Delaware Valley High Density QL2 LiDAR Project Report

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Delaware Valley 2015 High Density QL2 LiDAR and Orthoimagery acquisition task order, issued by the USGS National Geospatial Technical Operations Center (NGTOC), under their Geospatial Products and Services Contract (GPSC) on April 10, 2015. The combined task orders yielded one study area covering approximately 3,260 square miles over the Philadelphia Metro area. The intent of this document is to only provide specific validation information for the LiDAR data acquisition/collection work completed for the project.

1.2. Scope

The scope of the LiDAR portion of the Delaware Valley 2015 task order included the acquisition of aerial topographic LiDAR using state of the art technology along with the necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems. 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 pts / m^2	2,300 m	40.0° 28.0° over Philly City Center	30% 60% over Philly City Center	≤ 9.25 cm

1.3. Location / Coverage

The Delaware Valley 2015 LiDAR project boundary consists of eight continuous counties included in the Philadelphia Metro area within the states of Pennsylvania New Jersey. The project area totals approximately 3,260 square miles as shown in Figure 1 on the following page.

1.4. Duration

LiDAR data was acquired from April 12, 2015 through November 25, 2015 in a total of twenty-one total lifts to complete coverage of the area. See "2.5. Time Period" for more details.

1.5. Issues

Due to weather and leaf pop, one section of data was not able to be collected, requiring a reflight on November 25, 2015.

1.6. Deliverables

The following products were produced and delivered:

- Unclassified raw point cloud swath, in LAS in version 1.4 format
- Classified point cloud, tiled, in LAS in version 1.4 format
- Hydro-flattened Bare Earth surface raster DEM, tiled, in ERDAS .IMG format
- Hydro-flattened breaklines, continuous, in Esri shapefile format
- Control calibration and QC checkpoints in Esri shapefile format
- Processing boundary in Esri shapefile format
- Tile index in Esri shapefile format
- Project, deliverable, and lift-level metadata in XML format

All geospatial deliverables were produced in NAD83 (2011) UTM Zone 18, meters; NAVD88 (Geoid 12A), meters. All tiled deliverables have a tile size of 1,500 meters x 1,500 meters and follow the US National Grid naming conventions.

Figure 1. Delaware Valley 2015 LiDAR Project Boundary

2. Planning / Equipment

2.1. Flight Planning

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. Issues" of this document.

Detailed project flight planning calculations were performed for the project name or area project using Leica Mission Pro planning software.

The entire target area was comprised of 456 planned flight lines and approximately 15,733 flight line kilometers for the LiDAR acquisition (Figure 2).

2.2. LiDAR Sensor

Quantum Spatial utilized a Leica LiDAR sensor (Figure 3), serial numbers 7234 and 8239, 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.

A brief summary of the aerial acquisition parameters for the project are shown in the LiDAR System Specifications in Table 2.

Figure 2. Planned LiDAR Flight Lines

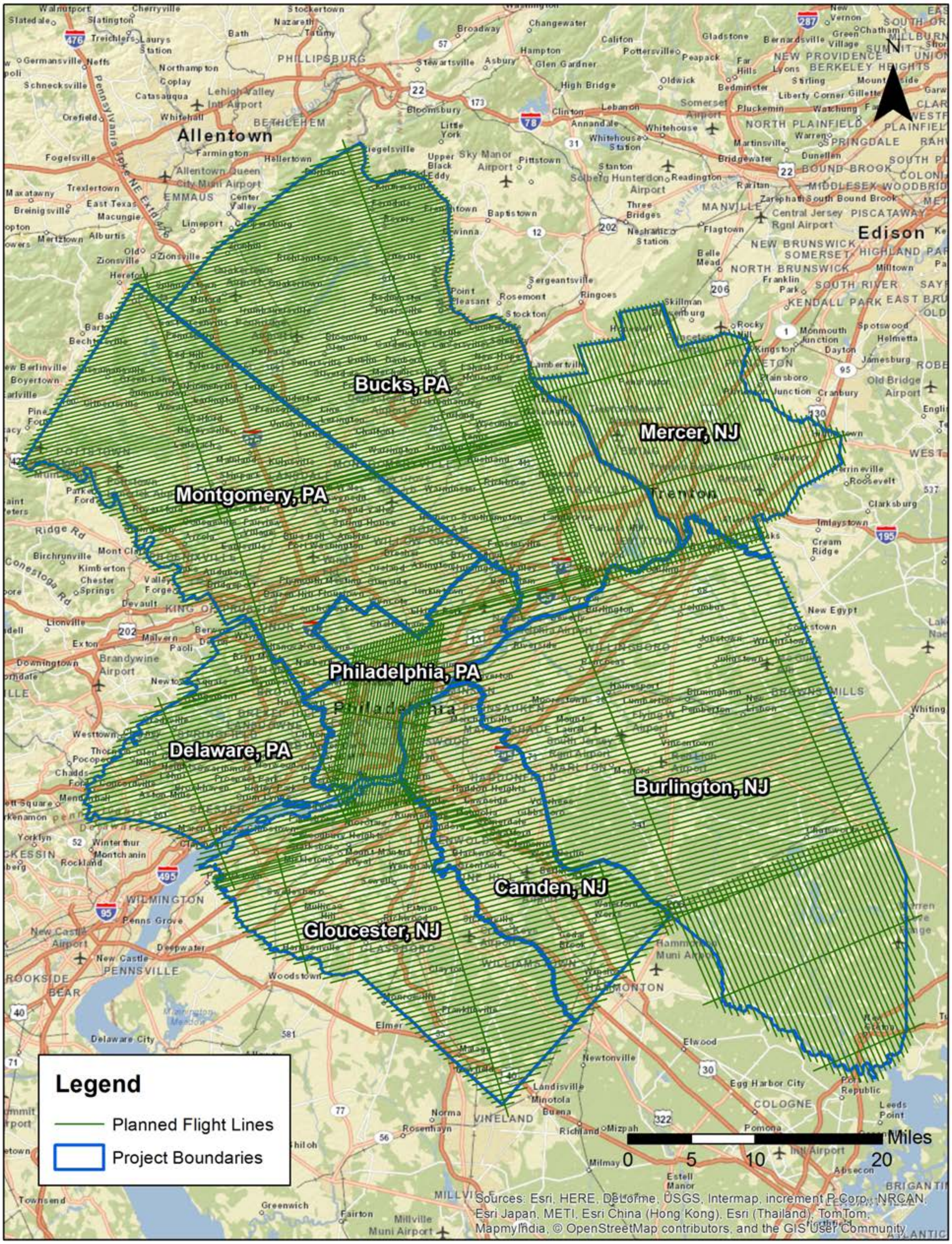


Table 2. Lidar System Specifications

		17N Cross Keys	31 E Eagles Nest	KCKZ Pennridge	KLOM Wings	KOCQ Brandywine	KVAY Downtown Philadelphia	KVAY South Jersey	N87 Trenton-Robinsville
Terrain and Aircraft Scanner	Flying Height AGL (m)	157	1580	1575	1800	1800	1590	1580	1390
	Recommended Ground Speed (kts)	150	150	150	150	150	150	150	150
Scanner	Field of View (deg)	36.0	36.0	29.0	29.0	29.5	28.0	36.0	35.0
	Scan Rate Setting Used (Hz)	40.5	40.5	26.0	51.0	51.0	57.0	40.5	47.5
Laser	Laser Pulse Rate Used (kHz)	595.8	693.6	532.4	623.2	622.4	528.8	693.6	591.0
	Multi Pulse in Air Mode	4	4	3	4	4	3	4	3
Coverage	Full Swath Width (m)	1023.50	1026.75	814.65	931.02	947.80	792.86	1026.75	876.53
	Line Spacing (m)	793.92	827.21	514.76	662.28	675.93	568.68	791.67	613.66
Point Spacing and Density	Maximum Point Spacing Across Track (m)	0.26	0.26	0.18	0.34	0.34	0.38	0.26	0.31
	Maximum Point Spacing Along Track (m)	0.95	0.95	1.48	0.76	0.76	0.68	0.95	0.81
	Average Point Density (pts/m^2)	8.05	8.00	7.65	7.85	7.70	7.79	8.00	7.95

Figure 3. Leica Sensor

2.3. Aircraft

All flights for the Delaware Valley 2015 project were accomplished through the use of customized planes. Plane type and tail numbers are listed below.

