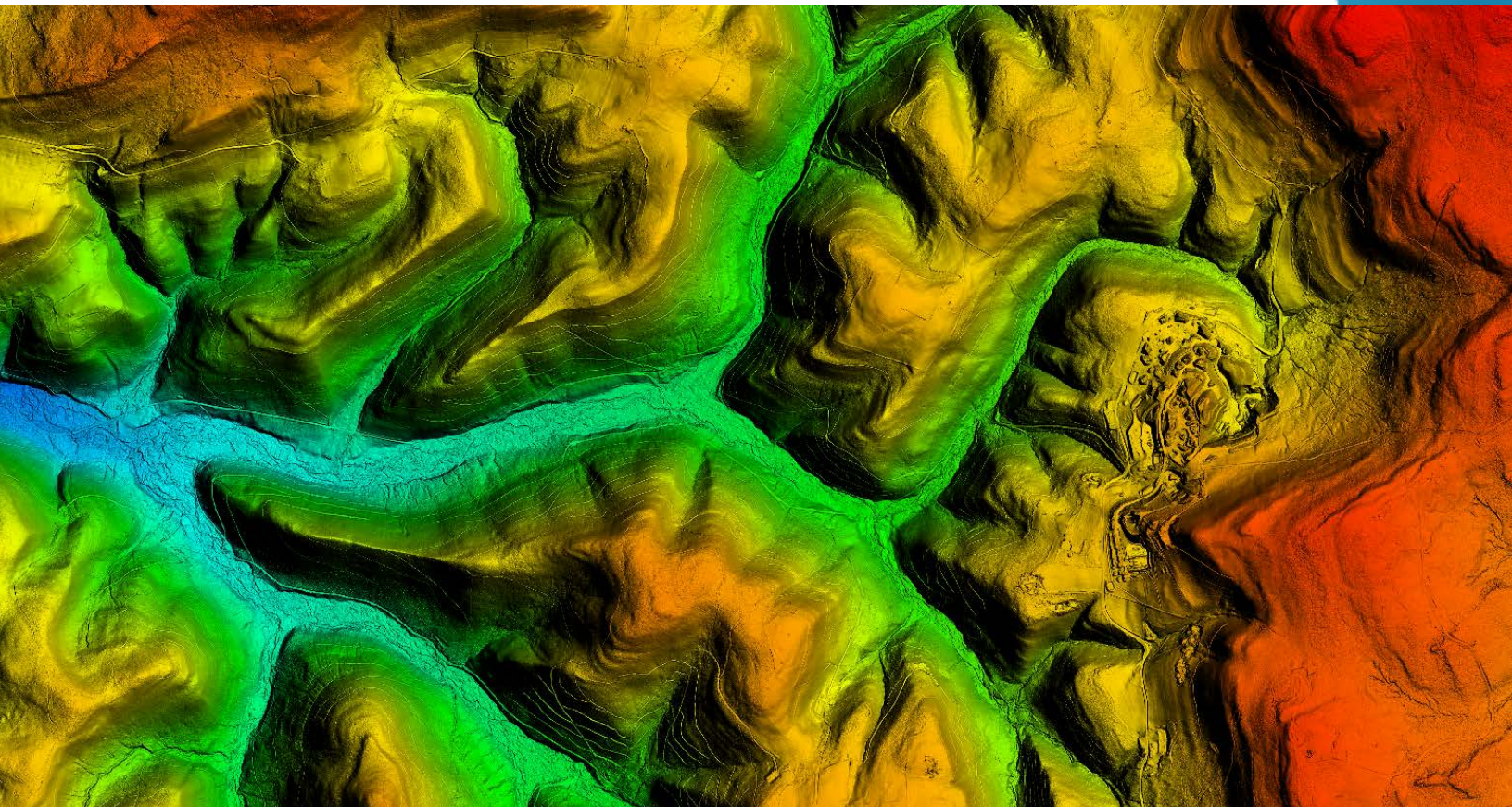


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PA_WESTERNPA_2019_D20 QL2 LIDAR PROJECT REPORT

Contract: G16PC00016
Task Order: #140G0220F0030

2020

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1. Summary / Scope

1.1. Summary

This report contains a summary of the PA_WesternPA_2019_D20 acquisition task order #140G0220F0030, issued by USGS under their Contract G16PC00016 on November 14, 2019. The QL2, State Plane North, portion of the task order yielded a project area covering approximately 6,282 square miles over Pennsylvania. The intent of this document is only to provide specific validation information for the data acquisition/collection, processing, and production of deliverables completed as specified in the task order.

1.2. Scope

Aerial topographic LiDAR was acquired 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	2300 m	58.5°	20%	≤ 10 cm

1.3. Coverage

The project boundary covers approximately 6,282 square miles over western Pennsylvania. A buffer of 100 meters was created to meet task order specifications. Project extents are shown in Figure 1.

1.4. Duration

LiDAR data was acquired from December 8, 2019 to May 2, 2020 in 34 total lifts. See “Section: 2.4. Time Period” for more details.

1.5. Issues

There were no major issues to report for this project.

PA_WesternPA_2019_D20 QL2 Projected Coordinate System: Pennsylvania State Plane North FIPS 3701 Horizontal Datum: NAD 1983(2011) Vertical Datum: NAVD88 (GEOID 12b) Units: US Feet	
Lidar Point Cloud	Classified Point Cloud in .LAS 1.4 format
Rasters	<ul style="list-style-type: none"> • 2-foot Hydro-flattened Bare Earth Digital Elevation Model (DEM) in GeoTIFF format • 2-foot Intensity images in GeoTIFF format
Vectors	Shapefiles (*.shp) <ul style="list-style-type: none"> • Project Boundary • LiDAR Tile Index • Continuous Hydro-flattened Breaklines Geodatabase (*.gdb) <ul style="list-style-type: none"> • 1-foot contours
Reports	Reports in PDF format <ul style="list-style-type: none"> • Focus on Delivery • Focus on Accuracy • Project Report
Metadata	XML Files (*.xml) <ul style="list-style-type: none"> • Breaklines • Classified Point Cloud • DEM • Intensity Imagery • Contours

