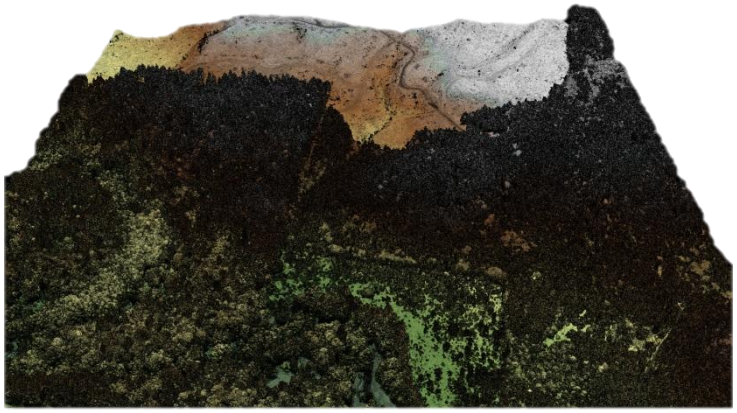
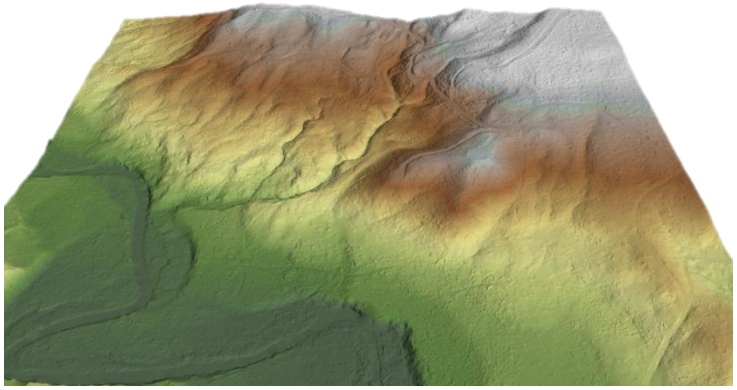
Lidar Technical Report

Oregon Department of Forestry Sites





Presented to:

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2600 State Street, Building E
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Submitted by:

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August 14th, 2015

Lidar Acquisition Report

Oregon Department of Forestry Sites

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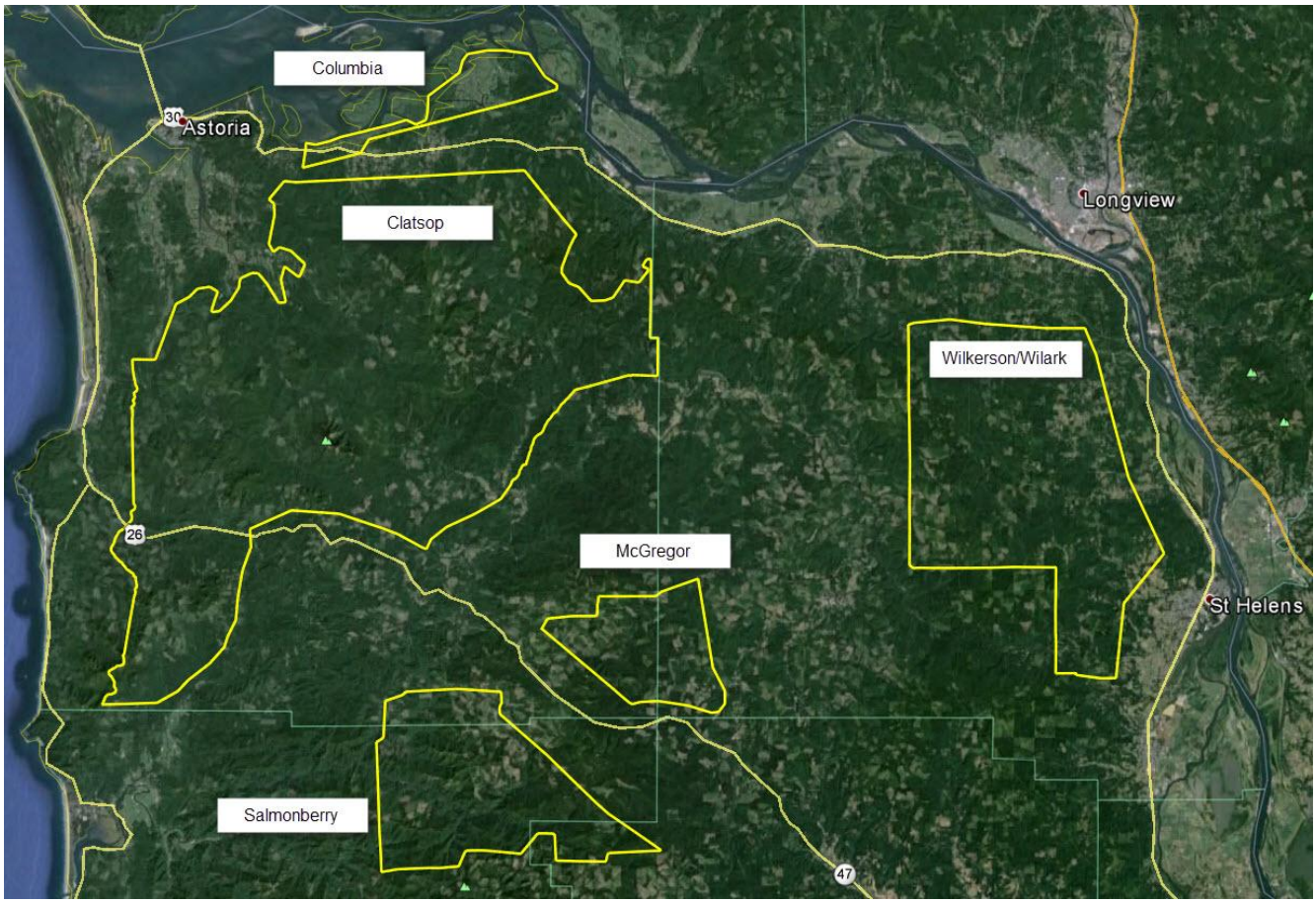
GeoTerra Federal Tax ID: 80-0001637
Period of Performance: April 2015 – August 2015

1. Project Overview

GeoTerra, Inc. was selected by Oregon Department of Forestry to provide Lidar remote sensing data including LAZ files of the classified Lidar points and surface models for approximately 591 square miles over five (5) sites in Northwest Oregon. 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.

The graphic below shows the project and its subareas:



Salmonberry site (69 square miles)
Wilkerson/Wilark site (134 square miles)
McGregor site (32 square miles)
Columbia site (16 square miles)
Clatsop site (340 square miles)

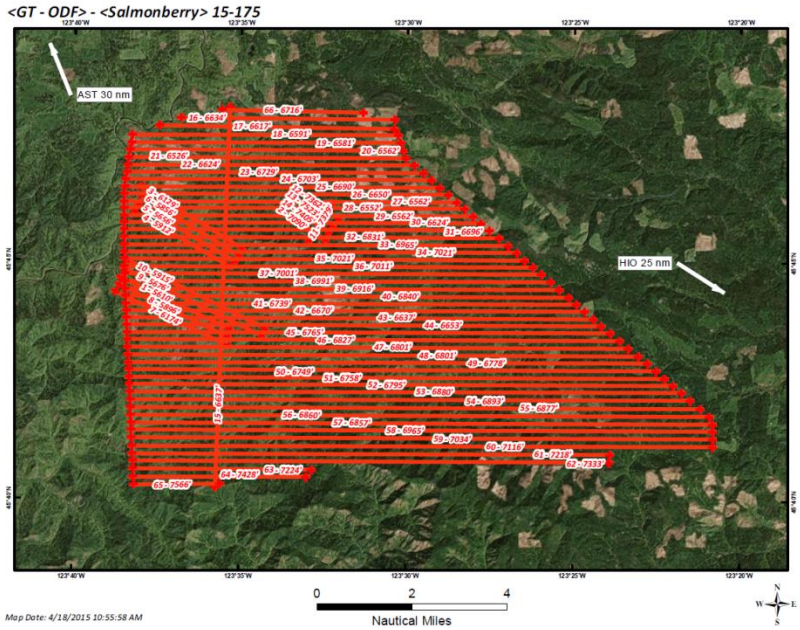
2. Lidar Acquisition and Processing

2.1 Flight Planning and Sensor Specification

The flight plan was developed to acquire Lidar data for approximately 591 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.

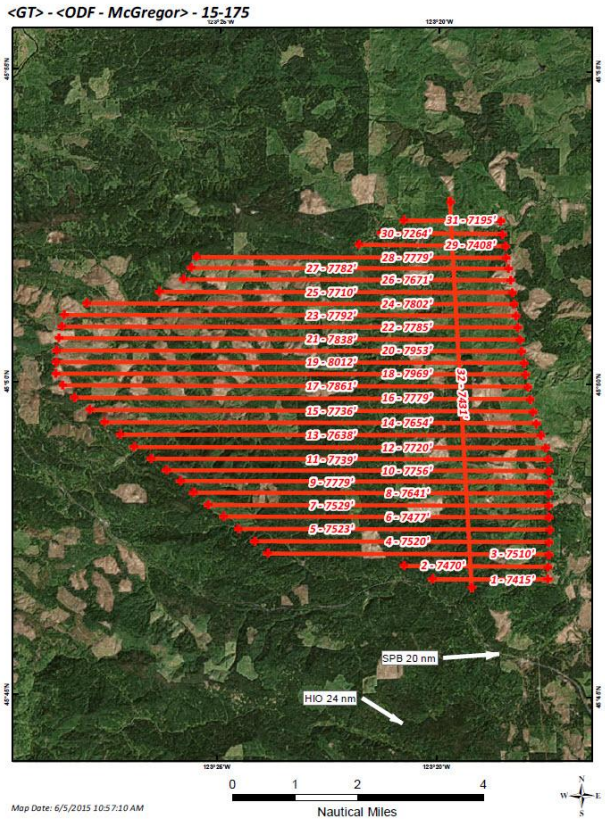
GeoTerra Inc. used both GeoTerra Lidar systems to acquire the area: Optech Orion H300 and the new Optech Galaxy. The Optech Orion H300 emits a pulse rate of 35 – 300 kHz and can record up to 4 range measurements per laser pulse emitted. The Optech Galaxy emits higher pulse rate of 35 – 550 kHz and can record up to 8 range measurements per laser pulse emitted.

Each site was carefully reviewed and analyzed to find optimum parameters:



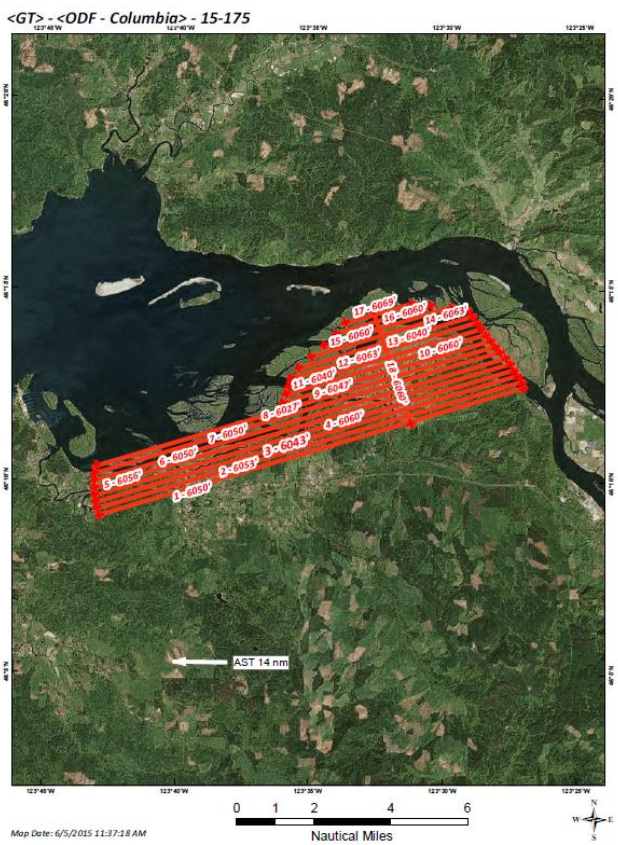
For Salmonberry site, Optech Orion H300:

- Pulse Repetition Frequency (PRF): 150 kHz (150,000 laser pulses per second)
- Scan Rate: 42 Hz (42 scan-lines per second)
- Target Collection Density: ≥ 4.12 pts/m² nominal point density - single swath
- Field of View (FOV): 26° minimum
- Laser Sidelap: 50% minimum (to reduce laser shadowing and gaps)
- Altitude: average 1525m Above Ground Level (AGL)
- Ground Speed: 85 knots
- Swath on flat ground: 702.15m



