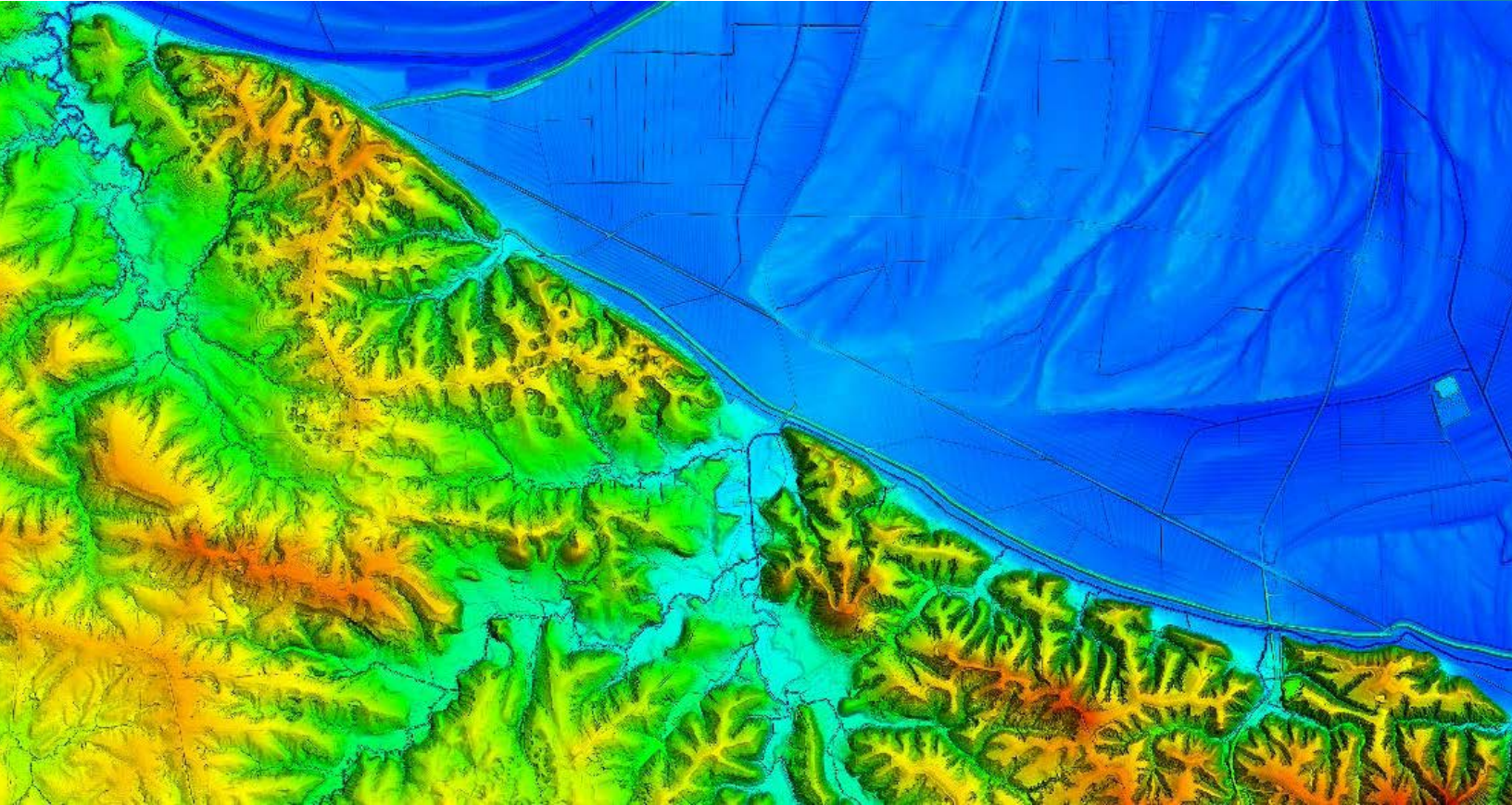




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WEST CENTRAL MISSOURI 2018 D19
LIDAR PROJECT REPORT
BLOCK 2, WORK UNIT 196680
Task Order 140G0219F0061

2020

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1. Summary / Scope

1.1. Summary

This report contains a summary of the West Central Missouri: Block 2, Work Unit 196680 LiDAR acquisition task order, issued by USGS under their Contract G16PC00016 on February 13, 2019. The task order yielded an area covering approximately 1,143 square miles over Missouri. 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 | 2000-2300 m | 60° | 30% | ≤ 10cm |

1.3. Coverage

The boundary for Block 1 covers approximately 1,143 square miles over Perry and Dunklin Counties in West Central, Missouri. 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 12, 2019 to April 9, 2020 in 4 total lifts. See “Section: 2.4. Time Period” for more details.

