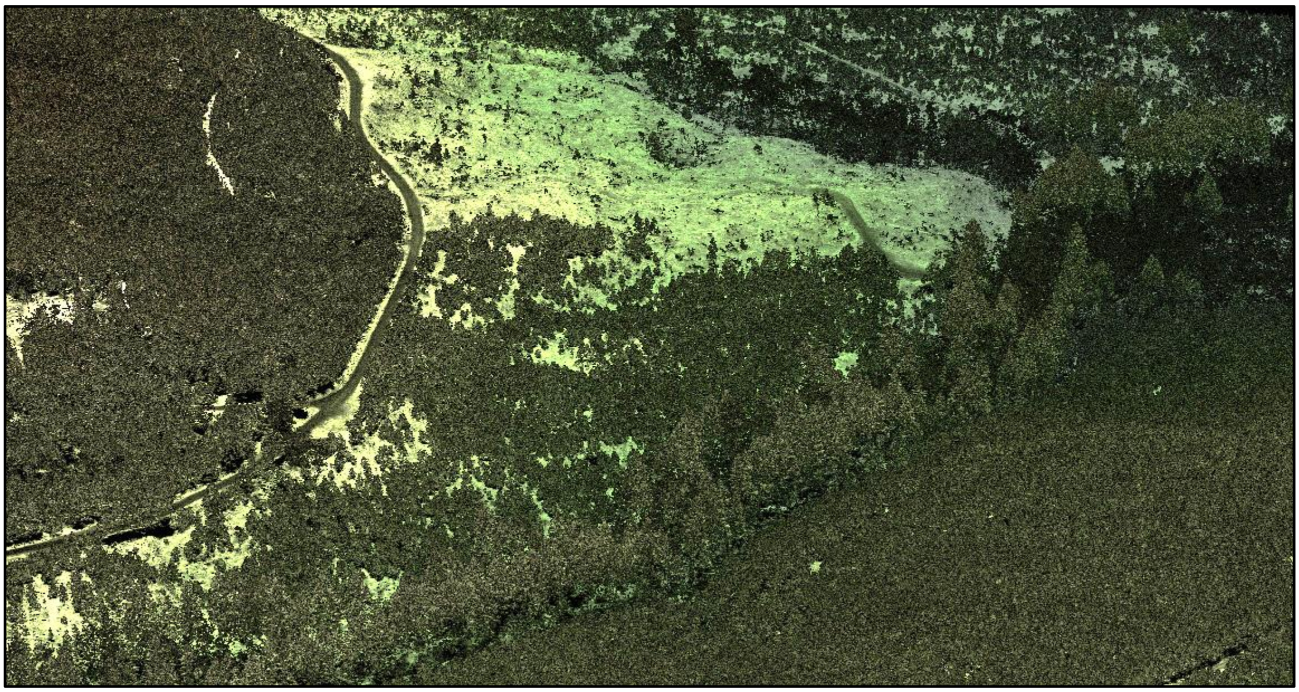
Lidar Technical Report

Oregon Department of Forestry
Abiqua Project



Presented to:
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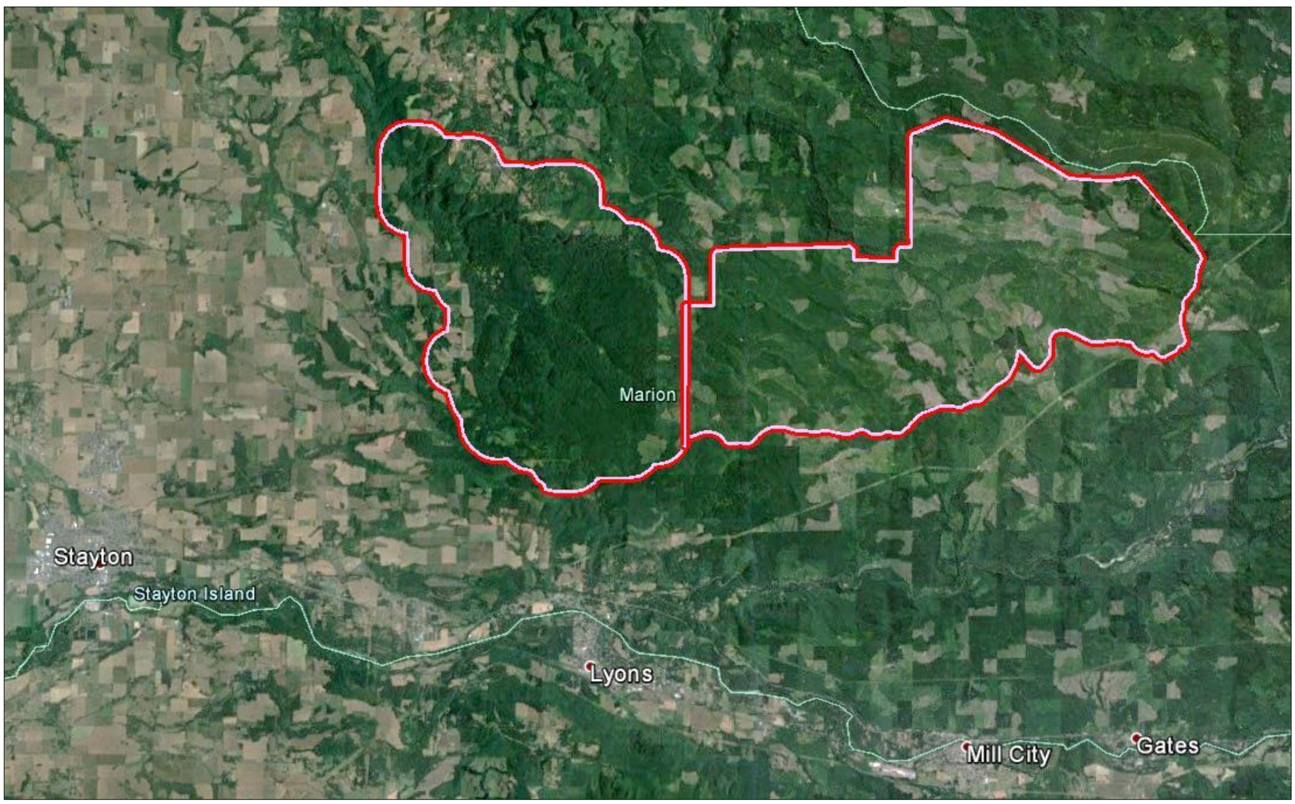
GeoTerra Federal Tax ID: 80-0001639
Period of Performance: March 2016 – June 2016

1. Project Overview

GeoTerra, Inc. was tasked by Oregon Department of Forestry to provide Lidar remote sensing data including LAZ files of the classified Lidar points and surface models for approximately 57 square miles over two (2) sites in Northwest Oregon. The western subarea is Silver Falls State Park while the eastern portion is defined as Abiqua. The overall project is known as Abiqua.