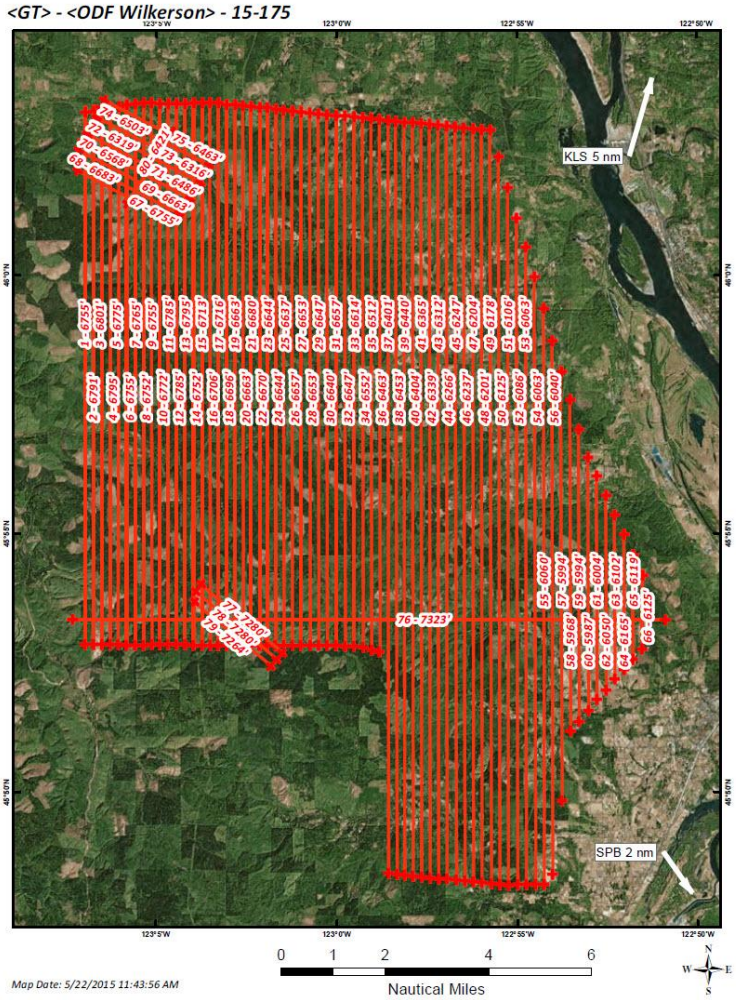
For McGregor site, Optech Orion H300:

- Pulse Repetition Frequency (PRF): 200 kHz (200,000 laser pulses per second)
- Scan Rate: 48 Hz (48 scan-lines per second)
- Target Collection Density: ≥ 4.18 pts/m² nominal point density - single swath
- Field of View (FOV): 24° minimum
- Laser Sidelap: 50% minimum (to reduce laser shadowing and gaps)
- Altitude: average 1925m Above Ground Level (AGL)
- Ground Speed: 93 knots
- Swath on flat ground: 818.34m



For Columbia site, Optech Orion H300:

- Pulse Repetition Frequency (PRF): 200 kHz (200,000 laser pulses per second)
- Scan Rate: 48 Hz (48 scan-lines per second)
- Target Collection Density: ≥ 4.34 pts/m² nominal point density - single swath
- Field of View (FOV): 24° minimum
- Laser Sidelap: 50% minimum (to reduce laser shadowing and gaps)
- Altitude: average 1850m Above Ground Level (AGL)
- Ground Speed: 93 knots
- Swath on flat ground: 786.46m



For Wilkerson/Wilark site, Optech Orion H300:

- Pulse Repetition Frequency (PRF): 225 kHz (225,000 laser pulses per second)
- Scan Rate: 52 Hz (52 scan-lines per second)
- Target Collection Density: ≥ 5.12 pts/m² nominal point density - single swath
- Field of View (FOV): 24° minimum
- Laser Sidelap: 50% minimum (to reduce laser shadowing and gaps)
- Altitude: average 1700m Above Ground Level (AGL)
- Ground Speed: 95 knots
- Swath on flat ground: 722.69m

2.2 Lidar Acquisition

GeoTerra, Inc. acquired Lidar sensor data with Optech Orion H300 mounted in Cessna 180 on following dates:

- Salmonerry site – April 19th and April 20th 2015
- Wilkerson/Wilark site – May 30th, June 5th and June 6th 2015
- McGregor site – June 6th, June 8th 2015
- Columbia site – June 8th, June 9th 2015

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

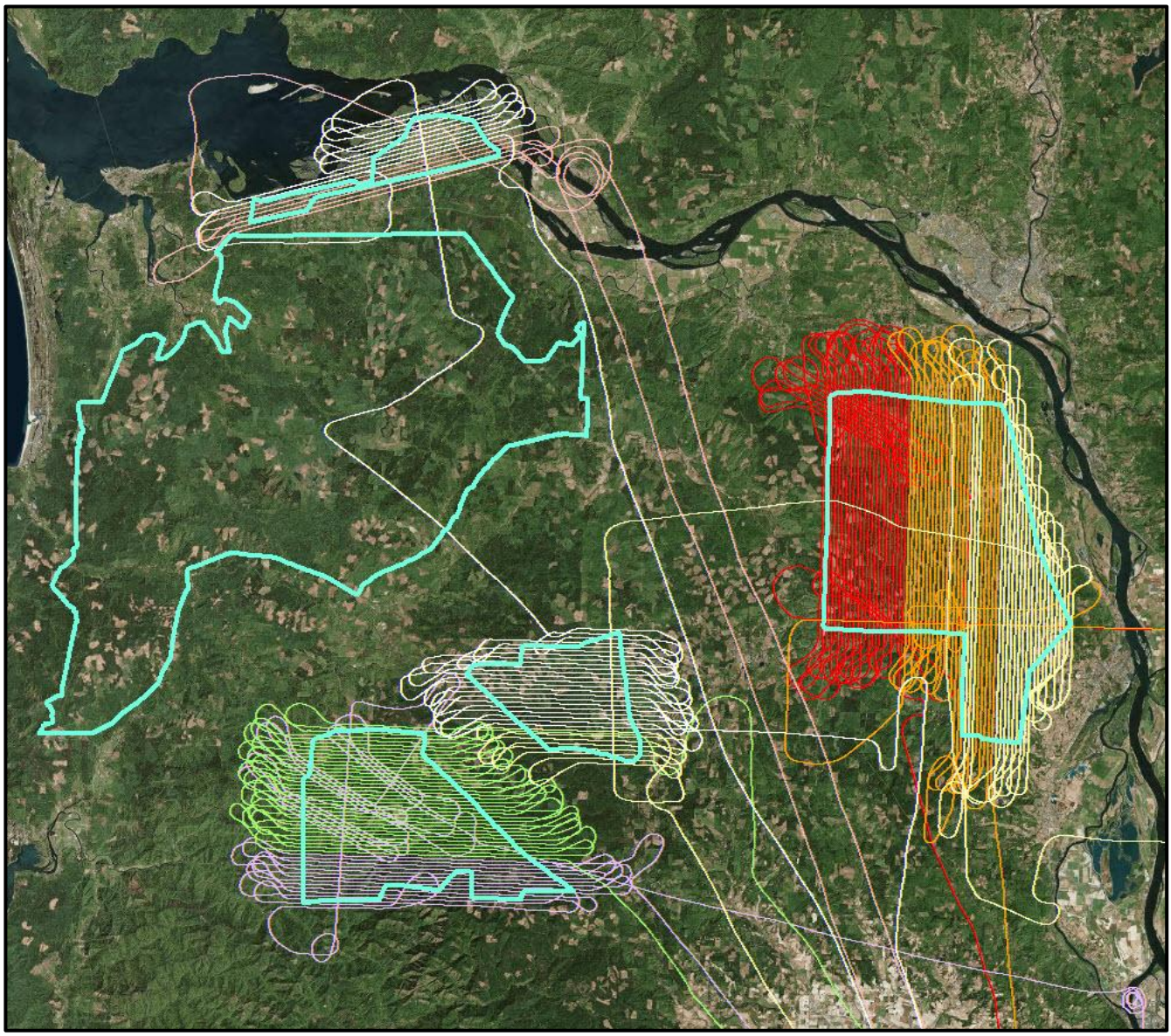
- Oregon Statewide Lambert
- Horizontal Datum: NAD83(2011)
- Vertical Datum: NAVD88
- Geoid 12A (CONUS)
- Unit of Measure: International Feet

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.

The Lidar data was acquired over several days in the spring of 2015 utilizing an Optech Orion H sensor with integrated Applanix POS AV GNSS/IMU system. 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, with the average IMU to GNSS Antenna Lever Arms being: x=-0.064, y=-0.229, z=1.058 m (x-right, y-fwd, z-up). The fixed offset between the IMU and the and the laser mirror is x=-0.051, y=-0.153, z=0.003 m (x-right, y-fwd, z-up). 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.



Display of trajectories over all flown sites

2.4 Survey control

Survey was established for Lidar verification control in northwestern Oregon for the Oregon Department of Forestry. As part of this project 21 static control points were established throughout the project area and additional kinematic QA/QC observations were taken on over 12 miles of roadway.

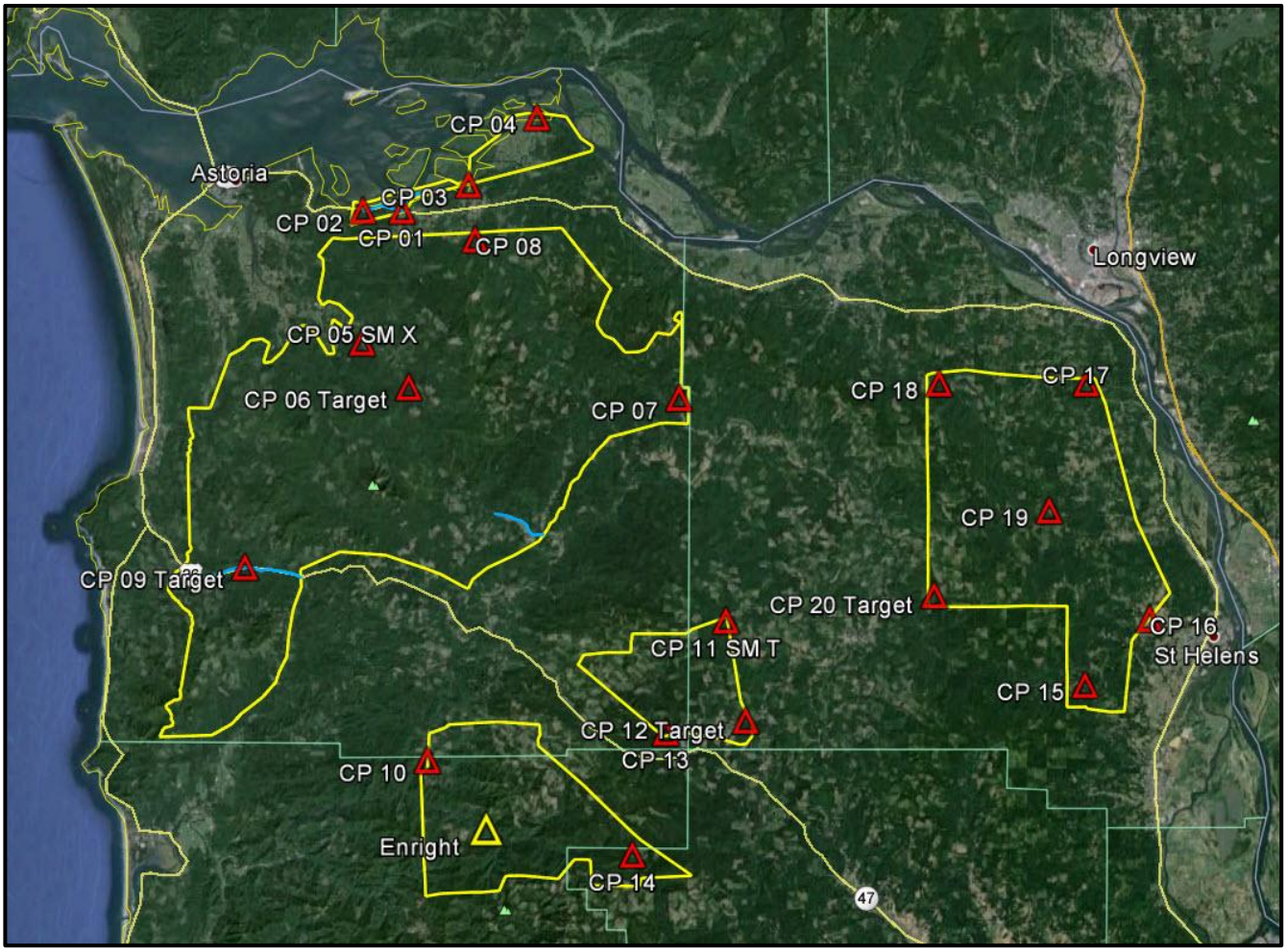
For the purpose of this project both horizontal and vertical control was based on nine (9) continuously operating reference stations (CORS) stations. CORS CATH, LWCK, P408, P409, P411, P414, P446 AND SEAS are part of the Oregon Real Time GPS Network (ORGN). NAD83[2011 Epoch 2010] values were established on the P405 processing and adjusting six (6) days of data to the surrounding ORGN CORS.

Global navigation satellite system (GNSS) observations were made between May 10th and June 12, 2015 utilizing Leica GX1230/AX1202GG and Leica ATX1230GG geodetic GNSS receivers.