1.5. Issues

There were no major issues to report for this delivery block.

| West Central Missouri Block 2 Projected Coordinate System: UTM Zone 15N Horizontal Datum: NAD1983(2011) Vertical Datum: NAVD88 (GEOID 12B) Units: Meters | |
|---|---|
| Lidar Point Cloud | Classified Point Cloud in .LAS 1.4 format |
| Rasters | 1-Meter DEM in GeoTIFF format 1-Meter Intensity images in GeoTIFF format 1-Meter Height Separation Rasters in GeoTIFF format |
| Vectors | Shapefiles (*.shp) <ul style="list-style-type: none"> • Project Boundary • LiDAR Tile Index • Calibration and QC Checkpoints (NVA/VVA) Geodatabase (*.gdb) <ul style="list-style-type: none"> • Continuous Hydro-flattened Breaklines |
| Reports | Reports in PDF format <ul style="list-style-type: none"> • Focus on Delivery • Survey Report • Block 2, Work Unit 196680 Report |
| Metadata | XML Files (*.xml) <ul style="list-style-type: none"> • Breaklines • Classified Point Cloud • DEM • Intensity Imagery Excel Files (*.xlsx) <ul style="list-style-type: none"> • Provisional Accuracy |

West Central MO Block 2 Project Boundary

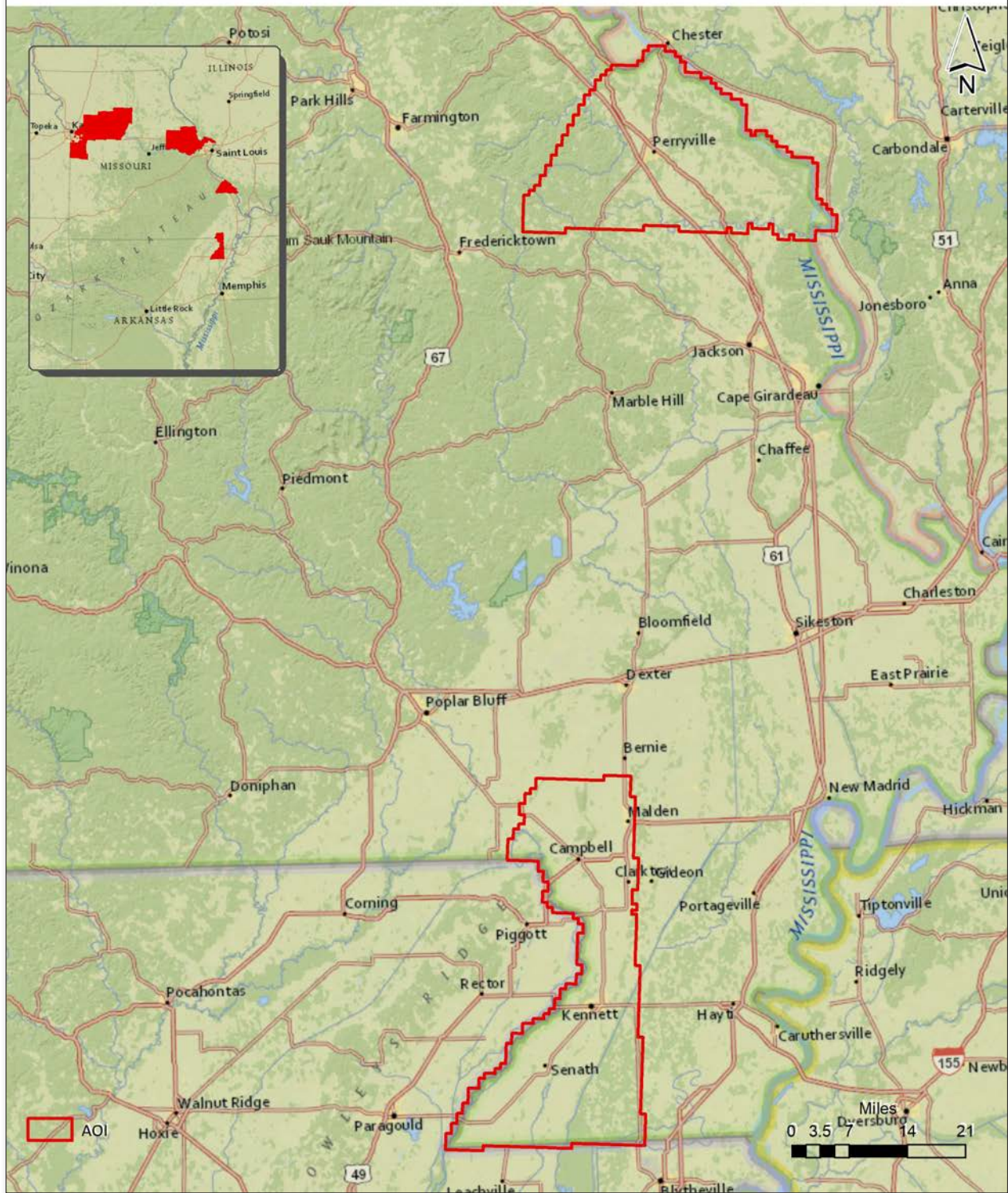


Figure 1. Project Boundary

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 planning software. The entire target area was comprised of 52 planned flight lines (Figure 2).

2.2. LiDAR Sensor

Quantum Spatial utilized a Riegl VQ1560i LiDAR sensor (Figure 3), serial number 3543 and a Riegl LMS-Q1560 (Figure 3), serial number 0754, for acquisition of block 2.

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 Riegl LMS-Q1560 system can collect data at a maximum pulse repetition rate of 800 kHz, affording an effective rate of 532,000 measurements on the ground. The sensor's multiple time around processing software automatically resolves range ambiguities and handles more than 10 simultaneous pulses in the air.