PA_WesternPA_2019_D20 QL2 Boundary

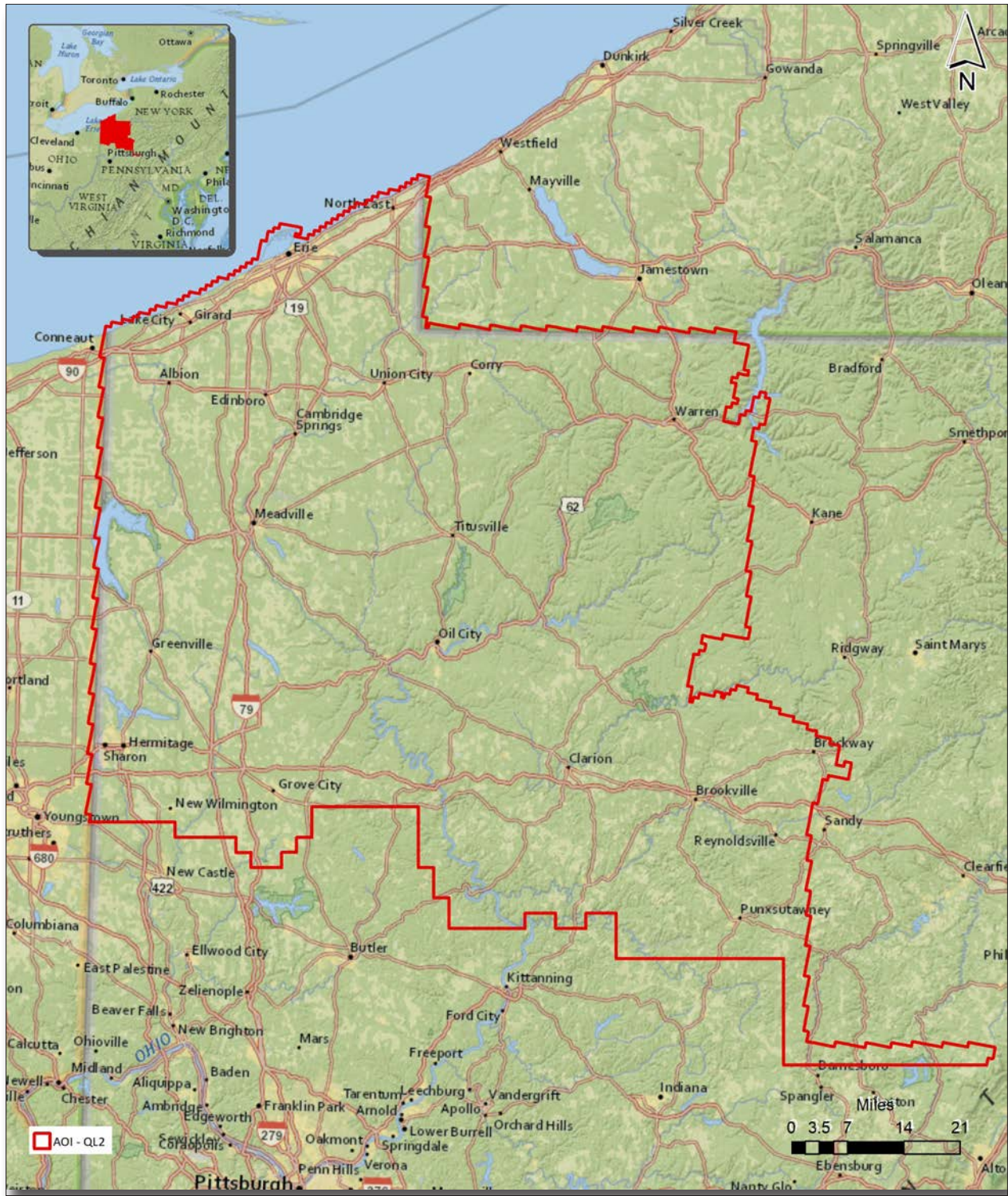


Figure 1. Project Boundary

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.

Detailed project flight planning calculations were performed for the project using RiPARAMETER and FMS Planner planning software. Planned flight lines are shown in Figure 2.

2.2. LiDAR Sensor

Quantum Spatial utilized the following sensors for lidar data acquisition:

Riegl VQ1560i: sensors 4046, 3061, 3543, 1264

Optech Galaxy Prime: sensor 419

The Riegl 1560i system has a laser pulse repetition rate of up to 2 MHz resulting in more than 1.3 million measurements 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 an unlimited number of targets per pulse from the laser.

The Optech Galaxy Prime system is capable of collecting data at a maximum frequency of 550 kHz. These systems utilize a Multi-Pulse in the Air option (MPIA). These sensors are also equipped with the ability to measure up to 8 returns per outgoing pulse

