www.sanborn.com | 1.866.726.2676

MNCPPC Lidar 2020

312020360

Lidar Report

June 2021

EXECUTIVE SUMMARY

The Sanborn Map Company, Inc. (Sanborn) was tasked to provide remote sensing services in the form of lidar. Utilizing a multi-return system, Light Detection and Ranging (Lidar) detects 3-dimensional positions and attributes to form a point cloud. The high accuracy airborne system is integrated with both Global Navigation Satellite System (GNSS) and an Inertial Measure Unit (IMU) for accurate position and orientation. Acquisition of the project area's ~1,074mi² was completed on January 7th, 2021.

The Leica TerrainMapper was used to collect data for the aerial survey campaign. The sensor is attached to the aircraft's underside and emits rapid laser pulses that are used to calculate ranges between the aircraft and subsequent terrain below. The Airborne Lidar System (ALS) is boresighted by completing multiple passes over a known ground surface before the project acquisition. During data processing, the system calibration parameters are updated and used during post-processing of the lidar point cloud.

Differential GNSS unit in aircraft sampled positions at 2Hz or higher frequency. Lidar data was only acquired when GNSS PDOP is ≤4 and at least 6 satellites are in view. Collection conditions were for leaf-off vegetation. The atmosphere was free of clouds and fog between the aircraft and ground. The ground was free of snow and extensive flooding or any other type of inundation.

The contents of this report summarize the methods used to establish the base station coordinates, perform the lidar data acquisition and processing as well as the results of these methods.

CONTENTS

1.0 INTRODUCTION

This document contains the technical write-up of the lidar campaign, including system calibration techniques, and the collection and processing of the lidar data.

1.1 Contact Information

Questions regarding the technical aspects of this report should be addressed to:

Shawn Benham, PMP
Vice President of Programs
The Sanborn Map Company, Inc.
1935 Jamboree Drive, Suite 100
Colorado Springs, CO 80920
(719) 502-1296
sbenham@sanborn.com

1.2 Purpose of Lidar Acquisition

The objective of this project is to collect accurate measurements of the bare-earth surface as well as above ground features to be provided as geometric inputs for surface and/or change modeling as is relates survey assessments.

1.3 Project Location

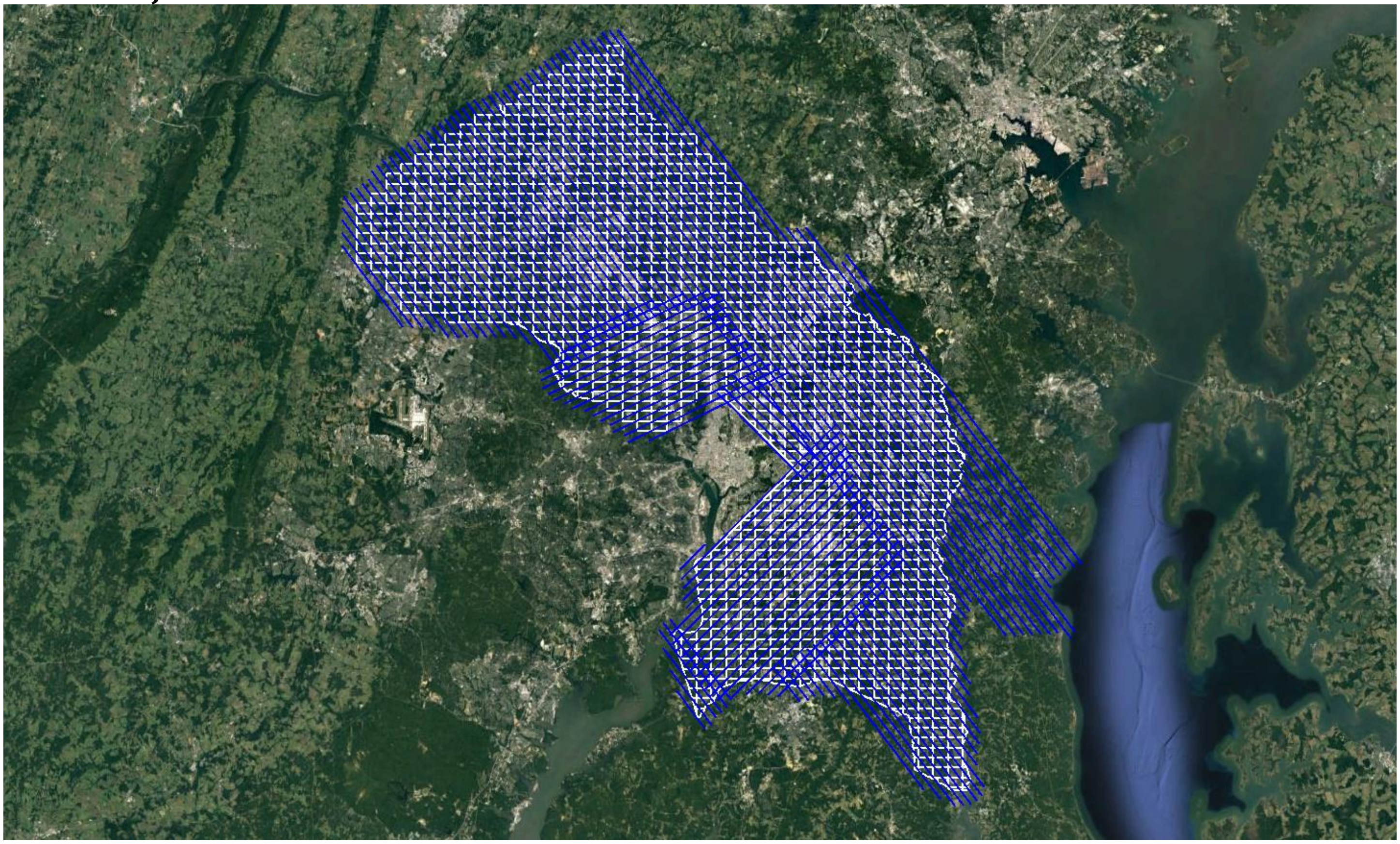


Figure 1: Tile Index and Trajectories As-Flown

2.0 ACQUISITION

2.1 Introduction

This section outlines the lidar system, flight reporting, and data acquisition methodology used during the collection of the lidar campaign. Although Sanborn conducts all lidar missions with the same rigorous and strict procedures and processes, all lidar collections are unique.

2.2 Acquisition Parameters

Sanborn specifically defined the collection parameters to accomplish the desired project specifications. **Table 1** shows the planned acquisition parameters utilized for this aerial survey with the sensor(s) installed.

Planned Acquisition Parameters	
Aircraft	N500Q - PIPER PA-31-310
Sensor	Leica TerrainMapper
Max Number of Returns	15
Point Spacing (m)	0.35
Point Density (pls/m²)	8.3
Flying Height (AGL) (m)	1763
Air Speed (kts)	146
Field of View (degrees)	40
Scan Rate (Hz)	150
Pulse Rate (kHz)	1251.9
Laser Footprint (m)	0.42
Wavelength (nm)	1064
Multi-Pulse	Yes
Swath Width (m)	1284
Overlap (%)	20

Table 1: Lidar Acquisition Parameters

2.3 Field Work Procedures

Sanborn's standard procedure before every mission is to perform pre-flight checks to ensure correct operation of all systems. All cables were checked, and the sensor head glass was cleaned. A three-minute static session was conducted on the ground with the engines running prior to take-off to establish fine-alignment of the IMU and to resolve GNSS ambiguities.

The project acquisition consisted of eleven (11) mission(s). During the data collection, the operator recorded information on log sheets which includes weather conditions, lidar operation parameters, flight line statistics and PDOP.

Preliminary data processing was performed in the field immediately following the missions for quality control of GNSS data and to ensure sufficient coverage of the project AOI. Any problematic data could then be re-flown immediately as required. Final data processing was completed in the Colorado Springs, CO office. **Table 2** below shows the flight acquisition metrics for the entire collection. **Table 3** contains the base station names and locations in operation during acquisition. Base station coordinates are provided in NAD83 (2011), Geographic Coordinate System, Ellipsoid, Meters.

Date	Sensor	Serial #	Tail #	MissionID	PDOP	Start (UTC)	End (UTC)
12/10/2020	Leica TerrainMapper	TM91555	N500Q	20201210A	1.3	14:19:21	18:36:26
12/10/2020	Leica TerrainMapper	TM91556	N500Q	20201210B	1.3	20:25:48	22:14:36
12/10/2020	Leica TerrainMapper	TM91557	N500Q	20201210C	1.3	22:18:15	23:20:56
12/11/2020	Leica TerrainMapper	TM91558	N500Q	20201211A	1.1	23:27:48	4:17:40
12/27/2020	Leica TerrainMapper	TM91559	N500Q	20201227A	0.9	15:24:27	17:56:13
12/28/2020	Leica TerrainMapper	TM91560	N500Q	20201228A	1.0	19:59:27	22:47:49
12/29/2020	Leica TerrainMapper	TM91561	N500Q	20201229A	1.1	16:00:45	17:52:24
12/29/2020	Leica TerrainMapper	TM91562	N500Q	20201229B	1.1	19:25:30	0:04:38
12/30/2020	Leica TerrainMapper	TM91563	N500Q	20201230A	1.2	13:58:42	18:54:29
12/30/2020	Leica TerrainMapper	TM91564	N500Q	20201230B	1.2	21:49:45	1:26:35
1/7/2021	Leica TerrainMapper	TM91565	N500Q	20210107A	1.0	14:19:51	19:59:04

