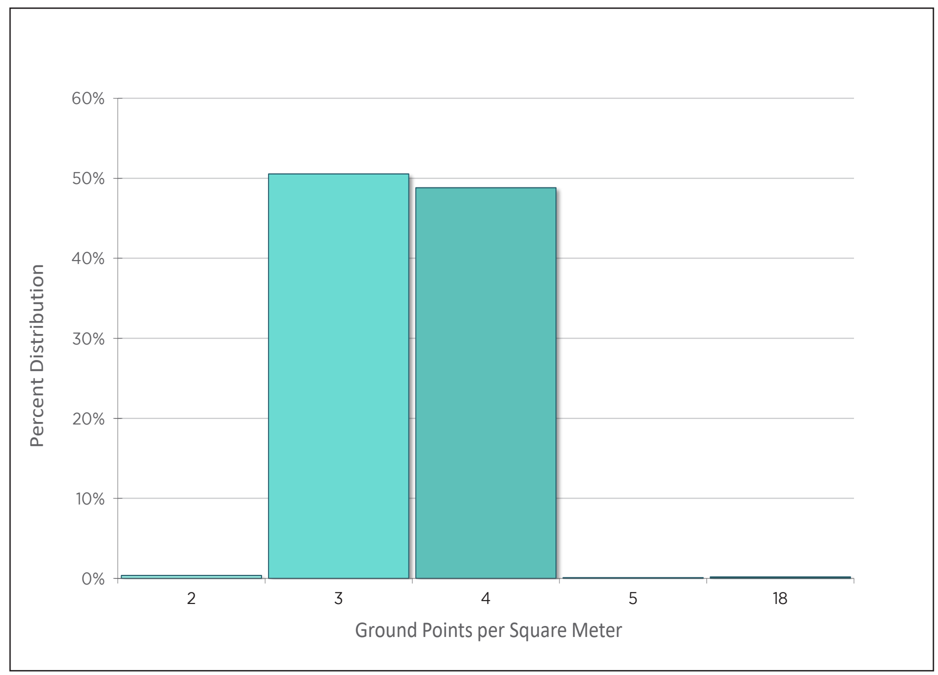

Figure 11: Average ground density per 0.75' USGS Quad (color scheme aligns with density chart).

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Appendix A : PLS Certification

Quantum Spatial, Inc. provided LiDAR services for the OLC Harney 3DEP 2018 project as described in this report.

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

John T. English
John T. English (Nov 29, 2018)

Nov 29, 2018

John English, GISP
Project Manager
Quantum Spatial, Inc.

I, Evon P. Silvia, PLS, 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 August 1 and 5, 2018.

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

Nov 29, 2018

Evon P. Silvia, PLS
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REGISTERED
PROFESSIONAL
LAND SURVEYOR

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EXPIRES: 06/30/2020