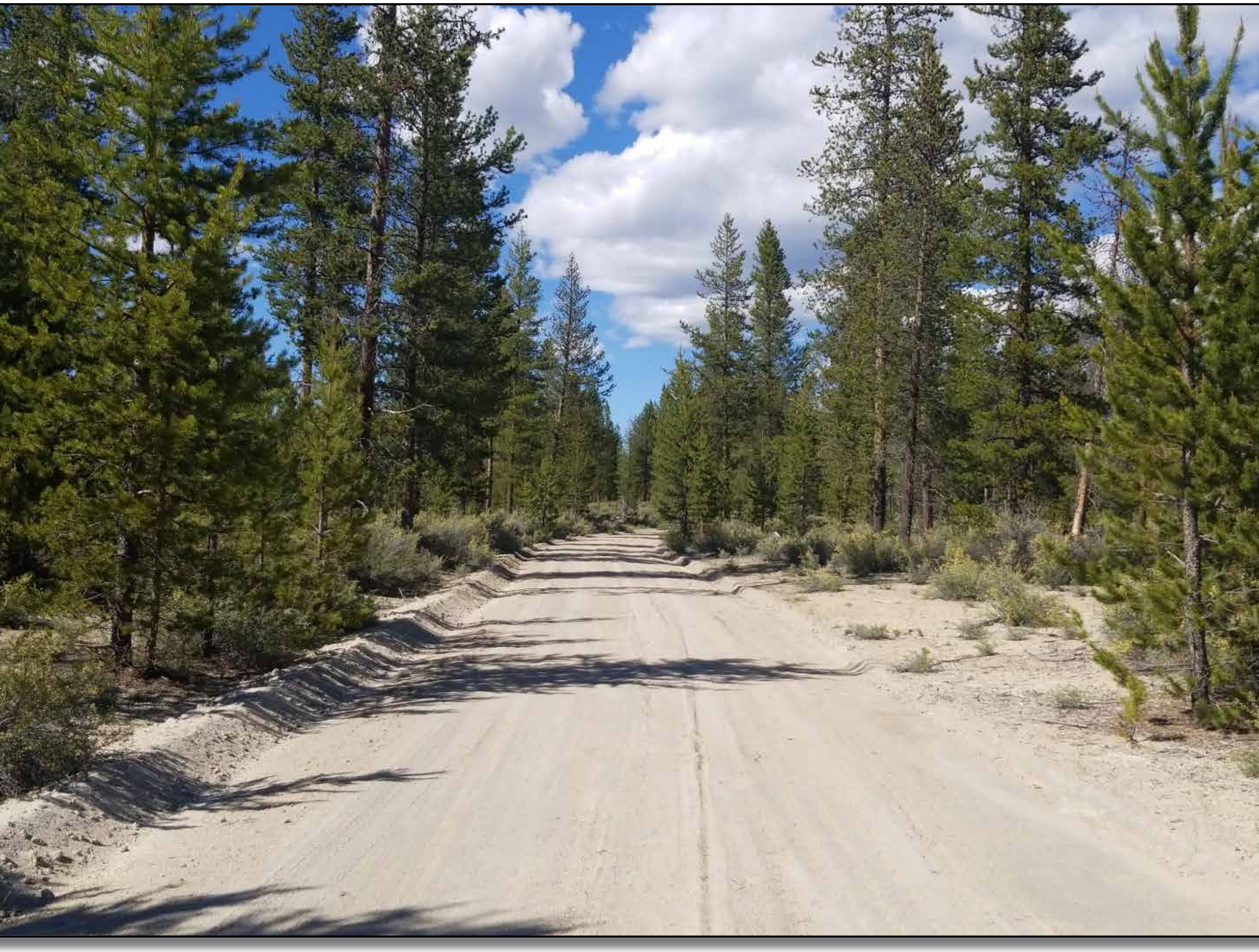
Submitted: August 16, 2019

Technical Data Report

2019 DAS-GEO Gilchrist LiDAR



Above: Scenic image taken during the ground survey

PA # DASPS-1009-17
Work Order Contract # DASPS-1627-19

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Salem, OR

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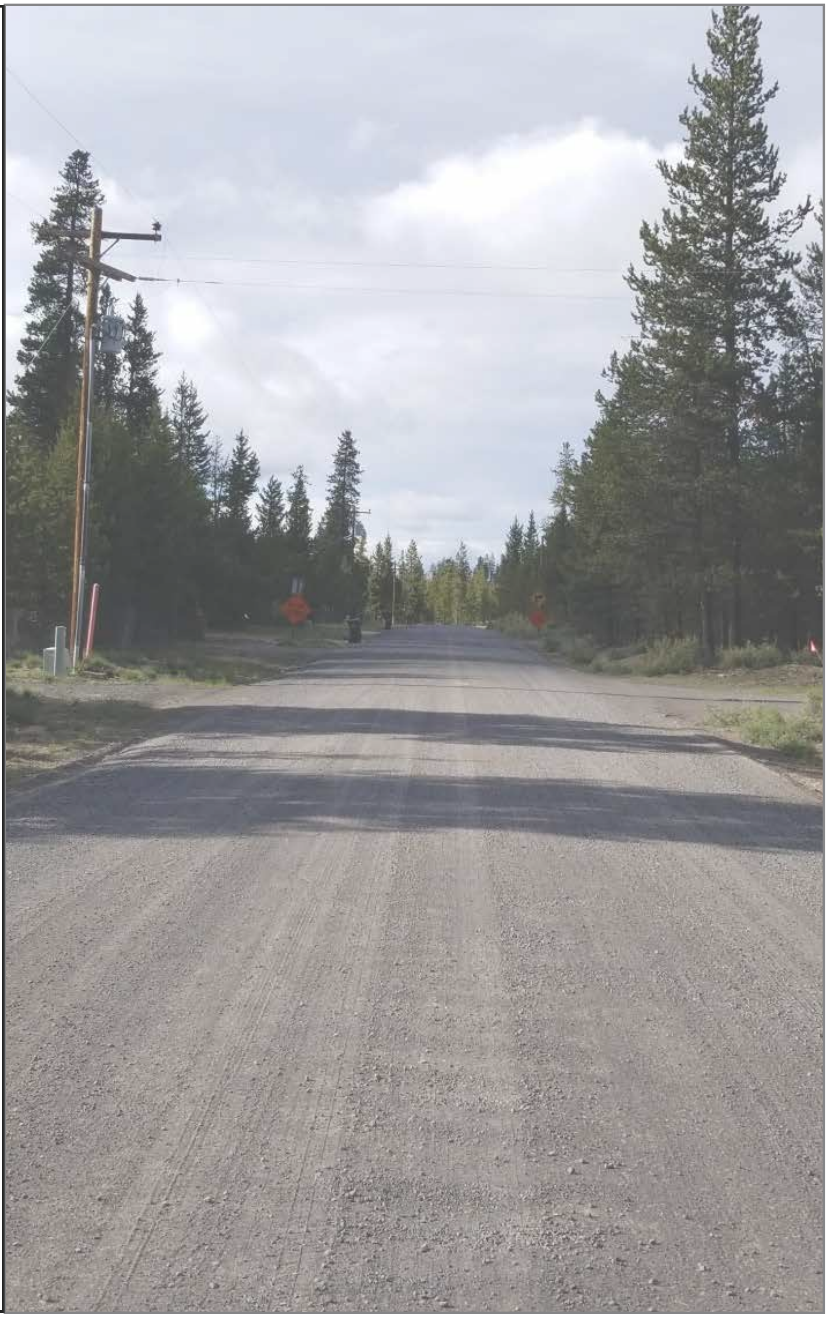


Overview

The Oregon Department of Administrative Services Geospatial Enterprise Office (DAS-GEO) contracted with Quantum Spatial, Inc. (QSI) in June 2019 to collect Light Detection and Ranging (LiDAR) data for the 2019 DAS-GEO Gilchrist LiDAR study area. This report summarizes the data collection and processing of the Gilchrist study area. A total of 192,686 acres of eight pulses per square meter (PPSM) LiDAR data were acquired and delivered to the client. The ground survey was performed between June 7 and June 12, 2019. The LiDAR data were collected between June 1 and June 5, 2019, with final delivery to DAS-GEO on August 16, 2019.

Table 1. Project overview

2019 Oregon State LiDAR Gilchrist LiDAR Project Overview	
Study Area	187,324 acres AOI 192,686 acres BAOI
Acquisition Dates	6/1/2019 - 6/5/2019*
Data Delivery	August 16, 2019

*See acquisition map on page 8 for acquisition dates.

PROJECTION
Oregon Lambert Conic Conformal (OGIC)

DATUM
Horizontal:
North American Datum of 1983 (2011)
Vertical:
North American Vertical Datum 1988, GEOID 12B

UNITS
International Feet

Project Extent

The 2019 DAS-GEO Gilchrist LiDAR project area is located across Deschutes, Klamath, and Lake Counties in the state of Oregon. LiDAR was collected to establish current ground elevation conditions.