Table 2: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
DCDC	SmartNet	n/a	38 56 45.80863	077 05 52.45034	56.762
GODE	CORS	AF9646	39 01 18.18970	076 49 36.57472	15.845
LOYF	CORS	DK7414	38 58 28.07429	076 31 19.88530	-14.498
MDAN	SmartNet	n/a	39 07 53.75850	076 47 25.53132	36.341
MDDM	SmartNet	n/a	39 19 05.90460	077 11 45.52334	203.006
MDUM	SmartNet	n/a	38 49 00.68897	076 45 06.93394	-12.564
VALN	SmartNet	n/a	38 43 42.02175	077 11 02.29779	-1.619
ZDC1	CORS	DF9217	39 06 05.71469	077 32 33.86746	80.896

Table 3: GNSS Reference Station Coordinates

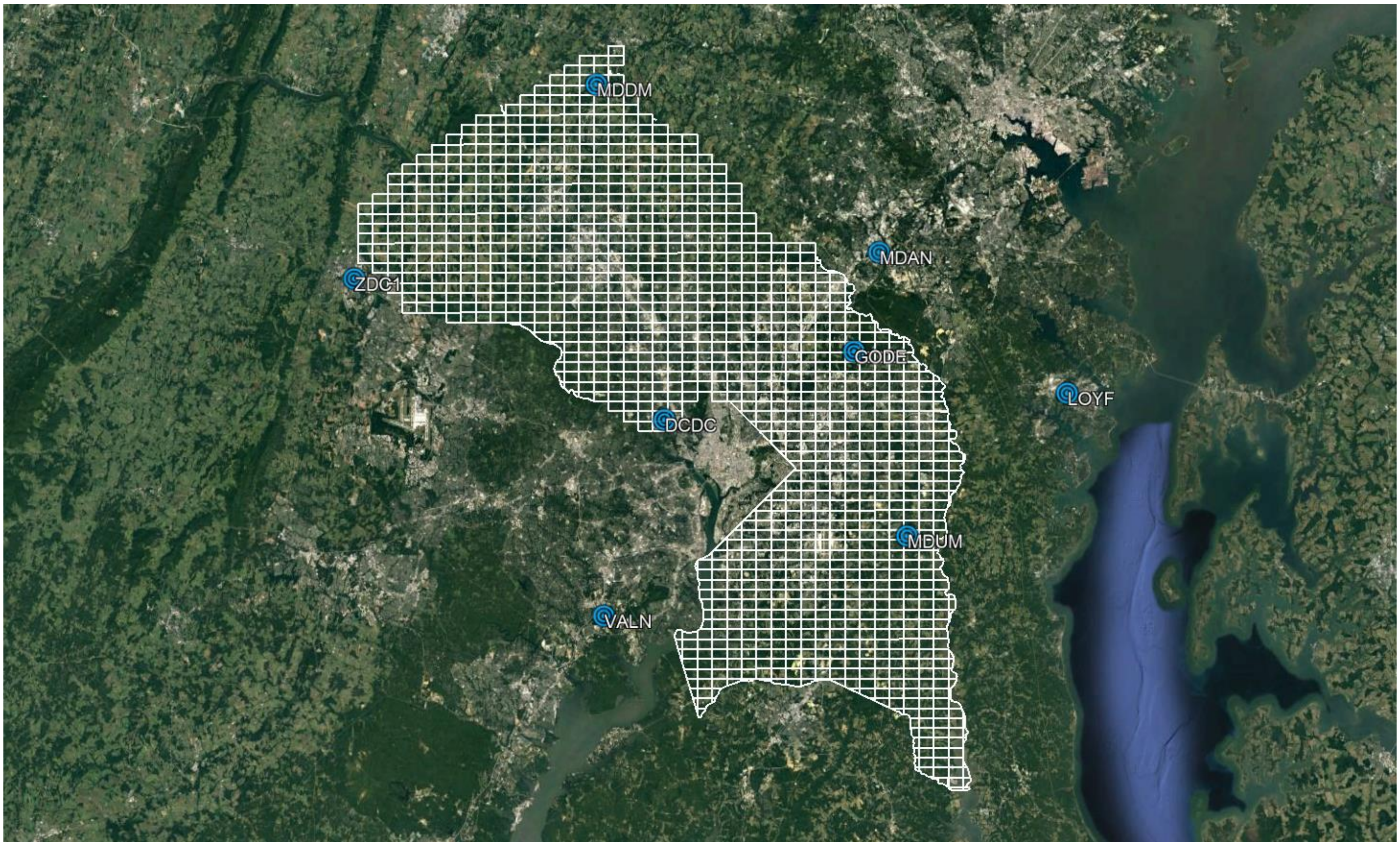


Figure 2: GNSS Reference Stations

3.0 PROCESSING

3.1 Introduction

The GNSS/IMU data was post-processed using Waypoint Inertial Explorer software to create Smoothed Best Estimate Trajectory (SBET) file(s). The SBET was then combined with the laser range measurements in Leica HxMap software to produce the 3-dimensional coordinates resulting in an accurate set of Raw Point Cloud (RPC) mass points. These raw swath (*.las) files are output in WGS84, UTM, Ellipsoid, Meters and transformed to the project Coordinate Reference System (CRS) upon ingest into GeoCue before project wide lidar matching.

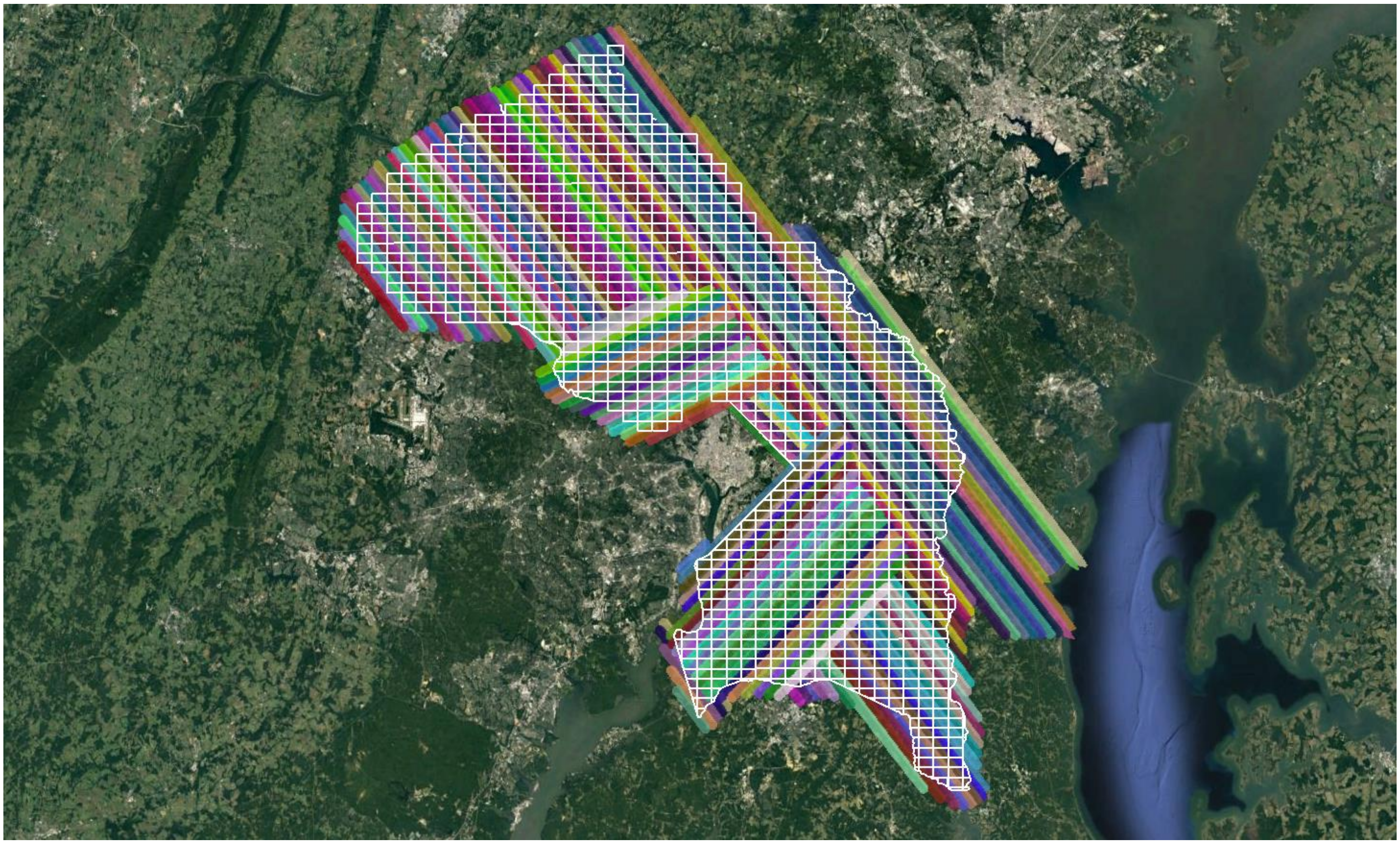
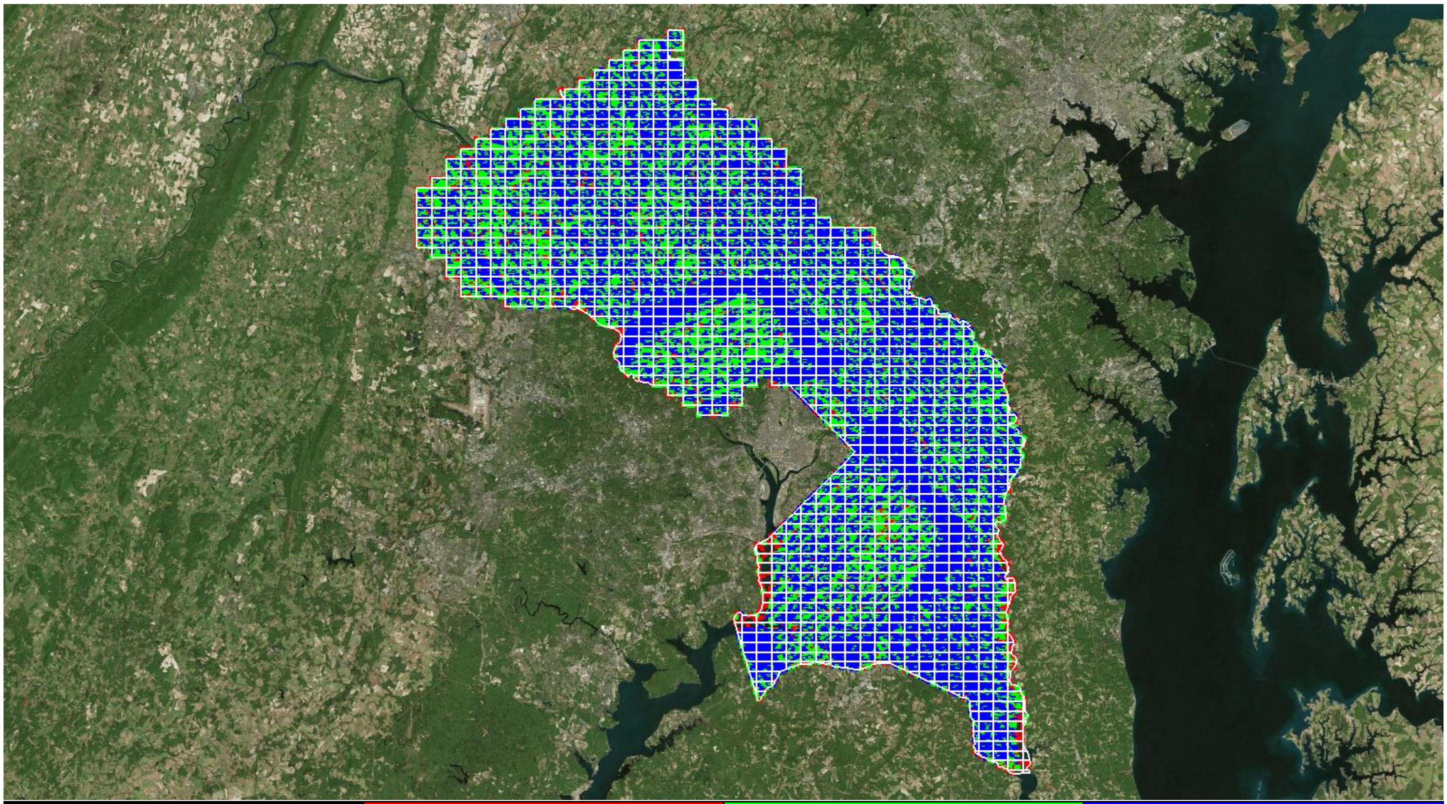


