West Virginia 2016
2016 QL2 LiDAR Project Report

USGS Contract # G16PC00016
Requisition # 0040304832
Task Order # G16PD01236

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1. Summary / Scope

1.1. Summary

This report contains a summary of the West Virginia 2016 QL2 LiDAR acquisition task order, issued by USGS National Geospatial Technical Operations Center (NGTOC) under their Geospatial Product and Services Contract (GPSC) on September 22, 2016. The task order yielded a project area covering approximately 3,485 square miles over two Areas of Interest in southwestern West Virginia. 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	1,550 m	40°	30%	≤ 10 cm

1.3. Coverage

The project boundary covers approximately 3,485 total square miles across two Areas of Interest that include the following counties:

Elk River AOI

- Clay
- Kanawha
- Roane

East AOI

- Fayette
- Greenbrier
- Monroe
- Nicholas
- Pocahontas
- Raleigh
- Summers
- Webster

A buffer of 100 meters was created to meet task order specifications. LiDAR extents are shown in Figure 1.

1.4. Duration

LiDAR data was acquired from November 22, 2016 to December 28, 2016 in 29 total lifts. See "Section: 2.5. Time Period" for more details.

1.5. Issues

There were no issues to report for this project.

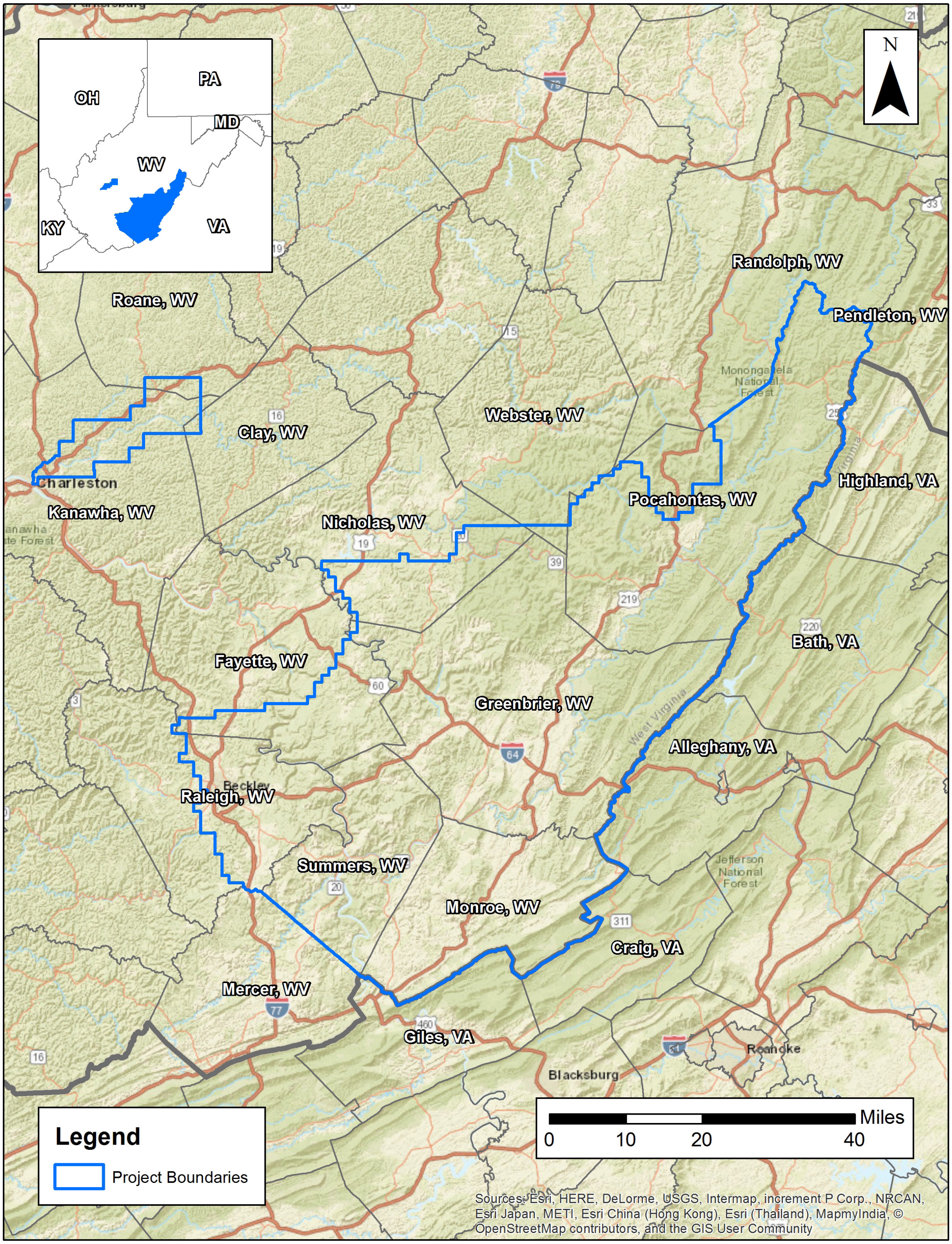
1.6. Deliverables

The following products were produced and delivered:

- Raw LiDAR point cloud data swaths in .LAS 1.4 format
- Classified LiDAR point cloud data, tiled, in .LAS 1.4 format
- 1-meter hydro-flattened bare-earth DEM, tiled, in ERDAS .IMG format
- Continuous hydro-flattened breaklines in Esri file geodatabase format
- 1-meter intensity imagery, tiled, in GeoTIFF format
- -foot contours in Esri file geodatabase format
- Calibration and QC Checkpoints in Esri shapefile format
- FOCUS on Accuracy report in .PDF 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 UTM Zone 17, meters; NAVD88 (GEOID12B), meters. All tiled deliverables have a tile size of 1,500 meters x 1,500 meters. Tile names are derived from client-provided index.

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 MissionNAV planning software. The entire target area was comprised of 306 planned flight lines measuring approximately 8,382 total flight line miles (Figure 2).

2.2. LiDAR Sensor

Quantum Spatial utilized two Optech Galaxy LiDAR sensors (Figure 3), serial numbers 354 and 356, during the project. These systems are 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.

