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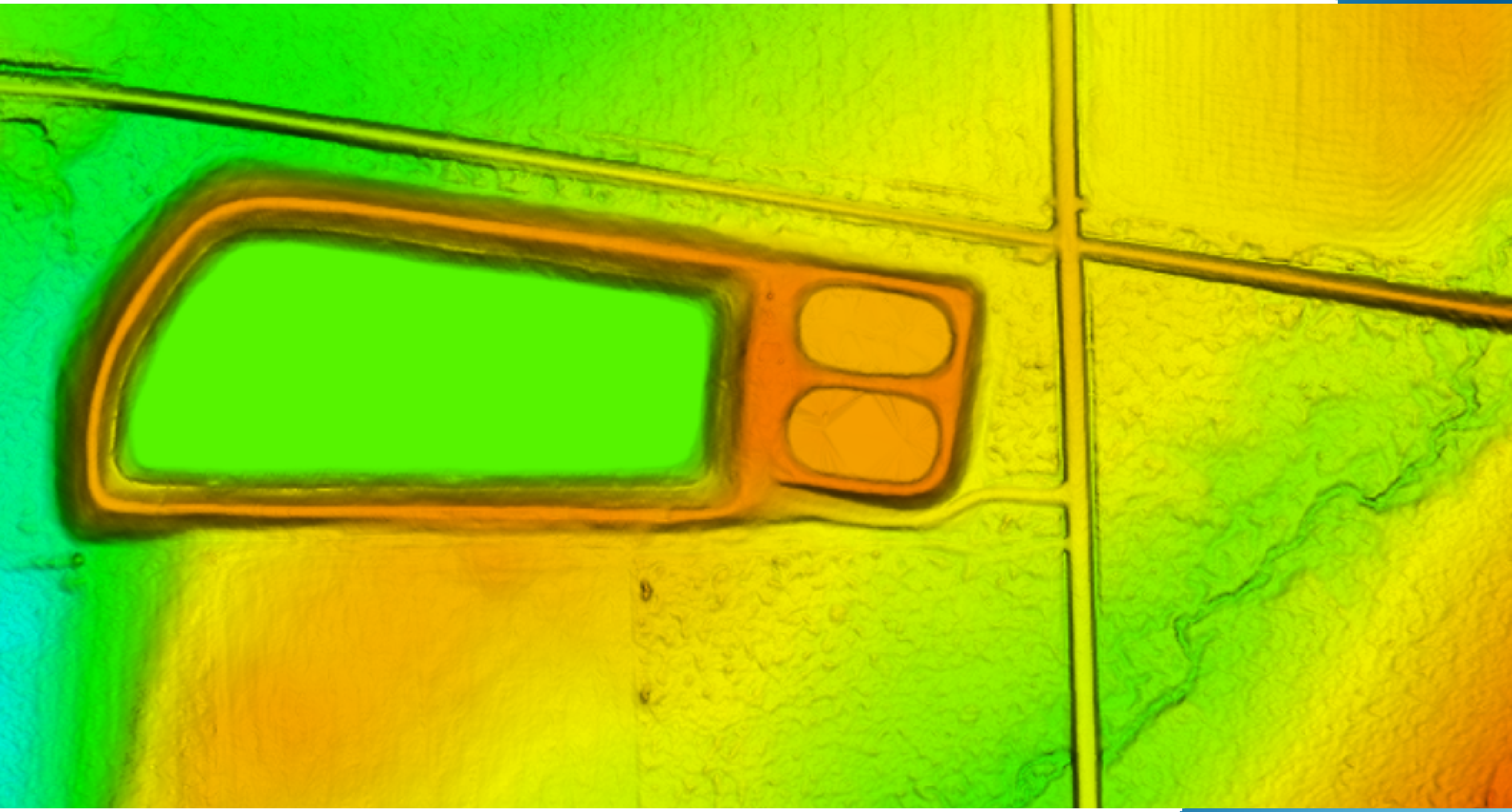

WI_BROWNRUSK_2020_B20
LIDAR PROCESSING REPORT

Project ID: 193613
Work Unit: 193610

2022

Submitted: November 2, 2022

Prepared for:

USGS
science for a changing world

Prepared by:

NV5
GEOSPATIAL
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1. Summary / Scope

1.1. Summary

This report contains a summary of the WI_BrownRusk_2020_B20, Work Unit 193610 lidar acquisition task order, issued by USGS under their Contract G16PC00016 on May 13, 2020. The task order yielded a project area covering approximately 939 square miles over Wisconsin. 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 / m²	2300 m	58.5°	20%	≤ 10 cm

1.3. Coverage

The project boundary covers approximately 939 square miles over Wisconsin. Project extents are shown in Figure 1.

1.4. Duration

Lidar data was acquired from May 9, 2020 to May 11, 2020 in two total lifts. See “Section: 2.4. Time Period” for more details.

1.5. Issues

There are no issues to report.