LiDAR Collection Planes

- Piper Navajo (twin-piston) Tail Numbers: N22GE and N262AS
- Cessna Caravan (single-turboprop), Tail Number: N269JE

These aircraft provided an ideal, stable aerial base for LiDAR acquisition. These aerial platforms 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 a state-of-the-art Leica LiDAR system. Some of the operating aircraft can be seen in Figure 4 below.

Figure 4. Some of Quantum Spatial's Planes

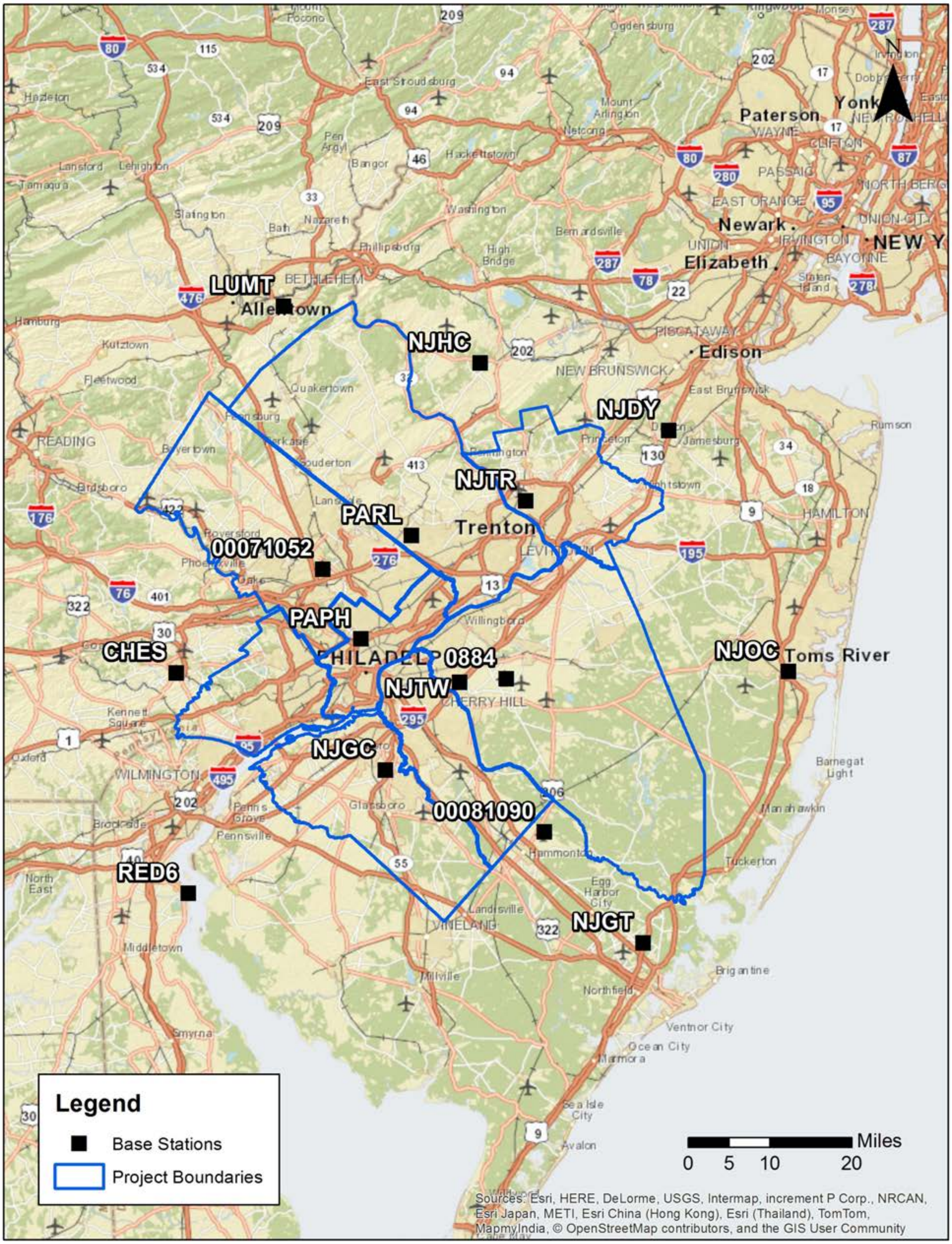
2.4. Base Station Information

GPS base stations were utilized during all phases of flight (Table 3). The base station locations were verified using NGS OPUS service and subsequent surveys. Base station locations are depicted in Figure 5. 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)
CHES	39° 57′ 5.91984″	75° 36′ 1.15234″	109.439
PAPH	40° 0′ 47.34854″	75° 10′ 34.78766″	27.809
NJTW	39° 56′ 11.04311″	74° 56′ 58.71204″	-20.002
PARL	40° 11′ 46.22401″	75° 3′ 35.66418″	76.548
NJGC	39° 46′ 52.79148″	75° 7′ 11.25002″	-3.994
RED6	39° 33′ 42.03605″	75° 34′ 11.82143″	-25.942
NJHC	40° 30′ 5.80472″	74° 54′ 4.01548″	95.918
NJTR	40° 15′ 27.46254″	74° 47′ 48.07181″	41.271
NJDY	40° 22′ 52.07372″	74° 27′ 56.3016″	4.283
00081090	39° 40′ 17.53623″	74° 45′ 20.45774″	-15.919
NJGT	39° 28′ 28.25439″	74° 31′ 50.93862″	-11.096
NJOC	39° 57′ 10.02328″	74° 11′ 36.59328″	-8.184
0884	39° 56′ 33.93018″	74° 50′ 33.02071″	-18.796
00071052	40° 8′ 11.65176″	75° 15′ 51.95986″	54.132
LUMT	40° 36′ 5.74811″	75° 21′ 27.13397″	251.338

Figure 5. Base Station Locations



2.5. Time Period

Project specific flights were conducted over several months. Twenty-one LiDAR sorties, or aircraft lifts were completed. Accomplished LiDAR sorties are listed below.

- Apr 12, 2015 A (N22GE, SN8239)
- Apr 12, 2015 B (N22GE, SN8239)
- Apr 13, 2015 A (N22GE, SN8239)
- Apr 15, 2015 A (N22GE, SN8239)
- Apr 15, 2015 B (N22GE, SN8239)
- Apr 16, 2015 A (N22GE, SN8239)
- Apr 16, 2015 B (N22GE, SN8239)
- Apr 18, 2015 A (N262AS, SN7178)
- Apr 18, 2015 A (N22GE, SN8239)
- Apr 19, 2015 A (N262AS, SN7178)
- Apr 19, 2015 B (N262AS, SN7178)
- Apr 19, 2015 A (N269JE, SN7234)
- Apr 19, 2015 A (N22GE, SN8239)
- Apr 19, 2015 B (N22GE, SN8239)
- Apr 22, 2015 A (N269JE, SN7234)
- Apr 22, 2015 B (N269JE, SN7234)
- Apr 24, 2015 A CrossKeys (N269JE, SN7234)
- Apr 24, 2015 A KVAY (N269JE, SN7234)
- Apr 25, 2015 A (N269JE, SN7234)
- May 23, 2015 A (N22GE, SN8239)
- Nov 25, 2016 A (N22GE, 7178)

3. Processing Summary

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

Similar information was also collected for imagery:

- Job / Project #
- System
- Flight Date / Lift Number
- Flight Line Number
- Flight Line Start Time
- Flight Line Stop Time
- Image Range
- F-Stop Setting
- Shutter Setting

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

3.2. LiDAR Processing

Inertial Explorer 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. Inertial Explorer 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 georeferenced point cloud from the LiDAR missions.

