Olga Lake, Michigan
QL1 LiDAR Project Report

USGS Contract # G16PC00016
Task Order # G16PD00340

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Contents

List of Figures

List of Tables

List of Appendices

1. Summary / Scope

1.1. Summary

This report contains a summary of the Olga Lake, MI 2016 QL1 LiDAR and Orthoimagery acquisition task order, issued by USGS National Geospatial Technical Operations Center (NGTOC) under their Geospatial Product and Services Contract v.3 (GPSC 3) on April 19, 2016. The task order yielded a project area covering approximately 31 square miles around Olga Lake, Michigan. 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
≥ 4 pts / m^2	1,448 m	30°	50%	≤ 10 cm

1.3. Coverage

The LiDAR project boundary covers approximately 31 square miles and encompasses the upland forest habitat around Olga Lake in Lake and Wexford counties in the Lower Peninsula of Michigan. LiDAR extents are shown in Figure . The processing boundary was buffered by 100 meters to meet task order specifications.

1.4. Duration

LiDAR data was acquired on June 17, 2016 in one total lift. See "Section: 2.5. Time Period" for more details.

1.5. Issues

There were no issues with this project.

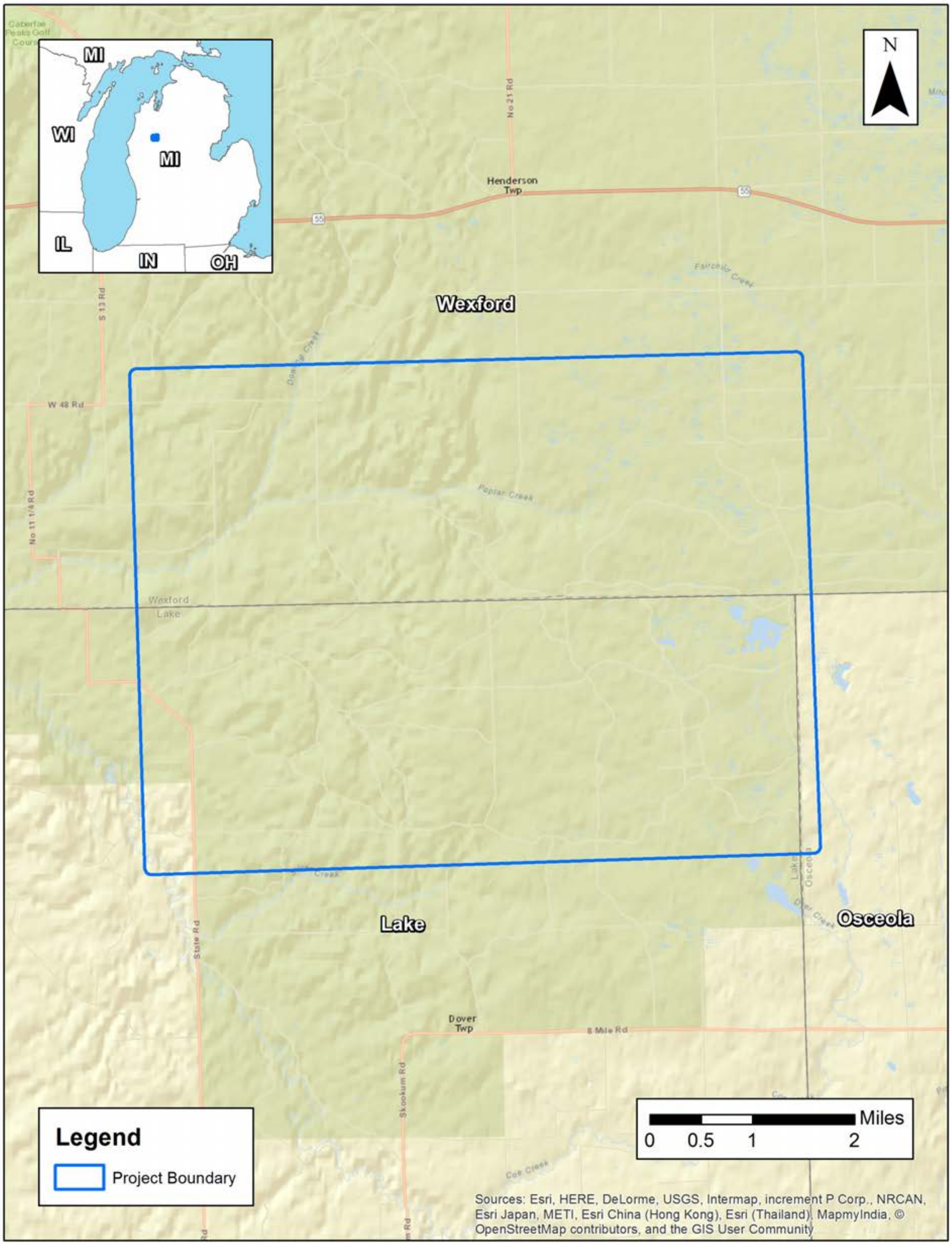
1.6. Deliverables

The following products were produced and delivered:

- Raw LiDAR point cloud data swaths in LAS 1.4 format
- Classified point cloud data, tiled, in LAS 1.4 format
- Bare-earth point cloud data, tiled, in LAS 1.4 format
- 0.75-meter hydro-flattened bare-earth surface raster DEM in Esri Grid format
- Hydro-flattened breaklines in Esri file geodatabase format
- 0.75-meter intensity images tiled, in GeoTIFF format
- Processing boundary in Esri shapefile format
- Tile index in Esri shapefile format
- Calibration and QC checkpoints in Esri shapefile format
- Accuracy assessment in Excel .XLSX format
- Project-, deliverable-, and tile-level metadata in .XML format

All geospatial deliverables were produced in NAD83 (2011) UTM Zone 16, meters; NAVD88 (Geoid 12B), meters. All tiled deliverables have a tile size of 1,500 meters x 1,500 meters.

