Minnesota DNR Lake County 2018 LiDAR Project Report

Photo courtesy of R27182818 at https://en.wikipedia.org/wiki/Boundary_Waters_Canoe_Area_Wilderness#/media/File:Pose_lake_Minnesota.jpg. This image is free to use according to CC BY-SA 3.0

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Minnesota DNR Lake County 2018 LiDAR acquisition task order, issued by the Minnesota Department of Natural Resources under their Contract T-Number I6AAP-17 on 4 September 2018. The task order yielded a project area covering 623 square miles over Lake County, 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
18 pts / m²	1,310 m	30°	50%	≤ 10 cm

1.3. Coverage

The project boundary covers approximately 623 square miles over Lake County, Minnesota. These extents are shown in Figure 1.

1.4. Duration

LiDAR data was acquired from 22 September 2018 to 22 October 2018 in seven total lifts. See "Section: 2.5. 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
- 30 cm hydro-flattened bare earth digital elevation model (DEM) tiles in GeoTIFF format
- 30 cm digital surface model (DSM) tiles in GeoTIFF format
- 30 cm intensity imagery tiles in GeoTIFF format
- Processing boundary in Esri shapefile format
- Tile index in Esri shapefile format
- Calibration and QC checkpoints (NVA/VVA) in Esri shapefile format
- Photo QC checkpoints in Esri shapefile format
- Flight lines in Esri shapefile format
- Flight logs in .PDF format
- Survey report in .PDF format
- FOCUS report in .PDF format
- FOCUS on Deliverables report in .PDF format
- FOCUS on Accuracy report in .PDF format
- FGDC compliant metadata in .XML format

All geospatial deliverables were produced with a horizontal datum/projection of UTM 15 North, NAD83 (2011) and a vertical datum/projection of NAVD88, GEOID 12B. All tiled deliverables have a tile size of 750 meters x 750 meters.