During the sensor trajectory processing (combining GPS & IMU datasets) certain statistical graphs and tables are generated within the Inertial Explorer 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 Cloud Pro 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 both the All Point Cloud Data and the Bare Earth. 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.

3.3. LAS Classification Scheme

The classification classes are determined by the USGS Version 1.2 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 – Low Noise – Low points, manually identified above or below the surface that could be noise points in point cloud.
- Class 8 – Model Key Point
- 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 – Bridge Decks – Points falling on bridge decks.
- Class 18 – High Noise – 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).

3.4. 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.

3.5. 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.

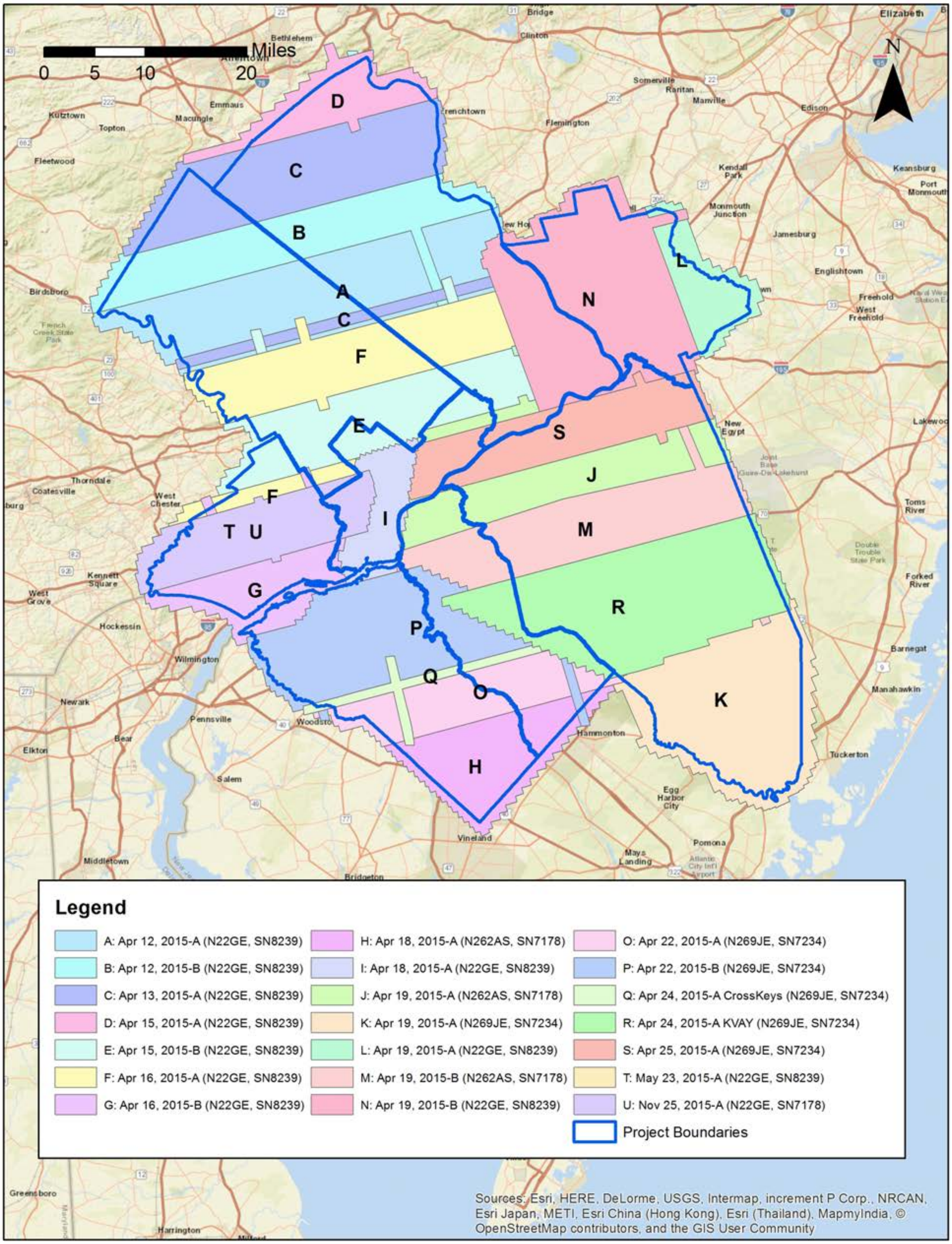
3.6. Hydro-Flattening Raster DEM Process

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a 2.5 foot 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.

4. Project Coverage Verification

The project name or area 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



5. Ground Control & Checkpoint Collection

Quantum Spatial completed a field survey of 76 ground control (calibration) points along with 155 QA points in Vegetated and Non-Vegetated land cover classifications (total of 237 points) as an independent test of the accuracy of this project.

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 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, 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 in NAD83 (2011) UTM Zone 18N Meters; NAVD88 (Geoid 12A), Meters. In this document, horizontal coordinates for ground control and QA points for all LiDAR classes are reported in the same projection.

The required accuracy testing was performed on the LiDAR dataset (both the LiDAR point cloud and derived DEMs) according to the USGS LiDAR Base Specification Version 1.2 (2014). The locations for all tested QA points are shown in Figure 9 and Figure 10. The summary below provides the results of this testing.

More information about the ground control points and checkpoints can be found in the survey report in Appendix B.

5.1. Point Cloud Testing

Raw Nonvegetated Vertical Accuracy (Raw NVA): The tested Raw NVA for the dataset was found to be 0.04 m in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.085 m. This dataset meets the required NVA of 19.6 cm 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. See Figure 8 and Table 5.

5.2. Digital Elevation Model (DEM) Testing

The tested Nonvegetated Vertical Accuracy (NVA) for the dataset captured from the DEM using bi-linear interpolation to derive the DEM elevations was found to be 0.041 m in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.081 m. This dataset meets the required NVA of ≤ 19.6 cm at the 95% confidence level (based on NSSDA). See Figure 9 and Table 6.

The tested Vegetated Vertical Accuracy (VVA) for the dataset captured from the DEM using bi-linear interpolation for all classes (including the bare earth class) was found to be 0.263 m, which is stated in terms of the 95th percentile error. Therefore the data meets the required VVA of ≤ 29.4 cm. This test was based on the 95th percentile error (based on ASPRS guidelines) across all land cover categories. See Figure 10 and Table 7.