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 planning software. The entire target area was comprised of 34 planned flight lines measuring approximately total 247.82 flight line miles (Figure 3).

2.2. LiDAR Sensor

Quantum Spatial utilized a Leica ALS 70 LiDAR sensor (Figure 3), serial number 7178, during the project. The system is capable of collecting data at a maximum frequency of 500 kHz, which affords elevation data collection of up to 500,000 points 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 4 returns per outgoing pulse from the laser and these come in the form of 1st, 2nd, 3rd and last returns. 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

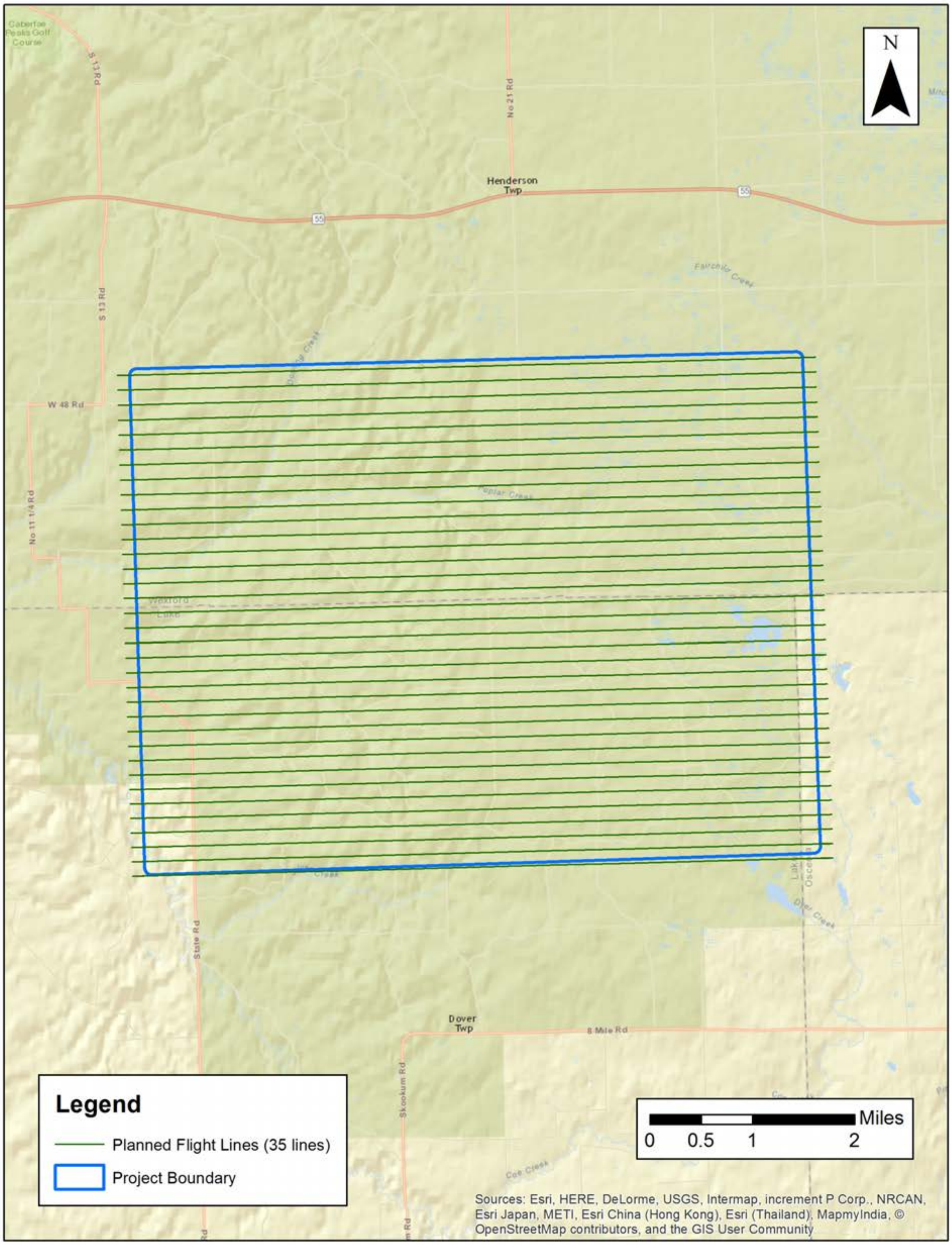


Table 2. Lidar System Specifications

Terrain and Aircraft Scanner	Flying Height	1,750 m
	Recommended Ground Speed	140 kts
Scanner	Field of View	30°
	Scan Rate Setting Used	59.9 Hz
Laser	Laser Pulse Rate Used	321.0 kHz
	Multi Pulse in Air Mode	Enabled
Coverage	Full Swath Width	937.82 m
	Line Spacing	740.37 m
Point Spacing and Density	Maximum Point Spacing Along Track	0.77 m
	Maximum Point Spacing Along Track (in of phase)	1.20 m
	Maximum Point Spacing Along Track (out of phase)	0.60 m
	Average Point Density	4.75 pts / m^2

