Oshkosh 3 Rivers 2018
LiDAR Project Report

USGS Contract # G16PC00016
Task Order # 140G0219F0026

Submitted: June 8, 2020

Prepared by:

Quantum Spatial, Inc
523 Wellington Way, Suite 375
Lexington, KY 40503
859-277-8700

Contents

List of Figures

List of Tables

1. Summary / Scope

1.1. Summary

This report contains a summary of the Oshkosh 3 Rivers 2018 LiDAR acquisition task order, issued by the USGS under their Contract G16PC00016 on 13 November 2018. The task order yielded a project area covering 5096 square miles over Wisconsin and Minnesota. 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
2.98 pts / m^2	2150 m	40°	30%	≤ 10 cm

1.3. Coverage

The project boundary covers 5086 square miles over Wisconsin and Minnesota. 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 19 April 2019 to 21 May 2019 in 20 total lifts. See "Section: 2.4. Time Period" for more details.

1.5. Issues

There were no major issues to report for this project.

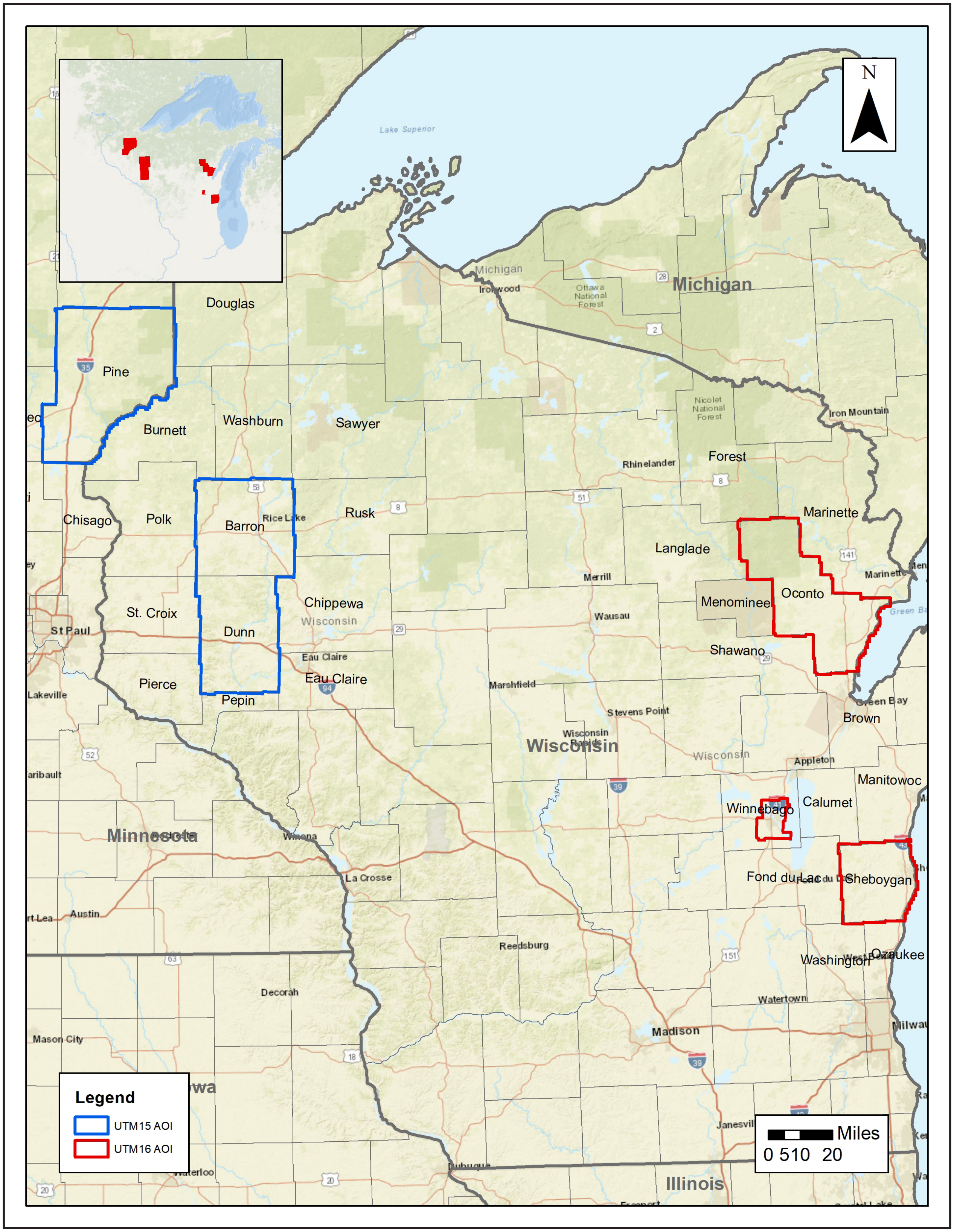
1.6. Deliverables

The following products were produced and delivered:

- Classified LiDAR point cloud data tiles in .LAS 1.4 format
- Continuous hydro-flattened breaklines in Esri file geodatabase format
- 1-meter hydro-flattened bare earth digital elevation model (DEM) tiles in ERDAS .IMG format
- 1-meter intensity imagery tiles in GeoTIFF format
- FOCUS report in .PDF format
- FOCUS on Deliverables report in .PDF format
- FOCUS on Accuracy report in .PDF format
- Metadata in .XML format

All geospatial deliverables were produced with a horizontal datum/projection of NAD 1983 2011 UTM Zones 16N and 15N and a vertical datum/projection of NAVD88 GEOID12B. All tiled deliverables were provided as 1500 m x 1500 meter tiles.

