AIRBORNE TOPOGRAPHIC LIDAR REPORT

SANDY DELAWARE & MARYLAND

Contract No. G10PC00025
Requisition Nos. 0040108687 and 0040109021
Task Order No. G13PD00884

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Completed by Quantum Spatial

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Sandy Delaware & Maryland LiDAR acquisition task order, issued by the US Geological Survey, under their National Geospatial Technical Operations Center (NGTOC), under their Geospatial Products and Services Contract (GPSC) on August 23, 2013. The combined task orders yielded one study area consisting of the state of Delaware and Dorchester and Caroline Counties in Maryland, two small study areas in Wicomico County, Maryland, and Poplar Island in Talbot County, Maryland. The intent of this document is to only provide specific validation information for the LiDAR data acquisition/collection work completed for the USGS project.

1.2. Scope

The scope of the Sandy Delaware & Maryland LiDAR task order included the acquisition of aerial topographic LiDAR using state of the art technology, along with necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems, for the Delaware and Maryland region. The aerial data collection was designed with the following specifications listed in Table 1 below.

Table 1. Originally Planned LiDAR Specifications

Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
2.70 pts / m^2	6,398'	40.0 degrees	27.68%	9.25 cm or better

1.3. Location / Coverage

The Sandy Delaware & Maryland LiDAR project boundary consists of an area in Delaware and portions of Maryland. The project area totals approximately 3,069 square miles as shown in Figure 1 on the following page.

Figure 1. Sandy DE & MD LiDAR Project Boundary

1.4. Duration

The first mission was flown on December 17, 2013 and it took eighteen total lifts to complete coverage of the area. See section 2.4 for more details.

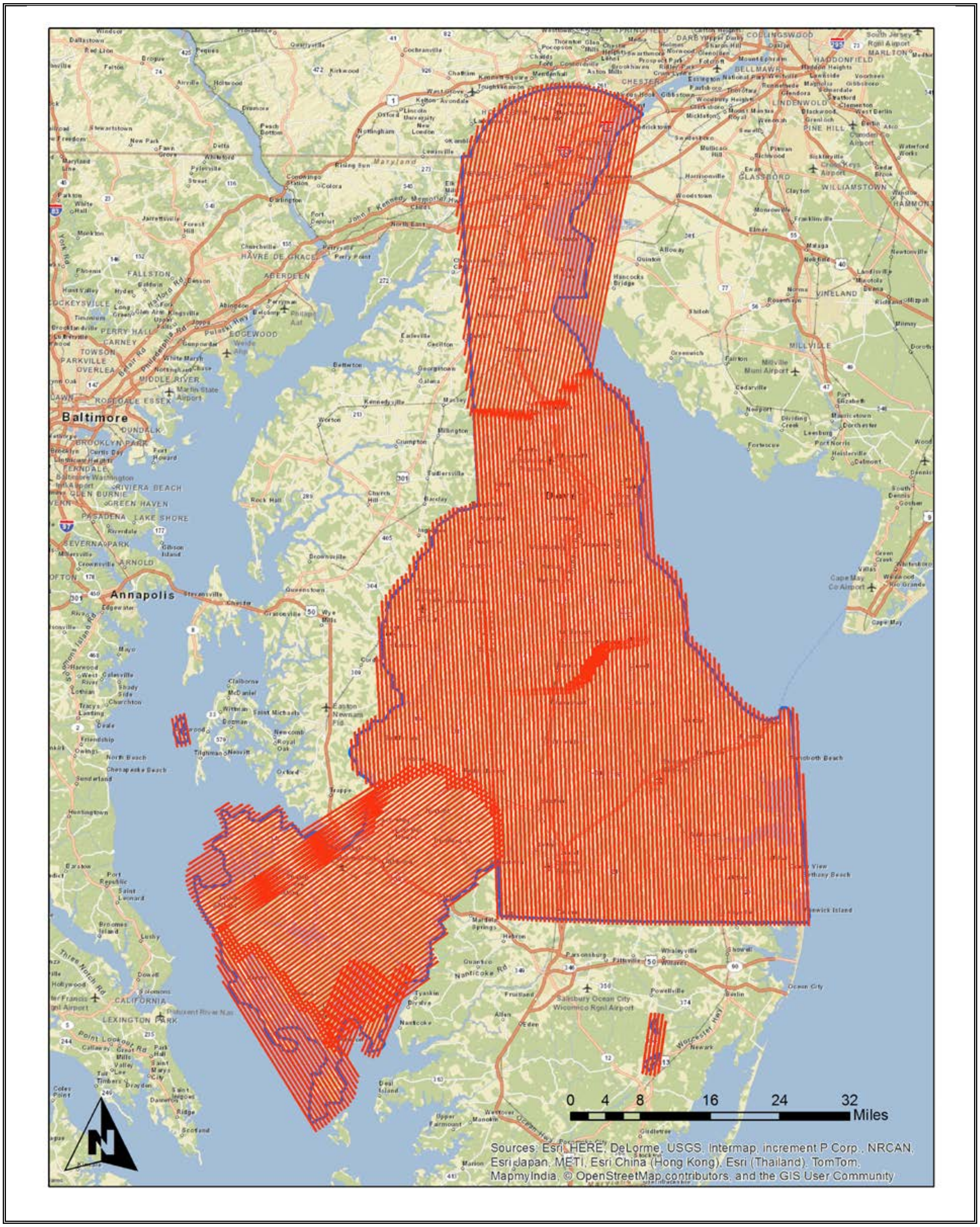
1.5. Issues

No issues were encountered during the project.

2. Planning / Equipment

The entire target area was comprised of 309 planned flight lines and approximately 12762 flight line kilometers. Please refer to Figure 2 on the following pages.

Figure 2. Originally Planned Flight Lines



Detailed project flight planning calculations were performed for the Sandy Delaware & Maryland LiDAR project using Leica Mission Pro planning software. Flight planning was based on the unique project requirements and characteristics of the project site. The basis of planning included: required accuracies, type of development, amount / type of vegetation within project area, required data posting, and potential altitude restrictions for flights in project vicinity. Please note that certain values in the table below are listed as "Variable" due to the various flight plans used, as described in Section 1.5 of this document. A brief summary of the aerial acquisition parameters for the project are shown in the LiDAR System Specification Table 2 below:

Table 2. LiDAR System Specifications

Terrain and Aircraft	Flying Height AGL: 6398 ft
	Recommended Ground Speed (GS): 150 kts
Scanner	Field of View (FOV): 40º
	Scan Rate Setting used (SR): 43.1 Hz
Laser	Laser Pulse Rate used: 287,800 Hz
	Multi Pulse in Air Mode: Enabled
Coverage	Full Swath Width: 1383.09 meters
	Line Spacing: 1000.20 meters
Point Spacing and Density	Maximum Point Spacing Across Track: 0.90 m
	Maximum Point Spacing Along Track: 0.90 m
	Average Point Density: 2.70 pts / m^2

2.1. Equipment: Aircraft

All flights for the Sandy Delaware & Maryland project were accomplished through the use of two customized Piper Navajos (Tail Numbers: N73TM and N812TB).This aircraft provided an ideal, stable aerial base for LiDAR acquisition. This aerial platform has relatively fast cruise speeds which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds which proved ideal for collection of high-density, consistent data posting using state-of-the-art Leica LiDAR systems.

2.2. LIDAR SENSOR

Quantum Spatial utilized a Leica LiDAR sensor (see Figure 3), serial numbers 7220 and 7161, during the project. The system is capable of collecting data at a maximum frequency of 500 kHz, which affords elevation data collection of up to 500,000 points per second. The system utilizes a Multi-Pulse in the Air option (MPIA). The sensor is also equipped with the ability to measure up to 4 returns per outgoing pulse from the laser and these come in the form of 1st, 2nd, 3rd and last returns. The intensity of the returns is also captured during aerial acquisition.