Figure 1. Project Boundary

Legend
AOI
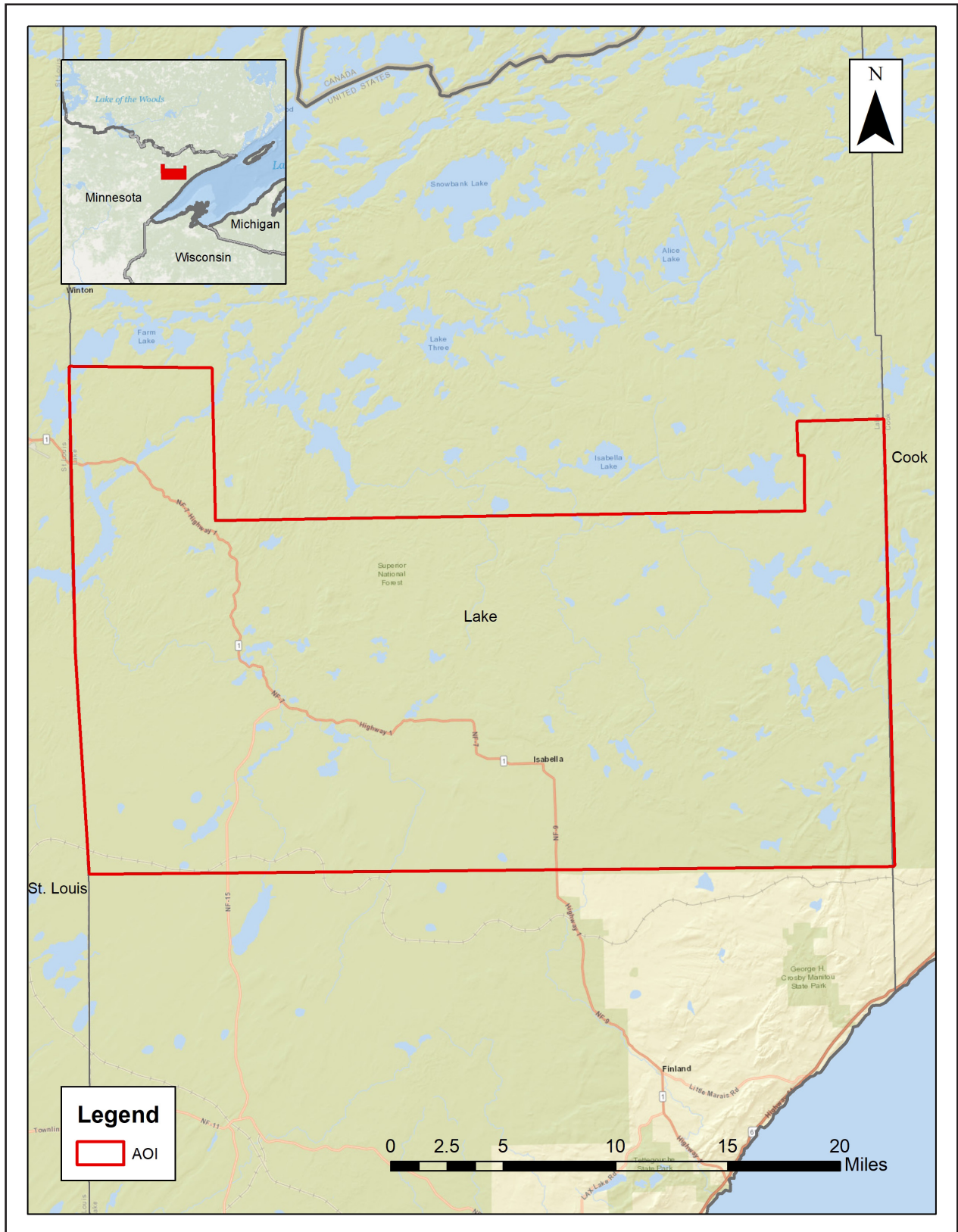
2. Planning / Equipment

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 RiPARAMETER planning software. The entire target area was comprised of 77 planned flight lines (Figure 2).

2.2. LiDAR Sensor

Quantum Spatial utilized a Riegl 1560i LiDAR sensor (Figure 3), serial number 3069, 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.

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

Legend

— Planned Flight Lines

▭ AOI

0   2.5   5   10   15   20
Miles
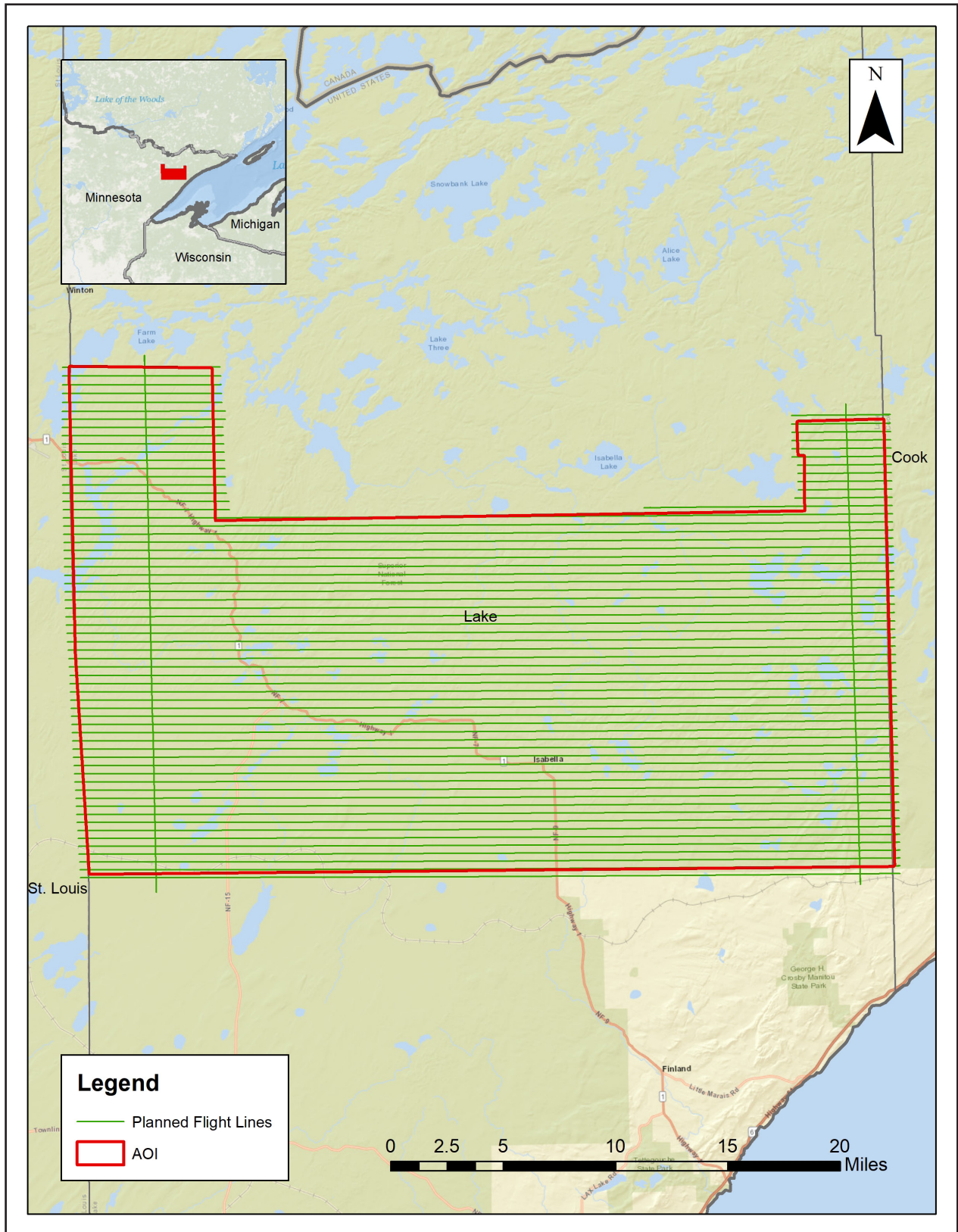
Table 2. LiDAR System Specifications