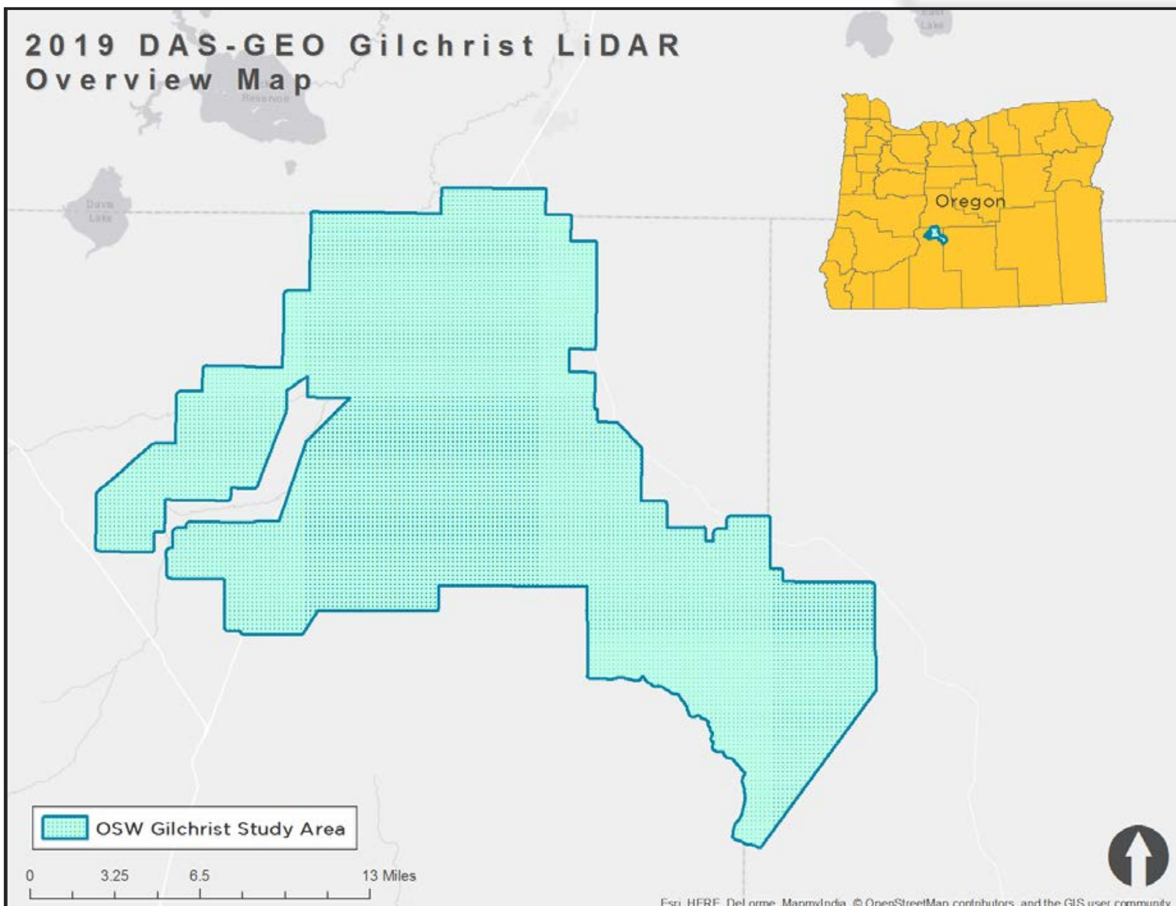


Figure 1. Overview map

Deliverables

The following data have been provided in Oregon Lambert to DAS-GEO for the 2019 Gilchrist LiDAR survey on an external drive from QSI:

- 8 ppsm LiDAR point cloud in *.las format (including X, Y, Z, return number, intensity, GPS time stamp, scan angle, and flightline); processed in LAS 1.4 and converted to LAS 1.2 prior to delivery.
    - Class 1 = processed/unclassified (default)
    - Class 2 = bare earth
    - Class 7 = low noise
    - Class 9 = water
    - Class 10 = ignored ground (near a breakline)
    - Class 17 = bridge decks
    - Class 18 = high noise
- Vector Datasets
    - Area of interest (AOI) in *.shp format
    - Buffered area of interest (BAOI) in *.shp format
    - *.las and intensity tiling scheme in *.shp format
    - DEM tiling scheme in *.shp format
    - Ground survey points (used as control) and reserved ground survey points (used for testing) in *.shp format
    - SBET point file in *.shp format
- Raster Datasets
    - 3 ft resolution Bare Earth Digital Elevation Model (BE DEM) in ESRI format
    - 3 ft resolution Highest Hit (HH) DEM in ESRI format
    - 1.5 ft resolution intensity raster in GeoTIFF format
- Technical data report
- Metadata

Acquisition

For the survey of the DAS-GEO Gilchrist Study Area, QSI employed a Cessna Grand Caravan aircraft with a crew including an airborne remote sensor operator and a ground survey technician. LiDAR acquisition from the aircraft was accomplished with the Leica ALS80 onboard high performance laser scanning systems.

Planning

Flightlines were developed using Mission Pro software for the Leica ALS80 sensor. Careful planning of the pulse rate, flight altitude, and ground speed ensured that data quality and coverage conditions were met while optimizing flight paths and ensuring the necessary pulse density of greater than eight points per square meter.

The known factors were prepared for, such as: GPS constellation availability, acquisition windows, and resource allocation. In addition, a variety of logistical barriers were anticipated, namely private property access and acquisition personnel logistics. Finally, weather hazards and conditions affecting flight were continuously monitored due to their impact on the daily success of airborne and ground operations.

Ground Survey

QSI conducted a ground survey to support airborne LiDAR collection between June 7 and June 12, 2019.

Monumentation

A combination of QSI-set monuments, NGS monuments, and permanent base stations from the Oregon Real-time GNSS Network (ORGN) were used for collection of ground survey points (GSPs) using real time kinematic (RTK) and post processed kinematic (PPK) survey techniques. Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. RINEX files and final coordinates for flight support were provided using the ORGN. The coordinates used for these stations are provided as Antenna Reference Point (ARP) height in NAD83(2011) epoch 2010.00. Please see page 6 for ORGN locations and QSI and NGS monument locations in tabular and cartographic format.

Ground Survey Points

The ground survey for the DAS-GEO Gilchrist LiDAR project was conducted between June 7 and June 12, 2019. Ground survey data were used for data calibration and accuracy assessment purposes. Ground survey points (GSPs) were collected using RTK techniques. For RTK surveys, either the ORGN was utilized to broadcast a kinematic correction to a roving receiver; or a base receiver was positioned at a nearby monument to broadcast a kinematic correction to a roving receiver. For PPK surveys, however, these corrections were post-processed. RTK and PPK surveys recorded observations for a minimum of five seconds on each GCP/GSP in order to support longer baselines for post-processing.

All 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 required to be less than 1.5 centimeters horizontal and 2.0 centimeters vertical in order to be accepted.

Table 2. Receiver equipment specifications

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static
Trimble R10 GNSS	Integrated GNSS Antenna R10	TRMR10	Rover

Table 3. QSI and NGS survey monuments and ORGN stations referenced during 2019 DAS-GEO Gilchrist ground survey and calibration. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid 12B.

	PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
ORGN	LAPN	43° 39’ 52.55204”	-121° 30’ 21.55207”	1279.374	55.296
	CHEM	43° 13’ 27.68494”	-121° 47’ 08.94043”	1440.413	60.084
NGS Monument	PB0722	43° 16’ 27.52667”	-121° 21’ 19.29017”	2233.779	31.662
QSI Monuments	GILCHRIST_01	43° 27’ 50.43846”	-121° 41’ 56.04278”	1335.997	89.688
	GILCHRIST_02	43° 25’ 08.60726”	-121° 15’ 55.72945”	1399.681	22.146

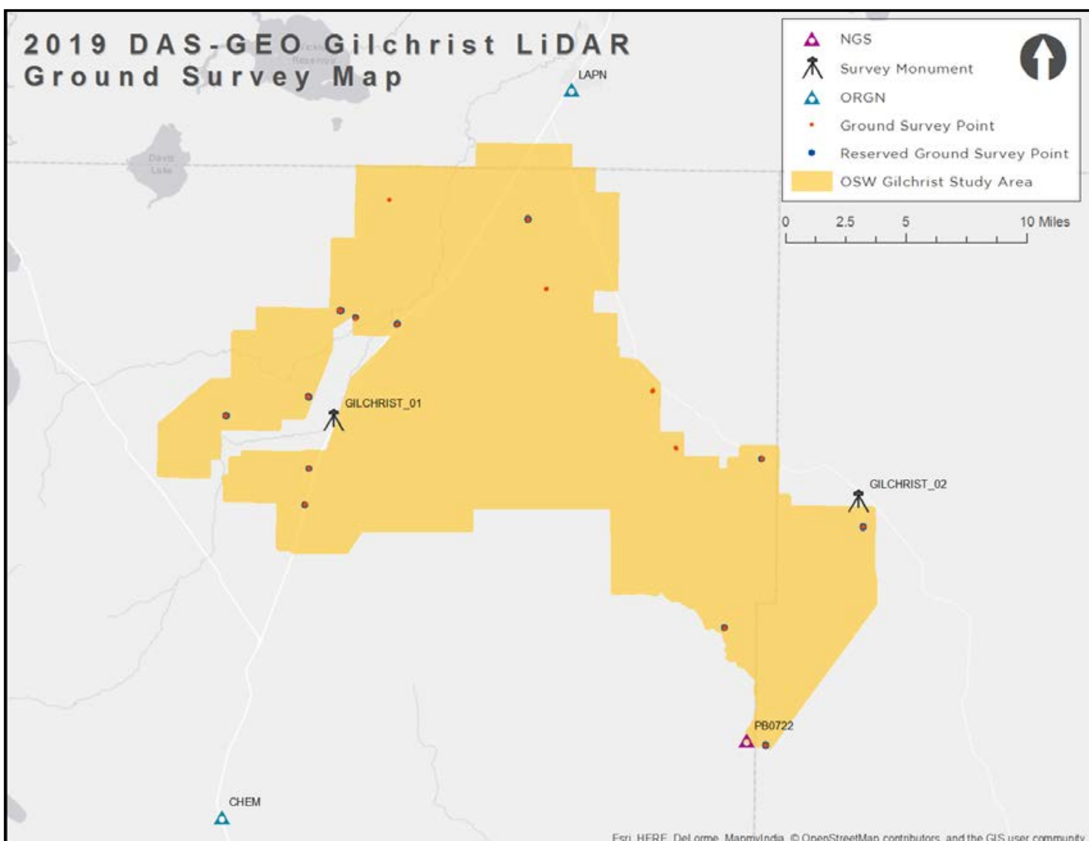


Figure 2. Ground survey map


Figure 2a. Gilchrist_01 monument


Figure 2b. Gilchrist_02 monument

Figure 2c. NGS monument

Airborne Survey

All data for the 2019 DAS-GEO Gilchrist project area were flown between June 1 and June 5, 2019 utilizing a Leica ALS80 sensor mounted in a Cessna Grand Caravan aircraft.