The three (3) base stations and photo control station 130 were tied to directly to the four (4) CORS stations as well as multiple ties between adjacent base stations. With the exception of Station 112, the 21 control stations was occupied on at least two (2) distinct times with a minimum planned sidereal shift of two (2) hour between the start of observations. Real-time Kinematic (RTK) GNSS observations utilizing the ORGN were acquired at five (5) the stations, 101, 102, 103, 104 and 108. Static GNSS observations of at least 15 minutes were acquired at the remaining station as well as station 108. With the exception of station 112, each station was tied to at least two (2) base stations. Station 112 was destroyed at some point between scheduled observations.

The resulting data was processed and adjusted with Leica Geo Office (LGO) software Suite. The processed base lines were adjusted by least squares methods. Due to the hostile GNSS environment created by the steep forested canyon walls, not all observations were used in the final adjustment. The absolute accuracy of the 17 static GNSS control points was better than 0.10 feet in any direction horizontally and 0.15 feet vertically with a median horizontally accuracy of better than 0.03 feet horizontally and 0.05 feet vertically at 95% confidence. The four (4) RTK stations fell considerably outside of these values but multiple measurements to these points resulted differences that matched the overall accuracies achieved in the network adjustment. The RTK value for station 108 differs from the static value by 0.02 feet horizontally and vertically.

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



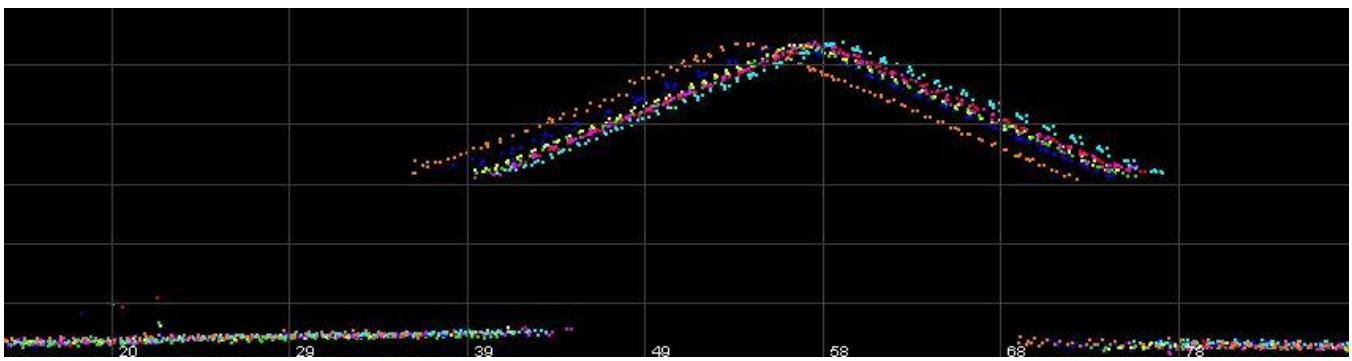
Control points layout

2.5 Relative and Absolute Adjustment

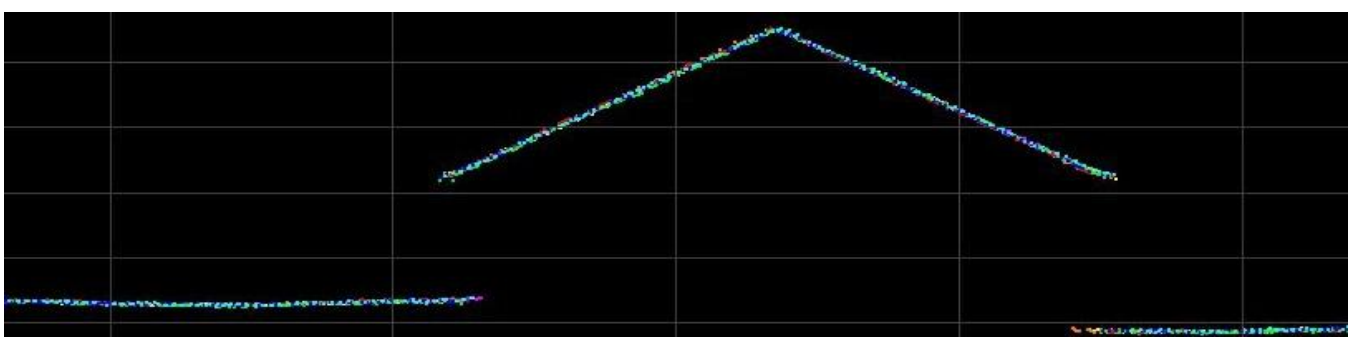
Relative and absolute adjustment of all strips was accomplished using Optech LMS software and TerraMatch. Optech LMS performs automated extraction of planar surfaces from the cloud of points according to specified parameters per project. Tie plane determination then establishes the correspondence between 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



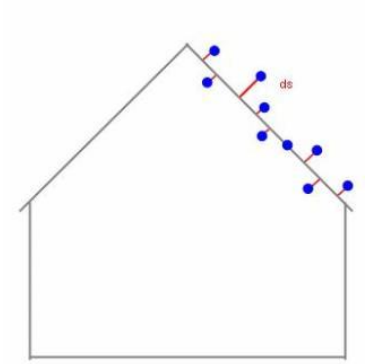
Planes in overlapping strips prior adjustment



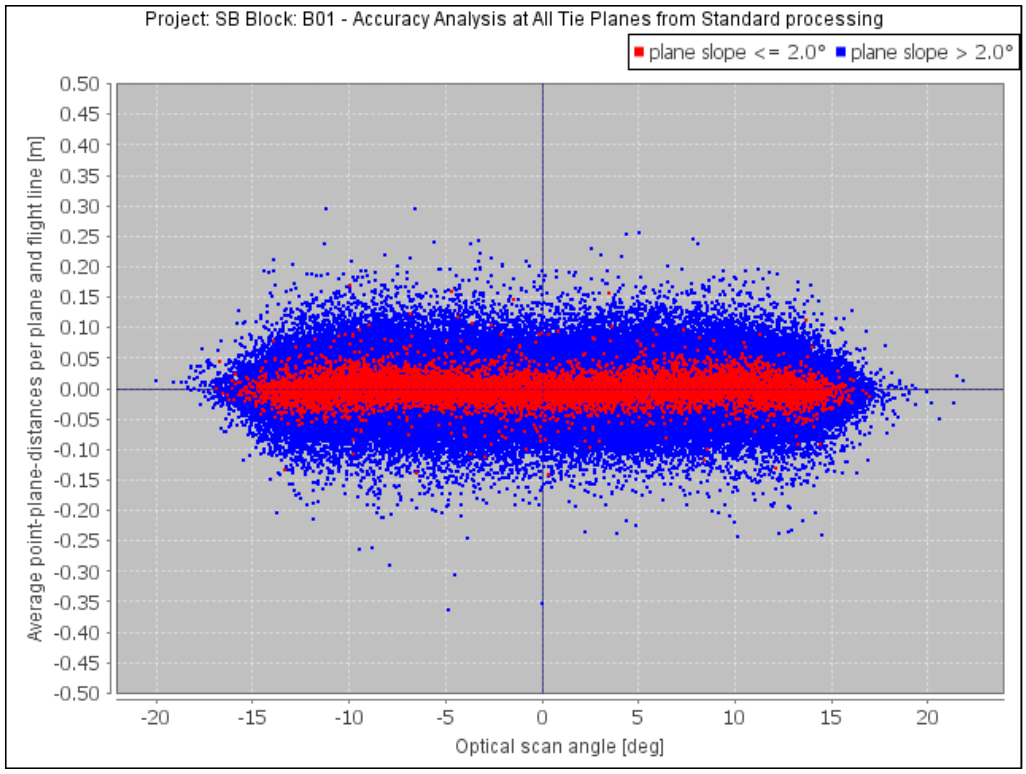
Planes in overlapping strips after adjustment

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.

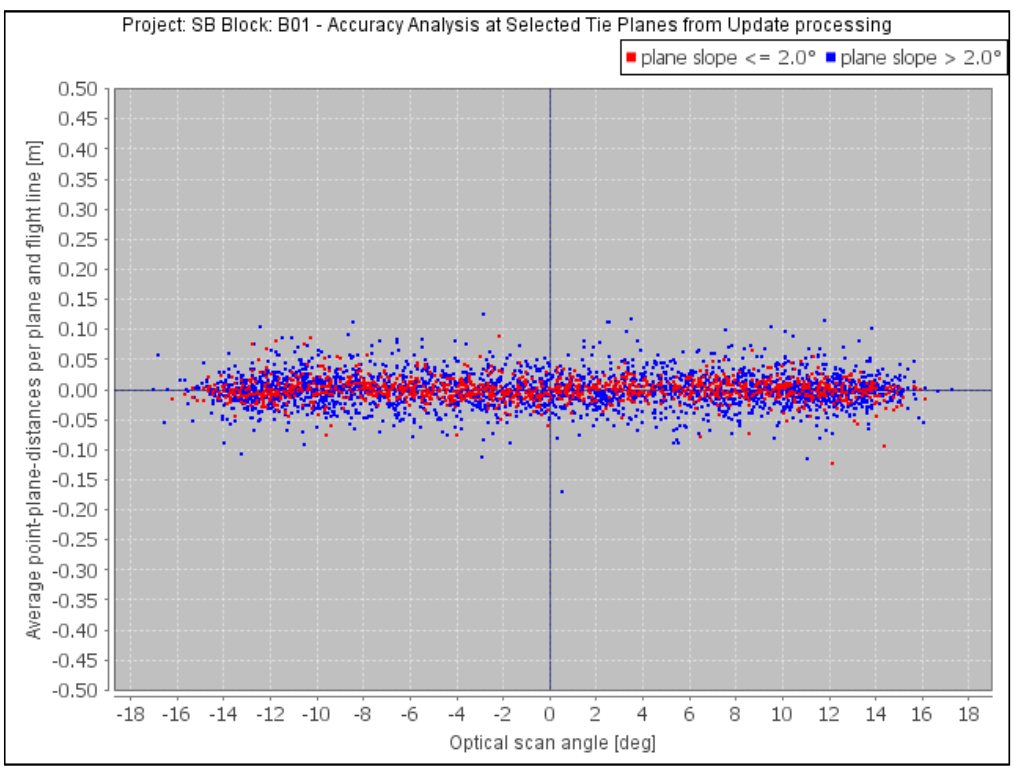
Point to Plane Analysis



ds – point to plane distance



Results from all plane matching plotted over optical scan angle before adjustment (Salmonberry site)



Results from selected plane matching plotted over optical scan angle after adjustment (Salmonberry site)

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.

Twenty one (21) premarked control points were used in absolute fit assessment of the data. Overall fit is very good. Below are tables with statistical analysis on measured control points.

SALMONBERRY

Name	X	Y	Z	Surface Z	Type	Delta Z
1	514045.99	1481167.11	295.39	295.474	Control	**-0.084**
2	567069.84	1454565.54	1865.6	1865.59	Control	**0.010**
3	528317.45	1463179.35	506.41	506.519	Control	**-0.109**

Vertical Error Mean:	-0.061
Vertical Error Range:	[-0.109,0.010]
Vertical Skew:	0.473
Vertical RMSE:	**0.080**
Vertical NMAS/VMAS Accuracy (90% CI):	±0.131
Vertical ASPRS/NSSDA Accuracy (95% CI):	±0.156
Vertical Accuracy Class:	0.08
Vertical Min Contour Interval:	0.24

COLUMBIA

Name	X	Y	Z	Surface Z	Type	Delta Z
101	512256.12	1625478.89	82.89	82.848	Control	**0.042**
102	501883.05	1625910.58	30.44	30.475	Control	**-0.035**
103	529884.58	1632392.27	15.06	15.156	Control	**-0.096**
104	548070.44	1648976.03	13.74	14.062	Control	**-0.322**

Vertical Error Mean:	-0.103
Vertical Error Range:	[-0.322,0.042]
Vertical Skew :	-0.627
Vertical RMSE:	**0.170**
Vertical NMAS/VMAS Accuracy (90% CI):	±0.280
Vertical ASPRS/NSSDA Accuracy (95% CI):	±0.334
Vertical Accuracy Class:	0.18
Vertical Min Contour Interval:	0.54

