Oklahoma FEMA 2016
QL2 LiDAR Project Report

USGS Contract # G16P00016
Requisition # 0040307569
Task Order # G19PD00013

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Oklahoma FEMA 2016 QL2 LiDAR acquisition task order, issued by USGS National Geospatial Technical Operations Center (NGTOC) under their Geospatial Product and Services Contract (GPSC v.3) on December 1, 2016. The task order yielded a project area covering approximately 14,759 total square miles over eight separate Areas Of Interest across Oklahoma. The intent of this document is only to provide specific validation information for the data acquisition/collection work 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 / m²	2,100 m	40°	30%	≤ 10 cm

1.3. Coverage

The LiDAR project boundary covers 14,759 square miles across the folloing areas of interest:

Base Option AOIs – approximately 11,226 total square miles:
- Woodward-Dewey-Blaine: full/partial coverage of Woodward, Dewey, Blaine, Major and Alfalfa Counties
- Osage-Tulsa-Wagner-Muskogee: full/partial coverage of Kay, Osage, Pawnee, Tulsa, Rogers, Wagoner, Muskogee and Sequoyah Counties
- McIntosh-Pittsburg-Haskell: full/partial coverage of McIntosh, Pittsburg, Haskell, Sequoyah and Hughes Counties
- Choctaw-Atoka: full/partial coverage of Atoka, Choctaw and Pushmataha Counties

Option A AOIs – approximately 3,350 total square miles:
- Grant-Western-Kay: partial coverage of Grant and Kay Counties
- Harmon-Greer-Beckham: partial coverage of Harmon, Greer and Beckham Counties
- Roger Mills-Ellis-Harper: partial coverage of Ellis and Harper and Roger Mills Counties
-

Option B AOI – approximately 183 total square miles:
- OK_USGS: includes partial coverage of Alfalfa and Major Counties

A buffer of 100 meters was created to meet task order specifications. Project extents are shown in Figure 1 and Figure 2.

1.4. Duration

LiDAR data was acquired from December 13, 2016 to April 7, 2017 in 90 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
- Calibration and QC checkpoints in Excel and Esri shapefile formats
- Processing boundary in Esri shapefile format
- Tile index in Esri shapefile format
- Project-, deliverable-, and lift-level metadata in .XML format

Geospatial deliverables were produced in the following spatial reference systems:

NAD83 (2011) UTM Zone 14 - EPSG Code 6343, meters; NAVD88 (GEOID12B), meters was used for the following AOIs:

- Woodward-Dewey-Blaine
- Grant-Western-Kay
- Harmon-Greer-Beckham
- Roger Mills-Ellis-Harper
- OK_USGS

NAD83 (2011) UTM Zone 15 - EPSG Code 6344, meters; NAVD88 (GEOID12B), meters was used for the following AOIs:

- Osage-Tulsa-Wagoner-Muskogee
- McIntosh-Pittsburg-Haskell
- Choctaw-Atoka

All tiled deliverables have a tile size of 1,500 meters x 1,500 meters. Tile names are derived from US National Grid.

Figure 1. Project Boundary - UTM 14 AOI

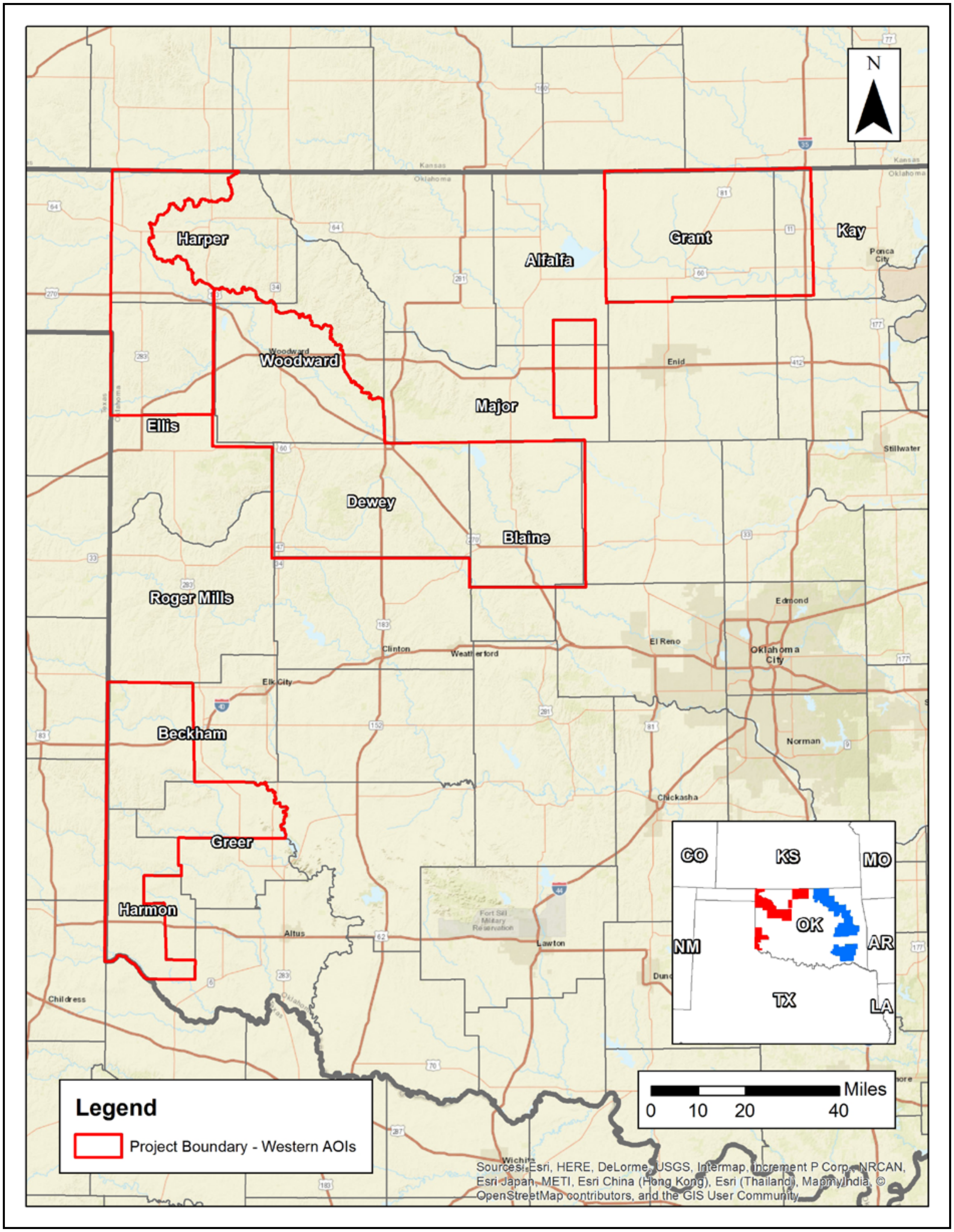
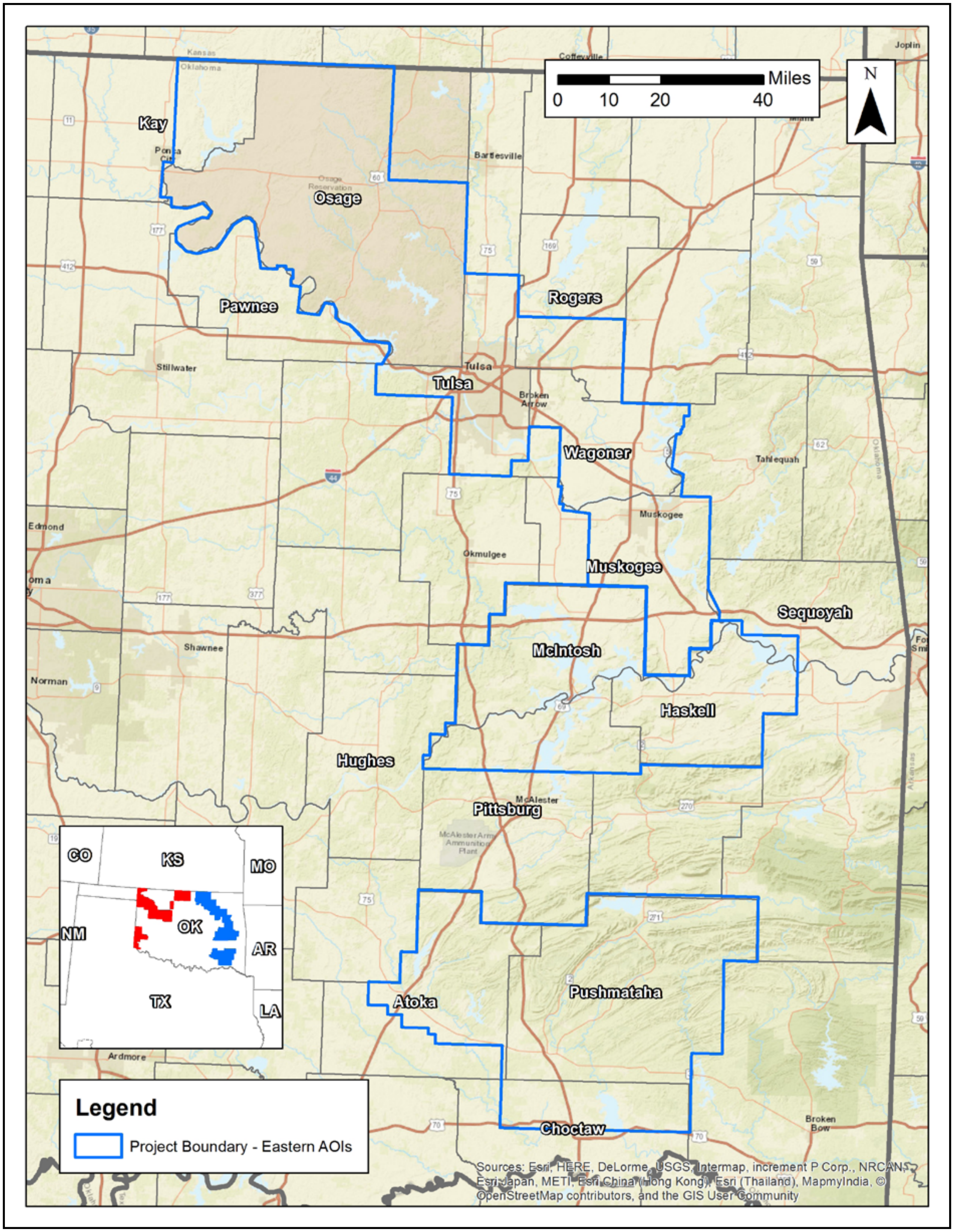