WI_BrownRusk_2020_B20 Work Unit 193610 Projected Coordinate System: WISCRS Rusk Feet Horizontal Datum: NAD83(2011) Vertical Datum: NAVD88 (GEOID 18) Units: Feet	
Lidar Point Cloud	Classified Point Cloud in .LAS 1.4 format
Rasters	• 1-meter Hydro-flattened Bare Earth Digital Elevation Model (DEM) in GeoTIFF format • 1-meter Intensity images in GeoTIFF format • 1-meter Swath Separation images in GeoTIFF format
Vectors	Shapefiles (*.shp) • Project Boundary • Lidar Tile Index • Calibration and QC Checkpoints (NVA/VVA) Geodatabase (*.gdb) • Continuous Hydro-flattened Breaklines
Reports	Reports in PDF format • Focus on Delivery • Focus on Accuracy • Processing Report
Metadata	XML Files (*.xml) • Breaklines • Classified Point Cloud • DEM • Intensity Imagery

WI_BrownRusk_2020_B20
Work Unit 193610 Boundary

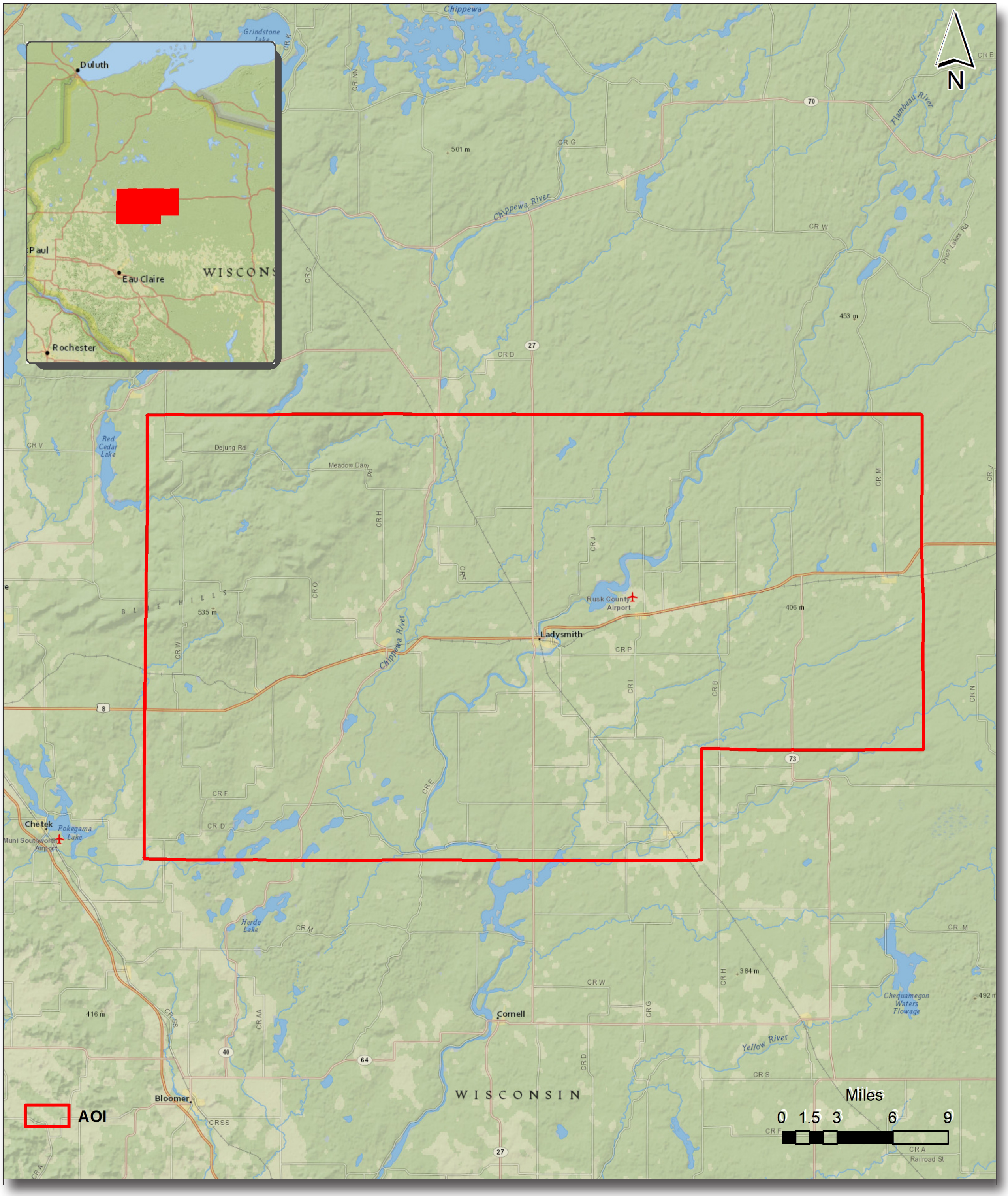


Figure 1. Work Unit Boundary

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. Planned flight lines are shown in Figure 2.

2.2. Lidar Sensor

NV5 Geospatial utilized a Riegl VQ1560ii lidar sensor (Figure 3), serial number 4045 for data acquisition.

The Riegl 1560II system is a dual channel waveform processing airborne scanning system. It has a laser pulse repetition rate of up to 4 MHz resulting in up to 2.66 million measurements per second. The system utilizes a Multi-Pulse in the Air option (MPIA) and an integrated IMU/GNSS unit.