Figure 7. LiDAR Ground Control Points Used in Calibration

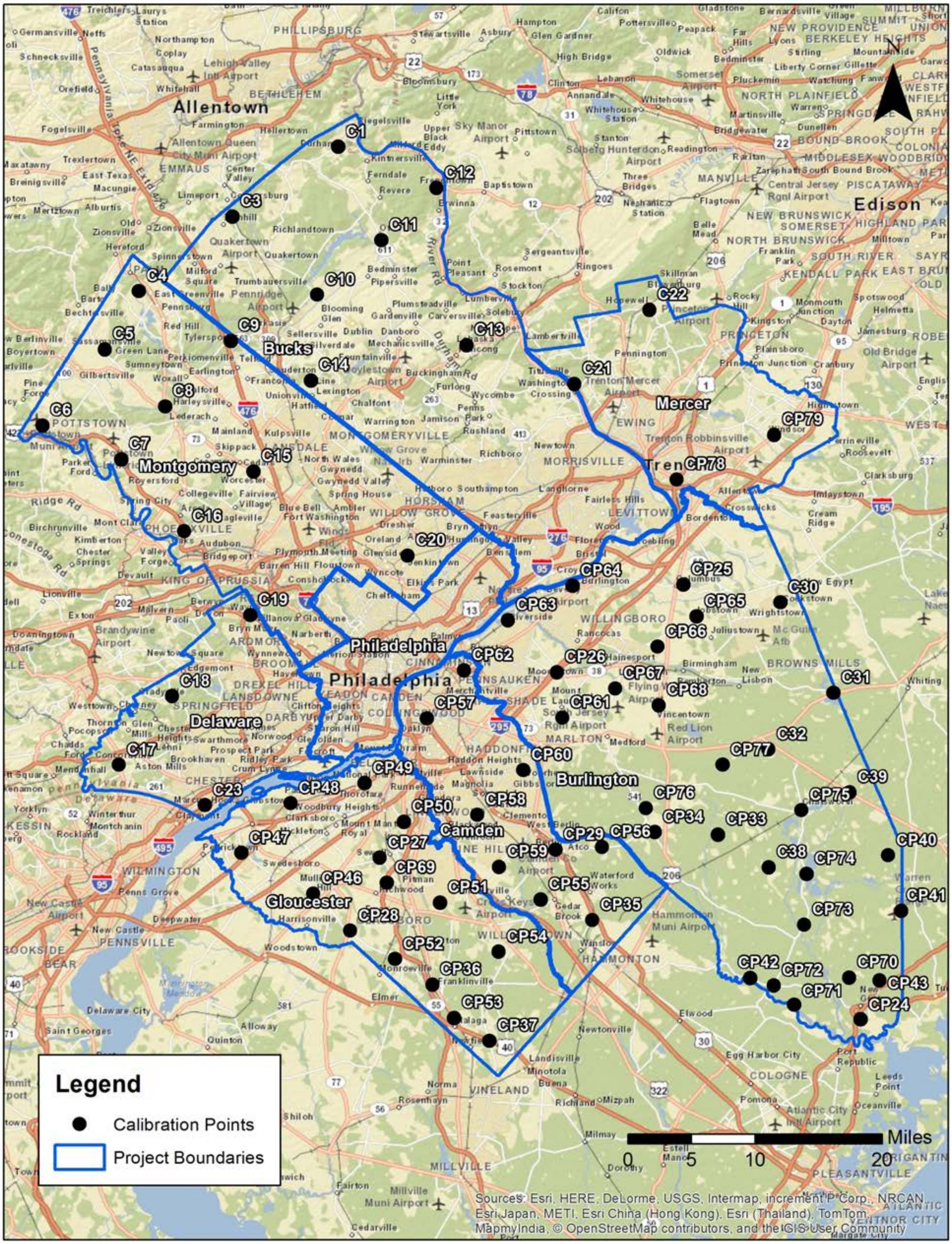


Table 4. LiDAR Ground Control-Calibration Point Report

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
C1	481038.52	4491359.73	83.67	83.69	0.02
C3	467694.60	4482528.39	186.93	186.91	-0.02
C4	455823.98	4473101.21	97.12	97.11	-0.01
C5	451577.95	4465722.25	115.57	115.59	0.02
C6	443701.25	4456080.62	48.65	48.65	0.00
C7	453614.68	4451794.69	75.91	75.91	0.00
C8	459161.52	4458489.48	67.24	67.23	-0.01
C9	467474.00	4466793.72	170.16	170.18	0.02
C10	478424.43	4472624.50	116.33	116.33	0.00
C11	486508.65	4479529.28	103.76	103.77	0.01
C12	493490.42	4486141.79	119.17	119.12	-0.05
C13	497298.86	4466241.91	94.29	94.27	-0.02
C14	477628.90	4461772.15	167.02	167.01	-0.01
C15	470332.84	4450278.08	77.31	77.30	-0.01
C16	461616.05	4442680.42	32.99	33.03	0.04
C17	453340.50	4413135.05	117.80	117.75	-0.05
C18	460055.03	4421846.58	128.59		
C19	469970.84	4432094.75	119.87	119.87	0.00
C20	489850.10	4439610.34	56.36	56.41	0.05
C21	510943.78	4461326.15	18.55	18.56	0.01
C22	520437.69	4470732.77	52.48	52.48	0.00
C23	464190.00	4408028.76	8.72	8.72	0.00
C30	536981.13	4433696.92	29.58	29.57	-0.01
C31	543710.14	4422271.67	32.51	32.47	-0.04
C32	535503.24	4415104.07	32.73	32.72	-0.01
C38	535539.82	4400182.28	17.71	17.67	-0.04
C39	545754.09	4409673.57	40.81	40.81	0.00
CP24	547150.03	4380951.77	0.85	0.87	0.02
CP25	524718.16	4435951.60	21.99	21.93	-0.06
CP26	508744.96	4424856.06	12.34	12.26	-0.08
CP27	486309.41	4401391.79	46.25	46.24	-0.01
CP28	482573.78	4392160.51	41.41	41.32	-0.09
CP29	508557.42	4402389.99	50.65	50.65	0.00

Number	Easting	Northing	Known Z	Laser Z	Dz
CP33	529108.81	4404320.07	17.01	16.98	-0.03
CP34	521124.20	4404633.12	25.12	25.10	-0.02
CP35	513192.68	4393488.95	30.83	30.86	0.03
CP36	492983.94	4385354.16	32.67	32.63	-0.04
CP37	500184.56	4378228.29	36.40	36.36	-0.04
CP40	550604.31	4401690.39	29.75	29.77	0.02
CP41	552295.84	4394697.04	40.83	40.82	-0.01
CP42	533160.04	4386164.43	1.40	1.42	0.02
CP43	549516.69	4385862.48	7.25	7.28	0.04
CP46	477927.47	4396862.74	33.98	34.01	0.03
CP47	468823.34	4401984.71	4.60	4.62	0.02
CP48	475044.91	4408298.30	3.55	3.60	0.05
CP49	484387.60	4410827.71	7.21	7.25	0.04
CP50	489382.52	4405925.26	22.36	22.34	-0.02
CP51	493948.65	4395705.13	47.12	47.10	-0.02
CP52	488253.55	4388571.68	41.30	41.31	0.01
CP53	495727.08	4381123.05	27.61	27.59	-0.02
CP54	501360.32	4389490.68	38.48	38.50	0.02
CP55	506661.23	4396120.77	47.04	47.03	-0.01
CP56	514450.99	4402732.97	30.40	30.37	-0.03
CP57	492292.67	4419031.85	3.79	3.78	-0.01
CP58	498659.83	4406835.29	20.53	20.50	-0.02
CP59	501435.93	4400255.07	44.32	44.32	0.00
CP60	504458.74	4412491.38	45.32	45.34	0.02
CP61	509447.90	4419128.40	21.06	21.05	-0.01
CP62	497012.58	4425119.70	15.11	15.09	-0.02
CP63	502552.15	4431445.39	4.90	4.93	0.03
CP64	510714.72	4435809.67	1.87	1.89	0.02
CP65	526383.16	4431921.99	22.00	22.12	0.12
CP66	521472.95	4428091.48	22.25	22.21	-0.04
CP67	516118.47	4422816.04	14.23	14.28	0.05
CP68	521622.09	4420677.10	12.57	12.63	0.06
CP69	487223.13	4398233.64	41.34	41.33	-0.01
CP70	545710.44	4386236.29	10.21	10.24	0.03
CP71	538730.11	4382791.89	1.66	1.65	-0.01
CP72	536167.92	4385228.90	8.18	8.20	0.02