The LiDAR system for the Leica ALS80 sensor was set to acquire ≥333,000 laser pulses per second (i.e. 333 kHz pulse rate) and flown at 1,650 meters above ground level (AGL), capturing a 40 degree field of view. These settings and flight parameters are developed to yield points with an average native density of ≥8 over terrestrial surfaces. The native pulse density is the number of pulses emitted by the LiDAR system. Some types of surfaces (e.g., 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 vary according to distributions of terrain, land cover, and water bodies.

The study area was surveyed with opposing flight line side-lap of ≥60% (≥100% overlap) for the ALS80 sensor to reduce laser shadowing and increase surface laser painting. The system allows for an unlimited number of LiDAR return measurements per pulse, and all discernible laser returns were processed for the output data set.

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. 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 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 among every mission using proprietary methods.

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).

Weather conditions were constantly assessed in flight, as adverse conditions not only affect data quality, but can prove unsafe for flying.

Table 4. LiDAR survey specifications

LiDAR Survey Specifications	
Mission	6/1/2019 - 6/5/2019
Aircraft	Cessna Grand Caravan
Sensor	Leica ALS80
Targeted Altitude	1,650 m AGL
Targeted Aircraft Speed	105 knots
Targeted Pulse Density	≥ 8 pulses/m^2
Laser Pulse Rate	333,000 Hz
Field of View	40˚
Mirror Scan Rate	50 Hz

*See acquisition map on following page for acquisition dates.

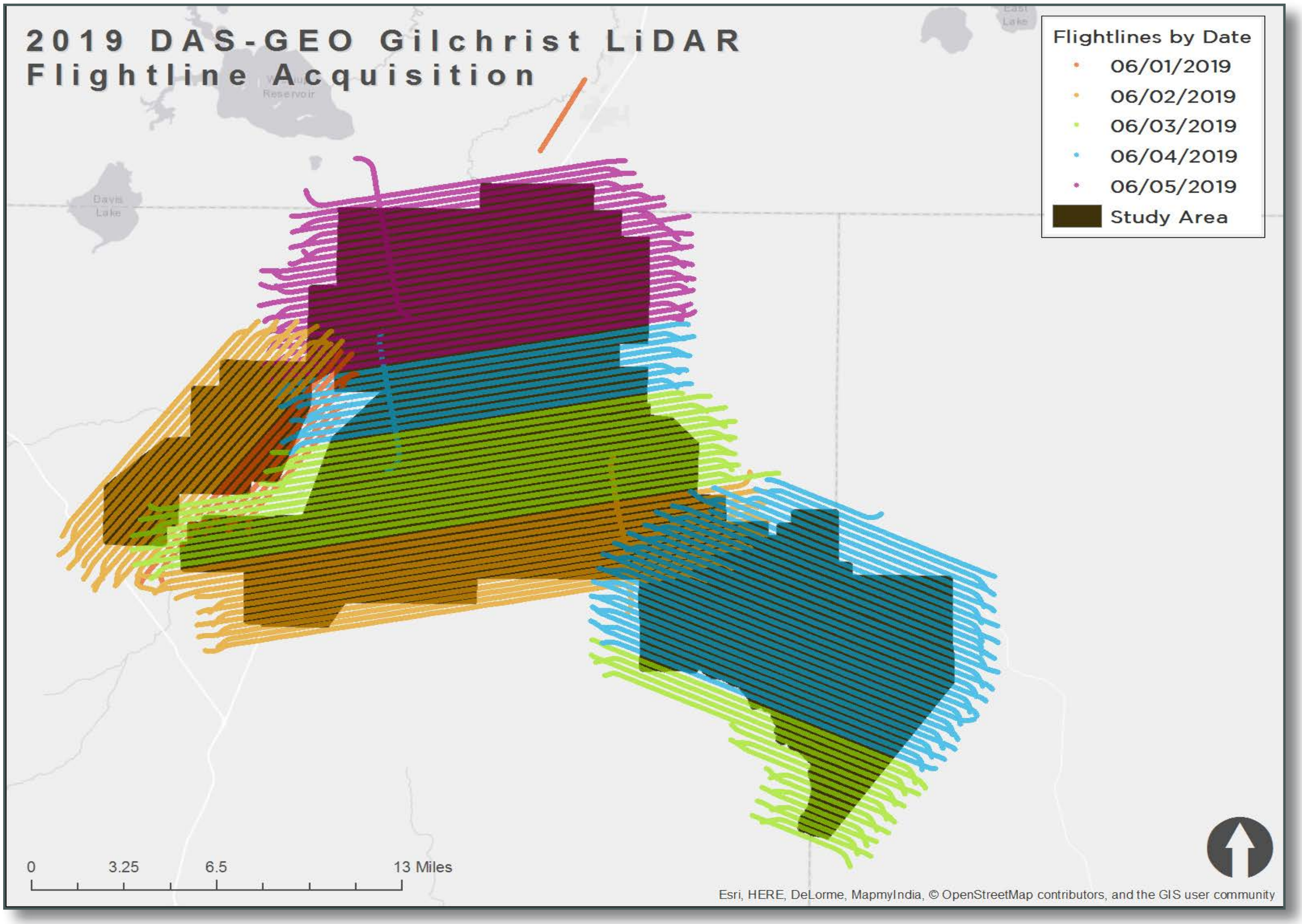
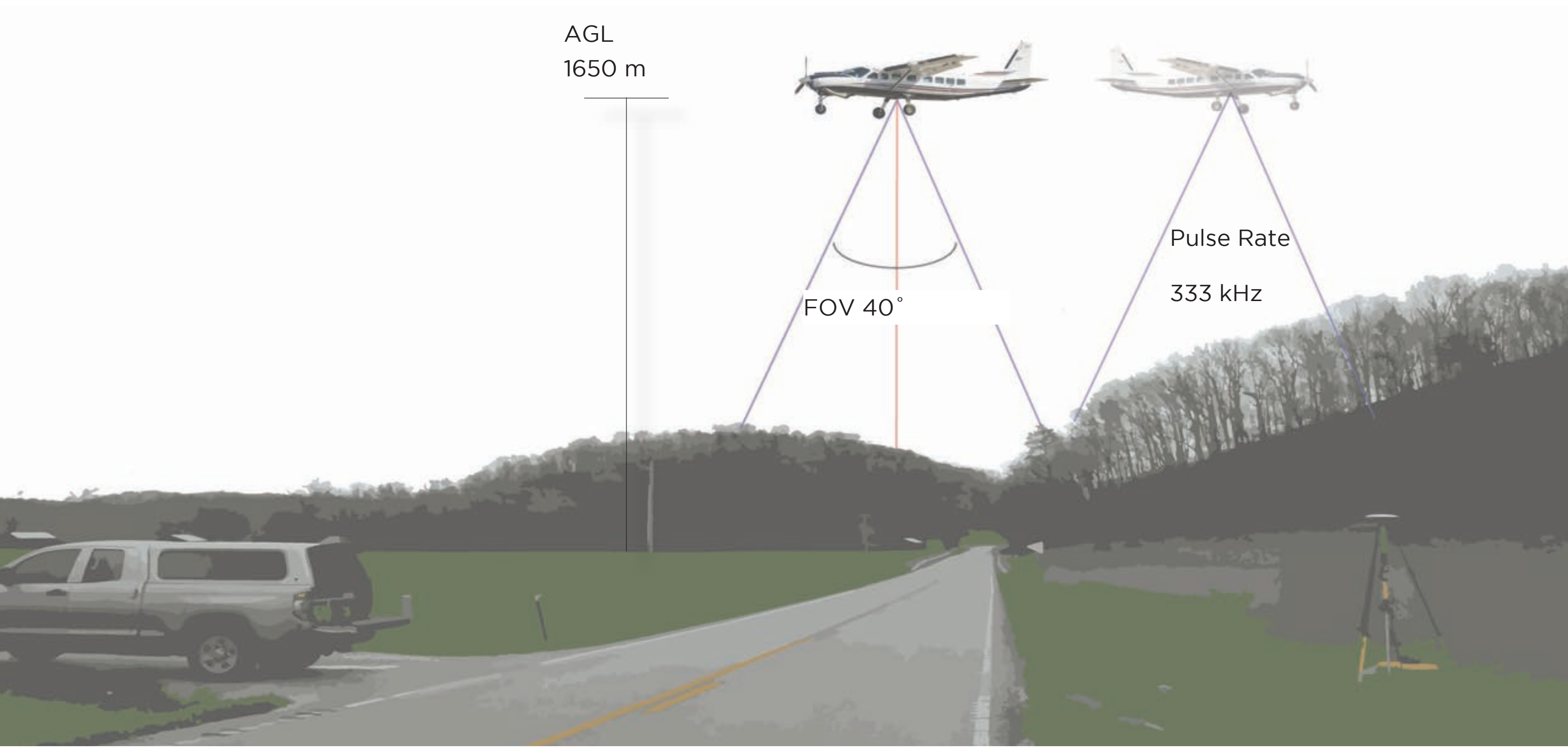


Figure 3. Acquisition flightline map of the 2019 DAS-GEO Gilchrist study area.



Processing

This section describes the processing methodologies for all data acquired by QSI for the 2019 DAS-GEO Gilchrist LiDAR project. All data and layers represented in this project reflect the conditions of the project area at time of flight. Any changes to ground conditions, natural features, or infrastructure occurring after the date of survey will not be reflected in the delivered data.