Figure 2. Planned Flight Lines

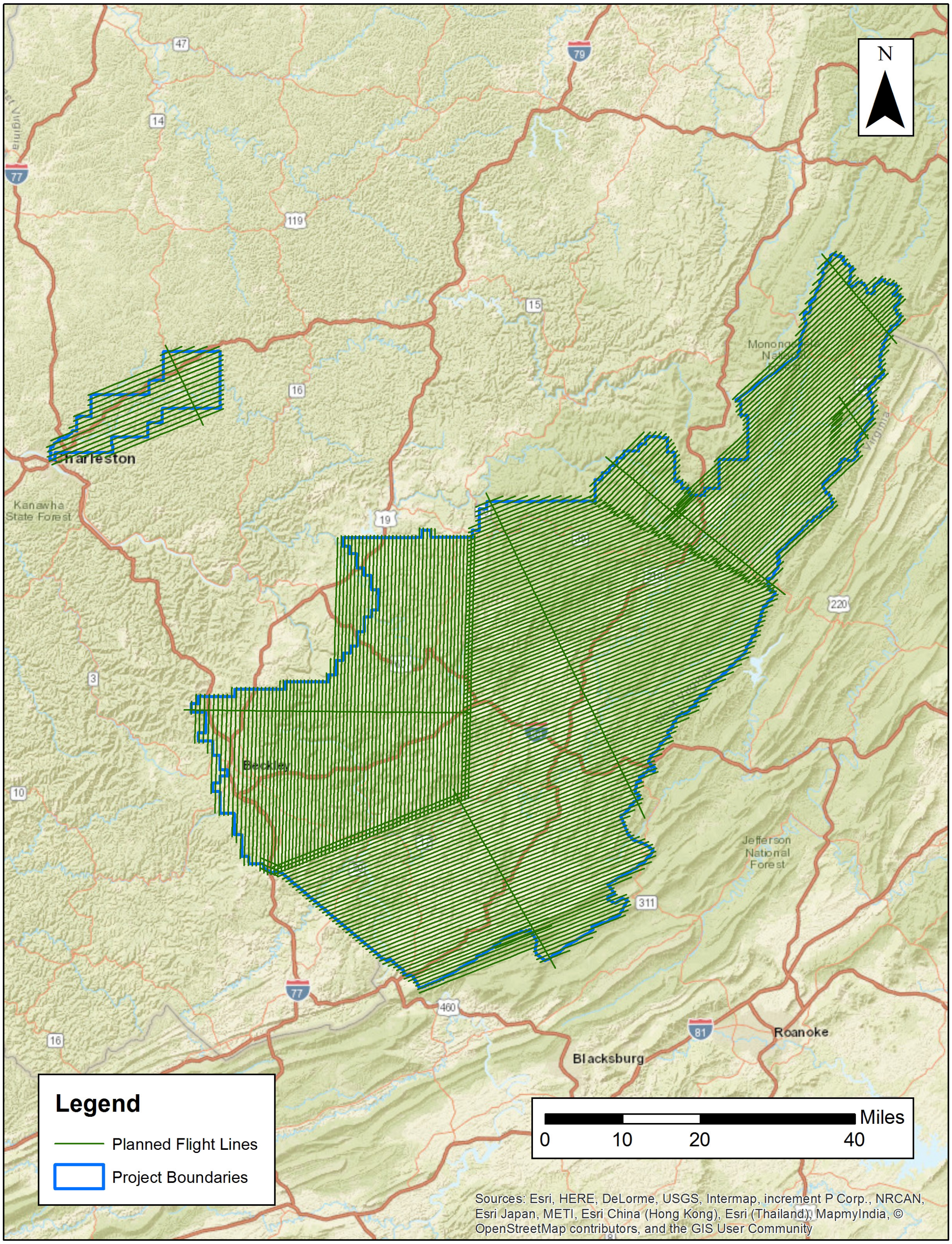


Table 2. Lidar System Specifications

Terrain and Aircraft Scanner	Flying Height	1,550 m
	Recommended Ground Speed	130 kts
Scanner	Field of View	43°
	Scan Rate Setting Used	52 Hz
Laser	Laser Pulse Rate Used	250 kHz
	Multi Pulse in Air Mode	Enabled
Coverage	Full Swath Width	1,221.12 m
	Line Spacing	2,400 m
Point Spacing and Density	Point Spacing	0.64 m
	Average Point Density	3.06 pts / m^2

Figure 3. Optech Galaxy LiDAR Sensor

2.3. Aircraft

Quantum Spatial, Inc. partnered with Keystone Aerial Surveys, Inc. to acquire data for this project. All flights for the project were accomplished through the use of customized planes. Plane type and tail numbers are listed below.

- Piper Navajo (twin-piston), Tail Number: N812TB
- Cessna Executive Skyknight (twin-piston), Tail Number: N4181T
-

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 Optech LiDAR systems. Some of Quantum Spatial's operating aircraft can be seen in Figure 4 below.