		1560i
Terrain and Aircraft Scanner	Flying Height	1,306 m
	Recommended Ground Speed	145 kts
Scanner	Field of View	58.5°
	Scan Rate Setting Used	41.5 Hz
Laser	Laser Pulse Rate Used	193 kHz
	Multi Pulse in Air Mode	yes
Coverage	Full Swath Width	1,463 m
	Line Spacing	658 m
Point Spacing and Density	Average Point Spacing	0.236 m
	Average Point Density	18 pts / m²

Figure 3. Riegl 1560i LiDAR Sensor

2.3. Aircraft

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

LiDAR Collection Plane
- Cessna T206 Turbo Stationair (single piston), Tail Number: 683AC

This aircraft provided an ideal, stable aerial base for LiDAR and orthoimagery acquisition. This aerial platform has relatively fast cruise speeds which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds proving ideal for collection of high-density, consistent data posting using a state-of-the-art Riegl 1560i LiDAR system. Some of Quantum Spatial's operating aircraft can be seen in Figure 4 below.

Figure 4. Some of Quantum Spatial's Planes

2.4. Continuously Operating Reference Station (CORS) Information

Continuously Operating Reference Stations (CORS) were utilized during all lifts (Table 3). These stations provide Global Navigation Satellite System (GNSS) data consisting of carrier phase and code range measurements in support of three dimensional positioning, meteorology, space weather, and geophysical applications throughout the United States. CORS locations are depicted in Figure 5.

Table 3. CORS Locations

CORS	Longitude	Latitude	Ellipsoid Height (m)
MNVI	92 33 41.43356 W	47 31 23.77164 N	415.233
GDMA	90 20 28.47144 W	47 44 54.75711 N	158.250
WIBL	91 05 08.72582 W	46 51 58.80345 N	201.710
WIS5	92 00 54.73297 W	46 42 18.17202 N	160.282
WIS6	92 00 56.14297 W	46 42 18.36572 N	160.241

