

Lidar Mapping Project Report

For Submittal to Oregon Department of Forestry

Project Name: Private Forest Accords

Contract # ODF-1109A-20

Task Order # 4

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Presented to:

**Oregon Department of Forestry
2600 State Street, Bldg. D
Salem, OR 97310**

Submitted by:

**GeoTerra, Inc.
860 McKinley St
Eugene, OR 97402**

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1. Project Overview

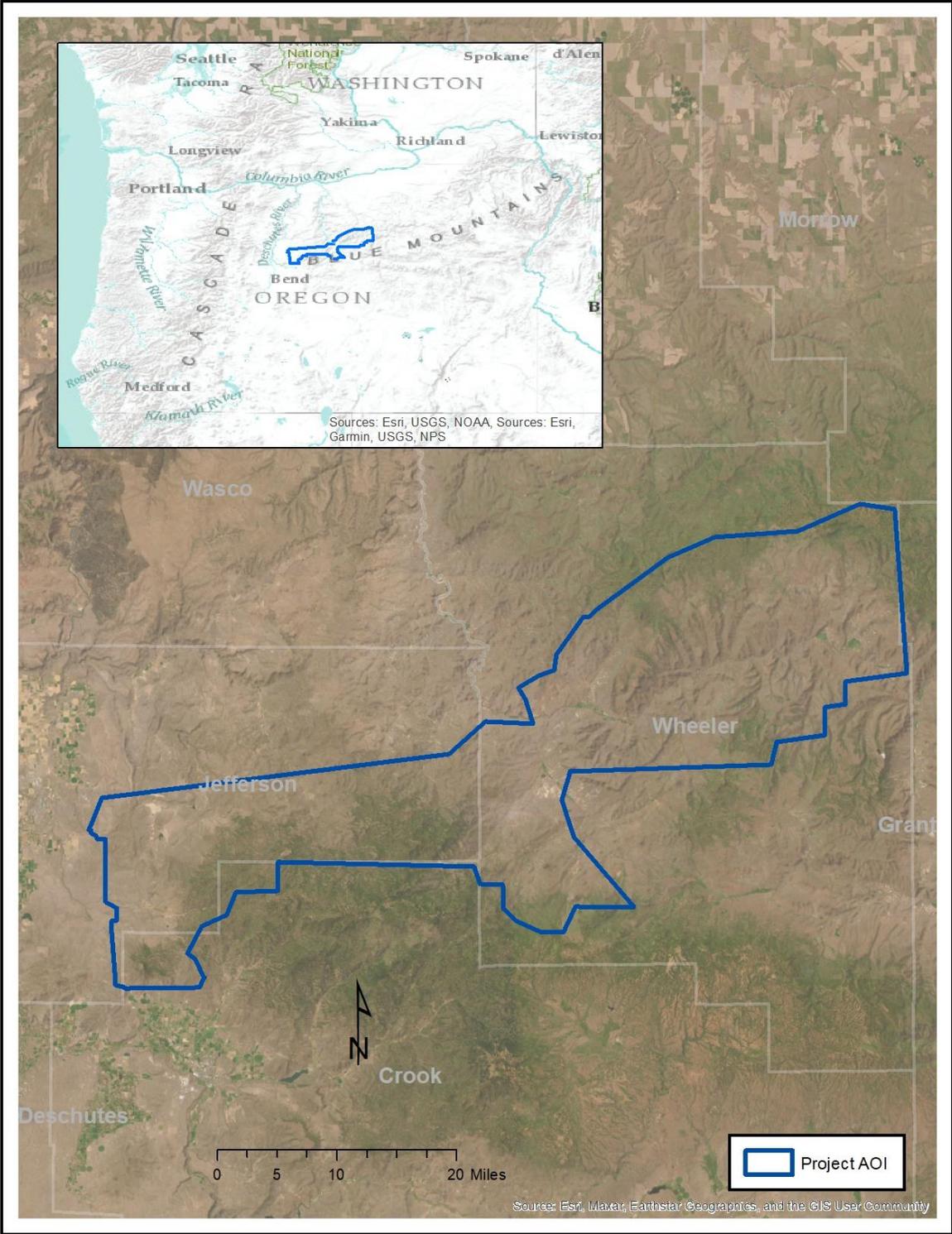


Figure 1. The project area of interest (AOI) for Lidar acquisition, processing, and deliverables.