Figure 4. Some of Quantum Spatial's Planes

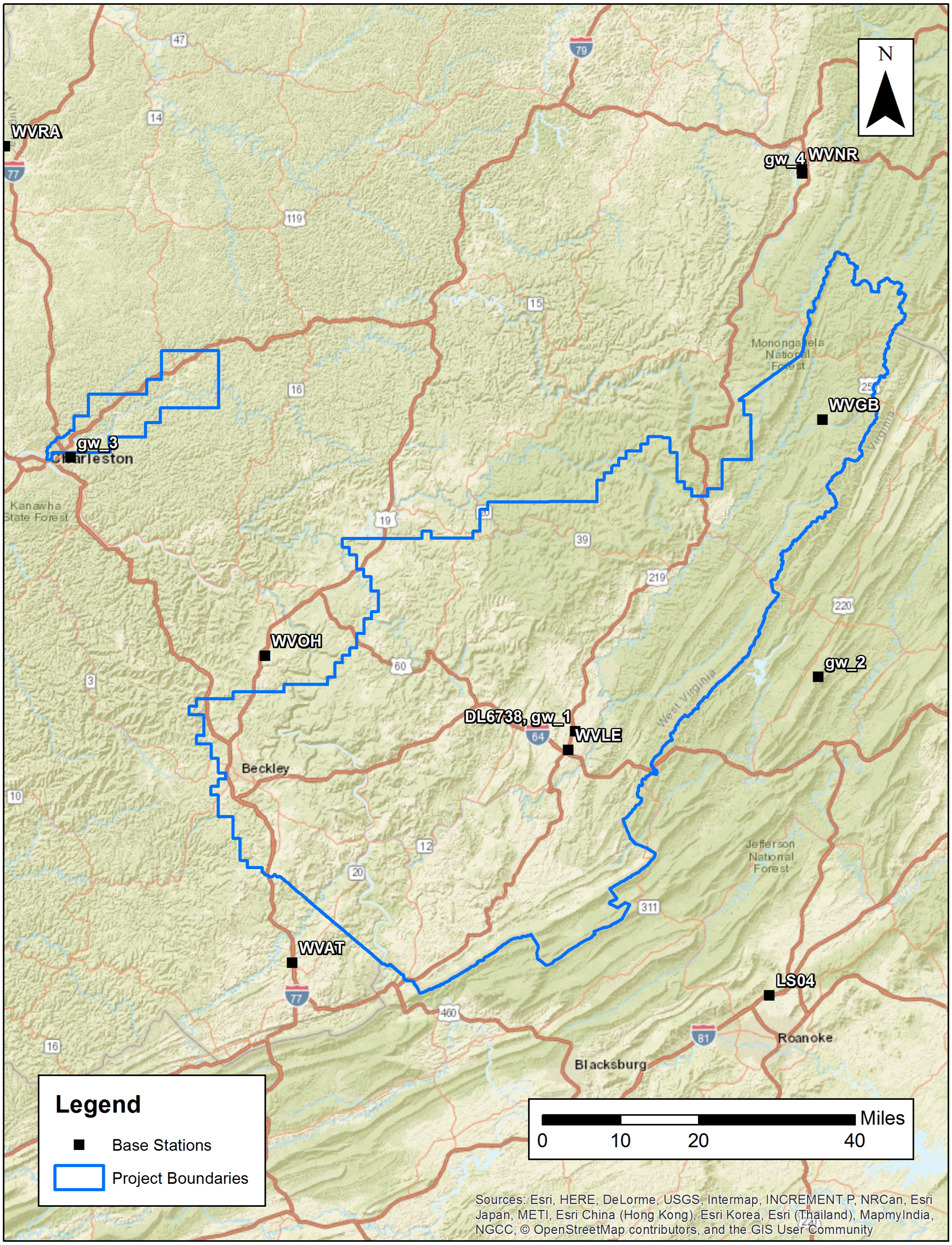
2.4. Base Station Information

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	Longitude	Latitude	Ellipsoid Height (m)
DL6738, gw_1	80° 24′ 17.69345″	37° 51′ 22.96505″	663.645
gw_2	79° 50′ 5.86991″	37° 57′ 11.65532″	1115.719
gw_3	81° 35′ 26.79271″	38° 21′ 52.56034″	266.378
gw_4	79° 51′ 26.64719″	38° 53′ 15.02161″	567.671
LS04	79° 57′ 26.96981″	37° 21′ 47.13927″	325.458
OHWA	81° 25′ 6.10231″	39° 25′ 33.42516″	165.564
WVAT	81° 4′ 4.37831″	37° 25′ 42.6511″	705.98
WVGB	79° 49′ 1.29517″	38° 25′ 48.42536″	812.469
WVLE	80° 25′ 18.55683″	37° 49′ 20.20234″	656.501
WVNR	79° 51′ 30.26994″	38° 53′ 44.50553″	582.775
WVOH	81° 7′ 55.78614″	37° 59′ 53.72284″	597.484
WVRA	81° 45′ 4.86863635″	38° 56′ 28.89164″	147.9782

