# Lincoln County, WI
# QL2 LiDAR Project Report

USGS Contract # G10PC00026
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Task Order # G15PD00294

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Prepared by:

Quantum Spatial, Inc
523 Wellington Way, Suite 375
Lexington, KY 40503

859-277-8700

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# 1. Summary / Scope

## 1.1. Summary

This report contains a summary of the Lincoln County, Wisconsin QL2 LiDAR acquisition task order, issued by the USGS National Geospatial Technical Operations Center (NGTOC), under their Geospatial Product and Services Contract on ordered on April 20, 2015. The task orders yielded one study area covering all of Lincoln County. The intent of this document is to only provide specific validation information for the LiDAR data acquisition/collection work completed as specified in the task order.

## 1.2. Scope

The scope of the Lincoln County, WI LiDAR task order included the acquisition of aerial topographic LiDAR 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 |
|---|---|---|---|---|
| 2.2 pts / $m^2$ | 2,100 m | 40° | 30% | ≤ 10 cm |

## 1.3. Location / Coverage

The LiDAR project boundary consists of the entirety of Lincoln County, Wisconsin. The area totals approximately 946 square miles as shown in Figure 1 on the following page. A 100-meter processing boundary was used for this project.

## 1.4.Duration

The LiDAR missions were flown from April 15, 2015 to April 16, 2015 in a total of 5 lifts in order to achieve complete coverage of the area.

## 1.5. Issues

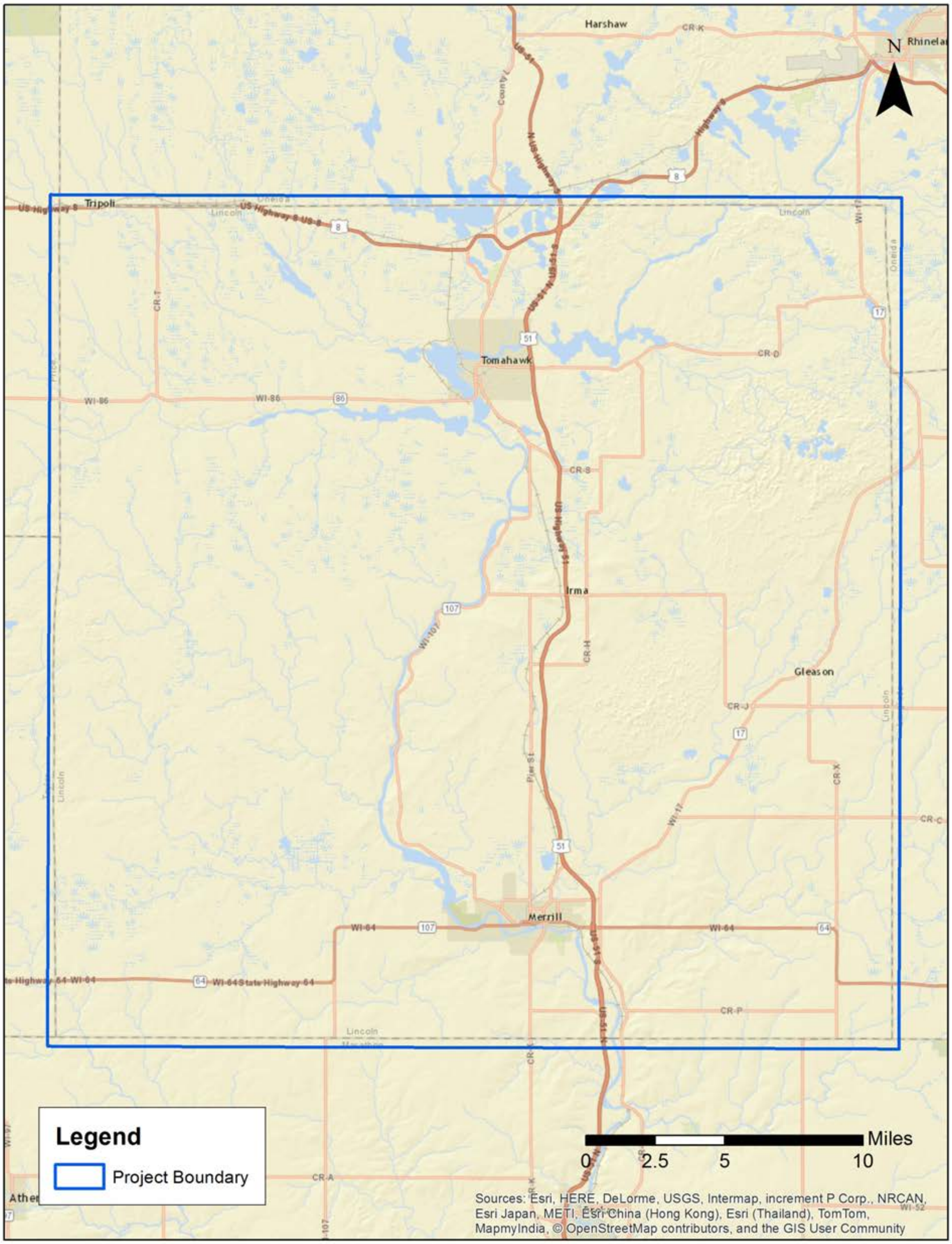
There were no issues with this project.

## 1.6. Deliverables

The following products were produced and delivered:

- Uncalibrated, unclassified raw point cloud swath LAS in version 1.4 format
- Classified point cloud tiled LAS in version 1.4 format
- Hydro flattened raster DEM in Esri Grid format
- Hydro flattened breaklines in Esri shapefile format
- Ground control points in shapefile format
- 2’ contours in Esri Shapefile format
- Processing boundary in Esri File Geodatabase format
- Tile Index in Esri shapefile format
- Project and deliverable level metadata in XML format
- GPS/IMU Processing Statistics, Flight Logs, and Base Station Logs in PDF format (See Appendix A)
- Survey Report in PDF Format (See Appendix B)

**Figure 1. Lincoln County, WI LiDAR 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. Please note that certain values in the table below are listed as "Variable" due to the various flight plans used, as described in "Section: 1.5. Issues" of this document.

Detailed project flight planning calculations were performed for the project using Leica Mission Pro planning software.

The entire target area was comprised of 52 planned flight lines measuring approximately 2716 flight line kilometers for the LiDAR acquisition (Figure 2).