Figure 3. Leica ALS 70 LiDAR Sensor

2.3. Aircraft

All flights for the project were accomplished through the use of a customized Piper Navajo (twin-piston). This aircraft provided an ideal, stable aerial base for LiDAR acquisition. This aerial platform 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 Leica 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. 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 5. 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

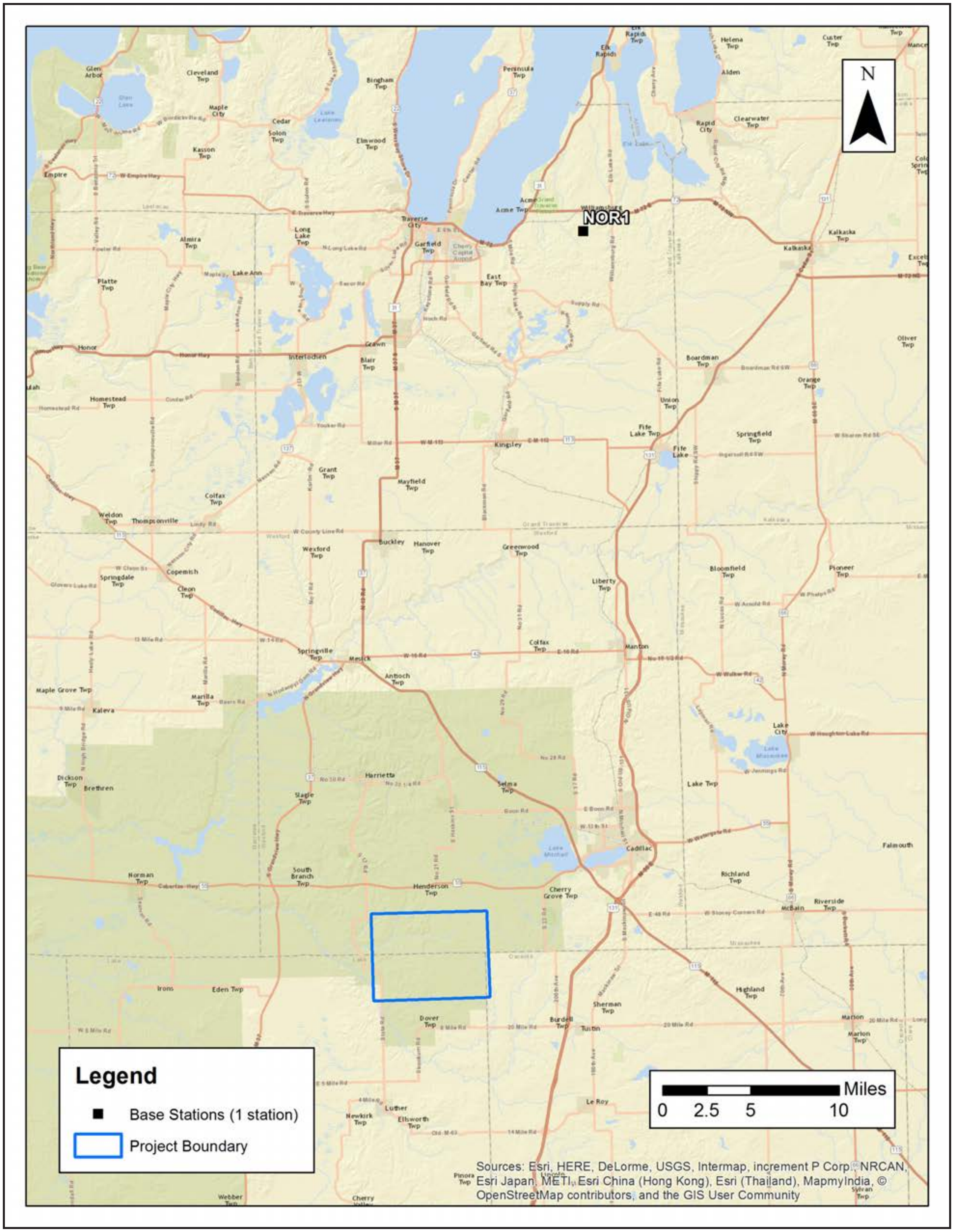
Base Station	Latitude	Longitude	Ellipsoid Height (m)
NOR1	44° 45' 20.94223"	85° 26' 13.7457"	365.107

2.5. Time Period

Project specific flights were conducted over one day. One LiDAR sortie, or aircraft lift was completed. Accomplished LiDAR sorties are listed below.

- Jun 17, 2016-B (N73TM, SN7178)

Figure 5. Base Station Locations



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 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 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 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 Inertial Explorer 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. 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 3 – Low Vegetation (Tall grass/weeds and crops) – Vegetation 0 - 5 feet tall.
- Class 4 – Medium Vegetation (Brush lands and short trees) – Vegetation 5 - 20 feet tall.
- Class 5 – High Vegetation (Forested areas, fully covered by trees) – Vegetation over 20 feet tall.
- Class 6 – Buildings and Man-Made Structures – Points falling on buildings, structures inside of water bodies, docks, and piers.
- 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 0.5 meter 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 bridge decks were classified to Class 17. Standard automated classification of vegetation was performed using the classification scheme above.