Figure 3. Leica ALS70 LiDAR System

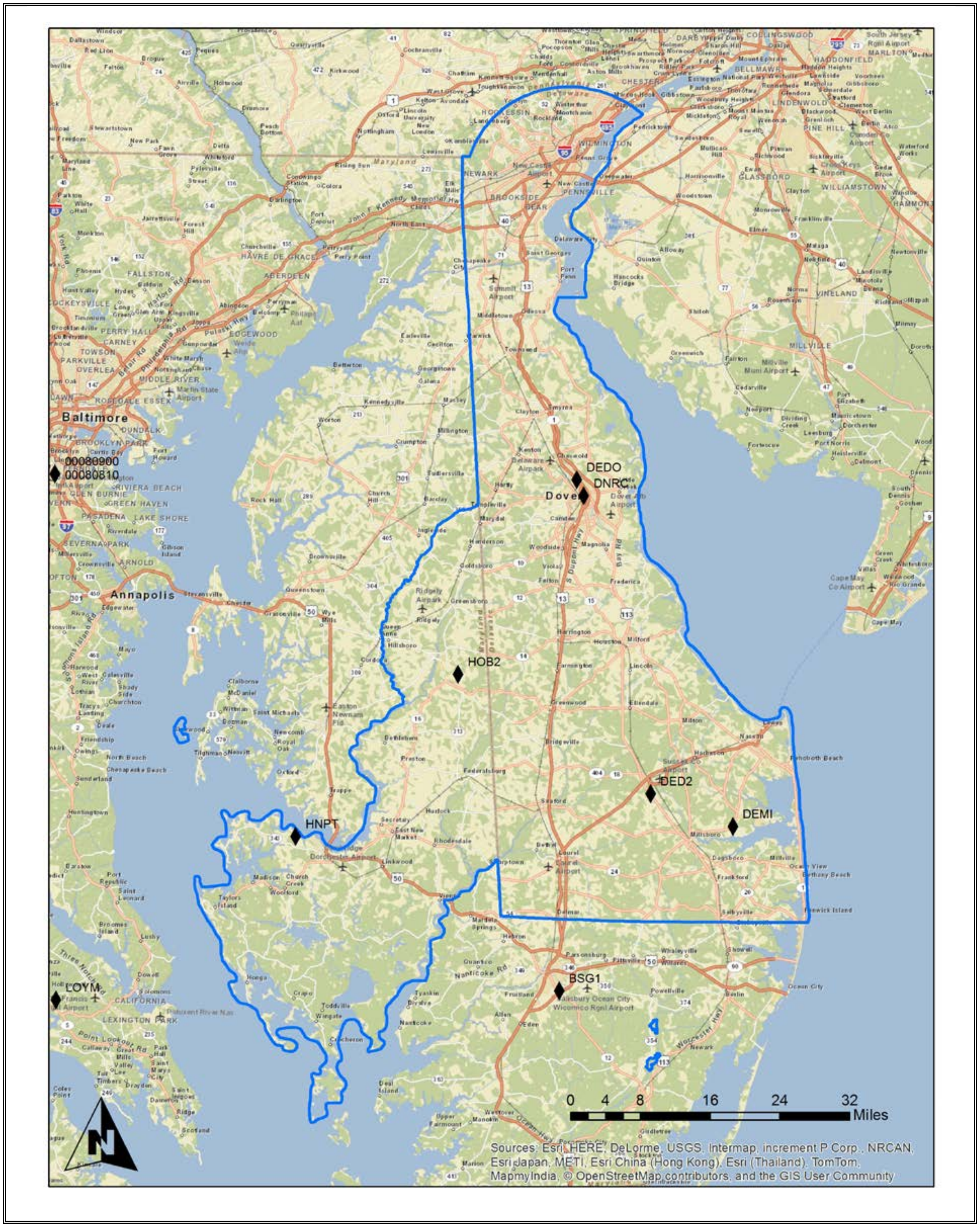
2.3. Base Station Information

GPS base stations were utilized during all phases of flight (see Table 3 below). The base station locations were verified using NGS OPUS service and subsequent surveys. Data sheets, graphical depiction of base station locations or log sheets used during station occupation are available in Appendix A.

Table 3. Base Station Locations

Base Station	Latitude	Longitude	Ellipsoid Height (m)
BSG1	38° 20' 8.97781"	75° 34' 10.2804646"	-17.638
DNRC	39° 9' 36.28523"	75° 31' 24.948103"	-13.915
HOB2	38° 51' 41.56636"	75° 47' 21.6050303"	-17.076
LOYM	38° 18' 38.11892"	76° 37' 57.9738707"	6.11
DED2	38° 39' 52.2824"	75° 22' 38.7621111"	-13.581
DEDO	39° 11' 12.28034"	75° 32' 19.7112828"	-3.18
DEMI	38° 36' 36.97516"	75° 12' 10.314808"	-26.102
HNPT	38° 35' 19.71004"	76° 7' 49.331908"	-26.674
00080810	39° 11' 9.09667"	76° 39' 17.882707"	6.878
00080900	39° 11' 9.0964"	76° 39' 17.8269191"	6.904

Figure 4. Base Station Locations



2.4. Time Period

Project specific flights were conducted over several months. Eighteen sorties, or aircraft lifts were completed. Accomplished sorties are listed below:

- 20131217_7220
- 20131228A_7161
- 20131228B_7161
- 20140101A_7161
- 20140101B_7161
- 20140211_7161
- 20140228A_7161
- 20140228B_7161
- 20140311_7161
- 20140313_7161
- 20140322_7161
- 20140323_7161
- 20140327A_7161
- 20140327B_7161
- 20140331_7161
- 20140406A_7161
- 20140406B_7161
- 20140406C_7161

3. Processing Summary

Applanix + POSPac Mobile Mapping Suite software was used for post-processing of airborne GPS and inertial data (IMU), which is critical to the positioning and orientation of the LiDAR sensor during all flights. POSPac combines aircraft raw trajectory data with stationary GPS base station data yielding a "Smoothed Best Estimate Trajectory (SBET) necessary for additional post processing software to develop the resulting geo-referenced point cloud from the LiDAR missions.

During the sensor trajectory processing (combining GPS & IMU datasets) certain statistical graphs and tables are generated within the Applanix POSPac processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis include: Max horizontal / vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory. All relevant graphs produced in the POSPac processing environment for each sortie during the Quantum Spatial project mobilization are available in Appendix A.

The generated point cloud is the mathematical three dimensional composite of all returns from all laser pulses as determined from the aerial mission. Laser point data are imported into TerraScan and a manual calibration is performed to assess the system offsets for pitch, roll, heading and scale. At this point this data is ready for analysis, classification, and filtering to generate a bare earth surface model in which the above-ground features are removed from the data set. Point clouds were created using the Leica ALS Post Processor software. GeoCue distributive processing software was used in the creation of some files needed in downstream processing, as well as in the tiling of the dataset into more manageable file sizes. TerraScan and TerraModeler software packages were then used for the automated data classification, manual cleanup, and bare earth generation. Project specific macros were developed to classify the ground and remove side overlap between parallel flight lines.

All data will manually be reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper will be used as a final check of the bare earth dataset. GeoCue was used to create the deliverable industry-standard LAS files for the Fully-Classified Point Cloud Data. In-house software will then used to perform final statistical analysis of the classes in the LAS files.

Metadata was generated for the project on a deliverable level.

3.1. Flight Logs

Flight logs were completed by LIDAR sensor technicians for each mission during acquisition. These logs depict a variety of information, including:

- Job / Project #
- Flight Date / Lift Number
- FOV (Field of View)
- Scan Rate (HZ)
- Pulse Rate Frequency (Hz)
- Ground Speed
- Altitude
- Base Station
- PDOP avoidance times
- Flight Line #
- Flight Line Start and Stop Times
- Flight Line Altitude (AMSL)
- Heading
- Speed
- Returns
- Crab

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc). Project specific flight logs for each sortie are available in Appendix A.

3.2. LAS Classification Scheme

The classification classes are determined by the USGS Version 1.0 specifications and are an industry standard for the classification of LIDAR point clouds. All data starts the process as Class 1 (Unclassified), and then through automated classification routines, the classifications are determined using TerraScan macro processing.

The classes used in the dataset are as follows and have the following descriptions:

- Class 1 – Processed, but Unclassified – These points would be the catch all for points that do not fit any of the other deliverable classes. This would cover features such as vegetation, cars, etc.
- Class 2 – Bare earth ground – This is the bare earth surface
- Class 7 – Noise – Low or high points, manually identified above or below the surface that could be noise points in point cloud.
- Class 9 – In-land Water – Points found inside of inland lake/ponds
- Class 10 – Ignored Ground – Points found to be close to breakline features. Points are moved to this class from the Class 2 dataset. This class is ignored during the DEM creation process in order to provide smooth transition between the ground surface and hydro flattened surface.
- Class 17 – Overlap Default (Unclassified) – Points found in the overlap between flight lines. These points are created through automated processing methods and not cleaned up during processing.
- Class 18 – Overlap Bare-earth ground – Points found in the overlap between flight lines. These points are created through automated processing, matching the specifications determined during the automated process, that are close to the Class 2 dataset (when analyzed using height from ground analysis)

- Class 25 – Overlap Water – Points found in the overlap between flight lines that are located inside hydro features. These points are created through automated processing methods and not cleaned up during processing.

3.3. Classified LAS Processing

The bare earth surface is then manually reviewed to ensure correct classification on the Class 2 (Ground) points. After the bare-earth surface is finalized; it is then used to generate all hydro-breaklines through heads-up digitization.

All ground (ASPRS Class 2) LiDAR data inside of the Lake Pond and Double Line Drain hydro flattening breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 3 feet was also used around each hydro flattened feature to classify these ground (ASPRS Class 2) points to Ignored ground (ASPRS Class 10). All Lake Pond Island and Double Line Drain Island features were checked to ensure that the ground (ASPRS Class 2) points were reclassified to the correct classification after the automated classification was completed.

All overlap data was processed through automated functionality provided by TerraScan to classify the overlapping flight line data to approved classes by USGS. The overlap data was classified to Class 17 (Overlap Default) and Class 18 (Overlap Ground). These classes were created through automated processes only and were not verified for classification accuracy. Due to software limitations within TerraScan, these classes were used to trip the withheld bit within various software packages. These processes were reviewed and accepted by USGS through numerous conference calls and pilot study areas.

All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper is used as a final check of the bare earth dataset. GeoCue was then used to create the deliverable industry-standard LAS files for all point cloud data. Quantum Spatial proprietary software was used to perform final statistical analysis of the classes in the LAS files, on a per tile level to verify final classification metrics and full LAS header information.

3.4. Hydro Flattening Breakline Process

Class 2 LiDAR was used to create a bare earth surface model. The surface model was then used to heads-up digitize 2D breaklines of Inland Streams and Rivers with a 100 foot nominal width and Inland Ponds and Lakes of 2 acres or greater surface area.

Elevation values were assigned to all Inland Ponds and Lakes, Inland Pond and Lake Islands, Inland Streams and Rivers and Inland Stream and River Islands using TerraModeler functionality.

Elevation values were assigned to all Inland streams and rivers using Quantum Spatial proprietary software.

All ground (ASPRS Class 2) LiDAR data inside of the collected inland breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 3 feet was also used around each hydro flattened feature. These points were moved from ground (ASPRS Class 2) to Ignored Ground (ASPRS Class 10).

The breakline files were then translated to ESRI Shapefile format using ESRI conversion tools.