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

Western Pennsylvania 2019 D20 QL2 Planned Flight Lines

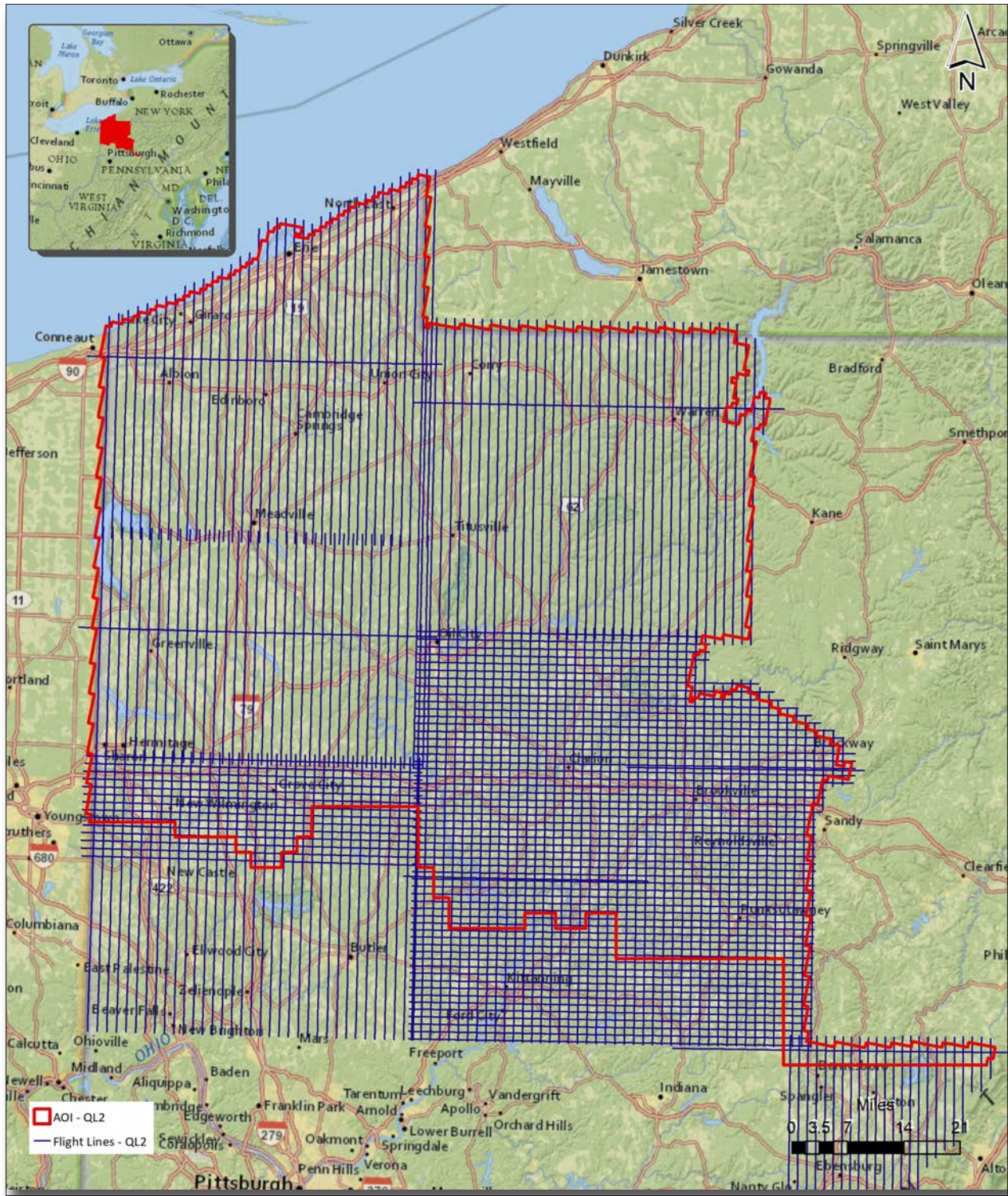


Figure 2. Planned Flight Lines

Table 2. LiDAR System Specifications

		Riegl VQ1560i	Optech Galaxy Prime
Terrain and Aircraft Scanner	Flying Height	2300 m	2438.4 m
	Recommended Ground Speed	140 kts	125 kts
Scanner	Field of View	58.5°	40
	Scan Rate Setting Used	159 Hz	54 Hz
Laser	Laser Pulse Rate Used	350 kHz	350 kHz
	Multi Pulse in Air Mode	yes	7
Coverage	Full Swath Width	2576 m	1775.16 m
	Line Spacing	2061 m	1420.13 m
Point Spacing and Density	Average Point Spacing	0.71 m	0.57 m
	Average Point Density	2 pts / m ²	3.07 pts / m ²

Figure 3. Riegl VQ1560i and Optech Galaxy Prime LiDAR Sensor



2.3. Aircraft

All flights for the project were accomplished through the use of a customized plane. Plane type and tail number are listed below.

LiDAR Collection Planes

- Piper Navajo (twin-piston), Tail Numbers: N22GE, CFXCI, CFKMA
- Piper Aztec (twin-piston), Tail Number: N7052H

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, proving ideal for collection of high-density, consistent data posting using a state-of-the-art Riegl VQ1560i and Optech Galaxy LiDAR system. Some of Quantum Spatial’s operating aircraft can be seen in Figure 4 below.

Figure 4. Some of Quantum Spatial’s Planes



2.4. Time Period

Project specific flights were conducted between December 8, 2019 and May 2, 2020. Thirty-four aircraft lifts were completed. Accomplished lifts are listed below.

- 12082019A (SN4046,N22GE)
- 01072020A (SN4046,N22GE)
- 03012020A (SN3061,N22GE)
- 03052020A (SN3543,C-FXCI)
- 03052020B (SN3543,C-FXCI)
- 03072020B (SN3061,N22GE)
- 03082020A (SN3061,N22GE)
- 03082020A (SN3543,C-FXCI)
- 03082020B (SN3061,N22GE)
- 03092020A (SN1264,C-FKMA)
- 03092020A (SN3061,N22GE)
- 03092020A (SN3543,C-FXCI)
- 03092020B (SN3061,N22GE)
- 03152020B (SN419,N7052H)
- 03152020C (SN419,N7052H)
- 03152020D (SN419,N7052H)
- 03162020A (SN3543,C-FXCI)
- 03182020A (SN3543,C-FXCI)
- 03182020A (SN419,N7052H)
- 03182020B (SN419,N7052H)
- 03222020A (SN3543,C-FXCI)
- 03222020A (SN419,N7052H)
- 03262020A (SN419,N7052H)
- 04022020C (SN419,N7052H)
- 04032020A (SN419, N7052H)
- 04032020A (SN419,N7052H)
- 04062020A (SN419,N7052H)
- 04062020C (SN419,N7052H)
- 04062020F (SN419,N7052H)
- 04062020G (SN419,N7052H)
- 04062020K (SN419,N7052H)
- 04202020A (SN419,N7052H)
- 04202020C (SN419,N7052H)
- 05022020A (SN419,N7052H)

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

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc).