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

WI_BrownRusk_2020_B20
Work Unit 193610 Planned Flight Lines

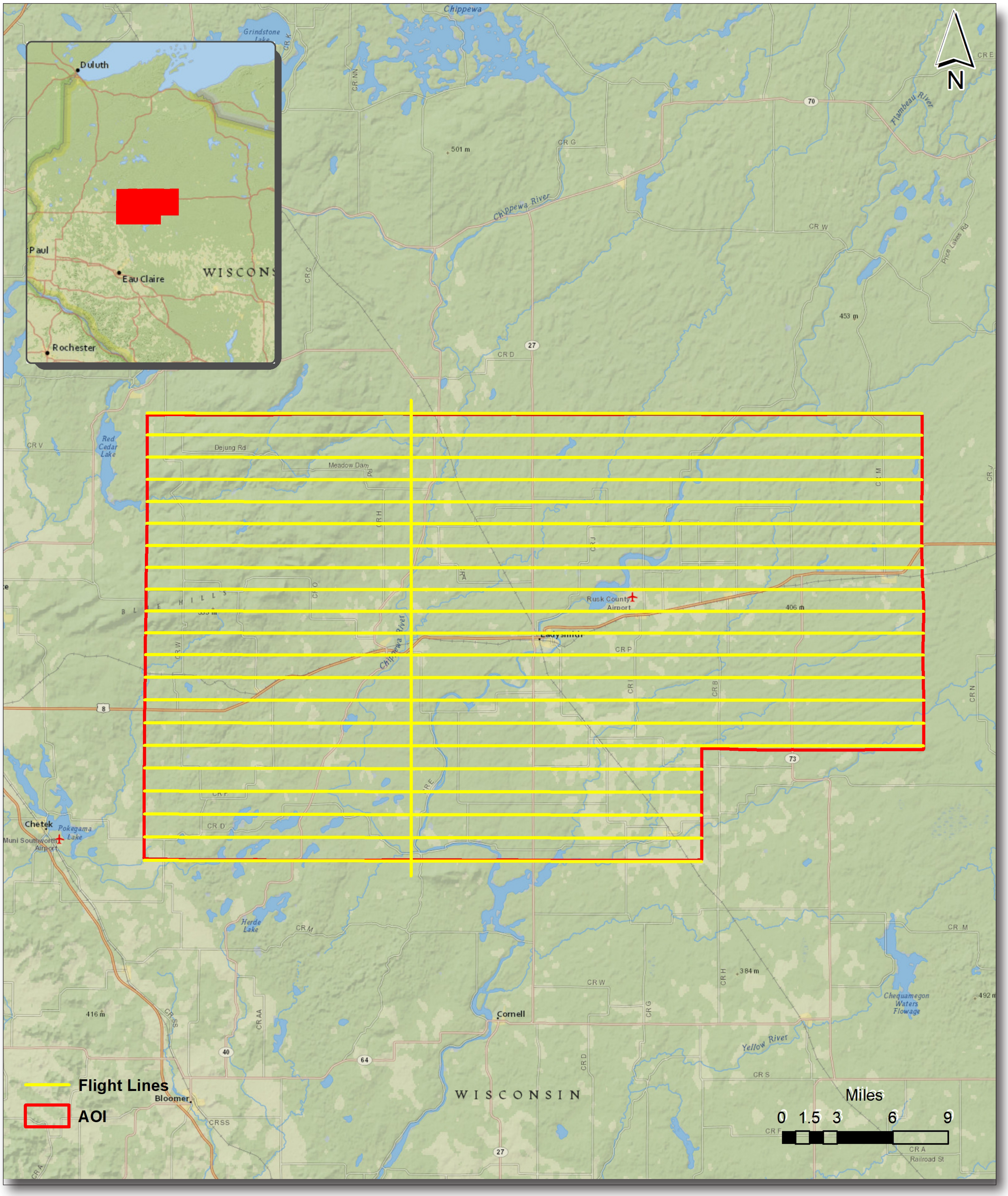


Figure 2. Planned Flight Lines

Table 2. Lidar System Specifications

		Riegl VQ1560ii (4045)
Terrain and Aircraft Scanner	Flying Height	2300 m
	Max Ground Speed	145 kts
Scanner	Field of View	58.5°
	Scan Rate Setting Used	2 x 160 lines per second
Laser	Laser Pulse Rate Used	2 x 500 kHz
	Multi Pulse in Air Mode	yes
Coverage	Full Swath Width	2577 m
	Line Spacing	2061.6 m
Point Spacing and Density	Average Point Spacing	0.71 m
	Average Point Density	2.0 pts / m²

Figure 3. Riegl VQ1560ii 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

- Cessna Caravan (single-turboprop), Tail Number(s): N208JA

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 VQ1560ii lidar system. Some of NV5 Geospatial's operating aircraft can be seen in Figure 4 below.

Figure 4. Some of NV5 Geospatial's Planes

2.4. Time Period

Project specific flights were conducted between May 9, 2020 and May 11, 2020. Two aircraft lifts were completed. Accomplished lifts are listed below.

Lift	Start UTC	End UTC
05092020A (SN4045,N208JA)	5/09/2020 2:27:16 PM	5/09/2020 5:19:16 PM
05112020B (SN4045,N208JA)	5/11/2020 5:58:03 PM	5/11/2020 9:30:10 PM

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 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. Using TerraScan, the vertical accuracy of the surveyed ground control is tested and any bias is removed from the data. 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	2020.1.22.1
Global Mapper	19.1;20.1
TerraModeler	21.008
TerraScan	21.016
TerraMatch	21.007

3.3. LAS Classification Scheme

The classification classes are determined by Lidar Base Specifications 2.1 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
6	Buildings	Points falling on buildings, structures inside of water bodies, docks, and piers.
7	Low Noise	Laser returns that are often associated with scattering from reflective surfaces, or artificial points below the ground surface
8	Model Key Points	Educated thinned dataset of the Class 2 ground class used to create the contours
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 proprietary tools. A buffer of 1 meter was also used around each hydro flattened feature to classify these ground (ASPRS Class 2) points to Ignored ground (ASPRS Class 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.