Airborne Lidar mapping technology provides 3D information for the surface of the Earth which includes terrain surface models, vegetation characteristics and man-made features. Lidar technology is capable of penetrating gaps in forest canopies and to reach the ground below allowing for creation of accurate bare earth and vegetation surfaces.



Area of interest

2. Lidar Acquisition and Processing

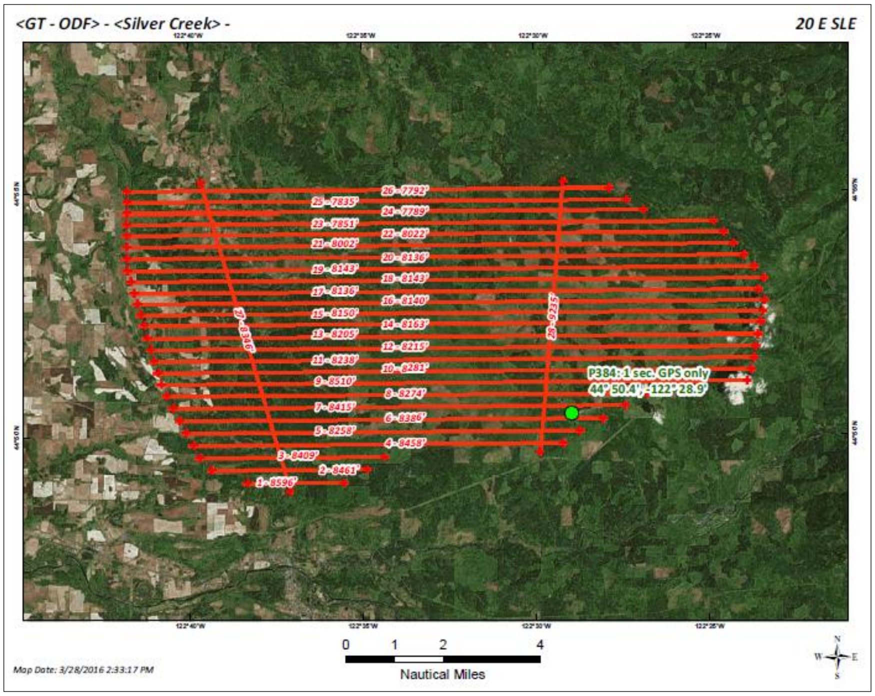
2.1 Flight Planning and Sensor Specification

The flight plan was developed to acquire Lidar data for approximately 57 square miles per the project boundaries provided by the client. The flight plan was designed with minimum 50% overlapping strips minimizing laser shadowing and gaps to ensure final point density across the project. Lidar flight planning was performed using Optech Flight Management System (FMS) software to find optimum parameters to meet project requirements and to accommodate terrain changes.

GeoTerra Inc. used the Optech Galaxy Lidar system to acquire the areas. The Optech Galaxy emits higher pulse rate of 35 – 550 kHz and can record up to 8 range measurements per laser pulse emitted.

<u>For Abiqua site, Optech Galaxy flight planning specifications:</u>

- Pulse Repetition Frequency (PRF): 450 kHz (450,000 laser pulses per second)
- Scan Rate: 60 Hz (60 scan-lines per second)
- Target Collection Density: ≥ 6.22 pts/m² nominal point density - single swath / 12.0 ppsm total
- Field of View (FOV): 30° minimum
- Laser Sidelap: 50% minimum (to reduce laser shadowing and gaps)
- Altitude: average 2150 m Above Ground Level (AGL)
- Ground Speed: 109 knots



2.2 Lidar Acquisition

GeoTerra, Inc. acquired Lidar sensor data with the Optech Galaxy mounted in Cessna 180 aircraft on March 30th , 2016. Real time data was monitored closely to review any errors and gaps prior to de-mobilization from the project site.

PROJECT COORDINATE SYSTEM AND DATUM

- Oregon Statewide Lambert
- Horizontal Datum: NAD83(2011)
- Vertical Datum: NAVD88
- Geoid 12A (CONUS)
- Unit of Measure: International Feet

2.3 Airborne GNSS (AGNSS) Survey

During the aerial Lidar missions, the Airborne GNSS (AGNSS) technique was employed which entails obtaining the X,Y,Z coordinates of the laser during the aerial acquisition. The data collected during the flight is post-processed into a Smoothed Best Estimate of Trajectory (SBET) binary file of the laser trajectory which is the combined processed data from both GNSS satellite data and

Inertial Motion Unit (IMU) data and is used along with the ground control points to geo-reference the laser point cloud during the mapping process.

During the flights the receiver on board the aircraft logged GNSS data at a 1.0" (1 Hz) interval and IMU data at a .005” (200 Hz) interval.

After the flight, the GNSS data was post-processed using NovAtel's Waypoint Products Group Inertial Explorer Version 8.60.4609 software utilizing the Precise Point Positioning (PPP) feature with precise orbit and clock correction files. For each flight the Inertial Explorer software computed lever arm offsets between the IMU and the L1 phase center of the aircraft antenna. The two lever arms were combined algebraically to produce the SBET file at the laser mirror for each flight, this resulted in a precise trajectory of the laser that was output as an NAD83 (2011) SBET file with data points each 1/200 of a second.