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

West Central MO Block 2 Flight Lines

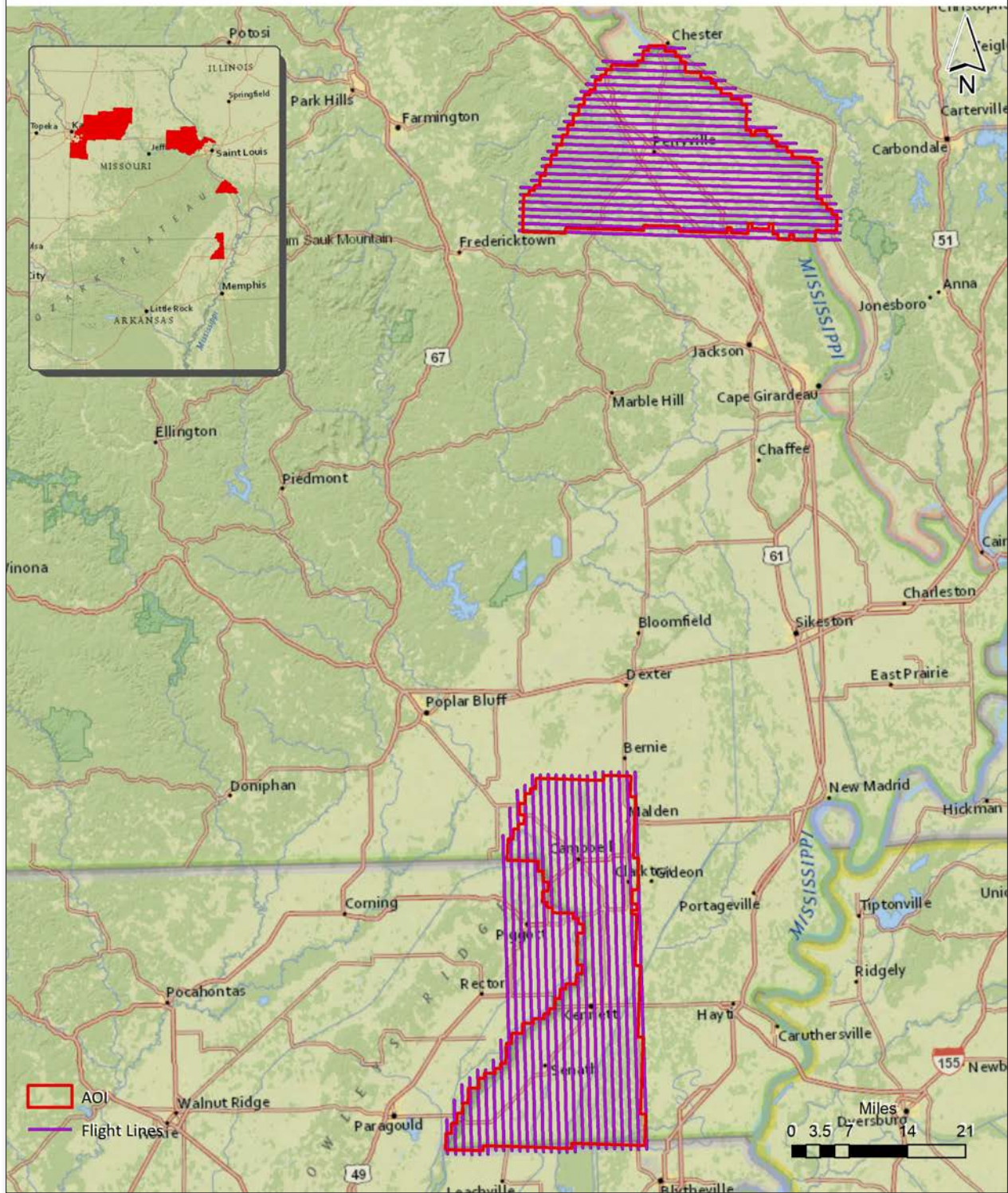


Figure 2. Planned Flight Lines

Table 2. LiDAR System Specifications

| | | Riegl VQ1560i | Riegl LMS-Q1560 |
|------------------------------|--------------------------|--------------------------|--------------------------|
| Terrain and Aircraft Scanner | Flying Height | 2000 m | 2300 m |
| | Recommended Ground Speed | 160 kts | 160 kts |
| Scanner | Field of View | 60° | 60° |
| | Scan Rate Setting Used | 179 Hz | 191 Hz |
| Laser | Laser Pulse Rate Used | 700 kHz | 800 kHz |
| | Multi Pulse in Air Mode | yes | yes |
| Coverage | Full Swath Width | 2309 m | 2655 m |
| | Line Spacing | 1616 m | 1859 m |
| Point Spacing and Density | Average Point Spacing | 0.65 m | 0.60 m |
| | Average Point Density | 2.4 pts / m ² | 2.8 pts / m ² |

Figure 3. Riegl VQ 1560i and Riegl LMS-Q1560 LiDAR sensors



2.3. Aircraft

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

LiDAR Collection Planes

- Piper Navajo, Tail Numbers: C-FXCI, C-GKSX

These aircraft provided an ideal, stable aerial base for LiDAR acquisition. These aerial platforms have 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 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. Time Period

Block 2 specific flights were conducted between December 12, 2019 and April 9, 2020. Four aircraft lifts were completed. Accomplished lifts are listed below.

- 20191212A (SN3543, C-FXCI)
- 20200222A (SN3543, C-FXCI)
- 20200409A (SN0754, C-GKSX)
- 20200409B (SN0754, C-GKSX)

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 the RiPROCESS 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. 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 | 8.4 |
| RiPROCESS | 1.8.6 |
| GeoCue | 2017.1.14.1 |
| Global Mapper | 19.1;20.1 |
| TerraModeler | 20.004 |
| TerraScan | 20.011 |
| TerraMatch | 20.004 |

3.3. LAS Classification Scheme

The classification classes are determined by the USGS Version 1.3 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. |

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.

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'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 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'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 1-meter 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 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. GeoTIFF files with a cell size of 1-meter were then provided as the deliverable for this dataset requirement.