3.2. LiDAR Processing

Applanix + POSPac 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. Applanix 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.

Point clouds were created using RiPROCESS and Opetch LMS software. The generated point cloud is the mathematical three dimensional composite of all returns from all laser pulses as determined from the aerial mission. The point cloud is imported into GeoCue distributive processing software. Imported data is tiled and then calibrated using TerraMatch and proprietary software. Using TerraScan, the vertical accuracy of the surveyed ground control is tested and any bias is removed from the data. TerraScan and TerraModeler software packages are then used for automated data classification and manual cleanup. The data are manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler.

DEMs and Intensity Images are then generated using proprietary software. In the bare earth surface model, above-ground features are excluded from the data set. Global Mapper is used as a final check of the bare earth dataset.

Finally, proprietary software is used to perform statistical analysis of the LAS files.

Software	Version
Applanix + POSPac	8.6
RiPROCESS	1.8.6
Optech LMS	4.4
GeoCue	19.1;20.1
Global Mapper	21.008
TerraModeler	21.016
TerraScan	21.007
TerraMatch	20.004

3.3. LAS Classification Scheme

The classification classes are determined by the USGS Version 2.1 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:

Table 3. LAS Classifications

	Classification Name	Description
1	Processed, but Unclassified	Laser returns that are not included in the ground class, or any other project classification
2	Bare earth	Laser returns that are determined to be ground using automated and manual cleaning algorithms
7	Low Noise	Laser returns that are often associated with scattering from reflective surfaces, or artificial points below the ground surface
9	Water	Laser returns that are found inside of hydro features
17	Bridge Deck	Laser returns falling on bridge decks
18	High Noise	Laser returns that are often associated with birds or artificial points above the ground surface
20	Ignored Ground	Ground points that fall within the given threshold of a collected hydro feature.
22	Temporal Exclusion	Points that are excluded due to differences in collection dates

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 20). 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.

Any noise that was identified either through manual review or automated routines was classified

to the appropriate class (ASPRS Class 7 and/or ASPRS Class 18) followed by flagging with the withheld bit.

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's 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-Flattened Breakline Processing

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 streams and rivers using Quantum Spatial's 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 20).

The breakline files were then translated to Esri file geodatabase format using Esri conversion tools.

Breaklines are reviewed against lidar intensity imagery to verify completeness of capture. All breaklines are then compared to TINs (triangular irregular networks) created from ground only points prior to water classification. The horizontal placement of breaklines is compared to terrain features and the breakline elevations are compared to lidar elevations to ensure all breaklines match the lidar within acceptable tolerances. Some deviation is expected between breakline and lidar elevations due to monotonicity, connectivity, and flattening rules that are enforced on the breaklines. Once completeness, horizontal placement, and vertical variance is reviewed, all breaklines are reviewed for topological consistency and data integrity using a combination of Esri Data Reviewer tools and proprietary tools.

3.6. Hydro-Flattened Raster DEM Processing

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a 2-foot Raster DEM. Using automated scripting routines within proprietary software, a GeoTIFF 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.

3.7. Intensity Image Processing

GeoCue software was used to create the deliverable intensity images. All withheld points were

ignored during this process. This helps to ensure a more aesthetically pleasing image. The GeoCue software was then used to verify full project coverage as well. GeoTIFF files with a cell size of 2-foot were then provided as the deliverable for this dataset requirement.

3.8. Contour Processing

Using automated scripting routines within ArcMap, a terrain surface was created using the ground (ASPRS Class 2) LiDAR data as well as the hydro-flattened breaklines. This surface was then used to generate the final 1-foot contour dataset in Esri File Geodatabase format.