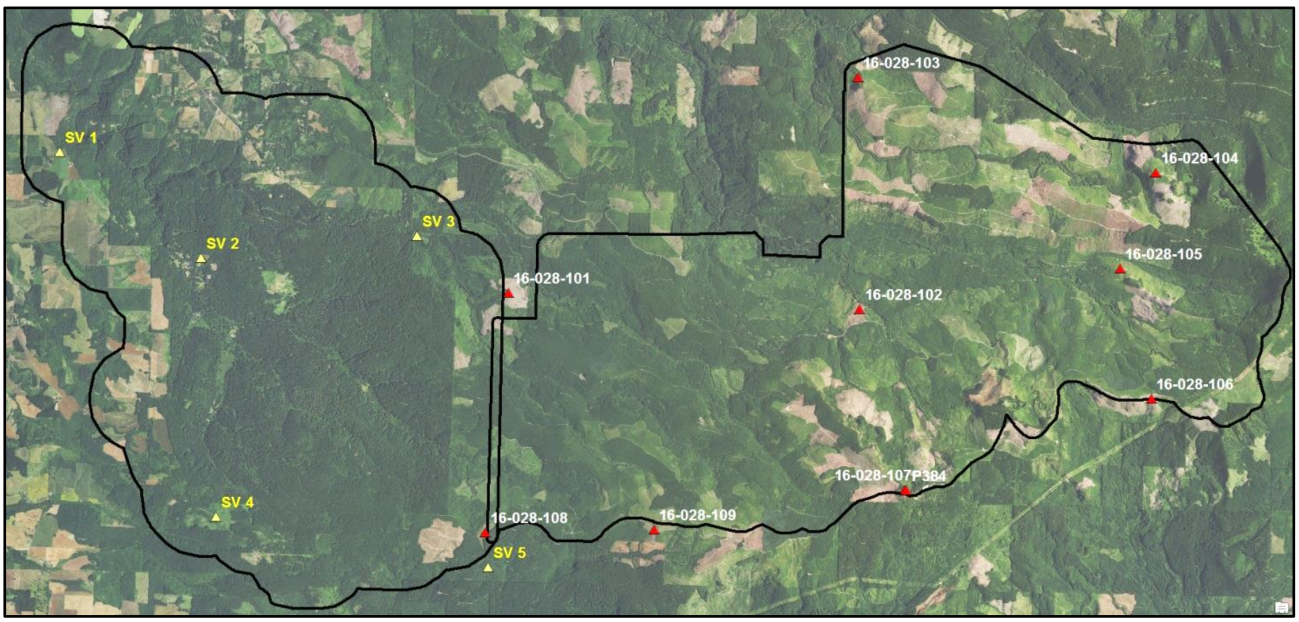
Aircraft trajectories

2.4 Survey control

Survey control was acquired for Lidar verification in the Abiqua portion of the project for the Oregon Department of Forestry. Nine (9) static control points were established throughout the project area by GeoTerra land surveyor, Shelby Griggs.

Historical control was used for the Silver Falls western subarea as well as existing 2006 Lidar from a previous project performed by GeoTerra, Inc. for the Oregon Parks and Recreation Department.

For detailed description of each control point see attached 'Control Report'.



Layout of survey control: SV1--SV5 are control points from 2006, 16-028-101—16-028-109 are control points from 2016

2.5 Laser Post-Processing

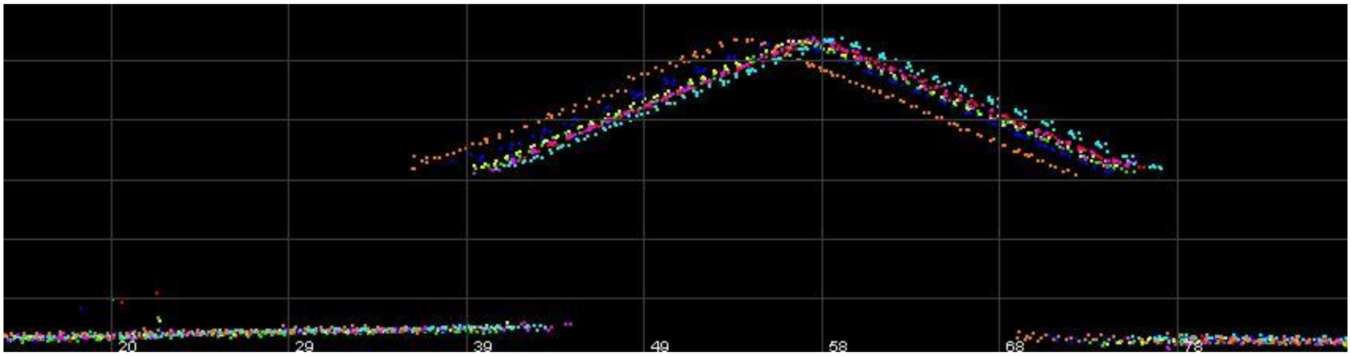
Raw range data from the sensor was decoded using Optech's LMS software. Instrument corrections were applied to the laser ranges and scan angles, and then the range files were split into the separate flight lines. The laser point computation uses the results of decoding, description of the instrument and locations of the aircraft (from the SBET files) as input data and calculates the coordinates of points for each laser pulse from the sensor.

2.6 Relative and Absolute Adjustment

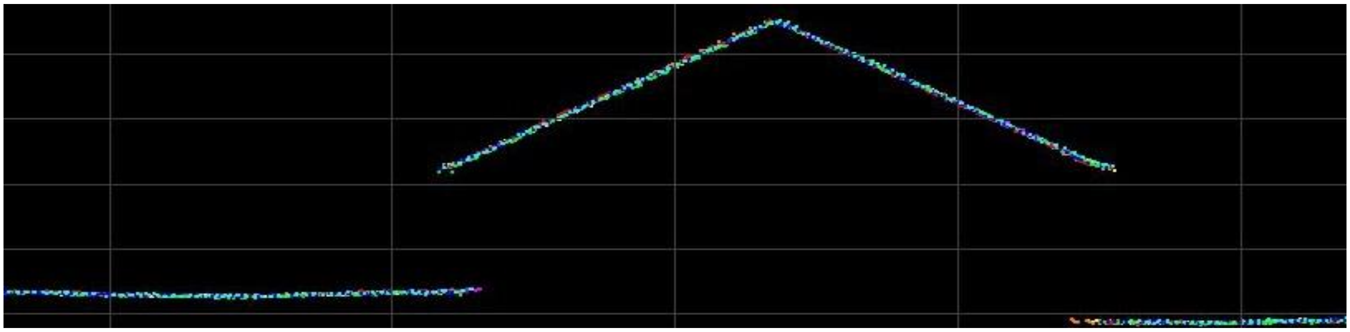
Relative and absolute adjustment of all strips was accomplished using Optech LMS software and TerraMatch. Optech LMS performs automated extraction of planar surfaces from the cloud of points according to specified parameters per project. Tie plane determination then establishes the correspondence between planes in overlapping flight lines. All plane centers of all lines that form a block are sorted into a grid. Plane surfaces from overlapping flight lines are used, co-located to within an acceptable tolerance, and are then tested for correspondence.

A set of appropriate tie planes is selected for the self-calibration. Selection criteria are size and shape, number of laser points, slope, orientation with respect to flight direction, location within the flight line and fitting error. All these criteria have an effect as they determine the geometry of the adjustment. Self-Calibration parameters are then calculated and used to re-calculate the laser point coordinates (X,Y,Z). The planar surfaces are re-calculated as well for a final adjustment.