Figure 5. CORS Locations
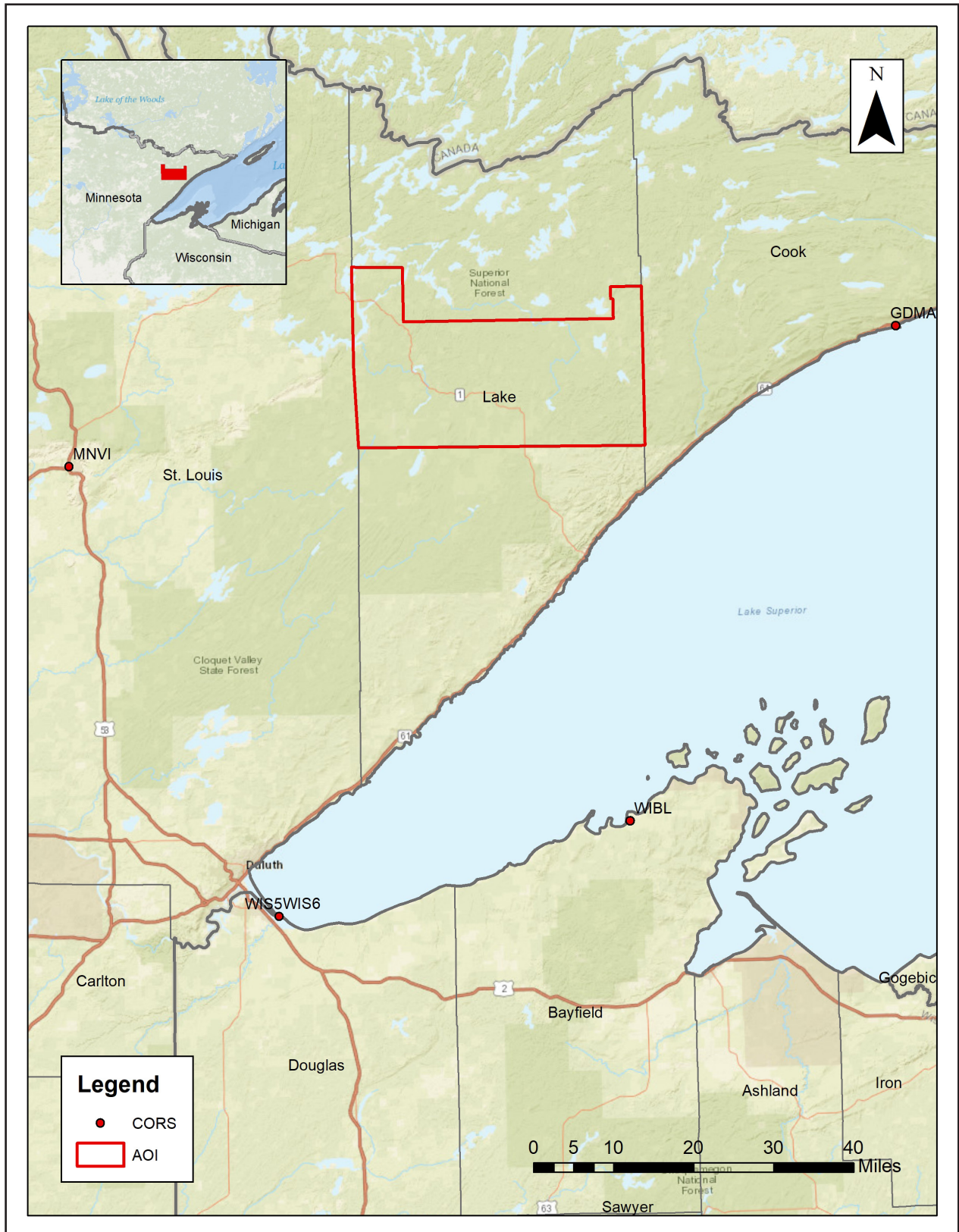
2.5. Time Period

Project specific flights were conducted over two months. Seven aircraft lifts were completed. Accomplished lifts are listed below.

- 20180922A (SN3069, 683AC)
- 20180926A (SN3069, 683AC)
- 20180929A (SN3069, 683AC)
- 20181004A (SN3069, 683AC)

- 20181017A (SN3069, 683AC)
- 20181018A (SN3069, 683AC)
- 20181022A (SN3069, 683AC)

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.

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 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

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 3 – Low Vegetation
- Class 4 – Medium Vegetation
- Class 5 – High Vegetation
- Class 6 – Buildings – Points falling on buildings, structures in water bodies, docks, and piers.
- Class 7 – Noise – Manually identified below surface points that could be noise points.
- Class 8 – Model key points
- Class 9 – Water – Points found inside of inland lake/ponds
- Class 12 – Overlap
- Class 18 – High Noise – Manually identified above surface points that could be noise points.
- Class 20 – Ignored Ground – Points found to be close to breakline features. Points are moved to this class from Class 2. This class is ignored during the DEM creation process in order to provide smooth transition between the ground surface and hydro flattened surface.