## 2.2. LiDAR Sensor

Quantum Spatial utilized a Leica ALS70 LiDAR sensor (Figure 3) during the project (serial numbers 7161 and 7234). 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 LiDAR Flight Lines

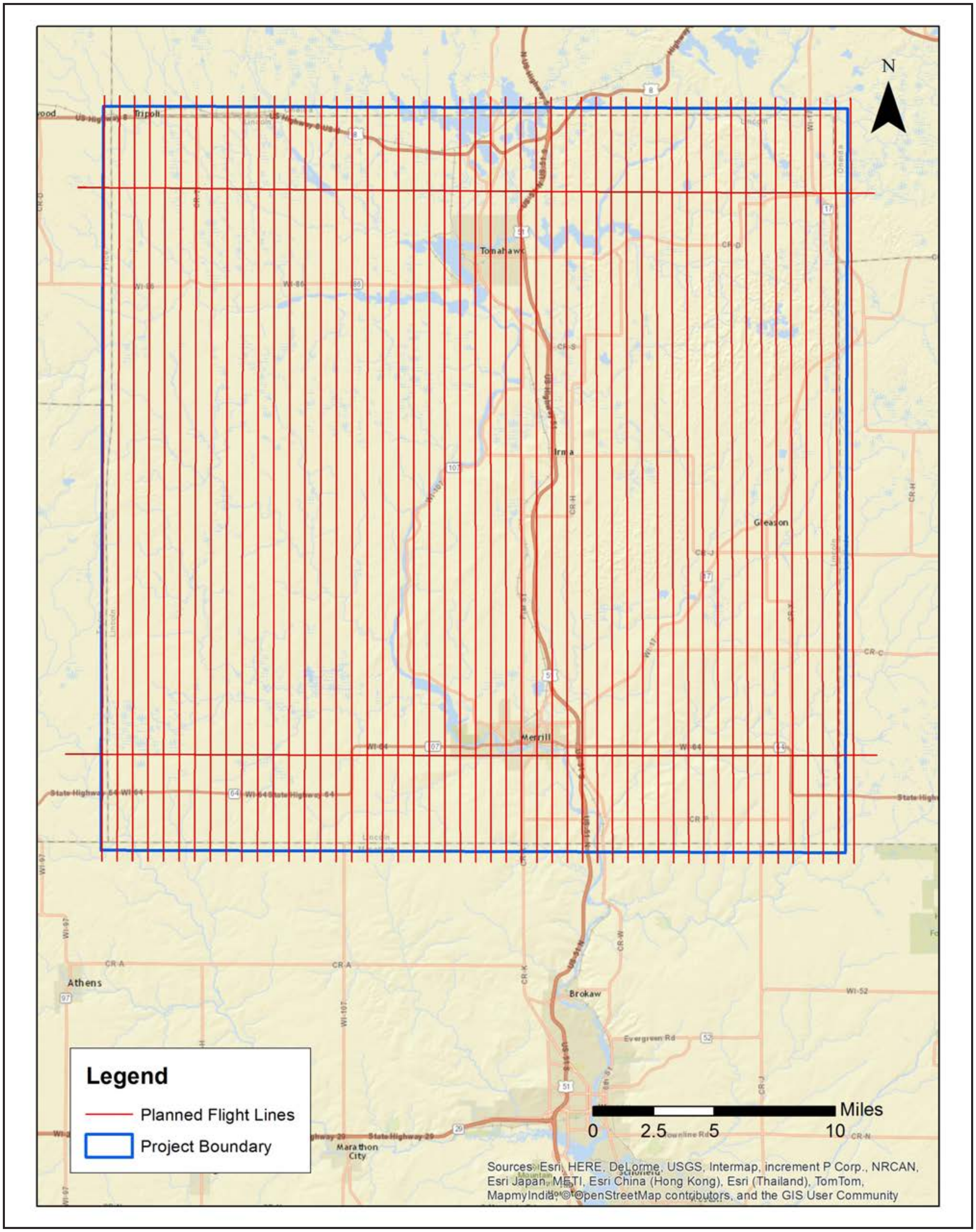


**Table 2. Lidar System Specifications**

| | | Leica ALS70 7161 | Leica ALS70 7234 |
|---|---|---|---|
| Terrain and Aircraft Scanner | Flying Height AGL (m) | 1900 m | 1900 m |
| Terrain and Aircraft Scanner | Recommended Ground Speed (kts) | 140 | 140 |
| Scanner | Field of View (deg) | 40.0 | 40.0 |
| Scanner | Scan Rate Setting Used (Hz) | 37.7 | 37.7 |
| Laser | Laser Pulse Rate Used (kHz) | 261 | 55.3 |
| Laser | Multi Pulse in Air Mode | Enabled | Disabled |
| Coverage | Full Swath Width (m) | 1528.67 | 1528.67 |
| Coverage | Line Spacing (m) | 1224.70 | 1224.70 |
| Point Spacing and Density | Maximum Point Spacing Along Track (m) | 0.95 | 2.25 |
| Point Spacing and Density | Maximum Point Spacing Along Track (m) | 0.96 | 1.91 |
| Point Spacing and Density | Average Point Density (pts / $m^2$) | 2.37 | 0.5 |

Figure 3. Leica ALS70 LiDAR Sensor

## 2.4. 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: N269JE
- Piper Navajo (twin-piston), Tail Number: N812TB

These aircraft provided an ideal, stable aerial base for LiDAR acquisition. These aerial platforms has relatively fast cruise speeds which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds which proved ideal for collection of high-density, consistent data posting using a state-of-the-art Leica ALS70 LiDAR system. Some of the operating aircraft can be seen in Figure 4 below.

