2020 Harney - Silver Creek

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Data collected for:
Oregon Department of Geology and Mineral Industries

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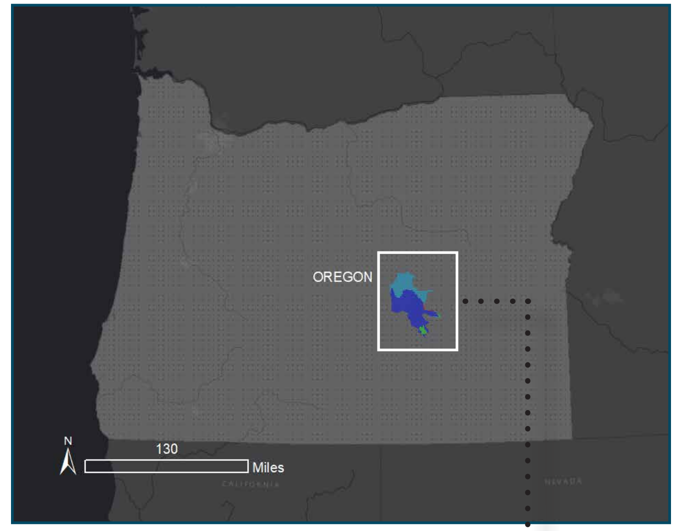
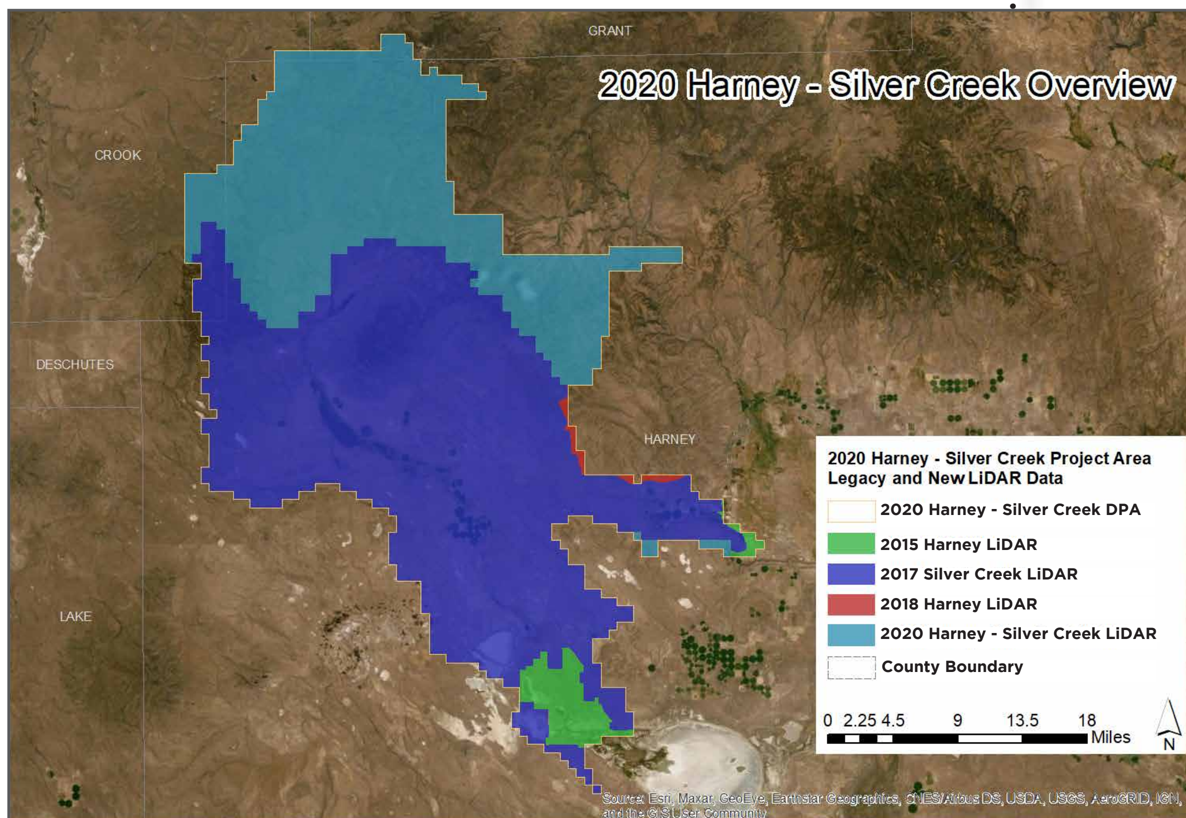
Project Overview

Figure 1: OLC Harney Silver Creek study area location



QSI has completed the acquisition and processing of Light Detection and Ranging (LiDAR) data describing the Oregon LiDAR Consortium's (OLC) 2020 Harney - Silver Creek Study Area. The 2020 Harney - Silver Creek DPA (defined project area) shown in Figure 1 encompasses 596,275.2 acres; and is primarily in Harney County, Oregon, but extends into Crook County and Grant County. Terminology used within this report aligns with OLC preferred language; Table 1 includes synonymous USGS 3DEP terminology.

The 2020 Harney - Silver Creek project is composed of Legacy and New Collection LiDAR data. Newly collected LiDAR data were acquired between July 27 and 28, 2020. Legacy datasets include 2015 Harney, 2017 OLC Silver Creek, and 2018 Harney lidar data (see Figure 1). 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. Vertical acccuracy was assessed and reported for newly collected data, legacy data, and combined data sources (see pages 13-16).



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.

QSI acquires and processes data in the most current, NGS-approved datums and geoid. All final deliverables for 2020 Harney - Silver Creek 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.