Figure 3: Raw Swath Coverage

The Leica HxMap pre-processing software created raw swath files with all return values. This multi-return information was processed and classified to obtain the required feature for delivery. All lidar data is processed using the ASPRS binary LAS format version 1.4. **Table 4** illustrates the achieved point cloud statistics.

Category	Value
Aggregate Total Points	60,565,334,054
Aggregate Nominal Pulse Spacing (m)	0.29
Aggregate Nominal Pulse Density (pls/m²)	11.6
Aggregate Nominal Pulse Spacing (ft)	0.96
Aggregate Nominal Pulse Density (pls/ft²)	1.1

Table 4: Point Cloud Statistics



No Data	< 8pts/m^2	8 to 16pts/m^2	> 16pts/m^2

Figure 4: Point Cloud Density

3.2 Coordinate Reference System

Horizontal Datum: North American Datum of 1983 (HARN)
Projection: State Plane Maryland (FIPS 1900)
Vertical Datum: North American Vertical Datum of 1988
Geoid Model: Geoid12B
Units: U.S. Survey Feet

3.3 Lidar Matching

Sanborn uses pre-processing software and the latest boresight values to combine the processed SBET with the laser scan files to produce the lidar point cloud. The data is processed by mission and/or block and is output in ASPRS LASv1.4 Point Data Record Format (PDRF) 6 with 16bit linearly scaled intensities to the nearest 0.001 3D position. Each mission is produced in WGS84, UTM, Ellipsoid, Meters and transformed to the project CRS upon import into GeoCue.