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 Quantum Spatial's proprietary software and TerraModeler functionality. 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 30 cm Raster DEM. Using automated scripting routines within ArcMap, 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 30 cm were then provided as the deliverable for this dataset requirement.
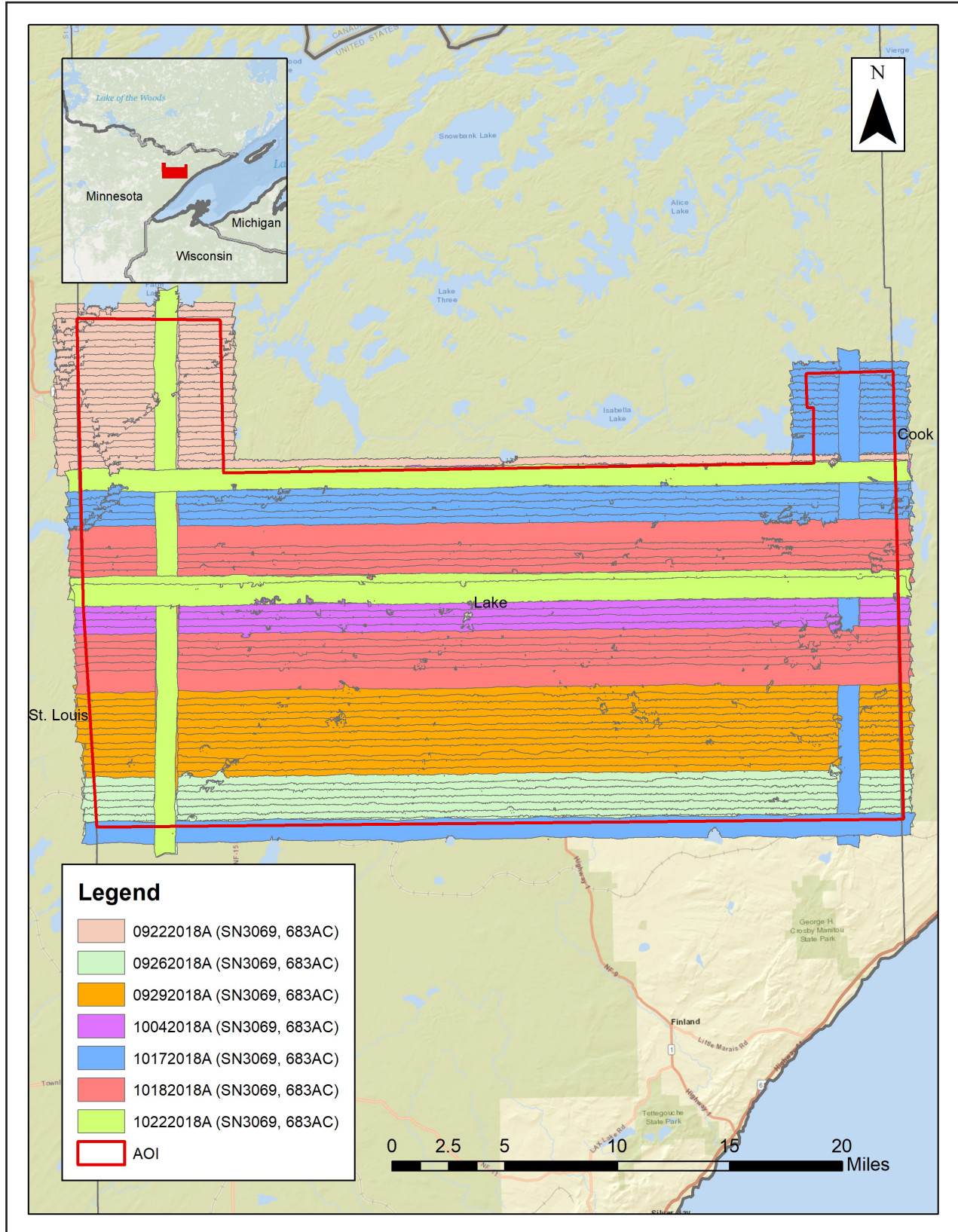
3.8. First Return Raster DSM Processing

First return LiDAR points were used to create a 30 cm first-return raster DSM. Using automated scripting routines within ArcMap, GeoTIFF files were created for each tile. Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

Figure 6. LiDAR Tile Layout

4. Project Coverage Verification

Coverage verification was performed by comparing coverage of processed .LAS files captured during project collection to generate project shape files depicting boundaries of specified project areas. Please refer to Figure 7.

Figure 7. LiDAR Flightline Coverage

Legend

▢	09222018A (SN3069, 683AC)
▢	09262018A (SN3069, 683AC)
▢	09292018A (SN3069, 683AC)
▢	10042018A (SN3069, 683AC)
▢	10172018A (SN3069, 683AC)
▢	10182018A (SN3069, 683AC)
▢	10222018A (SN3069, 683AC)
▭	AOI

5. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 14 ground control (calibration) points along with 70 blind QA points in Non-Vegetated and Vegetated land cover classifications (total of 84 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 (2018). For more information, see the Survey Report in Appendix B.