PA_WesternPA_2019_D20 QL2 5000 x 5000 Foot Tile Layout

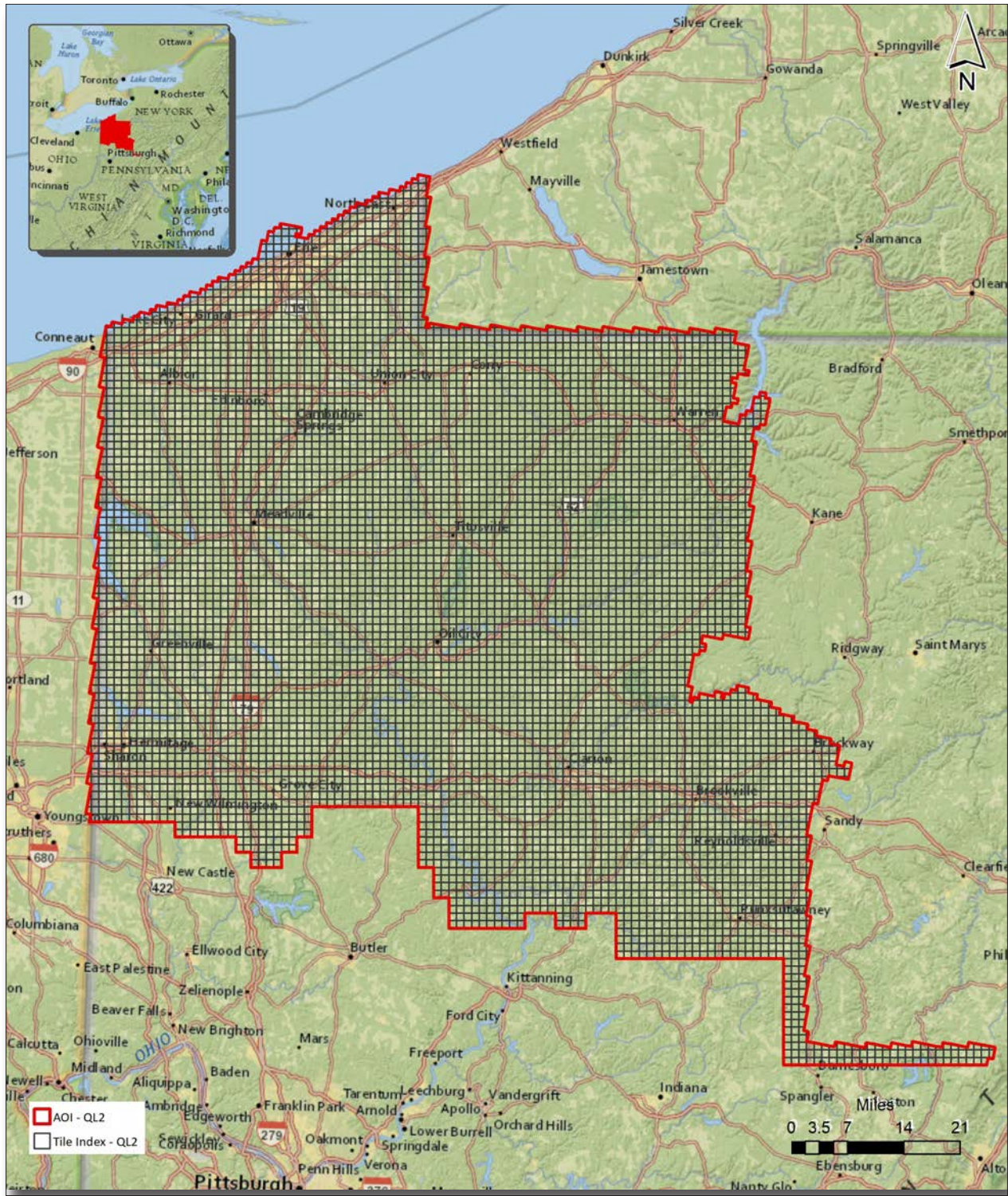


Figure 5. Lidar Tile Layout

PA_WesternPA_2019_D20 QL2 10000 x 10000 Foot Tile Layout

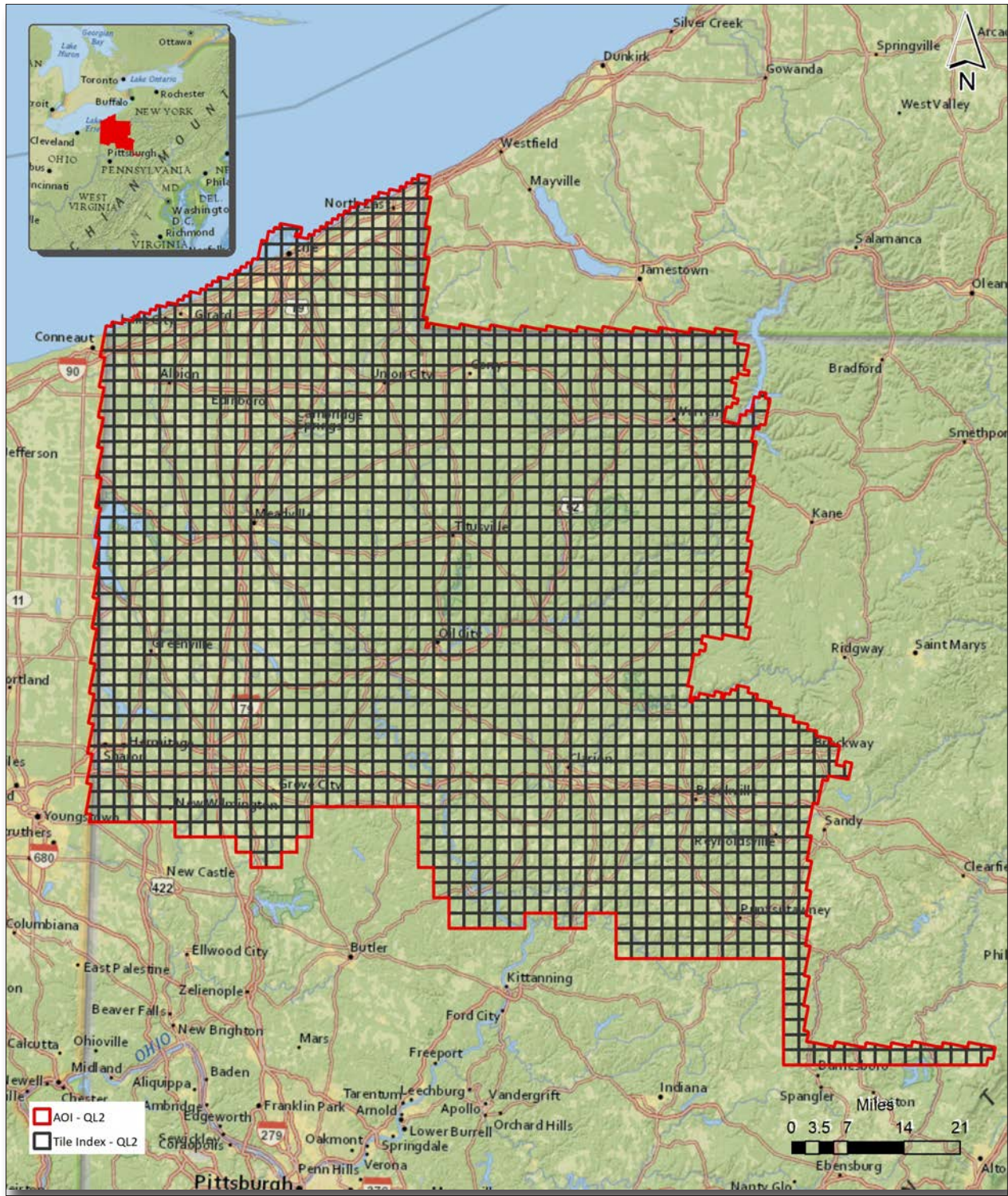


Figure 6. Lidar Tile Layout

4. Project Coverage Verification

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.