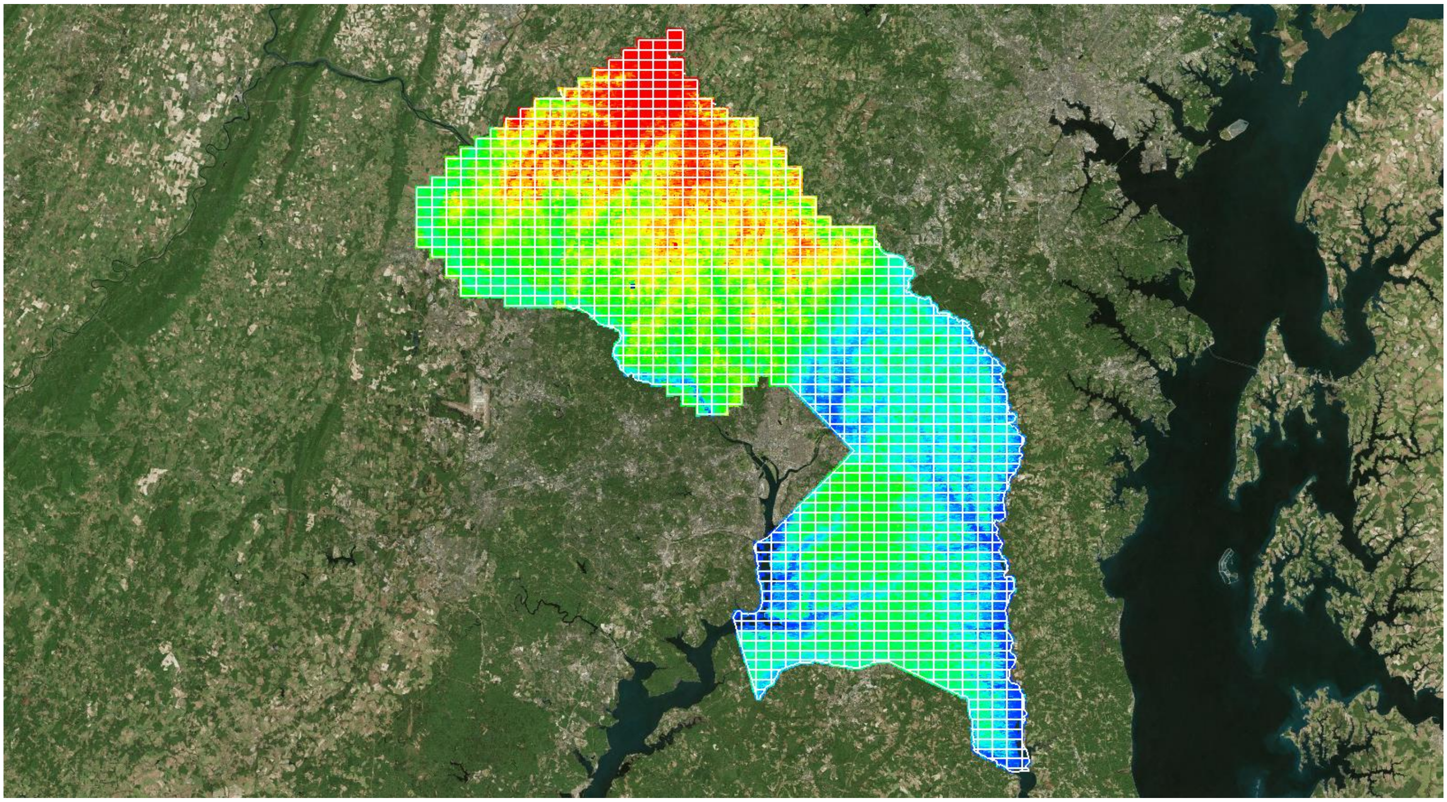


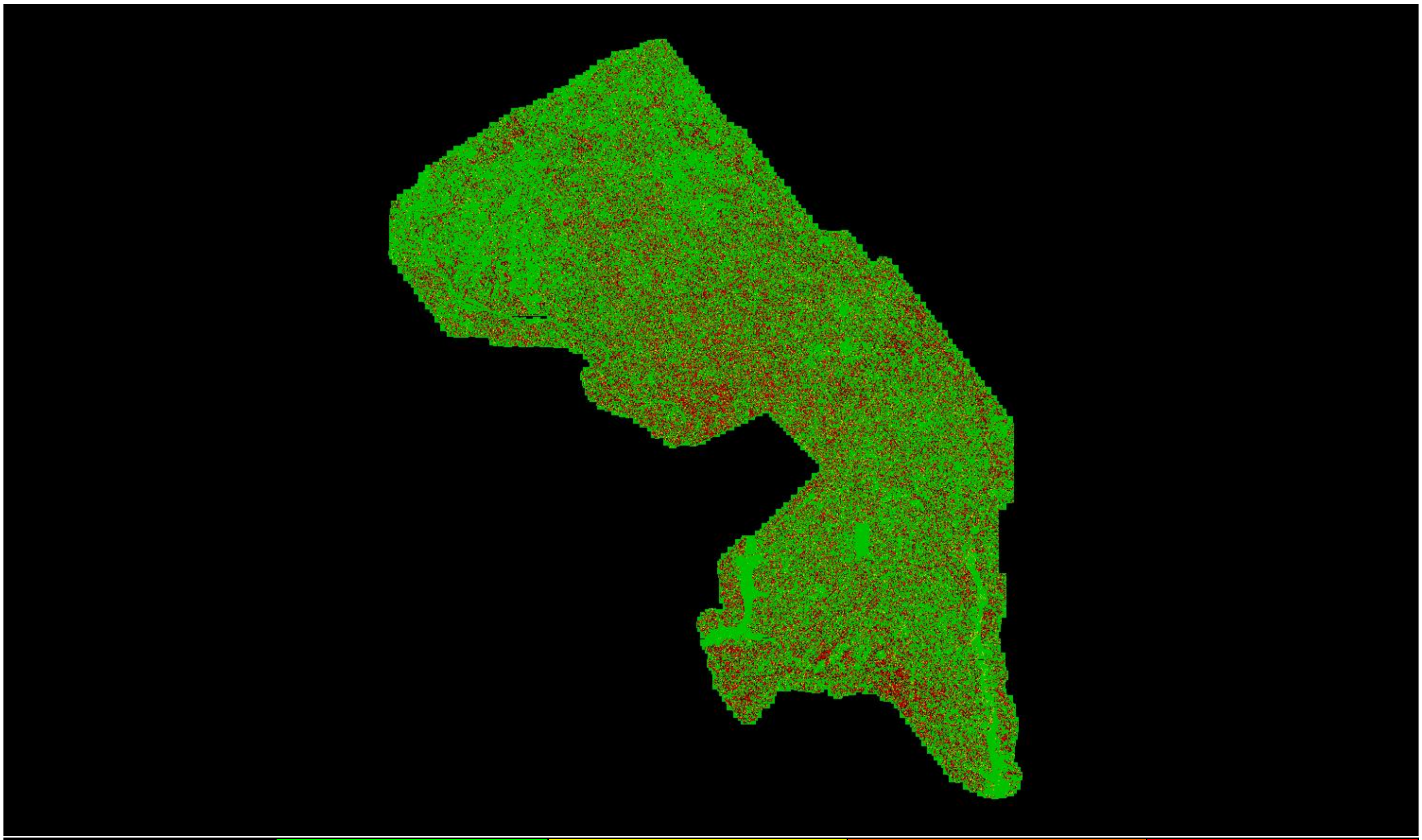
Figure 5: Point Cloud Elevation

Each mission is imported into GeoCue where each individual flight line is assigned a unique Source ID number. The SBET is cut per swath into TerraScan Trajectory files based on Source ID number and timestamp; these are utilized during the lidar matching process. The project area(s) are broken into logical blocks based on AOIs or predetermined delivery blocks and the individual flight lines are populated into lidar matching tile grids. These lidar matching tile grids are prepared for scanner, line, mission, block and eventual project wide lidar matching routines by first running point cloud filters to identify ground and building features to be used during any TerraMatch processes.

Sanborn takes advantage of both visual and statistical validation methodologies to review and ensure both the individual precision and alignment of the lidar dataset. Swath Precision Images modulated by Intensity are representative of the intraswath alignment and provide a holistic qualitative look at the goodness of fit within each swath. Swath Separation Images modulated by Intensity are representative of the interswath alignment and provide a holistic qualitative look at the positional quality of the point cloud. The images are reviewed in their entirety. Furthermore, the set of TerraMatch Tie Lines are used to produce a Tie Line Report to statistically assess the X. Y. and Z offset averages and magnitudes for the whole project including each line individually. This visual and statistical review guarantees the relative accuracy of the lidar dataset. **Table 5** outlines the relative accuracy requirements of the project. **Tables 6 – 9** are the relative accuracies achieved.

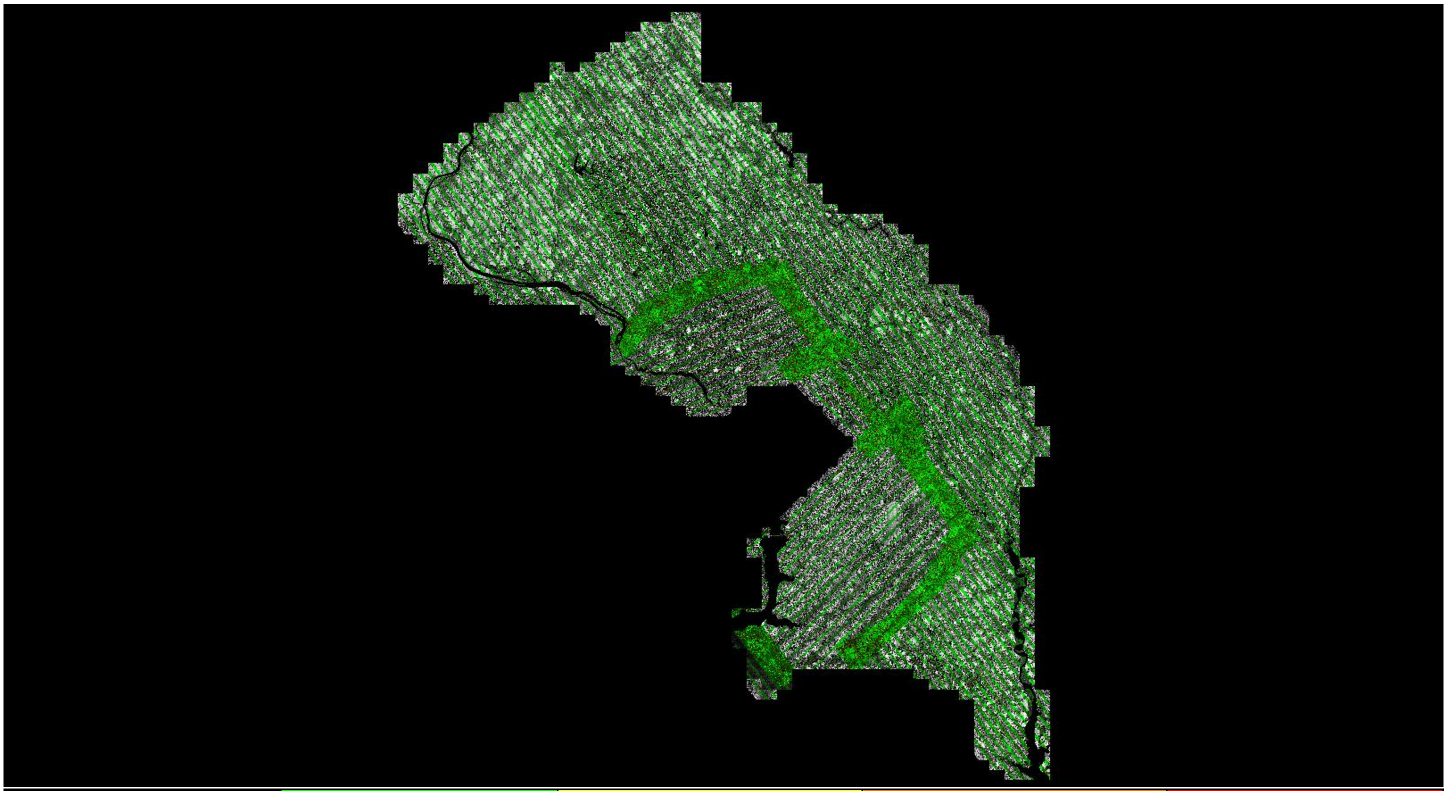
Category	Value (m)	Value (ft)
Smooth Surface Repeatability	≤0.060	≤0.197
Swath overlap difference, RMSDz	≤0.080	≤0.262

Table 5: Relative Accuracy Requirements



No Data	< 0.06m	0.06m to 0.12m	0.12m to 0.18m	> 0.18m
No Data	< 0.197ft	0.197ft to 0.394ft	0.394ft to 0.591ft	> 0.591ft

Figure 6: Swath Precision



No Data	< 0.08m	0.08m to 0.16m	0.16m to 0.24m	> 0.24m
No Data	< 0.262ft	0.262ft to 0.524ft	0.524ft to 0.786ft	> 0.786ft