Figure 5. Base Station Locations



2.5. Time Period

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

- Nov 22, 2016-A (N812TB, SN356)
- Nov 23, 2016-A (N812TB, SN356)
- Nov 27, 2016-A (N812TB, SN356)
- Nov 27, 2016-B (N812TB, SN356)
- Nov 28, 2016-A (N812TB, SN356)
- Dec 04, 2016-A (N4181T, SN354)
- Dec 05, 2016-A (N4181T, SN354)
- Dec 05, 2016-B (N4181T, SN354)
- Dec 07, 2016-A1 (N4181T, SN354)
- Dec 07, 2016-A2 (N4181T, SN354)
- Dec 07, 2016-B (N4181T, SN354)
- Dec 07, 2016-Re2 (N4181T, SN354)
- Dec 10, 2016-A (N4181T, SN354)
- Dec 10, 2016-A (N812TB, SN356)
- Dec 11, 2016-A (N4181T, SN354)
- Dec 11, 2016-A (N812TB, SN356)
- Dec 11, 2016-B (N812TB, SN356)
- Dec 13, 2016-A (N4181T, SN354)
- Dec 13, 2016-A (N812TB, SN356)
- Dec 20, 2016-A (N4181T, SN354)
- Dec 20, 2016-A (N812TB, SN356)
- Dec 20, 2016-B (N4181T, SN354)
- Dec 21, 2016-A (N4181T, SN354)
- Dec 21, 2016-B (N812TB, SN356)
- Dec 23, 2016-A (N4181T, SN354)
- Dec 23, 2016-A (N812TB, SN356)
- Dec 23, 2016-B (N4181T, SN354)
- Dec 28, 2016-A (N4181T, SN354)
- Dec 28, 2016-A (N812TB, SN356)

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). Project specific flight logs for each sortie are available in Appendix A.

3.2. LiDAR Processing

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 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 Optech DashMap 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 was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper was 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 was then used to perform final statistical analysis of the classes in the LAS files.

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 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 – Bridge Decks – Points falling on bridge decks.
- Class 18 – High Noise – High points, manually identified above the surface that could be noise points in point cloud.

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 1 meter 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 identified using the Overlap Flag, per LAS 1.4 specifications.

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-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 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 1 meter 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 file geodatabase format using Esri conversion tools.

3.6. Hydro-Flattened Raster DEM Processing

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.

3.7. Intensity Image Processing

GeoCue software was used to create the deliverable Intensity Images. All overlap classes 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. TIF/TWF files were then provided as the deliverable for this dataset requirement.