Figure 4. Some of Quantum Spatial's Planes

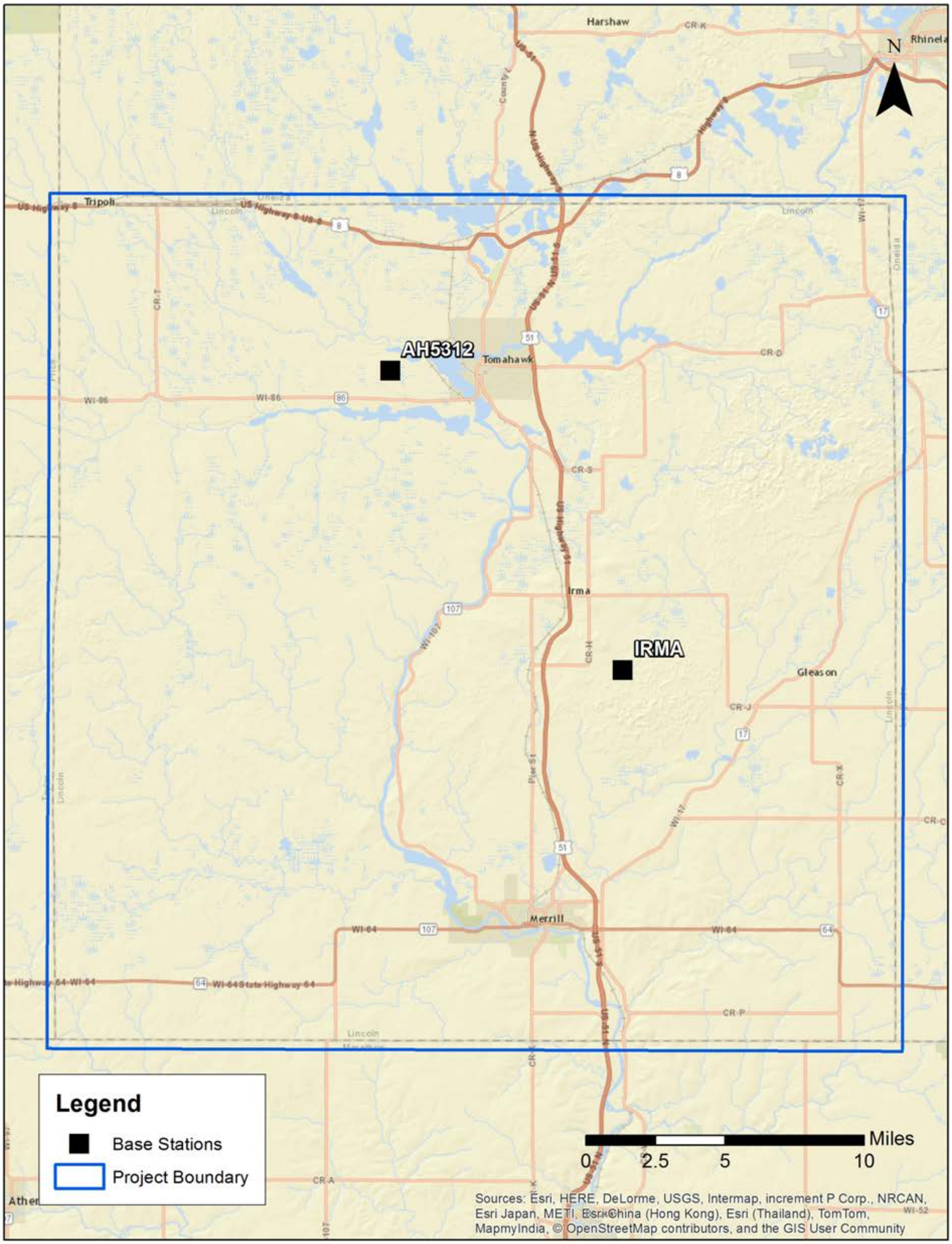
## 2.4. Base Station Information

**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) |
|---|---|---|---|
| IRMA | 45° 18′ 47.2043″ | 89° 37′ 33.35001″ | 444.786 |
| AH5312 | 45° 28′ 8.05736″ | 89° 47′ 51.33677″ | 421.514 |

Figure 5. Base Station Locations



## 2.6. Time Period

Project specific flights were conducted over two days. Five LiDAR sorties, or aircraft lifts were completed. Accomplished LiDAR sorties are listed below.

LiDAR Sorties

- Apr 15, 2015 A (7161)
- Apr 15, 2015 A (7234)
- Apr 16, 2015 A (7161)
- Apr 16, 2015 B (7161)
- Apr 16, 2015 A (7234)

# 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. All relevant graphs produced in the POSPac processing environment for each sortie during the Photo Science 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 ALS Post Processor software. GeoCue distributive processing software was used in the creation of some files needed in downstream processing, as well as in the tiling of the dataset into more manageable file sizes. TerraScan and TerraModeler software packages were then used for the automated data classification, manual cleanup, and bare earth generation. Project specific macros were developed to classify the ground and remove side overlap between parallel flight lines.

All data will manually be reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper will be 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 will then used to perform final statistical analysis of the classes in the LAS files.

Metadata was generated for the project on a deliverable level.

## 3.3. LAS Classification Scheme

The classification classes are determined by the USGS Version 1.2 specifications and are an industry standard for the classification of LIDAR point clouds. All data starts the process as Class 1 (Unclassified), and then through automated classification routines, the classifications are determined using TerraScan macro processing.

The classes used in the dataset are as follows and have the following descriptions:

- Class 1 – Processed, but Unclassified – These points would be the catch all for points that do not fit any of the other deliverable classes. This would cover features such as vegetation, cars, etc.
- Class 2 – Bare earth ground – This is the bare earth surface
- Class 7 – Low Noise – Low points, manually identified below the surface that could be noise points in point cloud.
- Class 8 – Model Key
- 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 1 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.

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 us 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. Hydro-Flattening Breakline Process

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 1 meter 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 shapefile format using ESRI conversion tools.

## 3.6. Hydro-Flattening Raster DEM Process

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.

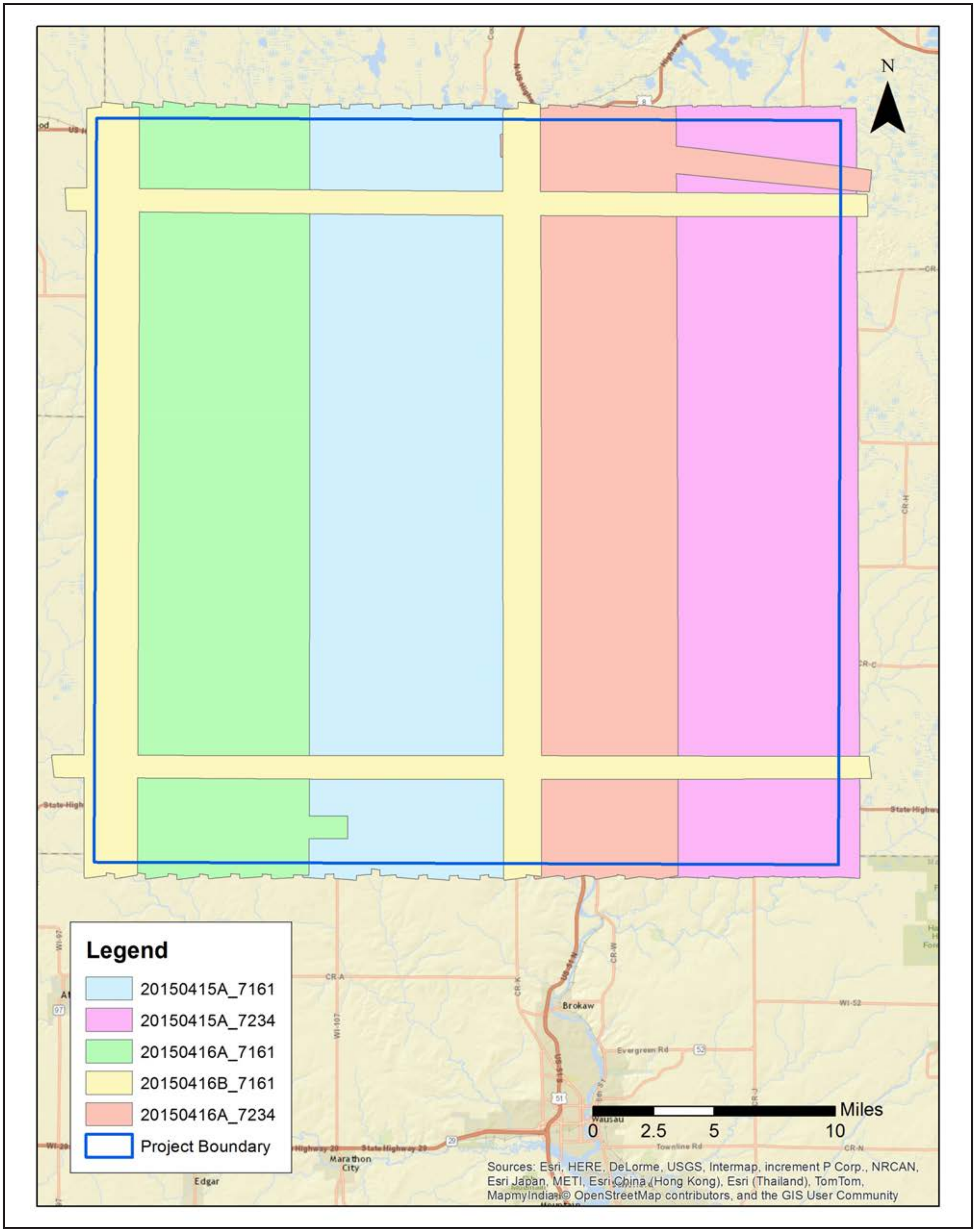
## 3.7. Contour Generation Process

Using automated scripting routines within ArcMap, a terrain surface was created using the ground (ASPRS Class 2) LiDAR data as well as the hydro-flattening breaklines. This surface was then used to generate the final 2 foot contour dataset in Esri file geodatabase format.