Tie Plane Self Calibration

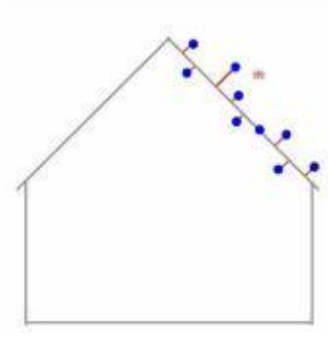


Planes in overlapping strips prior adjustment

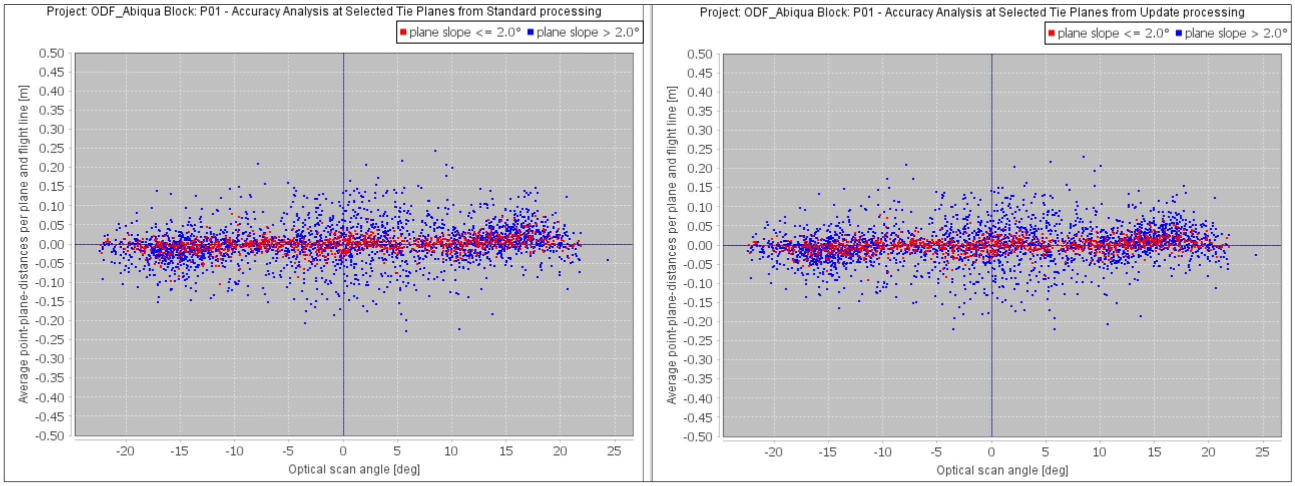


Planes in overlapping strips after adjustment

Point to plane analysis was performed to assess the internal fit of the data block. For each tie plane, the mean values are computed for each flight line that covers the tie plane. Mean values of the point to plane distances are plotted over scan angle



Point to plane distances



ODF Abiqua – mean values if the point to plane distances plotted over scan angle

Additionally each mission was further reviewed and adjusted in TerraMatch using tie lines approach. The software measures the difference between lines (observations) in overlapping strips. These observed differences are translated into correction values for the system orientation – easting, northing, elevation, heading, roll, pitch and mirror scale.

Abiqua	62263 section lines		
	X[ft]	Y[ft]	Z[ft]
Average magnitude	0	0	0.053
RMS values	0	0	0.069
Maximum values	0	0	0.465

After a tight relative fit was achieved, an absolute vertical check was performed using surveyed check points. The algorithm computes an average value for the height differences for all check points by comparison to the surface created from neighboring laser points within a specified radius around the check points.

Nine (9) premarked control points were used in absolute fit assessment of the data for the Abiqua portion of the project and five (5) 2006 historical control points were used in the Silver Falls portion of the project. Overall fit is very good. Below are tables with statistical analysis on measured control points.

Analysis on control points surveyed in 2016:

ID	X	Y	Z	Surface Z	Dz		[ft]
16-028-101	773822.2	1145014	2183.36	No-Data		Vertical Error Mean *:	0.035
16-028-102	795294.3	1144026	2361.1	2361.081	0.019	Vertical Error Range:	[-0.149,0.173]
16-028-103	795169.4	1158184	2788.8	2788.67	0.13	Vertical Skew:	-0.402
16-028-104	813375.4	1152345	3733.24	3733.159	0.081	Vertical RMSE:	0.106
16-028-105	811187.1	1146480	3145.72	3145.694	0.026	Vertical NMAS/VMAS Accuracy (90% CI):	±0.174
16-028-106	813094.5	1138568	3376.47	3376.507	-0.037	Vertical ASPRS/NSSDA Accuracy (95% CI):	±0.207
16-028-107	798063.6	1132973	3950.08	3949.907	0.173	Vertical Accuracy Class:	0.11
16-028-108	772421.5	1130383	2478.76	2478.909	-0.149	Vertical Min Contour Interval:	0.33
16-028-109	782729.9	1130540	2904.51	No-Data			

Analysis on historical control points from a Lidar project in 2016.

ID	X	Y	Z	Surface Z	Dz		[ft]
SV1	746420.7	1153594	1492.798	1492.874	-0.076	Vertical Error Mean *:	-0.306
SV2	755035	1147135	1383.856	1383.827	0.029	Vertical Error Range:	[-0.689,0.029]
SV3	768216	1148496	1639.021	1639.507	-0.486	Vertical Skew:	-0.109
SV4*	755963.4	1131333	1886.315	1887.004	-0.689	Vertical RMSE:	0.424
SV5	772569.9	1128282	2041.445	No-Data		Vertical NMAS/VMAS Accuracy (90% CI):	±0.697
						Vertical ASPRS/NSSDA Accuracy (95% CI):	±0.830
						Vertical Accuracy Class:	0.43
						Vertical Min Contour Interval:	1.29

*Note:

SV4 control point is in the location that drastically changed as far as terrain cover and ground hence the higher residual.