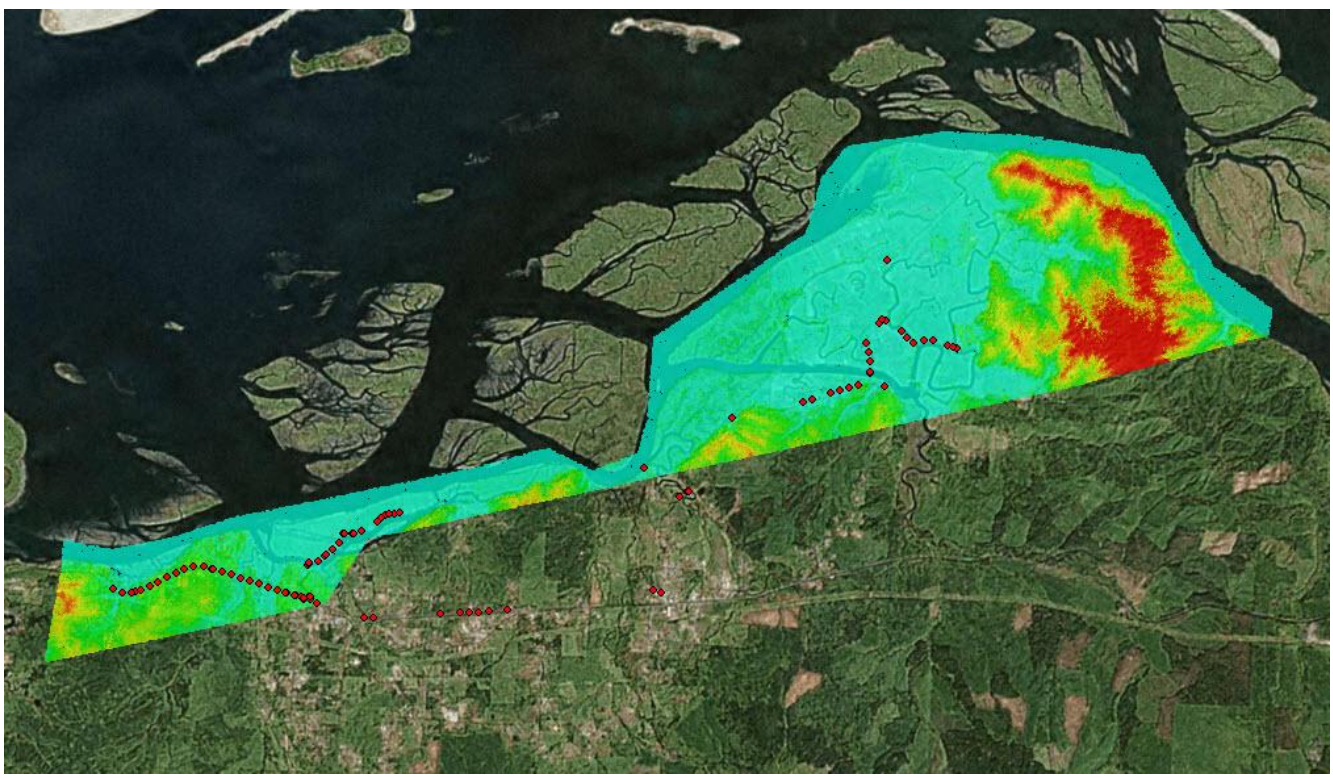
McGREGOR

Name	X	Y	Z	Surface Z	Type	Delta Z
111	593789.46	1514909.79	777.61	777.625	Control	**-0.015**
112	598149.24	1488609.92	723.5	723.297	Control	**0.203**
113	576295.19	1485898.66	1429.04	1429.057	Control	**-0.017**

Vertical Error Mean :	0.057
Vertical Error Range:	[-0.017,0.203]
Vertical Skew :	0.577
Vertical RMSE:	**0.118**
Vertical NMAS/VMAS Accuracy (90% CI):	±0.194
Vertical ASPRS/NSSDA Accuracy (95% CI):	±0.232
Vertical Accuracy Class:	0.12
Vertical Min Contour Interval:	0.36

WILKERSON/WILARK								
Name	X	Y	Z	Surface Z	Type	Delta Z	Vertical Error Mean :	0.271
115	688770.57	1495729.69	553.65	553.555	Control	**0.095**	Vertical Error Range:	[0.095,0.510]
117	690926.38	1573749.29	607.57	607.383	Control	**0.187**	Vertical Skew :	0.384
118	652162.42	1575118.99	316.96	316.803	Control	**0.157**	Vertical RMSE:	**0.314**
119	679926.81	1540785.41	905.31	904.905	Control	**0.405**	Vertical NMAS/VMAS Accuracy (90% CI):	±0.516
120	648179.9	1520848.59	1296.47	1295.96	Control	**0.510**	Vertical ASPRS/NSSDA Accuracy (95% CI):	±0.615
							Vertical Accuracy Class:	0.32
							Vertical Min Contour Interval:	0.96

Additionally Columbia and Clatsop sites had RTK QC/QA points collected. Below is distribution and table of comparisons to Lidar ground surface.



ID	X	Y	Z	Surface Z	Type	Delta Z
10565	542331.46	1639989.87	4.44	4.933	Control	-0.493
10502	542685.48	1640079.47	10.42	10.856	Control	-0.436
10500	542766.33	1643300.48	5.95	6.361	Control	-0.411
10558	542623.01	1636656.51	11.41	11.807	Control	-0.397
10550	538295.96	1635803.93	4.78	5.176	Control	-0.396
10501	542683.02	1640120.47	10.69	11.068	Control	-0.378
10554	539795.62	1636275.79	7.68	8.056	Control	-0.376
10551	538355.13	1635823.29	5.11	5.466	Control	-0.356
10556	540760.81	1636575.22	7.52	7.865	Control	-0.345
10560	541858.83	1637406.1	25.31	25.651	Control	-0.341
10424	514604.35	1628884.56	12.34	12.679	Control	-0.339
10559	541853.35	1637324.58	24.54	24.874	Control	-0.334
10572	546260.22	1638727.52	11.89	12.21	Control	-0.32
10566	542495.8	1640146.26	4.63	4.939	Control	-0.309
10315	508111.38	1626679.98	54.76	55.057	Control	-0.297
10503	545948.94	1638819.08	9.15	9.443	Control	-0.293
10555	540281.14	1636426.12	7.76	8.05	Control	-0.29
10413	514976.18	1628996.99	12.73	13.007	Control	-0.277
10317	509085.53	1626356.02	25.11	25.384	Control	-0.274
10552	538833.47	1635973.06	6.97	7.242	Control	-0.272
10567	543546.71	1639522.4	12.68	12.937	Control	-0.257
10420	516477.54	1629891.41	12.56	12.809	Control	-0.249
10561	541860.8	1637436.16	25.39	25.624	Control	-0.234
10408	513076.49	1627708.74	12.36	12.59	Control	-0.23
10411	513988	1628851.29	12.62	12.847	Control	-0.227
10316	508597.95	1626517.66	37.35	37.571	Control	-0.221
10425	514103.06	1628849.92	12.21	12.428	Control	-0.218
10562	541887.37	1637937.79	8.27	8.487	Control	-0.217
10419	516981.7	1629945.95	11.92	12.127	Control	-0.207
10428	513110.02	1627731.92	12.66	12.862	Control	-0.202
10510	501866.52	1625948.43	29.53	29.725	Control	-0.195
10314	507623.69	1626839.95	71.45	71.643	Control	-0.193
10410	513820.88	1628378.14	12.72	12.91	Control	-0.19
10409	513476.23	1628015.22	12.66	12.841	Control	-0.181
10568	543782.69	1639237.13	12.68	12.852	Control	-0.172
10504	546430.91	1638682.98	11.68	11.851	Control	-0.171
10415	515829.99	1629480.94	11.91	12.08	Control	-0.17
10430	512213.05	1627353.08	21.1	21.245	Control	-0.145
10563	541815.18	1638436.15	4.79	4.928	Control	-0.138
10412	514488.86	1628874.14	12.13	12.26	Control	-0.13

10318	509566.87	1626196.94	21.6	21.728	Control	-0.128
10514	503786.29	1626111.03	64.24	64.359	Control	-0.119
10421	516023.06	1629678.82	11.55	11.663	Control	-0.113
10322	511488.1	1625573.07	74.48	74.592	Control	-0.112
10511	502325.47	1625727.73	30.35	30.461	Control	-0.111
10407	512676.47	1627427.18	12.56	12.66	Control	-0.1
10418	516700.32	1629926.37	12.3	12.395	Control	-0.095
10313	507140.3	1626989.72	83.21	83.302	Control	-0.092
10416	515831.33	1629482.7	11.9	11.986	Control	-0.086
10404	512114.07	1627180.69	12.85	12.933	Control	-0.083
10400	512246.73	1625495.33	82.83	82.909	Control	-0.079
10515	504253.07	1626323.4	75.89	75.968	Control	-0.078
10518	505642.59	1626959.47	95.31	95.38	Control	-0.07
10312	507055.75	1627015.07	84.88	84.947	Control	-0.067
10429	512707.77	1627434.4	12.55	12.611	Control	-0.061
10516	504719.68	1626536.67	86.49	86.542	Control	-0.052
10320	510530.79	1625877.67	38.9	38.949	Control	-0.049
10405	512182.89	1627289.02	18.66	18.709	Control	-0.049
10520	506641.56	1627129.45	92.44	92.452	Control	-0.012
10524	510031.41	1626043.88	25.57	25.578	Control	-0.008
10517	505183.44	1626750.54	93.67	93.675	Control	-0.005
10513	503318.71	1625899.19	52.76	52.761	Control	-0.001
10417	516210.47	1629811.51	12.51	12.504	Control	0.006
10571	545187.59	1639046.83	11.85	11.829	Control	0.021
10526	510989.6	1625725.97	56.16	56.138	Control	0.022
10321	511006.94	1625721.34	56.79	56.766	Control	0.024
10549	534547.45	1634976.48	13.67	13.644	Control	0.026
10570	544685.75	1639050.32	9.67	9.636	Control	0.034
10519	506130.51	1627119.15	96.94	96.904	Control	0.036
10512	502837.04	1625738.87	41.1	41.058	Control	0.042
10564	541684.93	1638924.75	5.1	5.057	Control	0.043
10545	529891.78	1632352.43	15.04	14.99	Control	0.05
10431	511792.43	1625504.68	83.89	83.84	Control	0.05
10530	512265.04	1625395.74	86.23	86.18	Control	0.05
10528	511960.03	1625407.45	88.26	88.199	Control	0.061
10527	511475.7	1625564.34	74.33	74.243	Control	0.087
10569	544189.82	1638942.2	15.42	15.33	Control	0.09
10522	507618.81	1626841.85	71.93	71.822	Control	0.108
10521	507138.21	1626999.32	83.74	83.627	Control	0.113
10523	508105.56	1626682.33	55.29	55.126	Control	0.164
10300	501861.42	1625946.59	30.02	29.852	Control	0.168
10529	511969.93	1625429.08	88.11	87.931	Control	0.179

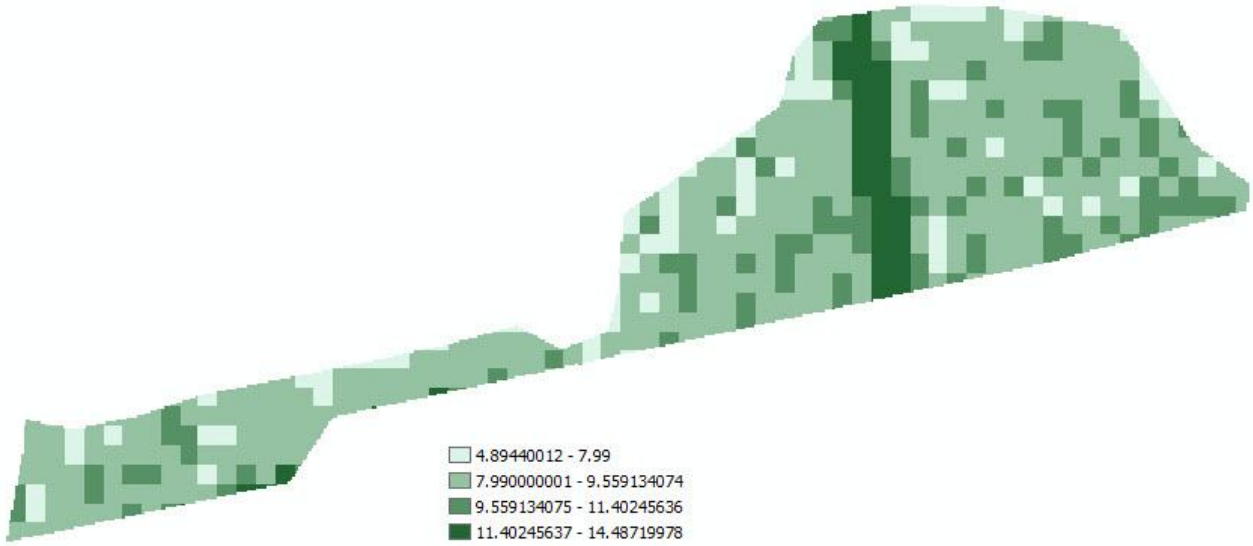
10531	512253.11	1625502.36	83.31	83.09	Control	0.22
10304	503043.82	1625778.22	46.71	46.368	Control	0.342

Vertical Error Mean*:	-0.125
Vertical Error Range:	[-0.493,0.342]
Vertical Skew:	0.131
Vertical RMSE:	**0.211**
Vertical NMAS/VMAS Accuracy (90% CI):	±0.347
Vertical ASPRS/NSSDA Accuracy (95% CI):	±0.413
Vertical Accuracy Class:	0.22
Vertical Min Contour Interval:	0.66