Table 1: OLC/3DEP synonymous terminology

OLC Terminology	USGS 3DEP Terminology
Area of Interest (AOI)	Defined Project Area (DPA)
Ground Survey Point (GSP)	Check Point

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

Table 2: 2020 Harney - Silver Creek delivery details

2020 Harney - Silver Creek	
Acquisition Dates	July 27 & 28, 2020
Defined Project Area	596,275.2 acres
Projection	OGIC Lambert
Datum: horizontal & vertical	NAD83 (2011) NAVD88 (Geoid 12B)
Units	International Feet

Figure 2: Zephyr GNSS Geodetic Model 2 antenna set up over Silver_Creek_04 monument

Deliverable OLC Products

Table 3: Products delivered for OLC Harney - Silver Creek study area.

2020 Harney - Silver Creek 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 4: Products delivered for 3DEP Harney - Silver Creek study area.

2020 Harney - Silver Creek Projection: OGIC Lambert Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID12B) Units: International Feet	
Points	LAS v 1.4 tiled by 3000 ft processing tiles • Default (1), Bare Earth (2), low noise (7), water (9), bridge decks (17), high noise (18) classified points LAS v 1.4 Swath files • Unclassified points
Rasters	3 ft resolution GeoTIFF tiled to match 3000 ft LAS processing tiles • Hydroflattened bare earth digital elevation model (DEM) • Bare earth DEM • Highest Hit DEM 1.5 ft resolution GeoTIFF tiled to match 3000 ft LAS processing tiles • LiDAR Intensities
Vectors	Shapefiles (*.shp) • Defined project area (DPA) • 3000 ft 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 • Aerial collection project flightlines
Metadata	• USGS-compliant metadata

Aerial Acquisition

LiDAR Survey

The 2020 LiDAR survey utilized a Riegl 1560i sensor mounted in a Cessna Caravan. Data were acquired on July 27 and 28, 2020. For system settings, please see Table 5. These settings are developed to yield points with an average native density of greater than eight pulses per square meter over terrestrial surfaces.

Acquisition parameters for data collected prior to 2020 have been previously reported in the applicable projects and included for reference in the delivery package. 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 5: OLC Harney-Silver Creek July 2020 LiDAR acquisition

OLC Harney-Silver Creek 2020 3DEP Acquisition	
Sensors Deployed	Riegl 1560i
Aircraft	Cessna Caravan
Survey Altitude (AGL)	1,950 m
Pulse Rate	2000 kHz
Pulse Mode	Multi (MPiA)
Field of View (FOV)	58.5°
Scan Rate	69.87 Hz
Overlap	100% overlap with 50% sidelap

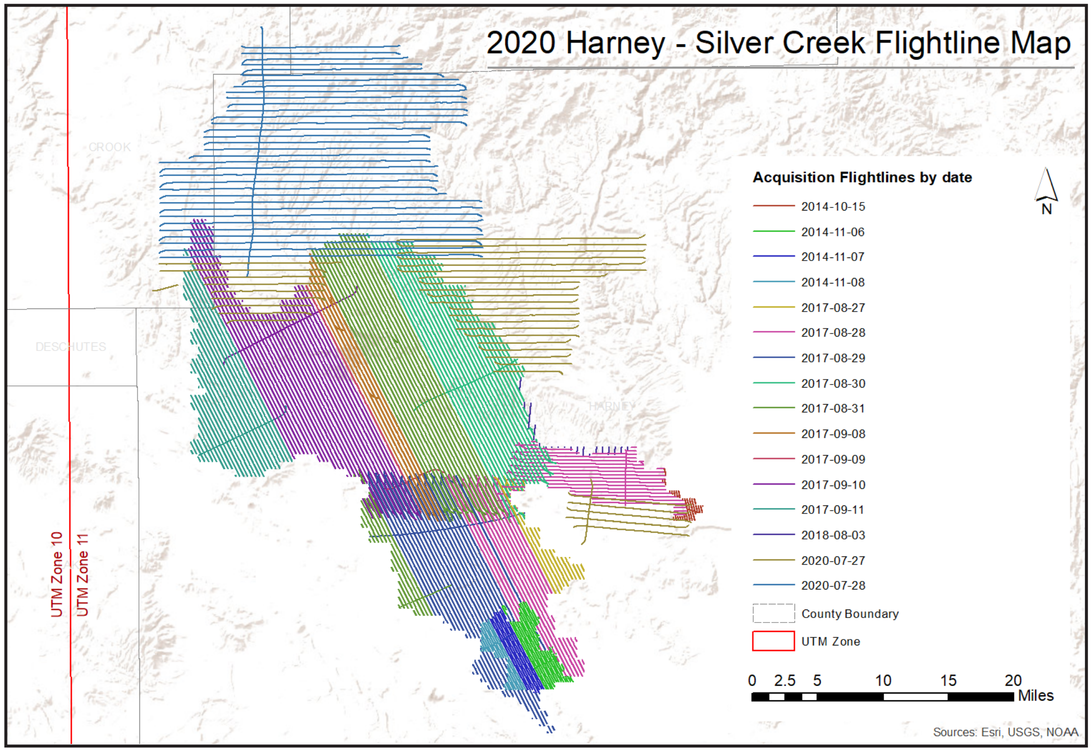


Figure 3: OLC Harney acquisition flightlines

Ground Survey

Ground control surveys for the entire Harney - Silver Creek LiDAR project boundary (legacy and newly collected LiDAR areas) were conducted between 6/16/2020 and 7/13/2020 to support data acquisition, including monumentation, ground control points (GCPs), and ground survey points (GSPs), as well as for accuracy testing. 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 6.

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 and R10-2 GNSS receivers. Total station surveys were conducted with Trimble M3 total stations.

Monumentation

Monuments were used for collection of ground control points and ground survey points using real time kinematic (RTK), total station (TS), 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), total station (TS), 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 FS surveys, however, these corrections were post-processed. RTK 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. Forested check points are collected using total stations in order to measure positions under canopy. Total station backsight and setup points are established using GNSS survey techniques.