Number	Easting	Northing	Known Z	Laser Z	Dz
CP73	540012.26	4392906.55	13.33	13.39	0.06
CP74	540309.995	4399345.399	17.119	17.10	-0.02
CP75	539636.26	4407406.41	29.70	29.73	0.03
CP76	519985.52	4407646.19	32.68	32.62	-0.06
CP77	529675.19	4413139.15	29.90	29.90	0.00
CP78	523881.14	4449264.18	19.09	19.10	0.01
CP79	536200.68	4454891.90	31.38	31.36	-0.02
Average Dz		0.00 m			
Minimum Dz		-0.089 m			
Maximum Dz		0.117 m			
Root Mean Square		0.033 m			
Std. Deviation		0.034 m			

Figure 8. Raw NVA Point Locations

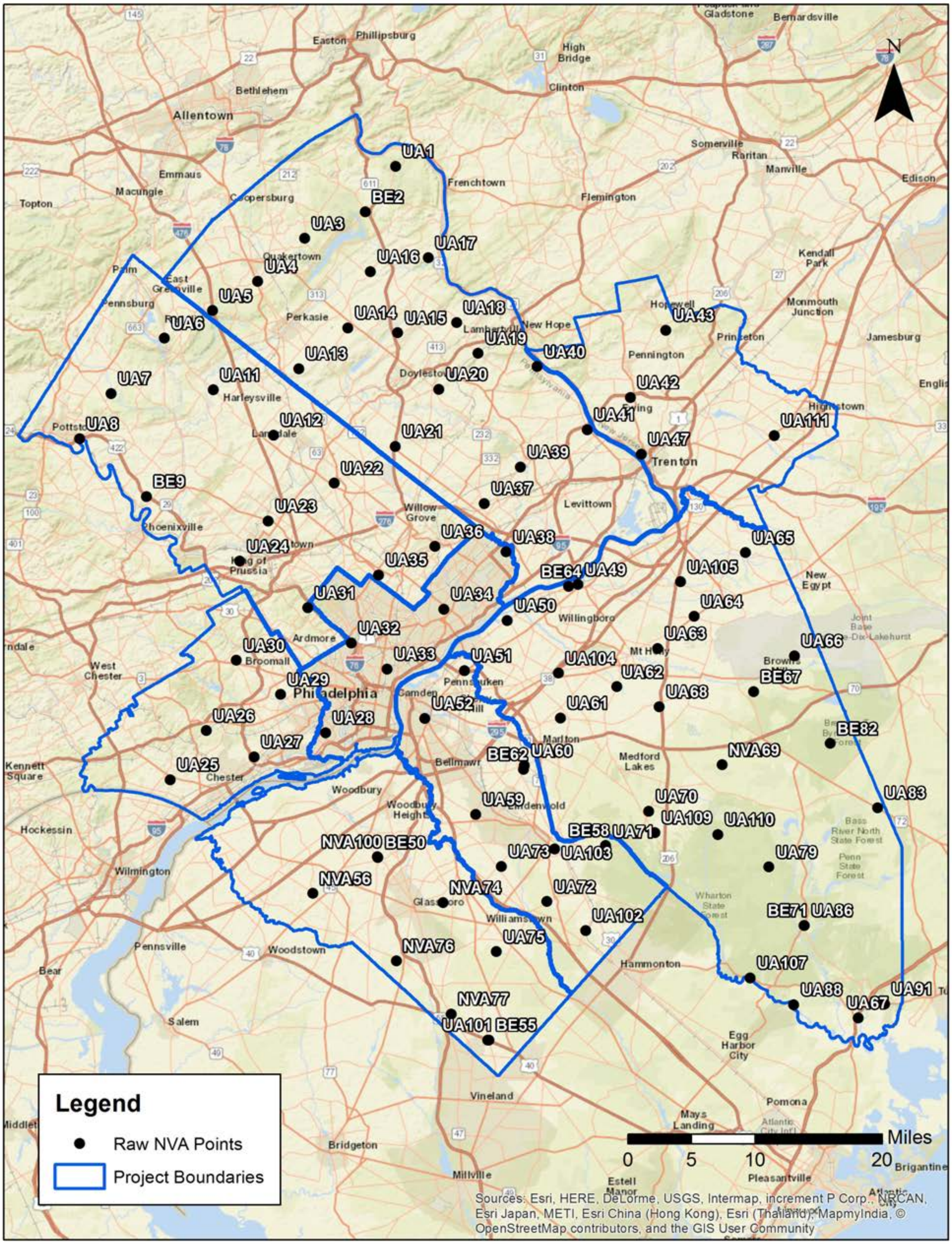


Table 5. LiDAR QA Point Report: Raw NVA

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
BE2	484489.50	4483119.17	159.32	159.28	-0.04
BE50	486090.22	4401431.25	43.53	43.56	0.03
BE55	500114.29	4378310.51	36.01	35.96	-0.05
BE58	514904.76	4402955.31	29.97	29.95	-0.02
BE62	504486.14	4412577.85	44.27	44.27	0.00
BE64	510200.85	4435705.05	3.37	3.33	-0.04
BE67	533612.34	4422418.17	16.61	16.60	-0.01
BE71	539990.88	4392826.77	12.58	12.66	0.08
BE82	543288.43	4415848.14	38.02	37.99	-0.03
BE9	456848.79	4447079.00	76.79	76.75	-0.04
NVA100	486031.32	4401513.80	42.82	42.81	0.00
NVA56	477852.96	4396881.77	32.08	32.10	0.02
NVA69	529610.29	4413143.12	29.71	29.70	0.00
NVA74	494333.29	4395708.84	44.82	44.76	-0.06
NVA76	488420.57	4388352.63	39.99	39.97	-0.02
NVA77	495377.49	4381620.82	31.77	31.75	-0.02
UA1	488312.93	4488869.52	184.23	184.20	-0.03
UA101	499994.46	4378326.22	34.75	34.71	-0.04
UA102	512389.21	4392173.35	35.45	35.48	0.03
UA103	508447.10	4402489.14	49.81	49.79	-0.02
UA104	508922.17	4424752.64	13.18	13.15	-0.03
UA105	524367.99	4436293.88	22.64	22.61	-0.03
UA106	550067.93	4382851.64	3.36	3.37	0.01
UA107	533177.79	4386195.28	1.16	1.18	0.02
UA109	521121.36	4404577.48	24.97	24.96	-0.01
UA11	465279.03	4460575.45	79.96	79.99	0.03
UA110	529105.67	4404332.58	16.95	16.95	0.00
UA111	536238.90	4454810.22	30.81	30.81	0.00
UA12	472886.22	4454864.91	92.28	92.27	-0.01
UA13	476097.16	4463274.05	189.29	189.32	0.03
UA14	482299.13	4468436.40	174.64	174.62	-0.01
UA15	488598.76	4467814.77	133.27	133.26	-0.01
UA16	485161.82	4475550.12	120.72	120.78	0.06