Figure 7: Swath Separation

Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
1	0.049	0.050	0.021	**43**	0.052	0.051	0.022	**85**	0.047	0.049	0.024
2	0.048	0.045	0.023	**44**	0.058	0.054	0.024	**86**	0.045	0.048	0.028
3	0.032	0.034	0.021	**45**	0.055	0.051	0.026	**87**	0.054	0.048	0.029
4	0.050	0.057	0.021	**46**	0.037	0.031	0.020	**88**	0.048	0.047	0.026
5	0.060	0.067	0.025	**47**	0.039	0.037	0.022	**89**	0.065	0.046	0.025
6	0.041	0.043	0.020	**48**	0.045	0.040	0.023	**90**	0.051	0.049	0.024
7	0.045	0.048	0.018	**49**	0.043	0.042	0.023	**91**	0.052	0.052	0.024
8	0.042	0.044	0.023	**50**	0.042	0.045	0.023	**92**	0.050	0.053	0.024
9	0.047	0.049	0.022	**51**	0.033	0.030	0.022	**93**	0.045	0.048	0.024
10	0.036	0.043	0.022	**52**	0.055	0.040	0.022	**94**	0.048	0.047	0.024
11	0.048	0.053	0.021	**53**	0.044	0.039	0.021	**95**	0.048	0.046	0.021
12	0.041	0.039	0.021	**54**	0.040	0.041	0.021	**96**	0.050	0.051	0.023
13	0.038	0.040	0.021	**55**	0.041	0.042	0.021	**97**	0.048	0.047	0.022
14	0.054	0.054	0.023	**56**	0.052	0.046	0.023	**98**	0.050	0.047	0.022
15	0.051	0.044	0.024	**57**	0.049	0.056	0.024	**99**	0.049	0.046	0.023
16	0.039	0.040	0.021	**58**	0.049	0.049	0.024	**100**	0.046	0.051	0.023
17	0.035	0.034	0.022	**59**	0.039	0.045	0.024	**101**	0.037	0.036	0.022
18	0.053	0.050	0.020	**60**	0.036	0.043	0.021	**102**	0.044	0.039	0.024
19	0.048	0.047	0.022	**61**	0.042	0.040	0.023	**103**	0.044	0.043	0.024
20	0.045	0.048	0.023	**62**	0.050	0.049	0.023	**104**	0.041	0.044	0.023
21	0.039	0.041	0.025	**63**	0.040	0.042	0.025	**105**	0.041	0.044	0.023
22	0.057	0.056	0.021	**64**	0.045	0.049	0.022	**106**	0.050	0.048	0.025
23	0.052	0.052	0.023	**65**	0.061	0.047	0.023	**107**	0.047	0.047	0.024
24	0.053	0.053	0.024	**66**	0.050	0.051	0.023	**108**	0.035	0.037	0.025
25	0.050	0.049	0.023	**67**	0.036	0.043	0.024	**109**	0.042	0.042	0.026
26	0.056	0.059	0.024	**68**	0.038	0.043	0.022	**110**	0.054	0.060	0.024
27	0.034	0.034	0.023	**69**	0.052	0.054	0.022	**111**	0.046	0.056	0.025
28	0.052	0.050	0.022	**70**	0.040	0.037	0.022	**112**	0.045	0.052	0.023
29	0.046	0.047	0.021	**71**	0.039	0.036	0.021	**113**	0.041	0.045	0.024
30	0.045	0.046	0.022	**72**	0.041	0.042	0.019	**114**	0.045	0.043	0.023
31	0.041	0.042	0.020	**73**	0.038	0.042	0.019	**115**	0.044	0.048	0.024
32	0.042	0.044	0.026	**74**	0.050	0.051	0.026	**116**	0.045	0.050	0.022
33	0.043	0.040	0.023	**75**	0.060	0.057	0.028	**117**	0.044	0.050	0.023
34	0.044	0.040	0.025	**76**	0.040	0.047	0.024	**118**	0.047	0.053	0.025
35	0.044	0.041	0.023	**77**	0.039	0.049	0.025	**119**	0.034	0.039	0.022
36	0.046	0.044	0.026	**78**	0.052	0.051	0.025	**120**	0.041	0.043	0.024
37	0.049	0.051	0.025	**79**	0.046	0.045	0.028	**121**	0.041	0.044	0.022
38	0.053	0.054	0.026	**80**	0.037	0.044	0.025	**122**	0.043	0.044	0.023
39	0.057	0.058	0.025	**81**	0.041	0.046	0.024	**123**	0.038	0.037	0.026
40	0.053	0.056	0.025	**82**	0.040	0.039	0.021	**124**	0.032	0.032	0.025
41	0.052	0.057	0.024	**83**	0.022	0.021	0.021	**125**	0.042	0.044	0.024
42	0.047	0.052	0.022	**84**	0.040	0.045	0.021	**126**	0.036	0.036	0.024

Table 6: Average Magnitudes by Line (Feet)

Category	X	Y	Z
Average Magnitude	0.045	0.045	0.023
RMS Values	0.066	0.067	0.030
Maximum Values	0.540	0.553	0.494
Observation Weight	433976.0	433976.0	761925.0

Table 7: Internal Observation Statistics (Feet)

Category	Mismatch
Average 3D Mismatch	0.05512
Average XY Mismatch	0.07195
Average Z Mismatch	0.02291

Table 8: Overall Relative Accuracy (Feet)

Category	Observations
Section Lines	131,084
Roof Lines	204,097

Table 9: Vector Observations

3.4 Lidar Classification

Lidar filtering was accomplished using GeoCue with TerraSolid processing and modeling software. The filtering process reclassifies all the data into classes within the point cloud classification scheme. Once the data is classified, the entire dataset is reviewed and manually edited for anomalies that are outside the required guidelines of the product specification or contract requirements. This can include, but is not limited to, classifying bridges, structures, filling culverts, and manually analyzing the bare-earth surface by classifying features that belong in non-extraneous classification codes. **Table 10** outlines a statistical summary of the point classes leveraged in the lidar dataset.

Code	Class	Points
1	Unclassified	43,427,476,383
2	Ground	17,025,783,210
7	Low Noise	49,568,737
9	Water	15,608,243
17	Bridge Decks	11,475,722
18	High Noise	34,765,808
20	Ignored Ground	655,951
Flag	Overlap	18,880,509,520
Flag	Withheld	84,334,545

Table 10: Lidar Classification Statistics

3.5 Accuracy Assessment

The lidar dataset was evaluated using a total of one hundred and twenty (120) check points (120 NVA). The result provided a vertical accuracy that fell within project specifications. Please see the **Attachment A** for the full Vertical Accuracy Report and the project *Metadata* for an in-depth accuracy assessment. **Table 11** outlines the absolute accuracy requirements of the project. **Table 12** shows high level statistics and mean errors for the area processed by Sanborn.

Category	Value (m)	Value (ft)
RMSEz	≤0.100	≤0.328
@ 95-Percent Confidence Level	≤0.196	≤0.643

Table 11: Absolute Accuracy Requirements

Broad Land Cover Type	# of Points	RMSEz	95% Confidence Level
NVA of Point Cloud	120	0.151	0.297
NVA of Bare Earth	120	0.156	0.306
NVA of DEM	120	0.156	0.305

Table 12: Vertical Accuracy Assessment of Check Points (Feet)