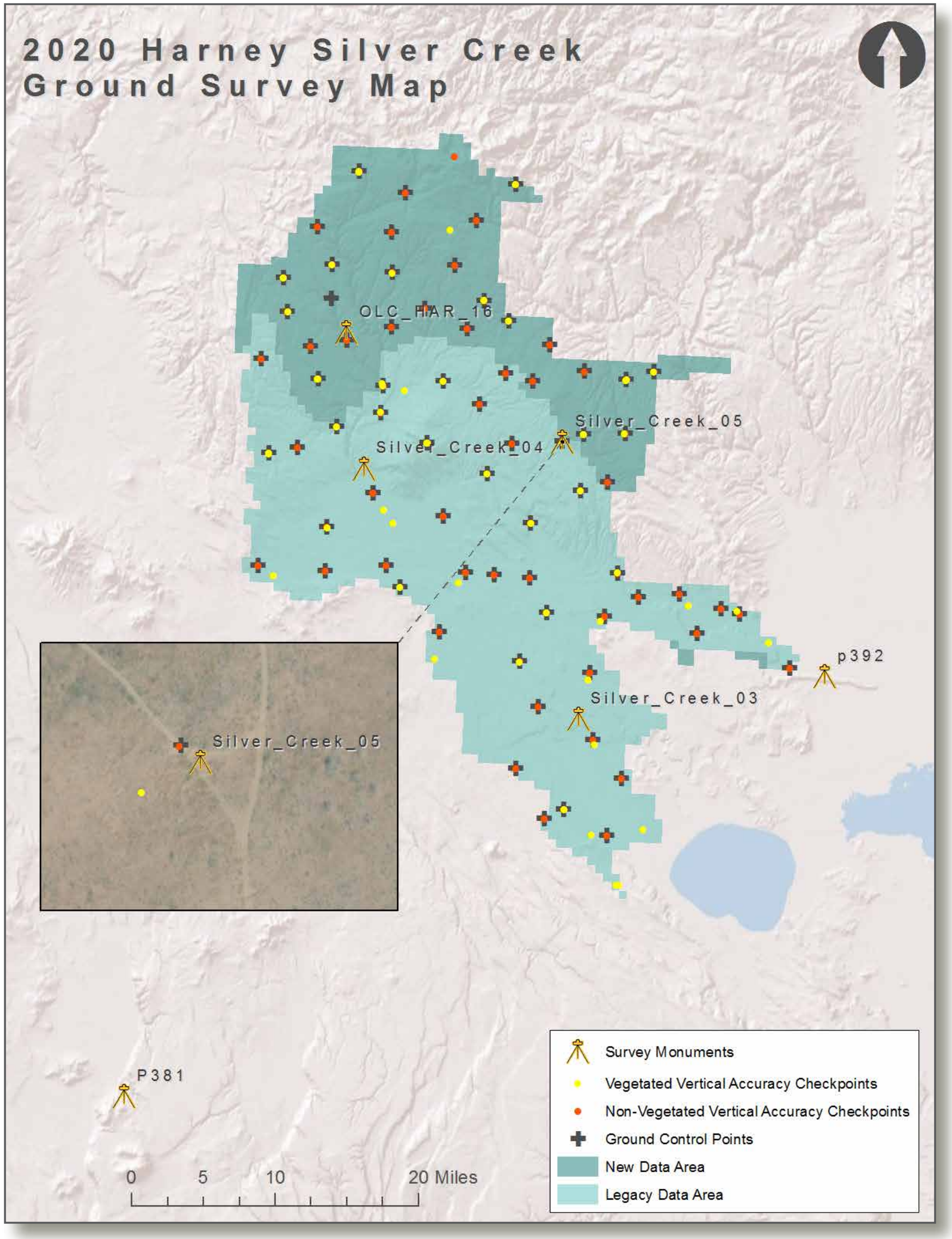


Figure 4: 2020 Harney - Silver Creek study area ground survey map

Figure 5: 2020 Harney - Silver Creek Ground Survey

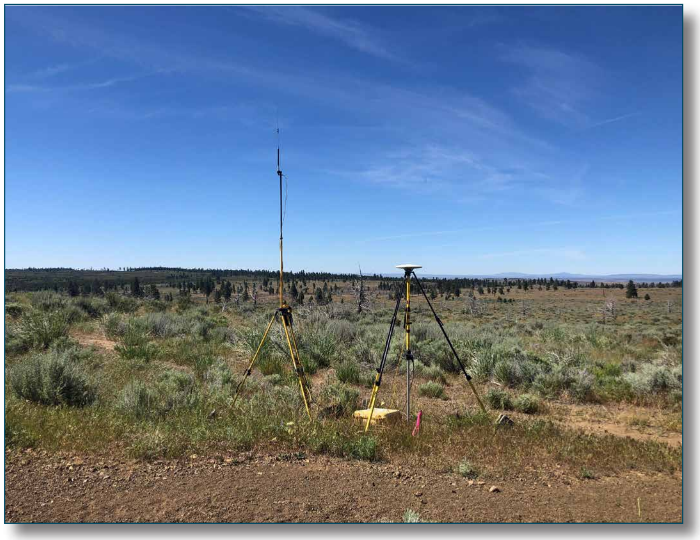


Figure 6: Silver_Creek_05 Survey Monument

Table 6: 2020 Harney - Silver Creek 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)
Silver_Creek_03	43° 23′ 50.75292″	-119° 20′ 28.83734″	1288.733	1308.231
Silver_Creek_04	43° 38′ 38.42976″	-119° 38′ 58.02469″	1337.860	1357.129
Silver_Creek_05	43° 40′ 37.07709″	-119° 22′ 27.50915″	1604.215	1623.156
p381	43° 00′ 06.38045″	-119° 57′ 06.43530″	1567.936	1588.004
p392	43° 26′ 48.31601″	-119° 00′ 03.54647″	1316.016	1335.342
OLC_HAR_16	43° 46′ 51.79589″	-119° 40′ 46.58578″	1455.502	1474.547
OLC_HAR_17	43° 53′ 01.06390″	-119° 37′ 15.90014″	1708.230	1727.054

Table 7: 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 Model 2	Integrated Antenna	TRMR8_GNSS	Rover
Trimble R10-2	Integrated Antenna	TRMR10-2	Rover
Trimble M3 Total Station	n/a	n/a	VVA

Table 8: 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 2020 Harney - Silver Creek 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 71 full and partial flightlines and over 19 billion sample points.