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 Leica MissionPro and RiPARAMETER planning software. The entire target area was comprised of 314 planned flight lines (Figures 2 and 3).

2.2. LiDAR Sensor

Quantum Spatial utilized Leica ALS80 and Riegl 1560i LiDAR sensors (Figure 4), serial numbers 8146, 3543, and 2738, during the project.

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 Leica ALS80 system is capable of collecting data at a maximum frequency of 1,000 kHz. The system utilizes a Multi-Pulse in the Air option (MPIA). The sensor also has the capacity for unlimited range returns from each outbound pulse. The intensity of the returns is also captured during aerial acquisition.

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

Figure 2. Planned Flight Lines - UTM15

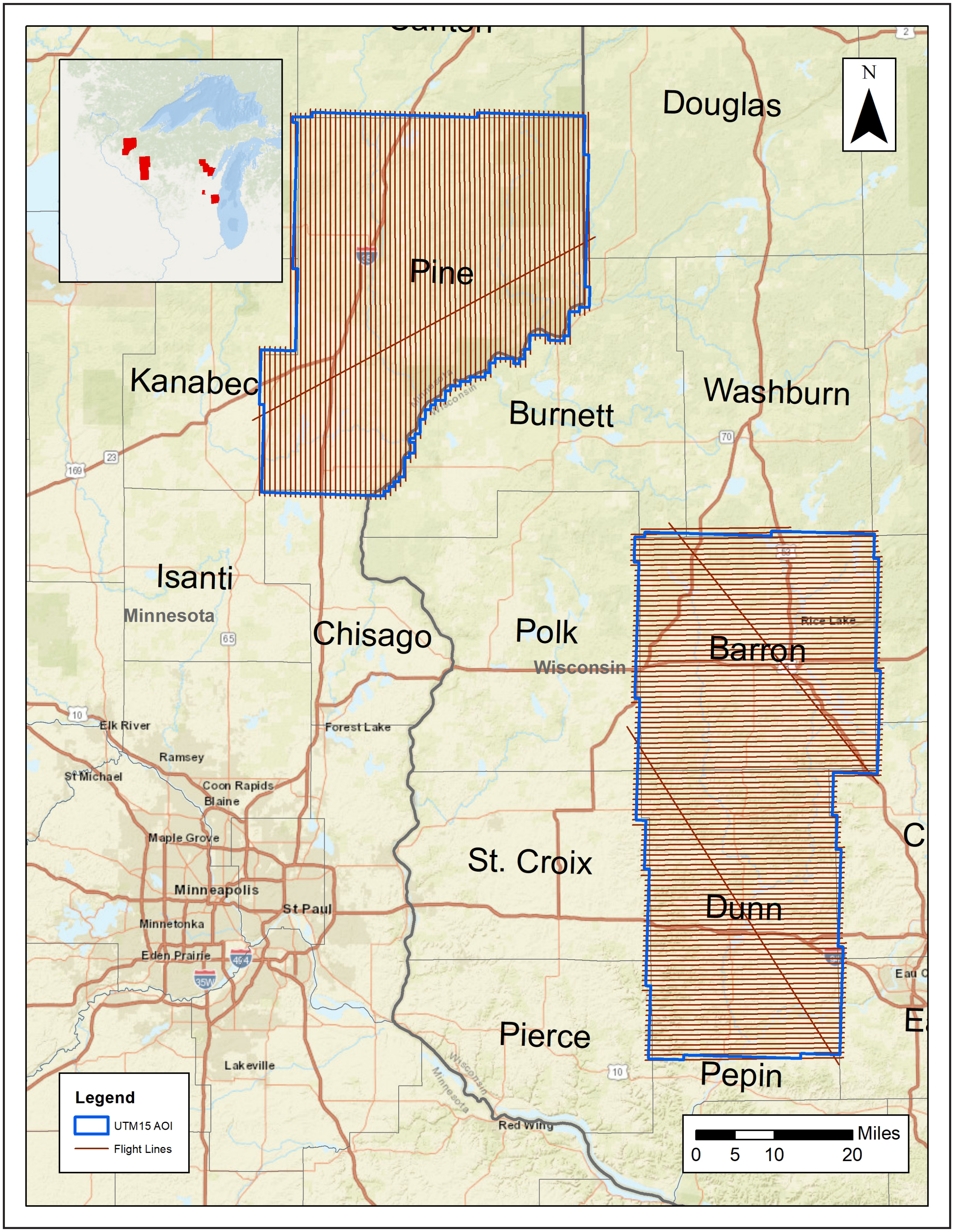


Figure 3. Planned Flight Lines - UTM16

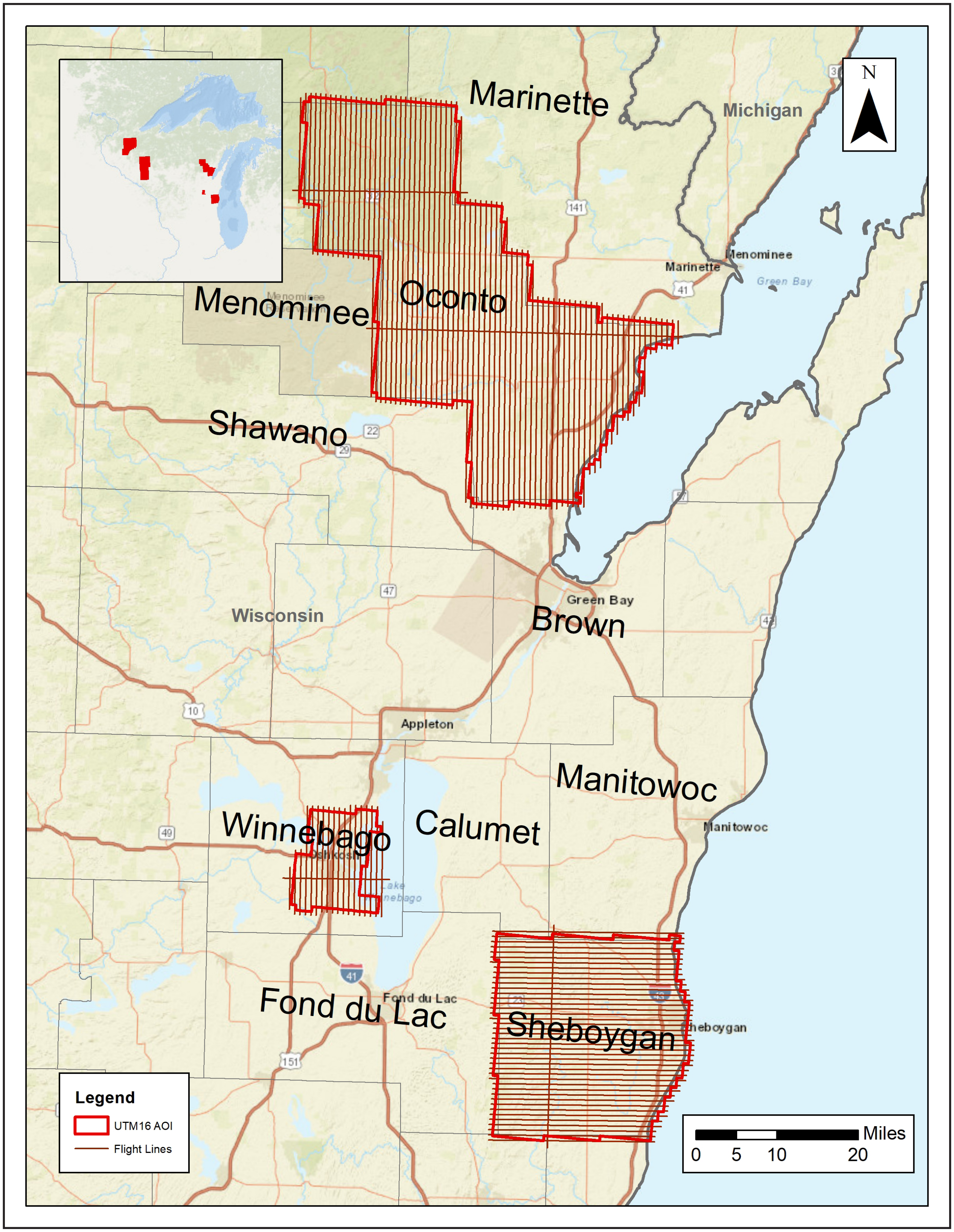
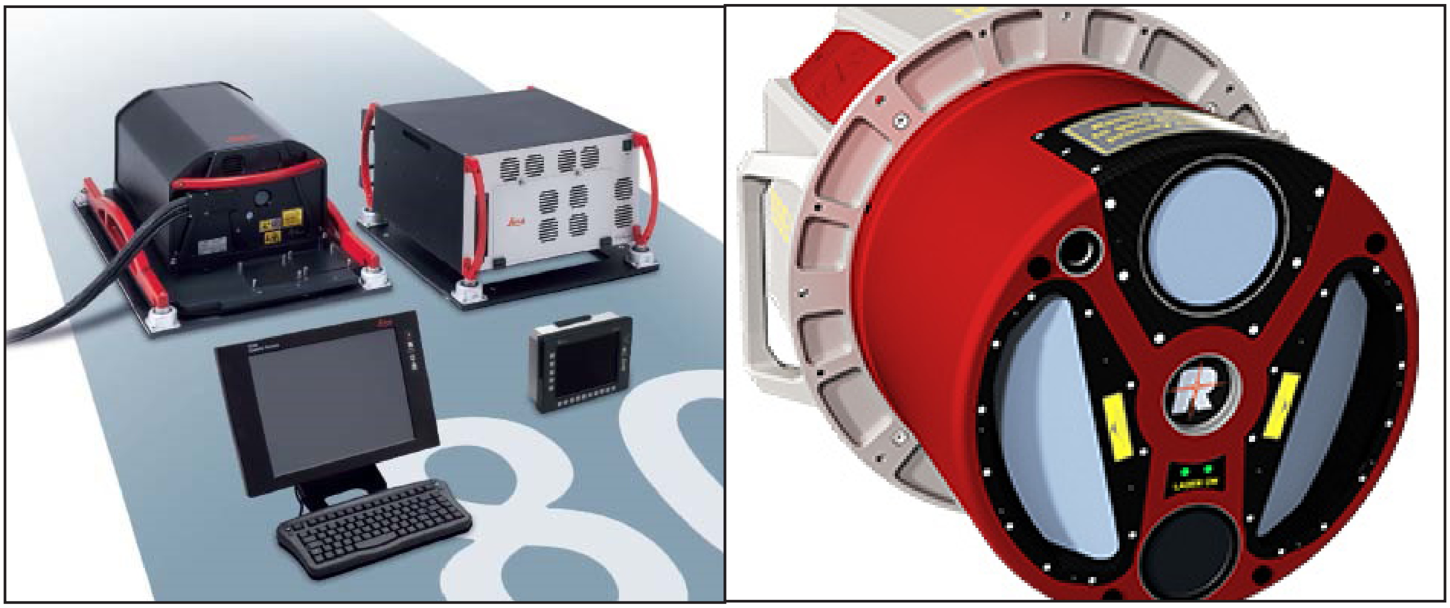