Figure 2. Project Boundary - UTM 15 AOI



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 Optech Flight Management Suite planning software. The entire target area was comprised of 834 planned flight lines (Figure 3).

2.2. LiDAR Sensor

Quantum Spatial utilized a Riegl 1560 LiDAR sensor (Figure 5), serial number 2220764 and 2221264; Optech Galaxy sensors (Figure 7), serial numbers 386 and 5060354; and an Optech Orion H (Figure 6), serial number 309, during the project.

The Riegl 1560i system has a laser pulse repetition rate of up to 2 MH. The system utilizes a Multi-Pulse in the Air option (MPIA). The sensor is equipped with the ability to measure up to an unlimited number of targets per pulse from the laser.

Optech Galaxy 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.

The Optech Orion H is capable of collecting data at a maximum frequency of 300 kHz. The system utilizes a Multi-Pulse in the Air option (MPIA), and is equipped with the ability to measure up to 5 returns per outgoing pulse from the laser (i.e., 1st, 2nd, 3rd, 4th, and last returns). The intensity values of the first four returns are 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 3. Planned Flight Lines - UTM 14 AOI

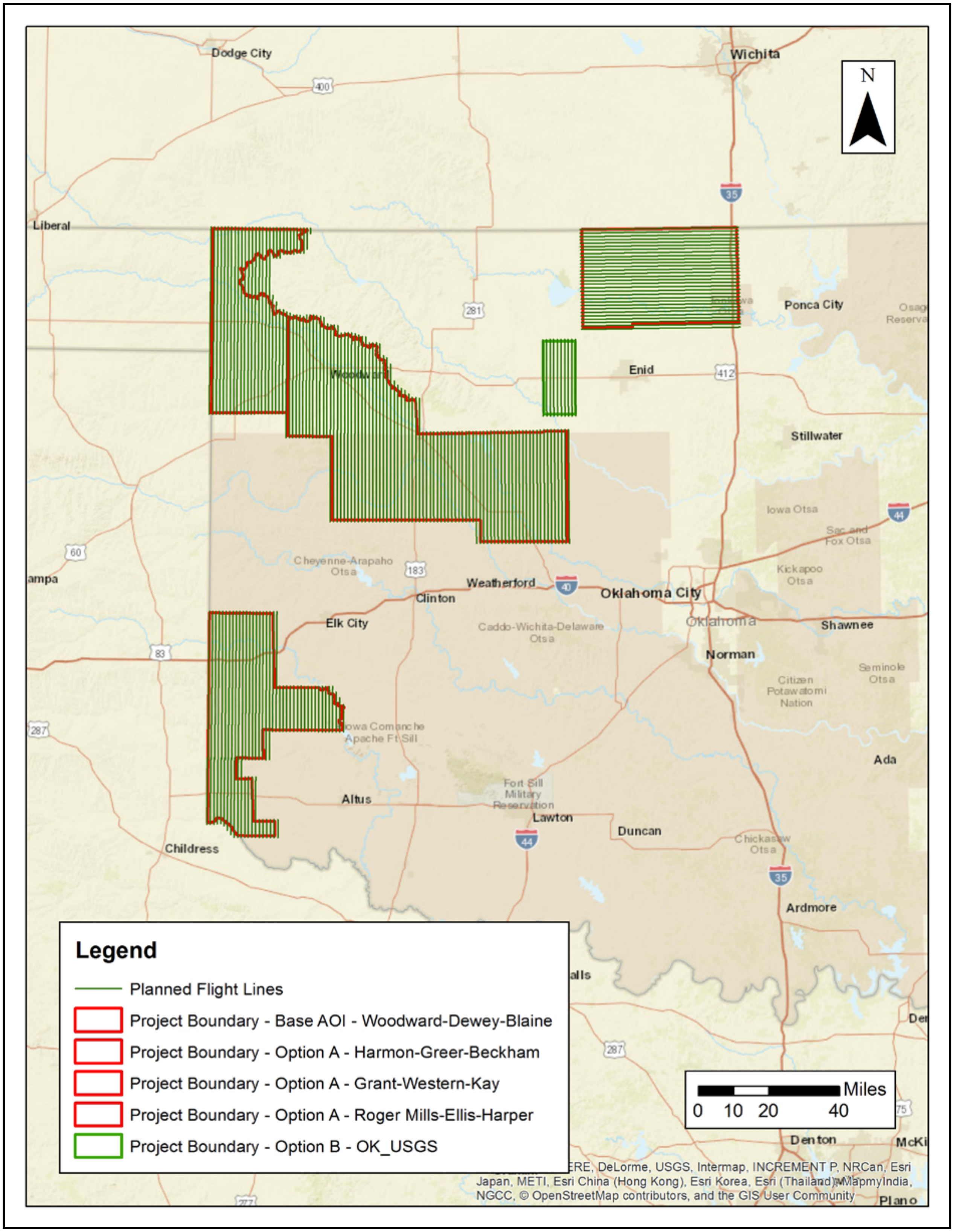


Figure 4. Planned Flight Lines - UTM 15 AOI

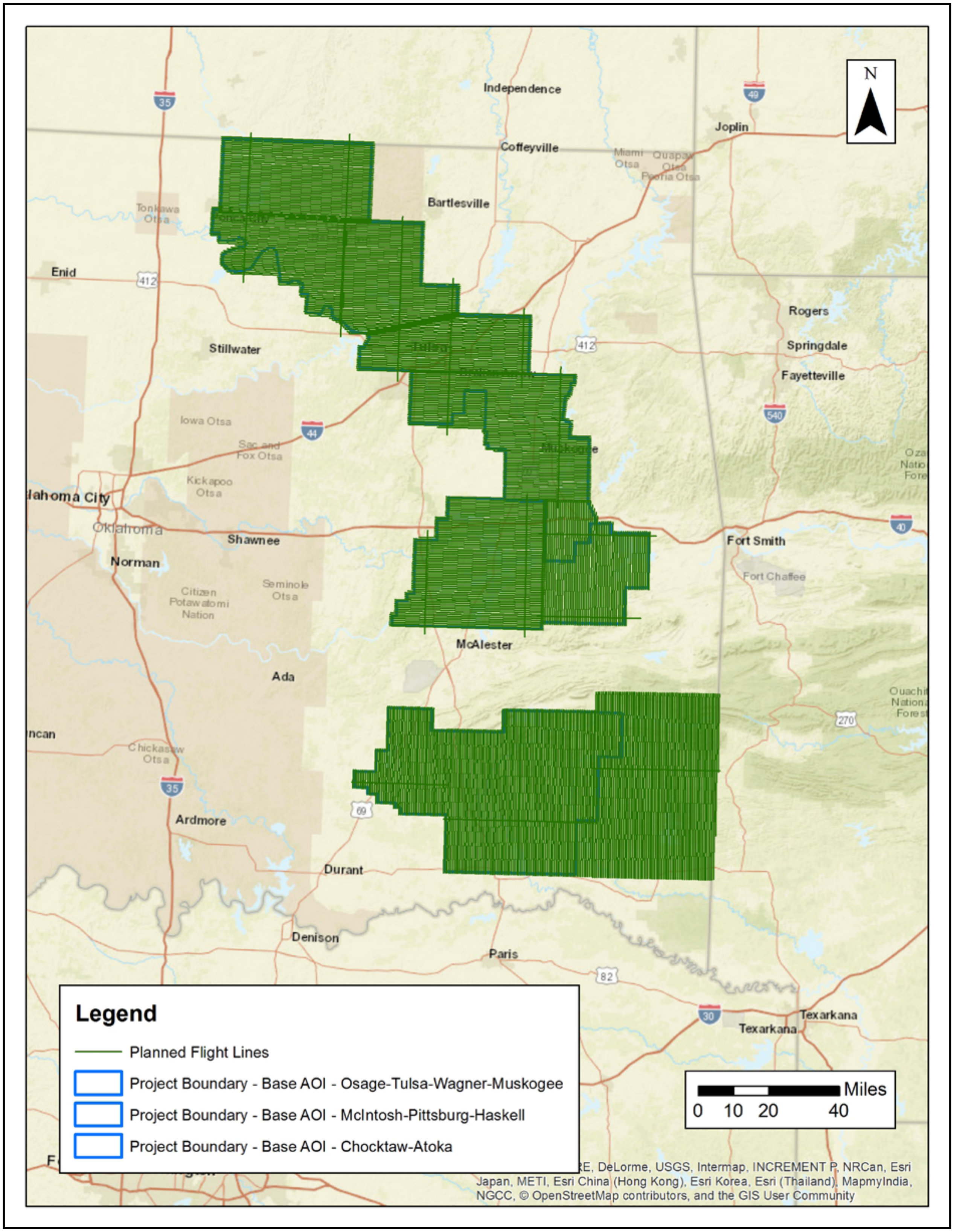


Table 2. Lidar System Specifications

Sensor	Maximum Frequency	Data Collection (points per second)	Multi-Pulse in Air Mode	Number of Returns
Riegl VQ-1560i Figure 5	2 MHz	800,000 points per second	Available	Unlimited
Optech Orion H300 Figure 6	300 kHz	225,000 points per second	Available	4
Optech ALTM Galaxy T1000 Figure 7	550 kHz	250,000 points per second	Available	8

Figure 5. Riegl VQ 1560i LiDAR Sensor

Figure 6. Optech Orion H300 Sensor

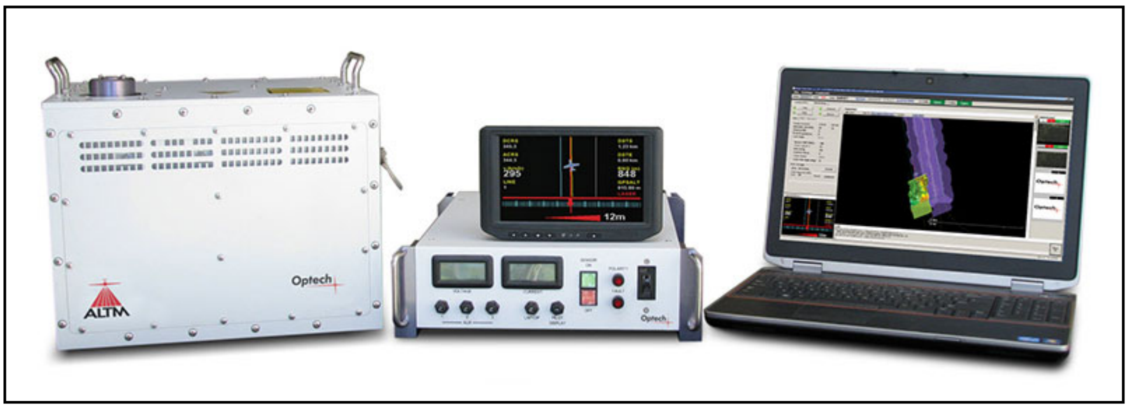


Figure 7. Optech Galaxy LiDAR Sensor

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:

- Cessna 402, Tail Number(s): NN2JJ
- Cessna 310, Tail Number(s): N7516Q
- Piper Navajo PA-31, Tail Number: N44RL
- Cessna 320D, Tail Number: N4181T
- Cessna 177RG, Tail Number N20AX

These aircraft provided an ideal, stable aerial base for LiDAR and orthoimagery 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 LiDAR systems. Some of Quantum Spatial's operating aircraft can be seen in Figure 8 below.