Table 9: Relative accuracy

Relative Accuracy Calibration Results		
Project Average	0.034 m	0.112 ft
Median Relative Accuracy	0.033 m	0.109 ft
1σ Relative Accuracy	0.035 m	0.114 ft
2σ Relative Accuracy	0.043 m	0.141 ft
Flightlines	n = 71	
Sample points	19,836,502,512	

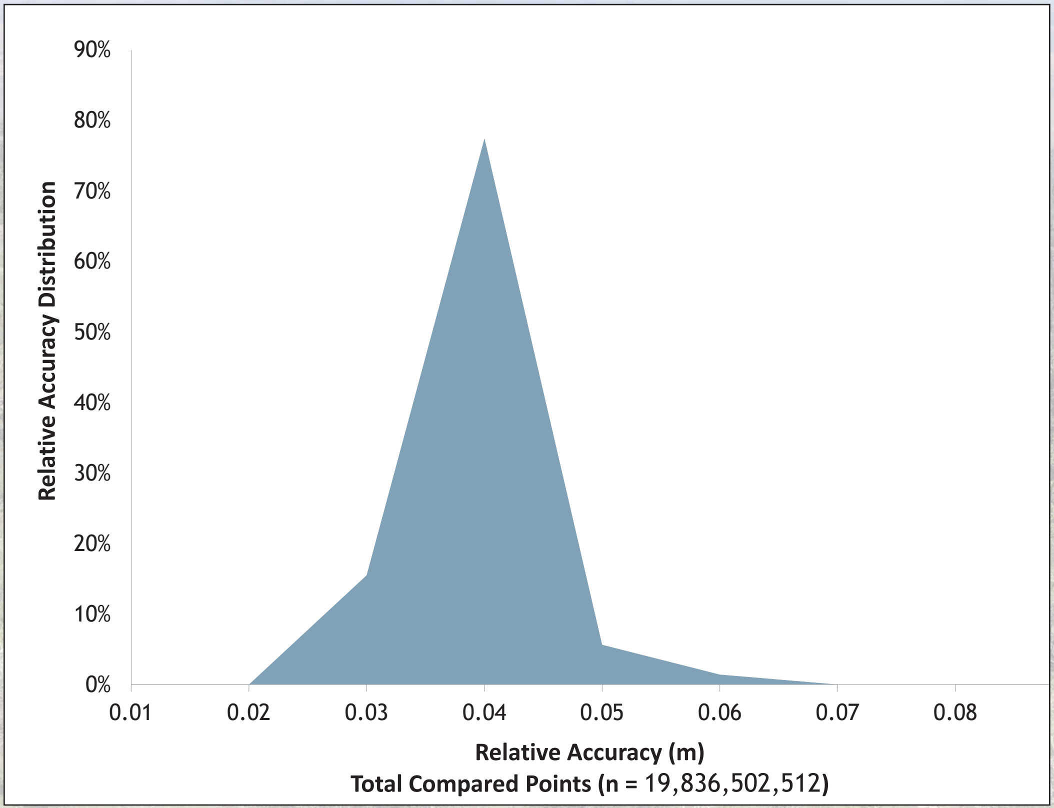


Figure 7: Relative accuracy based on 71 flightlines.

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.

The ground survey reflects conditions at the time of the survey in 2020; in addition to reporting the accuracy of the airborne survey, the ground survey may also indicate changes in the ground or vegetation conditions since the airborne survey. Therefore, vertical accuracy statistics are presented three times: once for the combined dataset, once for the legacy dataset, and once for the data collected in 2020.

For the 2020 Harney - Silver Creek study area, a total of 73 ground control points were collected and used for calibration of the LiDAR data. An additional 73 reserved ground survey points were collected for independent verification. LAS data from the 2020 Harney - Silver Creek 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 tables 11, 13, and 15 for results.

QSI collected 57 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 tables 12, 14, and 16 on the following pages.