# 4. Project Coverage Verification

The project name or area project area 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 22 control calibration points along with 99 QC checkpoints in Nonvegetated and Vegetated land cover classifications (total of 121 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 QA points the goal was a positional accuracy of 5 cm in terms of the RMSE.

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.

The project was delivered in NAD83 (2011) Wisconsin County Coordinate System - Lincoln County, US Survey Feet; NAVD88 (Geoid 12A) US Survey Feet. Additionally, all horizontal coordinates for ground control and QA points for all LiDAR classes are also reported in NAD83 (2011) Wisconsin County Coordinate System - Lincoln County, US Survey Feet.

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). The summaries below provide the results of this testing.

## 5.1. Point Cloud Testing

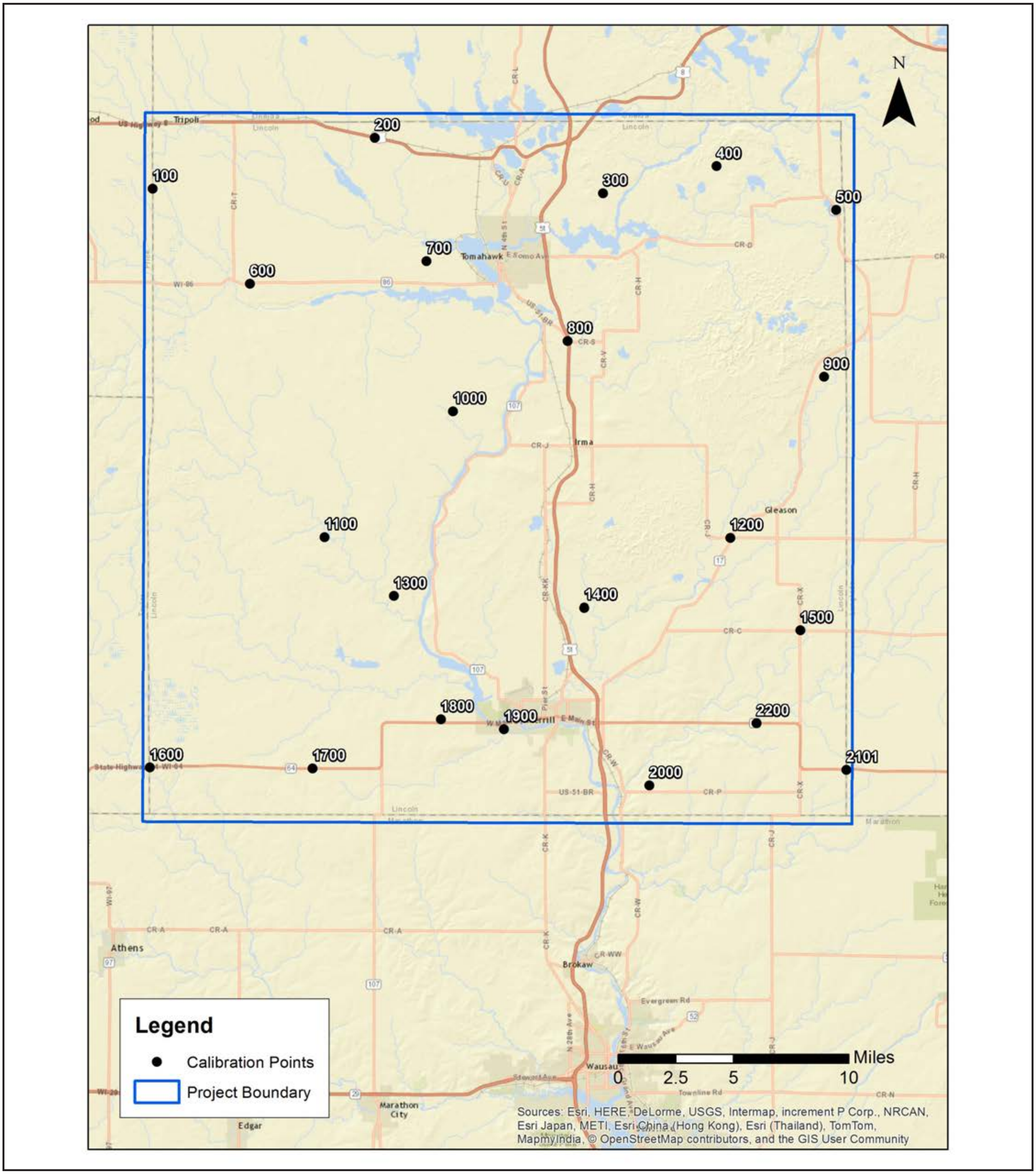
Raw Non-Vegetated Vertical Accuracy (Raw NVA): The tested Raw NVA for the dataset was found to be 0.144 Feet (4.4 cm) in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.282 Feet (8.6 cm). This dataset meets the required NVA of 0.643 Feet (19.6 cm) at the 95% 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. This is shown in Figure 8 and summarized in Table 5.

## 5.2. 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 0.148 Feet (4.5 cm) in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.290 Feet (8.8 cm). This dataset meets the required NVA of 0.643 Feet (19.6cm) at the 95% confidence level (based on NSSDA). This can be seen in Figure 9 and is summarized in 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 0.846 Feet (25.8 cm), which is stated in terms of the 95th percentile error. Therefore the data meets the required VVA of 0.965 Feet (29.4 cm). 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. LiDAR Ground Control Points Used in Calibration