West Central MO Block 2 Tile Index

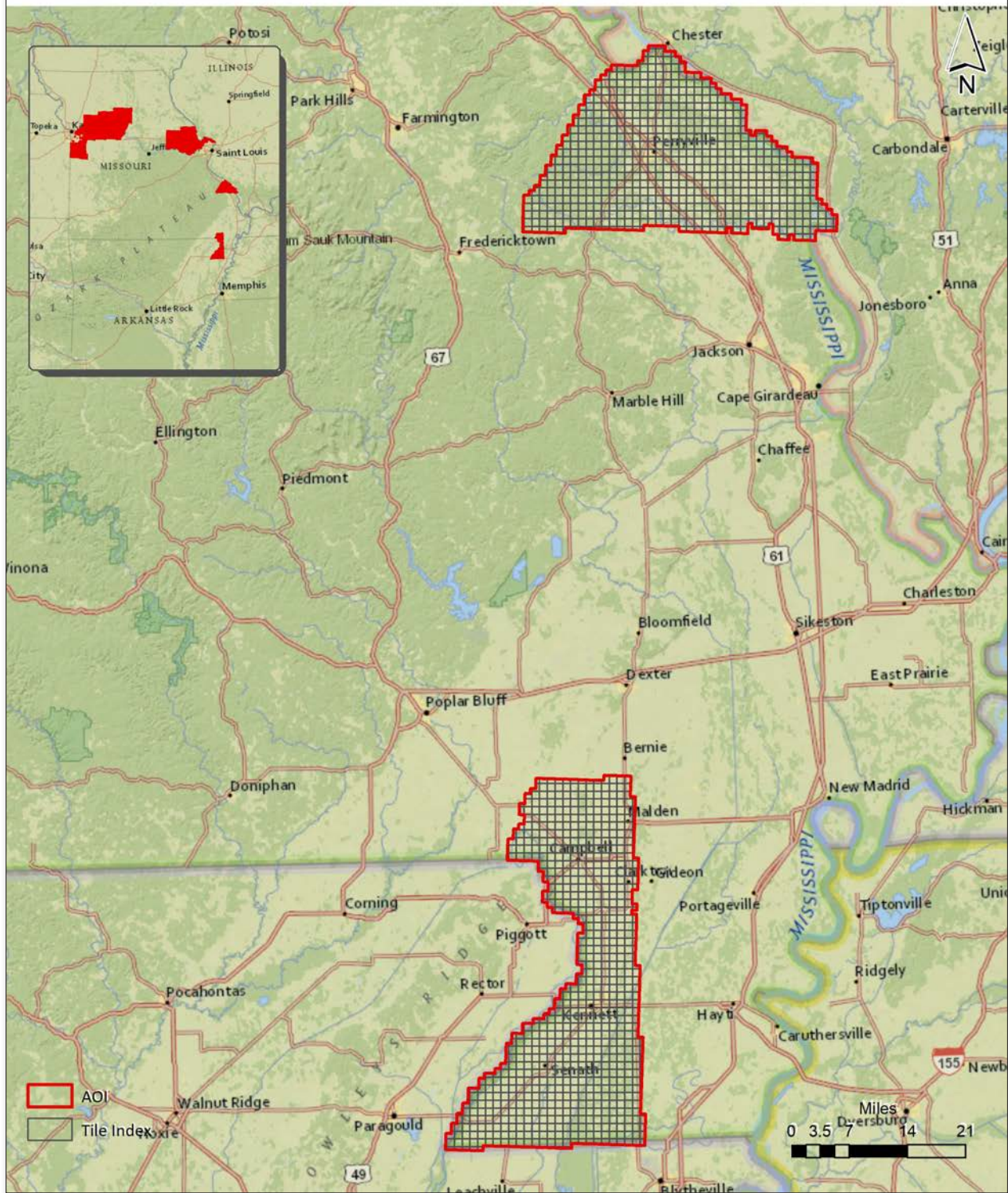


Figure 5. LiDAR Tile Layout

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.