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 was used as a final check of the bare earth dataset. GeoCue was then used to create the deliverable industry-standard LAS files for both the All Point Cloud Data and the Bare Earth. 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. Bare-Earth LAS Creation

The bare-earth LAS files were created from the fully classified LAS data. These files only contain Class 2 (Ground) points.

3.6. 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 30 meter 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 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 0.5 meters 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.

3.7. Hydro-Flattened Bare-Earth Raster DEM Creation

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a 0.75-meter raster DEM. Using automated scripting routines within ArcMap, an ERDAS .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.

3.8. Intensity Image Creation

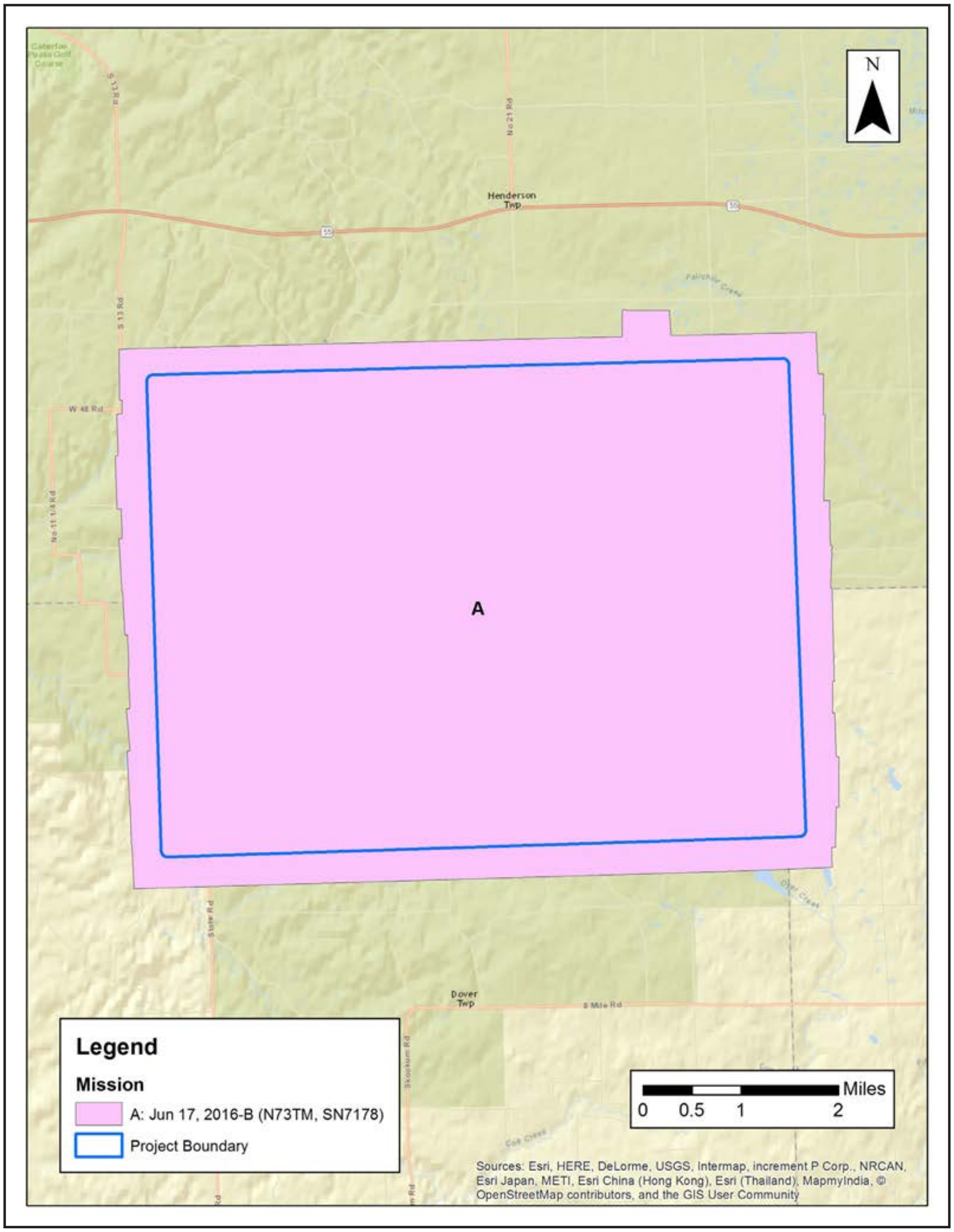
GeoCue software was used to create the deliverable Intensity Images with a 0.75-meter cell size. All overlap classes were ignored during this process. This helps to ensure a more aesthetically pleasing image. The GeoCue software was then used to verify full project coverage as well. TIF/

TWF 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 Figure 6.

Figure 6. Flightline Swath LAS File Coverage



5. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 8 ground control (calibration) points along with 25 blind QA points in Vegetated and Non-Vegetated land cover classifications (total of 33 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 NAD83 (2011) UTM Zone 16, meters; NAVD88 (Geoid 12B), meters.