Figure 8. Some of Quantum Spatial's Planes

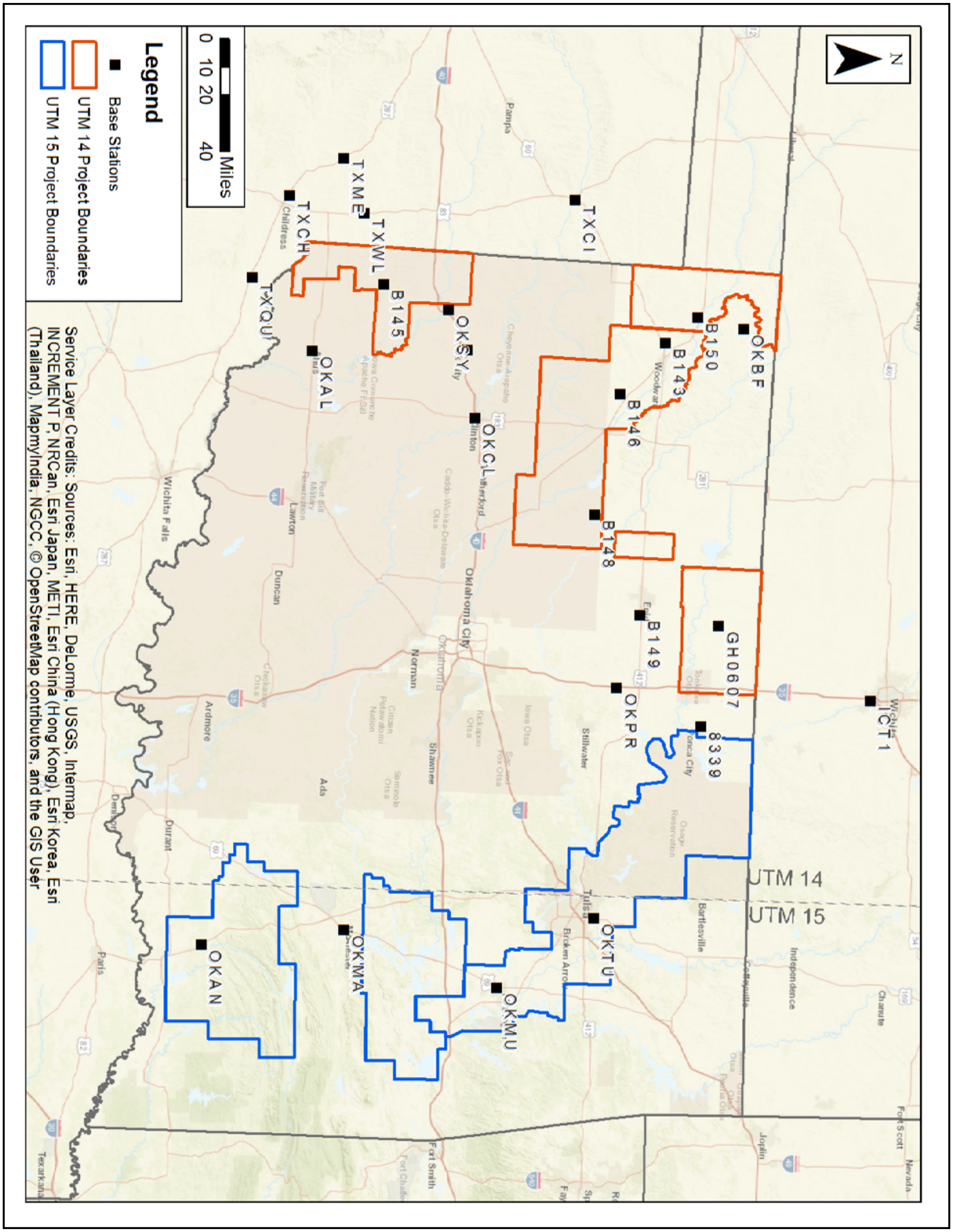
2.4. Base Station Information

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 9. 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)
8339	97° 6' 3.49192"	36° 43' 34.61468"	274.932
B143	99° 31' 8.01979"	36° 25' 58.23368"	637.133
B145	99° 45' 58.38386"	34° 58' 22.61007"	482.465
B146	99° 10' 40.53175"	36° 13' 0.35679"	550.506
B148	98° 24' 23.23565"	36° 7' 34.00332"	364.355
B149	97° 47' 12.26712"	36° 23' 2.35021"	237.741
B150	99° 41' 42.97609"	36° 35' 24.99247"	608.774
FK0626	99° 23' 41.48994"	35° 25' 31.59727"	576.684
GH0607	97° 44' 45.82546"	36° 47' 32.3194"	304.704
ICT1	97° 18' 31.95899"	37° 35' 15.77366"	364.412
OKAL	99° 19' 45.64728"	34° 37' 56.12468"	401.682
OKAN	95° 37' 16.84691"	34° 11' 42.70877"	141.477
OKBF	99° 38' 28.84114"	36° 49' 40.88178"	539.89
OKCL	98° 58' 17.24643"	35° 28' 59.34894"	470.786
OKMA	95° 44' 14.05644"	34° 55' 40.83441"	201.995
OKMU	95° 24' 5.82026"	35° 43' 0.06245"	161.437
OKPR	97° 19' 17.97563"	36° 16' 64.46474"	324.604
OKSY	99° 38' 15.65012"	35° 18' 53.9333"	567.214
OKTU	95° 51' 15.78258"	36° 12' 38.1139"	169.222
TXCH	100° 16' 41.77273"	34° 27' 34.54624"	565.142
TXCI	100° 22' 41.90761"	35° 55' 13.07187"	686.209
TXME	100° 31' 45.68086"	34° 43' 26.02325"	601.18
TXQU	99° 45' 17.95294"	34° 17' 57.93275"	455.308
TXWL	100° 12' 7.49947"	34° 50' 59.03771"	589.295

Figure 9. Base Station Locations



2.5. Time Period

Project specific flights were conducted over several months. Ninety aircraft lifts were completed. Accomplished lifts are listed below and on the following page. Lifts are separated by UTM zone and listed in chronological order.

UTM 14 Lifts

- Dec 13, 2016-A (N44RL, SN2220764)
- Dec 14, 2016-A (N44RL, SN2220764)
- Dec 15, 2016-A (N44RL, SN2220764)
- Dec 16, 2016-A (N44RL, SN2220764)
- Dec 21, 2016-A (N44RL, SN2220764)
- Jan 4, 2017-A (N44RL, SN2221264)
- Jan 9, 2017-A (N44RL, SN2221264)
- Jan 9, 2017-B (N44RL, SN2221264)
- Jan 10, 2017-A (N44RL, SN2221264)
- Jan 25, 2017-A (N44RL, SN2221264)
- Jan 25, 2017-B (N44RL, SN2221264)
- Jan 26, 2017-A (N44RL, SN2221264)
- Jan 26, 2017-B (N44RL, SN2221264)
- Jan 27, 2017-A (N44RL, SN2221264)
- Jan 27, 2017-B (N44RL, SN2221264)
- Feb 21, 2017-A (N44RL, SN2221264)

UTM 15 Lifts

- Jan 4, 2017-A (N7516Q, SN386)
- Jan 6, 2017-A (N7516Q, SN386)
- Jan 6, 2017-B (N7516Q, SN386)
- Jan 7, 2017-A (N7516Q, SN386)
- Jan 7, 2017-B (N7516Q, SN386)
- Jan 8, 2017-A (N7516Q, SN386)
- Jan 9, 2017-A (N7516Q, SN386)
- Jan 9, 2017-B (N7516Q, SN386)
- Jan 10, 2017-A (N7516Q, SN386)
- Jan 21, 2017-A (N7516Q, SN386)
- Jan 22, 2017-A (N7516Q, SN386)
- Jan 24, 2017-A (N7516Q, SN386)
- Jan 25, 2017-A (N7516Q, SN386)