PA_WesternPA_2019_D20 QL2 Lidar Coverage

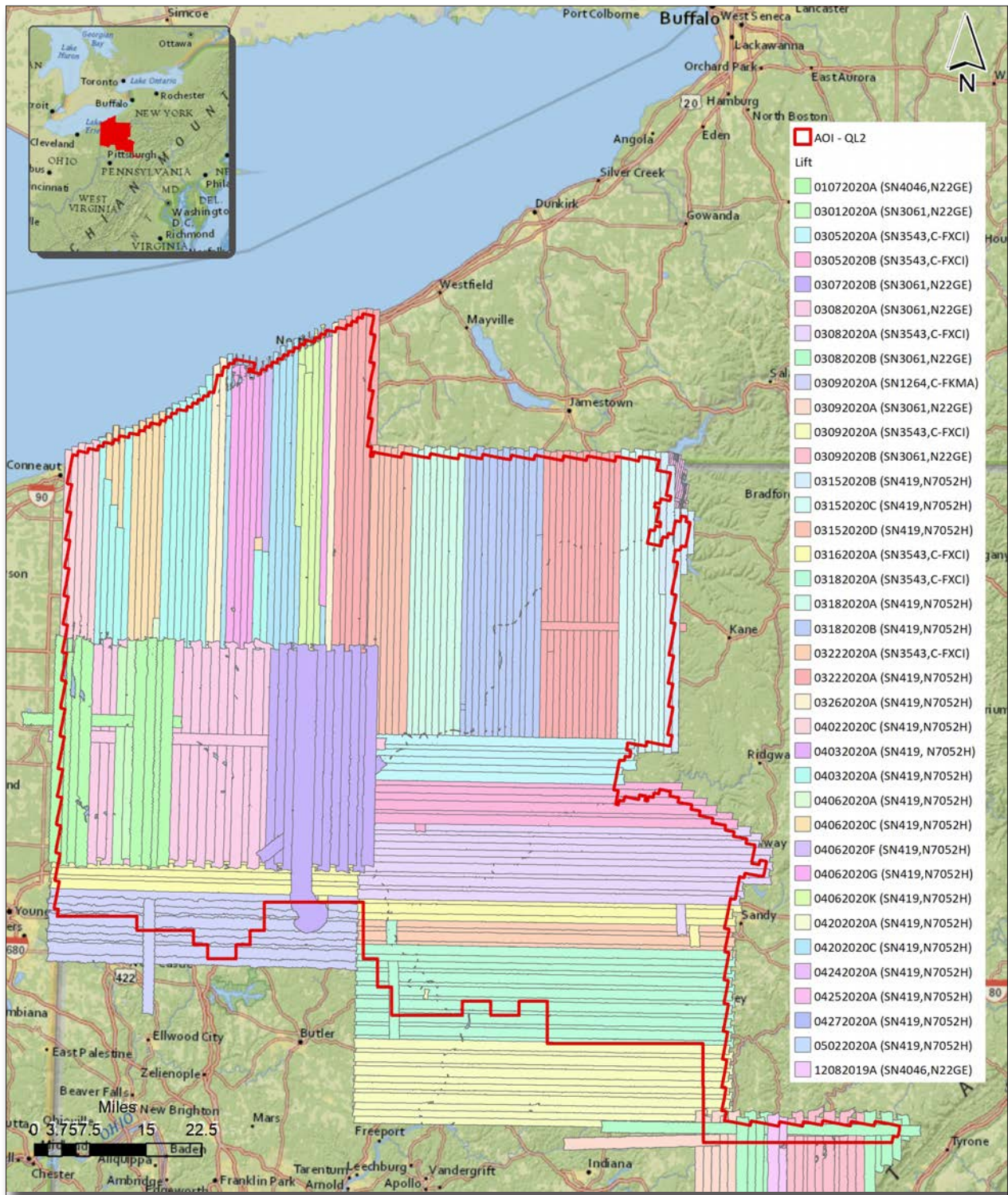


Figure 7. Lidar Coverage

5. Ground Control and Check Point Collection

On behalf of Quantum Spatial, JMT completed the field survey. A total of 274 points were used for calibration. Independent points were collected to assess the vertical accuracy of the data.

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.

5.1. Calibration Control Point Testing

Figure 7 shows the location of each bare earth calibration point for the project area. TerraScan was used to perform a quality assurance check using the LiDAR bare earth calibration points. The 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.

5.2. Point Cloud Testing

The project specifications require that only Non-Vegetated Vertical Accuracy (NVA) be computed for raw lidar point cloud swath files. The required accuracy (ACCz) is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the “bare earth” and “urban” land cover classes. The NVA was tested with 291 checkpoints located in bare earth and urban (non-vegetated) areas. These check points were not used in the calibration or post processing of the lidar point cloud data. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See survey report for additional survey methodologies.

Elevations from the unclassified lidar surface were measured for the x,y location of each check point. Elevations interpolated from the lidar surface were then compared to the elevation values of the surveyed control points. AccuracyZ has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using $RMSE(z) \times 1.9600$ as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines.

5.3. Digital Elevation Model (DEM) Testing

The project specifications require the accuracy (ACCz) of the derived DEM be calculated and reported in two ways:

1. The required NVA is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the “bare earth” and “urban” land cover classes. This is a required accuracy. The NVA was tested with 291 checkpoints located in bare earth and urban (non-vegetated) areas. See Figure 8.

2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for “brushlands/low trees” and “tall weeds/crops” land cover classes. The target VVA is: 29.4 cm at the 95th percentile, derived according to ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data, i.e., based on the 95th percentile error in all vegetated land cover classes combined. This is a target accuracy. The VVA was tested with 194 checkpoints located in tall weeds/crops and brushlands/low trees (vegetated) areas. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See Figure 9.

AccuracyZ has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using $RMSE(z) \times 1.9600$ as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines.

A brief summary of results are listed below.