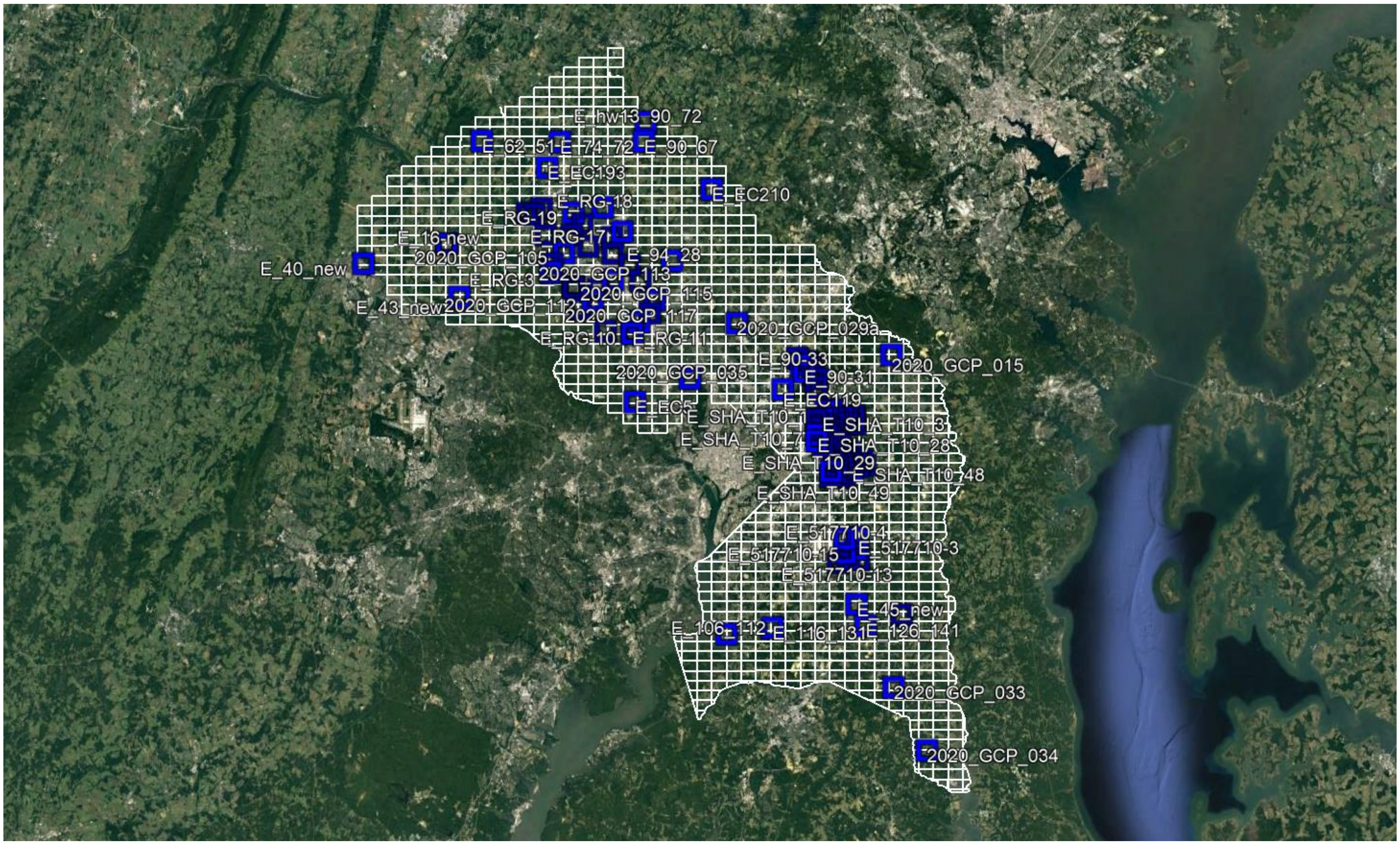


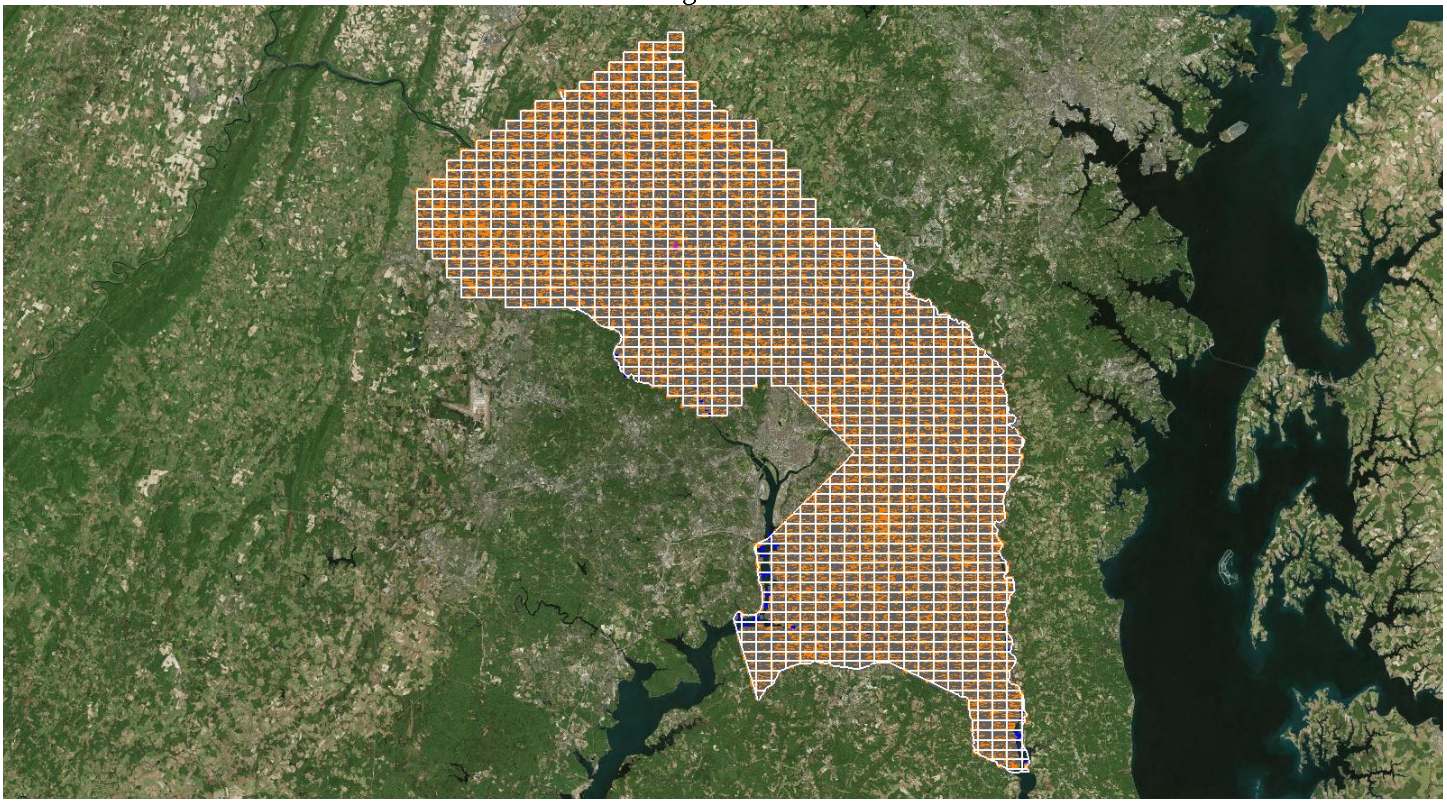
Figure 8: Non-vegetated Check Point Distribution

4.0 PRODUCT GENERATION

The following products were generated using the final coordinate system as defined in the contract:

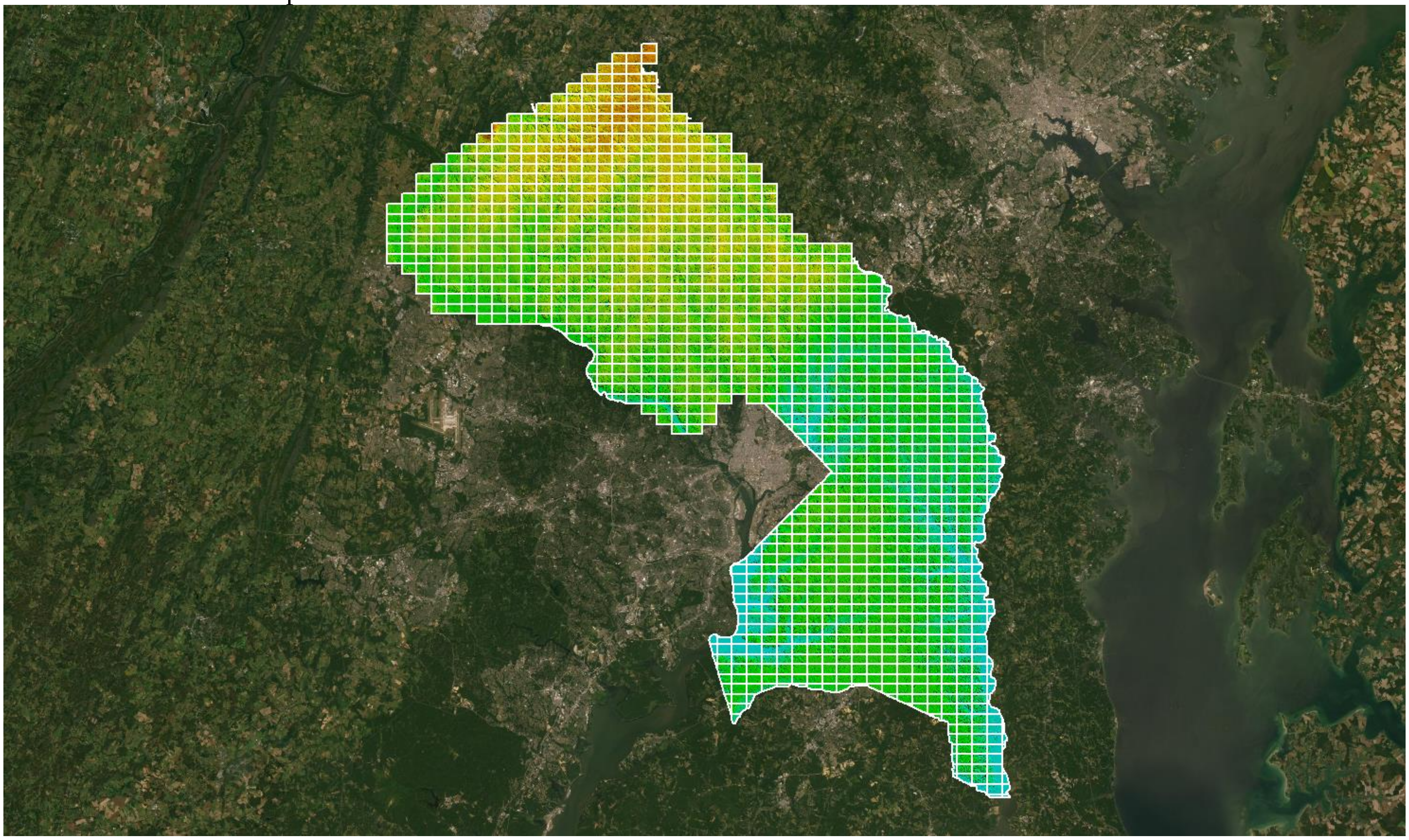
Classified Point Cloud

The Classified Point Cloud, containing all returns, is delivered in LASv1.4 (*.las) format and meets project specifications. The Classified Point Cloud contains file names referencing the tile index.