1.1 Description

GeoTerra, Inc. was selected by Oregon Department of Forestry (ODF) under contract #ODF-1109A-20, Task #4 to provide new Lidar acquisition and subsequent products during the 2022 calendar year for the Private Forest Accords project area as shown in Figure 1. Lidar specifications for the approximately 947 mi² area of interest (AOI) located in central Oregon were required to meet a minimum density of 8 pts/m² classified data in LAS v1.4 format with delivery of bare earth and highest-hit surface models and intensity images.

1.2 Purpose

This project and resulting data support efforts by ODF to fill in gaps of existing Lidar on private forest lands.

1.3 Specifications

All data delivered for this project was produced to meet the USGS Lidar Base Specifications v2022 Rev. A

1.4 Spatial Reference

All data for this project were produced using the following spatial data reference system:

- Horizontal Datum: NAD83(2011)(Epoch 2010.0)
- Horizontal Projection: Oregon Statewide Lambert
- Horizontal Units: International Feet
- Horizontal EPSG Code: 6557
- Vertical Datum: NAVD88
- Geoid Model: 18
- Vertical Units: International Feet
- Vertical Datum EPSG Code: 8228

1.5 Task Order Deliverables

Table 1, below, provides details of items that were processed and delivered for this project, with an indication of format and compliance to contractual specifications. The final tiling scheme of LAS and raster-formatted data was based on the provided ODF 3000'x3000' tiling scheme.

Table 1. Project delivery items and formats

Deliverable	Format	Compliance notes
Classified Point Cloud	LAS 1.4 PDRF 7	Each point includes GPS week and GPS second OR Posix time, easting, northing, elevation, intensity, return number, return classification, scan angle, point source ID.
Bare Earth Surface Model	GeoTIFF, 32-bit floating point	3-foot resolution hydro-flattened ground model.
Max Surface Height Model	GeoTIFF, 32-bit floating point	3-foot resolution from binning interpolation type and maximum value for determining cell value.
Intensity Images	16-bit GeoTIFF	3-foot resolution of 1 st -return intensity values, normalized in a linear fashion.
Survey Report	PDF	Describes control and checkpoint locations acquired for this project and methodology used.
Lidar Technical Report	PDF	This report: provides methodology used for planning, processing, assessment, and delivery of final data.

FGDC Metadata	XML	Per USGS 3DEP Lidar Specifications v2022 Rev. A
Swath Outlines	Geodatabase	Polygon of each flight swath
Project Index	Geodatabase	Polygons of final project delivery areas.
SBET Trajectories	Geodatabase	Vector data from aircraft sensor
Tile scheme	Geodatabase	3000' x 3000' tiles

1.6 Lidar Data Classification

Classified Lidar point cloud data were provided in las v1.4 format using the following classification scheme shown in Table 2:

Table 2. Lidar classification scheme applied to all point returns.

Lidar Classification Scheme	
Class 1	Processed, but not classified
Class W1	Processed, but not classified with a withheld flag
Class 2	Ground (bare earth)
Class W2	Ground (bare earth) with a withheld flag
Class W7	Low Noise – with a withheld flag
Class 9	Water
Class W9	Water with a withheld flag
Class 17	Bridge Deck
Class W18	High Noise – with a withheld flag
Class 20	Ignored ground near breaklines
Class W20	Ignored ground near breaklines with withheld flag

2. Acquisition

2.1 Flight Planning

Lidar acquisition was planned using Teledyne Optech Airborne Mission Manager to calculate optimum parameters to meet project requirements and accommodate terrain variations. FMS utilized an existing DEM surface to calculate best flight parameters and swath layout to meet desire point density. The project required a minimum aggregate density of 8 points per square meter. Point density was designed to be achieved through overlapping adjacent swaths by greater than 55%. Adjacent lines were flown in opposing directions. the Galaxy’s *PulseTRAK* and *SwathTRAK* technologies were employed during flight to allow the sensor to maintain regular point distribution and constant-width swaths despite changes in terrain.