3.5. HYDRO FLATTENING RASTER DEM PROCESS

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a 1 meter Raster DEM. Using automated scripting routines within ArcMap, an ERDAS Imagine IMG file was created for each tile. Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

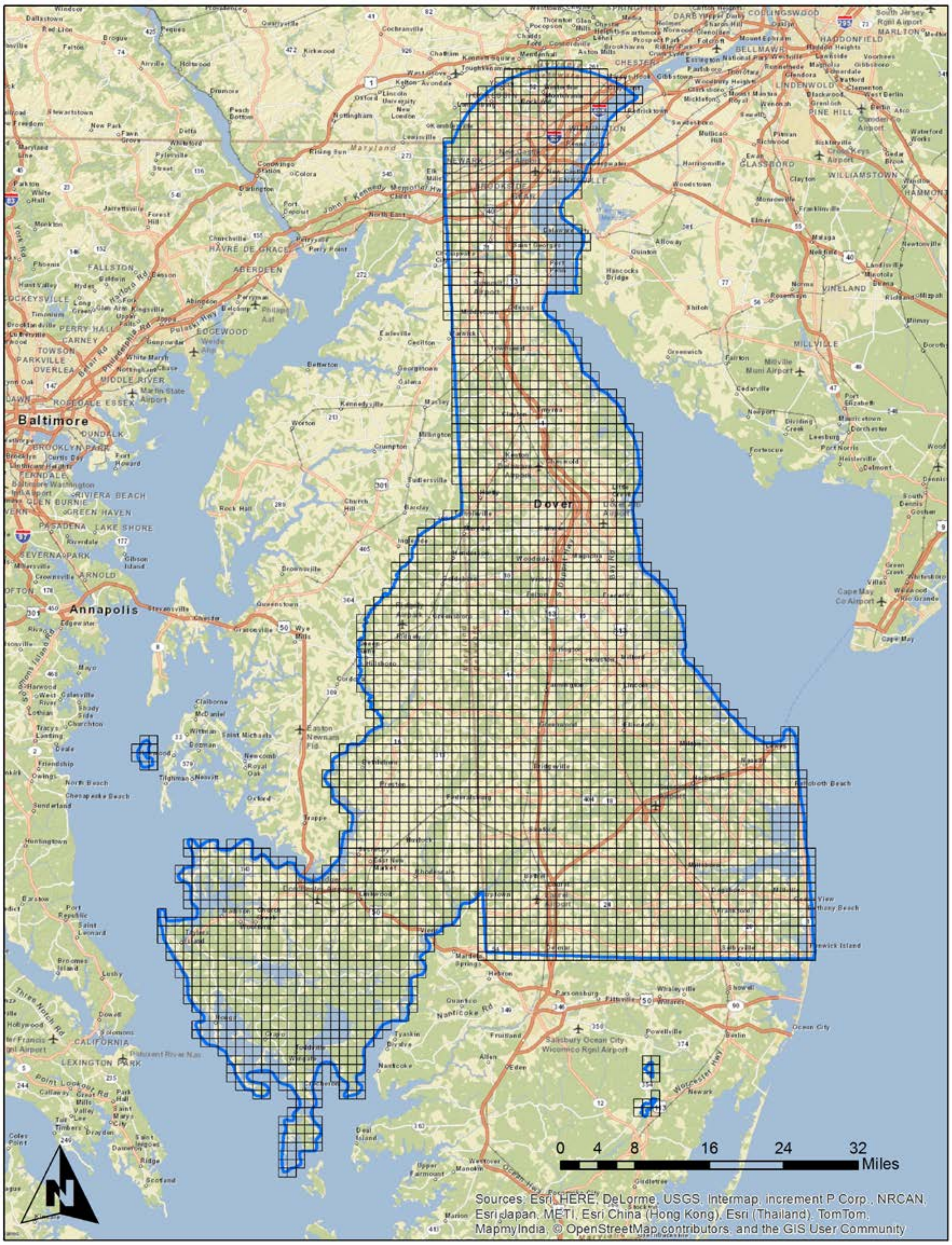
3.6. INTENSITY IMAGE PROCESS

GeoCue software was used to create the deliverable Intensity Images. All overlap classes (ASPRS class 17/18/25) were ignored during this process. This helps to ensure a more aesthetically pleasing image. GeoCue software was then used to verify full project coverage as well. TIF/TWF files were then provided as the deliverable for this dataset requirement.

4. DELIVERABLES

- Calibrated, unclassified raw point cloud swath LAS in version 1.2 format
- Classified point cloud tiled LAS in version 1.2 format
- Hydro flattened raster DEM in ERDAS .IMG format
- Hydro flattened breaklines in shape file format
- Intensity Image in TIF/TWF format
- Ground control points in shape file format
- As-flown flightlines in shape file format
- Tile index in shape file format
- Project and deliverable level metadata in XML format
- Accuracy Assessment in XLS format

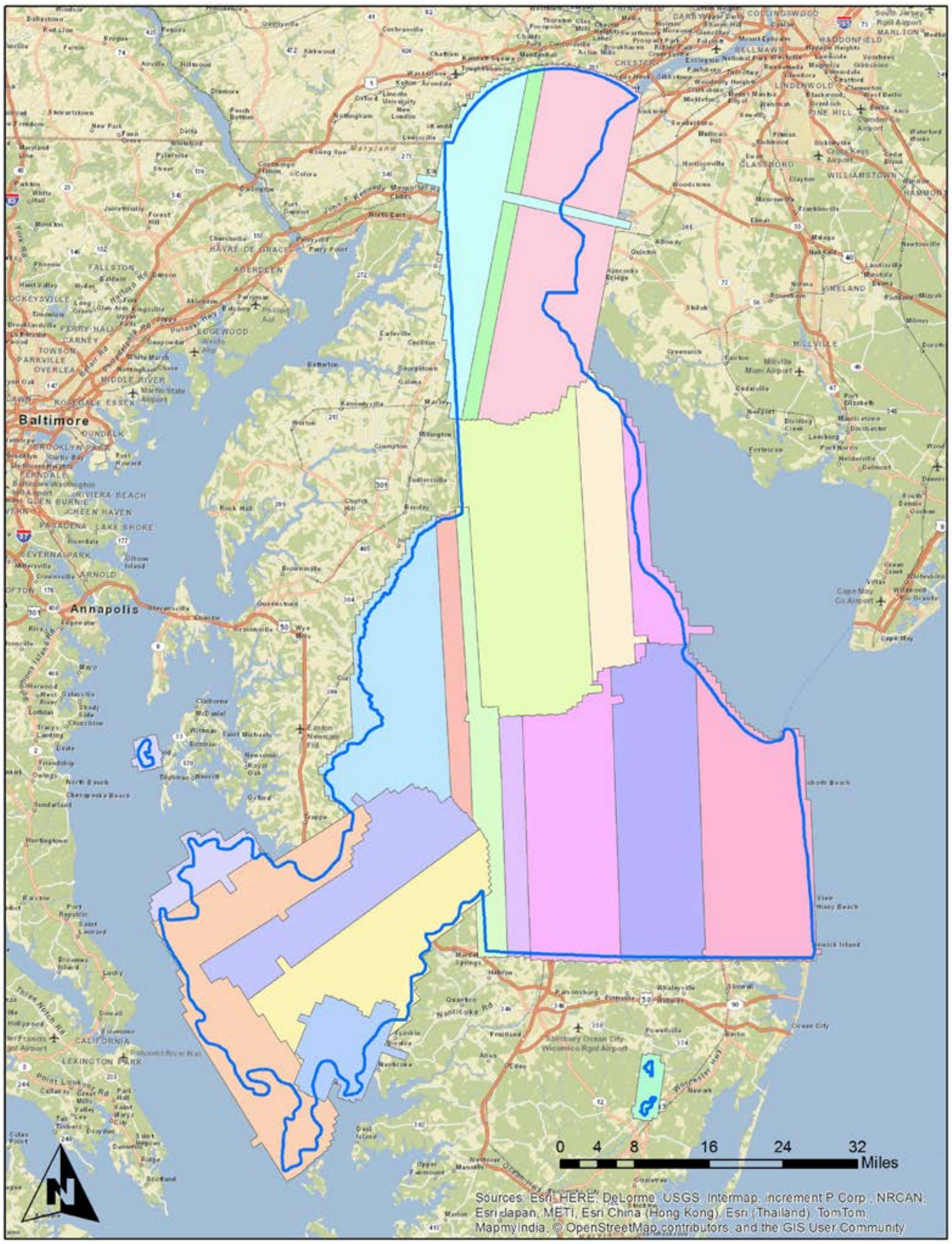
Figure 5. Sandy DE & MD LiDAR Tile Layout



5. Project Coverage Verification

The Sandy Delaware & Maryland LiDAR project area coverage verification was performed by comparing coverage of processed .LAS files captured during project collection to generate project shape files depicting boundaries of specified project areas. Please refer to Figure 6.

Figure 6. Flightline Swath LAS File Coverage



6. Ground Control and Check Point Collection

Compass Data completed a field survey of 78 ground control (calibration) points along with 99 blind QA points in four different land cover classifications (total of 177 points) as an independent test of the accuracy of this project. The land cover classifications were selected from the dominant classifications for this project area. These included:

- Bare earth and low grass
- Forested, fully covered by trees
- High grass, weeds, and crops
- Urban areas

A combination of precise GPS surveying methods, including static and RTK observations were used to establish the 3D position of ground calibration points and QA points for the point classes above. GPS was not an appropriate methodology for surveying in the forested areas during the leaf-on conditions for the actual field survey (which was accomplished after the LiDAR acquisition). Therefore the 3D positions for the forested points were acquired using a GPS-derived offset point located out in the open near the forested area, and using precise offset surveying techniques to derive the 3D position of the forested point from the open control point. The explicit goal for these surveys was to develop 3D positions that were three times greater than the accuracy requirement for the elevation surface. In this case of the blind QA points the goal was a positional accuracy of 5 cm in terms of the RMSE.