- Jan 25, 2017-B (N7516Q, SN386)
- Jan 26, 2017-A (N7516Q, SN386)
- Jan 27, 2017-A (N7516Q, SN386)
- Jan 27, 2017-B (N7516Q, SN386)
- Jan 27, 2017-A (N4181T, SN5060354)
- Jan 27, 2017-B (N4181T, SN5060354)
- Jan 27, 2017-C (N4181T, SN5060354)
- Jan 28, 2017-A (N7516Q, SN386)
- Jan 28, 2017-B (N7516Q, SN386)
- Jan 28, 2017-A (N4181T, SN5060354)
- Jan 29, 2017-A (N7516Q, SN386)
- Jan 29, 2017-B (N7516Q, SN386)
- Jan 30, 2017-A (N7516Q, SN386)
- Jan 30, 2017-B (N7516Q, SN386)
- Jan 30, 2017-A (N4181T, SN5060354)
- Jan 30, 2017-B (N4181T, SN5060354)
- Jan 31, 2017-A (N7516Q, SN386)
- Jan 31, 2017-B (N7516Q, SN386)
- Feb 1, 2017-A (N7516Q, SN386)
- Feb 1, 2017-B (N7516Q, SN386)
- Feb 1, 2017-A (N4181T, SN5060354)
- Feb 1, 2017-B (N4181T, SN5060354)
- Feb 3, 2017-A (N4181T, SN5060354)
- Feb 3, 2017-B (N4181T, SN5060354)
- Feb 7, 2017-A (N7516Q, SN386)
- Feb 7, 2017-B (N7516Q, SN386)
- Feb 7, 2017-A (N4181T, SN5060354)
- Feb 7, 2017-B (N4181T, SN5060354)
- Feb 8, 2017-A (N7516Q, SN386)
- Feb 9, 2017-A (N7516Q, SN386)
- Feb 9, 2017-B (N7516Q, SN386)
- Feb 9, 2017-A (N4181T, SN5060354)
- Feb 9, 2017-B (N4181T, SN5060354)
- Feb 10, 2017-A (N7516Q, SN386)
- Feb 10, 2017-B (N7516Q, SN386)

UTM 15 Lifts Continued

- Feb 10, 2017-A (N4181T, SN5060354)
- Feb 11, 2017-A (N7516Q, SN386)
- Feb 11, 2017-B (N7516Q, SN386)
- Feb 11, 2017-A (N4181T, SN5060354)
- Feb 11, 2017-B (N4181T, SN5060354)
- Feb 12, 2017-A (N7516Q, SN386)
- Feb 12, 2017-B (N7516Q, SN386)
- Feb 15, 2017-A (N7516Q, SN386)
- Feb 15, 2017-B (N7516Q, SN386)
- Feb 15, 2017-A (N4181T, SN5060354)
- Feb 15, 2017-B (N4181T, SN5060354)
- Feb 16, 2017-A (N7516Q, SN386)
- Feb 16, 2017-B (N7516Q, SN386)
- Feb 17, 2017-A (N7516Q, SN386)
- Feb 21, 2017-A (N7516Q, SN386)
- Feb 22, 2017-A (N7516Q, SN386)
- Feb 22, 2017-B (N7516Q, SN386)
- Feb 22, 2017-C (N7516Q, SN386)
- Feb 23, 2017-A (N7516Q, SN386)
- Feb 24, 2017-A (N7516Q, SN386)
- Feb 24, 2017-B (N7516Q, SN386)
- Feb 24, 2017-C (N7516Q, SN386)
- Feb 25, 2017-A (N7516Q, SN386)
- Mar 8, 2017-A (N2JJ, SN309)
- Mar 9, 2017-A (N2JJ, SN309)
- Apr 7, 2017-A (N26AX, SN5060354)

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

Inertial Explorer/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. Inertial Explorer/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 Inertial Explorer/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 Leica CloudPro software and 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 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 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 Creation

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 file geodatabase format using Esri conversion tools.