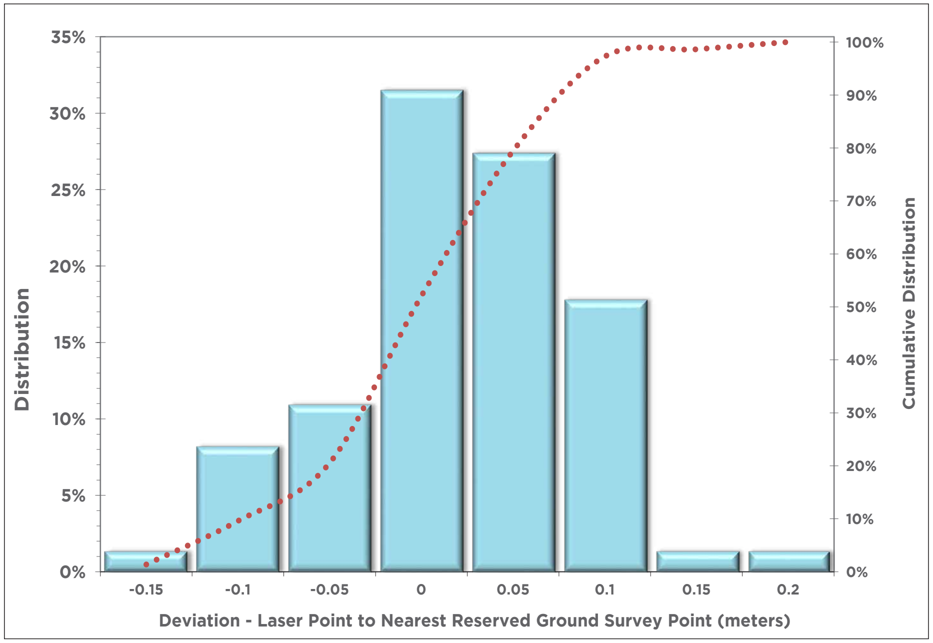


Figure 8: Non-Vegetated Vertical Accuracy distribution; points tested against the unclassified TIN.

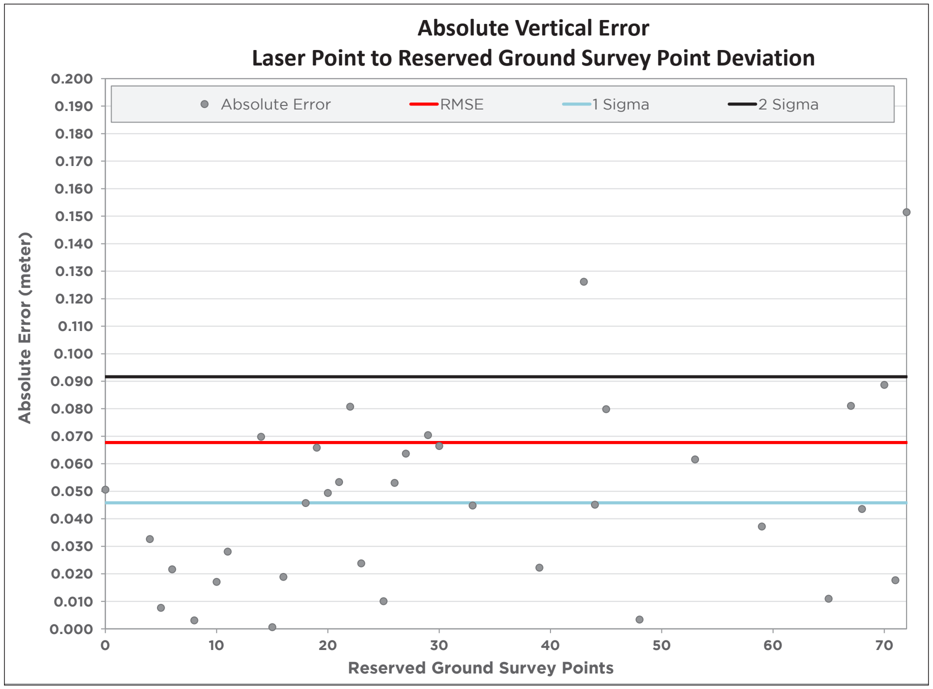


Figure 9: Reserved ground survey point absolute error; points tested against the unclassified TIN.

Vertical Accuracy: Combined Data

LAS Swath NVA:
Required NVA of the LiDAR-swath data is 19.6 centimeters according to specification. 2020 Harney - Silver Creek NVA at a 95 percent confidence level (derived according to NSSDA, in open terrain using 0.068 m (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA)) is **0.133 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. 2020 Harney - Silver Creek NVA at a 95 percent confidence level (derived according to NSSDA, in open terrain using 0.066 m (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA)) is **0.129 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 **0.177 m** at the 95th percentile using National Digital Elevation Program (NDEP)/ASPRS Guidelines against the DEM using 57 VVA points.

Table 10: Non-Vegetated Vertical Accuracy results

Non-vegetated Vertical Accuracy	Tested against Unclassified TIN		Tested against BE DEM	
Sample Size (n)	73 Reserved Ground Survey Points		73 Reserved Ground Survey Points	
Vertical Accuracy at 95% confidence level (RMSE*1.96)	**0.133 m**	0.435 ft	**0.129 m**	0.423 ft
Root Mean Square Error	0.068 m	0.222 ft	0.066 m	0.216 ft
Standard Deviation	0.046 m	0.150 ft	0.047 m	0.154 ft
Minimum Deviation	-0.294 m	-0.966 ft	-0.152 m	-0.499 ft
Maximum Deviation	0.151 m	0.497 ft	0.129 m	0.423 ft

Table 11: Vegetated Vertical Accuracy results

Vegetated Vertical Accuracy	Tested against BE DEM	
Sample Size (n)	57 Reserved Ground Survey Points	
Vertical Accuracy at 95th percentile	**0.129 m**	0.177 ft
Root Mean Square Error	0.066 m	0.217 ft
Standard Deviation	0.059 m	0.194 ft
Minimum Deviation	-0.180 m	-0.591 ft
Maximum Deviation	0.179 m	0.587 ft

Vertical Accuracy: Legacy Collection

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 0.081 m (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA)) is **0.158 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 0.082 m (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA)) is **0.160 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 **0.145 m** at the 95th percentile using National Digital Elevation Program (NDEP)/ASPRS Guidelines against the DEM using 35 VVA points.