LiDAR

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, 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:

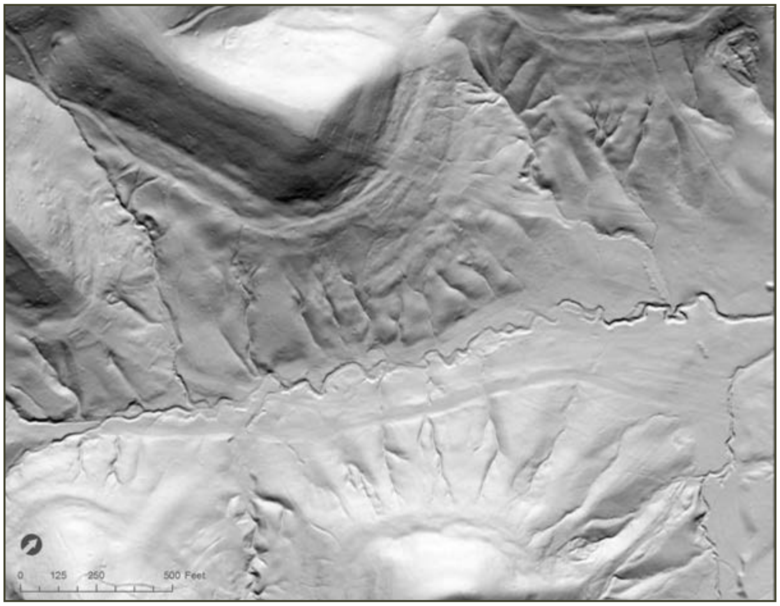


Figure 4. Bare earth DEM hillshade within the 2019 DAS-GEO Gilchrist study area.

Table 5. LiDAR processing work flow

LiDAR 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.	POSGNSS, Trimble Business Center 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.	Leica CloudPro
Import raw laser points into subset bins (less than 500 megabytes, to accommodate file size constraints in processing software). Filter for noise and perform manual relative accuracy calibration.	GeoCue 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 via direct comparisons of ground classified points to reserved ground survey data.	TerraScan
Assign headers (e.g., projection information, variable length record, project name, GEOTIFF tags) to *.las files.	Las Monkey

Results

Accuracy Assessment

Absolute 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 v 1.0 (ASPRS, 2014). The statistical model compares known 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 percent confidence level.

For the 2019 DAS-GEO Gilchrist LiDAR study area, a total of 350 GSPs were collected and used for calibration of the LiDAR data; these points were also used for testing, and therefore this data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 5.0 cm RMSEz Vertical Accuracy Class equating to a non-vegetated vertical accuracy (NVA) equal to +/- 9.0 cm at 95% confidence.

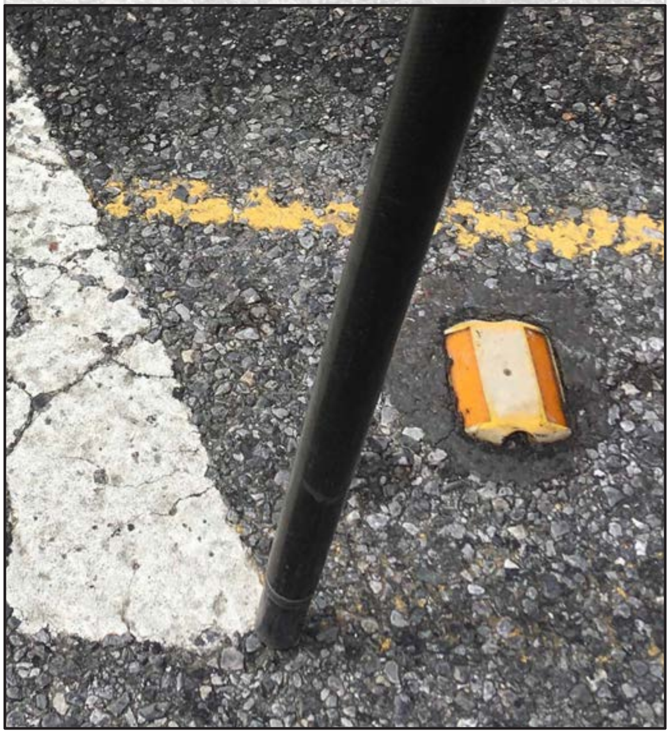


Table 6. Vertical accuracy results

Non-vegetated Vertical Accuracy Statistics	QSI Results
Sample Size	n = 350
NVA (1.96*RMSE)	0.090 m
Average Magnitude of Deviation	0.036 m
RMSE	0.046 m
Standard Deviation (1σ)	0.029 m

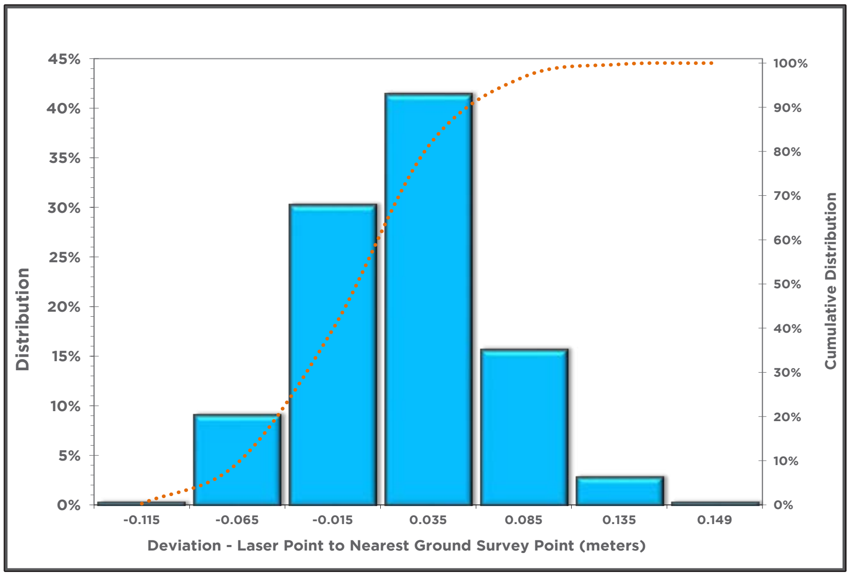


Figure 5. Frequency histogram for LiDAR surface deviation from ground survey point values.

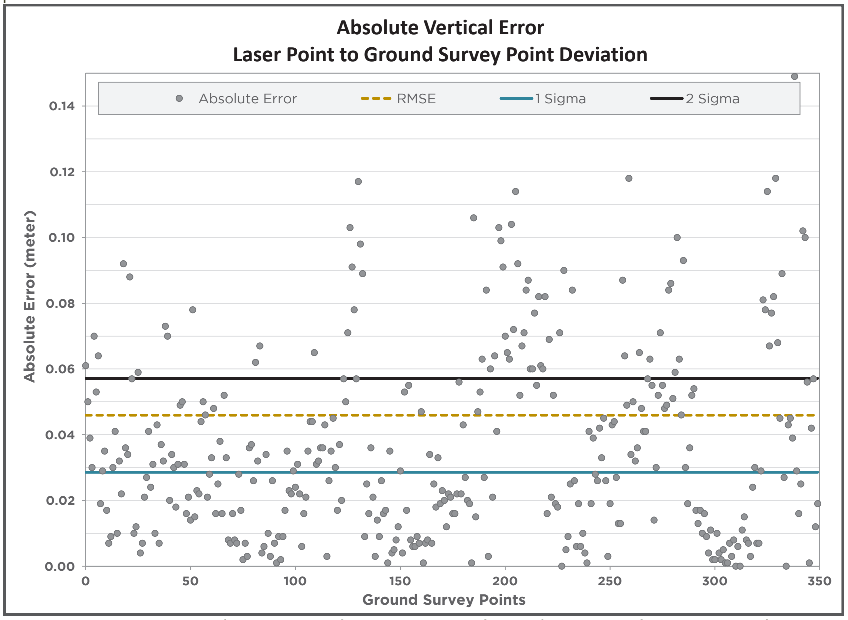


Figure 6. Frequency histogram for LiDAR surface deviation from ground survey point values.

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 cm). 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 130 flightlines and over 12 billion sample points. Relative accuracy is reported for the entire study area.

Table 7. Relative accuracy results

Relative Accuracy Statistics	QSI Results (meters)
Average	0.041 m
Median	0.040 m
1 Sigma	0.043 m
2 Sigma	0.051 m
Sample Survey Points	12,829,825,604
Flightlines	n = 130

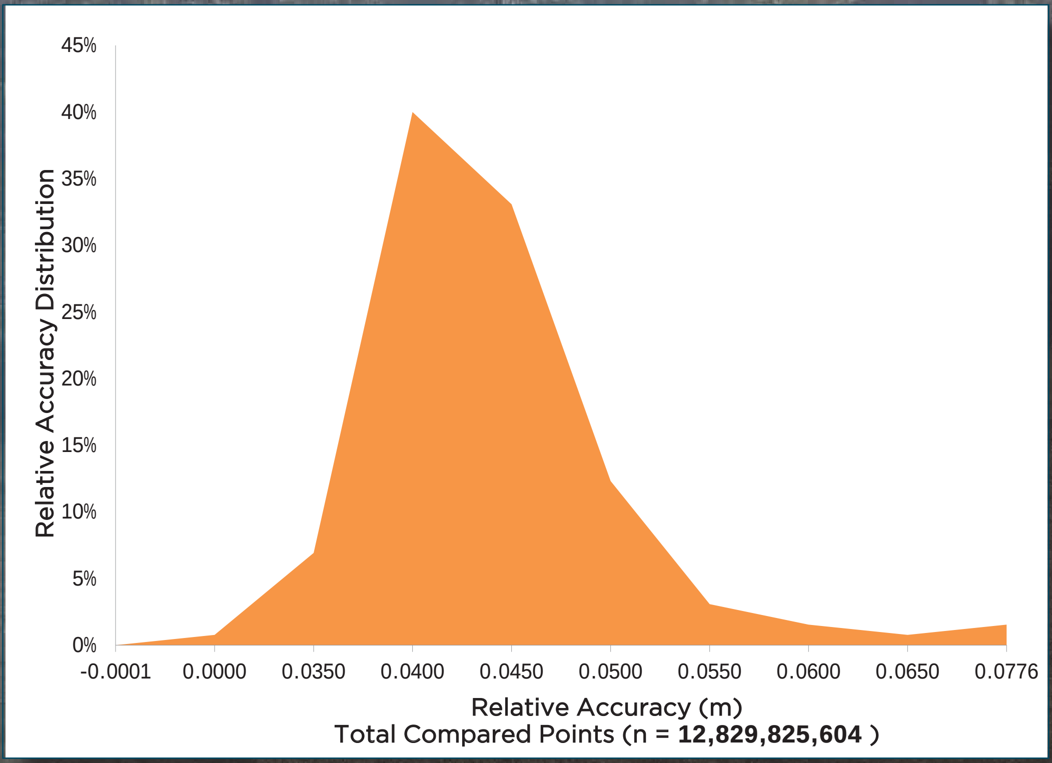


Figure 7. Frequency plot for relative vertical accuracy between flight lines.