3.6. Hydro-Flattened Raster DEM Creation

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a one-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 Creation

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

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 Figures 10 and 11.

Figure 10. Flightline Swath LAS File Coverage - UTM Zone 14 AOI

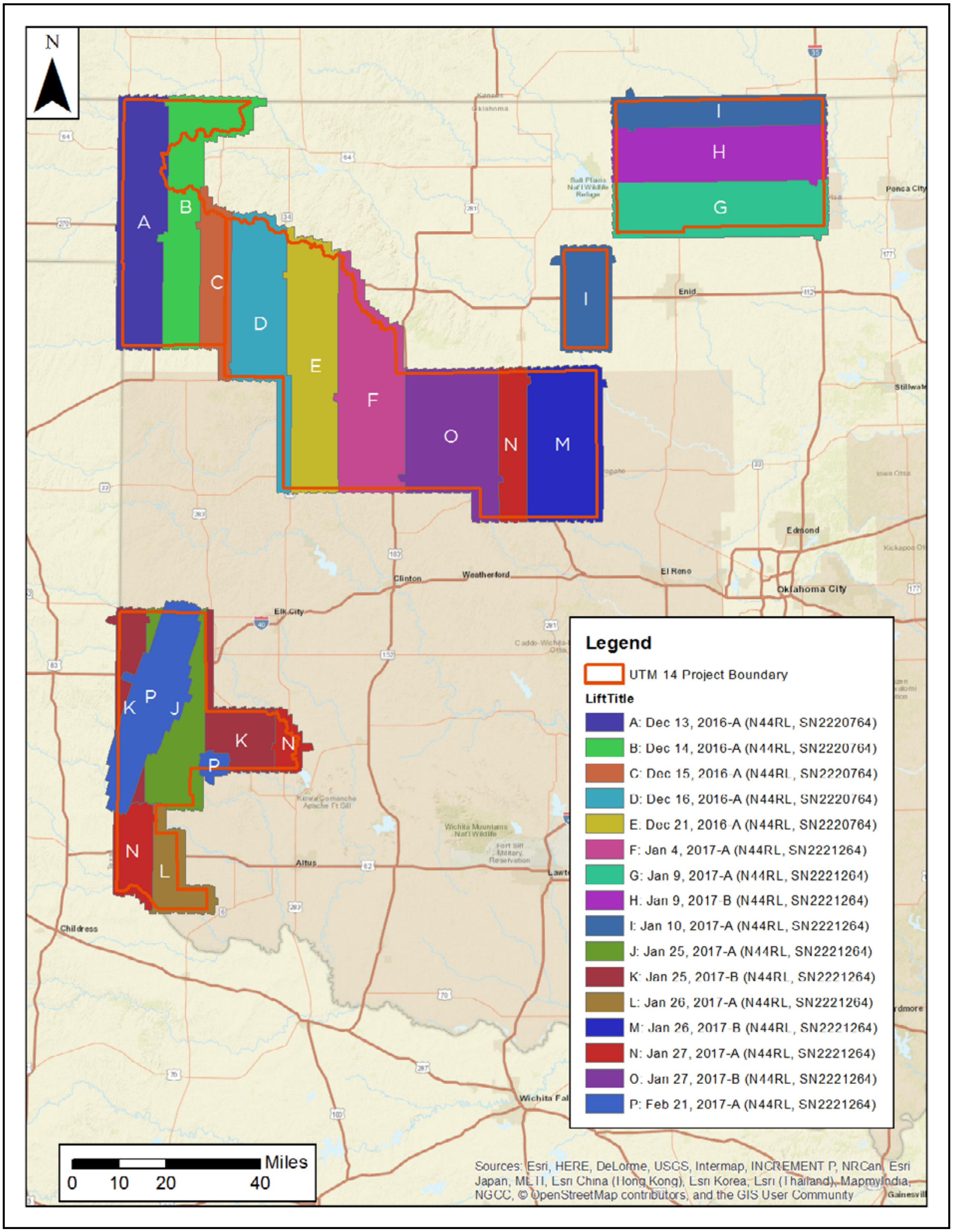
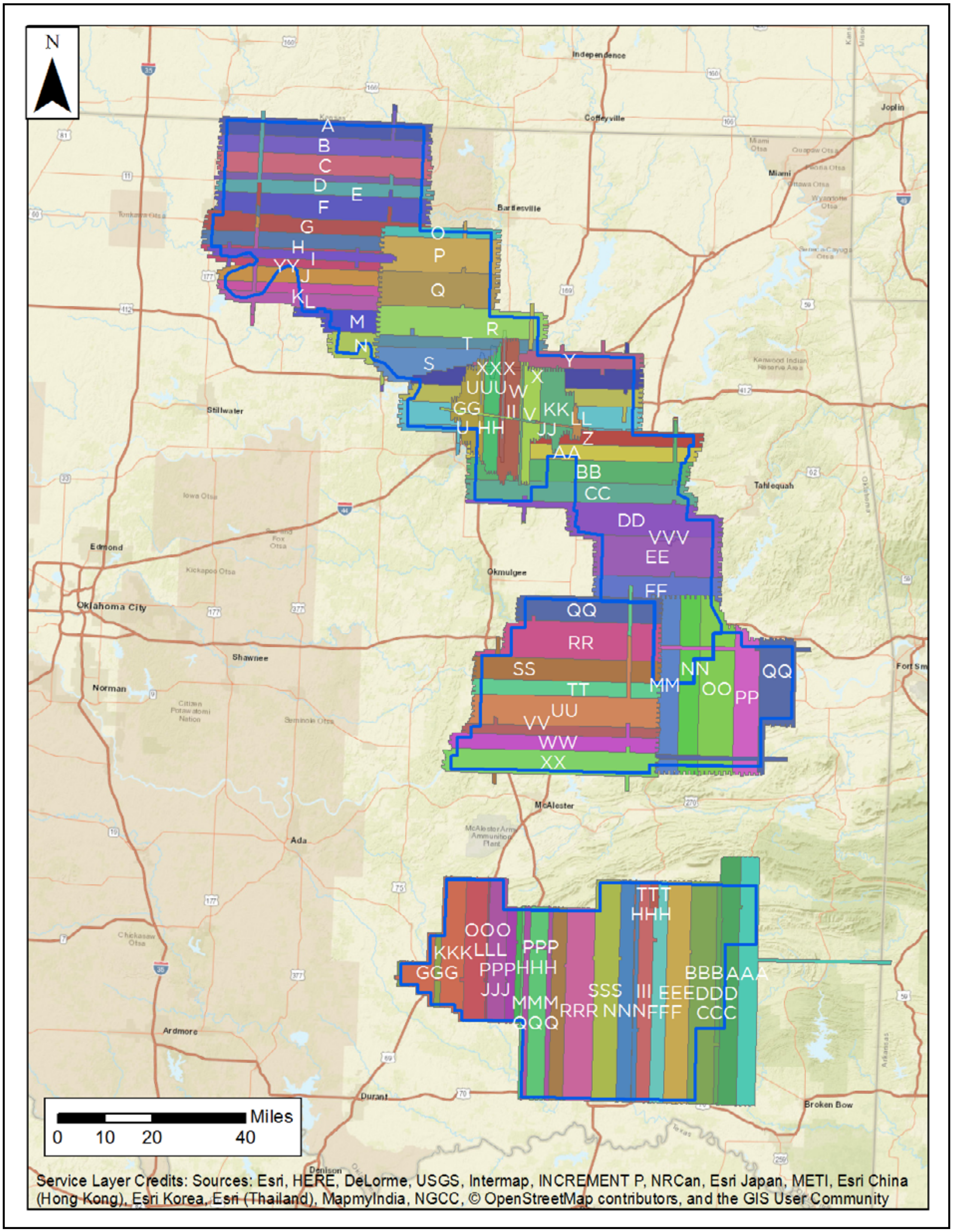


Figure 11. Flightline Swath LAS File Coverage - UTM Zone 15 AOI
(see legend on following page)