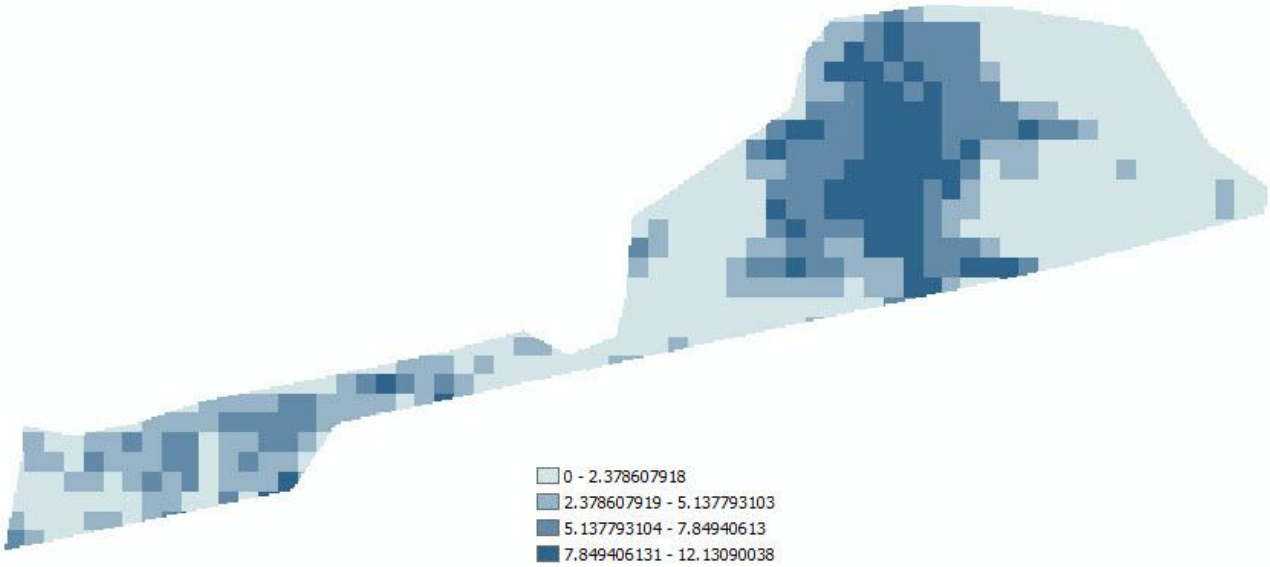
2.6 Point Density

The final point density of all combined Lidar strips within the project boundary was calculated for first return and ground using LP360 on 1000ft by 1000ft cell sizes. Point density is based upon acquisition at a 50% sidelap with a planned average of 4 to 6 points per meter for each strip, and meeting a final overall acquired density of 8 to 12 points per meter in consideration of planned minimum sidelap.
Because of the terrain characteristics on some of the sites, parameters were set to acquire with a minimal impact of PIA/MTA zone changed (Multiple Pulse in Air). Additional lines were designs to cover potential PIA/MTA zone dropouts.

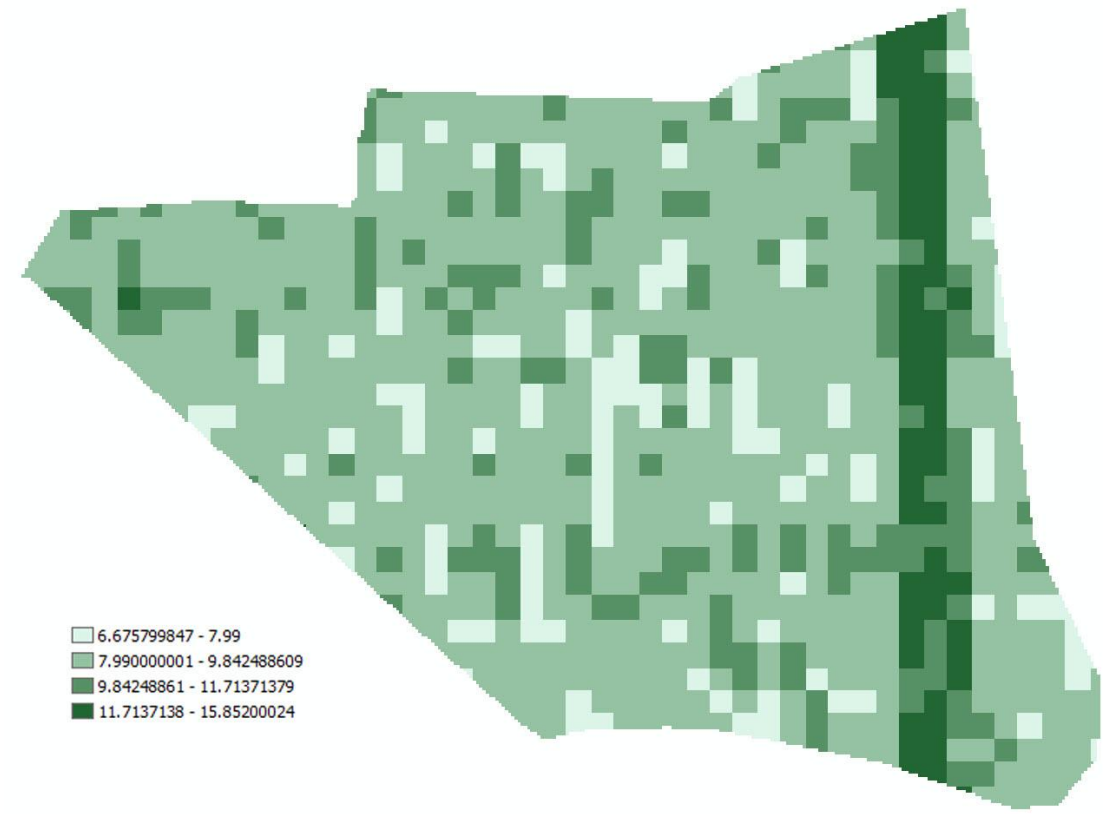
	Average first return point density [p/m^2]	Average ground return point density [p/m^2]
Columbia	9.08	3.40
McGregor	9.24	3.23
Wilkerson	11.28	3.34
Salmonberry	12.99	6.84