Density Results

The native pulse density is the number of pulses emitted by the LiDAR system. The pulse density resolution specification for the 2019 DAS-GEO Gilchrist LiDAR survey area was eight pulses per square meter (ppsm); Quantum Spatial achieved 15.85 ppsm. Images on the following pages show ground and pulse density values for the Gilchrist study area. Density histograms have been calculated based on first return laser point density and ground-classified laser point density.

Table 8. Density results

Density	QSI Results (meters)
Average pulse density	15.85 ppsm
Average ground point density	2.19 ppsm

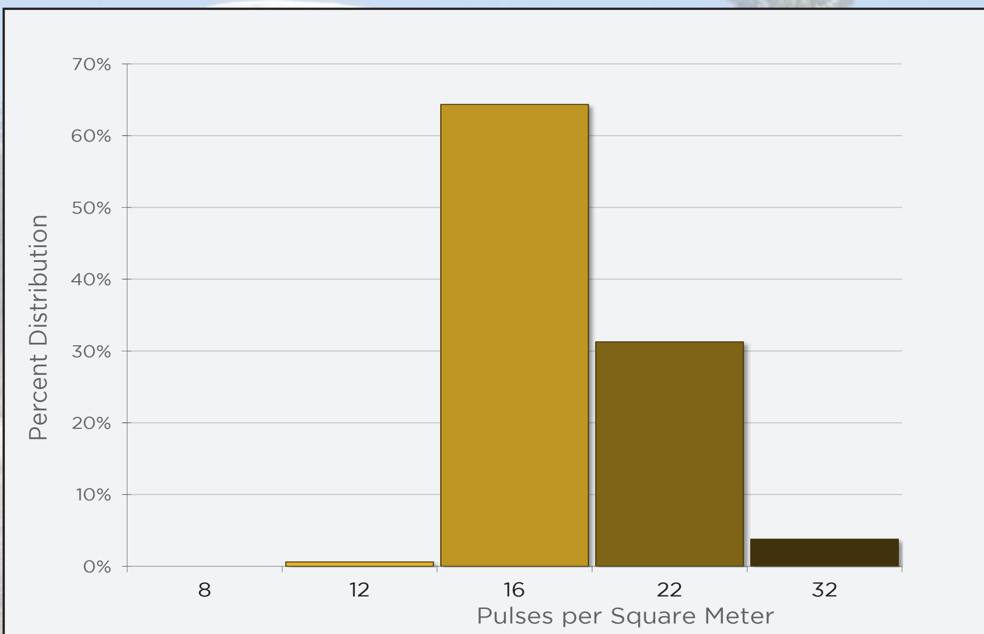


Figure 8. Pulse density histogram

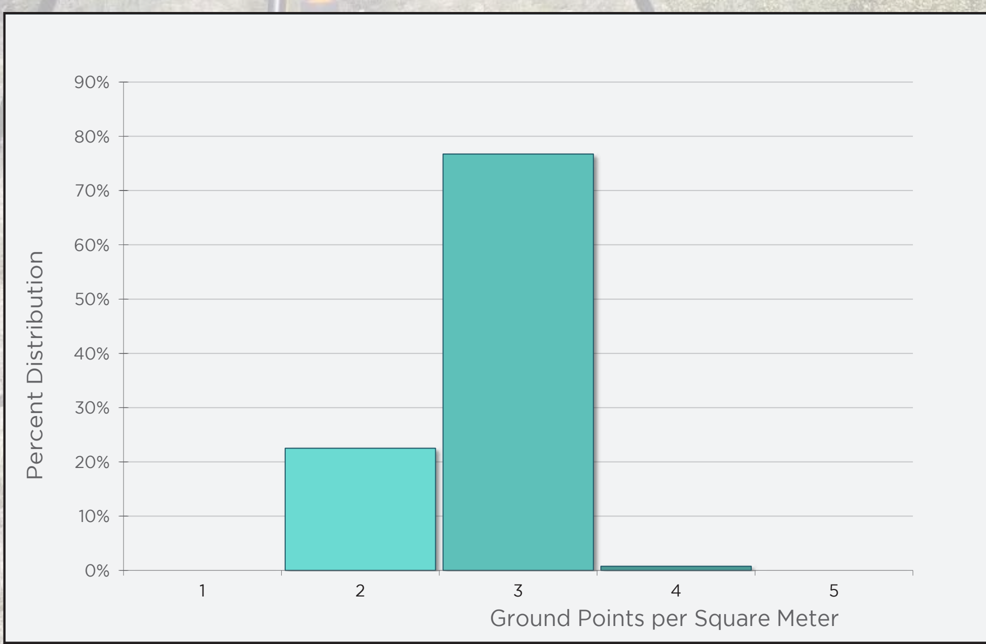


Figure 9. Ground density histogram

Pulse Density Map

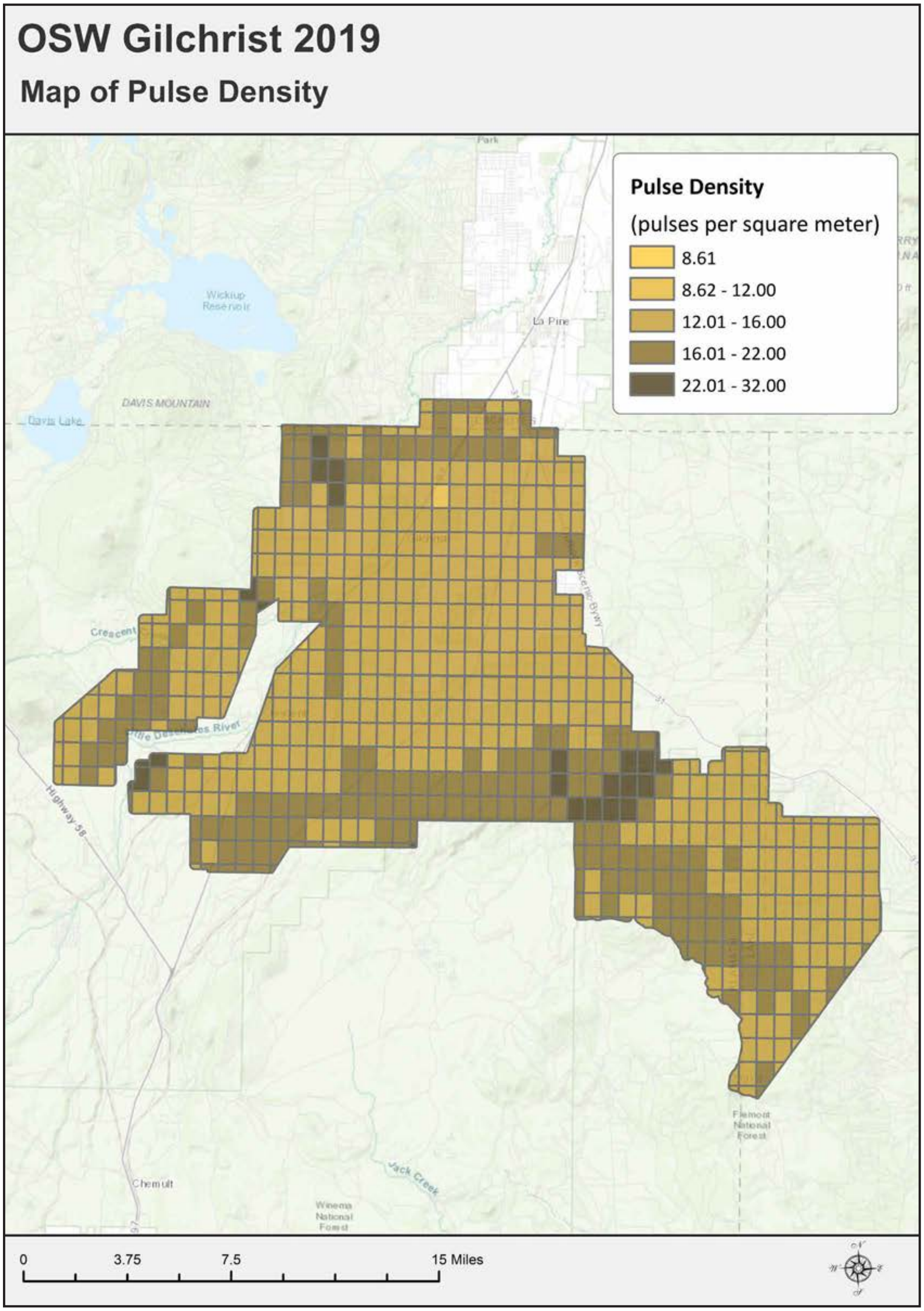


Figure 10. Pulse density map for the 2019 DAS-GEO Gilchrist LiDAR study area.