Legend

UTM 15 Project Boundary

LiftTitle

A: Jan 4, 2017-A (N7546Q, SN386)
AA: Feb 1, 2017-B (N7516Q, SN386)
AAA: Jan 27, 2017-A (N4181T, SN5060354)
B: Jan 6, 2017-A (N7546Q, SN386)
BB: Feb 7, 2017-A (N7516Q, SN386)
BBB: Jan 27, 2017-B (N4181T, SN5060354)
C: Jan 6, 2017-B (N7516Q, SN386)
CC: Feb 7, 2017-B (N7516Q, SN386)
CCC: Jan 27, 2017-C (N4181T, SN5060354)
D: Jan 7, 2017-A (N7516Q, SN386)
DD: Feb 8, 2017-A (N7516Q, SN386)
DDD: Jan 28, 2017-A (N4181T, SN5060354)
E: Jan 7, 2017-B (N7516Q, SN386)
EE: Feb 9, 2017-A (N7516Q, SN386)
EEE: Jan 30, 2017-A (N4181T, SN5060354)
F: Jan 8, 2017-A (N7516Q, SN386)
FF: Feb 9, 2017-B (N7516Q, SN386)
FFF: Jan 30, 2017-B (N4181T, SN5060354)
G: Jan 9, 2017-A (N7516Q, SN386)
GG: Feb 10, 2017-A (N7516Q, SN386)
GGG: Feb 1, 2017-A (N4181T, SN5060354)
H: Jan 9, 2017-B (N7516Q, SN386)
HH: Feb 10, 2017-B (N7516Q, SN386)
HHH: Feb 1, 2017-B (N4181T, SN5060354)
I: Jan 10, 2017-A (N7516Q, SN386)
II: Feb 11, 2017-A (N7516Q, SN386)
III: Feb 3, 2017-A (N4181T, SN5060354)
J: Jan 12, 2017-A (N7516Q, SN386)
JJ: Feb 11, 2017-B (N7516Q, SN386)
JJJ: Feb 3, 2017-B (N4181T, SN5060354)
K: Jan 22, 2017-A (N7516Q, SN386)
KK: Feb 12, 2017-A (N7516Q, SN386)
KKK: Feb 7, 2017-A (N4181T, SN5060354)
L: Jan 24, 2017-A (N7516Q, SN386)
LL: Feb 12, 2017-B (N7516Q, SN386)
LLL: Feb 7, 2017-B (N4181T, SN5060354)
M: Jan 25, 2017-A (N7516Q, SN386)
MM: Feb 15, 2017-A (N7516Q, SN386)
MMM: Feb 9, 2017-A (N4181T, SN5060354)
N: Jan 25, 2017-B (N7516Q, SN386)
NN: Feb 15, 2017-B (N7516Q, SN386)
NNN: Feb 9, 2017-B (N4181T, SN5060354)
O: Jan 26, 2017-A (N7516Q, SN386)
OO: Feb 16, 2017-A (N7516Q, SN386)
OOO: Feb 10, 2017-A (N4181T, SN5060354)
P: Jan 27, 2017-A (N7516Q, SN386)
PP: Feb 16, 2017-B (N7516Q, SN386)
PPP: Feb 11, 2017-A (N4181T, SN5060354)
Q: Jan 27, 2017-B (N7516Q, SN386)
QQ: Feb 17, 2017-A (N7516Q, SN386)
QQQ: Feb 11, 2017-B (N4181T, SN5060354)
R: Jan 28, 2017-A (N7516Q, SN386)
RR: Feb 22, 2017-A (N7516Q, SN386)
RRR: Feb 15, 2017-A (N4181T, SN5060354)
S: Jan 28, 2017-B (N7516Q, SN386)
SS: Feb 22, 2017-B (N7516Q, SN386)
SSS: Feb 15, 2017-B (N4181T, SN5060354)
T: Jan 29, 2017-A (N7516Q, SN386)
TT: Feb 22, 2017-C (N7516Q, SN386)
TTT: Apr 7, 2017-A (N26AX, SN5060354)
U: Jan 29, 2017-B (N7516Q, SN386)
UU: Feb 23, 2017-A (N7516Q, SN386)
UUU: Feb 25, 2017-N (N2JJ, SN309)
V: Jan 30, 2017-A (N7516Q, SN386)
VV: Feb 24, 2017-A (N7516Q, SN386)
VVV: Mar 9, 2017-B (N2JJ, SN309)
W: Jan 30, 2017-B (N7516Q, SN386)
WW: Feb 24, 2017-B (N7516Q, SN386)
X: Jan 31, 2017-A (N7516Q, SN386)
XX: Feb 24, 2017-C (N7516Q, SN386)
XXX: Mar 8, 2017-A (N2JJ, SN309)
Y: Jan 31, 2017-B (N7516Q, SN386)
YY: Feb 25, 2017-A (N7516Q, SN386)
Z: Feb 1, 2017-A (N7516Q, SN386)

5. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 358 ground control (calibration) points along with 458 blind QA points in Vegetated and Non-Vegetated land cover classifications (total of 816 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 in Appendix B.

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). In this document, horizontal coordinates for ground control and QA points for all LiDAR classes are reported in UTM 14 and UTM 15.

5.1. Calibration Control Point Testing

Figures 12 and 13 show 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 271 checkpoints located in bare earth and urban (non-vegetated) areas (note that 270 points were used to test DEM NVA). 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 Figures 14 and 15.

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 270 checkpoints located in bare earth and urban (non-vegetated) areas (note that 271 points were used to test raw NVA). See Figures 14 and 15.

2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for "Forested areas", "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 187 checkpoints located in forested areas, 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 16 and 17.

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.

A brief summary of results are listed below. For more information, see the FOCUS on Accuracy Report.

Table 4. Summary of LiDAR Acccuracy

Category	Target	Measured	Point Count
Raw NVA	0.196 m	0.092 m	271
NVA	0.196 m	0.093 m	270
VVA	0.294 m	0.185 m	187