Any noise that was identified either through manual review or automated routines was classified to the appropriate class (ASPRS Class 7 and/or ASPRS Class 18) followed by flagging with the withheld bit.

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. NV5 Geospatial'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 streams and rivers using NV5 Geospatial'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 1 meter 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 withheld points 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.

3.8. Height Separation Raster Processing

Swath Separation Images are rasters that represent the interswath alignment between flight lines and provide a qualitative evaluation of the positional quality of the point cloud. Proprietary software was used to create 1-meter raster images in GeoTIFF format.

WI_BrownRusk_2020_B20
Work Unit 193610 Tile Layout

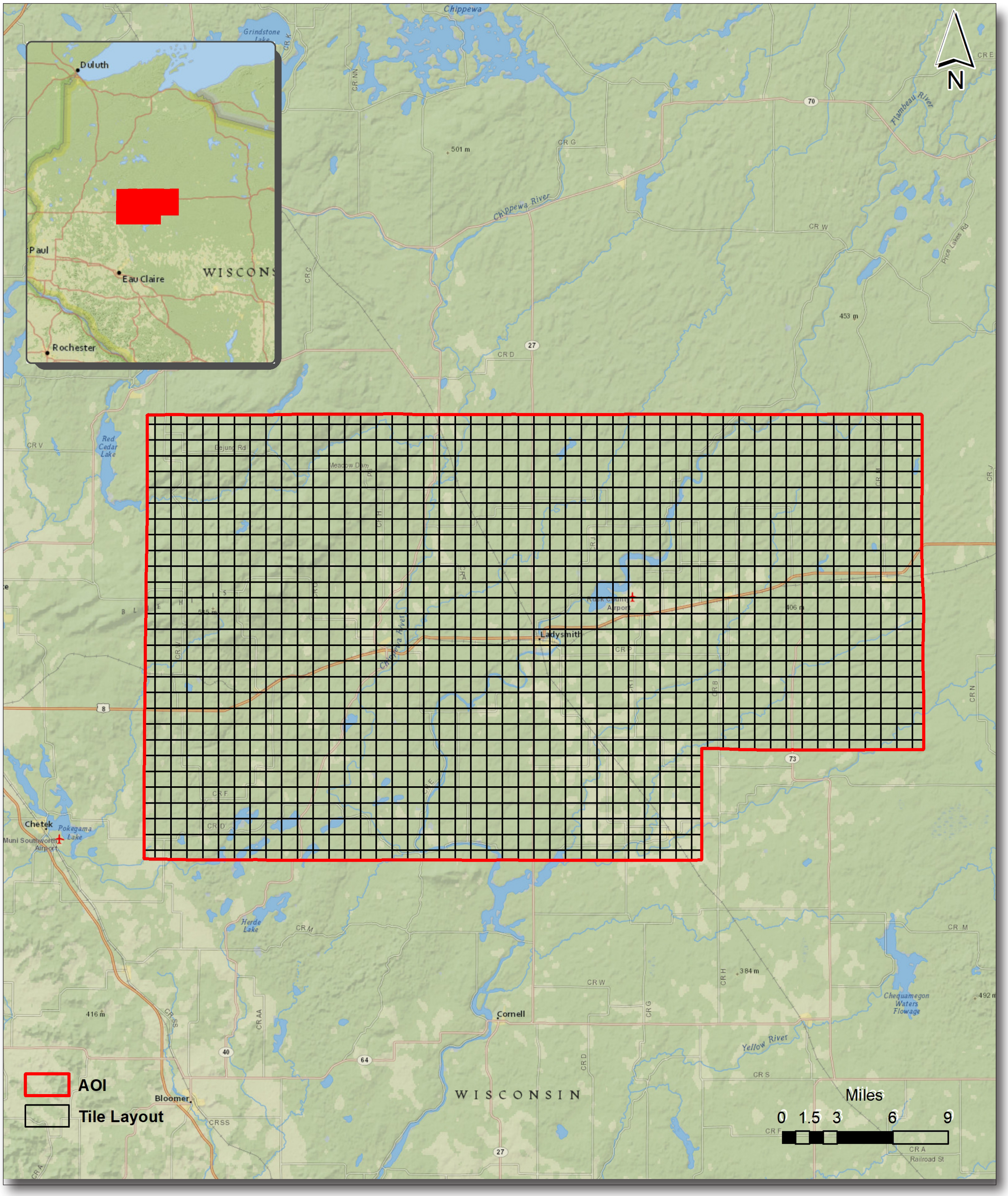


Figure 5. Lidar Tile Layout

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.