Figure 7 shows the location of each bare earth calibration point for the project area. Table 4 depicts the Control Report for the LiDAR bare earth calibration points shown in Figure 7, as computed in TerraScan as a quality assurance check. Note that these results of the surface calibration are not an independent assessment of the accuracy of these project deliverables, but the statistical results do provide additional feedback as to the overall quality of the elevation surface.

The project was delivered using the following horizontal projection(s): NAD83, Universal Transverse Mercator, Zone 18, Meters, as well as NAD83 2011 Delaware State Plane FIPS 0700, Meters and NAD83 2011 Maryland State Plane FIPS 1900, Survey Feet. In this document, horizontal coordinates for ground control and QA points for all LiDAR classes are reported in UTM Zone 18, meters.

The required accuracy testing was performed on the LiDAR dataset (both the LiDAR point cloud and derived DEM's) according to the USGS LiDAR Base Specification Version 1.0 (2012). The locations for all tested blind QA points are shown in Figure 8. The summary below provides the results of this testing:

Point Cloud Testing

- Raw Fundamental Vertical Accuracy (Raw FVA): The tested Raw FVA for the dataset was found to be 0.055 meters in terms of the RMSEz. The resulting FVA stated as the 95% confidence level (RMSEz x 1.96) is 0.107 meters. This dataset ***meets*** the required FVA of 0.1813 meters (18.13 centimeters) at the 95% confidence level (according to the National Standard for Spatial Database Accuracy (NSSDA)), based on TINs derived from the final calibrated and controlled LiDAR swath data. This is summarized in Table 5.

Digital Elevation Model (DEM) Testing

- Fundamental Vertical Accuracy (FVA): The tested FVA for the dataset captured from the DEM using bi-linear interpolation to derive the DEM elevations was found to be 0.063 meters in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.123 meters. This dataset ***meets*** the required FVA of 0.1813 meters (18.13 centimeters) at the 95% confidence level (based on NSSDA). This is summarized in Table 6.

- Supplemental Vertical Accuracy (SVA): The tested SVA accuracies for the dataset for each of the land cover classes other than open ground are summarized below. These results are stated in terms of the 95th percentile error (based on ASPRS guidelines) for each of the land cover classes other than open ground.

  The following land cover classes were tested and the resulting 95th percentile error values are listed below:

  - Forested, Fully Covered by Trees: 0.528 meters (Table 7)
  - High Grass, Weeds, and Crops: 0.146 (Table 8)
  - Urban Areas: 0.122 meters (Table 9)

- Consolidated Vertical Accuracy (CVA): The tested CVA for the dataset captured from the DEM using bi-linear interpolation for all classes (including the bare earth class) was found to be 0.141 meters, which is stated in terms of the 95th percentile error. Therefore the data ***meets*** the required CVA of 0.269 meters (26.9 centimeters). This test was based on the 95th percentile error (based on ASPRS guidelines) across <u>all</u> land cover categories

  This is also summarized in Table 10.