Ground Density Map

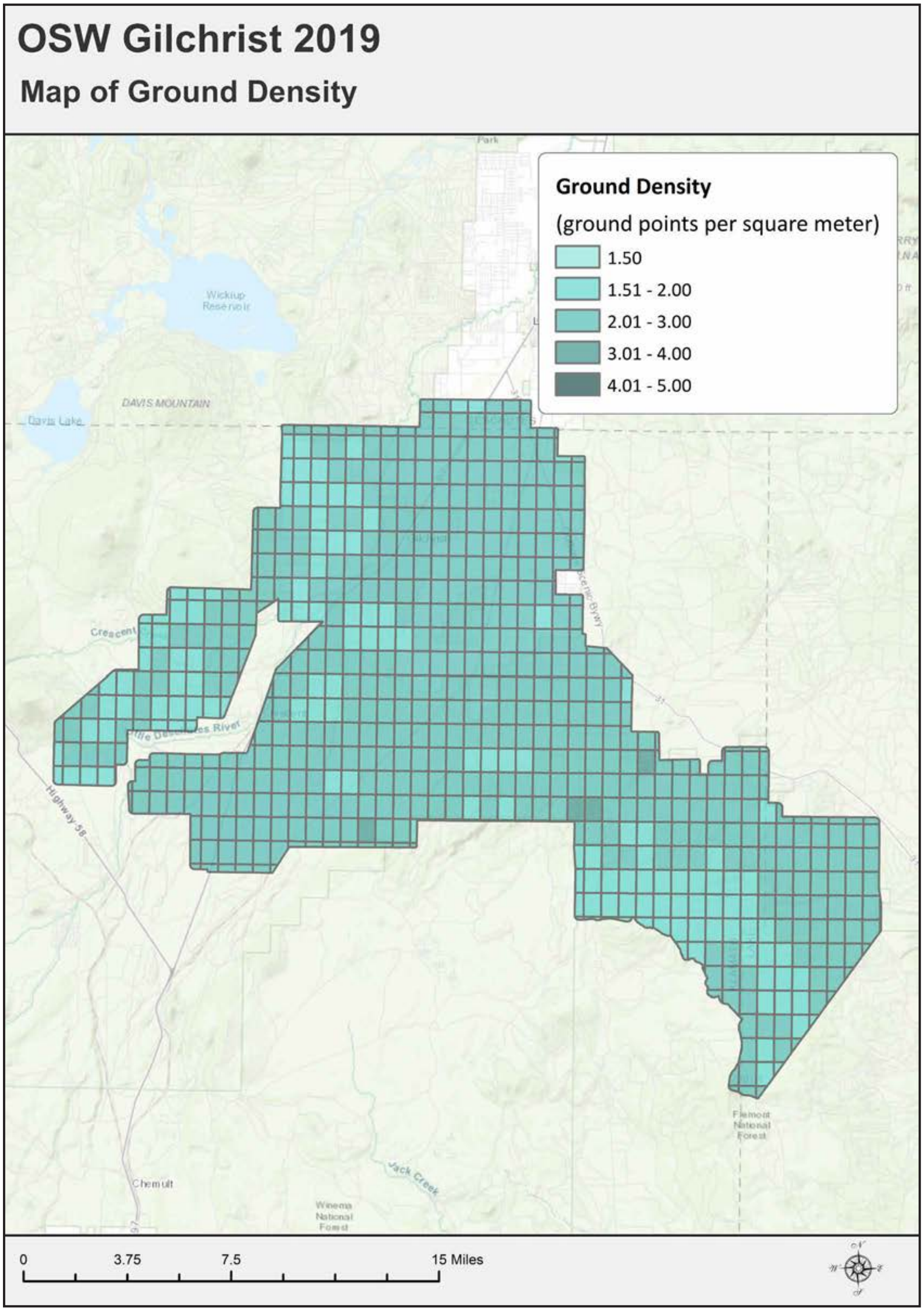
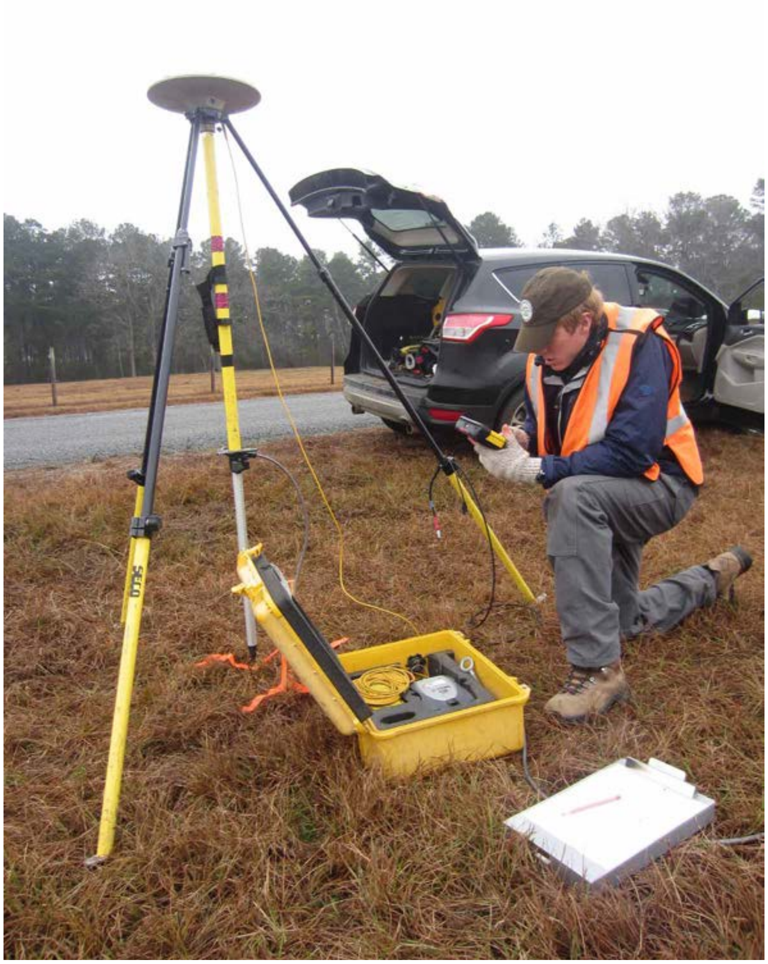


Figure 11. Ground density map for the DAS-GEO Gilchrist LiDAR study

Best Practices

QSI Standards

QSI has high standards and adheres to best practices in all efforts. In the laboratory, quality checks are built in throughout processing steps, and automated methodology allows for rapid data processing. QSI's innovation and adaptive culture rises to technical challenges and the needs of clients like DAS-GEO. Reporting and communication to our clients are prioritized through regular updates and meetings.



Appendix A: PLS Certification

Quantum Spatial, Inc. provided LiDAR services for the 2019 DAS-GEO Gilchrist 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 (Sep 4, 2019)

Sep 4, 2019

John English, GISP, PMP
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 on June 7-12, 2019 for the ground survey and on June 1-5, 2019 for the airborne 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".

Sep 5, 2019

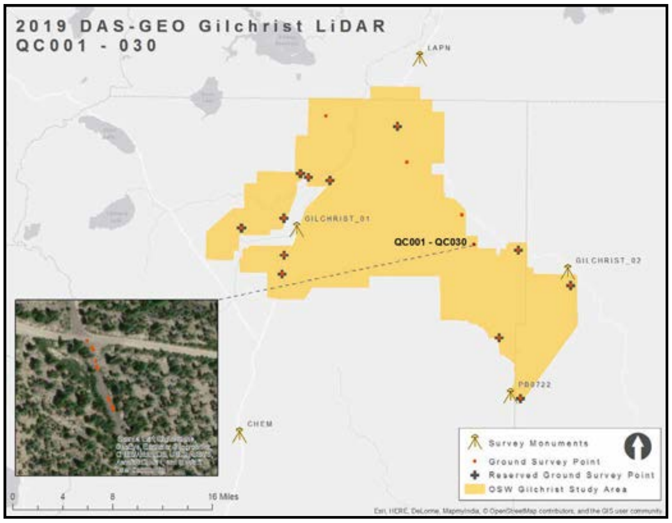
Evon P. Silvia, PLS
Quantum Spatial, Inc.
Corvallis, OR 97330