West Central MO Block 2 Coverage

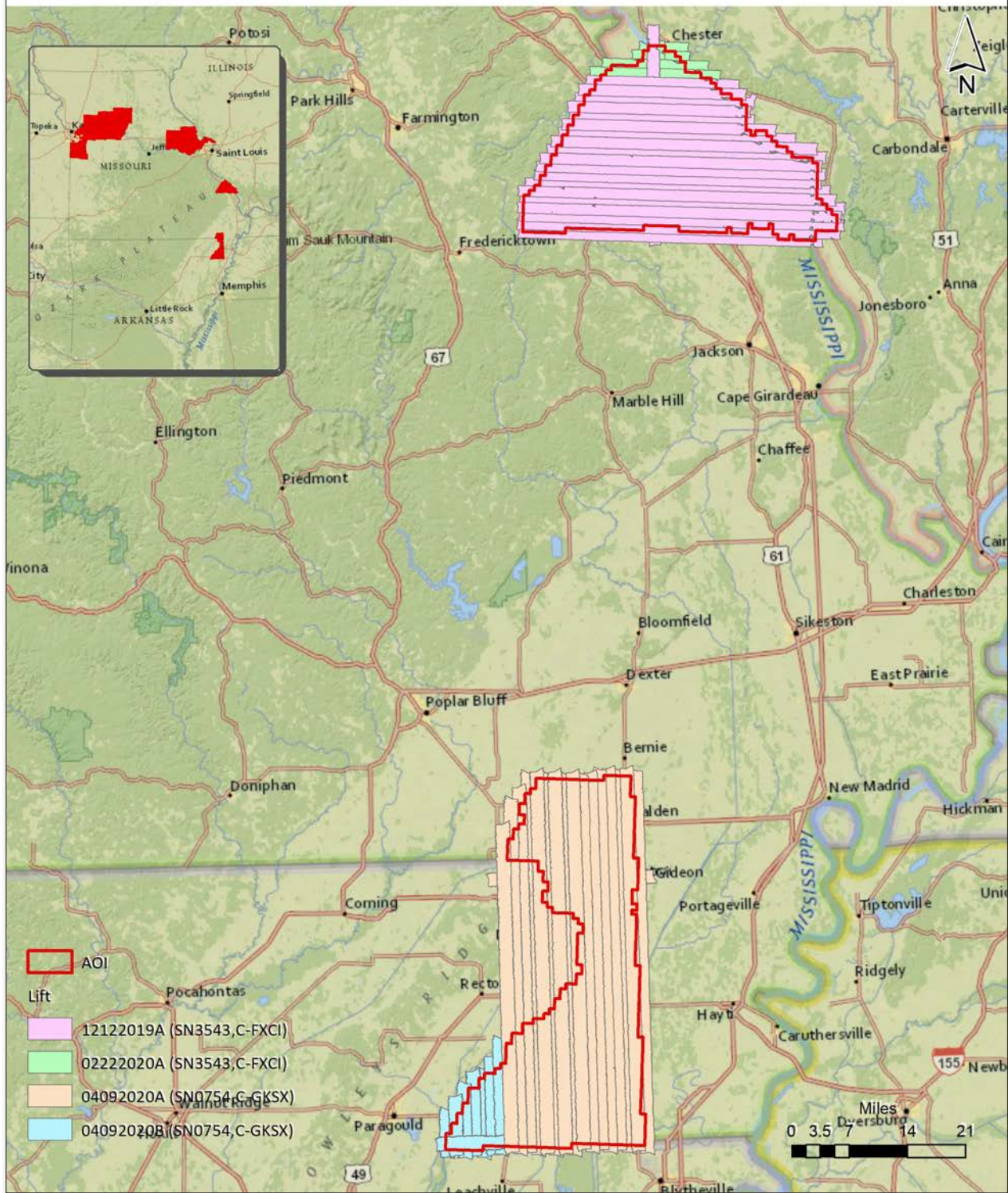


Figure 6. LiDAR Flight Line Coverage

5. Ground Control and Check Point Collection

On behalf of Quantum Spatial, Wood PLC completed a field survey of 189 ground control (calibration) points along with 219 blind QA points in Non-Vegetated and Vegetated land cover classifications (total of 408 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.

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 1.3.

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 165 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 135 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 84 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)/ASPRS Guidelines.

A brief summary of results are listed below.

| | Target | Measured | Point Count |
|---------|--------|----------|-------------|
| Raw NVA | 0.196 | 0.089 | 165 |
| NVA | 0.196 | 0.093 | 135 |
| VVA | 0.294 | 0.148 | 84 |