	Target	Measured	Point Count
Raw NVA	0.196 m	0.0715 m	291
NVA	0.196 m	0.0712 m	291
VVA	0.294 m	0.1193 m	194

PA_WesternPA_2019_D20 Calibration Points

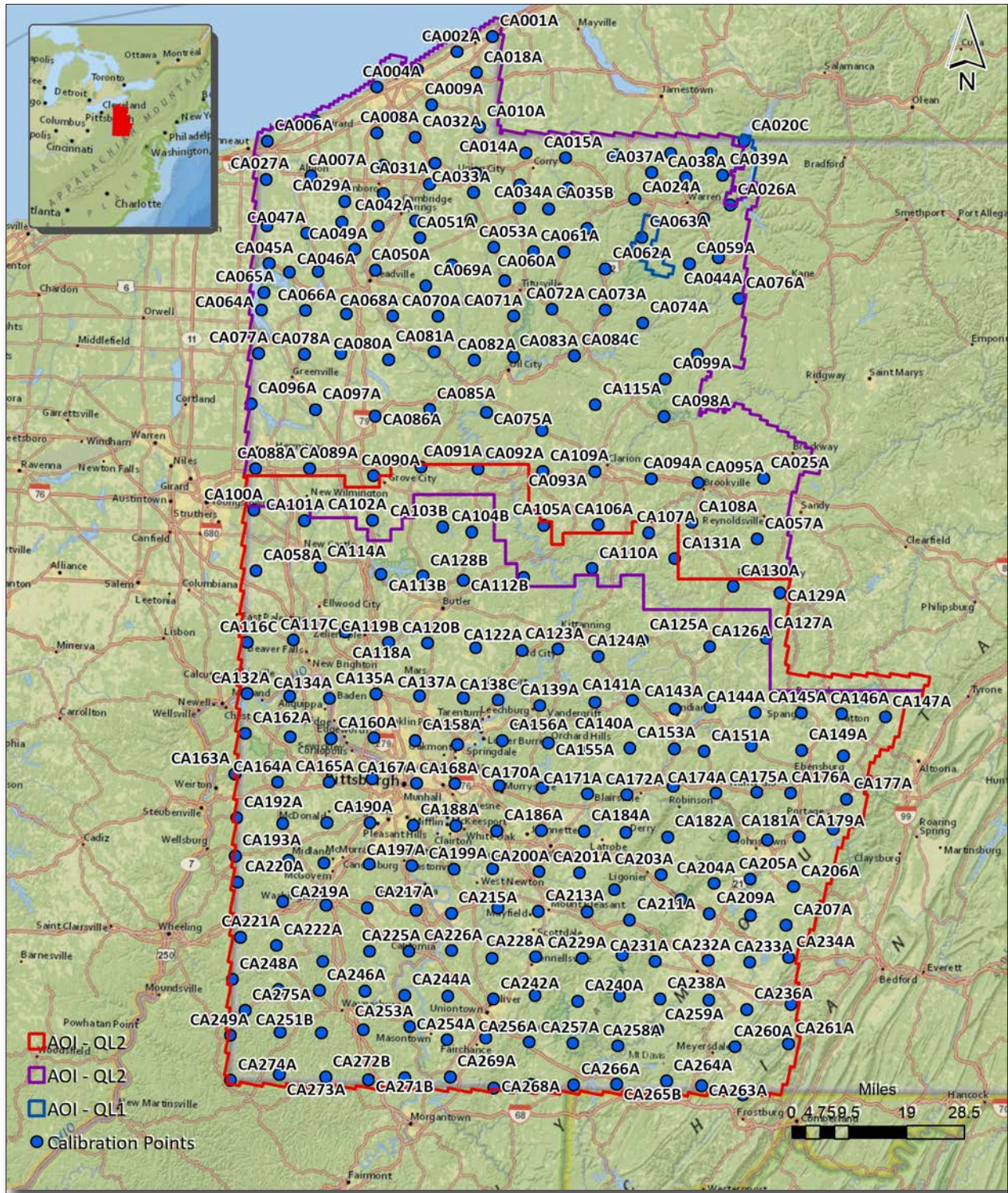


Figure 8. Calibration Control Point Locations