5.1. Calibration Control Point Testing

Figure 7 shows the location of each bare earth calibration point for the project area. Table 4 depicts the Control Report for the LiDAR bare earth calibration points, as computed in TerraScan as a quality assurance check. 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

Raw Nonvegetated Vertical Accuracy (Raw NVA): The tested Raw NVA for the dataset was found to be 0.042 meters in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.083 meters. This dataset meets the required NVA of 0.196 meters at the 95% confidence level (according to the National Standard for Spatial Database Accuracy (NSSDA)), based on TINs derived from the final calibrated and controlled LiDAR swath data. See Figure 8 and Table 5.

5.3. Digital Elevation Model (DEM) Testing

The tested Non-Vegetated Vertical Accuracy (NVA) for the dataset captured from the DEM using bi-linear interpolation to derive the DEM elevations was found to be 0.045 meters in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.087 meters This dataset meets the required NVA of 0.196 meters at the 95% confidence level (based on NSSDA). See Figure 9 and Table 6.

The tested Vegetated Vertical Accuracy (VVA) for the dataset captured from the DEM using bi-linear interpolation for all classes (including the bare earth class) was found to be 0.113 meters, which is stated in terms of the 95th percentile error. Therefore the data meets the required VVA of 0.294 meters. This test was based on the 95th percentile error (based on ASPRS guidelines) across all land cover categories. See Figure 10 and Table 7.

Figure 7. Calibration Control Point Locations

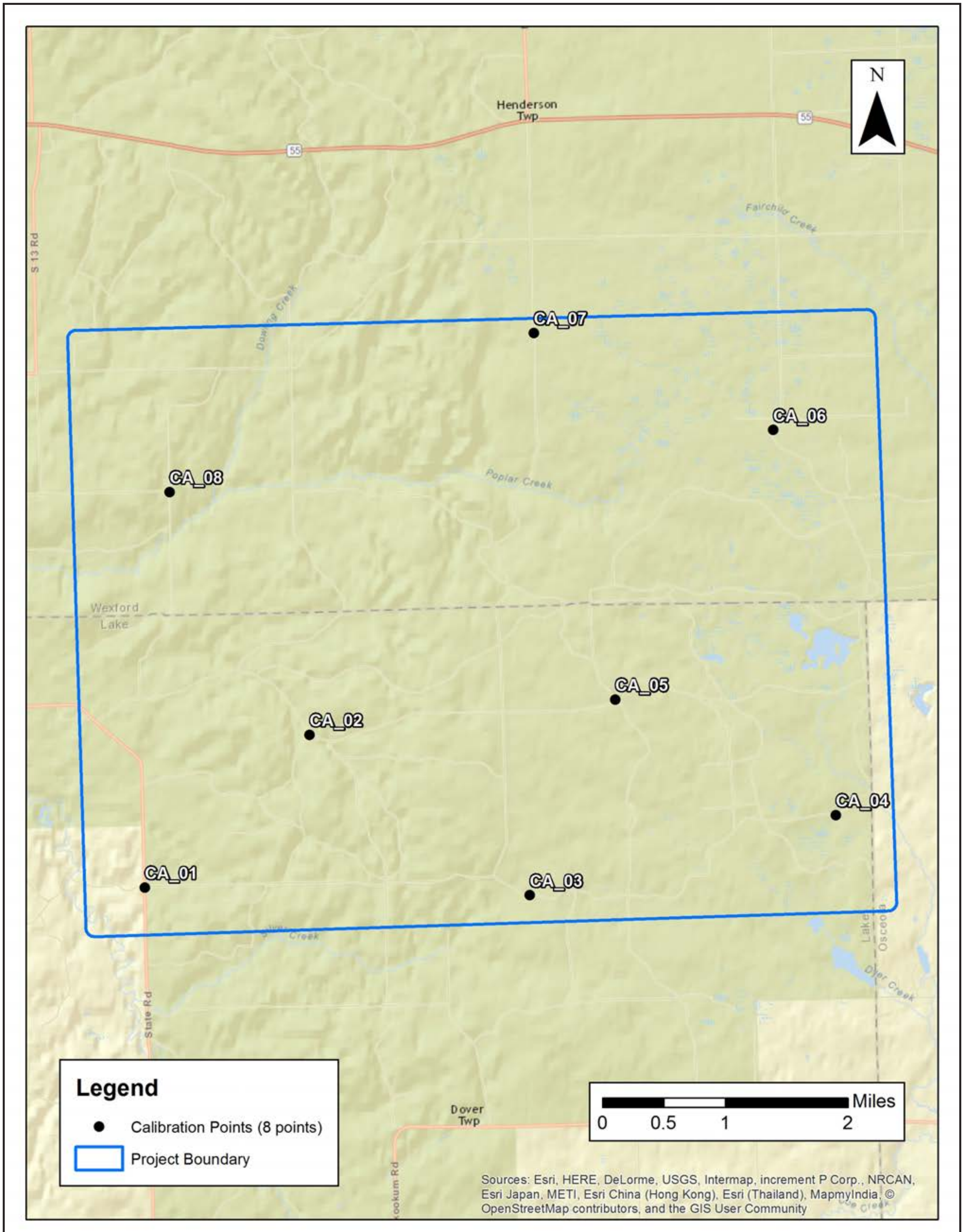


Table 4. Calibration Control Point Report

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
CA_01	605314.883	4887432.588	308.85	308.82	-0.03
CA_02	607474.879	4889434.262	350.12	350.10	-0.02
CA_03	610358.498	4887331.632	374.57	374.58	0.01
CA_04	614375.364	4888380.442	375.30	375.37	0.07
CA_05	611481.604	4889898.307	386.61	386.63	0.02
CA_06	613551.216	4893432.274	399.72	399.70	-0.02
CA_07	610413.882	4894703.624	410.05	410.05	0.00
CA_08	605635.497	4892616.309	343.28	343.29	0.01
	Average Dz	0.010 m			
	Minimum Dz	-0.030 m			
	Maximum Dz	0.075 m			
	Root Mean Square	0.032 m			
	Std. Deviation	0.034 m			