WI_BrownRusk_2020_B20
Work Unit 193610 Lidar Coverage

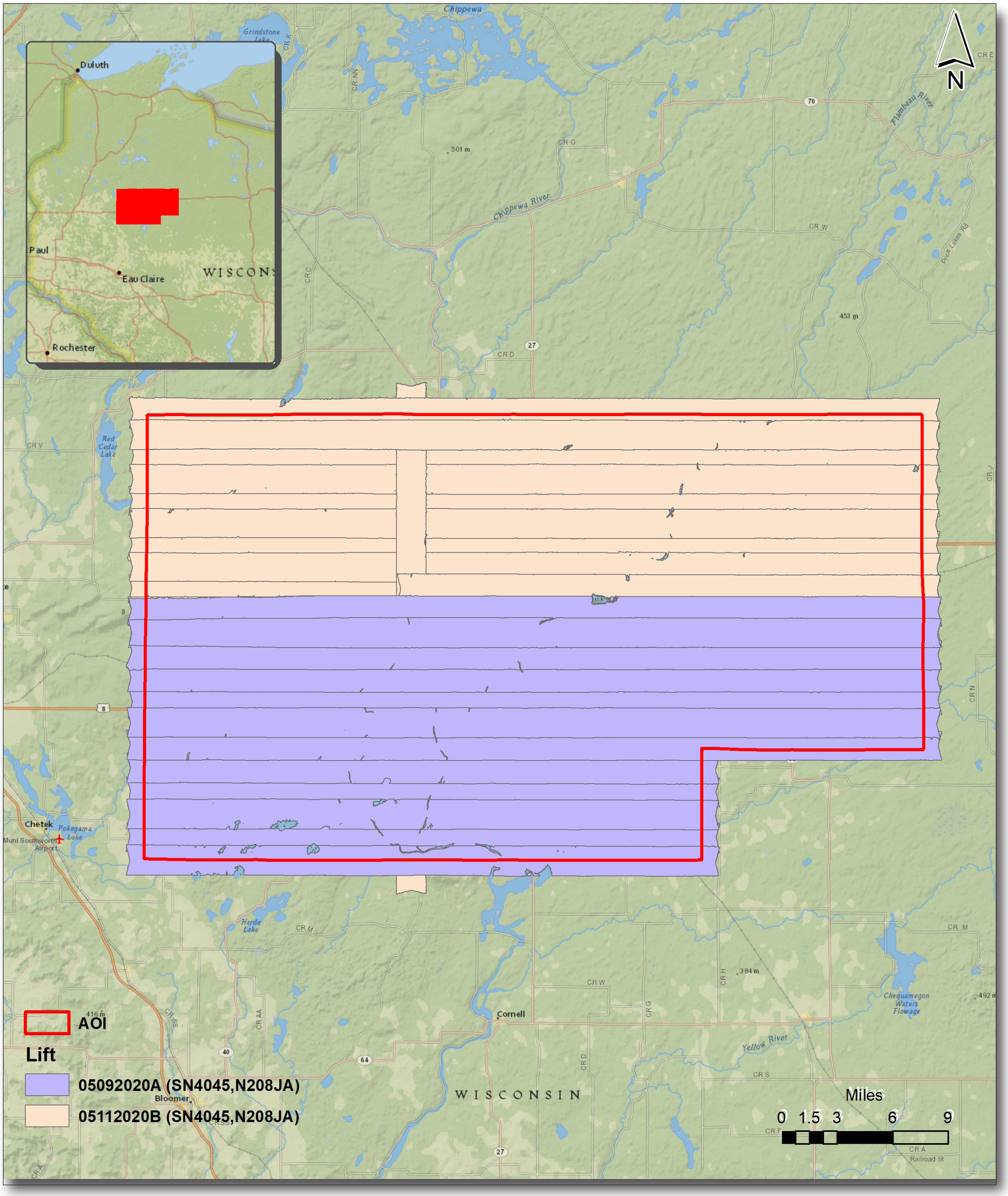


Figure 6. Lidar Coverage

5. Ground Control and Check Point Collection

On behalf of NV5 Geospatial, Ayres completed the field survey. Ground control (calibration) points, along with NVA and VVA points, were collected as a part of the survey.

WISCORS Network through VRS connection was the origination of the control used with checksand calibration. GPS methods were used where VRS connection and obstructions permitted. Other areas used control set by VRS RTK methods and robotic total station methods were used. OPUS observations of a 45 minute minimum were taken on control points where necessary.

All work was performed in and referenced to NAD83 (2011), NAVD 88(2012), Geoid 18, WISCRS, Rusk County Zone in Meters. Established horizontal and vertical coordinate values on the points by a minimum of two – 180 epoch observations with separate initializations using RTK GPS and the WISCORS network. The resultant coordinates and elevations provided in the deliverables are an average of the two observations. Check shots were taken on numerous NGS control points (see field notes) to verify that the values obtained are consistent with the datum/adjustment as described herein and meet the 33 centimeter vertical accuracy requirement at the 95% confidence level. Points not able to be directly occupied by GPS means were measured using Total Station methods from control point pairs set utilizing GPS methods outlined above.

For more information, see the Survey Report.

5.1. Calibration Control Point Testing

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 34 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) x 1.9600 as defined by the

National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS 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 34 checkpoints located in bare earth and urban (non-vegetated) areas. See Figure 7.
>
> 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 26 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 8.