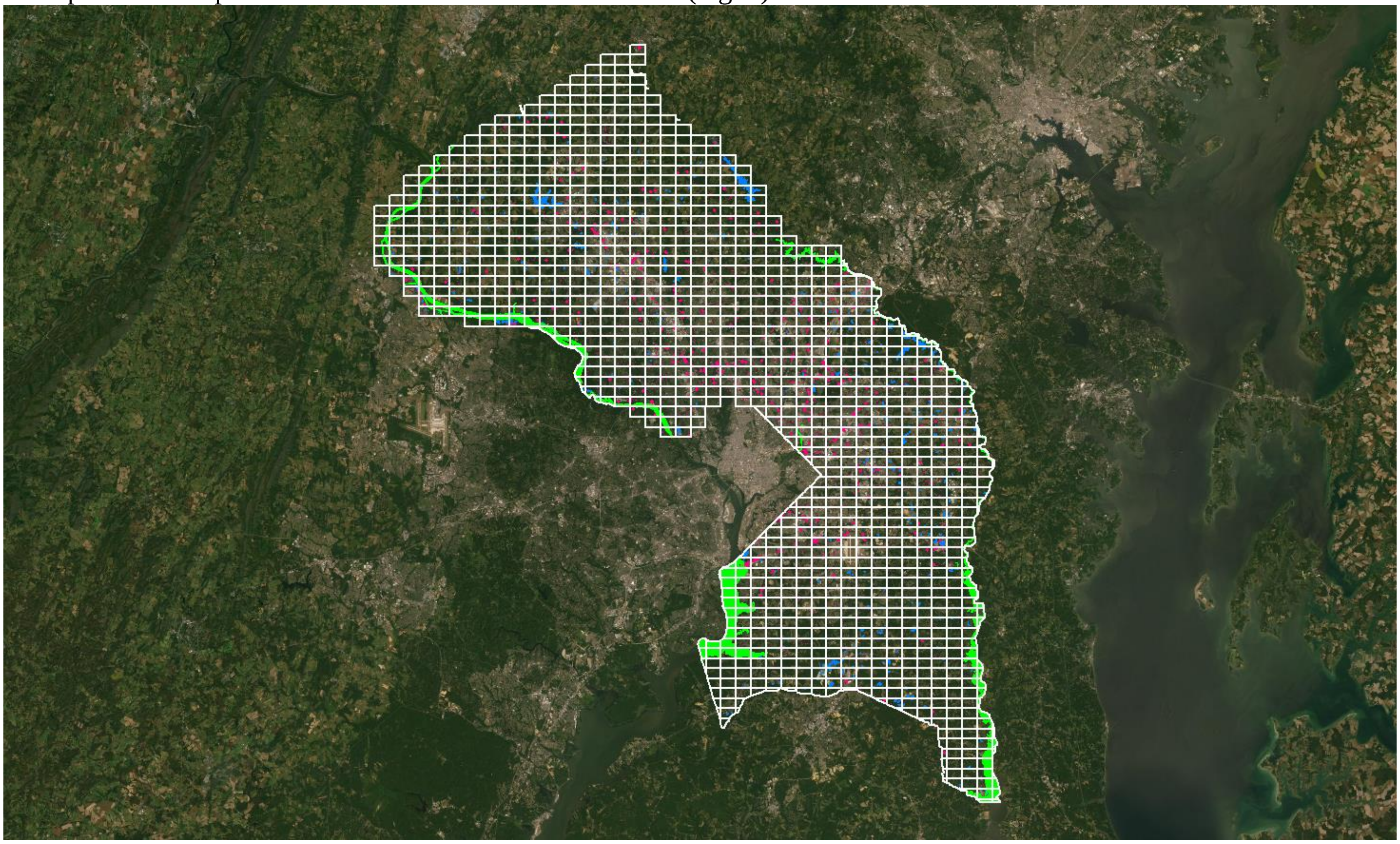
Bare-earth Digital Elevation Model (DEM)

32-bit GeoTIFF (*.tif) elevation rasters were created from the bare-earth points in the processed lidar dataset and hydro-flattened breaklines. Bare-earth rasters were produced the bilinear interpolation methodology and GDAL v2.4.0 was used to define the CRS. Each pixel contains an elevation.



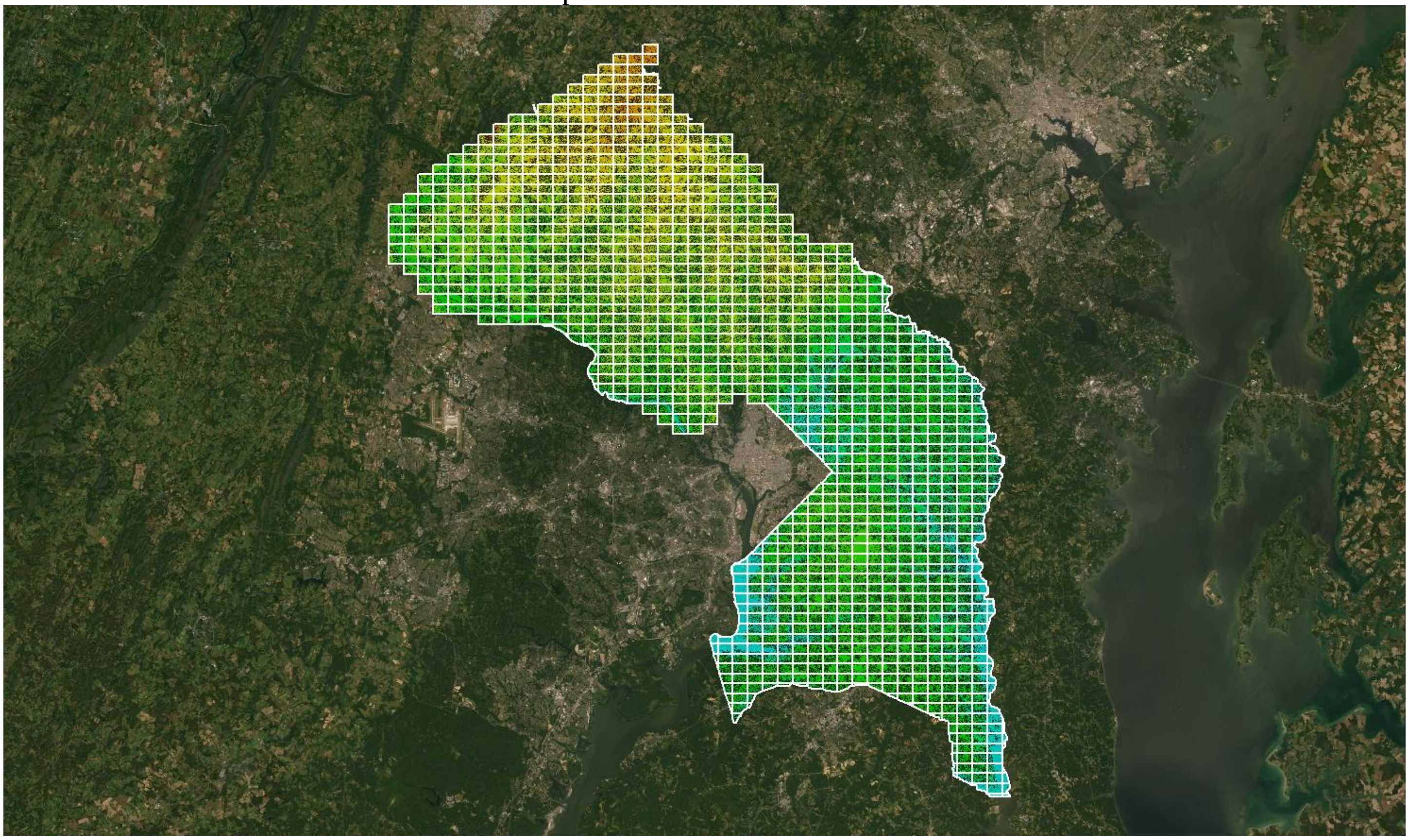
Breaklines

Hydro-flattened breaklines were generated from digitized water features conflated to the elevations derived from the bare-earth points in the processed lidar dataset. Delivered in Esri (*.gdb) format.



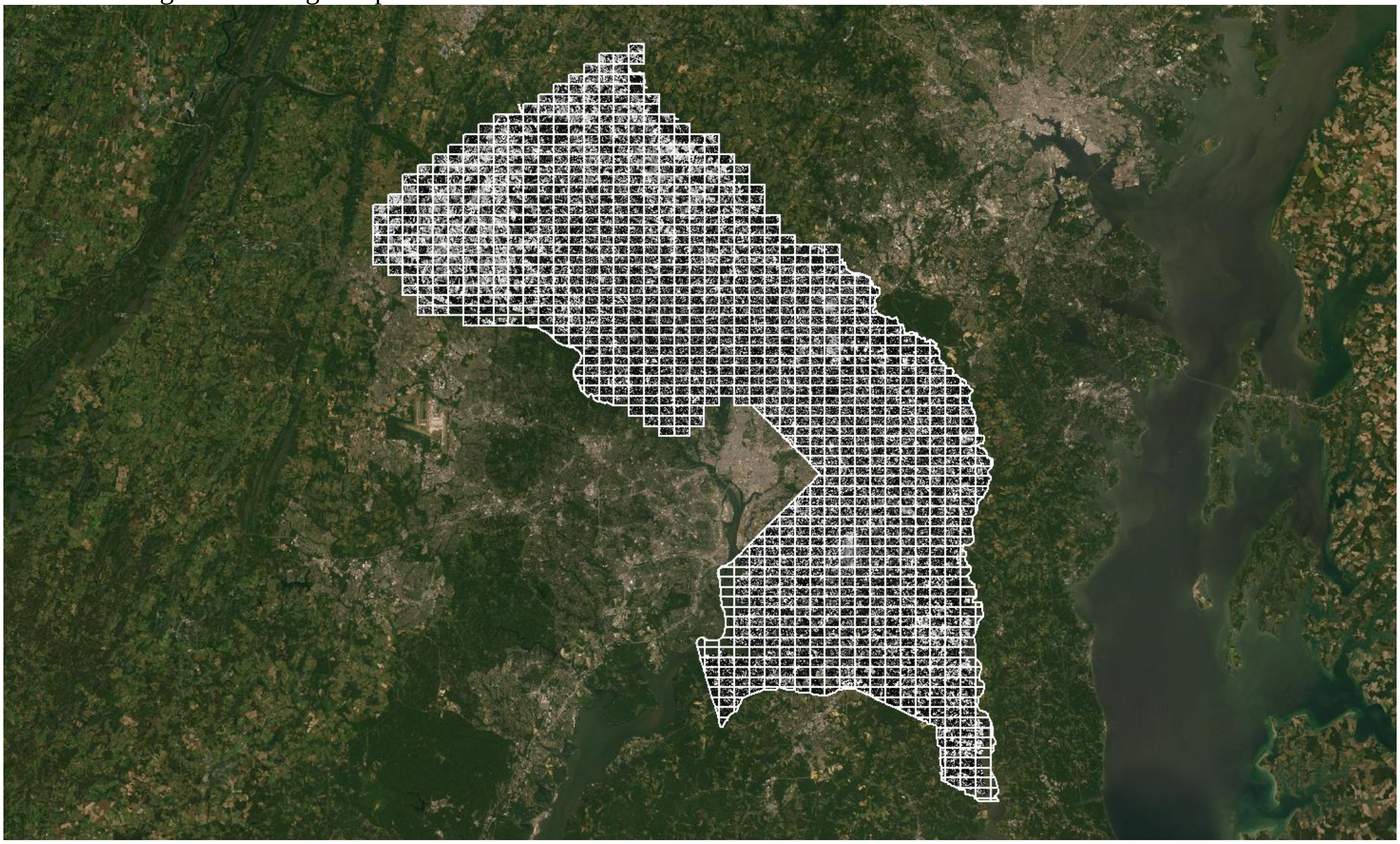
First-return Digital Surface Model (DSM)

32-bit GeoTIFF (*.tif) elevation rasters were created from the first-return points in the processed lidar dataset. All overlap classes were ignored during this process. First-return rasters were produced the bilinear interpolation methodology and GDAL v2.4.0 was used to define the CRS. Each pixel contains an elevation.