GeoTerra utilized an Optech Galaxy T2000 sensor, mounted in a Cessna 210 aircraft to acquire new lidar data for all areas. During flight, the on-board receiver logged GNSS data at 1 Hz interval and IMU data at 200 Hz interval. Acquisition parameters including pulse rate, flight altitude, orientation relative to terrain, scan angle, and ground speed were optimized to meet contract specifications and objectives. Acquisition conditions at the time of each mission were free of clouds, fog, snow, and flooding. The flight acquisition specifications for this project are shown in Table 3, below.

Table 3. Lidar Acquisition Specifications.

LiDAR Settings & Specifications	
Aircraft Used	Cessna 210
Sensor	Optech Galaxy T2000
Intensity	12-bit, scaled to 16-bit
Wavelength	1064 nm
Beam Divergence	0.16 mrad
Maximum Sensor Returns Per Pulse	8
Target Pulse Rate	600 kHz
Scan Frequency	73 Hz
Target Aircraft Speed	120 kts
Maximum Scan Angle	20°
Maximum Survey Altitude (AGL)	6500 ft (1981 m)
Swath-to-Swath Overlap	> 55%
Average Swath Width (Flat Ground)	4731 ft (1442m)
Maximum Beam Diameter on ground	31.7 cm
Aggregate Resolution/Density	≥ 8 pulses/m ²
Aggregate Nominal Point Spacing	≤ 0.35 m
Planned Accuracy	RMSE _Z ≤ 10 cm

2.2 Acquisition Timeline

Dates of acquisition is shown in Table 4 and Figure 2, below.

Table 4. Date of Lidar acquisition

Area Name	Dates of Acquisition
Private Forest Accords	September 23 – October 13, 2022