Figure 8. QC Checkpoint Locations - Raw NVA

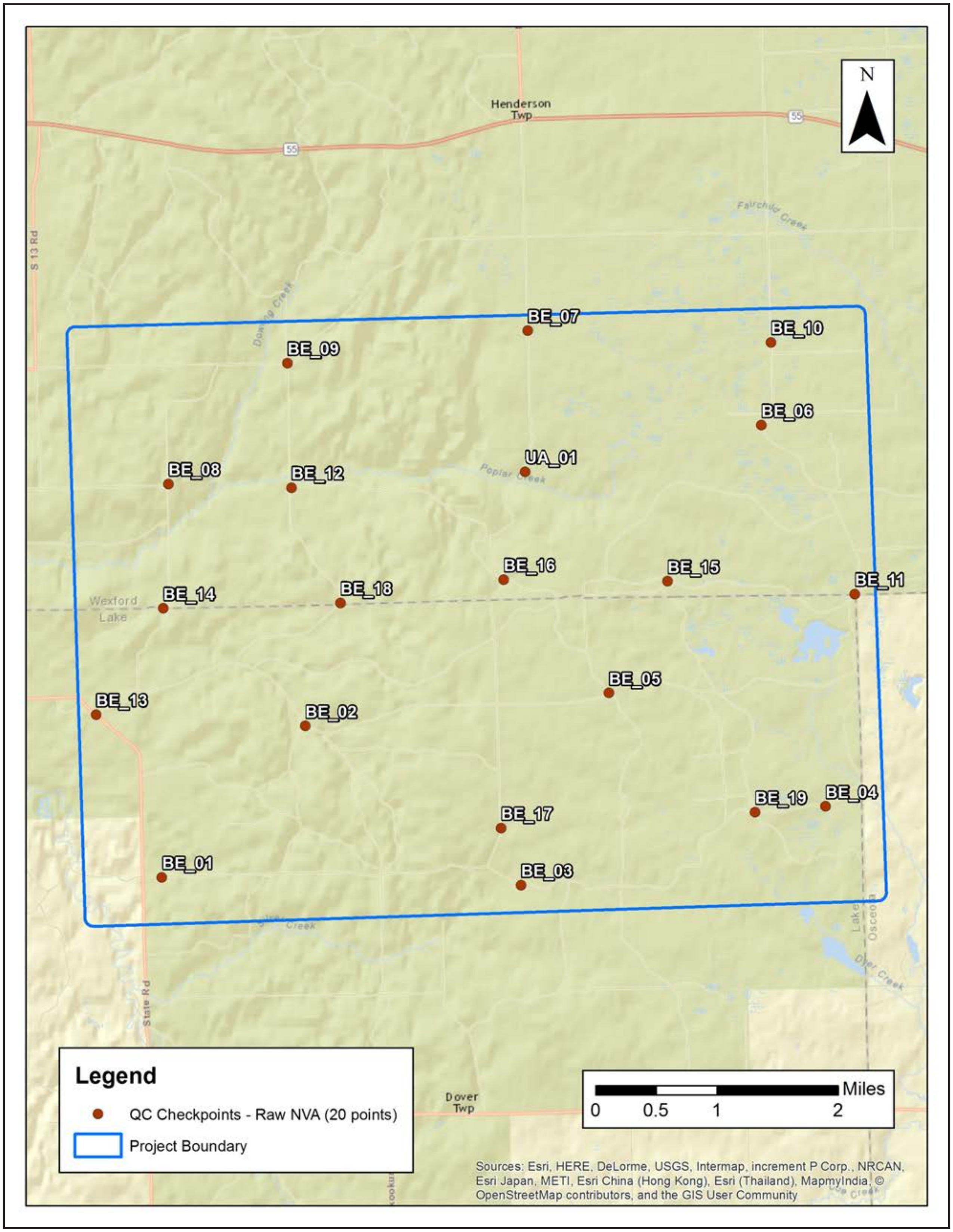


Table 5. QC Checkpoint Report - Raw NVA

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
BE_01	605561.154	4887438.062	312.56	312.59	0.03
BE_02	607464.238	4889447.149	350.14	350.14	0.00
BE_03	610324.167	4887335.839	373.46	373.40	-0.06
BE_04	614364.845	4888379.290	375.81	375.78	-0.03
BE_05	611494.179	4889884.823	386.33	386.34	0.01
BE_06	613515.533	4893432.142	400.44	400.43	-0.01
BE_07	610414.356	4894690.890	410.11	410.11	0.00
BE_08	605647.666	4892652.708	345.37	345.35	-0.02
BE_09	607227.881	4894257.101	354.25	354.28	0.03
BE_10	613641.865	4894531.202	392.56	392.51	-0.05
BE_11	614753.499	4891189.451	389.44	389.35	-0.09
BE_12	607281.515	4892604.365	337.86	337.88	0.02
BE_13	604689.336	4889598.512	315.29	315.27	-0.02
BE_14	605578.925	4891001.256	330.99	330.98	-0.01
BE_15	612267.228	4891361.069	381.07	381.07	0.00
BE_16	610092.906	4891381.882	380.89	380.90	0.01
BE_17	610060.684	4888091.029	397.07	397.15	0.08
BE_18	607929.367	4891071.537	354.84	354.84	0.00
BE_19	613430.082	4888301.784	384.63	384.70	0.07
UA_01	610380.590	4892812.839	371.58	371.67	0.09