Table 12: Non-Vegetated Vertical Accuracy results

Non-vegetated Vertical Accuracy	Tested against Unclassified TIN		Tested against BE DEM	
Sample Size (n)	45 Reserved Ground Survey Points		45 Reserved Ground Survey Points	
Vertical Accuracy at 95% confidence level (RMSE*1.96)	**0.158 m**	0.519 ft	**0.160 m**	0.525 ft
Root Mean Square Error	0.081 m	0.265 ft	0.082 m	0.268 ft
Standard Deviation	0.053 m	0.172 ft	0.053 m	0.174 ft
Minimum Deviation	-0.294 m	-0.966 ft	-0.152 m	-0.499 ft
Maximum Deviation	0.151 m	0.497 ft	0.298 m	0.978 ft

Table 13: Vegetated Vertical Accuracy results

Vegetated Vertical Accuracy	Tested against BE DEM	
Sample Size (n)	35 Reserved Ground Survey Points	
Vertical Accuracy at 95th percentile	**0.145 m**	0.176 ft
Root Mean Square Error	0.074 m	0.241 ft
Standard Deviation	0.078 m	0.256 ft
Minimum Deviation	-0.180 m	-0.591 ft
Maximum Deviation	0.179 m	0.587 ft

Vertical Accuracy: 2020 LiDAR Collection

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 0.038 m (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA)) is **0.075 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 0.024 m (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA)) is **0.048 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 **0.082 m** at the 95th percentile using National Digital Elevation Program (NDEP)/ASPRS Guidelines against the DEM using 22 VVA points.

Table 14: Non-Vegetated Vertical Accuracy results

Non-vegetated Vertical Accuracy	Tested against Unclassified TIN		Tested against BE DEM	
Sample Size (n)	28 Reserved Ground Survey Points		28 Reserved Ground Survey Points	
Vertical Accuracy at 95% confidence level (RMSE*1.96)	**0.075 m**	0.247 ft	**0.048 m**	0.158 ft
Root Mean Square Error	0.038 m	0.126 ft	0.024 m	0.080 ft
Standard Deviation	0.022 m	0.074 ft	0.014 m	0.045 ft
Minimum Deviation	-0.046 m	-0.152 ft	-0.052 m	-0.171 ft
Maximum Deviation	0.081 m	0.265 ft	0.043 m	0.141 ft

Table 15: Vegetated Vertical Accuracy results

Vegetated Vertical Accuracy	Tested against BE DEM	
Sample Size (n)	22 Reserved Ground Survey Points	
Vertical Accuracy at 95th percentile	**0.082 m**	0.031 ft
Root Mean Square Error	0.036 m	0.119 ft
Standard Deviation	0.051 m	0.168 ft
Minimum Deviation	-0.122 m	-0.400 ft
Maximum Deviation	0.018 m	0.059 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.