Figure 7. LiDAR Ground Control Points Used in Calibration

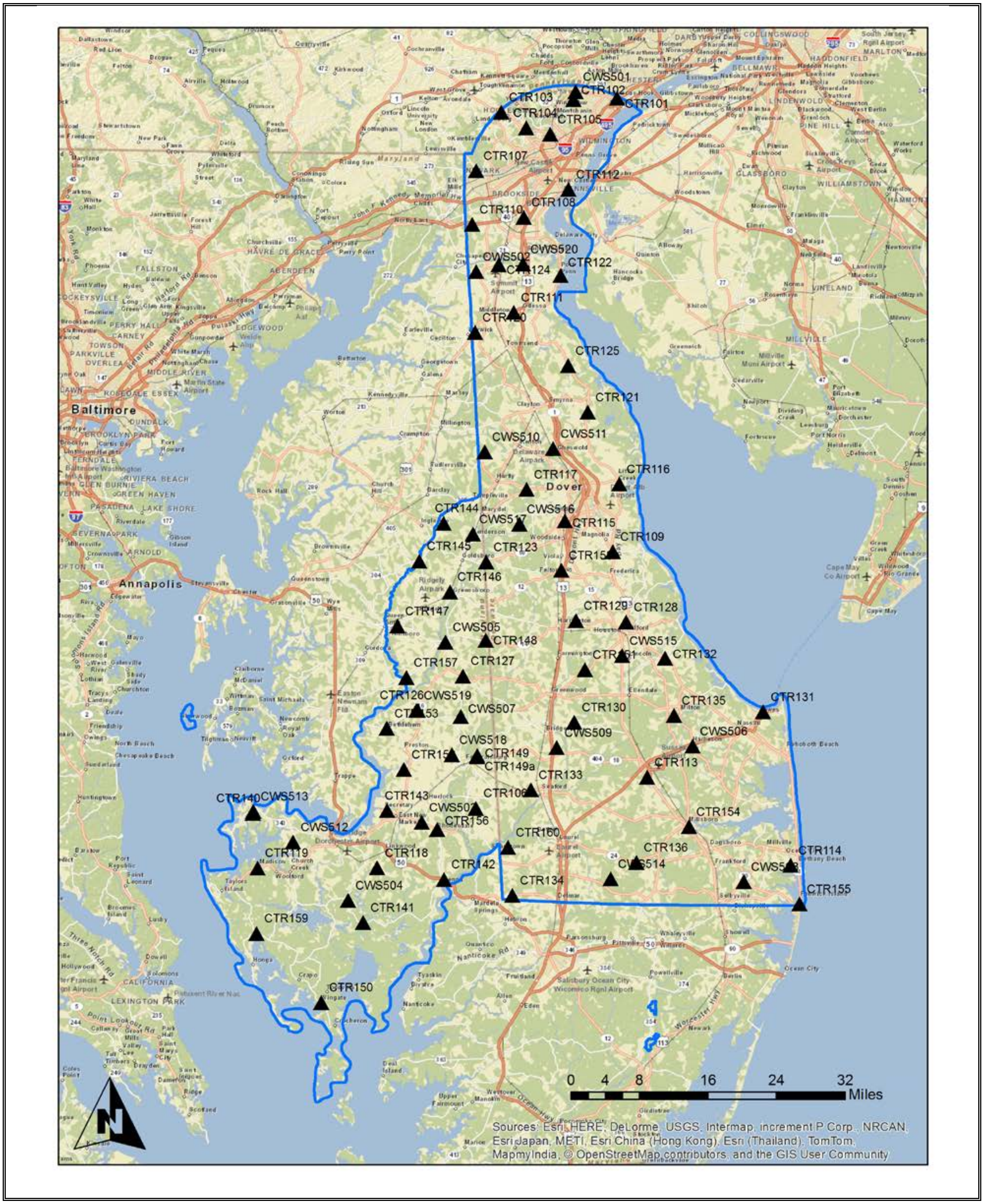


Figure 8. All Final LiDAR QA Point Locations

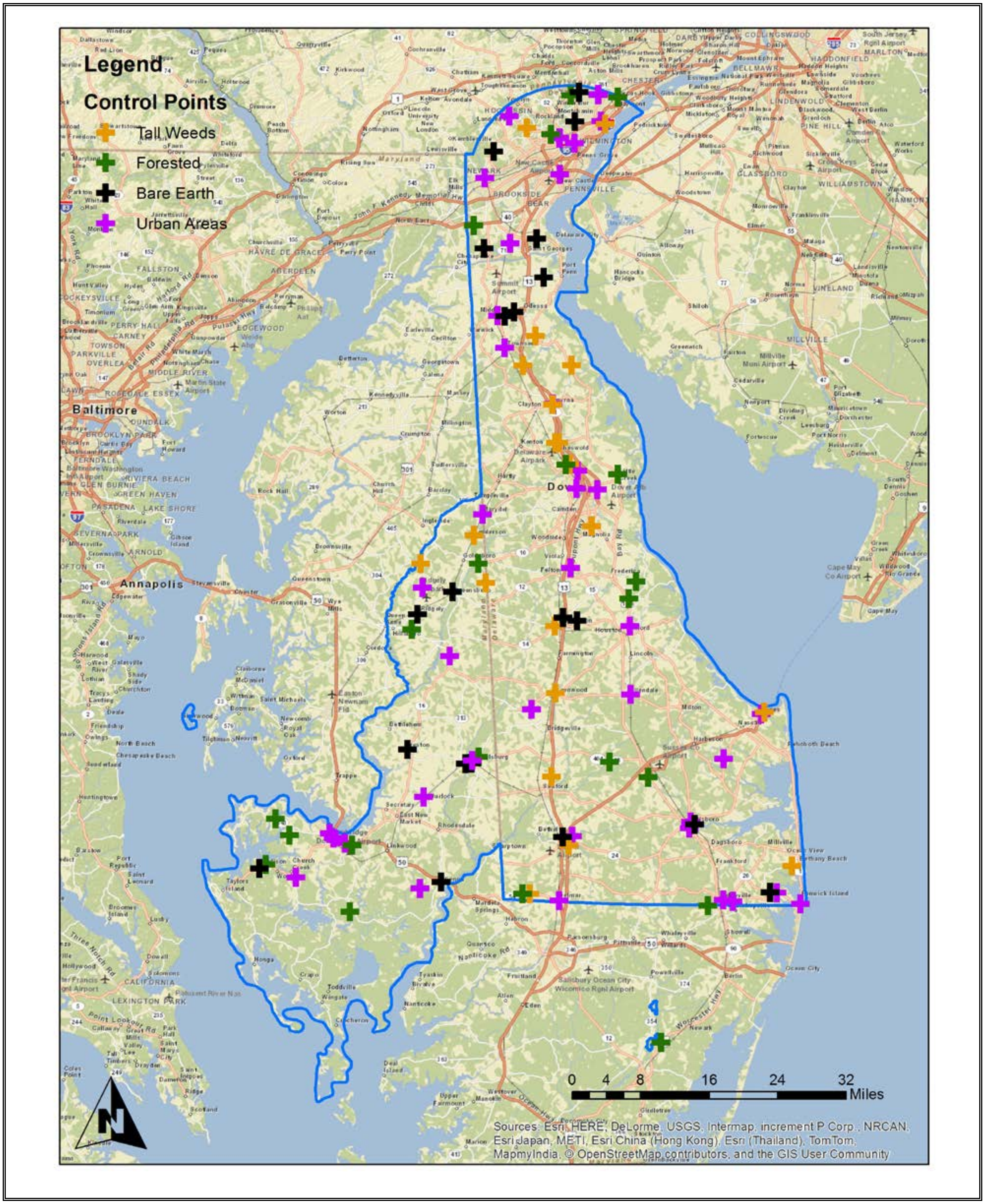


Figure 9. Bare Earth (BE) QA Point Locations

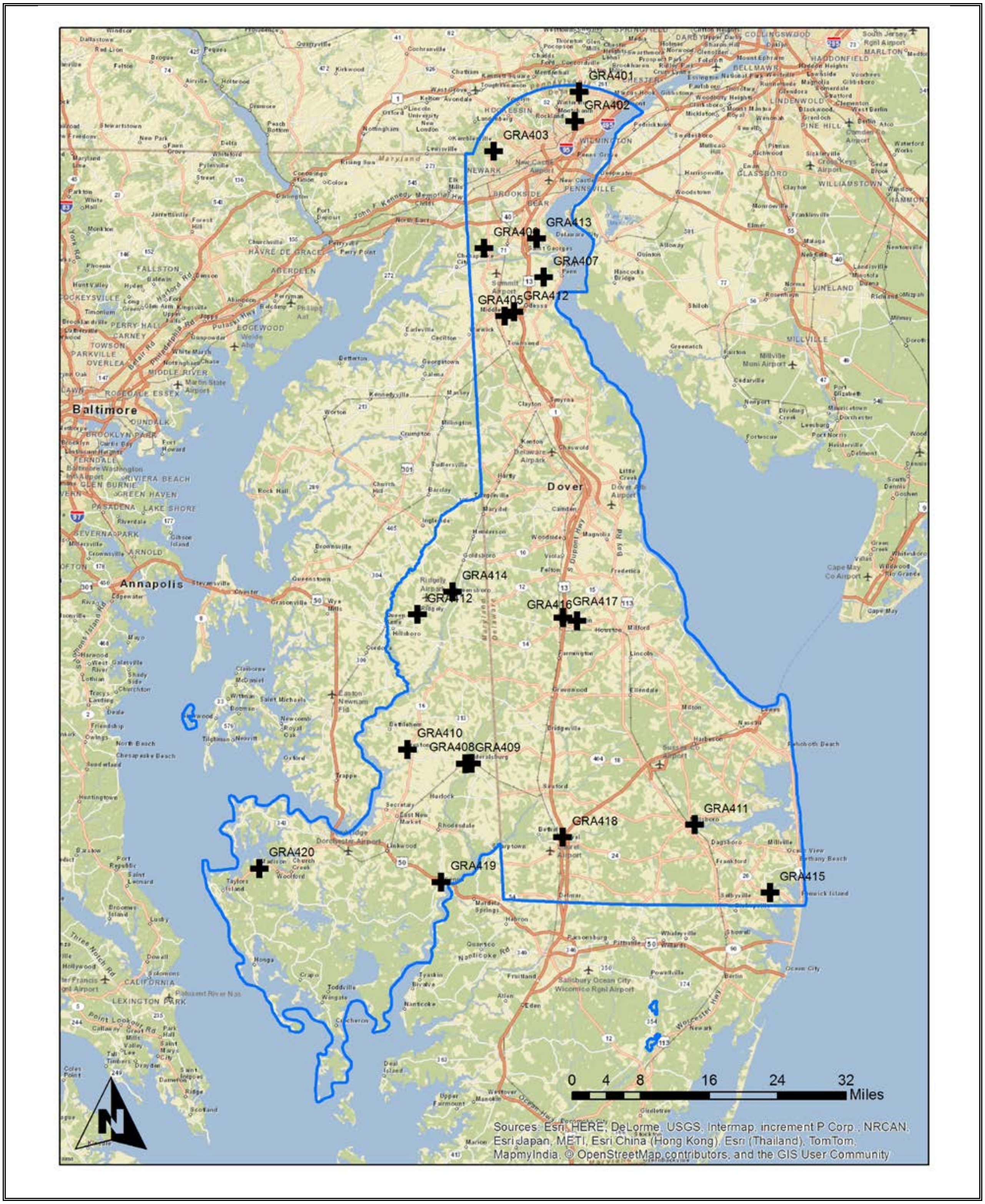


Figure 10. Forested (FO) QA Point Locations

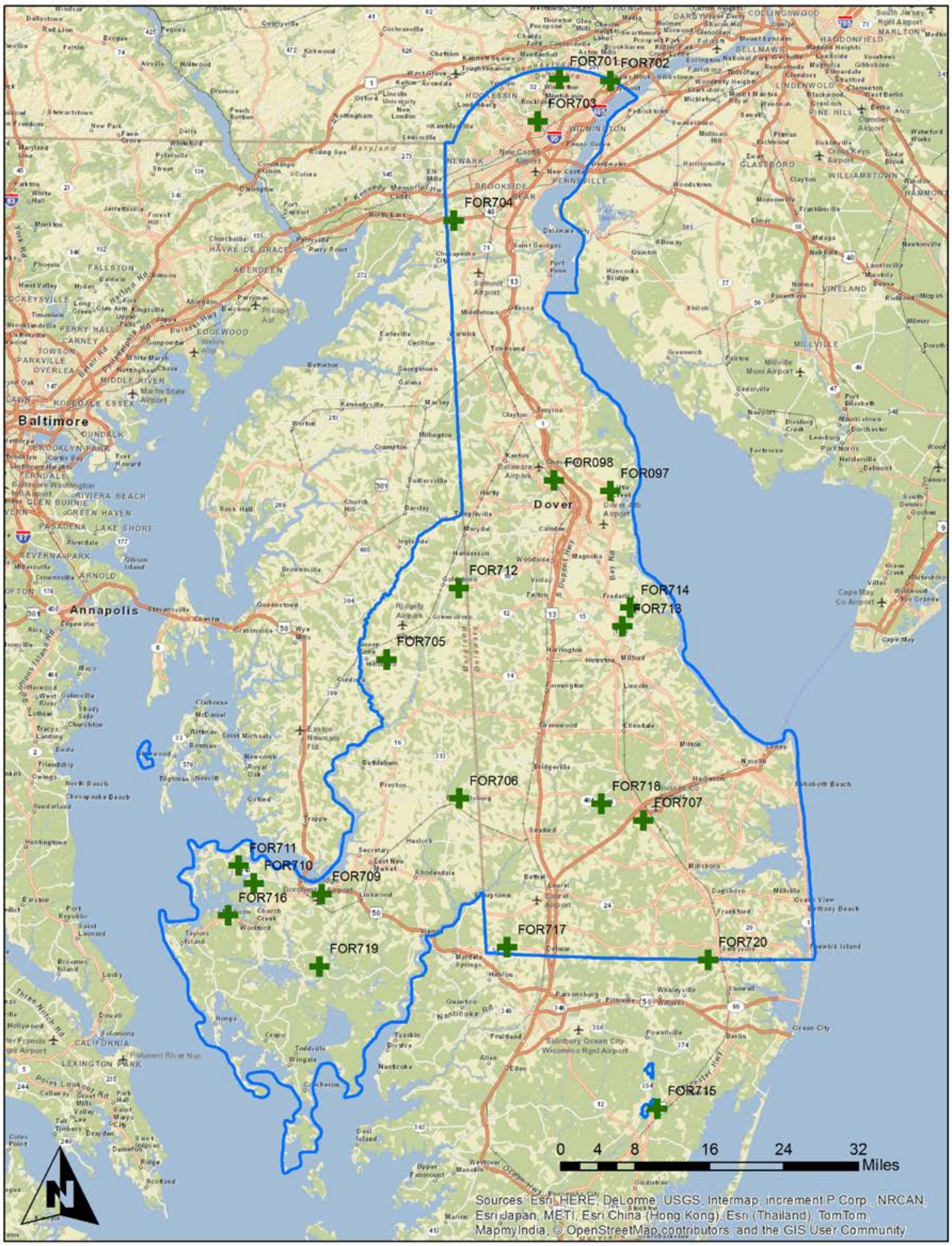


Figure 11. Tall Weeds/Crops (TW) QA Point Locations

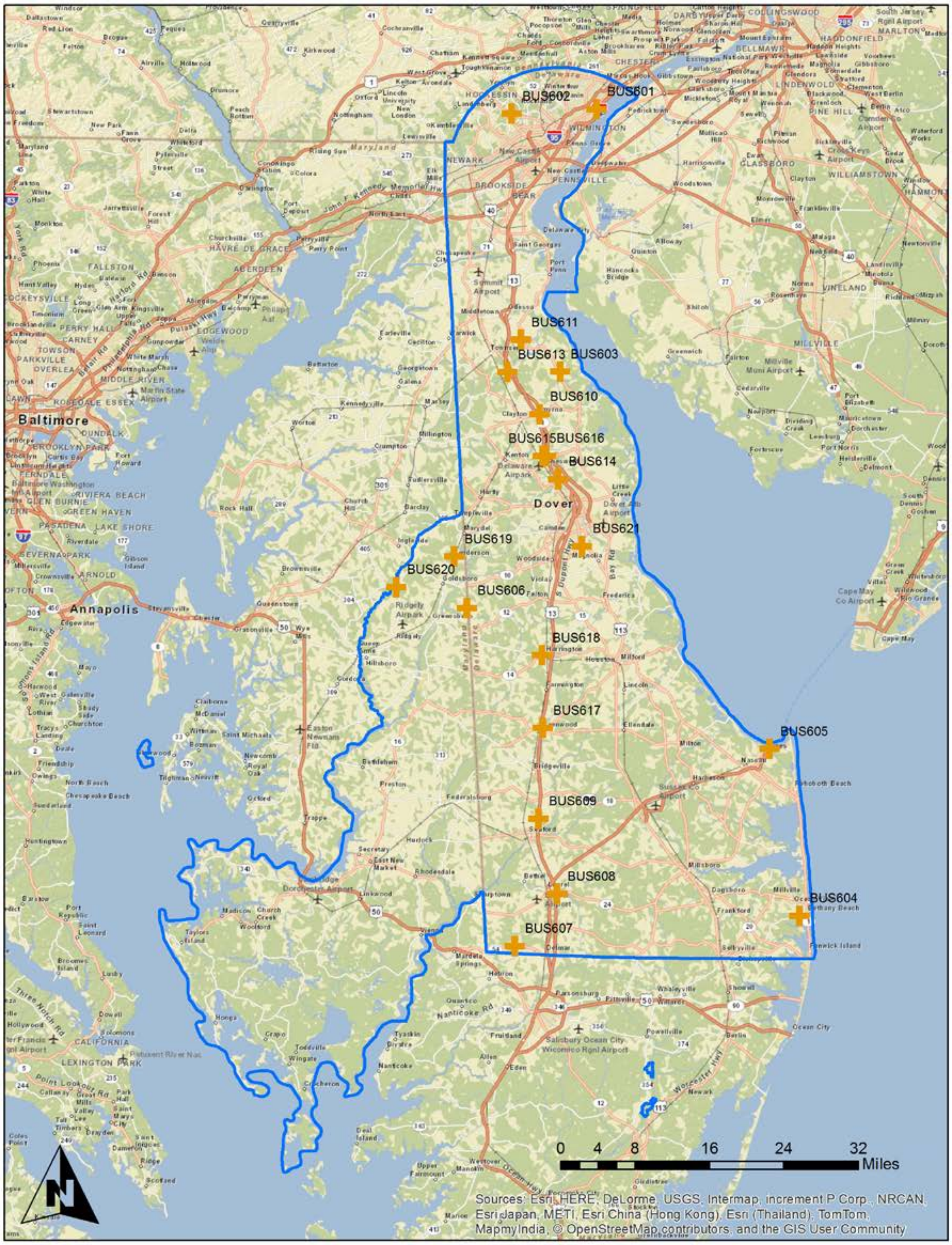


Figure 12. Urban Area (UA) QA Point Locations

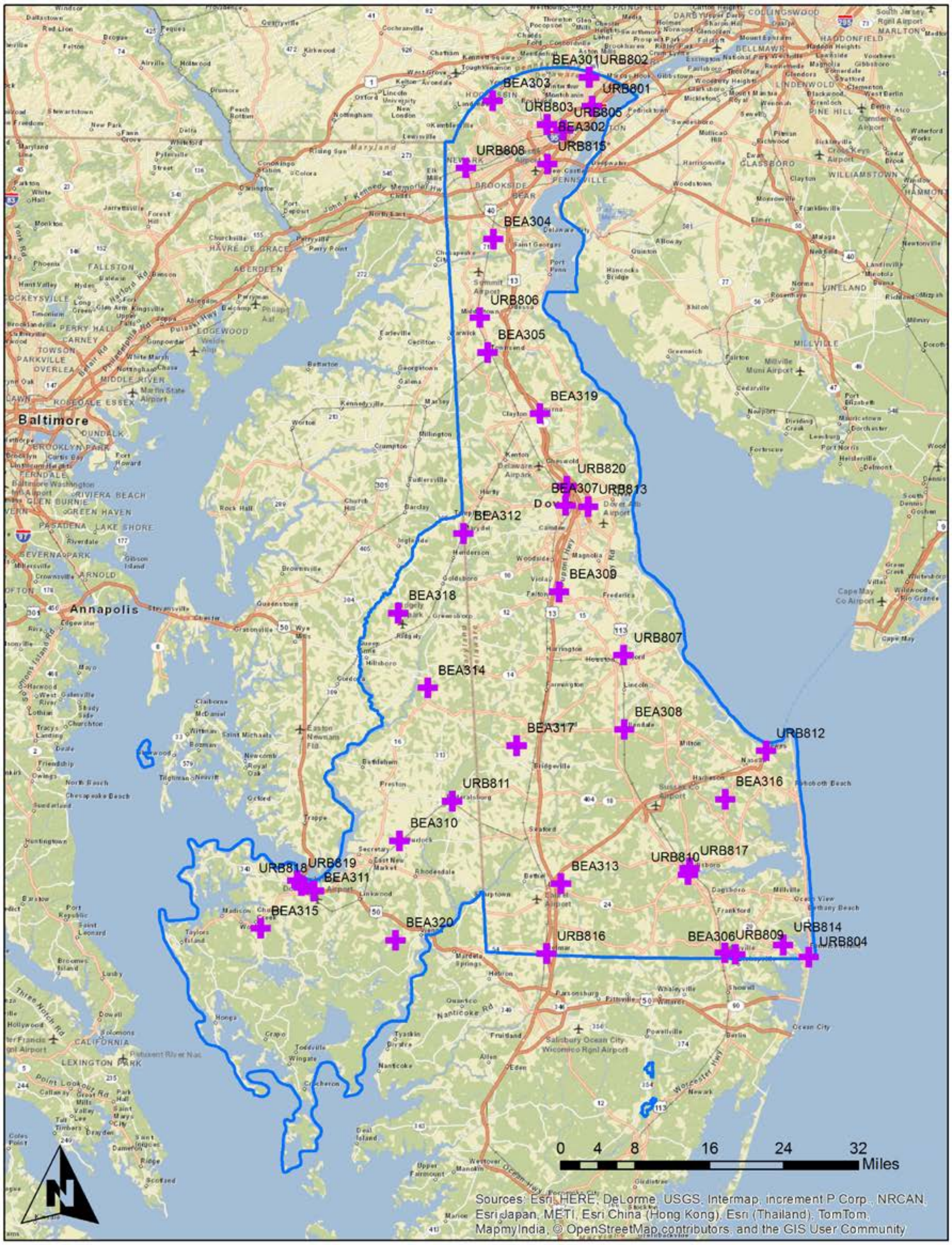


Table 4. LiDAR Ground Control Point Report (Units = Meters)

Number	Easting	Northing	Known Z	Laser Z	Dz
CTR101	461019.65	4407684.78	34.73	34.84	0.11
CTR102	452811.00	4407418.31	118.73	118.73	0.00
CTR103	439218.76	4405105.39	117.30	117.14	-0.16
CTR104	443912.25	4402161.32	85.41	85.26	-0.15
CTR105	448412.65	4400939.76	52.68	52.65	-0.03
CTR106	434455.30	4274124.45	13.49	13.49	0.00
CTR107	434482.84	4394047.54	57.92	57.78	-0.14
CTR108	443453.91	4385287.98	11.96	11.87	-0.09
CTR109	460194.95	4322411.62	7.06	7.04	-0.02
CTR110	433768.69	4383939.48	23.35	23.09	-0.26
CTR111	441584.87	4367435.29	16.48	16.46	-0.02
CTR112	451892.20	4390541.78	1.49	1.46	-0.03
CTR113	466674.00	4279916.41	14.68	14.67	-0.01
CTR114	493671.13	4263383.83	1.21	1.30	0.09
CTR115	451172.16	4328185.10	17.53	17.58	0.05
CTR116	461412.02	4335102.84	1.76	1.79	0.03
CTR117	443971.00	4334110.27	20.75	20.79	0.04