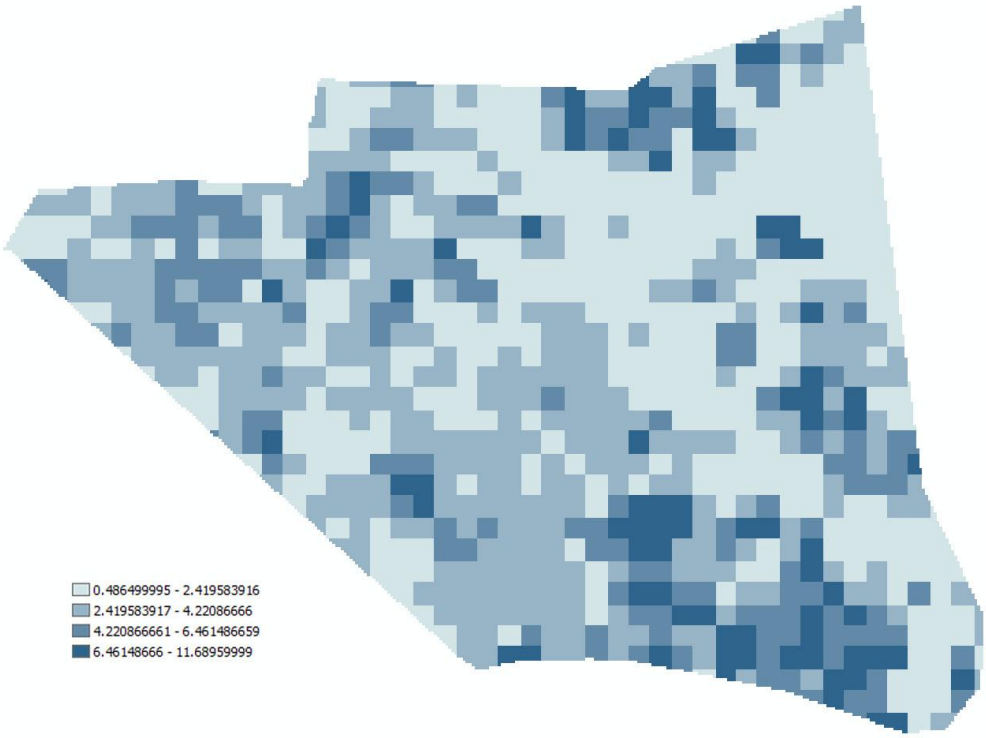
Columbia – first return point density



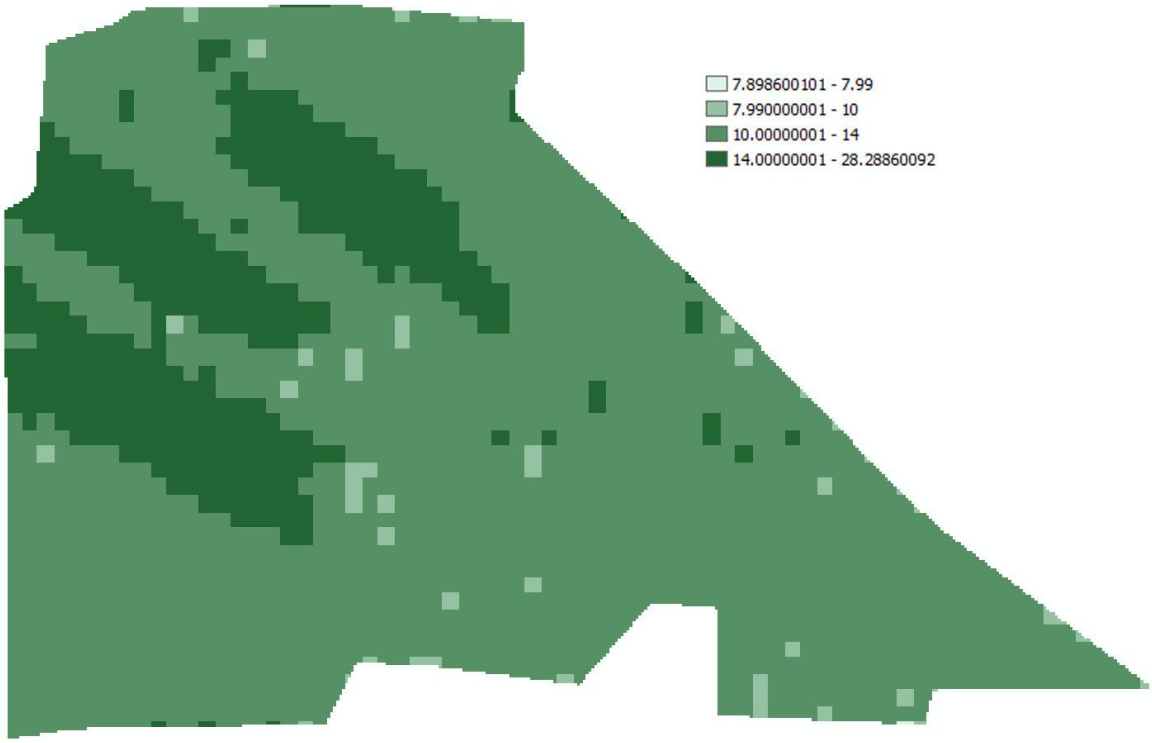
Columbia – ground return point density



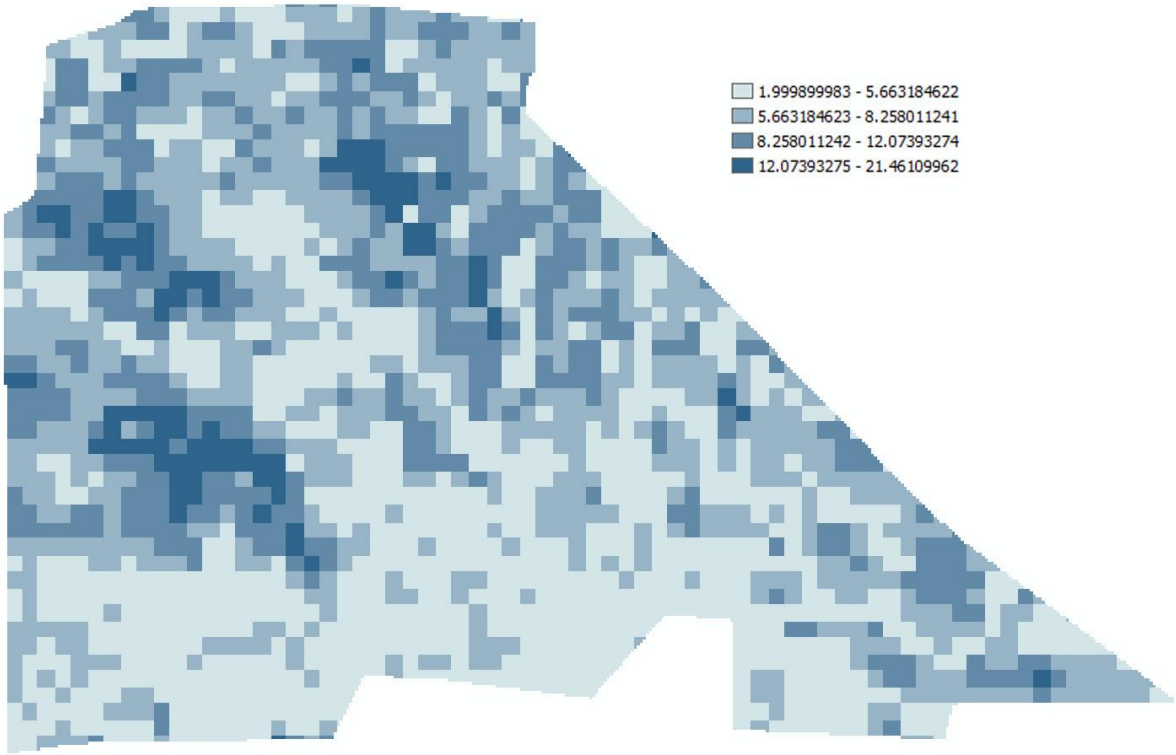
McGregor – first return point density



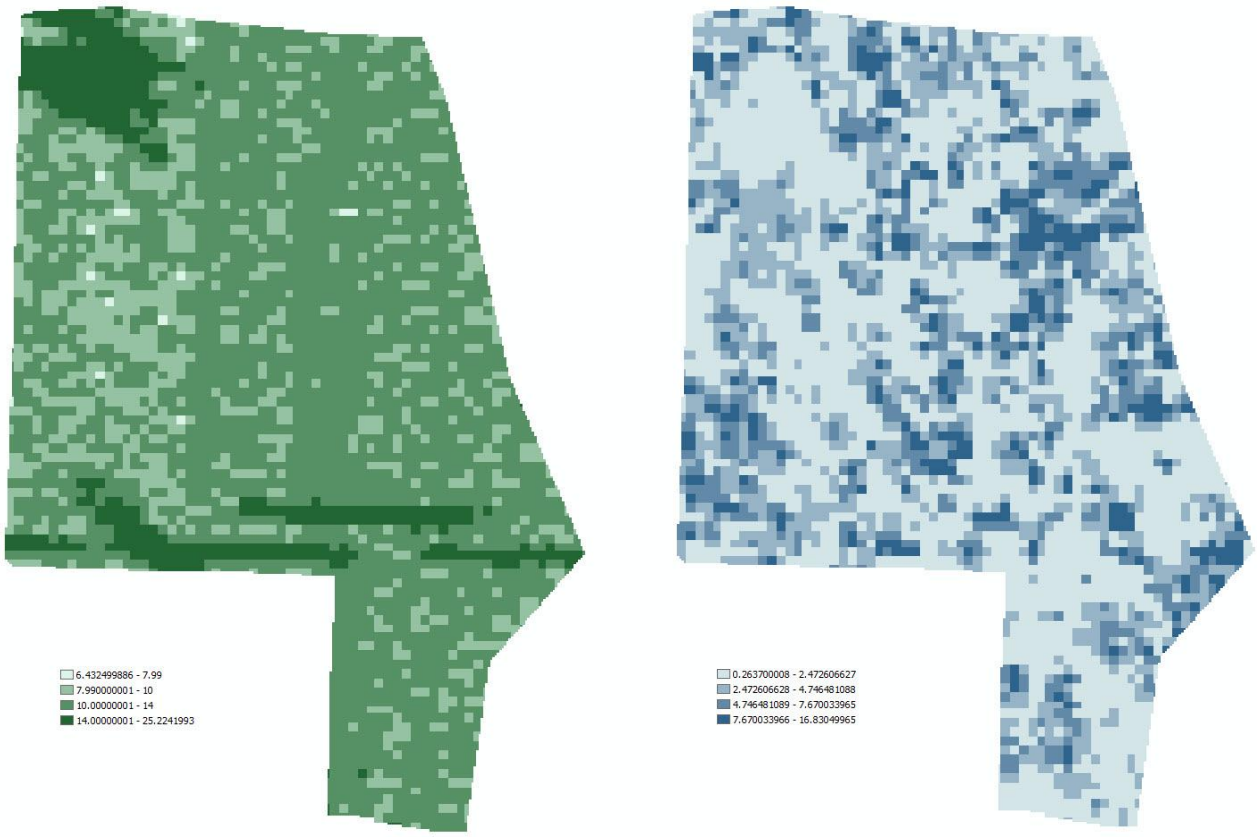
McGregor – ground return point density



Salmonberry – first return point density



Salmonberry – ground return point density

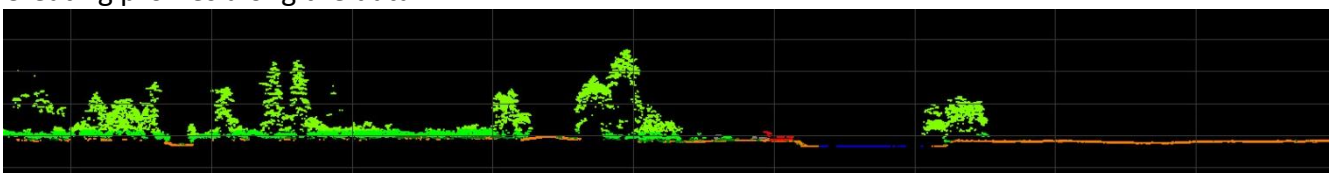


Wilkerson – first return point density and ground return point density

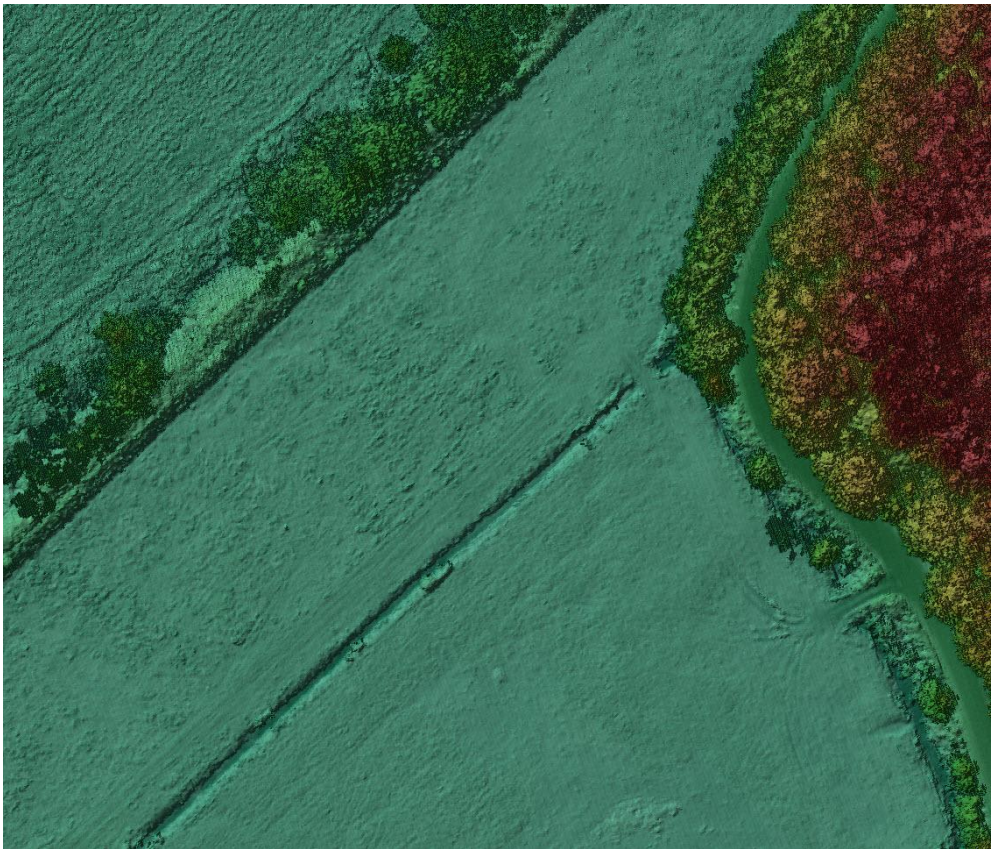
2.7 Point Cloud Classification

Once the point cloud adjustment was achieved with desired relative accuracy, all strips were exported from Optech LMS into LAS format. Data in LAS format was first automatically classified followed by strict QC procedures. Each site was evaluated for size and was cut into working tiles of a manageable size and manually checked and edited using TerraSolid and LP360 to correct any misclassification using the following methods:

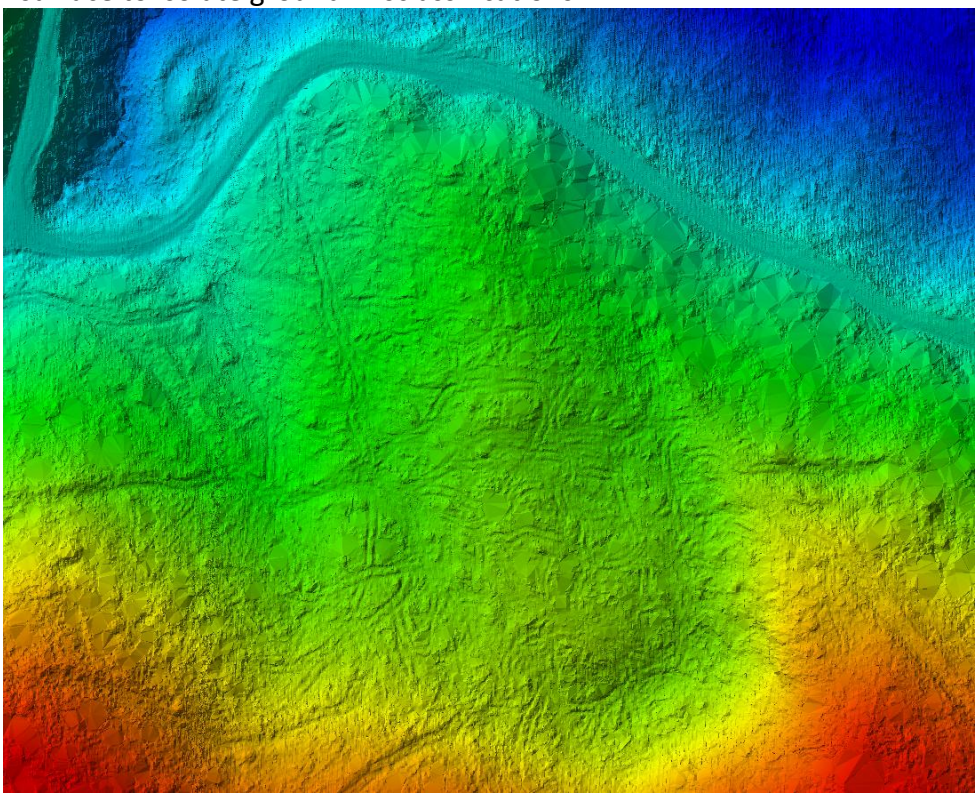
- Creating profiles along the data



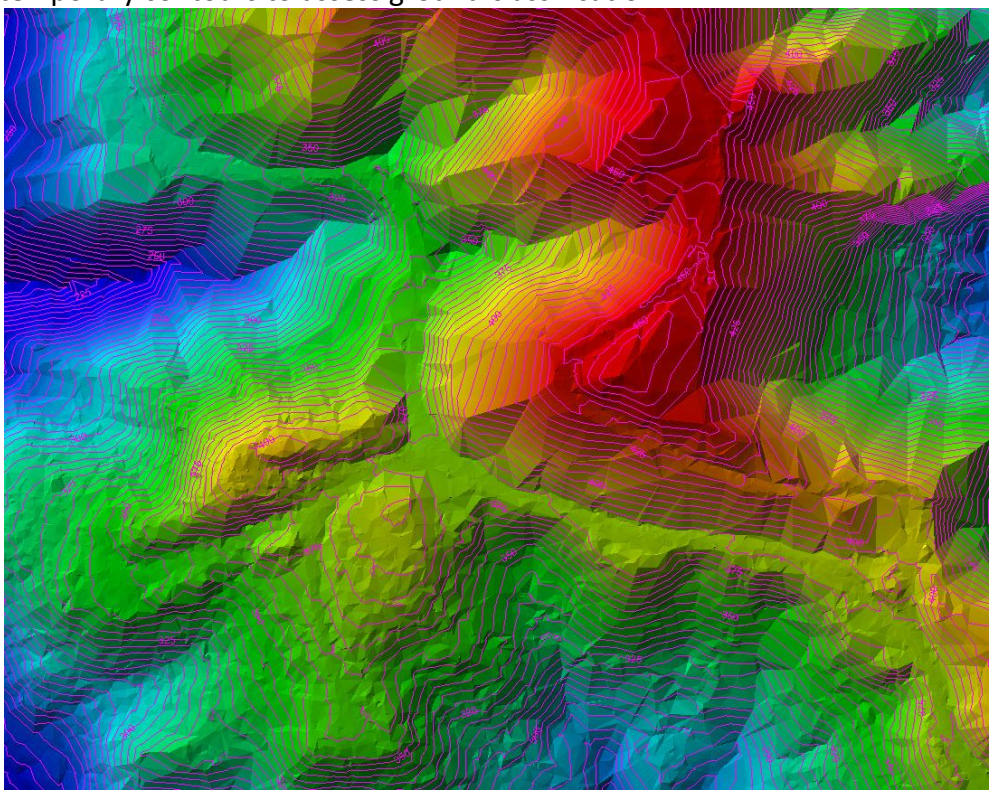
- Creating TIN surface



- Creating TIN surface to isolate ground misclassifications



- Displaying temporary contours to assess ground classification



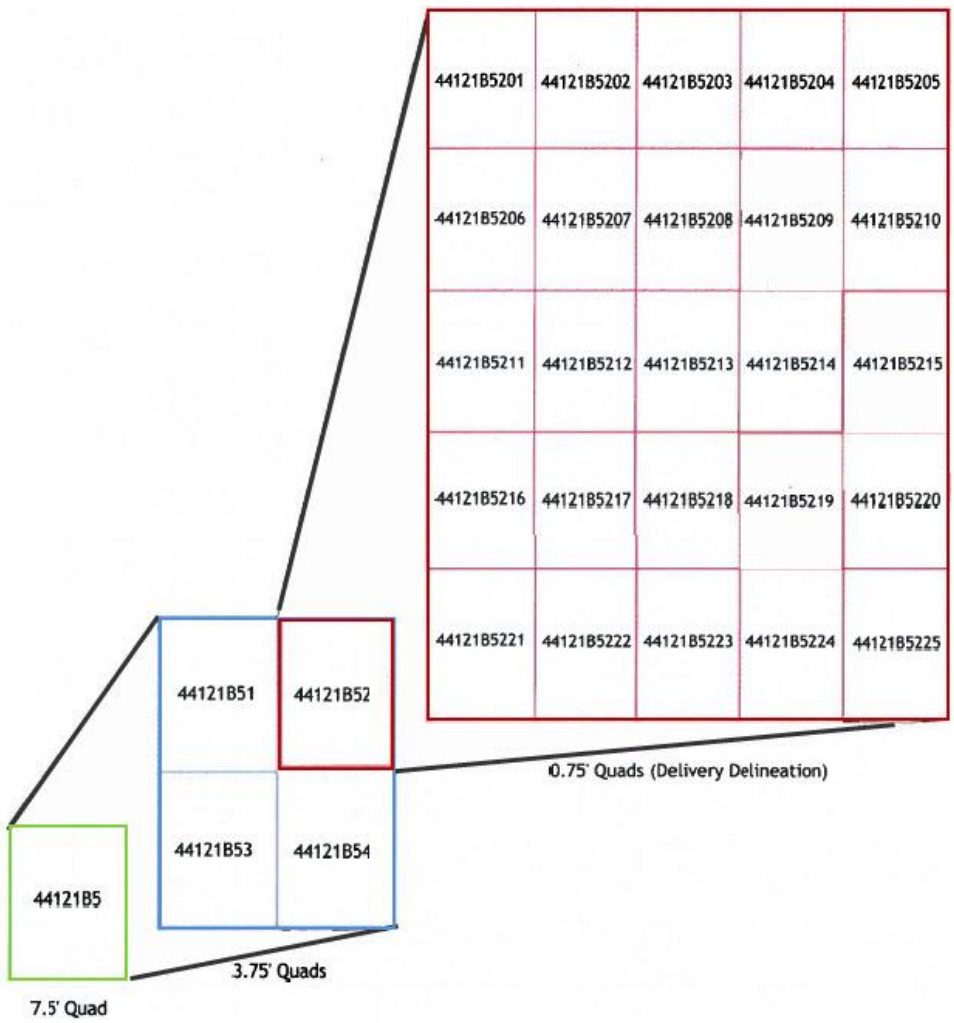
- Generating intensity images over an area to identify features as well as using streaming imagery

Following classes were delineated in the process of classification:

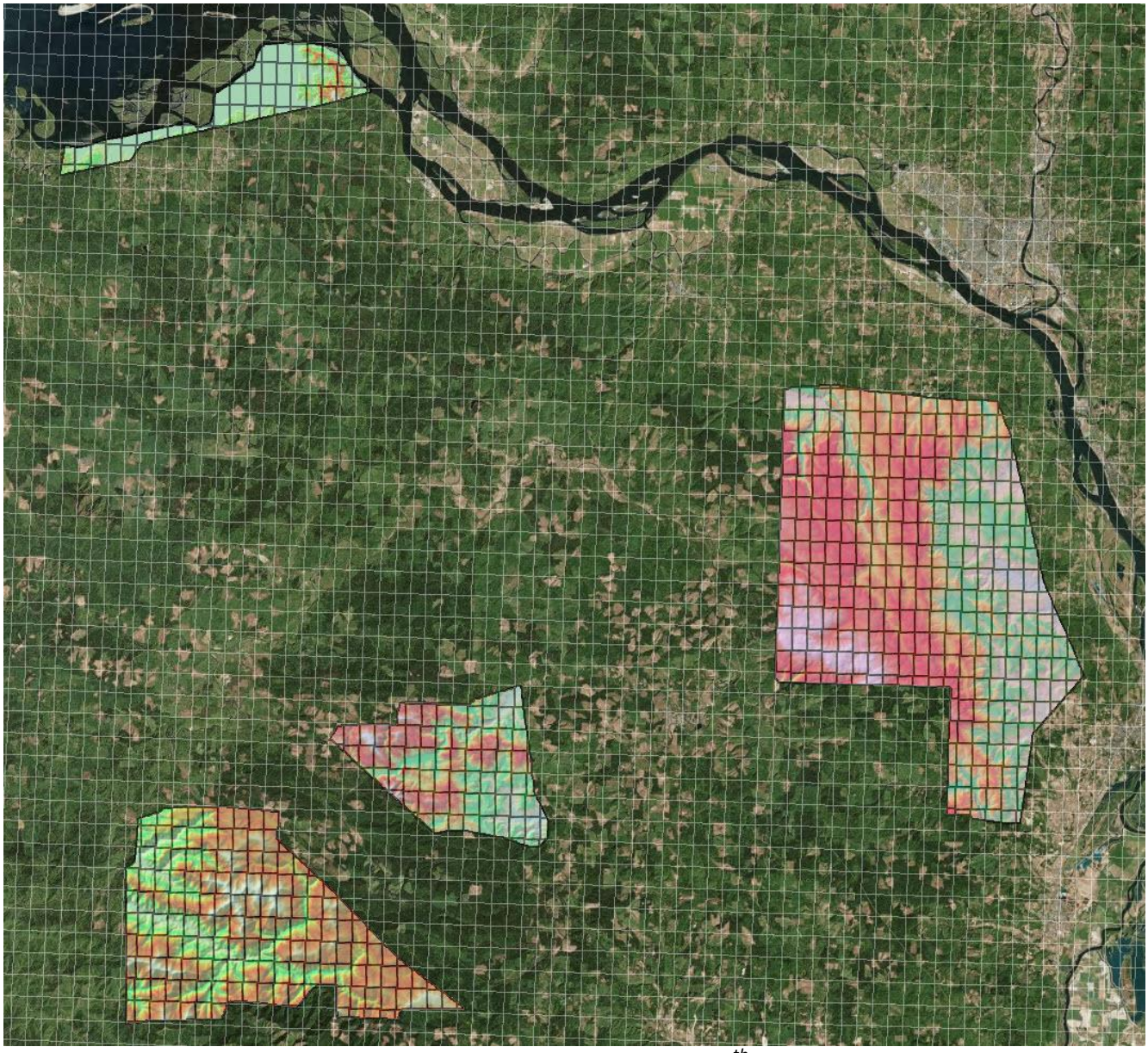
- 01_Unclassified (temporary)
- 02_Ground
- 03_Low Vegetation
- 04_Medium Vegetation
- 05_High Vegetation
- 06_Buildings and Associated Structures
- 09_Water – points reflected off water bodies
- 10_Unclassified (Permanent)

2.8 Tiling Scheme

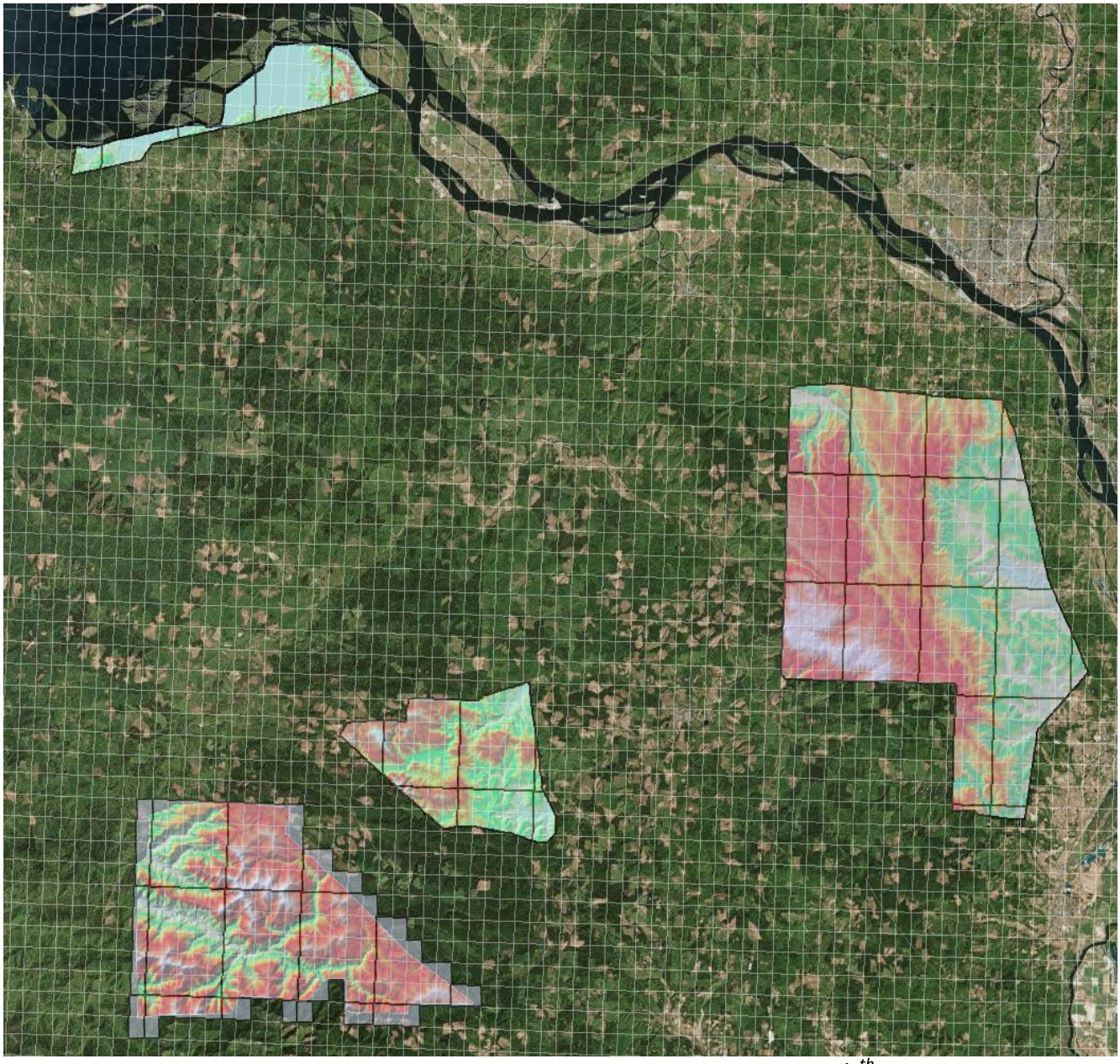
Final adjusted points were split into tiles over a buffered project boundary.
A tile index file has been provided with the deliverables.



Naming scheme



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



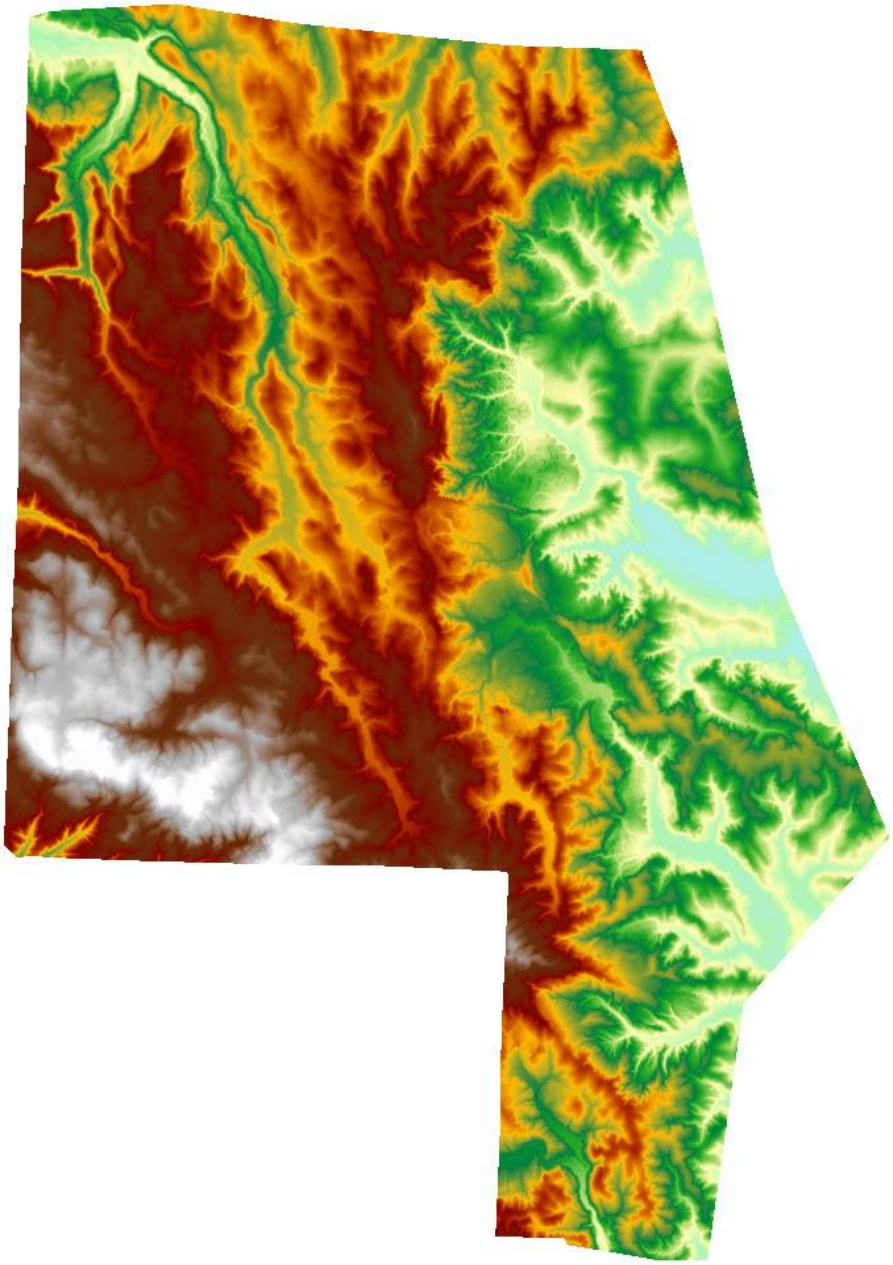
Overview of tiling scheme for Intensity Image tiles on all flown sites – 1/4th USGS 7.5-minue quadrangle (3.75 minute by 3.75 minute)

3. ArcGIS Raster Processing

3’ floating point Ground and First Return ESRI raster grids were generated using the Lidar points as input to the LAS Dataset to Raster tool and converting an ESRI terrain dataset of the Lidar ground surface into File Geodatabase raster.