Number	Easting	Northing	Known Z	Laser Z	Dz
UA17	492446.41	4477300.86	133.09	133.08	-0.01
UA18	496042.75	4469115.38	115.39	115.36	-0.03
UA19	498778.99	4465221.97	73.35	73.36	0.01
UA20	493806.69	4460654.38	92.76	92.73	-0.03
UA21	488266.59	4453438.56	76.15	76.14	-0.01
UA22	480563.81	4448792.66	97.97	98.00	0.03
UA23	472236.87	4443988.47	66.38	66.42	0.05
UA24	468636.54	4438894.83	54.16	54.17	0.01
UA25	459802.50	4411248.37	68.17	68.15	-0.02
UA26	464377.08	4417480.71	85.31	85.31	0.00
UA27	470429.01	4414154.27	23.59	23.55	-0.04
UA28	479491.14	4417195.19	1.98	1.93	-0.05
UA29	473787.56	4422043.97	71.44	71.38	-0.06
UA3	476838.72	4479760.04	153.67	153.63	-0.04
UA30	468198.20	4426364.29	104.13	104.17	0.04
UA31	477219.17	4433016.46	105.16	105.18	0.02
UA32	482724.55	4428546.17	32.22	32.10	-0.12
UA33	487266.89	4425270.86	19.02	19.00	-0.02
UA34	494441.78	4432828.34	33.29	33.35	0.06
UA35	486177.19	4437163.41	109.92	109.91	-0.01
UA36	493287.03	4440774.58	35.90	35.91	0.01
UA37	499552.74	4446198.76	31.25	31.26	0.02
UA38	502310.67	4440093.36	34.78	34.81	0.03
UA39	504131.85	4450838.04	46.52	46.55	0.03
UA4	470887.95	4474313.50	159.62	159.62	0.00
UA40	506214.73	4463539.01	24.26	24.29	0.03
UA41	512549.15	4455551.74	25.01	25.03	0.02
UA42	518008.59	4459633.23	55.45	55.46	0.01
UA43	522524.96	4468127.61	74.60	74.65	0.05
UA47	519400.14	4452456.87	19.11	19.10	-0.01
UA49	511380.15	4435957.28	1.94	1.93	-0.01
UA5	465192.75	4470616.22	164.77	164.75	-0.02
UA50	502459.93	4431398.04	4.82	4.81	-0.01
UA51	497037.82	4425064.16	15.16	15.20	0.04
UA52	492040.07	4419009.21	4.05	4.00	-0.05
UA59	498446.36	4406889.70	17.21	17.14	-0.07

Number	Easting	Northing	Known Z	Laser Z	Dz
UA6	459090.87	4467121.95	95.90	95.92	0.02
UA60	504591.13	4413038.49	32.95	32.96	0.01
UA61	509164.84	4419064.02	19.98	19.98	0.00
UA62	516285.82	4423022.81	13.67	13.68	0.01
UA63	521484.94	4427859.88	21.15	21.12	-0.03
UA64	526069.75	4431932.94	22.32	22.30	-0.02
UA65	532561.49	4439978.94	29.57	29.84	0.27
UA66	538769.44	4426927.49	29.90	29.88	-0.02
UA67	546829.51	4381108.52	1.41	1.42	0.01
UA68	521688.92	4420493.57	11.96	12.00	0.04
UA7	452354.11	4460116.82	85.96	85.92	-0.04
UA70	520357.11	4407262.36	30.84	30.86	0.02
UA71	514904.45	4402824.87	31.04	31.06	0.02
UA72	507463.52	4395840.40	42.95	42.95	0.00
UA73	501725.59	4400289.61	44.13	44.16	0.03
UA75	501078.00	4389511.49	39.86	39.84	-0.02
UA79	535540.20	4400228.03	17.27	17.20	-0.07
UA8	448348.46	4454400.97	46.11	46.14	0.03
UA83	549285.48	4407721.36	58.86	58.88	0.02
UA86	540007.72	4392831.87	12.71	12.70	-0.01
UA88	538696.86	4382792.68	1.42	1.43	0.01
UA91	550166.42	4382885.54	3.89	3.91	0.02

Average Dz	0.00 m
Minimum Dz	-0.12 m
Maximum Dz	0.27 m
Root Mean Square	0.04 m
95% Confidence	0.085 m