## Figure 8. LiDAR Raw NVA Point Locations

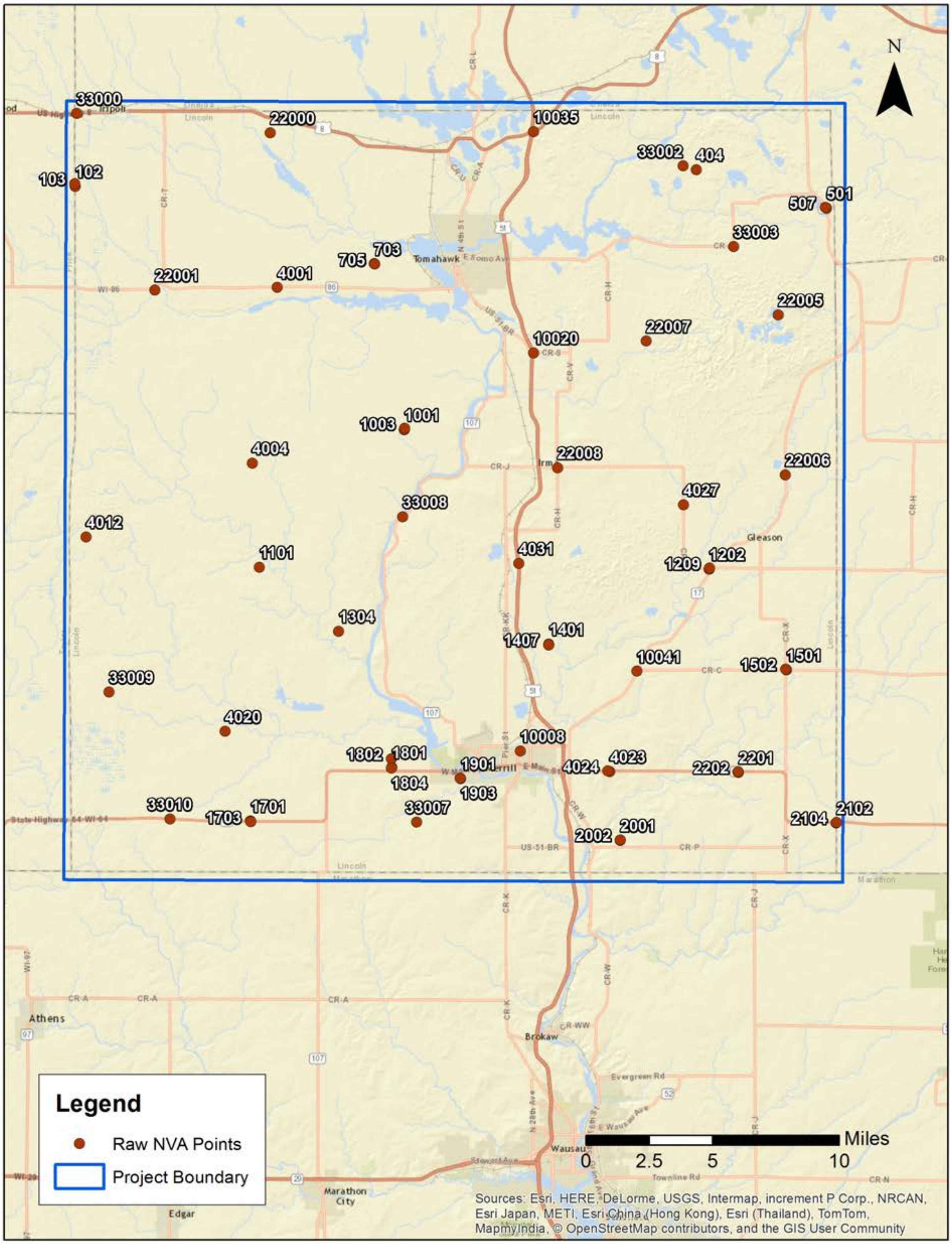


Figure 9. LiDAR NVA QA Point Locations

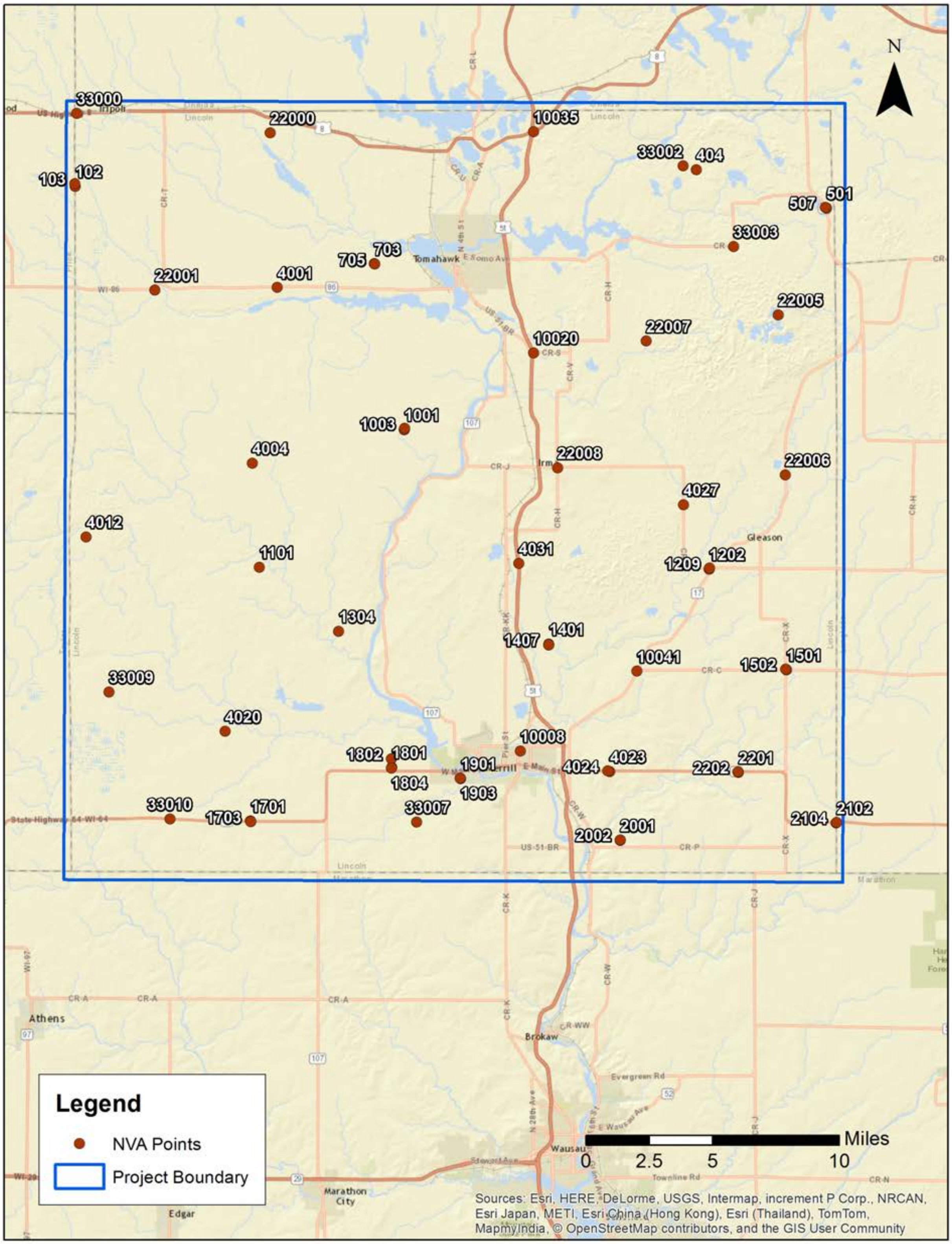


Figure 10. LiDAR VVA Point Locations

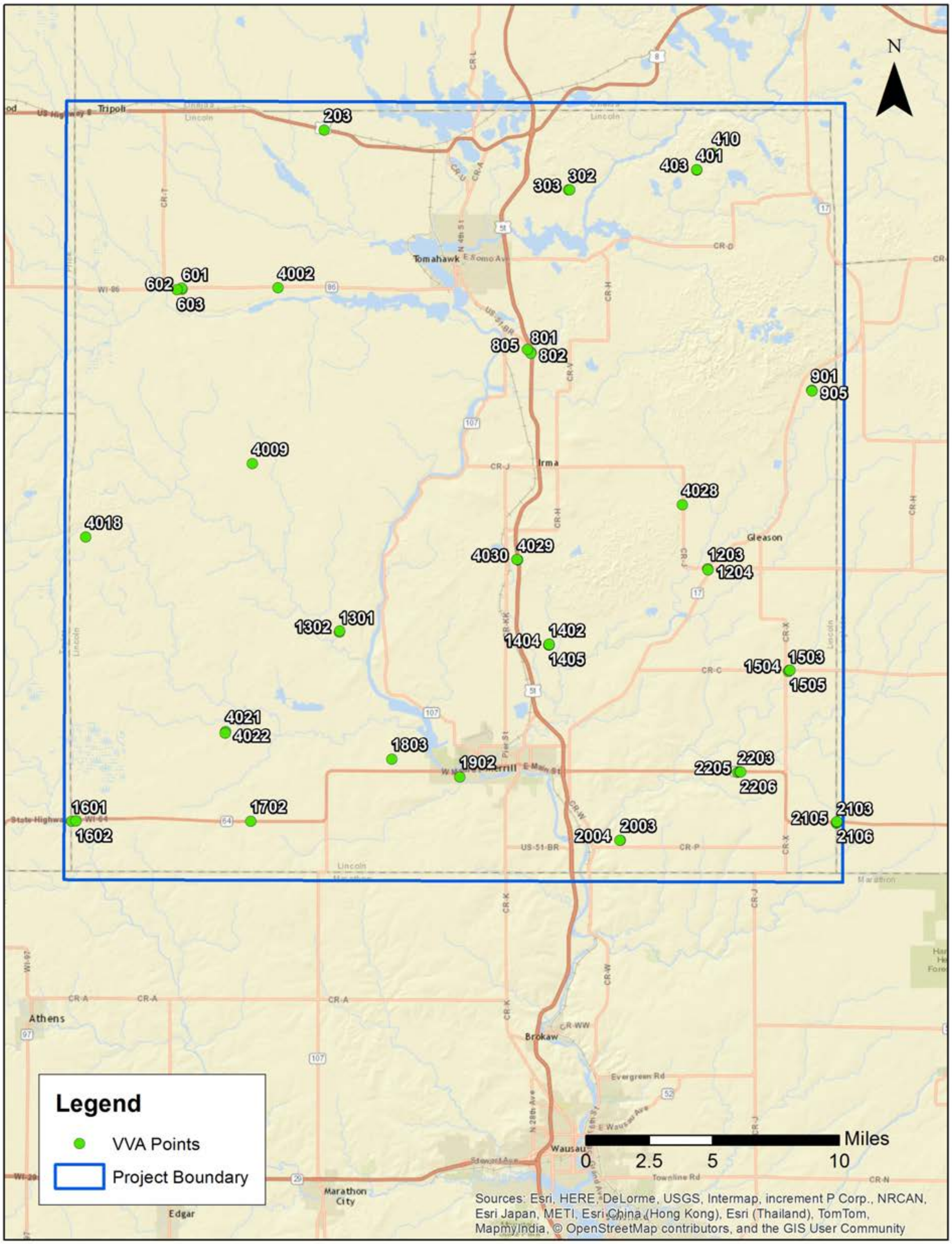


**Table 4. LiDAR Ground Control Point Report**

**Units = US Survey Feet**

| Number | Easting | Northing | Known Z | Laser Z | Dz |
|---|---|---|---|---|---|
| 100 | 301566.35 | 243934.17 | 1595.15 | 1595.23 | 0.09 |
| 200 | 352438.60 | 255603.50 | 1510.57 | 1510.51 | -0.06 |
| 300 | 404640.70 | 242861.54 | 1524.12 | 1523.93 | -0.19 |
| 400 | 430639.47 | 249095.17 | 1537.14 | 1537.00 | -0.14 |
| 500 | 458034.32 | 239068.47 | 1651.56 | 1651.54 | -0.02 |
| 600 | 323827.91 | 222164.04 | 1508.31 | 1508.42 | 0.11 |
| 700 | 364241.81 | 227362.12 | 1489.89 | 1489.92 | 0.03 |
| 800 | 396573.05 | 209006.35 | 1443.18 | 1443.09 | -0.09 |
| 900 | 455319.20 | 200811.81 | 1558.54 | 1558.47 | -0.07 |
| 1000 | 370316.26 | 192890.69 | 1473.74 | 1473.75 | 0.02 |
| 1100 | 340920.16 | 164063.61 | 1393.35 | 1393.53 | 0.18 |
| 1200 | 433794.14 | 163881.75 | 1433.27 | 1433.02 | -0.25 |
| 1300 | 356737.58 | 150578.81 | 1335.27 | 1335.28 | 0.01 |
| 1400 | 400389.34 | 147980.93 | 1349.72 | 1349.80 | 0.08 |
| 1500 | 449848.56 | 142833.44 | 1437.89 | 1437.80 | -0.09 |
| 1600 | 300906.19 | 111383.34 | 1440.98 | 1441.05 | 0.07 |
| 1700 | 338170.72 | 111162.13 | 1400.86 | 1401.01 | 0.15 |
| 1800 | 367557.03 | 122418.92 | 1420.18 | 1420.20 | 0.02 |
| 1900 | 382001.11 | 120142.18 | 1276.09 | 1276.22 | 0.13 |
| 2000 | 415246.59 | 107286.34 | 1378.62 | 1378.54 | -0.08 |
| 2101 | 460385.44 | 110853.11 | 1486.33 | 1486.22 | -0.11 |
| 2200 | 439799.40 | 121507.20 | 1417.28 | 1417.21 | -0.07 |

| | |
|---|---|
| Average Dz | -0.01 |
| Minimum Dz | -0.250 |
| Maximum Dz | 0.185 |
| Root Mean Square | 0.112 |
| Std. Deviation | 0.114 |

**Table 5. LiDAR QA Point Report: Raw NVA**

**Units = US Survey Feet**

| Number | Easting | Northing | Known Z | Laser Z | Dz |