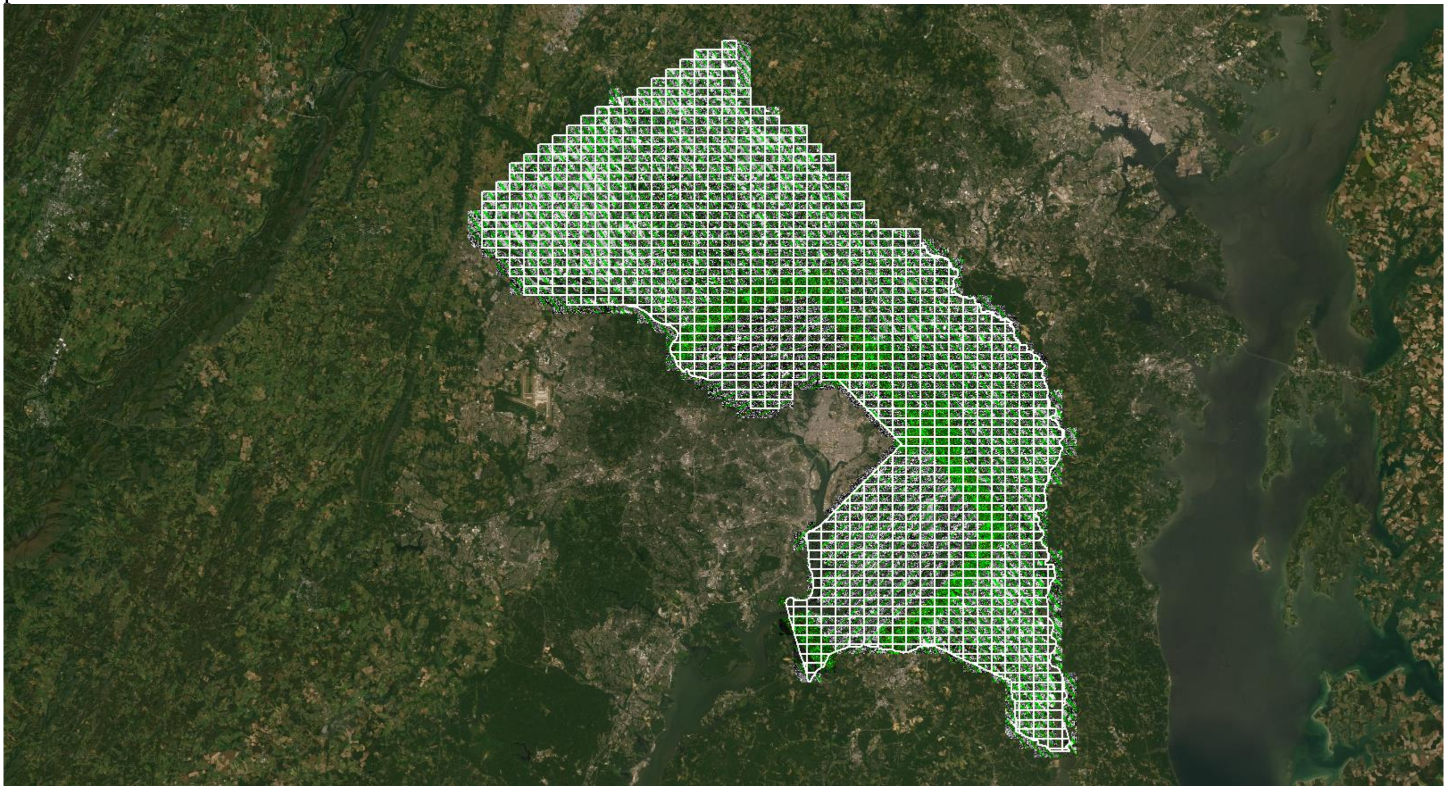
First-return Intensity Images

8-bit GeoTIFF (*.tif) intensity rasters were created from the first-return points in the processed lidar dataset. All overlap classes were ignored during this process. GDAL v2.4.0 was used to define the CRS.



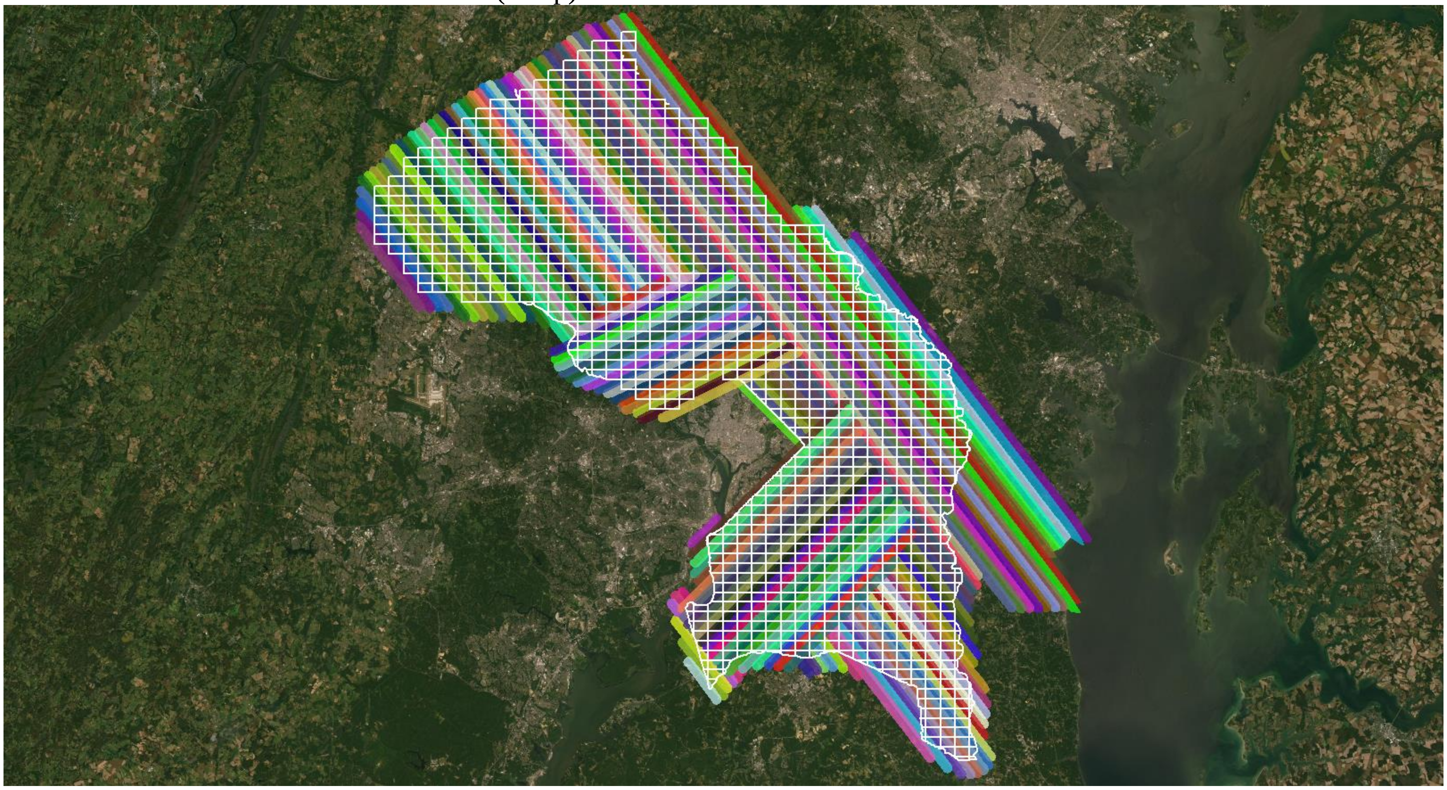
Last-return Swath Separation Images

24-bit GeoTIFF (*.tif) swath separation images modulated by intensity were created from the last-return points in the processed lidar dataset. GDAL v2.4.0 was used to define the CRS.



Swath Polygons

Polygons features representing either the convex or concave hull of swaths, where each record is an individual swath or channel within a swath. Delivered in Esri (*.shp) format.



Other Deliverables

Metadata
Vertical Accuracy Report

A final quality assurance process was undertaken to validate all deliverables for the project. Prior to release of data for delivery, Sanborn's Quality Control/Quality Assurance department reviews the data and then releases it for delivery.