Figure 9. NVA Point Locations

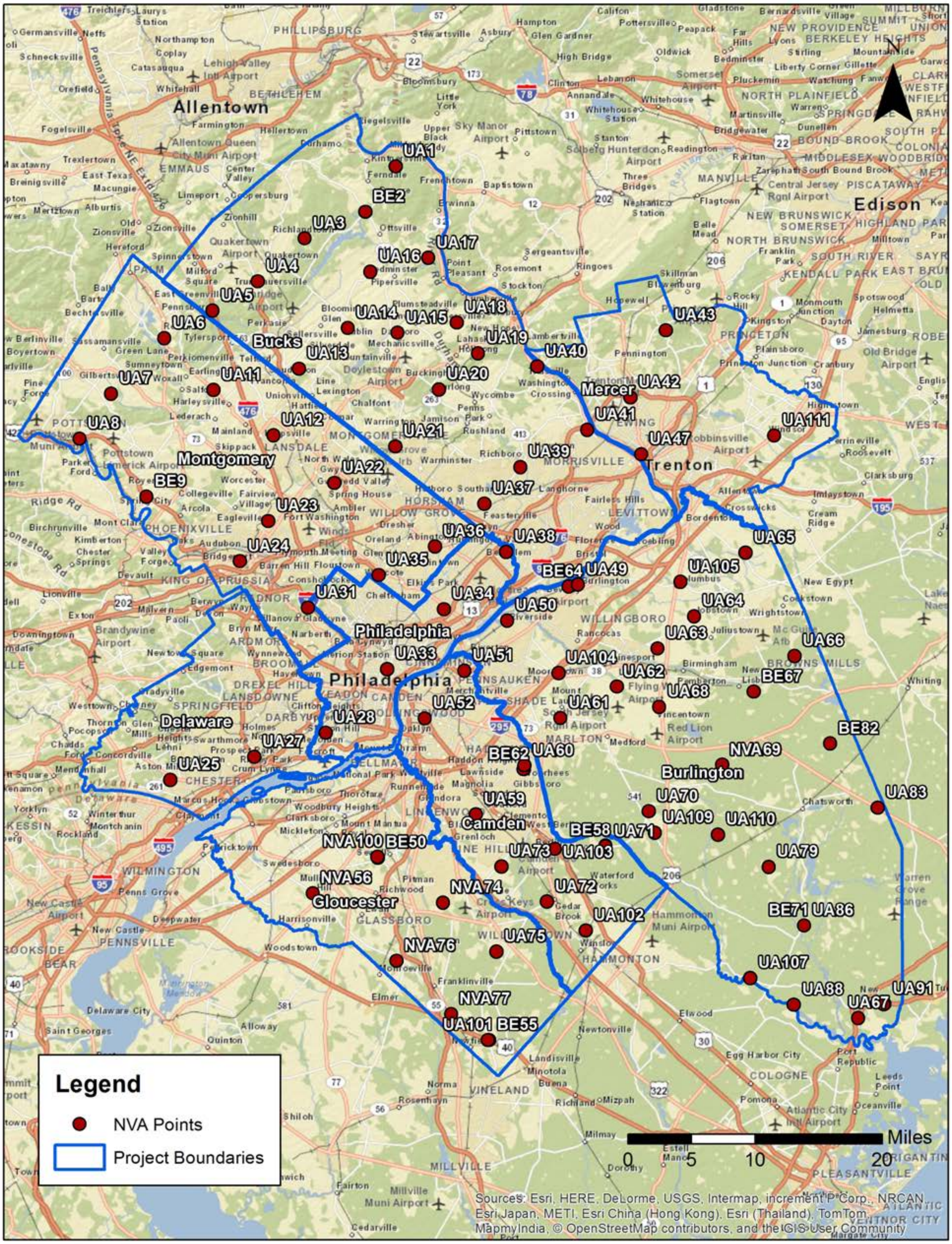


Table 6. LiDAR QA Point Report: NVA

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
BE2	484489.50	4483119.17	159.32	159.28	-0.04
BE9	456848.79	4447079.00	76.79	76.75	-0.04
BE50	486090.22	4401431.25	43.53	43.52	-0.01
BE55	500114.29	4378310.51	36.01	35.95	-0.07
BE58	514904.76	4402955.31	29.97	29.96	-0.01
BE62	504486.14	4412577.85	44.27	44.26	-0.01
BE64	510200.85	4435705.05	3.37	3.33	-0.04
BE67	533612.34	4422418.17	16.61	16.59	-0.03
BE71	539990.88	4392826.77	12.58	12.66	0.07
BE82	543288.43	4415848.14	38.02	37.99	-0.03
NVA56	477852.96	4396881.77	32.08	32.09	0.01
NVA69	529610.29	4413143.12	29.71	29.70	0.00
NVA74	494333.29	4395708.84	44.82	44.76	-0.06
NVA76	488420.57	4388352.63	39.99	39.97	-0.01
NVA77	495377.49	4381620.82	31.77	31.75	-0.03
NVA100	486031.32	4401513.80	42.82	42.81	0.00
UA1	488312.93	4488869.52	184.23	184.21	-0.01
UA3	476838.72	4479760.04	153.67	153.63	-0.04
UA4	470887.95	4474313.50	159.62	159.63	0.01
UA5	465192.75	4470616.22	164.77	164.74	-0.03
UA6	459090.87	4467121.95	95.90	95.92	0.02
UA7	452354.11	4460116.82	85.96	85.92	-0.04
UA8	448348.46	4454400.97	46.11	46.14	0.03
UA11	465279.03	4460575.45	79.96	79.97	0.01
UA12	472886.22	4454864.91	92.28	92.28	0.00
UA13	476097.16	4463274.05	189.29	189.32	0.03
UA14	482299.13	4468436.40	174.64	174.62	-0.02
UA15	488598.76	4467814.77	133.27	133.28	0.01
UA16	485161.82	4475550.12	120.72	120.76	0.04
UA17	492446.41	4477300.86	133.09	133.08	0.00
UA18	496042.75	4469115.38	115.39	115.36	-0.03
UA19	498778.99	4465221.97	73.35	73.35	0.00
UA20	493806.69	4460654.38	92.76	92.74	-0.02

Number	Easting	Northing	Known Z	Laser Z	Dz
UA21	488266.59	4453438.56	76.15	76.14	-0.01
UA22	480563.81	4448792.66	97.97	98.01	0.03
UA23	472236.87	4443988.47	66.38	66.42	0.04
UA24	468636.54	4438894.83	54.16	54.17	0.01
UA25	459802.50	4411248.37	68.17	68.15	-0.02
UA26	464377.08	4417480.71	85.31	85.30	-0.01
UA27	470429.01	4414154.27	23.59	23.55	-0.04
UA28	479491.14	4417195.19	1.98	1.94	-0.04
UA29	473787.56	4422043.97	71.44	71.38	-0.06
UA30	468198.20	4426364.29	104.13	104.16	0.03
UA31	477219.17	4433016.46	105.16	105.17	0.01
UA32	482724.55	4428546.17	32.22	32.14	-0.08
UA33	487266.89	4425270.86	19.02	19.01	-0.01
UA34	494441.78	4432828.34	33.29	33.36	0.08
UA35	486177.19	4437163.41	109.92	109.92	0.01
UA36	493287.03	4440774.58	35.90	35.92	0.02
UA37	499552.74	4446198.76	31.25	31.25	0.01
UA38	502310.67	4440093.36	34.78	34.82	0.03
UA39	504131.85	4450838.04	46.52	46.55	0.04
UA40	506214.73	4463539.01	24.26	24.29	0.03
UA41	512549.15	4455551.74	25.01	25.03	0.02
UA42	518008.59	4459633.23	55.45	55.47	0.01
UA43	522524.96	4468127.61	74.60	74.63	0.03
UA47	519400.14	4452456.87	19.11	19.10	-0.01
UA49	511380.15	4435957.28	1.94	1.91	-0.02
UA50	502459.93	4431398.04	4.82	4.81	0.00
UA51	497037.82	4425064.16	15.16	15.17	0.01
UA52	492040.07	4419009.21	4.05	3.99	-0.06
UA59	498446.36	4406889.70	17.21	17.15	-0.07
UA60	504591.13	4413038.49	32.95	32.96	0.01
UA61	509164.84	4419064.02	19.98	19.97	0.00
UA62	516285.82	4423022.81	13.67	13.69	0.02
UA63	521484.94	4427859.88	21.15	21.12	-0.03
UA64	526069.75	4431932.94	22.32	22.30	-0.02
UA65	532561.49	4439978.94	29.57	29.84	0.27
UA66	538769.44	4426927.49	29.90	29.89	-0.01

Number	Easting	Northing	Known Z	Laser Z	Dz
UA67	546829.51	4381108.52	1.41	1.42	0.01
UA68	521688.92	4420493.57	11.96	12.00	0.04
UA70	520357.11	4407262.36	30.84	30.85	0.01
UA71	514904.45	4402824.87	31.04	31.07	0.03
UA72	507463.52	4395840.40	42.95	42.95	0.00
UA73	501725.59	4400289.61	44.13	44.16	0.02
UA75	501078.00	4389511.49	39.86	39.83	-0.03
UA79	535540.20	4400228.03	17.27	17.21	-0.07
UA83	549285.48	4407721.36	58.86	58.87	0.01
UA86	540007.72	4392831.87	12.71	12.73	0.02
UA88	538696.86	4382792.68	1.42	1.43	0.01
UA91	550166.42	4382885.54	3.89	3.91	0.02
UA101	499994.46	4378326.22	34.75	34.73	-0.02
UA102	512389.21	4392173.35	35.45	35.42	-0.03
UA103	508447.10	4402489.14	49.81	49.82	0.00
UA104	508922.17	4424752.64	13.18	13.12	-0.05
UA105	524367.99	4436293.88	22.64	22.62	-0.02
UA106	550067.93	4382851.64	3.36	3.36	0.00
UA107	533177.79	4386195.28	1.16	1.18	0.02
UA109	521121.36	4404577.48	24.97	24.96	-0.01
UA110	529105.67	4404332.58	16.95	16.94	-0.01
UA111	536238.90	4454810.22	30.81	30.81	0.00
	Average Dz	0.00 m			
	Minimum Dz	-0.080 m			
	Maximum Dz	0.267 m			
	Root Mean Square	0.041 m			
	95% Confidence	0.081 m			