|---|---|---|---|---|---|
| 102 | 301602.10 | 243561.26 | 1594.84 | 1594.65 | -0.19 |
| 103 | 301564.01 | 244121.36 | 1594.65 | 1594.68 | 0.03 |
| 404 | 431174.35 | 247050.08 | 1533.95 | 1534.03 | 0.08 |
| 501 | 458259.24 | 238981.44 | 1653.85 | 1653.72 | -0.13 |
| 507 | 458038.40 | 239170.09 | 1649.83 | 1649.80 | -0.03 |
| 703 | 363958.86 | 227378.57 | 1487.12 | 1487.01 | -0.11 |
| 705 | 364054.02 | 227324.15 | 1487.95 | 1488.34 | 0.39 |
| 1001 | 370222.72 | 192737.42 | 1472.12 | 1471.98 | -0.14 |
| 1003 | 370291.34 | 193029.78 | 1470.23 | 1470.41 | 0.18 |
| 1101 | 340039.12 | 164069.13 | 1414.35 | 1414.38 | 0.03 |
| 1202 | 433804.26 | 163636.24 | 1432.58 | 1432.55 | -0.03 |
| 1209 | 433878.46 | 163883.40 | 1433.76 | 1433.70 | -0.06 |
| 1304 | 356571.46 | 150679.12 | 1344.04 | 1344.00 | -0.04 |
| 1401 | 400388.78 | 148025.01 | 1348.35 | 1348.34 | -0.01 |
| 1407 | 400329.77 | 147981.50 | 1349.80 | 1349.90 | 0.10 |
| 1501 | 449906.74 | 142769.27 | 1439.03 | 1438.99 | -0.04 |
| 1502 | 449734.43 | 142942.22 | 1439.16 | 1439.09 | -0.07 |
| 1701 | 338158.26 | 111223.07 | 1398.90 | 1399.13 | 0.23 |
| 1703 | 338183.74 | 111096.06 | 1401.44 | 1401.48 | 0.04 |
| 1801 | 367609.67 | 122441.58 | 1416.37 | 1416.35 | -0.02 |
| 1802 | 367563.69 | 124233.46 | 1397.49 | 1397.47 | -0.02 |
| 1804 | 367553.67 | 122246.19 | 1418.95 | 1419.00 | 0.05 |
| 1901 | 381988.34 | 120099.37 | 1275.45 | 1275.43 | -0.02 |
| 1903 | 381913.93 | 120134.32 | 1277.11 | 1277.36 | 0.25 |
| 2001 | 415252.29 | 107185.41 | 1383.72 | 1383.69 | -0.03 |
| 2002 | 415264.80 | 107301.83 | 1377.43 | 1377.44 | 0.01 |
| 2102 | 460332.57 | 110829.47 | 1485.43 | 1485.30 | -0.13 |
| 2104 | 460356.06 | 110911.07 | 1486.31 | 1486.17 | -0.14 |
| 2201 | 439923.11 | 121403.23 | 1426.75 | 1426.78 | 0.03 |
| 2202 | 439799.60 | 121416.04 | 1424.98 | 1424.96 | -0.02 |
| 4001 | 343755.02 | 222441.25 | 1468.29 | 1468.29 | 0.00 |
| 4004 | 338526.28 | 185780.31 | 1498.09 | 1498.19 | 0.10 |