CTR118	415889.89	4262919.65	4.26	4.16	-0.10
CTR119	393391.12	4262871.01	0.99	0.99	0.00
CTR120	434285.55	4363611.93	23.16	23.06	-0.10
CTR121	455517.79	4348658.20	5.38	5.38	0.00
CTR122	450368.24	4374373.97	1.82	1.85	0.03
CTR123	436376.72	4320465.25	15.93	15.92	-0.01
CTR124	438751.40	4376332.57	16.56	16.37	-0.18
CTR125	451770.55	4357400.48	5.54	5.57	0.03
CTR126	423543.19	4292546.42	13.77	13.74	-0.03
CTR127	432019.41	4299002.38	16.69	16.70	0.01
CTR128	462706.83	4309134.57	10.24	10.35	0.11
CTR129	453289.93	4309397.23	15.28	15.30	0.02
CTR130	452951.54	4290316.51	11.52	11.57	0.05
CTR131	488486.60	4292245.04	0.91	0.93	0.02
CTR132	470041.98	4302369.48	7.95	7.93	-0.02
CTR133	444806.28	4277577.83	9.58	9.55	-0.03
CTR134	441316.68	4257760.68	11.64	11.57	-0.07
CTR135	471721.90	4291570.77	10.04	10.12	0.08
CTR136	464623.09	4263966.88	14.81	14.98	0.17
CTR140	392549.89	4273156.35	1.12	0.99	-0.13
CTR141	413235.95	4252607.77	0.77	0.73	-0.04
CTR142	428431.31	4260729.60	4.01	3.95	-0.05
CTR143	417751.81	4273683.70	8.54	8.52	-0.02
CTR144	428355.27	4327722.76	17.93	17.86	-0.07
CTR145	423829.71	4320614.95	13.15	13.13	-0.02
CTR146	429584.62	4314811.92	11.74	11.79	0.05
CTR147	419718.66	4308389.12	16.90	16.87	-0.03
CTR148	436307.51	4305703.68	17.92	17.93	0.01
CTR149	434725.66	4284047.41	11.13	11.10	-0.03
CTR149A	434738.84	4283763.68	11.54	11.44	-0.10
CTR150	405378.42	4237564.49	0.90	0.84	-0.06