Figure 12. Calibration Control Point Locations - UTM 14 AOI

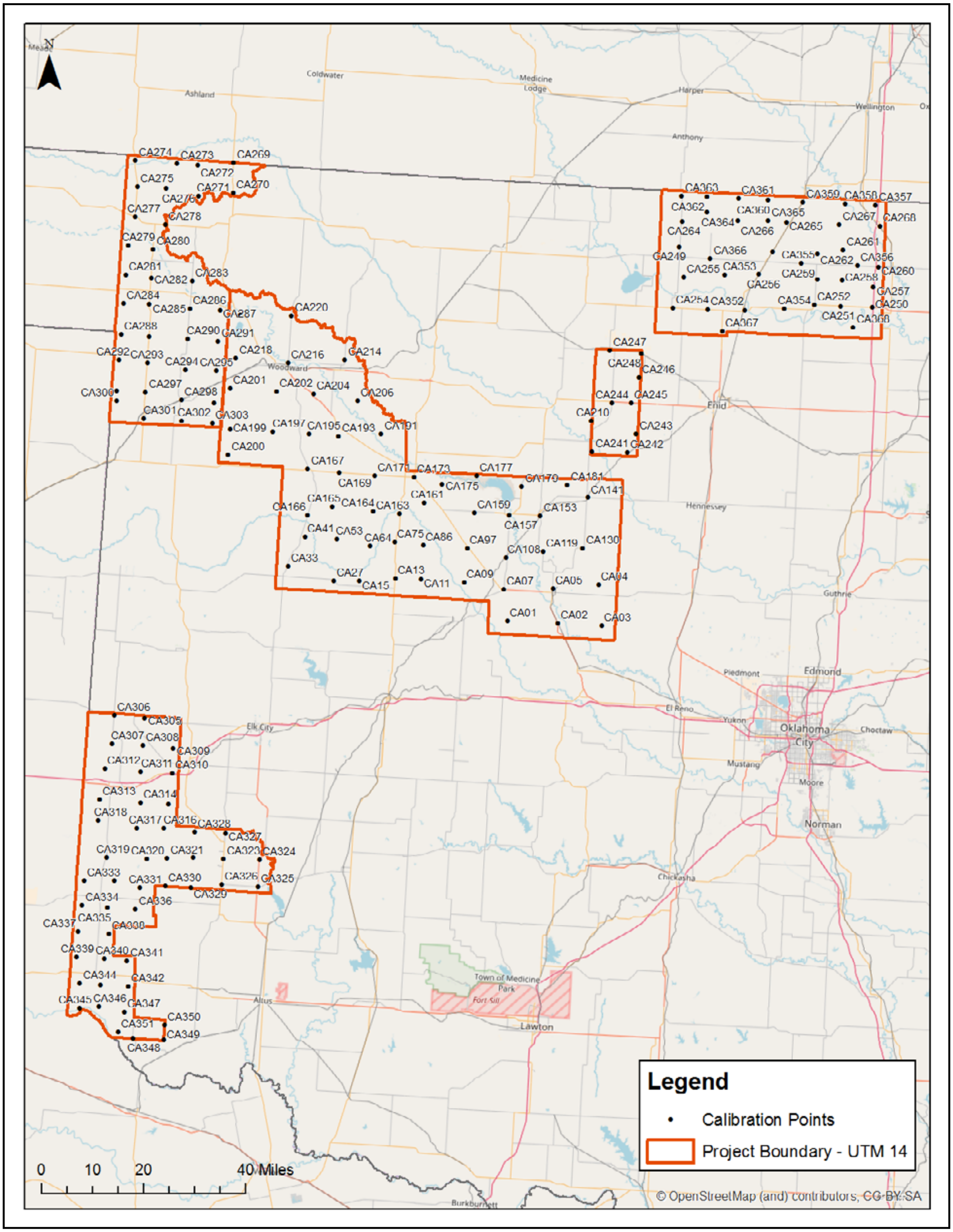


Figure 13. Calibration Control Point Locations - UTM 15 AOI

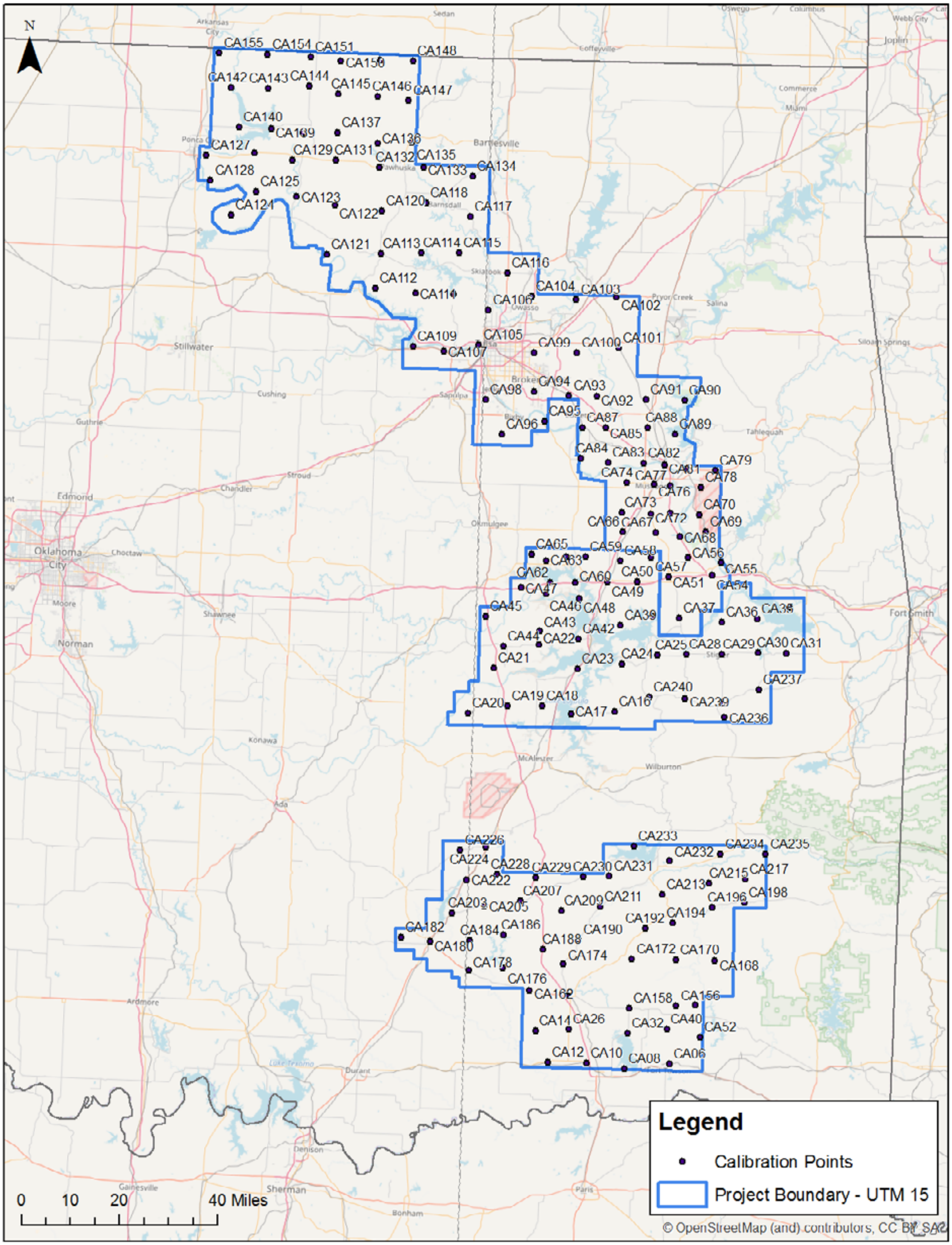


Figure 14. QC Checkpoint Locations - NVA - UTM 14 AOI