Table 2. LiDAR System Specifications

		ALS80	1560i
Terrain and Aircraft Scanner	Flying Height	2150 m	2000 m
	Recommended Ground Speed	160 kts	160 kts
Scanner	Field of View	40°	60°
	Scan Rate Setting Used	52 Hz	180 Hz
Laser	Laser Pulse Rate Used	381 kHz	700 kHz
	Multi Pulse in Air Mode	yes	yes
Coverage	Full Swath Width	1565 m	2309 m
	Line Spacing	1096 m	1616 m
Point Spacing and Density	Average Point Spacing	0.58 m	0.71 m
	Average Point Density	2.97 pts / m^2	1.99 pts / m^2

Figure 4. The Leica ALS80 and Riegl 1560i 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

- Twin-Piston Piper Navajo PA31, Tail Numbers: N6GR, C-FVZM, C-FFRY

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 state-of-the-art Leica ALS80 and Riegl 1560i LiDAR systems. Some of Quantum Spatial's operating aircraft can be seen in Figure 5 below.

Figure 5. Some of Quantum Spatial's Planes

2.4. Time Period

Project specific flights were conducted between 19 April 2019 and 21 May 2019. 19 aircraft lifts were completed. Accomplished lifts are listed below.

- 20190419A (SN8146, N6GR)
- 20190420A (SN8146, N6GR)
- 20190420B (SN8146, N6GR)
- 20190504A (SN8146, N6GR)
- 20190507A (SN8146, N6GR)
- 20190507B (SN8146, N6GR)
- 20190507A (SN2738, C-FVZM)
- 20190511A (SN2738, C-FVZM)
- 20190511A (SN8146, N6GR)
- 20190512A (SN8146, N6GR)
- 20190513A (SN8146, N6GR)
- 20190513A (SN2738, C-FVZM)
- 20190514A (SN2738, C-FVZM)
- 20190514A (SN8146, N6GR)
- 20190515A (SN2738, C-FVZM)
- 20190517A (SN3543, C-FFRY)
- 20190520A (SN3543, C-FFRY)
- 20190520B (SN2738, C-FVZM)
- 20190521A (SN2738, C-FVZM)

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

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.

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 and RiPROCESS 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 1.3 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:

- 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 – Water – Points found inside of inland lake/ponds
- 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.
- Class 20 – 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 21 – Snow – Where reliably identified
- Class 22 – Temporal Exclusion – Typically non-favored data in intertidal zones