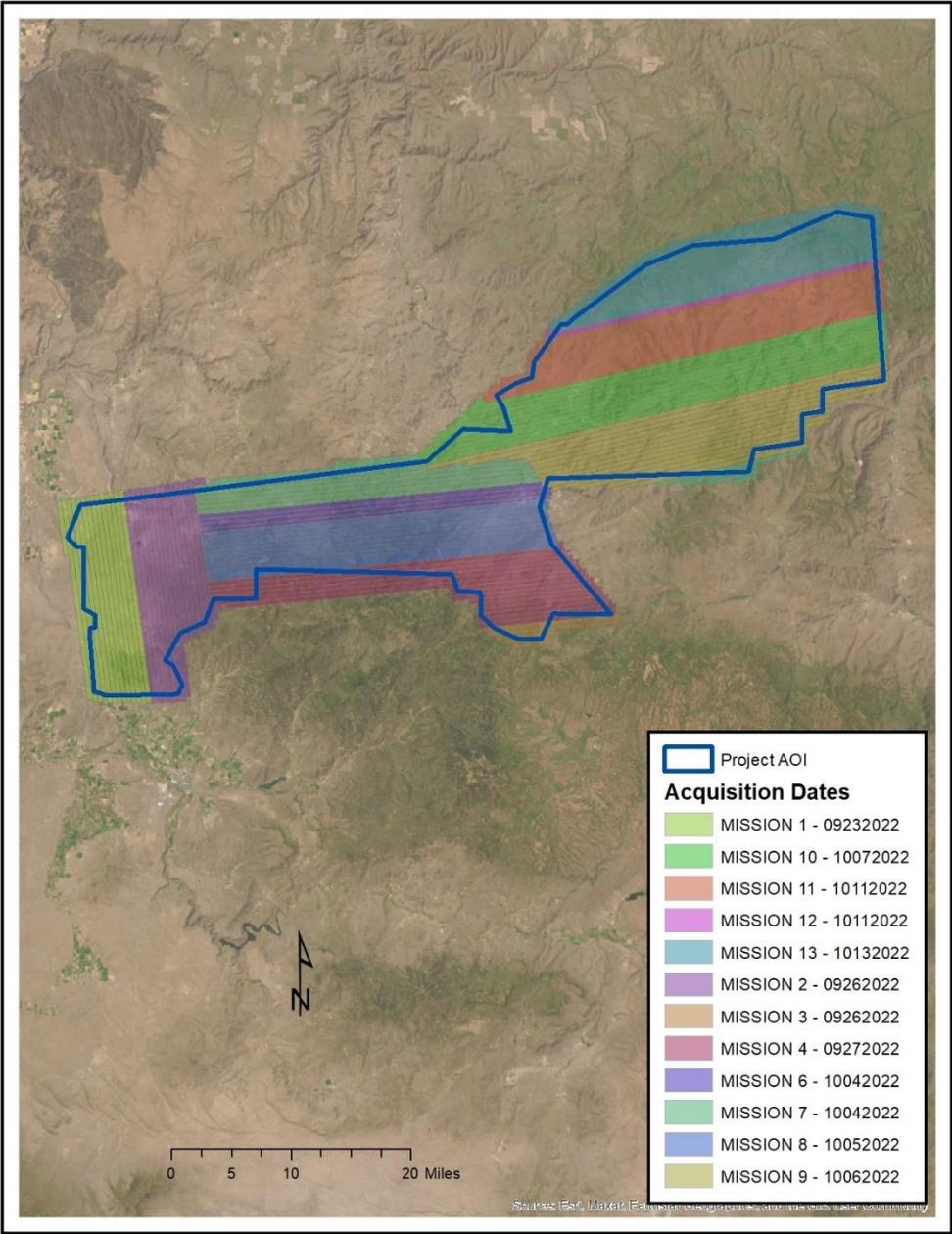


Figure 2. Dates of Lidar acquisition, by mission.

2.3 Post-Flight Evaluation

Upon completion of each mission, GeoTerra immediately reviewed the raw data to identify any potential issues affecting accuracy and the need for re-flights. Laser points were evaluated to ensure complete coverage of the project area. Positional Dilution of Precision (PDOP) during flight was assessed to ensure it remained below 3.0 to provide the best geometry of satellites for post processing.

3. Processing

3.1 SBET Processing

Kinematic corrections for aircraft position data were performed using the Precise Point Position (PPP) method. PPP utilizes an autonomous positioning method whereby data from the aircraft receiver is processed using dual frequency data and precise orbit and clock files. Processed GNSS data were then combined with IMU data using a loosely coupled technique where Novatel Inertial Explorer v8.9 also computes lever arm offsets between the IMU and the L1 phase center of the aircraft antenna. The final combined GNSS/IMU solution was output as a Smoothed Best Estimate Trajectory (SBET). Laser point positions were calculated by associating the SBET position to each laser point’s return time, scan angle and intensity; see Figure 3. Point positions were converted to orthometric elevations by applying a Geoid 18 correction.

3.2 Laser Post-Processing and Calibration

Data was processed into LAS format by flight line and used to perform the relative calibration and check for erroneous data. An initial auto-classification was performed and resulting ground points were used to perform an automatic line-to-line calibration to adjust for pitch, roll and heading, GPS/IMU drift, and mirror flex. Calibrations were applied to all returns and data was adjusted to surveyed ground control to achieve final adjusted positions. Table 5, below, provides a detailed list of equipment, software and processes used to produce the final calibrated data.