5.1. Calibration Control Point Testing

Figure 8 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 40 check points 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 check points 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 10.

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 40 checkpoints located in bare earth and urban (non-vegetated) areas. See Figure 10.
>
> 2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for "forest," "shrubs," 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 30 checkpoints located in forest, shrubs, and tall weeds (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. For more information, See the FOCUS on Accuracy report.

Point Class	Target	Measured	Point Count
Calibration	N/A	N/A	14
Raw NVA	0.196 m	0.111	40
NVA	0.196 m	0.110	40
VVA	0.294 m	0.216	30

Figure 8. Calibration Control Point Locations
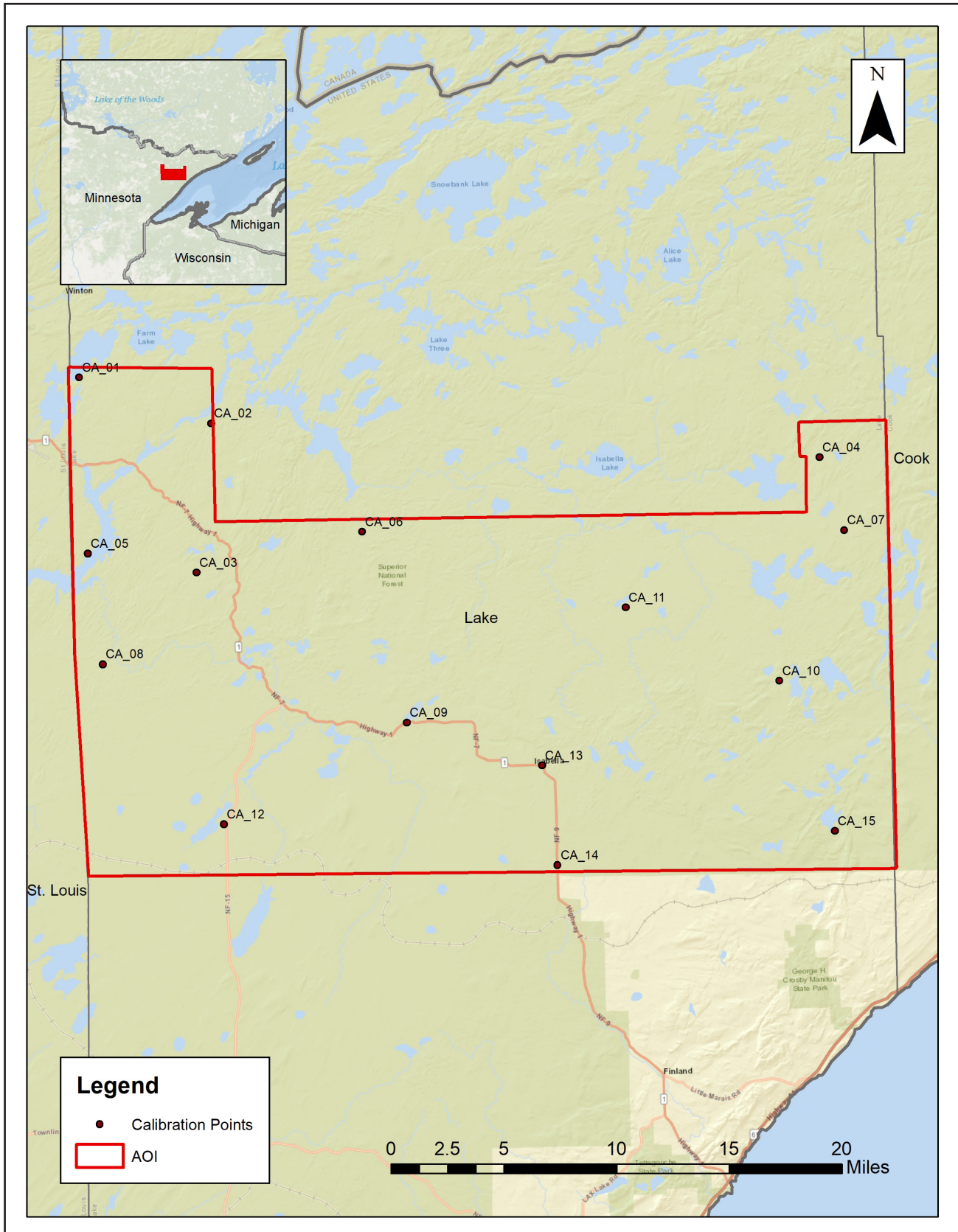
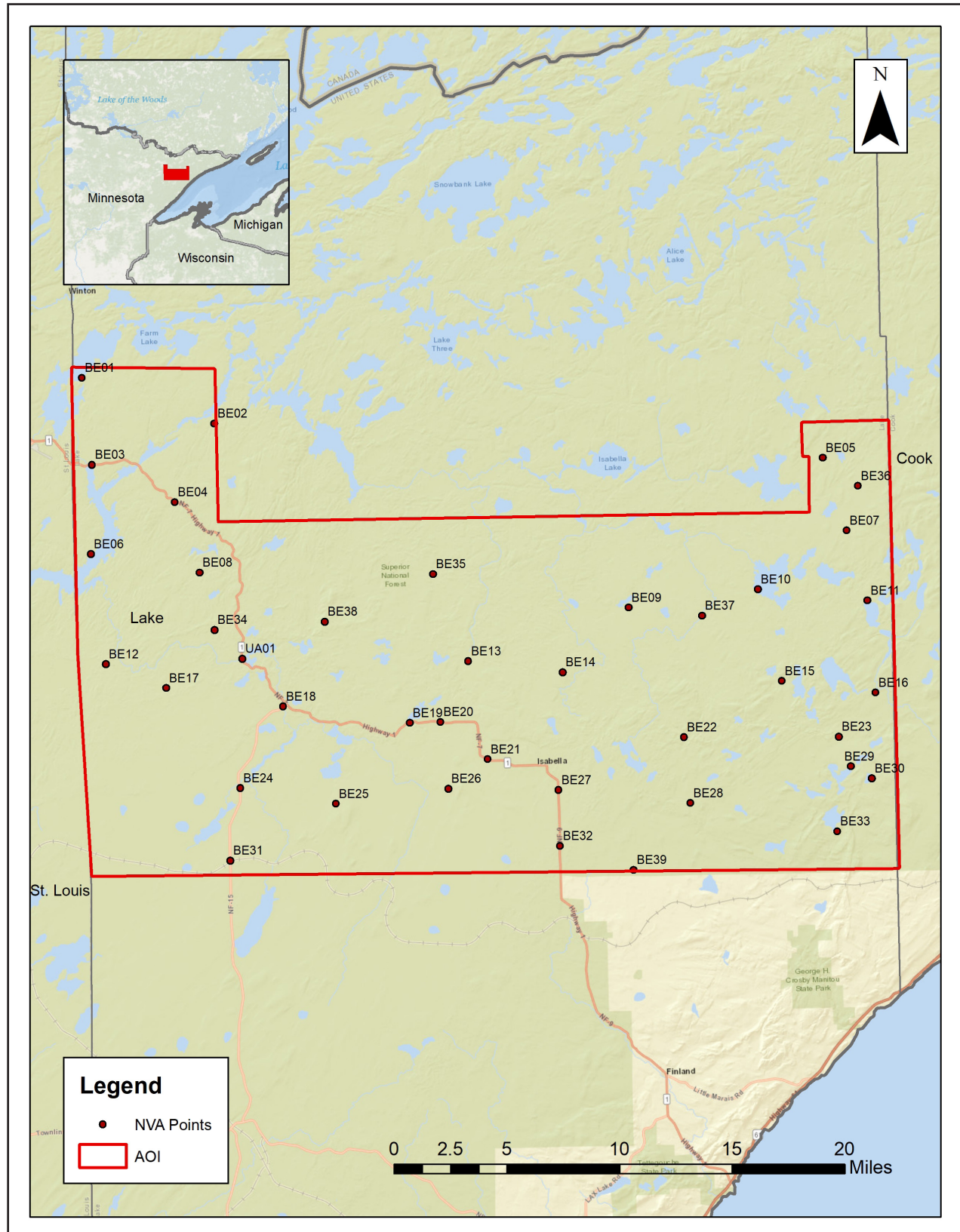## Figure 9. QC Checkpoint Locations - NVA

Legend

● NVA Points

☐ AOI

0   2.5   5   10   15   20
Miles

Figure 10. QC Checkpoint Locations - VVA

Legend

● VVA Points

▭ AOI

0   2.5   5   10   15   20
Miles