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

Figure 6. LiDAR Tile Layout - UTM 15

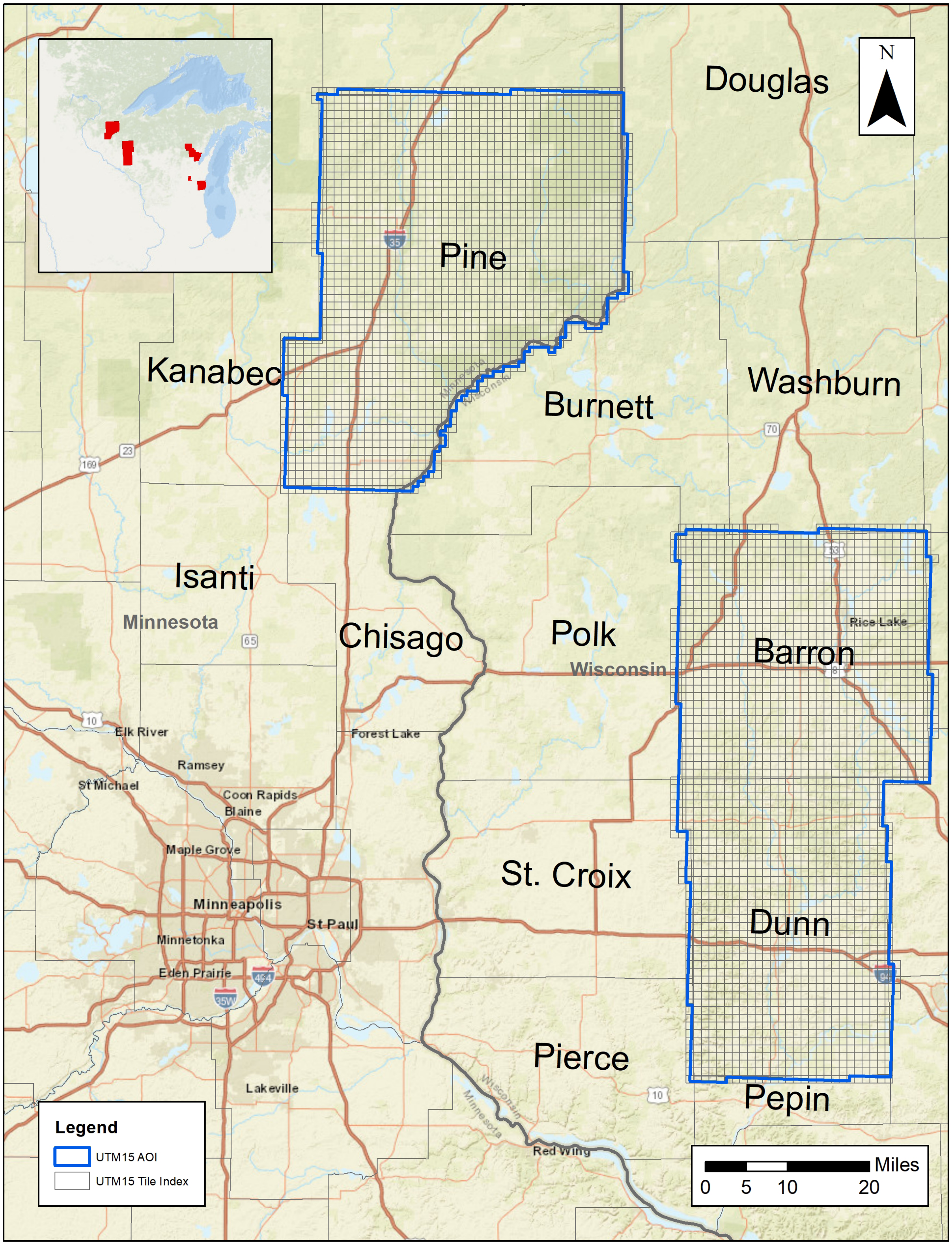
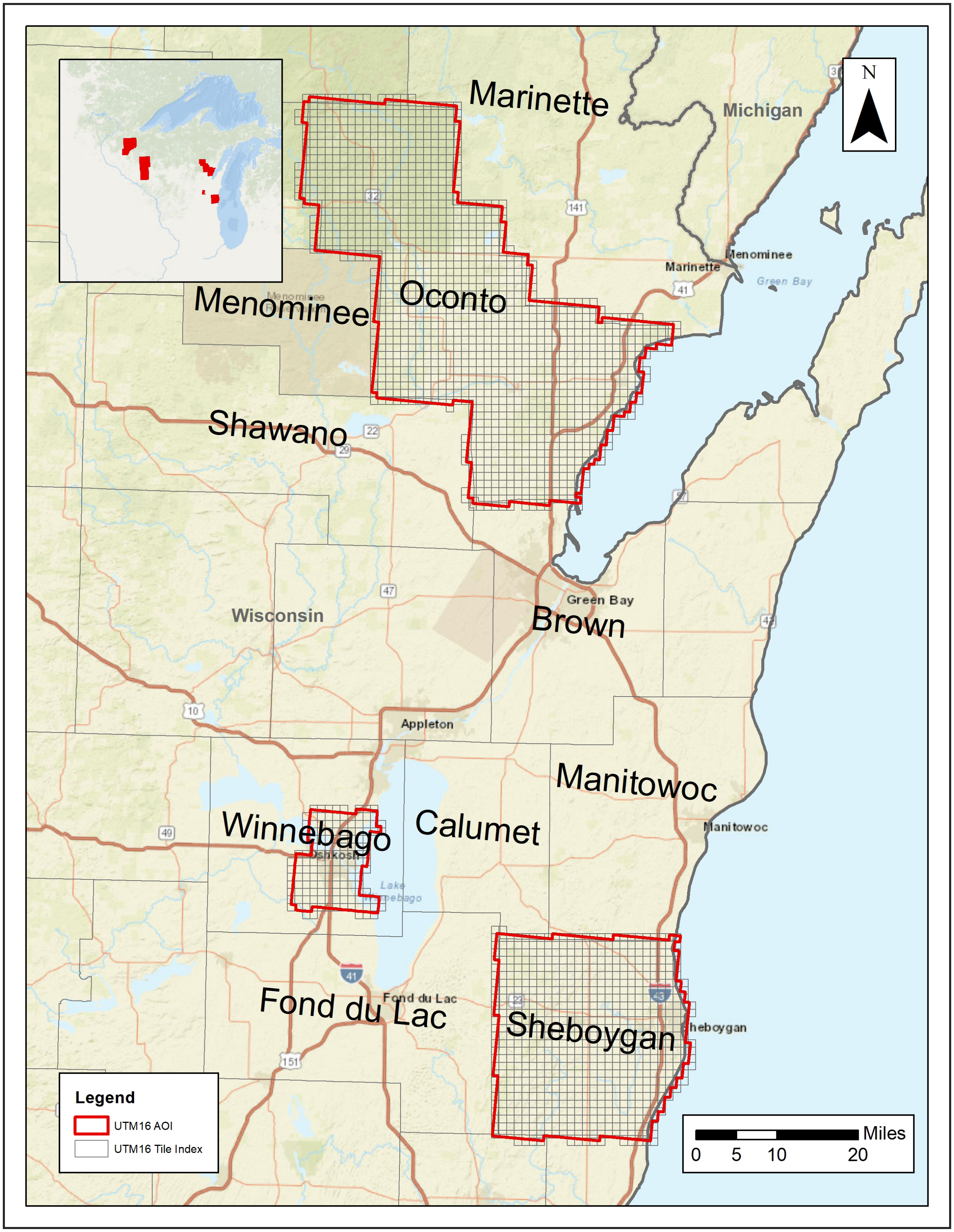