Table 5. Planning and Post-Processing Overview

Process	Software	Description
<i>Flight Planning</i>	Teledyne Optech Airborne Mission Manager	Data acquisition was planned in consideration to terrain, environmental factors, and project objectives.
<i>Flight Execution</i>	Optech Galaxy T2000	Sensor equipped with POS AV™ AP50 (OEM); Up to and 8 range measurements and intensities for each pulse; Internal solid-state drive SSD
<i>ABGPS Data Post Processing</i>	Novatel Inertial Explorer Version 8.60.6323	The data collected during the flight is post-processed into Smoothed Best Estimate of Trajectory (SBET) binary file of the IMU trajectory which is combined processed data from both GNSS satellite data and IMU data and is used to geo-reference the laser point cloud.
<i>Raw Lidar Post Processing to LAS Format</i>	Optech LMS (Lidar Management Suite)	Data was processed from range format to LAS format and preliminary adjustment was made using tie plane methodology.
<i>Lidar Strip Relative Adjustment</i>	TerraMatch	Additional relative adjustment was performed using tie line methodology to further improve fit especially in areas where tie planes were not found.
<i>Autoclassification</i>	TerraScan	Rigorous selected as well as custom created algorithms built within TerraScan were used to automatically classify the data.

Lidar Strip Absolute Adjustment

LP360

Data was compared to non-vegetated control points set in appropriate terrain for absolute adjustment.

3.3 Boresight Calibration

Prior to acquisition, a Boresight Calibration was performed to determine exact angles between the IMU and lidar reference frame. A local site was chosen with slopes in different directions to provide viable observations for calculation of angle offsets. The determined offset values were then transferred to sensor instruction files to use for downstream processing.

3.4 Relative Adjustment

Relative and absolute adjustment of all strips was accomplished using Optech *LMS* and TerraSolid *TerraMatch* software packages. *LMS* was used to perform automated extraction of planar surfaces from the point cloud. Tie planes were determined to establish correspondence between overlapping flight lines. Planes from overlapping flight lines were then compared and measured for spatial accuracy and used to co-locate all lines to within an acceptable tolerance.

A set of accurately calculated tie planes were selected for self-calibration. Selection criteria include variables such as: size and shape of the plane, the number of laser points, slope of plane, orientation of plane with respect to flight direction, location of plane within a flight line, and a fitting error. These criteria have an effect on overall correction, as they determine the geometry of the adjustment. Self-calibration adjustment parameters were then determined and used to re-calculate laser point locations (x,y,z). Planar surfaces were also re-calculated for a final adjustment. This project was broken into three blocks of equal size to perform relative adjustment and further processing. Each subsequent block was tied to the previously adjusted block. Table 6 shows results of the relative calibration for each block.

Table 6. Results of relative adjustment for each block.

Block	Number of Measured Section Lines	RMS (ft)	Maximum Value (ft)
West A	2,226,143	0.044	0.32
West B	7,311,124	0.067	0.32
East	1,104,129	0.065	0.32

3.5 Absolute Adjustment

After relative fit was established, surveyed control points acquired for the project were utilized to perform the absolute adjustment of Lidar points to ground coordinates. (Note: a separate Survey Report for the project is included with this delivery). The point cloud was classified and used to compare Lidar ground values to control values. A mean vertical offset from was calculated from all control within a project AOI and used to apply a final adjustment of the point cloud to absolute position. Table 7 shows results of ground control compared to final adjusted points. Figure 3 shows the location of all survey control used for final adjustment.

Table 7. Results of absolute adjustment as compared to surveyed ground control on open flat ground.