Average Dz	0.000 m
Minimum Dz	-0.086 m
Maximum Dz	0.094 m
Root Mean Square	0.042 m
95% Confidence Level	0.083 m

Figure 9. QC Checkpoint Locations - NVA

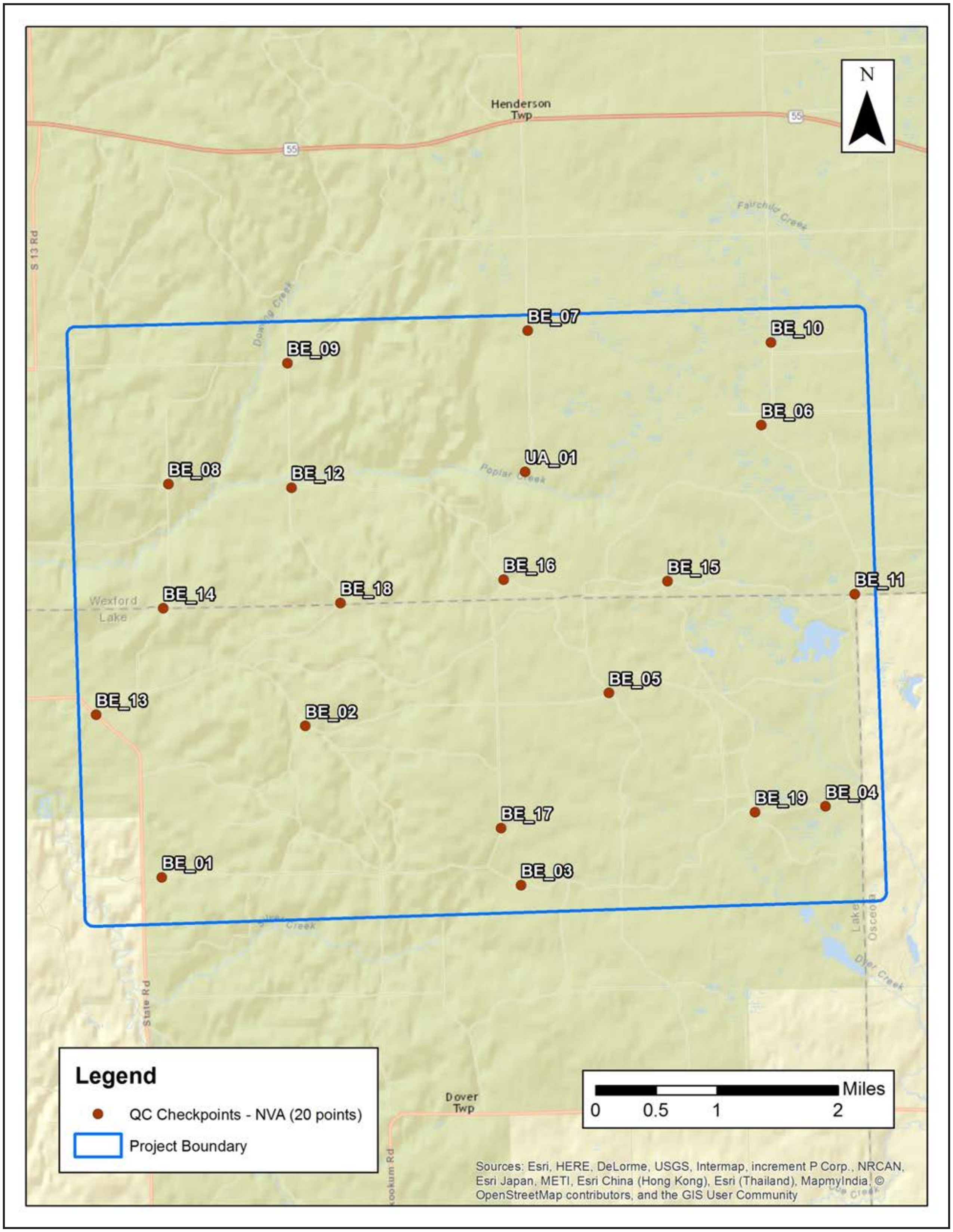


Table 6. QC Checkpoint Report - NVA

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
BE_01	605561.15	4887438.06	312.56	312.58	0.02
BE_02	607464.24	4889447.15	350.14	350.14	0.00
BE_03	610324.17	4887335.84	373.45	373.39	-0.07
BE_04	614364.85	4888379.29	375.81	375.77	-0.03
BE_05	611494.18	4889884.82	386.33	386.34	0.01
BE_06	613515.53	4893432.14	400.44	400.43	-0.01
BE_07	610414.36	4894690.89	410.11	410.11	0.00
BE_08	605647.67	4892652.71	345.37	345.33	-0.04
BE_09	607227.88	4894257.10	354.25	354.27	0.02
BE_10	613641.87	4894531.20	392.55	392.51	-0.04
BE_11	614753.50	4891189.45	389.44	389.35	-0.09
BE_12	607281.52	4892604.37	337.86	337.89	0.02
BE_13	604689.34	4889598.51	315.29	315.27	-0.01
BE_14	605578.93	4891001.26	330.99	330.98	-0.02
BE_15	612267.23	4891361.07	381.07	381.08	0.01
BE_16	610092.91	4891381.88	380.89	380.91	0.02
BE_17	610060.68	4888091.03	397.07	397.14	0.07
BE_18	607929.37	4891071.54	354.84	354.83	-0.01
BE_19	613430.08	4888301.78	384.63	384.72	0.09
UA_01	610380.59	4892812.84	371.58	371.66	0.09