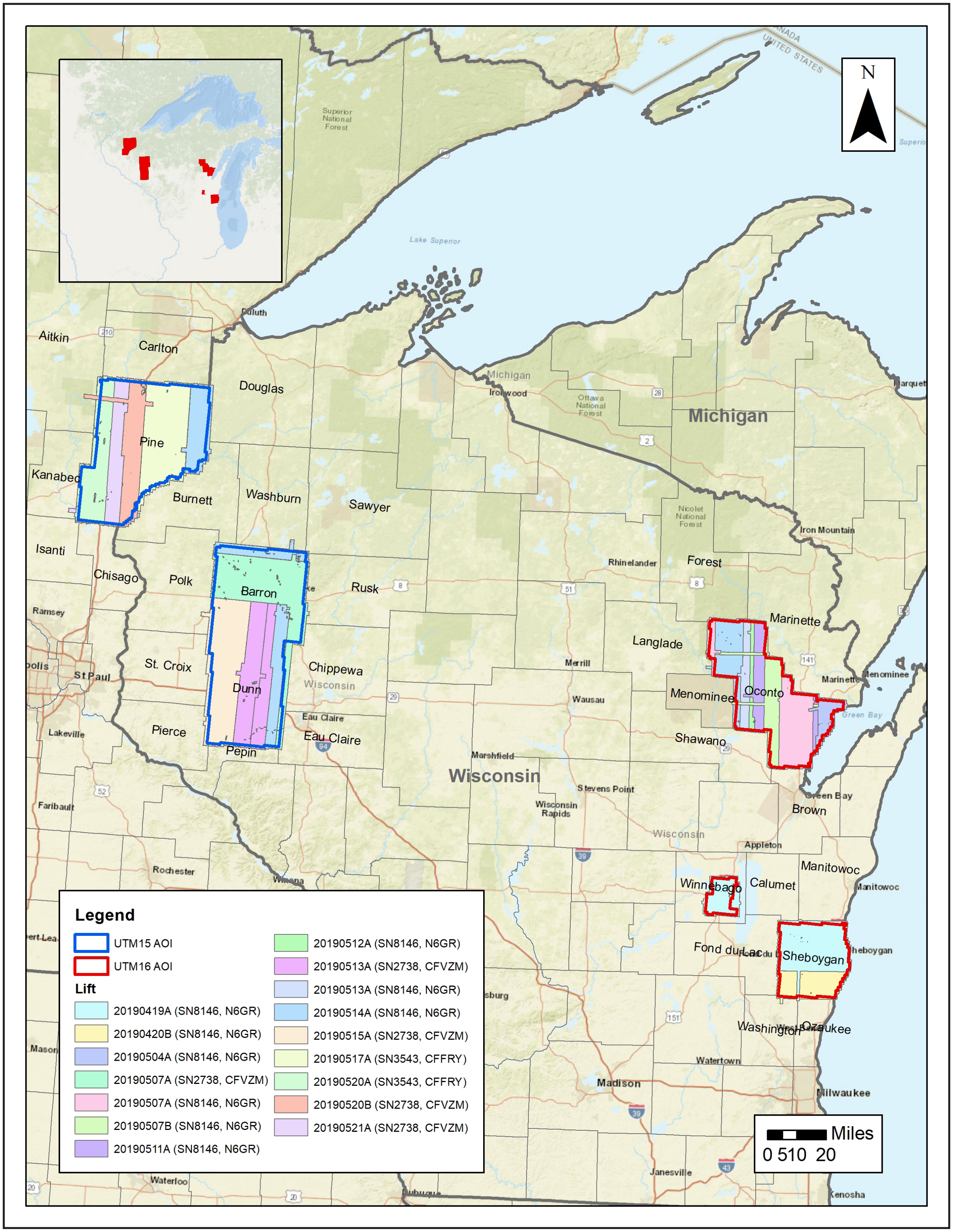
Figure 7. LiDAR Tile Layout - UTM 16



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 8.

Figure 8. LiDAR Flightline Coverage



5. Ground Control and Check Point Collection

Ayres Associates completed a field survey of 112 ground control (calibration) points along with 214 blind QA points in Non-Vegetated and Vegetated land cover classifications (total of 326 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 9 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. For the UTM 16 and UTM 15 project areas, the NVA was tested with 44 and 72 checkpoints, respectively. These points are 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) 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.

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. For the UTM 16 and UTM 15 project areas, the NVA was tested with 44 and 72 checkpoints, respectively. These points are located in bare earth and urban (non-vegetated) areas. See Figure 10.

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. For the UTM16 and UTM15 project areas, the VVA was tested with 31 and 67 checkpoints, respectively. These points are 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 11.

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.

	Target	UTM16 Measured	Point Count	UTM15 Measured	Point Count
Calibration	N/A	N/A	40	N/A	72
Raw NVA	0.196 m	0.0909 m	44	0.0623 m	72
NVA	0.196 m	0.0909 m	44	0.0652 m	72
VVA	0.294 m	0.1686 m	31	0.1521 m	67