West Central MO Block 2 Calibration Points

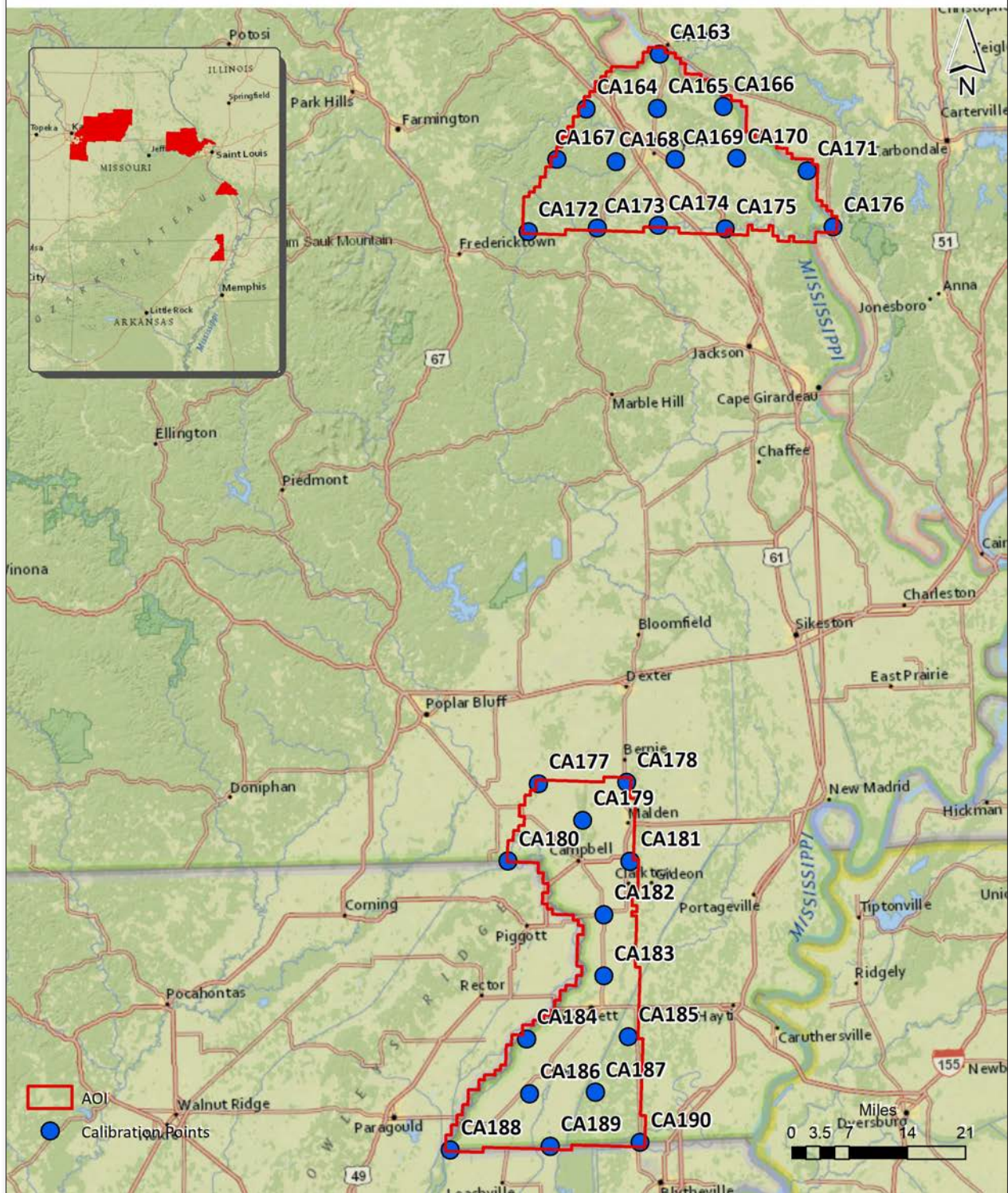


Figure 7. Calibration Control Point Locations