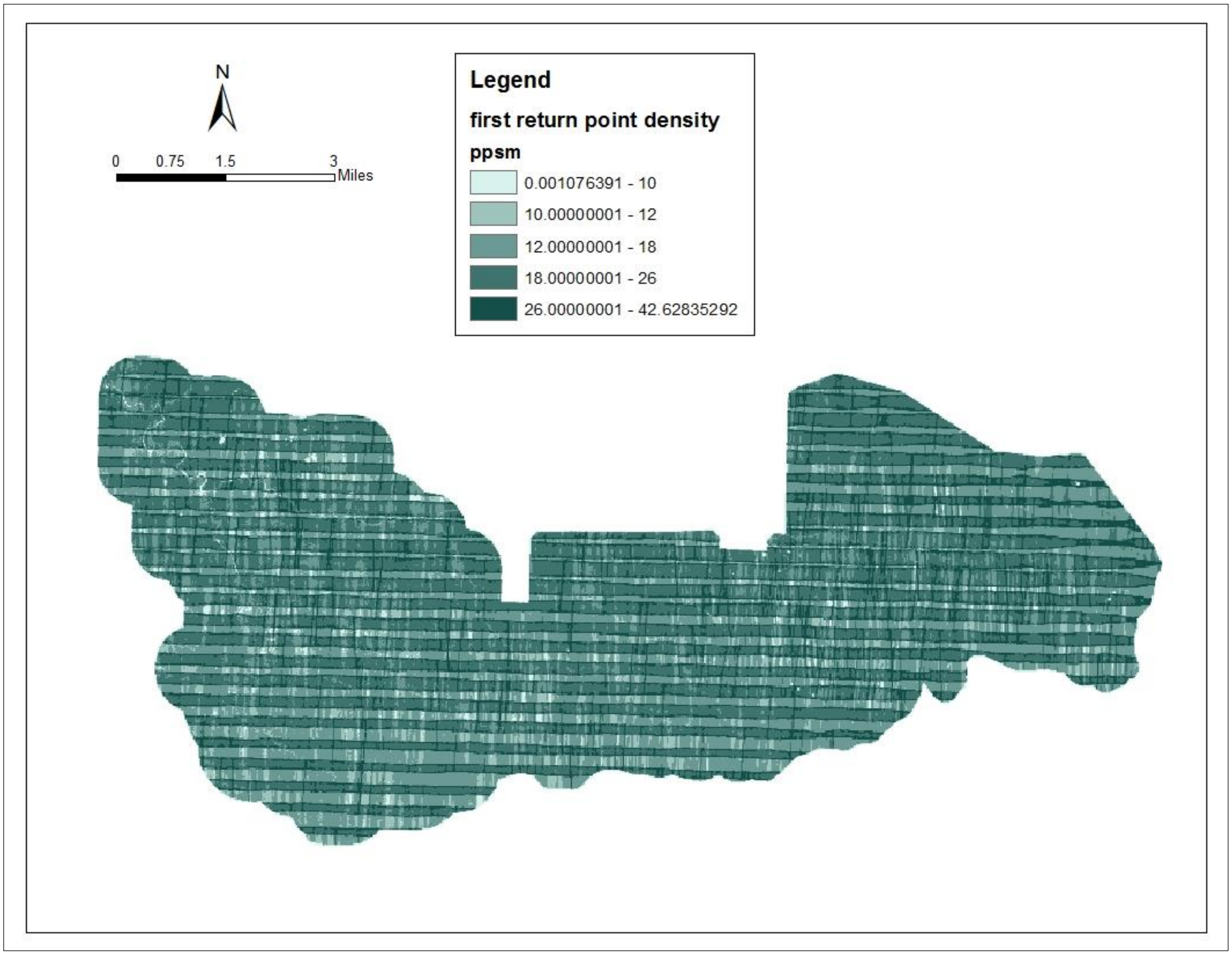
2.7 Point Density

Average point density for the project was calculated on all strips on 100ft by 100ft cell.

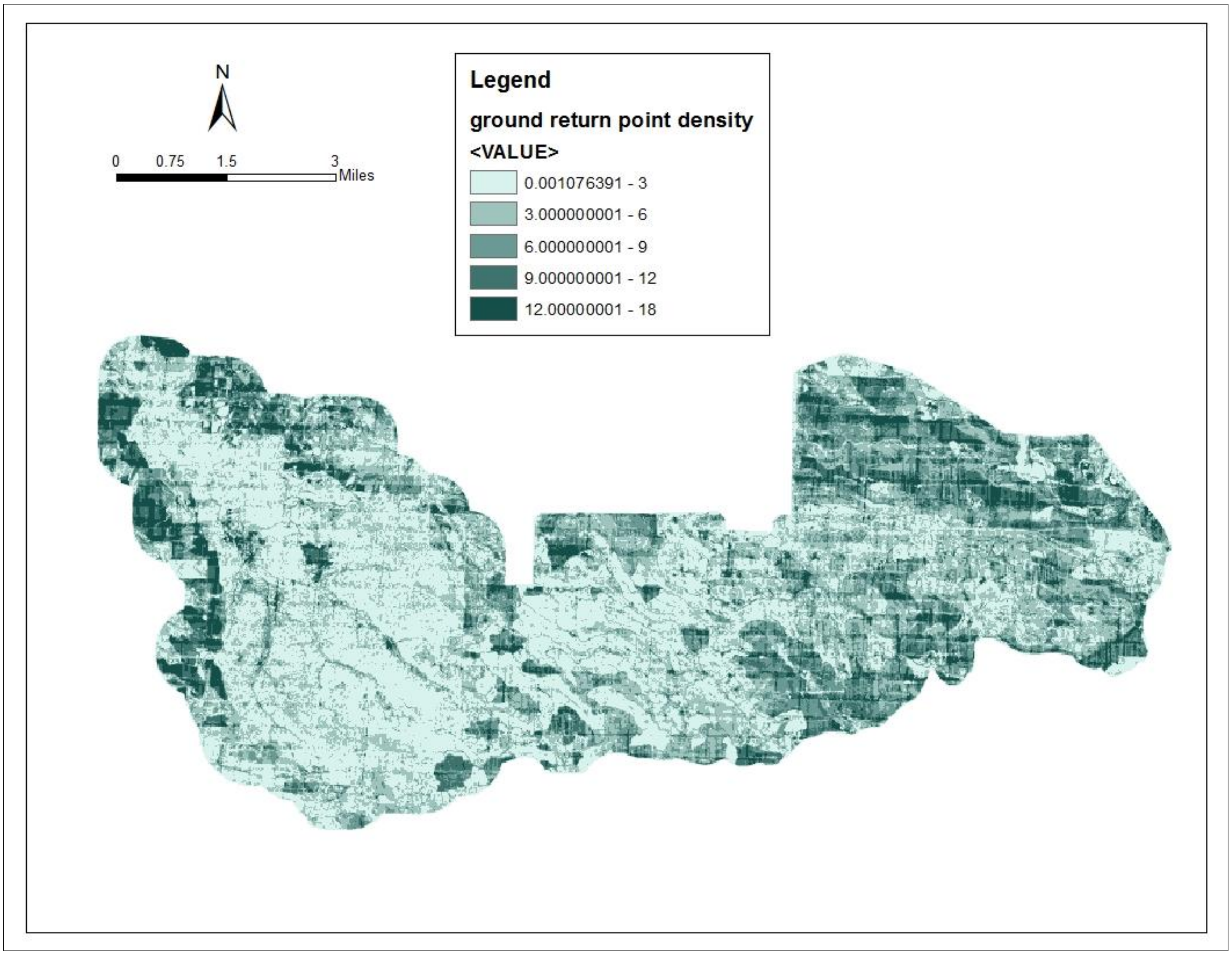
	Average first return point density [pts/m^2]	Average ground return point density [pts/m^2]
Abiqua	**19.74***	**5.02**

*average point density was also sampled after a 2deg of each strip was reclassified as class12_overlap and not taken into account for final classification.