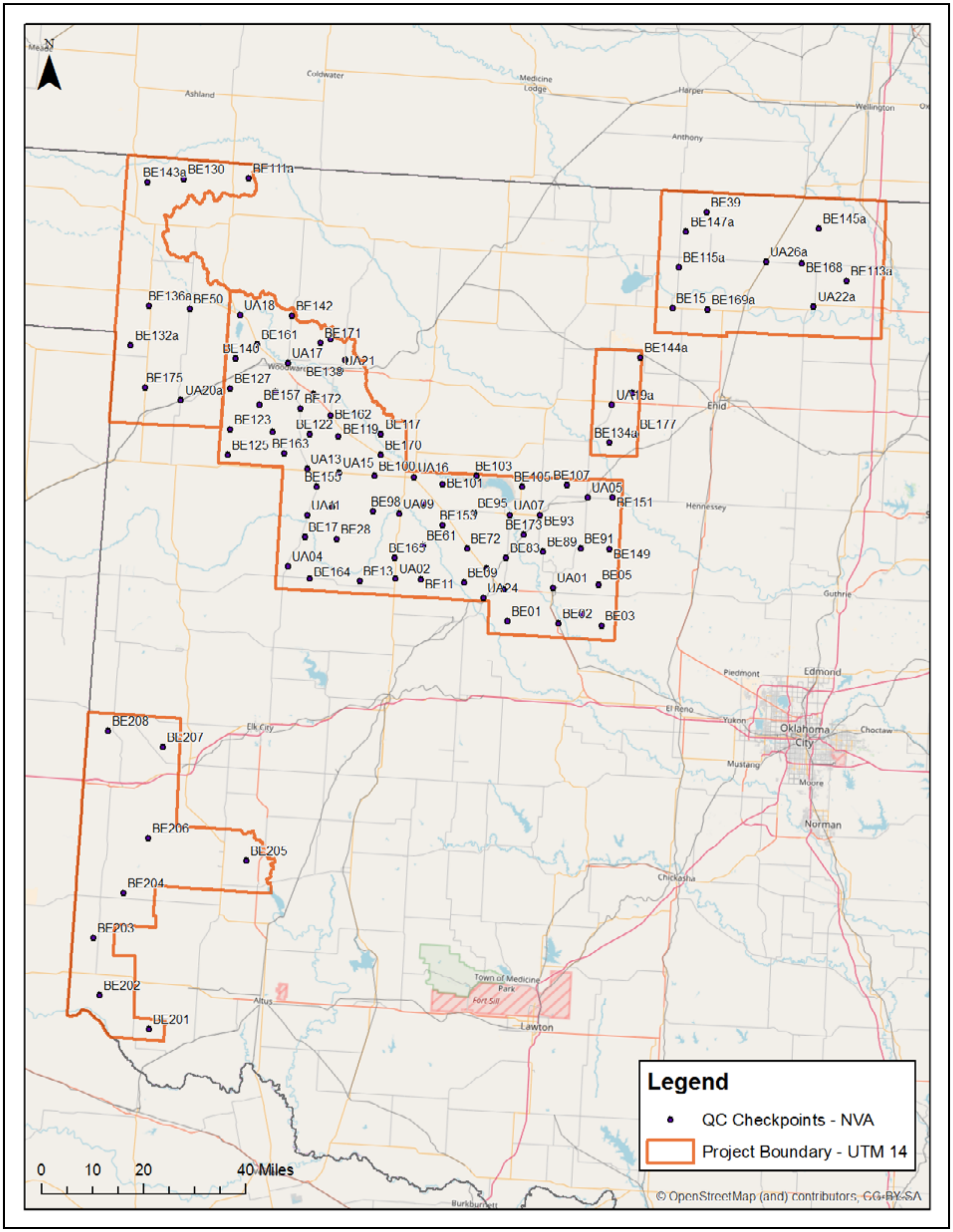


Figure 15. QC Checkpoint Locations - NVA - UTM 15 AOI

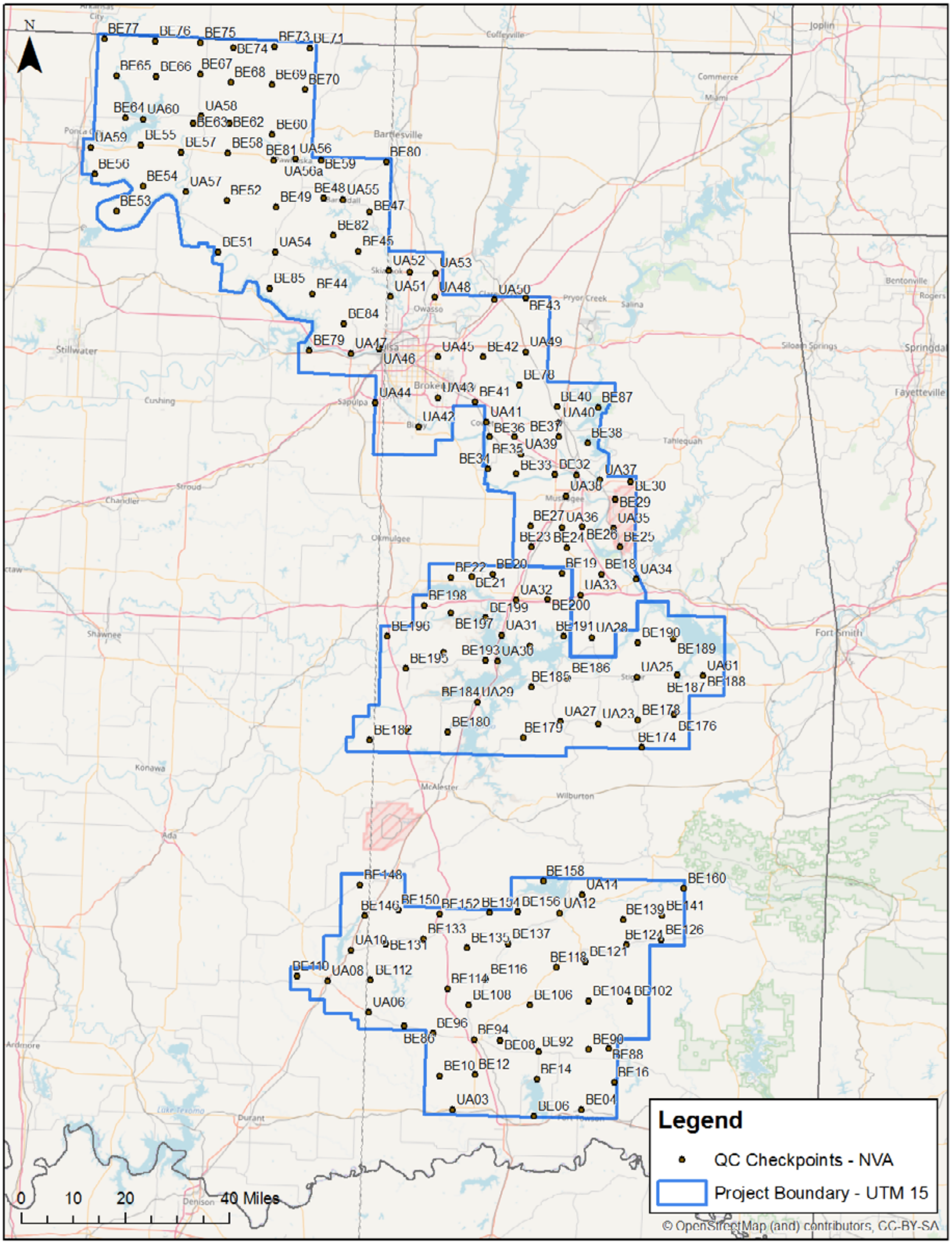


Figure 16. QC Checkpoint Locations - VVA - UTM 14 AOI

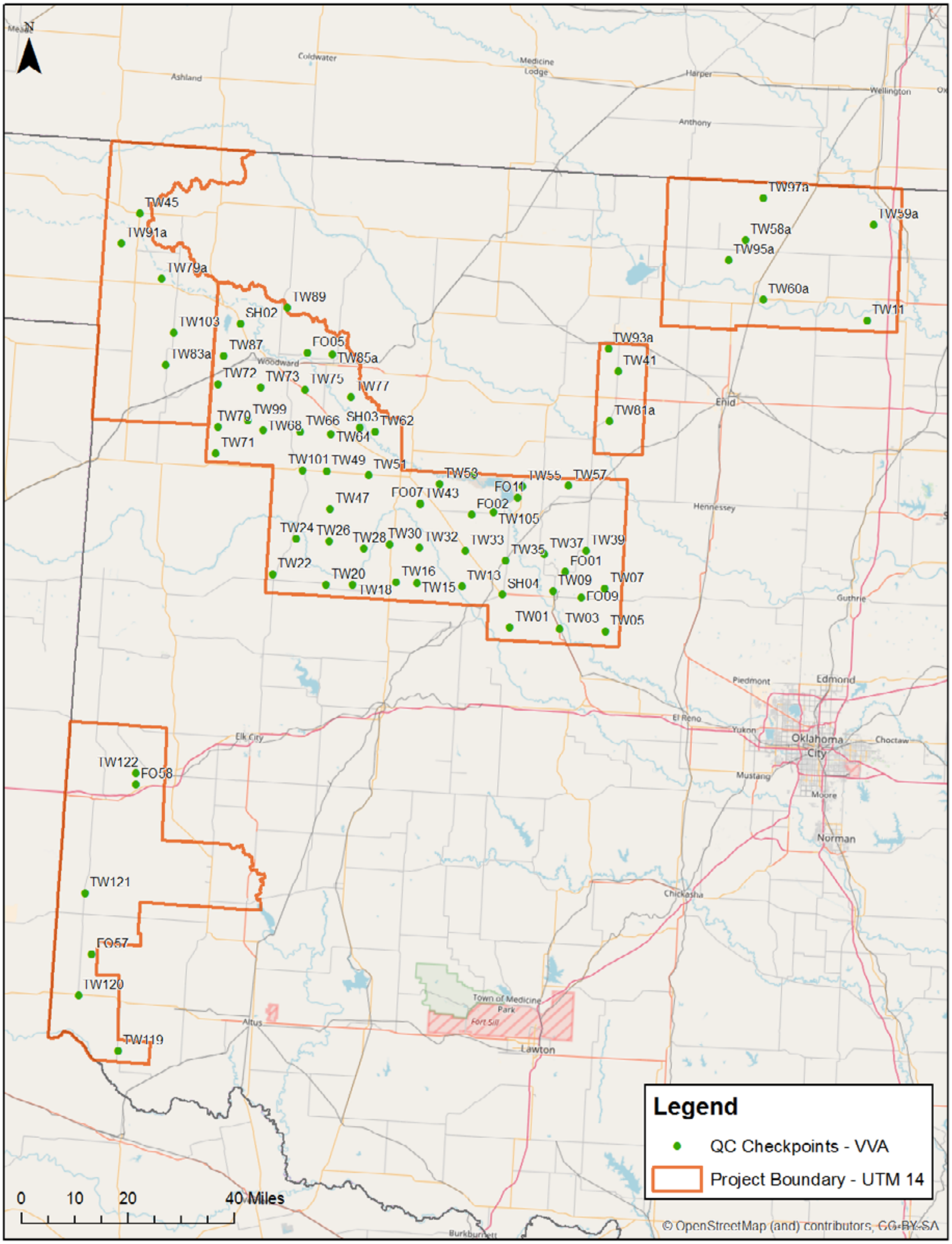


Figure 17. QC Checkpoint Locations - VVA - UTM 15 AOI