Figure 9. Calibration Control Point Locations

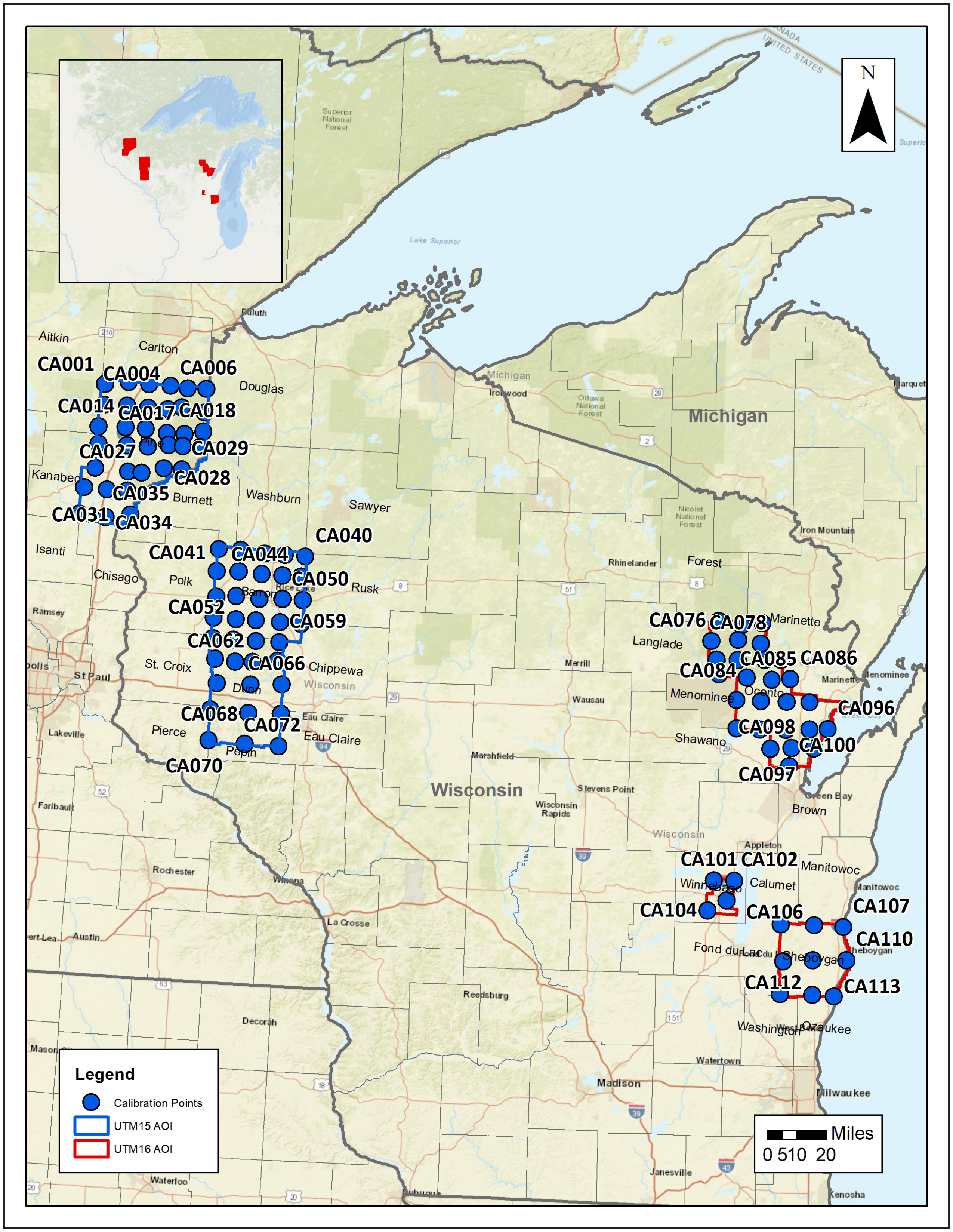


Figure 10. QC