PA_WesternPA_2019_D20 NVA Points

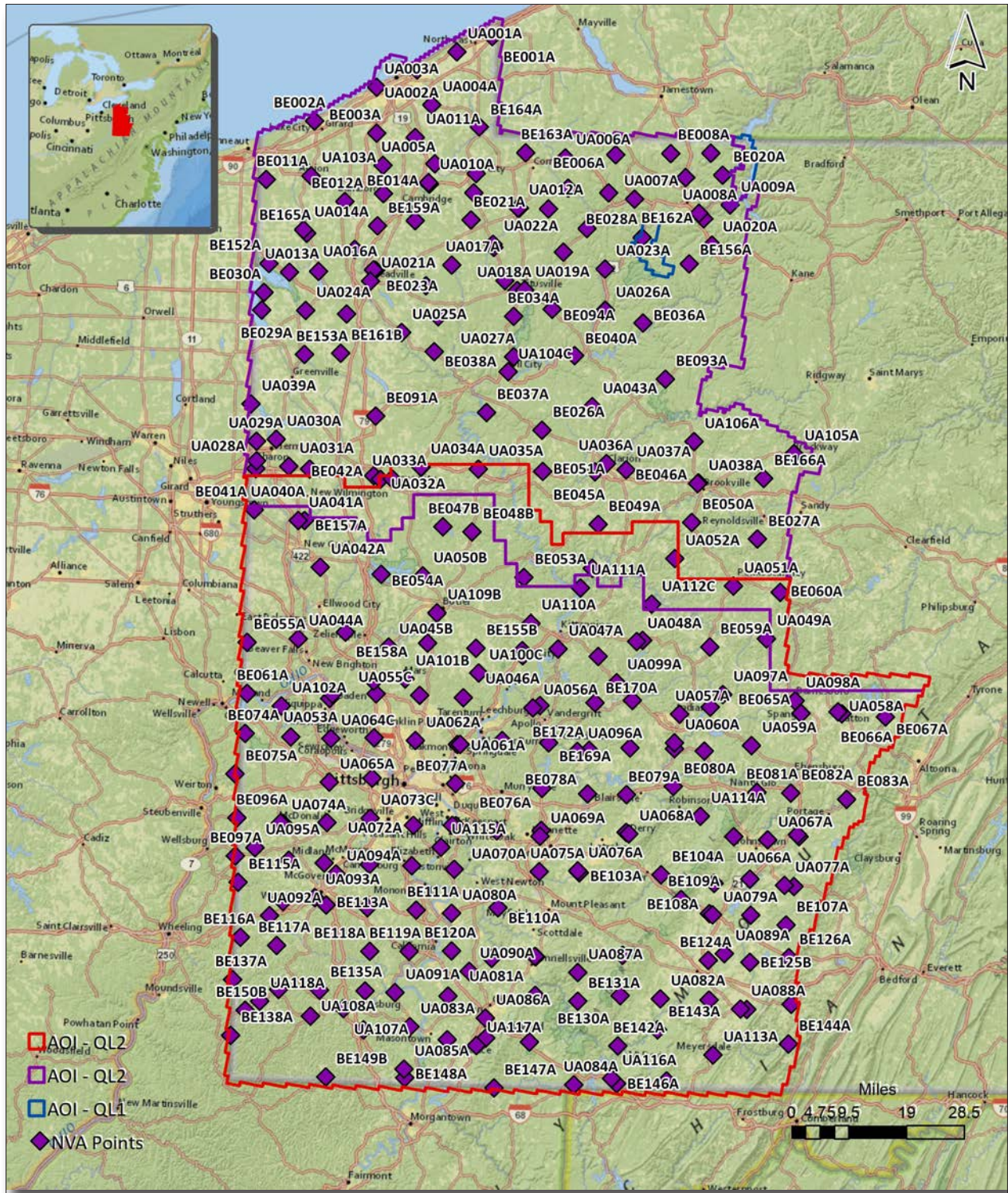


Figure 9. QC Checkpoint Locations - NVA

PA_WesternPA_2019_D20 VVA Points

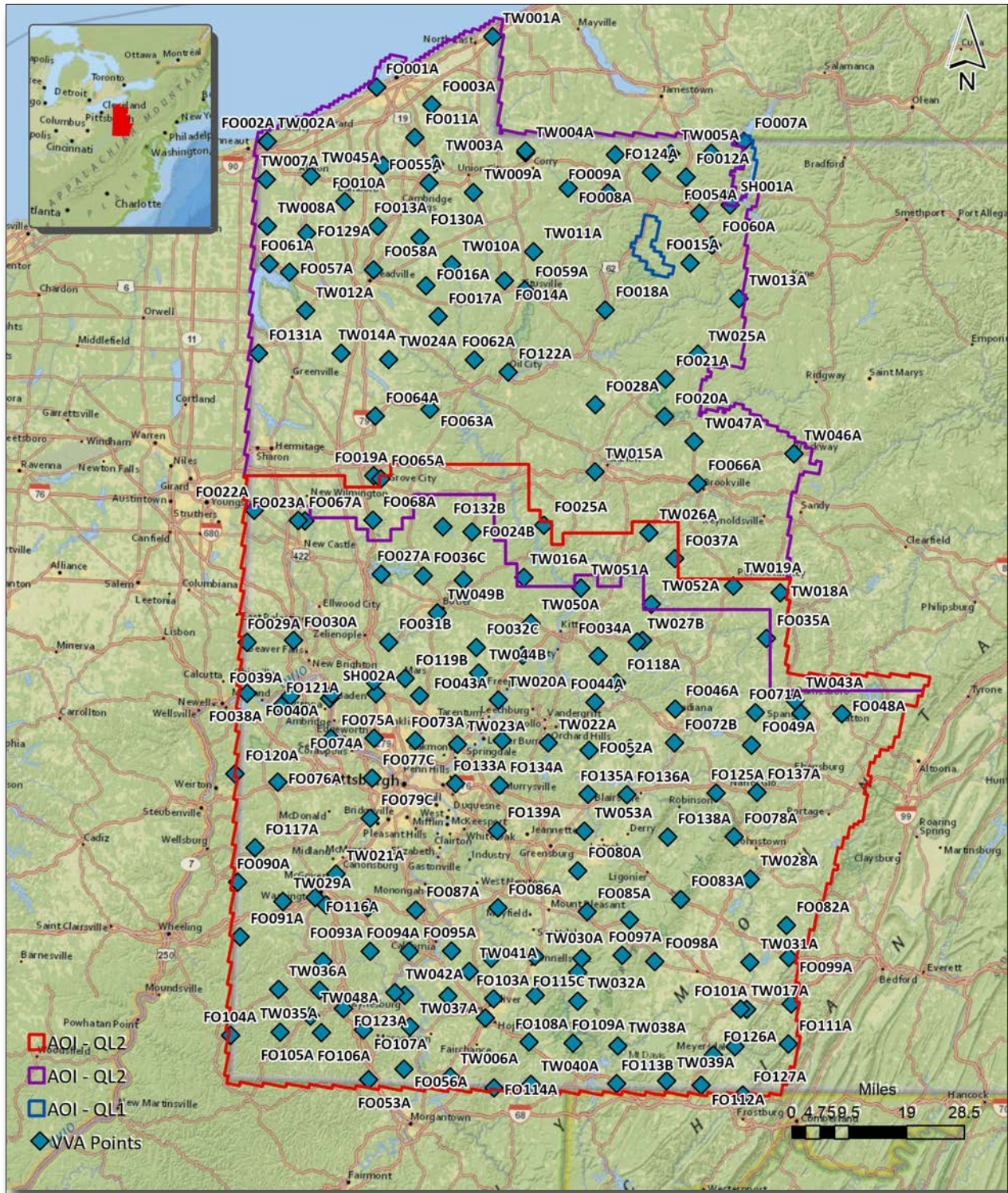


Figure 10. QC Checkpoint Locations - VVA