REGISTERED
PROFESSIONAL
LAND SURVEYOR

OREGON
JUNE 10, 2014
EVON P. SILVIA
81104LS

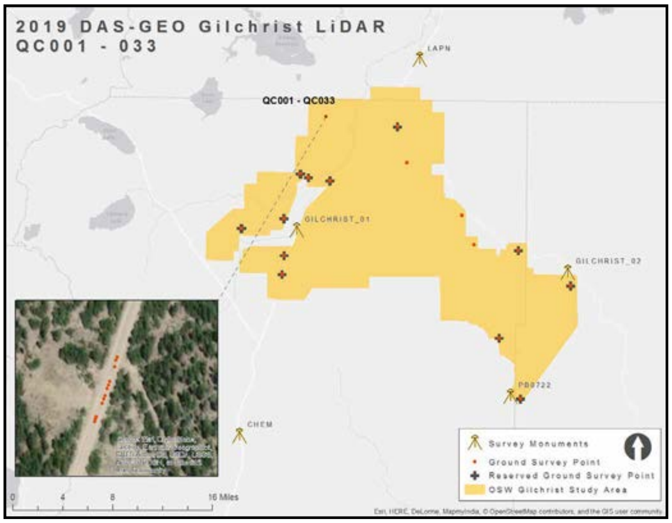
EXPIRES: 06/30/2020

Appendix B: Ground Survey Point Data



Ground Survey Point Group 001 - 030

Ground Survey Point 001 - 030 continued



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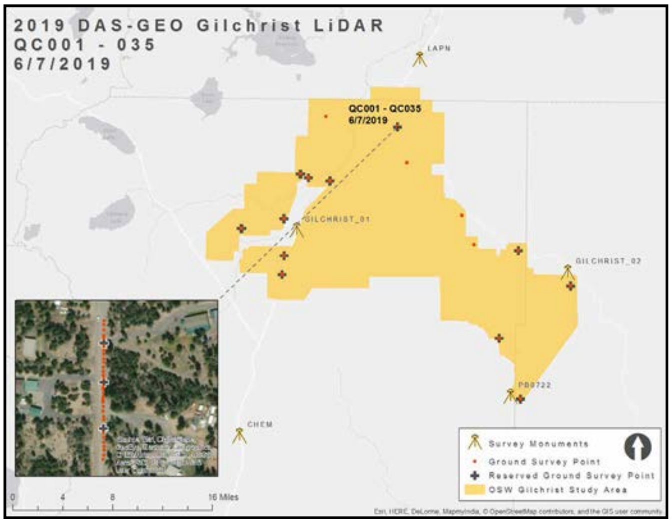
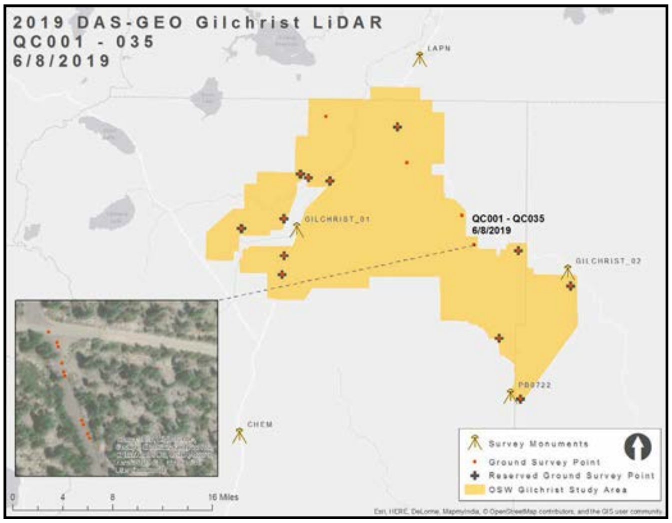


Ground Survey Point 001 - 035
6/7/2019

Ground Survey Point 001 - 035

6/7/2019 Continued

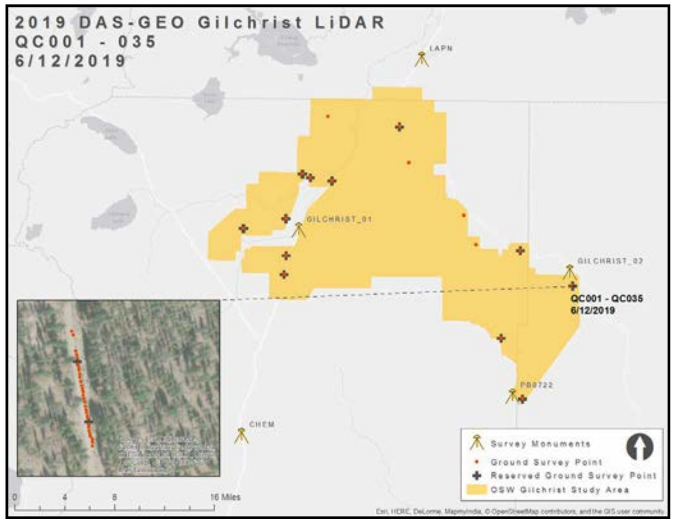


Ground Survey Point 001 - 035

6/8/2019

Ground Survey Point 001 - 035

6/8/2019 Continued

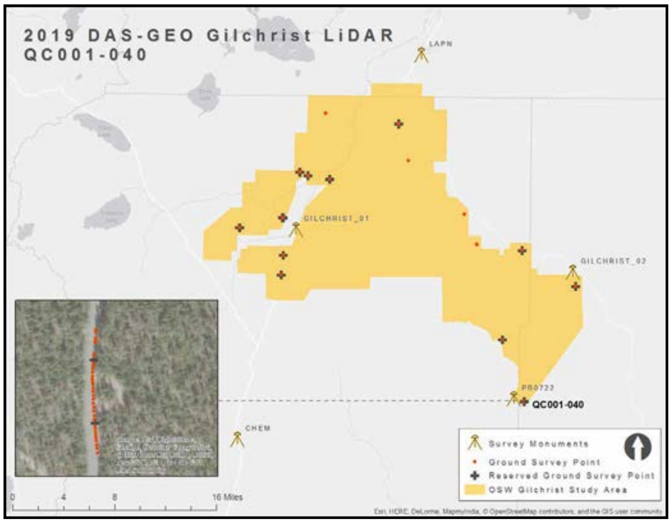


Ground Survey Point 001 - 035

6/12/2019

Ground Survey Point 001- 035

6/12/2019 Continued



Ground Survey Point 001 - 040

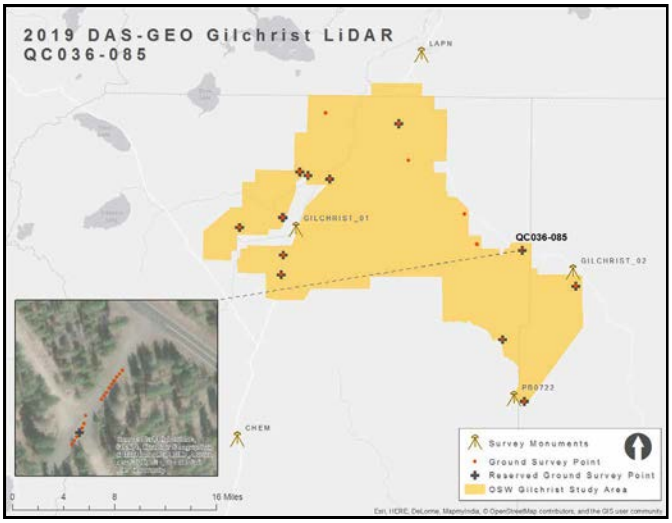
Ground Survey Point 001 - 040 Continued

Ground Survey Point 034 - 080

Ground Survey Point 034 - 085

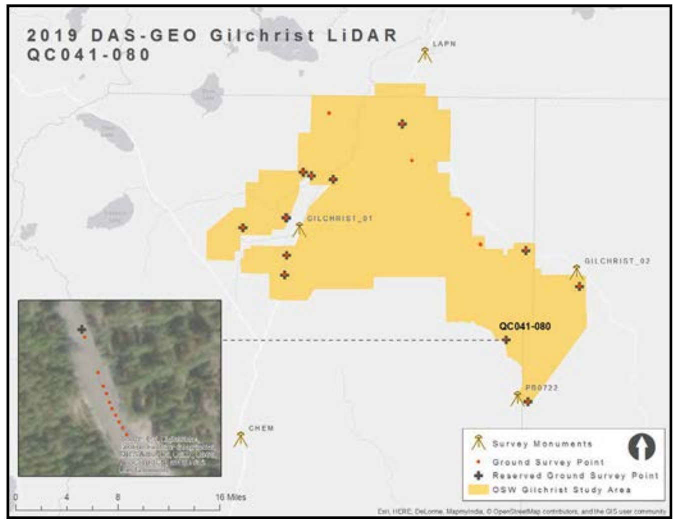
Ground Survey Point 035 - 070

Ground Survey Point 035 - 070



Ground Survey Point 036 - 085

Ground Survey Point 036 - 085



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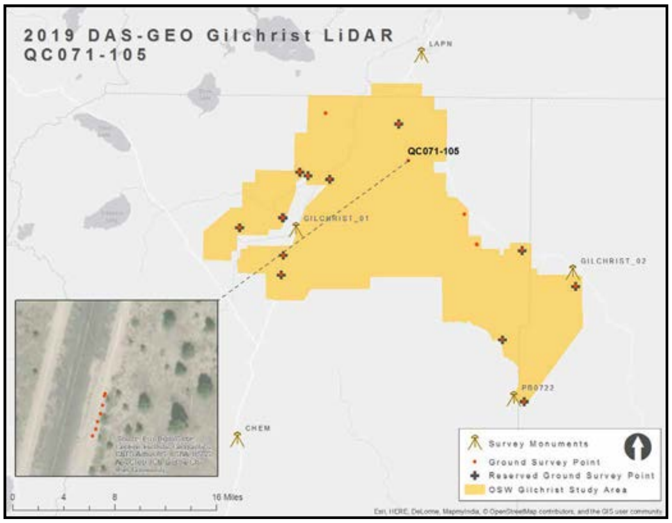

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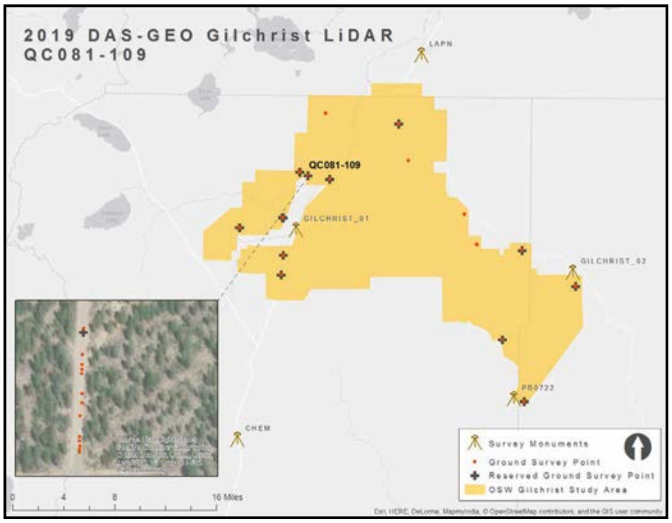
Ground Survey Point 071 - 105 Continued