| Number | Easting | Northing | Known Z | Laser Z | Dz |
|---|---|---|---|---|---|
| 4012 | 303909.42 | 170378.40 | 1620.95 | 1620.99 | 0.04 |
| 4020 | 332870.44 | 129926.67 | 1372.98 | 1373.36 | 0.38 |
| 4023 | 413093.43 | 121564.80 | 1426.45 | 1426.41 | -0.04 |
| 4024 | 412660.41 | 121715.85 | 1461.67 | 1461.51 | -0.16 |
| 4027 | 428442.26 | 177128.03 | 1487.30 | 1487.33 | 0.03 |
| 4031 | 394096.76 | 164860.19 | 1489.42 | 1489.31 | -0.11 |
| 10008 | 394415.96 | 125844.64 | 1277.72 | 1277.82 | 0.10 |
| 10020 | 397174.34 | 208755.99 | 1437.35 | 1437.38 | 0.03 |
| 10035 | 397224.60 | 254994.35 | 1481.79 | 1481.75 | -0.04 |
| 10041 | 418726.30 | 142488.85 | 1430.18 | 1430.09 | -0.09 |
| 22000 | 342312.59 | 254706.90 | 1507.68 | 1507.85 | 0.17 |
| 22001 | 318227.69 | 221942.82 | 1480.32 | 1480.42 | 0.10 |
| 22005 | 448234.32 | 216727.56 | 1835.81 | 1835.43 | -0.38 |
| 22006 | 449664.25 | 183352.04 | 1520.83 | 1520.86 | 0.03 |
| 22007 | 420662.43 | 211265.39 | 1544.44 | 1544.38 | -0.06 |
| 22008 | 402181.24 | 184815.86 | 1692.24 | 1692.11 | -0.13 |
| 33000 | 301969.05 | 258767.19 | 1567.71 | 1567.77 | 0.06 |
| 33002 | 428371.01 | 247793.96 | 1541.72 | 1541.68 | -0.04 |
| 33003 | 438950.15 | 230974.72 | 1594.70 | 1594.61 | -0.09 |
| 33007 | 372833.30 | 111011.57 | 1332.30 | 1332.71 | 0.41 |
| 33008 | 369932.68 | 174570.95 | 1410.46 | 1410.49 | 0.03 |
| 33009 | 308653.90 | 138134.13 | 1459.70 | 1459.47 | -0.23 |
| 33010 | 321366.05 | 111638.88 | 1432.03 | 1432.17 | 0.14 |

| | |
|---|---|
| Average Dz | 0.01 |
| Minimum Dz | -0.380 |
| Maximum Dz | 0.410 |
| Root Mean Square | 0.144 |
| 95% Confidence | 0.282 |

Table 6. LiDAR QA Point Report: NVA

Units = US Survey Feet

| Number | Easting | Northing | Known Z | Laser Z | Dz |
|---|---|---|---|---|---|
| 102 | 301602.10 | 243561.26 | 1594.84 | 1594.78 | -0.06 |
| 103 | 301564.01 | 244121.36 | 1594.65 | 1594.80 | 0.15 |
| 404 | 431174.35 | 247050.08 | 1533.95 | 1534.05 | 0.10 |
| 501 | 458259.24 | 238981.44 | 1653.85 | 1653.72 | -0.13 |
| 507 | 458038.40 | 239170.09 | 1649.83 | 1649.73 | -0.10 |
| 703 | 363958.86 | 227378.57 | 1487.12 | 1486.93 | -0.19 |
| 705 | 364054.02 | 227324.15 | 1487.95 | 1488.39 | 0.44 |
| 1001 | 370222.72 | 192737.42 | 1472.12 | 1471.98 | -0.14 |
| 1003 | 370291.34 | 193029.78 | 1470.23 | 1470.45 | 0.22 |
| 1101 | 340039.12 | 164069.13 | 1414.35 | 1414.37 | 0.02 |
| 1202 | 433804.26 | 163636.24 | 1432.58 | 1432.55 | -0.03 |
| 1209 | 433878.46 | 163883.40 | 1433.76 | 1433.70 | -0.06 |
| 1304 | 356571.46 | 150679.12 | 1344.04 | 1344.00 | -0.04 |
| 1401 | 400388.78 | 148025.01 | 1348.35 | 1348.33 | -0.02 |
| 1407 | 400329.77 | 147981.50 | 1349.80 | 1349.91 | 0.11 |
| 1501 | 449906.74 | 142769.27 | 1439.03 | 1438.98 | -0.05 |
| 1502 | 449734.43 | 142942.22 | 1439.16 | 1439.14 | -0.02 |
| 1701 | 338158.26 | 111223.07 | 1398.90 | 1399.18 | 0.28 |
| 1703 | 338183.74 | 111096.06 | 1401.44 | 1401.49 | 0.05 |
| 1801 | 367609.67 | 122441.58 | 1416.37 | 1416.39 | 0.02 |
| 1802 | 367563.69 | 124233.46 | 1397.49 | 1397.43 | -0.06 |
| 1804 | 367553.67 | 122246.19 | 1418.95 | 1418.98 | 0.03 |
| 1901 | 381988.34 | 120099.37 | 1275.45 | 1275.54 | 0.09 |
| 1903 | 381913.93 | 120134.32 | 1277.11 | 1277.35 | 0.24 |
| 2001 | 415252.29 | 107185.41 | 1383.72 | 1383.74 | 0.02 |
| 2002 | 415264.80 | 107301.83 | 1377.43 | 1377.48 | 0.05 |
| 2102 | 460332.57 | 110829.47 | 1485.43 | 1485.30 | -0.13 |
| 2104 | 460356.06 | 110911.07 | 1486.31 | 1486.14 | -0.17 |
| 2201 | 439923.11 | 121403.23 | 1426.75 | 1426.71 | -0.04 |
| 2202 | 439799.60 | 121416.04 | 1424.98 | 1424.86 | -0.12 |
| 4001 | 343755.02 | 222441.25 | 1468.29 | 1468.26 | -0.03 |
| 4004 | 338526.28 | 185780.31 | 1498.09 | 1498.23 | 0.14 |