3.1 Ground Surface

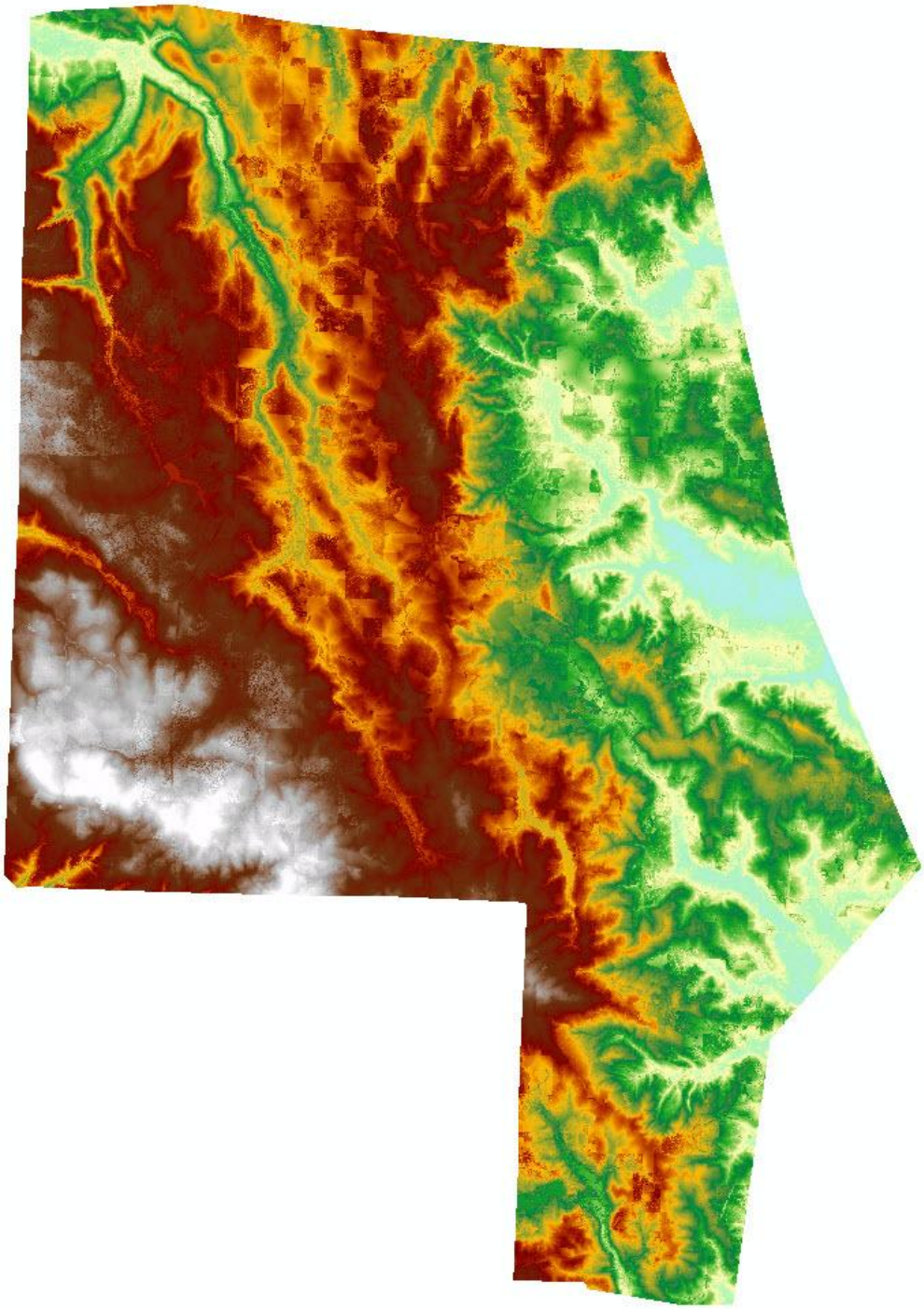
AS classified ground points used were on class 02. ERSI terrain dataset of the Lidar ground surface was created and then converted into File Geodatabase raster.



Example of Ground Terrain 3’ DEM Raster

3.2 First Return DSM Surface

3’ First Return raster was generated using first return Lidar points for all classes, excluding noise. LAS Dataset to Raster tool was used and interpolation type was a binning approach using maximum cell elevation and linear void filling.
Raster datasets were clipped to the project boundaries when appropriate.



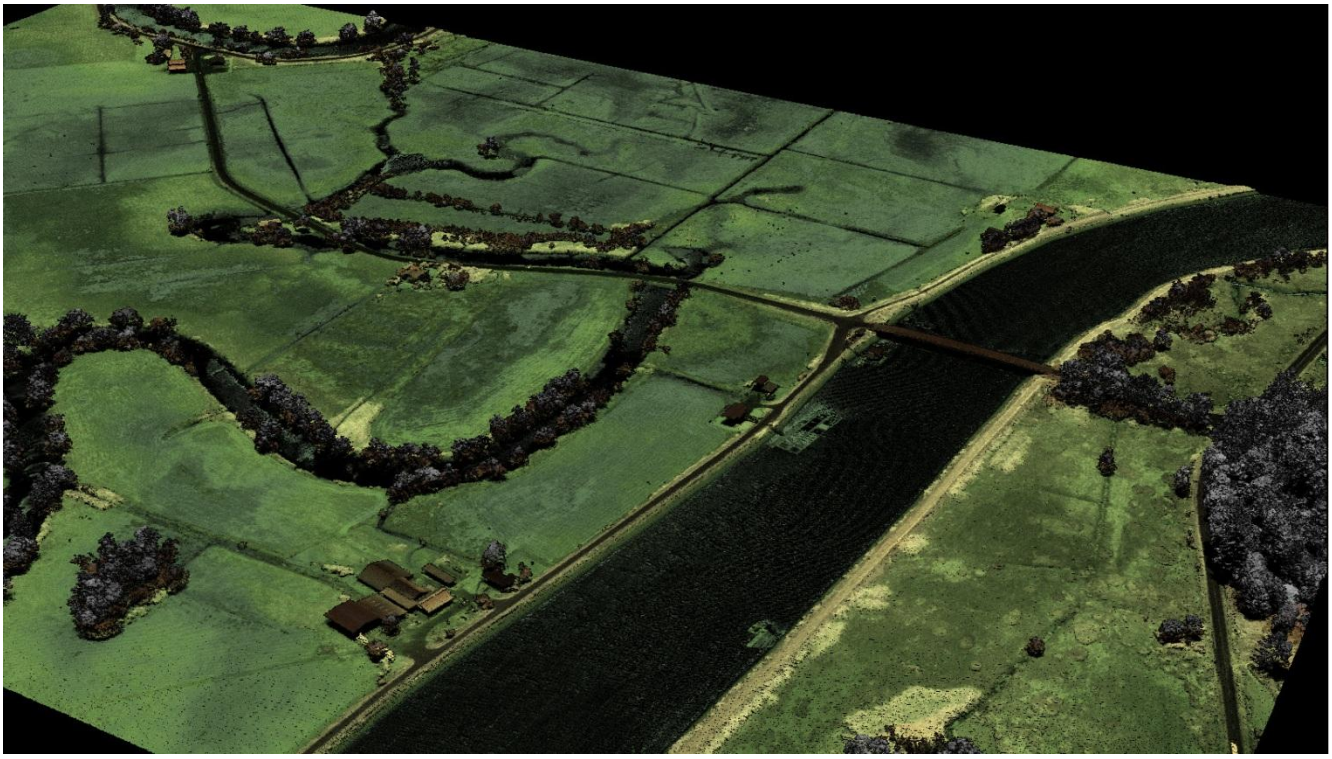
Example of First Return 3’ Raster Grid

3.3 Intensity Images

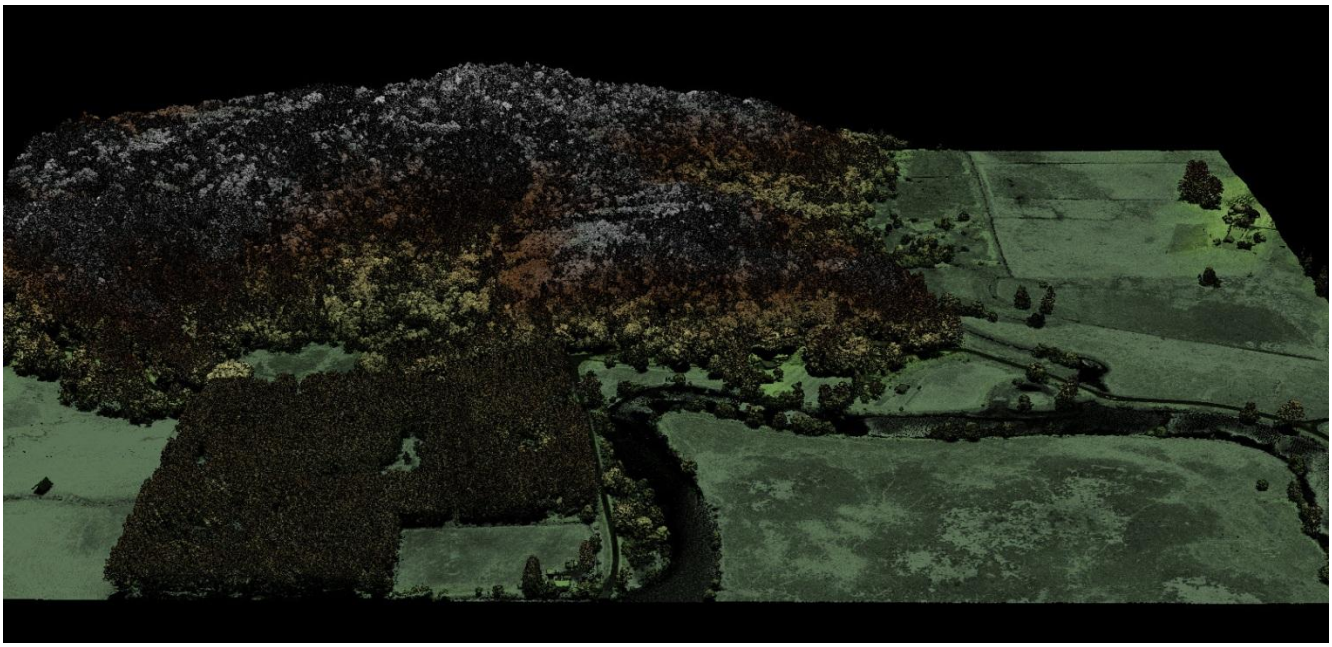
1.5' resolution Intensity TIFFs were generated using average intensity of first return points in each cell.

Example of Intensity Image for entire area of Wilkerson/Wilark

4. Miscellaneous graphics



Intensity shaded full point cloud (Columbia site)



Intensity shaded full point cloud (Columbia site)

5. Final Deliverables

- All-return point cloud in LAZ format
- Bare-earth surface model – ESRI file geodatabase floating point grid, 3ft cell size
- First Return (Highest Hit) DEM – ESRI file geodatabase floating point grid, 3ft cell size
- Intensity images – TIFF format, 1.5ft pixel size
- Aircraft trajectories (SBET files) – vector file geodatabase
- Tile Indexes - file geodatabase
- Lidar Technical Report
- Control Survey Report