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	Measured	Point Count
Raw NVA	**0.196 m**	**.0779 m**	**34**
NVA	**0.196 m**	**.0787 m**	**34**
VVA	**0.294 m**	**.0709 m**	**26**

WI_BrownRusk_2020_B20
NVA Points

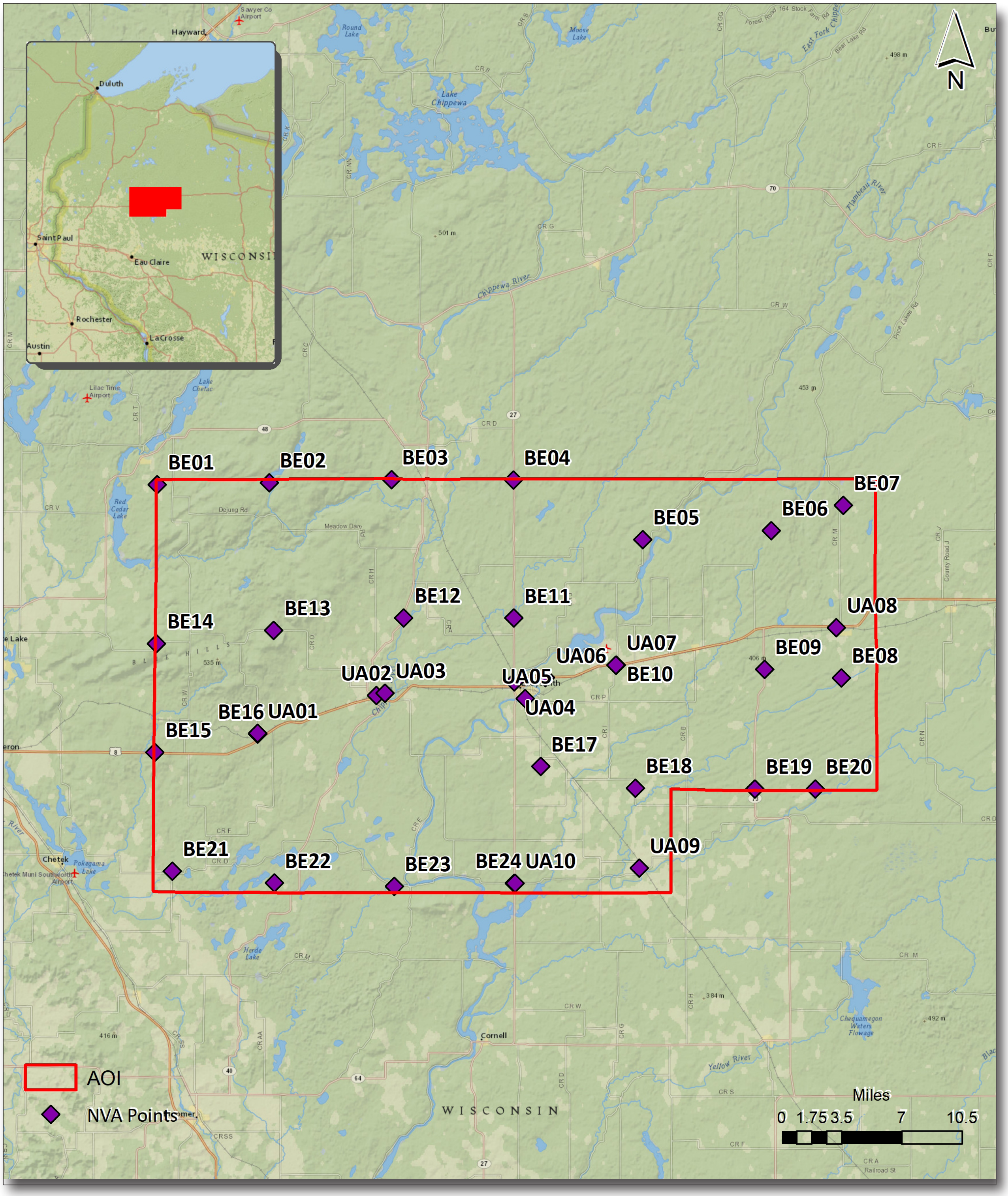


Figure 7. QC Checkpoint Locations - NVA

WI_BrownRusk_2020_B20
VVA Points

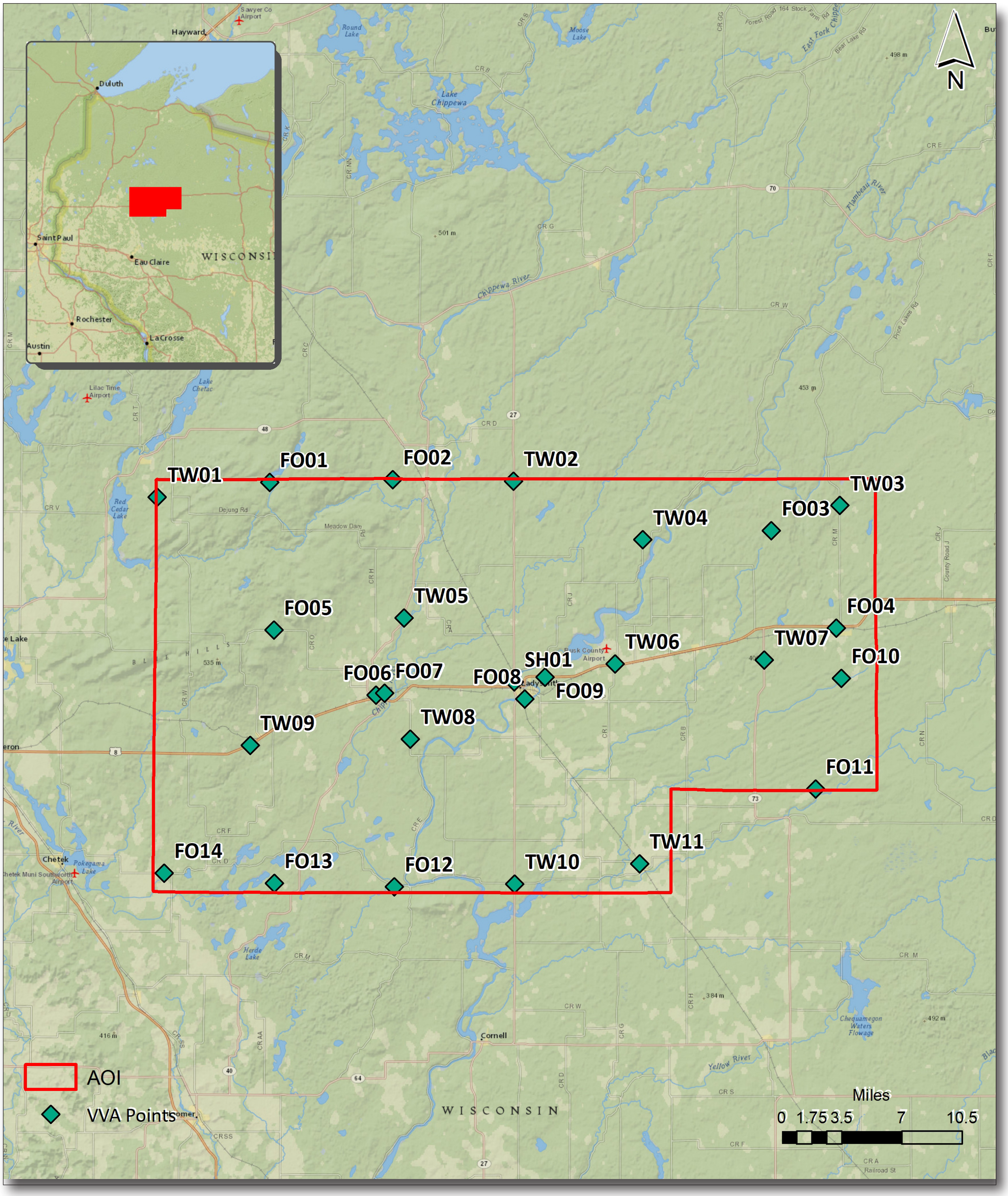


Figure 8. QC Checkpoint Locations - VVA

6. Geometric Accuracy

6.1. Horizontal Accuracy

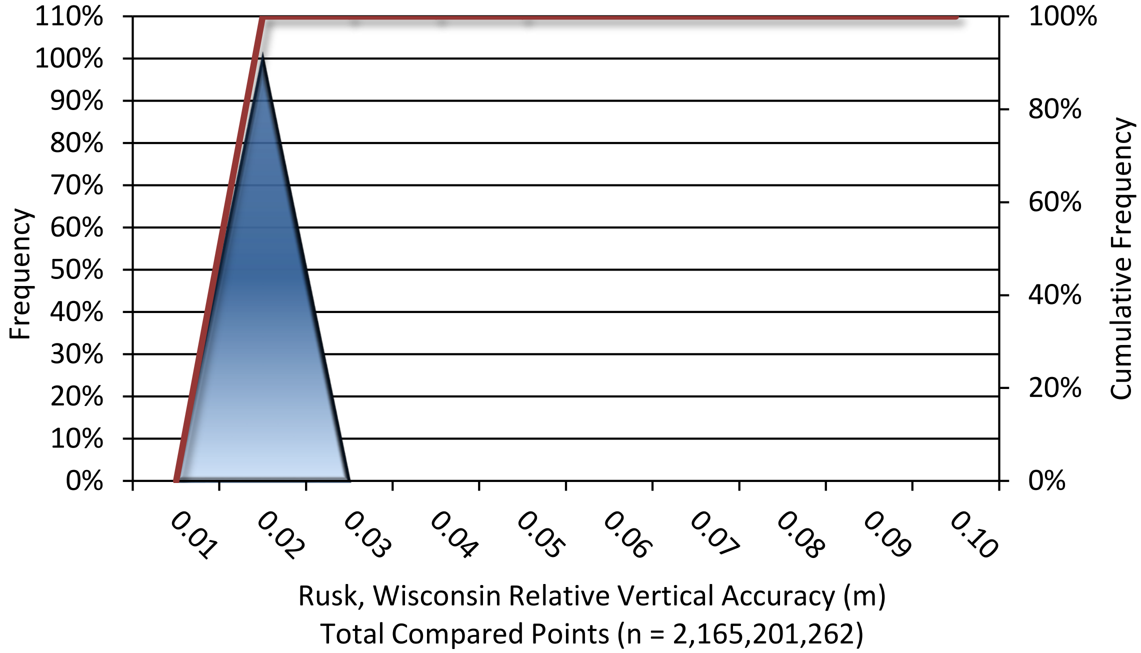
Lidar horizontal accuracy is a function of Global Navigation Satellite System (GNSS) derived positional error, flying altitude, and INS derived attitude error. The obtained $RMSE_r$ value is multiplied by a conversion factor of 1.7308 to yield the horizontal component of the National Standards for Spatial Data Accuracy (NSSDA) reporting standard where a theoretical point will fall within the obtained radius 95% of the time. Based on a flying altitude of 2300 meters, an IMU error of 0.002 decimal degrees, and a GNSS positional error of 0.015 meters, this project was compiled to meet 0.25 meter horizontal accuracy at the 95% confidence level. A summary is shown below.