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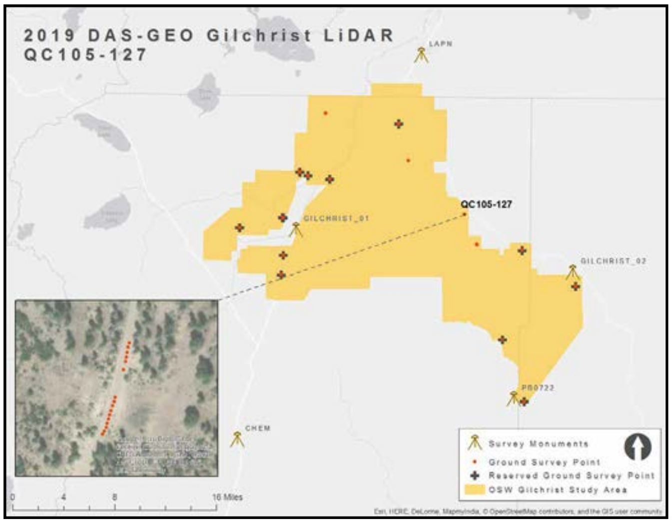

Ground Survey Point 105 - 127

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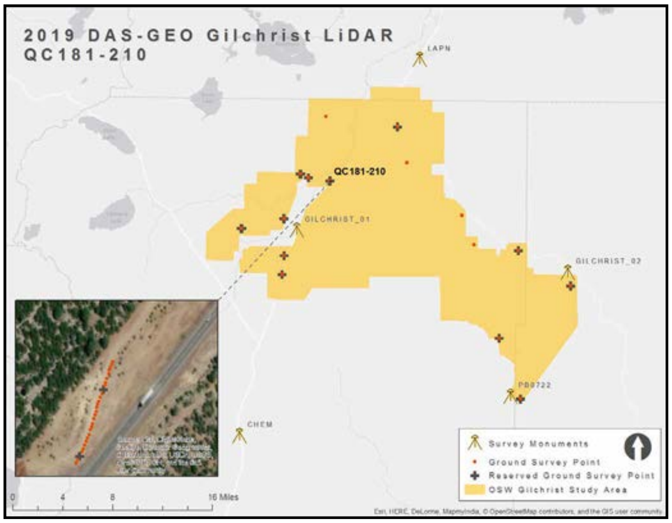
Ground Survey Point 110 - 145

Ground Survey Point 110 - 145 Continued

Ground Survey Point 146 - 180

Ground Survey Point 146 - 180 Continued

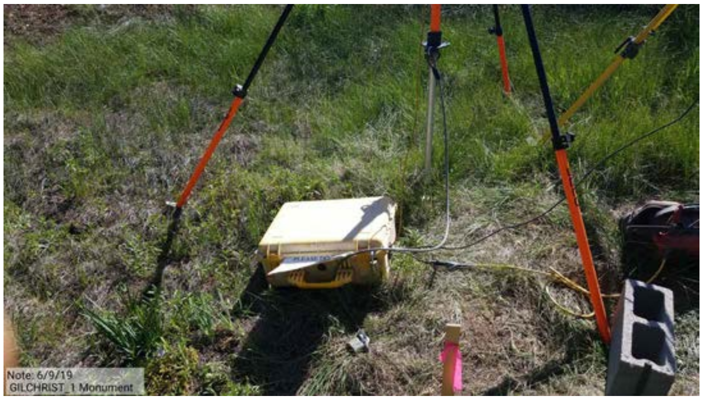


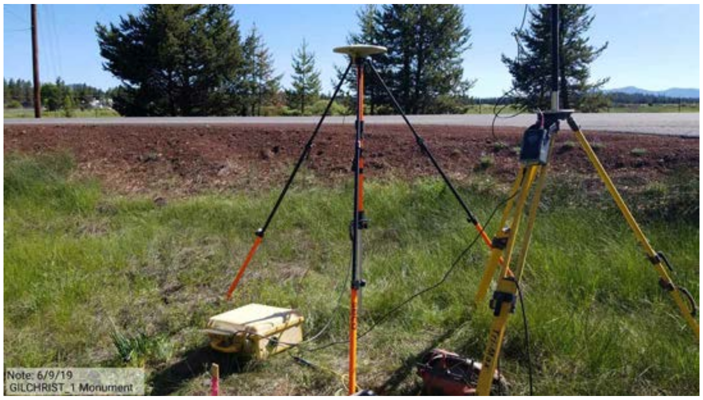
Ground Survey Point 181 - 210

Ground Survey Point 181 - 210 Continued

Appendix C: Monument Photos

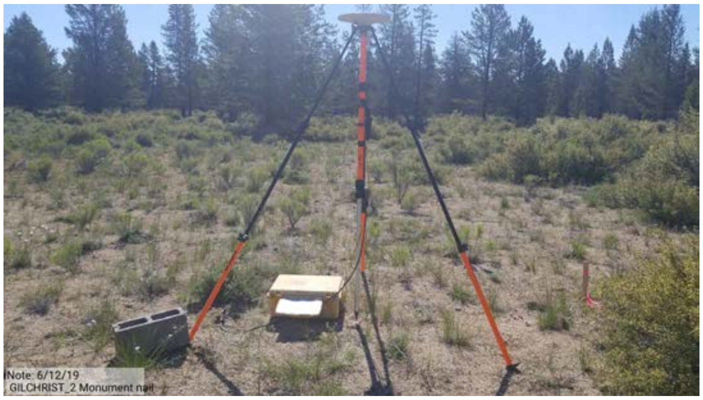
Gilchrist_01

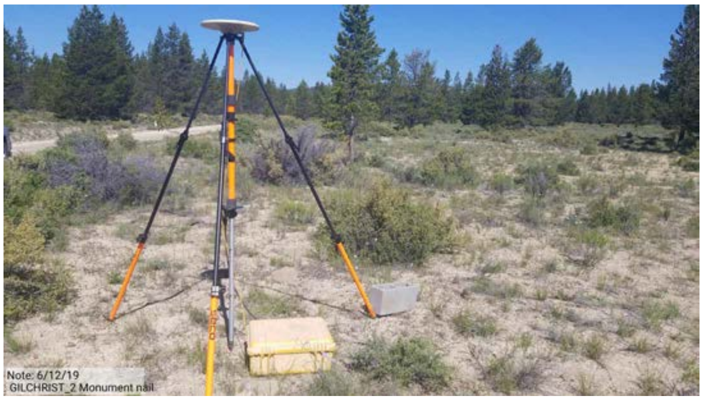


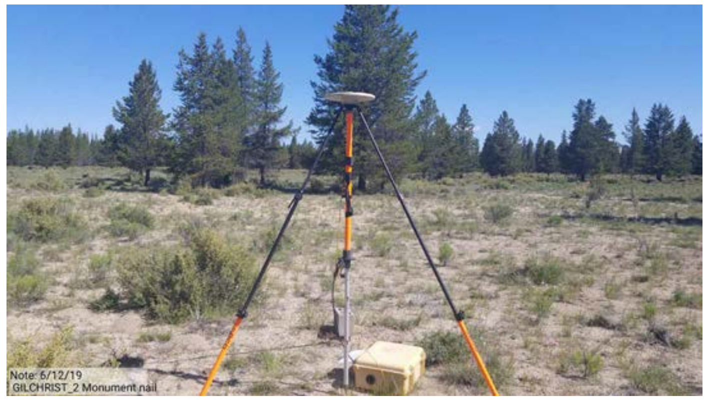


Gilchrist_01 Continued

Gilchrist_02







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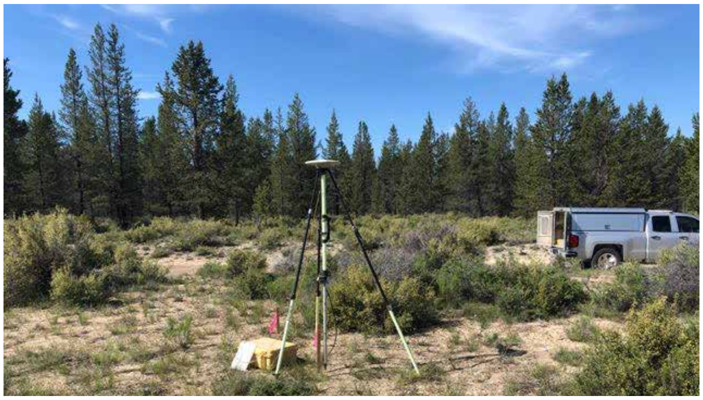


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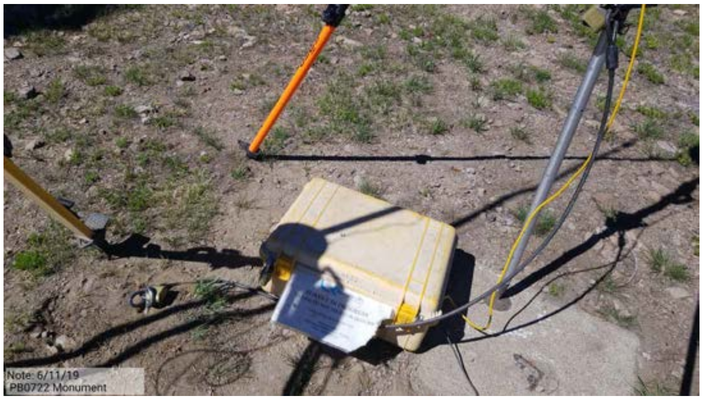

Thank You

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2019_OSW_Gilchrist_LiDAR_Data_Report_reduced

Final Audit Report 2019-09-05

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