Average Dz	0.000 m
Minimum Dz	-0.088 m
Maximum Dz	0.088 m
Root Mean Square	0.045 m
95% Confidence Level	0.087 m

Figure 10. QC Checkpoint Locations - VVA

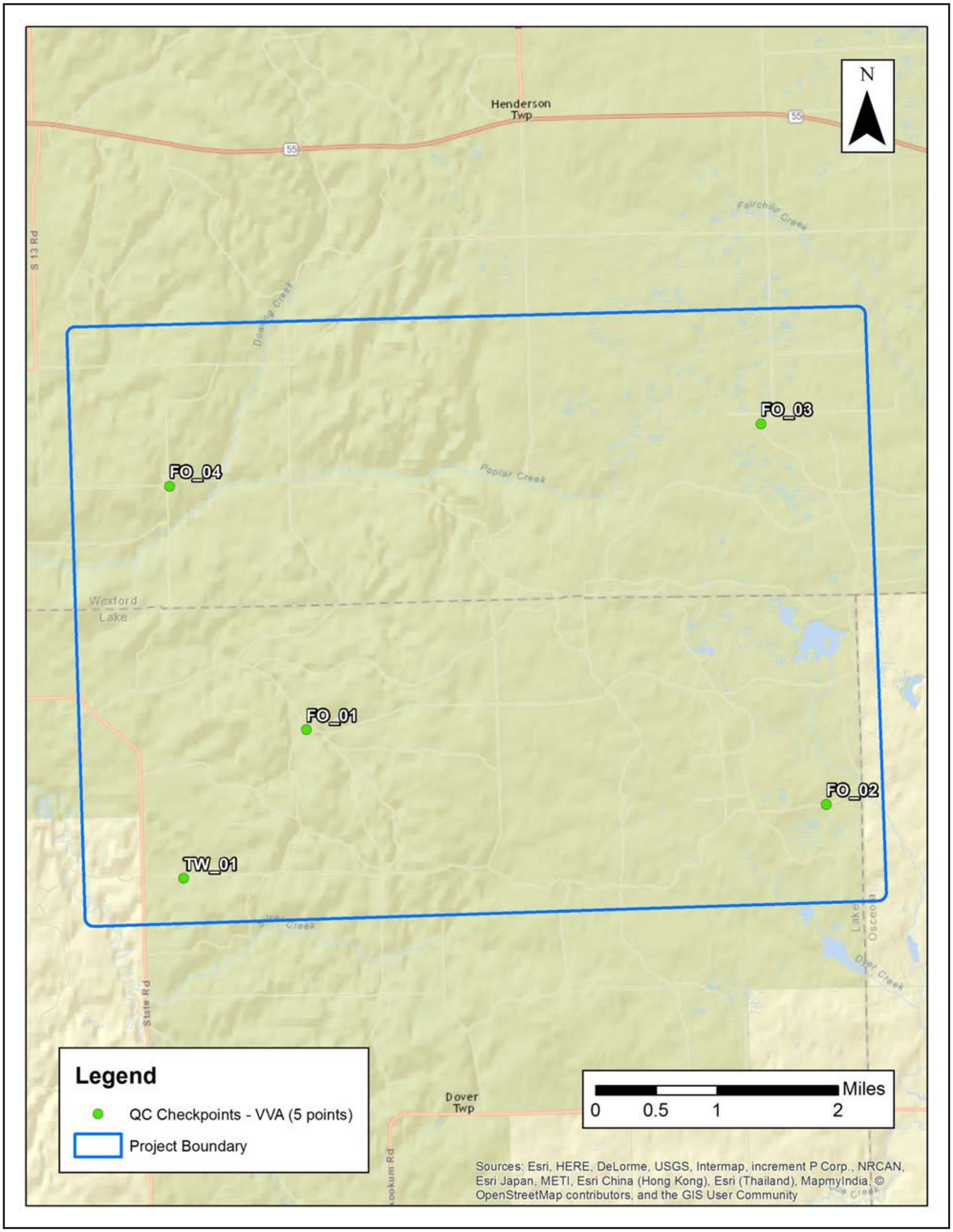


Table 7. QC Checkpoint Report - VVA

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
FO_01	607475.90	4889397.97	349.64	349.60	-0.04
FO_02	614376.89	4888404.33	374.29	374.40	0.12
FO_03	613507.28	4893451.01	400.33	400.42	0.09
FO_04	605663.24	4892624.12	343.15	343.30	0.15
TW_01	605848.90	4887424.47	319.69	319.71	0.02

Average Dz	0.070 m
Minimum Dz	-0.044 m
Maximum Dz	0.150 m
Root Mean Square	0.098 m
95th Percentile	0.113 m