The average density not including class12_overlap is **15.29** pts/m^2



First return density analysis

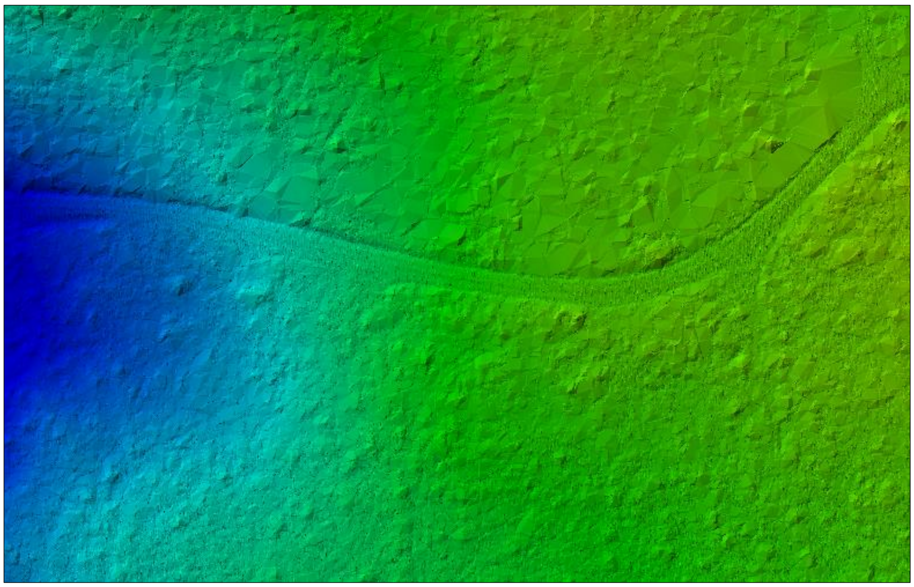


Ground return density analysis

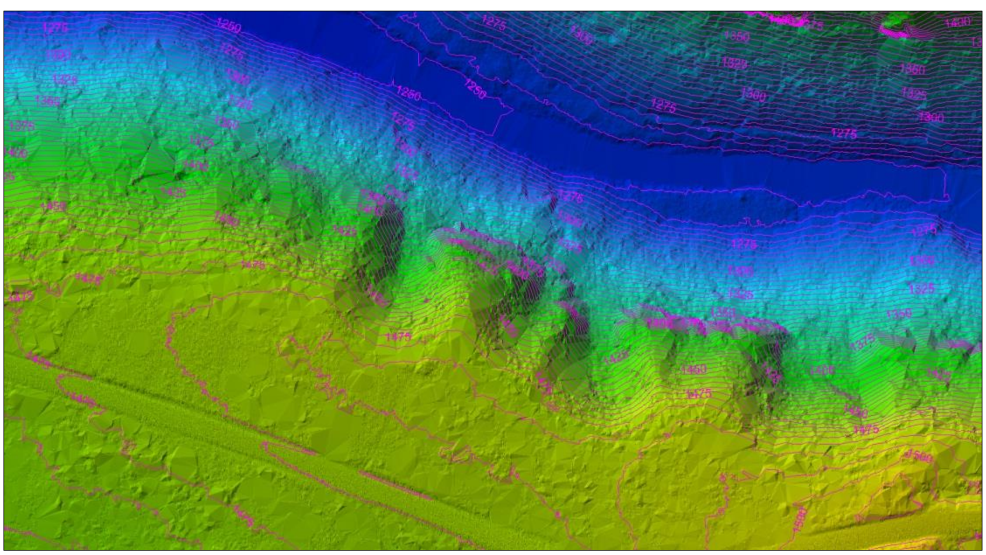
2.8 Point Cloud Classification

Once the point cloud adjustment was achieved with desired relative and absolute accuracy, all strips in LAS format were brought into classification software. Rigorous algorithms of TerraScan were used to first automatically classify the data. To ensure correct ground detection various parameters were selected to further improve ground classification. Furthermore data was reviewed systematically to clean avoidable misclassifications.

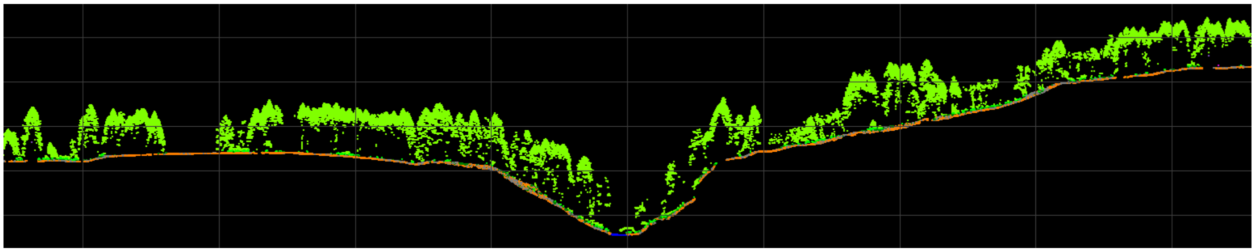
Displaying data by TIN



Displaying temporary contours



Creating profiles along the data



Display points by intensity

The procedure of automatic and manual classification involves:

- Classifying by angle to eliminate small portion of the data on the very edge that can be less accurate
- Classifying by echo – to include first, intermediate, last return tags in logical determination of classes
- Classifying low and isolated points to exclude from potential ground misclassifications
- Testing and fine tuning numerical parameters for ground surface building
- Classifying data above ground surface by height
- Classifying planar surfaces based on sampling building size in the area

Several routines were implemented to determine noise points:

* Isolated points – points that have few neighbors within a determined 3d search radius were classified as class18_high noise points.

* Height filter – after ground surface was created a height above ground was determined to delete points beyond that threshold.

* Manual checks using automatic and semi-automatic methods (subtracting ground from first return raster results in areas to check visually for any outstanding points); low points and noisy ground points were also found using several similar routines.

* Classifying points which are lower than others in their immediate neighborhood.

* Excluding points from ground surface that in the process of building ground triangles don't meet triangle edge length criteria – it ensures that some noisy points are excluded from ground surface.