West Central MO Block 2 NVA Points

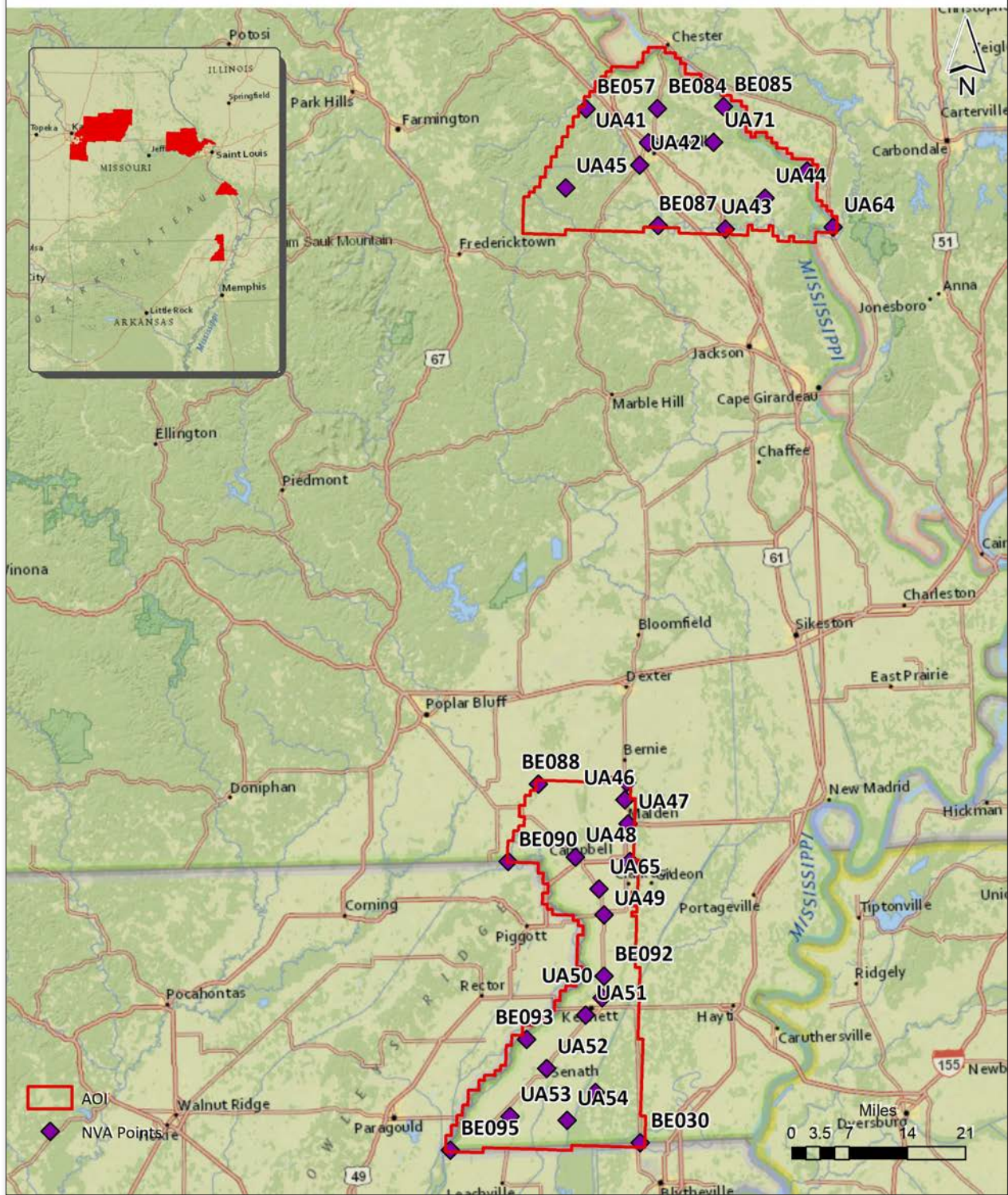


Figure 8. QC Checkpoint Locations - NVA