Horizontal Accuracy	
$RMSE_r$	0.14 m
	0.47 ft
ACC_r	0.25 m
	0.82 ft

6.2. Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the lidar system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the WI_BrownRusk_2020_B20 project was 0.049 feet (0.015 meters). A summary is shown below.

Relative Vertical Accuracy	
Sample	22 flight line surfaces
Average	0.049 ft
	0.015 m
Median	0.048 ft
	0.015 m
RMSE	0.049 ft
	0.015 m
Standard Deviation (1σ)	0.003 ft
	0.001 m
1.96σ	0.006 ft
	0.002 m



Project Report Appendices

The following section contains the appendices as listed in the WI_BrownRusk_2020_B20 Lidar Project Report.

Appendix A

Flight Logs

Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 5/9/2020

Lift: A B C D E Pg __ of __

Project: USGS Rusk **Proj #:** 36742 **Flight Mgmt File:**

Aircraft: 208JA **Begin Hobbs:** 7930.4 **End Hobbs:** 7935.8 **Total:** 5.4 **Pilot:** Dan L. **Co-Pilot:** **Tech:**

Dep Apt: KSBM **Dep Time (Lcl):** 8:05 **(Z):** **Arr Apt:** KSBM **Arr Time (Local):** 1:30 **(Z):** **Tot Time Aloft:** 5:25

CORS: Y [✓ N] **Sta 1:** **Sta 2:** **Flyovers:** Y / N **If Y, times: Sta1)** **Sta2)**

GPS Unit: Y / N **Sta 1:** **Sta 2:** **Flyovers:** Y / N **If Y, times: Sta1)** **Sta2)**

Gd Temp beg: 7 °c **End:** 14 °c **OAT beg:** -9 °c **End:** -5 °c **Altimeter begin:** 3013 **end:** 3008

LIDAR

Type 156011 **Serial #** 4045 **Alt AGL** 2300 m **Alt AMSL** 8500′ **Avg Terr Ht** 1200′ **Max Gdspd** 180 Kts **Avg Pt Spacing**

FOV 58.5 **Scan Freq** **MpIA** Y / N **Pulses in Air** **Pulse Rate** 2 X 500 KHz **Power** 100 **PPSM** 2

Beg GB **End GB** **Tot GB** **Storage Name/#**

Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/# Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
21	271°	142715		136	0.88/31	8576′	5°		Clear, Wind 32 Kts., E-W, Smooth
20	91°	144036							W-E
19	271°	145145					10°		6.7 MB/s E-W
18	91°	150438		171	0.96/29				W-E
17		151544							6.8 MB/s E-W
16		152845				8575′			W-E
15		154328			0.81/31				E-W
14		160108		174					Clouds above W-E
13		161548				8600′			E-W
12		163326			0.8/32				W-E
11		164748		141					Clouds/Haze on w side of line, E-W
10		170547							Haze on w side of line

Total Proj Lines: 22 **Lines Flown:** 12 **Lines Remain:** 10 **Online Time:** 3.25 h **Mob Time:** 2 10 min **Notes:**

Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 5/11/2020

Lift: A B C D E

Pg __ of __

Project: USGS Rusk **Proj #:** 36742 **Flight Mgmt File:**

Aircraft: 208JA **Begin Hobbs:** 7935.8 **End Hobbs:** 7942.7 **Total:** 6.9 **Pilot:** Dan L. **Co-Pilot:** **Tech:**

Dep Apt: KSBM **Dep Time (Lcl):** 8:00 **(Z):** **Arr Apt:** KSBM **Arr Time (Local):** **(Z):** **Tot Time Aloft:**

CORS: Y / [✓ N] **Sta 1:** **Sta 2:** **Flyovers:** Y / N **If Y, times: Sta1)** **Sta2)**

GPS Unit: Y / N **Sta 1:** **Sta 2:** **Flyovers:** Y / N **If Y, times: Sta1)** **Sta2)**

Gd Temp beg: 6 °c **End:** °c **OAT beg:** -12 °c **End:** °c **Altimeter begin:** 3023 **end:**

LiDAR

Type 1560ii FOV

Serial # 4045 Scan Freq

Alt AGL 2300 m MplA Y / N

Alt AMSL Pulses In Air

Avg Terr Ht Pulse Rate 2x500 KHz

Max Gdspd 180 Power 100

Avg Pt Spacing PPSM 2

Beg GB Storage Name/#

End GB

Tot GB

Line #	Hdg	Start (UTC):	End (UTC):	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
~~11 142501 271~~									
11	271	142501		143	0.94/30	8,624'			Clouds, Refly E-W
11	91°	175802		160	0.81/26	8,600'			7.8 MB/S W-E
10	271	182632		148	0.86/25				E-W
9	91°	184316							Just under clouds W-E flew slightly low for clouds
8	271°	185829		141					E-W
7	91°	191511		173					W-E
6		192955			0.93/24	8670'			E-W
5		194639							W-E
4		200054		140					light TURB E-W
3		201742							W-E
2		203152							E-W
1		204835		165	0.96/27	8700'			W-E
9		210536							reflew for clouds, Partial line
22	181°	212132		161					

Total Proj Lines: ~~12~~ 22 **Lines Flown:** 12 **Lines Remain:** 0 **Online Time:** 3:45 **Mob Time:** 3:09 **Notes:**