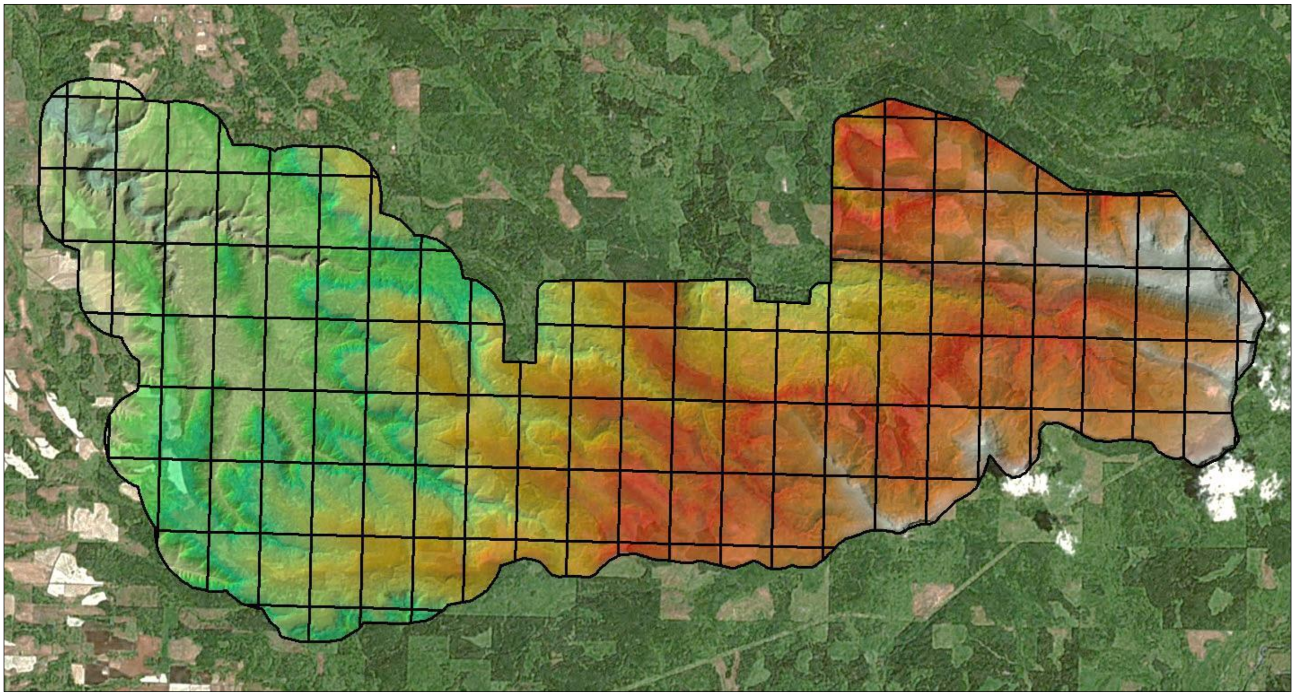
The following classes were delineated in the process of classification for the Focus Area:

- 01_Unclassified (temporary)
- 02_Ground
- 03_Low Vegetation
- 04_Medium Vegetation
- 05_High Vegetation
- 06_Buildings and Associated Structures
- 09_Water – points reflected off water bodies
- 10_Unclassified (Permanent)

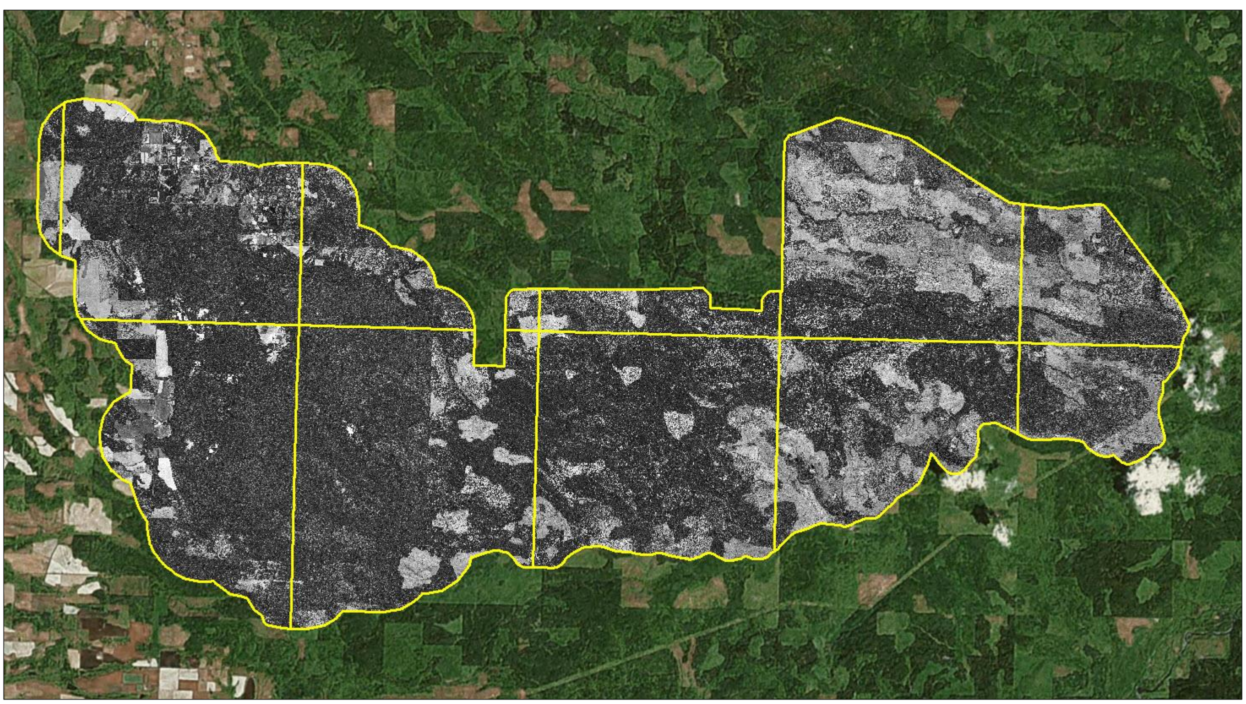
2.9 Tiling Scheme

Final adjusted points were split into tiles over a buffered project boundary.
A tile index file has been provided with the deliverables.

Naming Scheme



Overview of tiling scheme for Lidar tiles –
1/100th USGS 7.5-minute quadrangle (0.75 minute by 0.75 minute)



Overview of tiling scheme for Intensity Image tiles –
1/4th USGS 7.5-minue quadrangle (3.75 minute by 3.75 minute)