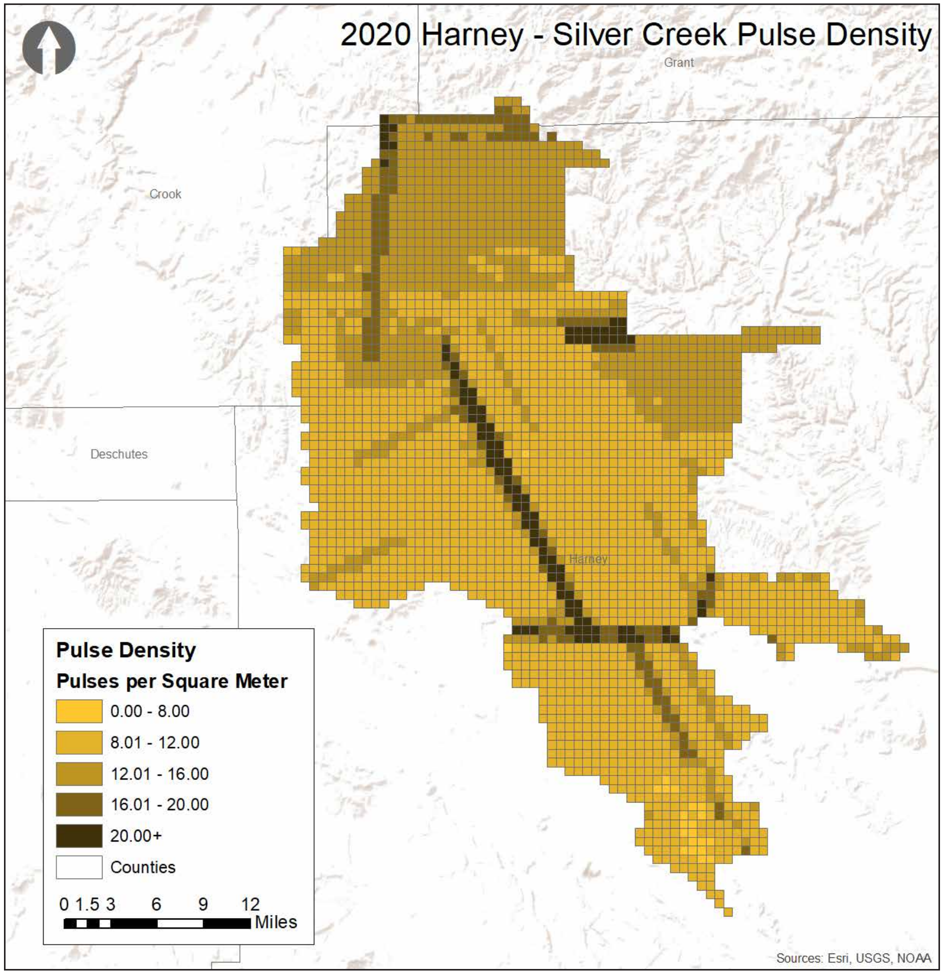


Table 16: Average pulse density

Average Pulse Density	pulses per square meter	pulses per square foot
	11.86	1.10

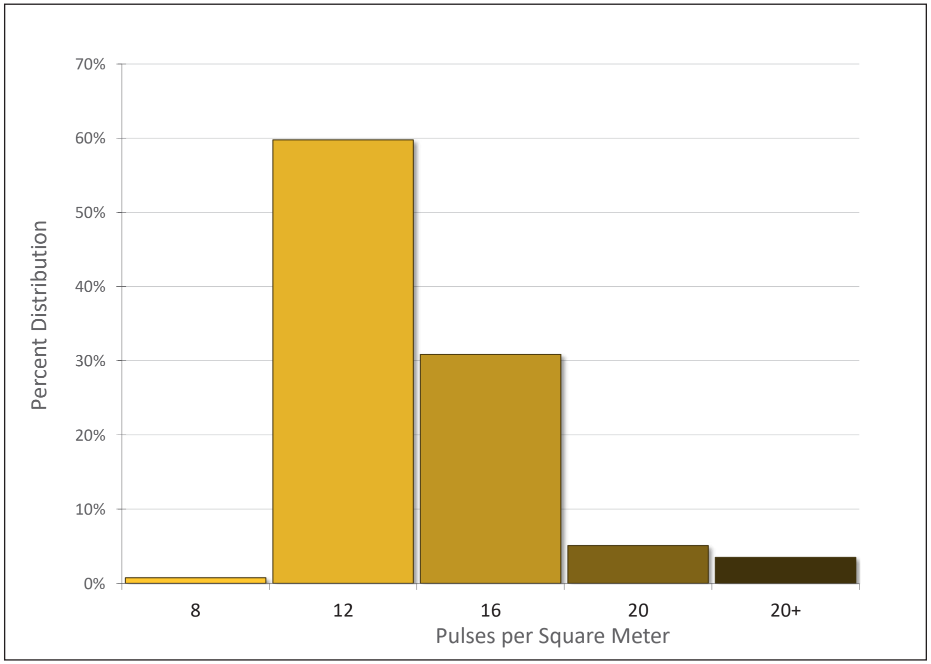


Figure 10: Average pulse density per 0.75' USGS Quad (color scheme aligns with density chart).

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 18 is a measure of ground-classified point data for the entire study area.