Number	Easting	Northing	Known Z	Laser Z	Dz
CTR151	454982.14	4300220.54	17.36	17.50	0.14
CTR152	420935.76	4281409.41	9.87	9.80	-0.07
CTR153	417690.84	4289144.72	13.01	12.96	-0.05
CTR154	474533.94	4270669.55	7.15	7.36	0.22
CTR155	495302.95	4256113.88	1.15	1.21	0.06
CTR156	427195.06	4270092.95	11.68	11.60	-0.08
CTR157	421365.35	4298689.04	10.01	9.99	-0.02
CTR158	450490.33	4318878.85	18.24	18.29	0.05
CTR159	393227.33	4250553.34	1.46	1.47	0.01
CTR160	440494.82	4266730.15	6.16	6.06	-0.10
CWS501	453221.45	4408914.56	118.04	118.09	0.05
CWS502	434507.99	4375094.01	16.62	16.43	-0.19
CWS503	424249.91	4271479.00	14.04	13.93	-0.11
CWS504	410440.28	4256837.47	1.82	1.72	-0.10
CWS505	428696.15	4305383.47	13.86	13.80	-0.06
CWS506	475205.34	4285817.60	13.44	13.43	-0.01
CWS507	431584.51	4291356.21	13.49	13.49	0.00
CWS508	484813.47	4260304.72	8.12	8.11	-0.01
CWS509	449674.57	4285518.45	11.55	11.55	0.00
CWS510	436135.77	4341192.56	18.83	18.79	-0.04
CWS511	448983.35	4341794.65	13.23	13.30	0.07
CWS512	400090.61	4267791.12	2.32	2.24	-0.08
CWS513	392587.39	4273551.42	1.21	1.06	-0.15
CWS514	459786.21	4260818.52	14.56	14.56	0.00
CWS515	461929.27	4302824.25	13.37	13.33	-0.04
CWS516	442638.82	4327564.04	17.18	17.16	-0.02
CWS517	433872.97	4325687.61	16.61	16.60	-0.01
CWS518	429924.78	4284206.51	12.92	12.81	-0.11
CWS519	423293.21	4292540.02	15.01	14.92	-0.09
CWS520	443302.58	4376480.59	12.98	12.94	-0.04

Average dz	-0.020 m
Minimum dz	-0.259 m
Maximum dz	0.215 m
Root Mean Square	0.084 m
Std Deviation	0.081 m

Table 5. Raw FVA - Bare Earth and Low Grass QA – Unclassified Points (Units = Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
GRA401	453667.76	4408940.75	124.62	124.60	-0.02
GRA402	452866.72	4403372.97	92.33	92.30	-0.03
GRA403	437618.53	4397774.97	87.32	87.25	-0.07
GRA405	439706.62	4366767.66	17.32	17.31	-0.01
GRA406	435776.49	4379522.63	22.38	22.34	-0.04
GRA407	447008.68	4374046.15	8.13	8.14	0.01
GRA408	433434.04	4282601.43	8.71	8.65	-0.06
GRA409	432273.43	4282517.32	8.11	8.05	-0.06
GRA410	421377.72	4285210.43	11.63	11.55	-0.08
GRA411	475382.87	4271041.07	6.58	6.55	-0.03
GRA412_Delaware	441407.43	4367513.33	17.38	17.34	-0.04
GRA412_Maryland	423265.52	4310599.63	16.73	16.66	-0.07
GRA413	445696.27	4381322.32	17.61	17.60	-0.01
GRA414	429847.94	4314880.41	11.46	11.41	-0.05
GRA415	489593.28	4258254.48	2.85	2.84	-0.01
GRA416	453309.69	4309427.29	15.15	15.28	0.13
GRA417	450665.93	4310027.53	17.43	17.44	0.01
GRA418	450595.33	4268720.96	9.69	9.77	0.08
GRA419	427706.03	4260243.27	3.05	3.00	-0.05
GRA420	393522.40	4262823.79	0.75	0.70	-0.05

Average dz	-0.020 m
Minimum dz	-0.080 m
Maximum dz	0.130 m
Root Mean Square	0.055 m
95% Confidence	0.107 m

Table 6. FVA - Bare Earth and Low Grass QA – Derived DEMs Classified (Units = Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
GRA401	453667.76	4408940.75	124.62	124.68	0.05
GRA402	452866.72	4403372.97	92.33	92.32	-0.01
GRA403	437618.53	4397774.97	87.32	87.22	-0.09
GRA405	439706.62	4366767.66	17.32	17.31	-0.01
GRA406	435776.49	4379522.63	22.38	22.30	-0.08
GRA407	447008.68	4374046.15	8.13	8.21	0.08
GRA408	433434.04	4282601.43	8.71	8.63	-0.08
GRA409	432273.43	4282517.32	8.11	8.01	-0.11
GRA410	421377.72	4285210.43	11.63	11.55	-0.08
GRA411	475382.87	4271041.07	6.58	6.56	-0.02
GRA412_Delaware	441407.43	4367513.33	17.38	17.35	-0.02
GRA412_Maryland	423265.52	4310599.63	16.73	16.66	-0.07
GRA413	445696.27	4381322.32	17.61	17.59	-0.02
GRA414	429847.94	4314880.41	11.46	11.43	-0.03
GRA415	489593.28	4258254.48	2.85	2.86	0.01
GRA416	453309.69	4309427.29	15.15	15.26	0.11
GRA417	450665.93	4310027.53	17.43	17.44	0.01
GRA418	450595.33	4268720.96	9.69	9.75	0.07
GRA419	427706.03	4260243.27	3.05	3.00	-0.05
GRA420	393522.40	4262823.79	0.75	0.70	-0.05

Average dz	-0.020 m
Minimum dz	-0.108 m
Maximum dz	0.109 m
Root Mean Square	0.063 m
95% Confidence	0.123 m

Table 7. SVA Forested, Fully Covered by Trees QA – Derived DEMs (Units = Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
FOR097_1	460938.76	4336986.66	4.71	4.85	0.13
FOR098_1	451195.00	4338843.25	9.55	9.74	0.19
FOR701_1	452119.45	4408322.02	115.67	115.75	0.08
FOR702_1	460926.92	4408006.39	35.04	35.16	0.11
FOR703_1	448347.64	4401011.31	51.72	55.27	3.55
FOR704_1	433858.25	4383829.06	22.00	21.89	-0.11
FOR705_1	422179.57	4307825.66	16.07	16.06	-0.01
FOR706_1	434797.08	4283752.94	11.34	11.23	-0.11
FOR707_1	466678.34	4279982.01	14.44	14.51	0.07
FOR709_1	410960.55	4267172.17	6.28	6.17	-0.11
FOR710_1	399192.92	4269070.36	3.77	3.75	-0.02
FOR711_1	396551.03	4272115.71	0.82	0.73	-0.09
FOR712_1	434706.55	4320212.74	15.42	15.41	-0.01
FOR713_1	463067.88	4313575.99	9.17	9.29	0.12
FOR714_1	464403.22	4316797.04	5.07	5.14	0.07
FOR716_1	394737.89	4263507.91	1.01	0.96	-0.05
FOR717_1	443081.23	4257994.86	12.86	12.89	0.03
FOR718_1	459435.04	4282837.78	10.18	10.15	-0.03
FOR719_1	410574.88	4254663.87	0.36	0.39	0.03

Average dz	0.020 m
Minimum dz	-0.114 m
Maximum dz	3.554 m
Root Mean Square	0.820 m
95th Percentile	0.528 m

Table 8. SVA High Grass/Weeds/Crops QA – Derived DEMs (Units = Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
BUS601	458567.84	4402951.82	6.73	6.86	0.14
BUS602	443892.03	4402188.42	83.46	83.40	-0.06
BUS603	452240.58	4357497.30	5.12	5.11	0.00
BUS604	493726.17	4263294.21	0.59	0.61	0.02
BUS605	488563.08	4292178.92	1.55	1.69	0.14
BUS606	436111.65	4316558.63	14.74	14.76	0.02
BUS607	444414.77	4258040.84	14.02	14.05	0.03
BUS608	451748.17	4267079.15	6.89	6.94	0.06
BUS609	448494.58	4280086.49	7.69	7.75	0.06
BUS610	448703.54	4350153.50	5.43	5.54	0.11
BUS611	445493.87	4363020.10	16.50	16.56	0.05
BUS613	443131.48	4357431.22	11.54	11.52	-0.01
BUS614	451913.50	4338890.04	9.91	10.02	0.11
BUS615	449274.89	4342914.66	11.22	11.33	0.12
BUS616	449837.61	4342953.84	10.91	11.03	0.11
BUS617	449250.53	4295793.13	15.56	15.68	0.12
BUS618	449087.53	4308386.19	18.03	18.05	0.02
BUS619	433870.94	4325472.63	17.76	17.78	0.02
BUS620	423879.94	4320184.38	13.34	13.44	0.09
BUS621	456069.48	4327256.00	9.41	9.66	0.25

Average dz	0.070 m
Minimum dz	-0.057 m
Maximum dz	0.254 m
Root Mean Square	0.098 m
95th Percentile	0.146 m