West Central MO Block 2 VVA Points

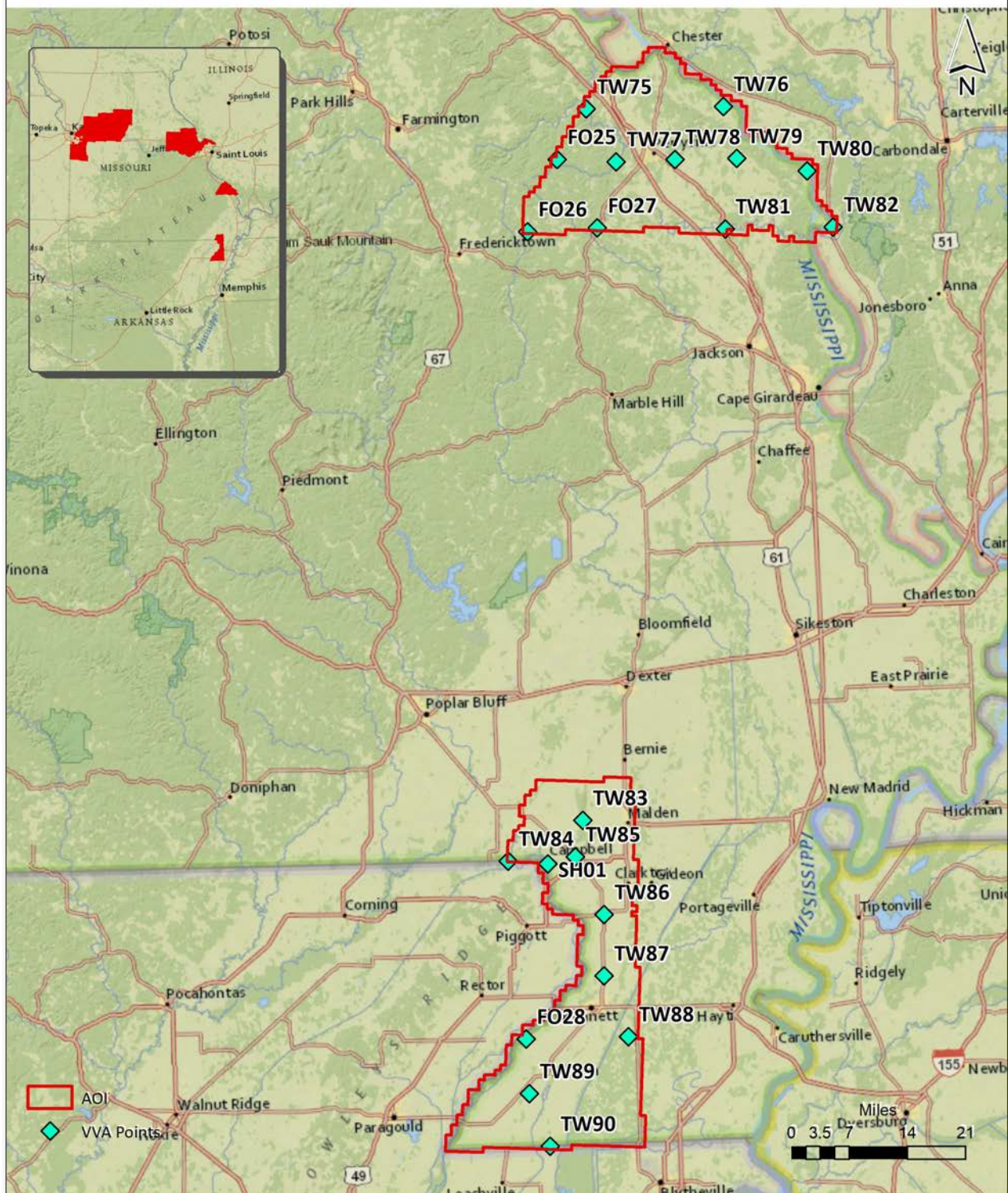


Figure 9. QC Checkpoint Locations - VVA