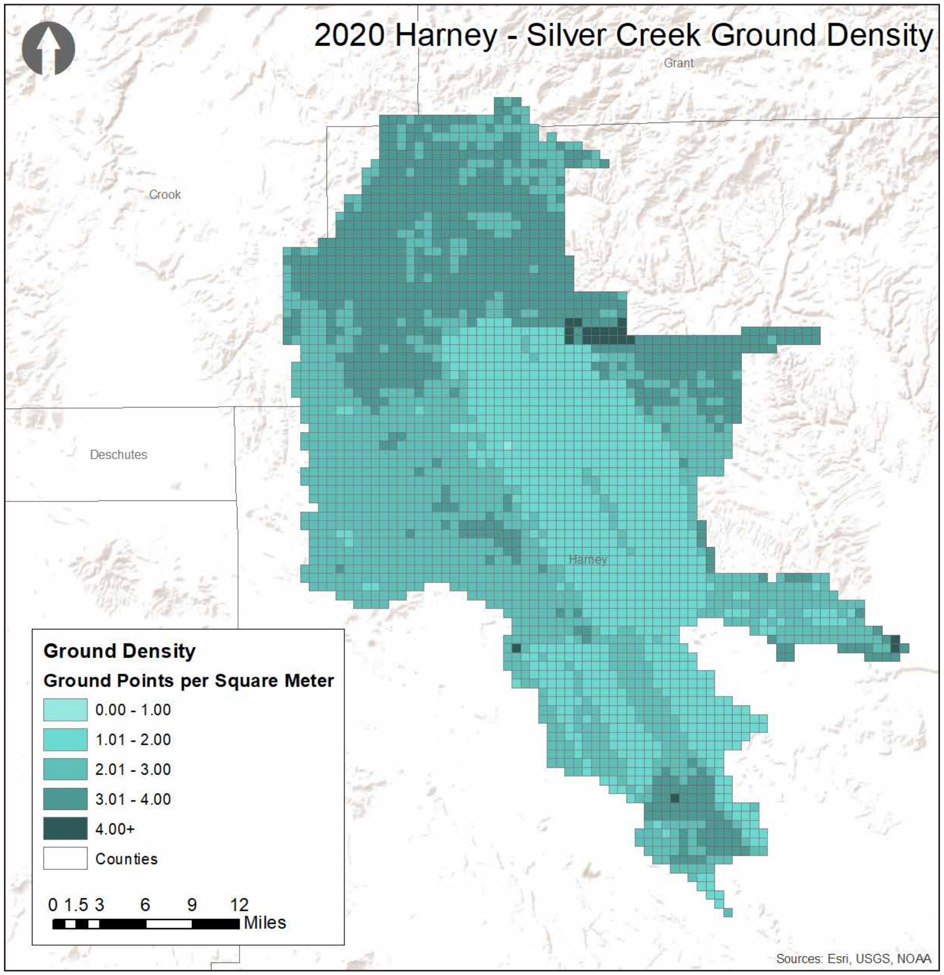


Table 17: Average ground density

Average Ground Density	points per square meter	points per square foot
	2.50	0.23

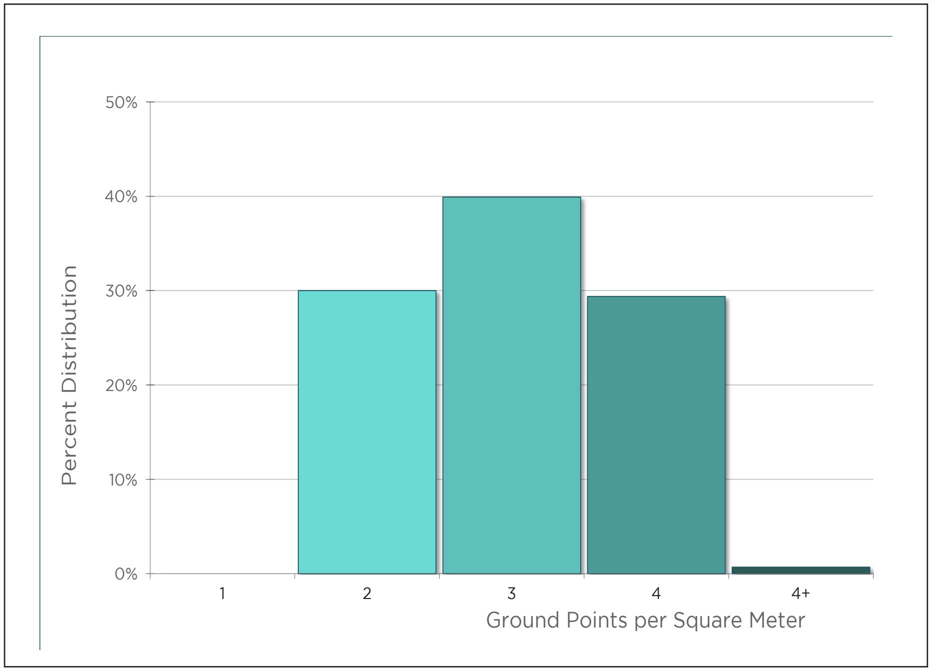


Figure 11: Average ground density per 0.75' USGS Quad (color scheme aligns with density chart).

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Appendix A : PLS Certification

Quantum Spatial, Inc. provided LiDAR services for the 2020 Harney – Silver Creek 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   Dec 22, 2020

John English, PMP
Project Manager
Quantum Spatial, Inc.

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 June 16, 2020 and July 13, 2020 for the new acquisition. Historic data from neighboring projects collected in 2014-2018 was integrated and assessed for its accuracy and currency using a new ground survey.

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   Dec 22, 2020

Evon P. Silvia, PLS
Quantum Spatial, Inc.
Corvallis, OR 97330

REGISTERED
PROFESSIONAL
LAND SURVEYOR

Evon P. Silvia

OREGON
JUNE 10, 2014
EVON P. SILVIA
81104LS

EXPIRES: 06/30/2022

Appendix B : Glossary

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

1.96 * RMSE Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set, based on the FGDC standards for Fundamental Vertical Accuracy (FVA) reporting.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma σ) and root mean square error (RMSE).

Absolute Accuracy: The vertical accuracy of Lidar data is described as the mean and standard deviation (sigma σ) of divergence of Lidar point coordinates from ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y, and z are normally distributed, and thus the skew and kurtosis of distributions are also considered when evaluating error statistics.

Relative Accuracy: Relative accuracy refers to the internal consistency of the data set (i.e., the ability to place a laser point in the same location over multiple flight lines), GPS conditions, and aircraft attitudes. Affected by system attitude offsets, scale, and GPS/IMU drift, internal consistency is measured as the divergence between points from different flight lines within an overlapping area. Divergence is most apparent when flight lines are opposing. When the Lidar system is well calibrated, the line-to-line divergence is low (<10 cm).

Root Mean Square Error (RMSE): A statistic used to approximate the difference between real-world points and the Lidar points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Data Density: A common measure of Lidar resolution, measured as points per square meter.

Digital Elevation Model (DEM): File or database made from surveyed points, containing elevation points over a contiguous area. Digital terrain models (DTM) and digital surface models (DSM) are types of DEMs. DTMs consist solely of the bare earth surface (ground points), while DSMs include information about all surfaces, including vegetation and man-made structures.

Intensity Values: The peak power ratio of the laser return to the emitted laser, calculated as a function of surface reflectivity.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Overlap: The area shared between flight lines, typically measured in percent. 100% overlap is essential to ensure complete coverage and reduce laser shadows.

Pulse Returns: For every laser pulse emitted, the number of wave forms (i.e., echos) reflected back to the sensor. Portions of the wave form that return first are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Real-Time Kinematic (RTK) Survey: A type of surveying conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

Post-Processed Kinematic (PPK) Survey: GPS surveying is conducted with a GPS rover collecting concurrently with a GPS base station set up over a known monument. Differential corrections and precisions for the GNSS baselines are computed and applied after the fact during processing. This type of ground survey is accurate to 1.5 cm or less.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Appendix C : Accuracy Controls

Relative Accuracy Calibration Methodology:

Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each survey area.

Automated Attitude Calibration: All data were tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flight line and used for line-to-line testing. System misalignment offsets (pitch, roll and heading) and scale were solved for each individual mission and applied to respective mission data sets. The data from each mission were then blended when imported together to form the entire area of interest.

Lidar accuracy error sources and solutions:

Type of Error	Source	Post Processing Solution
GPS (Static/Kinematic)	Long Base Lines	None
	Poor Satellite Constellation	None
	Poor Antenna Visibility	Reduce Visibility Mask
Relative Accuracy	Poor System Calibration	Recalibrate IMU and sensor offsets/settings
	Inaccurate System	None
Laser Noise	Poor Laser Timing	None
	Poor Laser Reception	None
	Poor Laser Power	None
	Irregular Laser Shape	None

Operational measures taken to improve relative accuracy:

Low Flight Altitude: Terrain following was employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (about 1/3000th AGL flight altitude).

Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return (i.e., intensity) is a function of laser emission power, laser footprint, flight altitude and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased and low flight altitudes can be maintained.

Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of 312o from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.

Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day. During all flight times, a dual frequency DGPS base station recording at 1 second epochs was utilized and a maximum baseline length between the aircraft and the control points was less than 13 nm at all times.

Ground Survey: Ground survey point accuracy (<1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. Ground survey points are distributed to the extent possible throughout multiple flight lines and across the survey area.

50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the nadir portion of one flight line coincides with the swath edge portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.

Opposing Flight Lines: All overlapping flight lines have opposing directions. Pitch, roll and heading errors are amplified by a factor of two relative to the adjacent flight line(s), making misalignments easier to detect and resolve.