Table 9. SVA Urban Areas QA Points – Derived DEMs (Units – Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
BEA301	457277.12	4408460.27	89.99	90.04	0.06
BEA302	450028.24	4400236.63	42.71	42.70	-0.01
BEA303	440558.42	4404446.26	79.66	79.63	-0.03
BEA304	440702.30	4380444.70	18.39	18.29	-0.10
BEA305	439702.04	4360840.35	19.30	19.33	0.03
BEA306	482587.19	4256603.52	10.23	10.30	0.07
BEA307	453193.68	4334295.50	11.11	11.23	0.12
BEA308	463353.68	4295555.20	15.02	15.04	0.02
BEA309	452071.92	4319405.90	18.53	18.58	0.06
BEA310	424445.34	4276275.00	14.20	14.10	-0.10
BEA311	409586.15	4267572.48	7.35	7.27	-0.08
BEA312	435531.85	4329492.46	17.69	17.70	0.01
BEA313	452412.62	4268815.80	8.31	8.32	0.01
BEA314	429343.03	4302733.38	14.45	14.41	-0.04
BEA315	400417.81	4261102.99	1.25	1.28	0.03
BEA316	480845.70	4283467.21	9.39	9.43	0.04
BEA317	444747.21	4292753.38	16.69	16.66	-0.03
BEA318	424228.93	4315692.86	18.17	18.15	-0.02
BEA319	448755.77	4350225.79	6.10	6.17	0.07
BEA320	423735.15	4259046.85	1.49	1.41	-0.09
URB801	457815.74	4403456.40	46.19	46.23	0.04
URB802	457342.69	4408509.77	90.28	90.34	0.07
URB803	449954.27	4400279.32	43.94	43.93	-0.01
URB804	495329.63	4256130.82	0.93	1.08	0.15
URB805	452784.96	4399321.47	21.91	21.87	-0.05
URB806	438369.17	4366868.14	19.83	19.57	-0.26
URB807	463254.20	4308387.58	5.87	5.82	-0.05
URB808	435930.43	4392771.41	34.51	34.11	-0.39
URB809	480798.70	4256888.36	10.66	10.70	0.04
URB810	474376.74	4270391.78	7.31	7.49	0.19
URB811	433580.44	4283137.08	8.81	8.77	-0.04
URB812	487896.36	4291843.52	4.29	4.35	0.05
URB813	457118.71	4334094.41	5.98	6.01	0.04
URB814	490883.17	4258246.87	1.83	1.86	0.03
URB815	450040.66	4393460.74	20.44	20.52	0.07
URB816	449920.93	4256733.08	15.26	15.25	-0.01
URB817	474680.55	4271516.92	6.92	6.98	0.05
URB818	407491.25	4268503.57	4.32	4.20	-0.12
URB819	406747.28	4269382.11	0.96	0.96	0.00
URB820	453395.95	4337667.02	9.86	9.94	0.08
Average dz	0.000 m				
Minimum dz	-0.394 m				
Maximum dz	0.185 m				
Root Mean Square	0.100 m				
95th Percentile	0.122 m				

Table 10. CVA for the 4 Classified Land Cover Classes (Units = Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
GRA401	453667.76	4408940.75	124.62	124.68	0.05
GRA402	452866.72	4403372.97	92.33	92.32	-0.01
GRA403	437618.53	4397774.97	87.32	87.22	-0.09
GRA405	439706.62	4366767.66	17.32	17.31	-0.01
GRA406	435776.49	4379522.63	22.38	22.30	-0.08
GRA407	447008.68	4374046.15	8.13	8.21	0.08
GRA408	433434.04	4282601.43	8.71	8.63	-0.08
GRA409	432273.43	4282517.32	8.11	8.01	-0.11
GRA410	421377.72	4285210.43	11.63	11.55	-0.08
GRA411	475382.87	4271041.07	6.58	6.56	-0.02
GRA412_Delaware	441407.43	4367513.33	17.38	17.35	-0.02
GRA412_Maryland	423265.52	4310599.63	16.73	16.66	-0.07
GRA413	445696.27	4381322.32	17.61	17.59	-0.02
GRA414	429847.94	4314880.41	11.46	11.43	-0.03
GRA415	489593.28	4258254.48	2.85	2.86	0.01
GRA416	453309.69	4309427.29	15.15	15.26	0.11
GRA417	450665.93	4310027.53	17.43	17.44	0.01
GRA418	450595.33	4268720.96	9.69	9.75	0.07
GRA419	427706.03	4260243.27	3.05	3.00	-0.05
GRA420	393522.40	4262823.79	0.75	0.70	-0.05
BUS601	458567.84	4402951.82	6.73	6.86	0.14
BUS602	443892.03	4402188.42	83.46	83.40	-0.06
BUS603	452240.58	4357497.30	5.12	5.11	0.00
BUS604	493726.17	4263294.21	0.59	0.61	0.02
BUS605	488563.08	4292178.92	1.55	1.69	0.14
BUS606	436111.65	4316558.63	14.74	14.76	0.02
BUS607	444414.77	4258040.84	14.02	14.05	0.03
BUS608	451748.17	4267079.15	6.89	6.94	0.06
BUS609	448494.58	4280086.49	7.69	7.75	0.06
BUS610	448703.54	4350153.50	5.43	5.54	0.11
BUS611	445493.87	4363020.10	16.50	16.56	0.05
BUS613	443131.48	4357431.22	11.54	11.52	-0.01
BUS614	451913.50	4338890.04	9.91	10.02	0.11
BUS615	449274.89	4342914.66	11.22	11.33	0.12
BUS616	449837.61	4342953.84	10.91	11.03	0.11
BUS617	449250.53	4295793.13	15.56	15.68	0.12
BUS618	449087.53	4308386.19	18.03	18.05	0.02
BUS619	433870.94	4325472.63	17.76	17.78	0.02
BUS620	423879.94	4320184.38	13.34	13.44	0.09
BUS621	456069.48	4327256.00	9.41	9.66	0.25
FOR097_1	460938.76	4336986.66	4.71	4.85	0.13
FOR098_1	451195.00	4338843.25	9.55	9.74	0.19
FOR701_1	452119.45	4408322.02	115.67	115.75	0.08
FOR702_1	460926.92	4408006.39	35.04	35.16	0.11
FOR703_1	448347.64	4401011.31	51.72	55.27	3.55
FOR704_1	433858.25	4383829.06	22.00	21.89	-0.11
FOR705_1	422179.57	4307825.66	16.07	16.06	-0.01
FOR706_1	434797.08	4283752.94	11.34	11.23	-0.11

Number	Easting	Northing	Known Z	LiDAR Z	Dz
FOR707_1	466678.34	4279982.01	14.44	14.51	0.07
FOR709_1	410960.55	4267172.17	6.28	6.17	-0.11
FOR710_1	399192.92	4269070.36	3.77	3.75	-0.02
FOR711_1	396551.03	4272115.71	0.82	0.73	-0.09
FOR712_1	434706.55	4320212.74	15.42	15.41	-0.01
FOR713_1	463067.88	4313575.99	9.17	9.29	0.12
FOR714_1	464403.22	4316797.04	5.07	5.14	0.07
FOR716_1	394737.89	4263507.91	1.01	0.96	-0.05
FOR717_1	443081.23	4257994.86	12.86	12.89	0.03
FOR718_1	459435.04	4282837.78	10.18	10.15	-0.03
FOR719_1	410574.88	4254663.87	0.36	0.39	0.03
BEA301	457277.12	4408460.27	89.99	90.04	0.06
BEA302	450028.24	4400236.63	42.71	42.70	-0.01
BEA303	440558.42	4404446.26	79.66	79.63	-0.03
BEA304	440702.30	4380444.70	18.39	18.29	-0.10
BEA305	439702.04	4360840.35	19.30	19.33	0.03
BEA306	482587.19	4256603.52	10.23	10.30	0.07
BEA307	453193.68	4334295.50	11.11	11.23	0.12
BEA308	463353.68	4295555.20	15.02	15.04	0.02
BEA309	452071.92	4319405.90	18.53	18.58	0.06
BEA310	424445.34	4276275.00	14.20	14.10	-0.10
BEA311	409586.15	4267572.48	7.35	7.27	-0.08
BEA312	435531.85	4329492.46	17.69	17.70	0.01
BEA313	452412.62	4268815.80	8.31	8.32	0.01
BEA314	429343.03	4302733.38	14.45	14.41	-0.04
BEA315	400417.81	4261102.99	1.25	1.28	0.03
BEA316	480845.70	4283467.21	9.39	9.43	0.04
BEA317	444747.21	4292753.38	16.69	16.66	-0.03
BEA318	424228.93	4315692.86	18.17	18.15	-0.02
BEA319	448755.77	4350225.79	6.10	6.17	0.07
BEA320	423735.15	4259046.85	1.49	1.41	-0.09
URB801	457815.74	4403456.40	46.19	46.23	0.04
URB802	457342.69	4408509.77	90.28	90.34	0.07
URB803	449954.27	4400279.32	43.94	43.93	-0.01
URB804	495329.63	4256130.82	0.93	1.08	0.15
URB805	452784.96	4399321.47	21.91	21.87	-0.05
URB806	438369.17	4366868.14	19.83	19.57	-0.26
URB807	463254.20	4308387.58	5.87	5.82	-0.05
URB808	435930.43	4392771.41	34.51	34.11	-0.39
URB809	480798.70	4256888.36	10.66	10.70	0.04
URB810	474376.74	4270391.78	7.31	7.49	0.19
URB811	433580.44	4283137.08	8.81	8.77	-0.04
URB812	487896.36	4291843.52	4.29	4.35	0.05
URB813	457118.71	4334094.41	5.98	6.01	0.04
URB814	490883.17	4258246.87	1.83	1.86	0.03
URB815	450040.66	4393460.74	20.44	20.52	0.07
URB816	449920.93	4256733.08	15.26	15.25	-0.01
URB817	474680.55	4271516.92	6.92	6.98	0.05
URB818	407491.25	4268503.57	4.32	4.20	-0.12
URB819	406747.28	4269382.11	0.96	0.96	0.00

Number	Easting	Northing	Known Z	LiDAR Z	Dz
URB820	453395.95	4337667.02	9.86	9.94	0.08

Average dz	0.050 m
Minimum dz	-0.394 m
Maximum dz	3.554 m
Root Mean Square	0.369 m
95th Percentile	0.141 m