	Private Forest Accords
<i>Number of Control Points</i>	19
<i>Vertical RMSEz</i>	0.08 ft

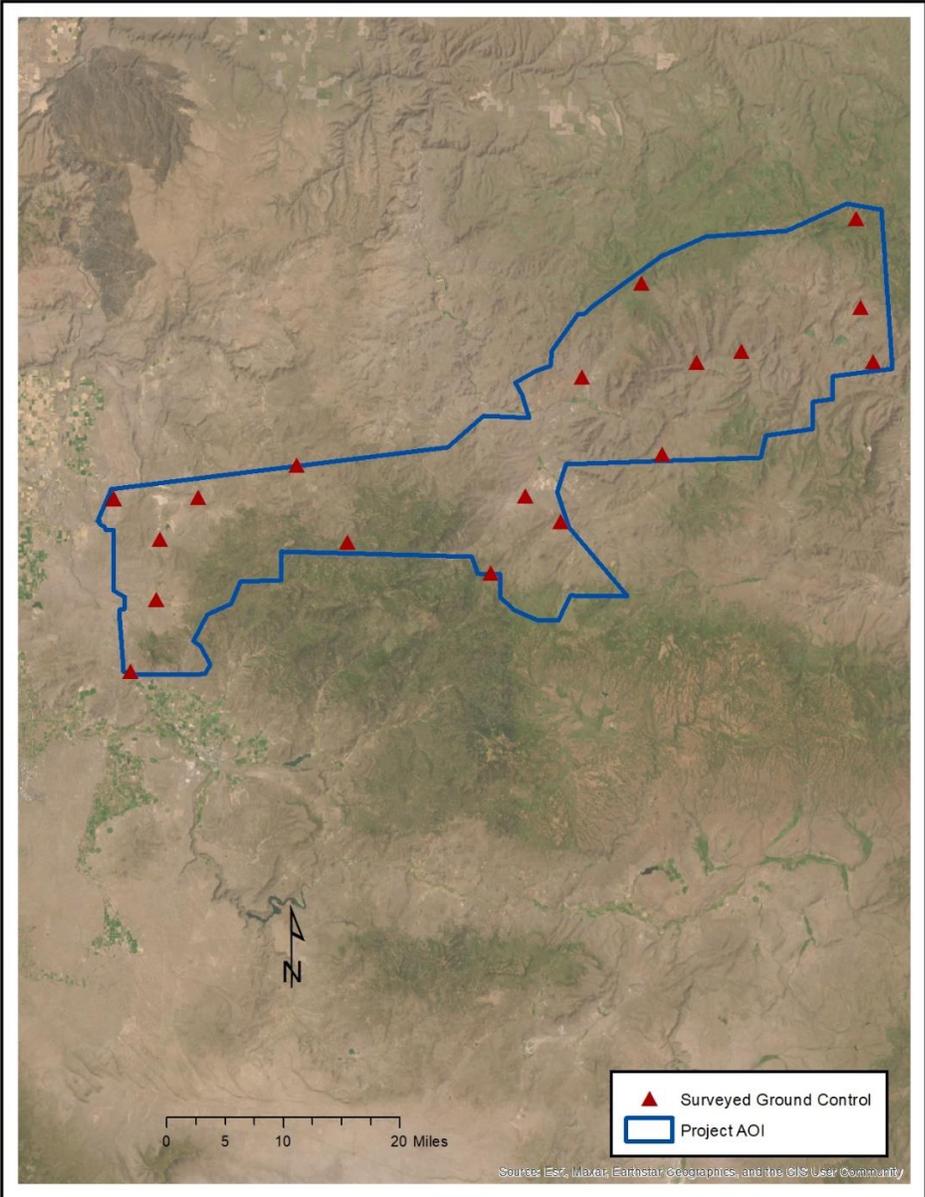


Figure 3. Location of all survey control used for Lidar adjustment.

3.6 Data Accuracy Statement

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.33 ft RMSEz Vertical Accuracy Class equating to NVA = +/- 0.65 ft at 95% confidence level and VVA = +/- 0.99 ft at the 95th percentile. Data was also produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.64 ft (19.5 cm) RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1.57 ft (47.9 cm) at a 95% confidence level.