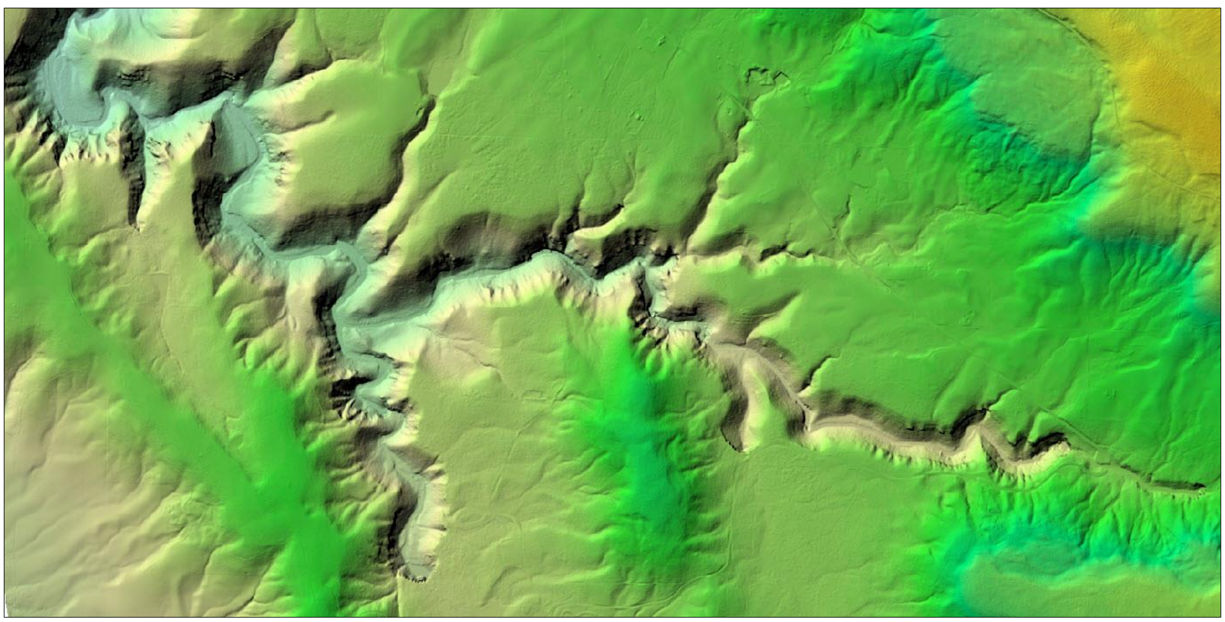
3. ArcGIS Raster Processing

3’ resolution floating point Ground and First Return ESRI raster grids were generated using the Lidar points as input to the LAS Dataset to Raster tool. The tool creates a raster using elevation values stored in the Lidar files referenced by the LAS Dataset.

This approach assigns output cell values based on the LiDAR points that fall within cell boundaries and interpolates the values of cells that do not contain any LAS points.

3.1 Ground Surface

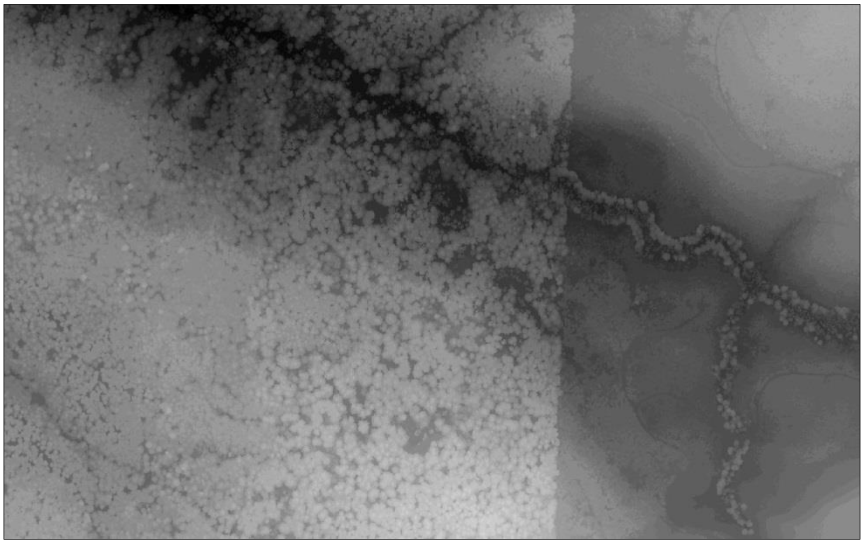
The ground points used were classified as class 02. The LAS Dataset to Raster tool was employed to create a 3’ file geodatabase raster, using binning interpolation with average cell elevation and linear void filling. The raster was clipped to the project boundaries when appropriate.



Sample of a ground surface

3.2 First Return DSM Surface

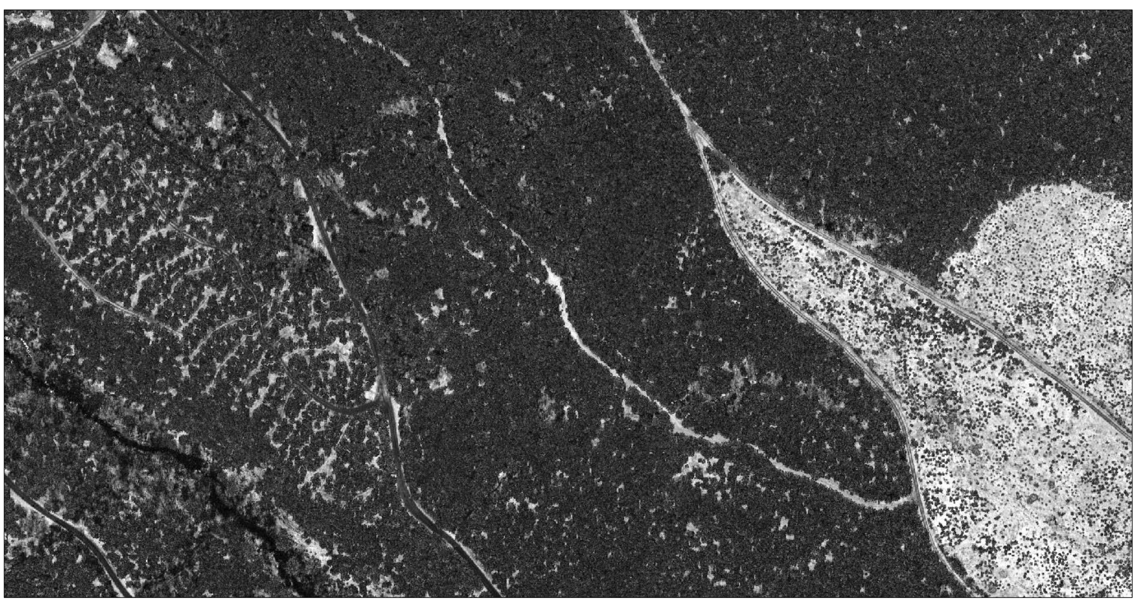
A 3' first return raster was generated using first return Lidar points for all classes excluding noise. The LAS Dataset to Raster tool was employed to create a file geodatabase raster, using binning interpolation with maximum cell elevation and linear void filling.



Sample of a highest hit DEM

3.3 Intensity Images

1.5 ft resolution intensity TIFFs were generated using average intensity of first return points in each cell.



Sample of intensity image

4. Final Deliverables

- All return point cloud – classified in compressed LAZ format
- Aircraft trajectories in vector file geodatabase format
- Tile Index in file geodatabase format
- Bare Earth surface model – ESRI file geodatabase floating point grid (3ft cell)
- First Return (Highest Hit) DEM – ESRI file geodatabase floating point grid (3ft cell)
- Intensity Images in TIFF format, 1.5ft pixel size
- Report and Technical Information in PDF format
- Control Survey Report