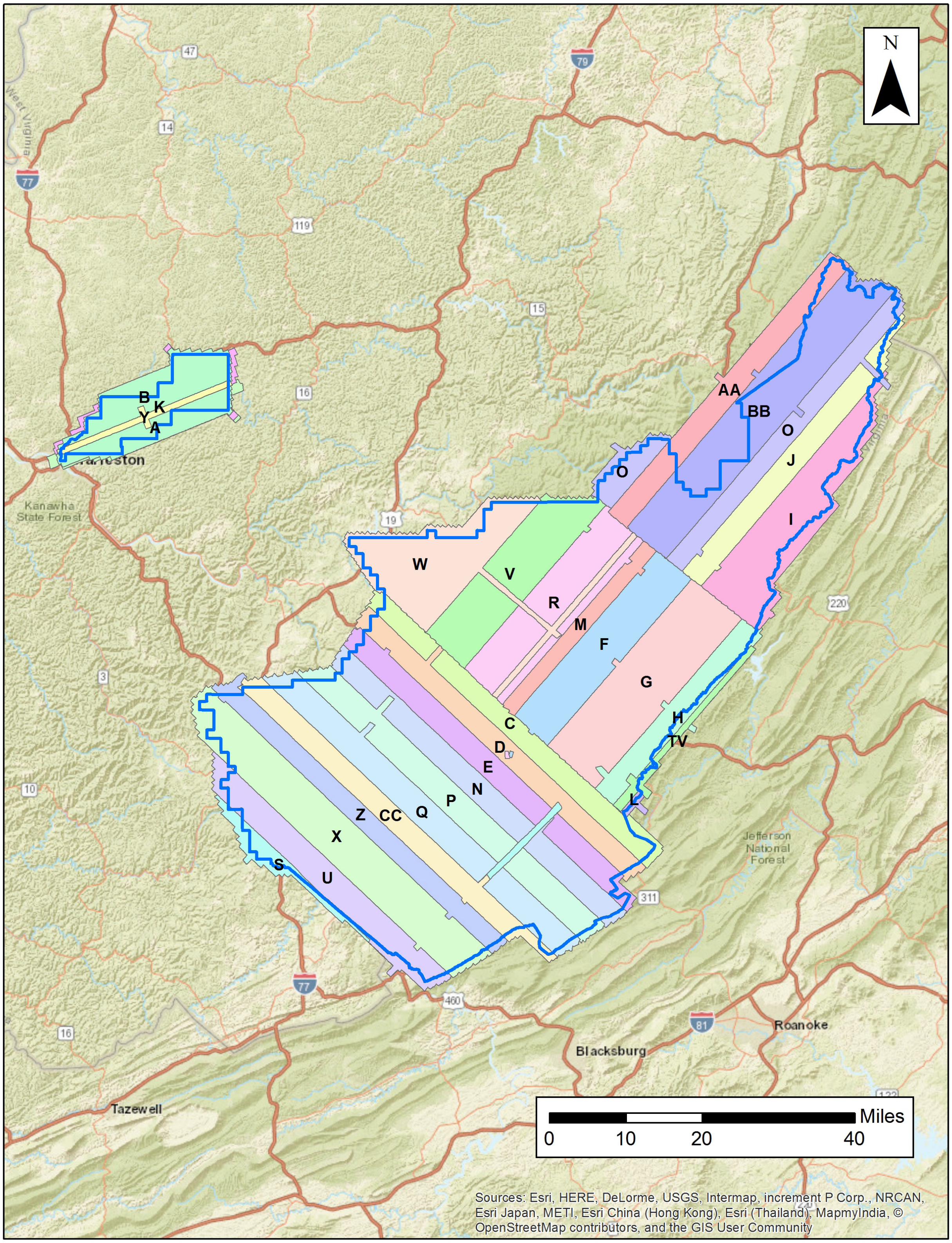
3.8. Contour Processing

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

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.

Figure 6. Flightline Swath LAS File Coverage



Legend

Lift

- A: Nov 22, 2016-A (N812TB, SN356)
- B: Nov 23, 2016-A (N812TB, SN356)
- C: Nov 27, 2016-A (N812TB, SN356)
- D: Nov 27, 2016-B (N812TB, SN356)
- E: Nov 28, 2016-A (N812TB, SN356)
- F: Dec 4, 2016-A (N4181T, SN354)
- G: Dec 5, 2016-A (N4181T, SN354)
- H: Dec 5, 2016-B (N4181T, SN354)
- I: Dec 7, 2016-A1 (N4181T, SN354)
- J: Dec 7, 2016-A2 (N4181T, SN354)
- K: Dec 7, 2016-B (N4181T, SN354)
- L: Dec 7, 2016-Re2 (N4181T, SN354)
- M: Dec 10, 2016-A (N4181T, SN354)
- N: Dec 10, 2016-A (N812TB, SN356)
- O: Dec 11, 2016-A (N4181T, SN354)
- P: Dec 11, 2016-A (N812TB, SN356)
- Q: Dec 11, 2016-B (N812TB, SN356)
- R: Dec 13, 2016-A (N4181T, SN354)
- S: Dec 13, 2016-A (N812TB, SN356)
- T: Dec 20, 2016-A (N4181T, SN354)
- U: Dec 20, 2016-A (N812TB, SN356)
- V: Dec 20, 2016-B (N4181T, SN354)
- W: Dec 21, 2016-A (N4181T, SN354)
- X: Dec 21, 2016-B (N812TB, SN356)
- Y: Dec 23, 2016-A (N4181T, SN354)
- Z: Dec 23, 2016-A (N812TB, SN356)
- AA: Dec 23, 2016-B (N4181T, SN354)
- BB: Dec 28, 2016-A (N4181T, SN354)
- CC: Dec 28, 2016-A (N812TB, SN356)
- Project Boundaries

5. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 83 ground control (calibration) points along with 165 blind QA points in Vegetated and Non-Vegetated land cover classifications (total of 248 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 blind QA points the goal was a positional accuracy of 5 cm in terms of the RMSE.

For more information, see the Survey Report.

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 1.2 (2014).

5.1. Calibration Control Point Testing

Figure 7 shows the location of each bare earth calibration point for the project area. 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.

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 93 of 94 checkpoints located in bare earth and urban (non-vegetated) areas; point BE_44 was removed as it fell outside the project area. 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) x 1.9600 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National

Digital Elevation Program (NDEP)/ASRPS Guidelines. See Figure 8.

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 93 of 94 checkpoints located in bare earth and urban (non-vegetated) areas; point BE_44 was removed as it fell outside the project area. See Figure 8.