3.7 Point Density

Aggregate point density within each project area is based upon acquisition at a > 50% swath overlap with a planned average of ≥ 4 points/m² for each strip to meet a final overall acquired density of ≥ 8 points/m² for first return pulses. Density for each site was calculated using *LP360* using nominally created 100'x100' tiles. First return and ground-classified lidar density for each project site is shown in Table 8, below.

Table 8. Lidar density results for first return and ground-only points.

	Private Forest Accords
<i>First Returns (pts/m²)</i>	11.72
<i>Ground Returns (pts/m²)</i>	1.93

3.8 Lidar Point Classification

Once the point cloud adjustment was achieved with desired relative and absolute accuracy, all data in LAS format were brought into classification software. Rigorous selection algorithms in *TerraScan* were used to automatically classify data and ensure accurate ground classification based on software parameters defined by the Lidar analyst. Data from the extreme edge of each swath, where most error occurs, was omitted during initial ground classification to increase quality. Ground identification was initiated at low-resolution seed points and increased in resolution and density with each passing review. A tailored approach was formulated for this project based on consideration of terrain and vegetation characteristics. While all identified high and low noise and overlap data was delivered with the final point cloud data, they are identified using a withheld bit flag are to be ignored.

A manual review of auto-classified point data was performed to refine the ground-classified surface points where the automated process had limited success, thus improving the final bare earth surface. Manual review was assisted by evaluation of maximum surface rasters for high noise and bare earth surface rasters to find low noise and other misclassifications. Finally, hydro-breaklines were manually created. All points within the bounds of identified hydro breaklines were classified as water points. In addition, bridge outlines were manually identified and used to classify all points on the top of each bridge deck. Bridge points were removed from the final bare earth surface. Software used for Lidar classification and review included TerraScan, LP360, and ArcGIS.

3.9 Hydrologic Flattening

Hydrologic breaklines were manually collected using ground-classified data on all bodies of water greater than 2 acres and on rivers and streams greater than 100-feet in width. A downstream constraint was applied to rivers and streams to ensure an equal elevation was maintained on both banks and provide an improved appearance to the final ground model. Ground points within 2-feet of hydro breaklines were reclassified as Class 20 (Ignored Ground).

3.10 Bare Earth or Digital Elevation Model (DEM)

Classified ground point data were combined with all breaklines to create a digital elevation model (DEM) at a 3-foot resolution. The resulting model was cut into 3000'x3000' tiles and delivered in a 32-bit floating GeoTIFF format. A final QC was performed on the resulting Bare Earth raster data to verify no anomalies remained after previous review processes and edits.

3.11 Maximum Surface Height Surface Model (DSM)

An additional maximum height surface model or digital surface model (DSM) was created using all unflagged data (excluding all flagged noise points). The resulting data was used to create a 3-foot resolution raster data set which was cut into 3000'x3000' tiles and delivered in a 32-bit floating GeoTIFF format.

3.12 Intensity Raster Data

The lidar sensor records up to 8 returns per pulse, each with a recorded 12-bit intensity or reflectance valued. Optech *LMS* software was utilized to evaluate the raw intensity values between overlapping strips and normalize data to a 1000m range value by means of histogram matching to adjust overall “brightness” between swaths. Data was exported to standard 16-bit values and exported from *LMS* to *LAS* format. GeoCue *LP360* was then used to create an intensity image using normalized reflectance values of all first return points. Data was exported from *LP360* at a 3-foot resolution to GeoTIFF format and tiled to the project’s 3000'x3000' tile scheme. The value of each cell in the raster image is equal to an average intensity value of all first return points found within that cell.

3.13 Metadata

FGDC-compliant metadata was produced in XML format to include a complete description of the project, purpose, vendor information, acquisition planning, results and dates, processing steps, and quality control results. One XML-formatted metadata was submitted for each of the following products:

- Classified Lidar Point Cloud
- Bare Earth (DEM) Raster
- Max Surface Height (DSM) Raster
- Intensity Raster

Examples of hill-shaded, bare earth surfaces within the project AOI, with applied color gradient based on elevation.