Checkpoint Locations - NVA

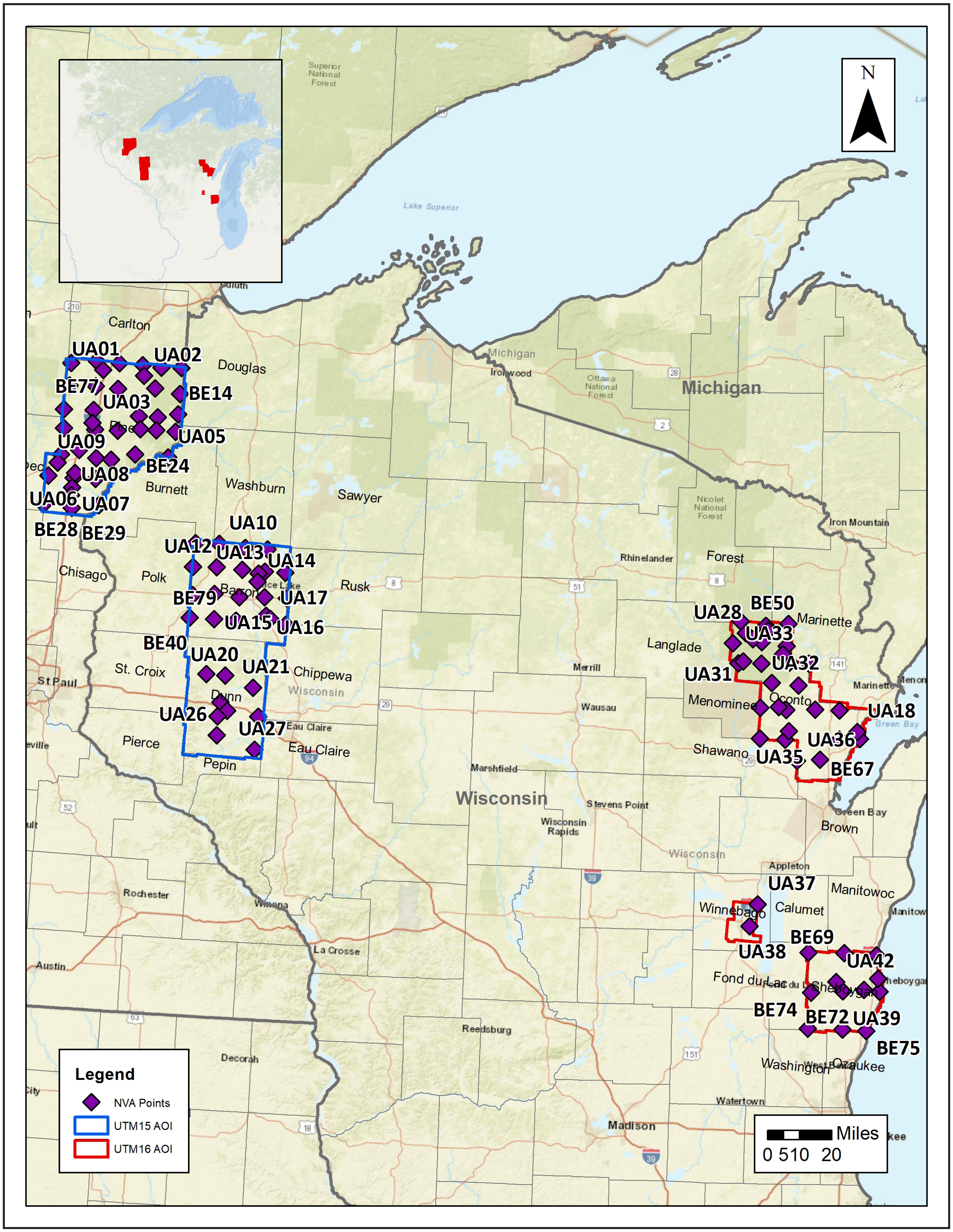


Figure 11. QC Checkpoint Locations - VVA