Figure 10. VVA Point Locations

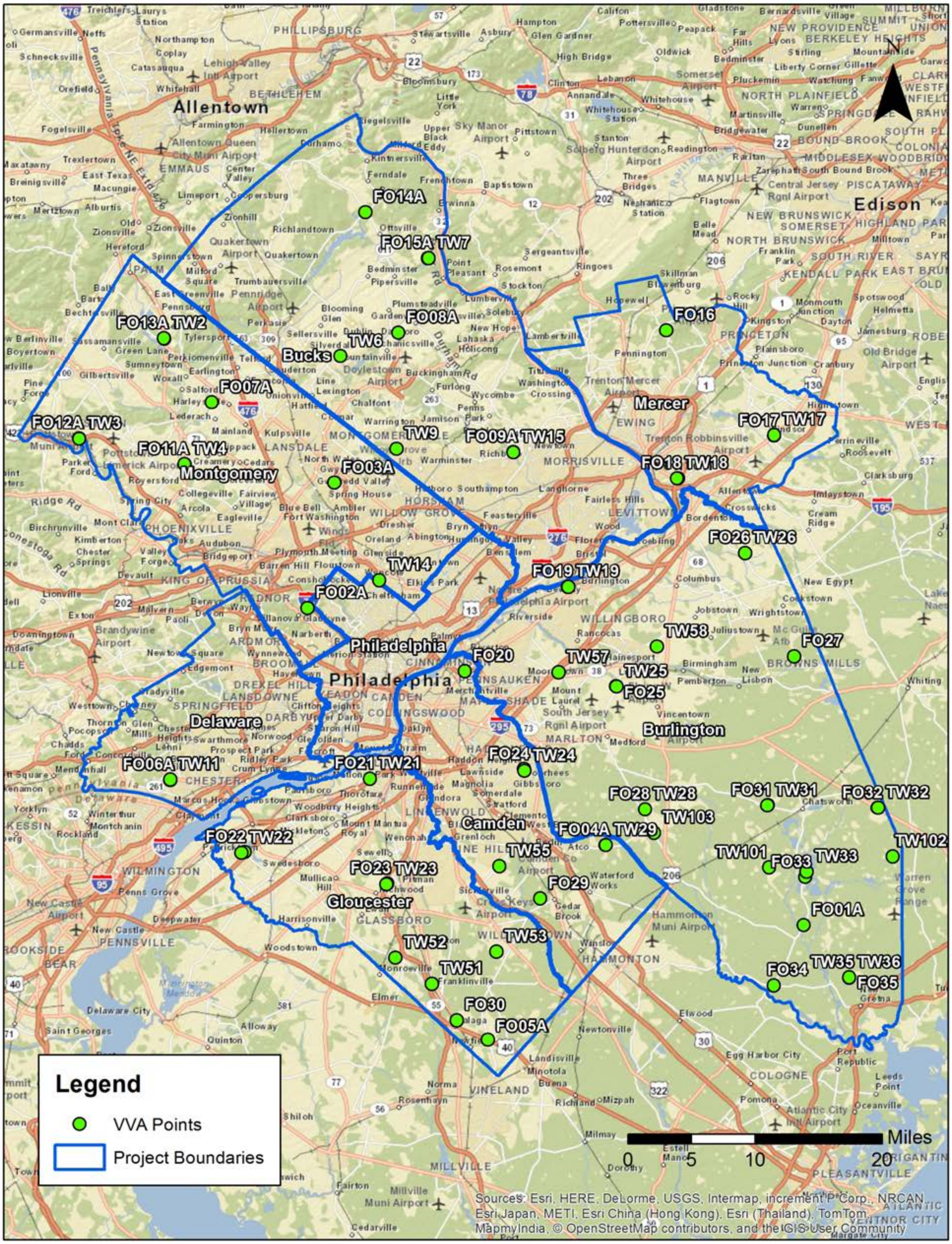


Table 7. LiDAR QA Point Report: VVA

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
FO01A	539950.80	4392850.43	11.81	11.98	0.17
FO02A	477194.94	4432990.87	104.33	104.46	0.12
FO03A	480563.64	4448835.61	99.76	99.91	0.14
FO04A	514886.77	4402999.81	29.68	29.79	0.11
FO05A	500007.06	4378351.75	34.35	34.50	0.15
FO06A	459837.46	4411244.47	69.47	69.58	0.12
FO07A	465093.69	4459006.56	56.82	57.07	0.24
FO08A	488671.03	4467819.29	136.90	137.06	0.16
FO09A	503227.35	4452726.00	33.73	34.00	0.27
FO10A	482767.10	4428542.43	33.19	33.26	0.07
FO11A	461691.50	4451151.13	34.25	34.39	0.14
FO12A	448333.52	4454451.16	44.42	44.53	0.12
FO13A	459083.27	4467092.71	97.66	97.63	-0.03
FO14A	484510.43	4483076.11	159.47	159.52	0.05
FO15A	492415.80	4477266.09	133.42	133.70	0.28
FO16	522564.78	4468118.54	74.65	74.63	-0.03
FO17	536197.37	4454780.15	29.67	29.70	0.03
FO18	524011.95	4449401.21	18.52	18.59	0.07
FO19	510133.64	4435696.50	3.50	3.48	-0.03
FO20	497090.99	4425013.08	13.07	13.09	0.02
FO21	485086.47	4411405.80	2.24	2.27	0.03
FO22	469201.80	4402115.17	1.69	1.71	0.02
FO23	487270.76	4398113.57	39.00	38.98	-0.03
FO24	504547.20	4412607.70	42.68	42.69	0.01
FO25	516190.70	4423109.11	12.67	12.68	0.02
FO26	532507.29	4439967.03	29.08	29.05	-0.03
FO27	538727.37	4426898.20	29.51	29.55	0.04
FO28	519874.69	4407511.25	31.72	31.74	0.02
FO29	506624.30	4396234.93	46.26	46.31	0.05
FO30	496039.04	4380808.46	35.89	35.89	0.00
FO31	535359.11	4408037.08	33.67	33.74	0.07
FO32	549315.59	4407678.70	58.13	58.11	-0.02
FO33	540127.97	4398930.01	17.47	17.45	-0.01

Number	Easting	Northing	Known Z	Laser Z	Dz
FO34	536160.10	4385254.87	7.44	7.46	0.02
FO35	545688.30	4386214.01	9.79	9.80	0.01
TW2	459051.23	4467114.02	96.34	96.40	0.07
TW3	448316.38	4454423.68	43.96	44.03	0.07
TW4	461655.02	4451183.36	36.90	36.89	-0.01
TW6	481345.36	4464853.43	194.17	194.18	0.01
TW7	492492.45	4477270.59	131.94	131.97	0.03
TW9	488418.45	4453127.80	70.44	70.48	0.04
TW11	459813.05	4411283.69	69.90	69.84	-0.05
TW13	482748.18	4428557.84	31.88	31.84	-0.04
TW14	486276.94	4436519.71	99.43	99.47	0.04
TW15	503222.82	4452704.23	35.05	35.10	0.05
TW17	536237.07	4454892.53	31.45	31.49	0.05
TW18	523923.98	4449381.49	19.34	19.46	0.11
TW19	510144.65	4435674.05	3.20	3.21	0.01
TW21	485100.31	4411403.42	2.41	2.40	-0.01
TW22	468814.53	4401995.83	4.85	4.84	-0.01
TW23	487152.11	4398038.66	40.74	40.77	0.03
TW24	504626.68	4412367.27	46.43	46.43	0.00
TW25	516234.23	4423056.25	12.77	13.02	0.25
TW26	532528.32	4439972.58	29.42	29.45	0.03
TW28	519883.76	4407530.25	31.68	31.75	0.08
TW29	514932.66	4402992.90	29.25	29.25	0.00
TW31	535312.53	4407997.52	34.21	34.17	-0.04
TW32	549328.23	4407709.79	58.35	58.40	0.05
TW33	540309.14	4399651.70	17.22	17.40	0.18
TW35	545712.70	4386258.16	9.45	9.76	0.31
TW36	545712.70	4386258.15	9.44	9.76	0.33
TW51	492920.67	4385432.09	32.31	32.29	-0.03
TW52	488297.34	4388750.50	41.19	41.25	0.06
TW53	501052.51	4389522.02	39.69	39.68	-0.01
TW55	501462.86	4400337.78	44.41	44.56	0.15
TW57	508912.19	4424874.74	12.57	12.54	-0.03
TW58	521367.14	4428125.85	22.44	22.42	-0.02
TW101	535578.53	4400169.25	18.63	18.56	-0.07
TW102	551191.05	4401575.92	28.84	28.97	0.12

Number	Easting	Northing	Known Z	Laser Z	Dz
TW103	521043.51	4404580.14	25.05	25.01	-0.04

Average Dz	0.03 m
Minimum Dz	-0.074 m
Maximum Dz	0.325 m
Root Mean Square	0.108 m
95th Percentile	0.263 m