2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for “forested” and “tall weeds” 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 69 of 71 checkpoints located in forested and tall weeds (vegetated) areas; points FO_40 and FO_58 were removed as they fell outside the project area. 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) x 1.9600 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ ASRPS Guidelines. See the FOCUS on Accuracy report for more information.

	Target	Measured	Points Used
Calibration RMSEz	≤ 0.10 m	0.0627 m	81
Raw NVA RMSEz at 95%	≤ 0.1960 m	0.1313 m	93
NVA RMSEz at 95%	≤ 0.1960 m	0.1259 m	93
VVA at 95th Percentile	≤ 0.2940 m	0.2409 m	69

Figure 7. Calibration Control Point Locations

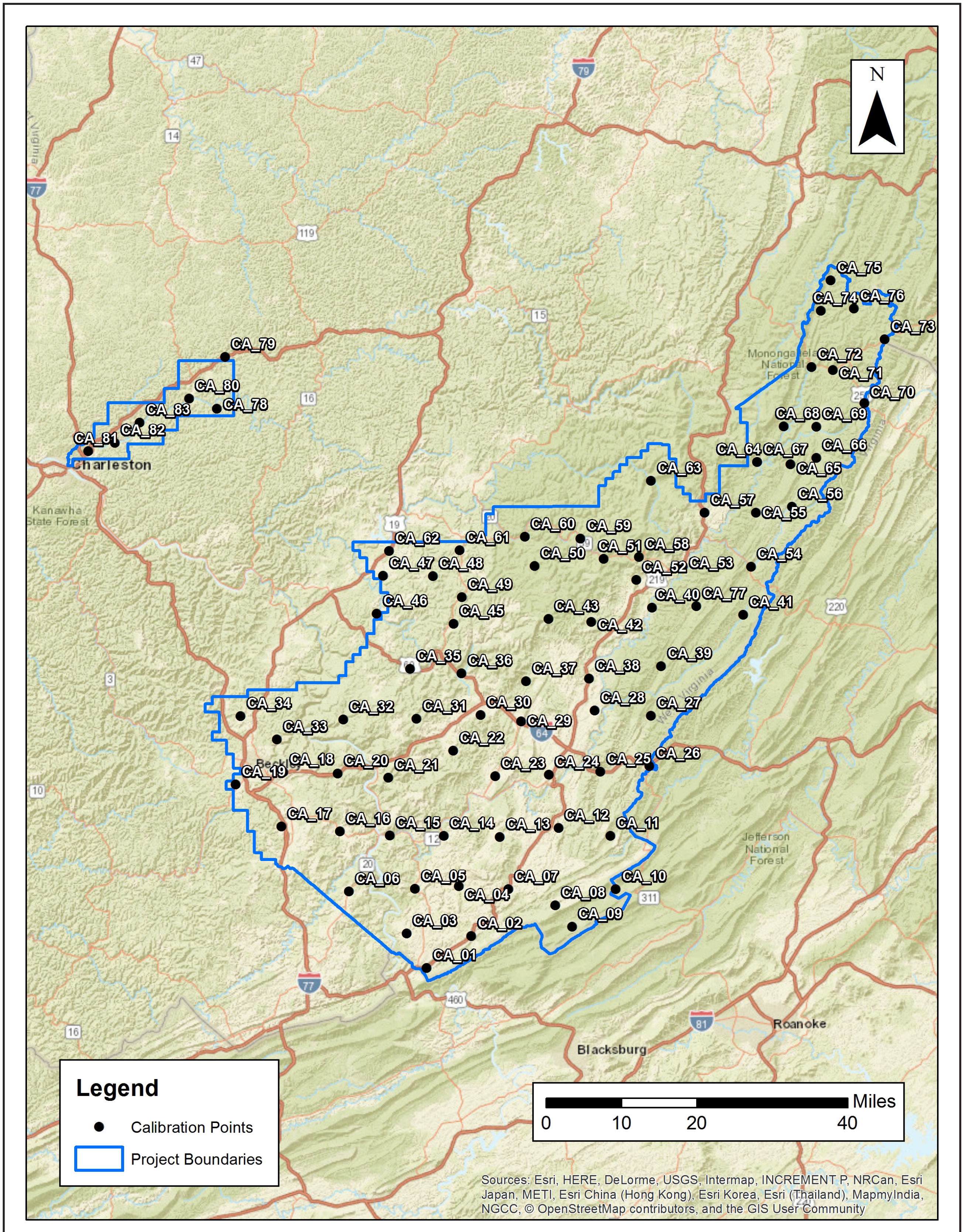


Figure 8. QC Checkpoint Locations - NVA

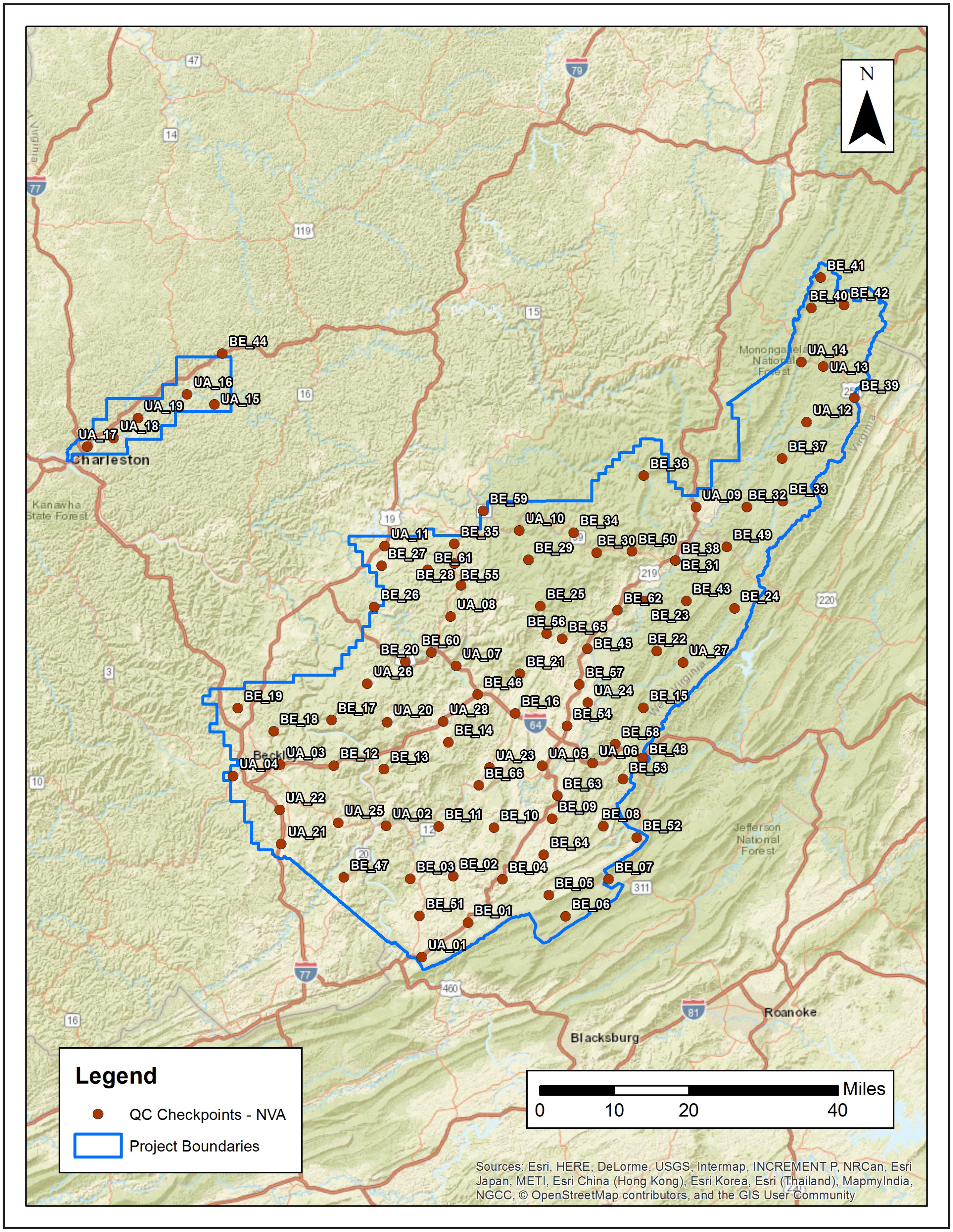


Figure 9. QC Checkpoint Locations - VVA