| Number | Easting | Northing | Known Z | Laser Z | Dz |
|---|---|---|---|---|---|
| 4012 | 303909.42 | 170378.40 | 1620.95 | 1620.98 | 0.03 |
| 4020 | 332870.44 | 129926.67 | 1372.98 | 1373.35 | 0.37 |
| 4023 | 413093.43 | 121564.80 | 1426.45 | 1426.37 | -0.08 |
| 4024 | 412660.41 | 121715.85 | 1461.67 | 1461.50 | -0.17 |
| 4027 | 428442.26 | 177128.03 | 1487.30 | 1487.31 | 0.01 |
| 4031 | 394096.76 | 164860.19 | 1489.42 | 1489.30 | -0.12 |
| 10008 | 394415.96 | 125844.64 | 1277.72 | 1277.81 | 0.09 |
| 10020 | 397174.34 | 208755.99 | 1437.35 | 1437.35 | 0.00 |
| 10035 | 397224.60 | 254994.35 | 1481.79 | 1481.81 | 0.02 |
| 10041 | 418726.30 | 142488.85 | 1430.18 | 1430.01 | -0.17 |
| 22000 | 342312.59 | 254706.90 | 1507.68 | 1507.87 | 0.19 |
| 22001 | 318227.69 | 221942.82 | 1480.32 | 1480.43 | 0.11 |
| 22005 | 448234.32 | 216727.56 | 1835.81 | 1835.46 | -0.35 |
| 22006 | 449664.25 | 183352.04 | 1520.83 | 1520.83 | 0.00 |
| 22007 | 420662.43 | 211265.39 | 1544.44 | 1544.34 | -0.10 |
| 22008 | 402181.24 | 184815.86 | 1692.24 | 1692.16 | -0.08 |
| 33000 | 301969.05 | 258767.19 | 1567.71 | 1567.80 | 0.09 |
| 33002 | 428371.01 | 247793.96 | 1541.72 | 1541.64 | -0.08 |
| 33003 | 438950.15 | 230974.72 | 1594.70 | 1594.60 | -0.10 |
| 33007 | 372833.30 | 111011.57 | 1332.30 | 1332.58 | 0.28 |
| 33009 | 308653.90 | 138134.13 | 1459.70 | 1459.50 | -0.20 |
| 33010 | 321366.05 | 111638.88 | 1432.03 | 1432.10 | 0.07 |

| | |
|---|---|
| Average Dz | -0.01 |
| Minimum Dz | -0.354 |
| Maximum Dz | 0.442 |
| Root Mean Square | 0.148 |
| 95% Confidence | 0.290 |

### Table 7. LiDAR QA Point Report: VVA

**Units = US Survey Feet**

| Number | Easting | Northing | Known Z | Laser Z | Dz |
|---|---|---|---|---|---|
| 203 | 353548.54 | 255315.94 | 1506.73 | 1507.08 | 0.35 |
| 302 | 404513.37 | 242784.36 | 1521.98 | 1522.26 | 0.28 |
| 303 | 404716.20 | 242829.36 | 1520.36 | 1520.58 | 0.22 |
| 401 | 431257.35 | 246951.80 | 1525.41 | 1525.58 | 0.17 |
| 403 | 431217.95 | 247052.05 | 1533.83 | 1534.06 | 0.23 |
| 410 | 434552.87 | 250443.11 | 1552.67 | 1553.15 | 0.48 |
| 601 | 323874.63 | 222092.00 | 1504.59 | 1505.40 | 0.81 |
| 602 | 323838.63 | 222276.95 | 1504.14 | 1504.67 | 0.53 |
| 603 | 322865.76 | 221992.93 | 1507.64 | 1507.82 | 0.18 |
| 801 | 396624.85 | 208965.79 | 1436.64 | 1437.50 | 0.86 |
| 802 | 396613.22 | 208713.50 | 1440.16 | 1440.55 | 0.39 |
| 805 | 395932.64 | 209487.04 | 1459.95 | 1459.62 | -0.33 |
| 901 | 455170.36 | 200998.38 | 1558.52 | 1558.36 | -0.16 |
| 905 | 455311.82 | 200858.91 | 1557.96 | 1558.25 | 0.29 |
| 1203 | 433506.96 | 163718.68 | 1425.16 | 1426.12 | 0.96 |
| 1204 | 433547.09 | 163533.36 | 1427.51 | 1427.64 | 0.13 |
| 1301 | 356674.11 | 150545.03 | 1335.29 | 1335.10 | -0.19 |
| 1302 | 356784.42 | 150744.16 | 1331.50 | 1331.94 | 0.44 |
| 1402 | 400374.40 | 147951.73 | 1348.28 | 1348.64 | 0.36 |
| 1404 | 400430.09 | 147950.33 | 1348.19 | 1348.50 | 0.31 |
| 1405 | 400434.00 | 148041.06 | 1347.80 | 1348.13 | 0.33 |
| 1503 | 450333.26 | 142474.24 | 1423.90 | 1424.25 | 0.35 |
| 1504 | 450512.27 | 142657.42 | 1420.91 | 1420.94 | 0.03 |
| 1505 | 450632.85 | 142719.96 | 1420.28 | 1420.52 | 0.24 |
| 1601 | 300870.21 | 111139.09 | 1440.68 | 1441.18 | 0.50 |
| 1602 | 301755.82 | 111261.20 | 1429.98 | 1430.40 | 0.42 |
| 1702 | 338228.59 | 111207.87 | 1404.73 | 1405.17 | 0.44 |
| 1803 | 367630.94 | 124146.05 | 1393.61 | 1394.46 | 0.85 |
| 1902 | 381791.51 | 120438.39 | 1277.21 | 1277.64 | 0.43 |
| 2003 | 415284.41 | 107225.25 | 1381.91 | 1382.15 | 0.24 |
| 2004 | 415193.87 | 107237.97 | 1378.65 | 1378.98 | 0.33 |
| 2103 | 460409.77 | 110796.61 | 1483.97 | 1484.49 | 0.52 |

| Number | Easting | Northing | Known Z | Laser Z | Dz |
|---|---|---|---|---|---|
| 2105 | 460363.42 | 111005.77 | 1486.26 | 1486.59 | 0.33 |
| 2106 | 460485.65 | 111073.34 | 1487.54 | 1487.78 | 0.24 |
| 2203 | 439745.93 | 121390.19 | 1423.78 | 1423.86 | 0.08 |
| 2205 | 440198.54 | 121464.62 | 1407.56 | 1407.74 | 0.18 |
| 2206 | 440377.67 | 121459.71 | 1414.61 | 1415.04 | 0.43 |
| 4002 | 343862.23 | 222397.95 | 1466.48 | 1466.78 | 0.30 |
| 4009 | 338552.20 | 185691.63 | 1495.41 | 1495.76 | 0.35 |
| 4018 | 303831.18 | 170396.63 | 1616.81 | 1617.16 | 0.35 |
| 4021 | 332980.72 | 129909.12 | 1372.59 | 1372.80 | 0.21 |
| 4022 | 332912.71 | 129518.02 | 1378.29 | 1378.71 | 0.42 |
| 4028 | 428230.88 | 177074.42 | 1476.21 | 1476.31 | 0.10 |
| 4029 | 393839.96 | 165618.99 | 1474.00 | 1474.25 | 0.25 |
| 4030 | 393742.68 | 165671.52 | 1472.44 | 1472.45 | 0.01 |

| | |
|---|---|
| Average Dz | 0.33 |
| Minimum Dz | -0.327 |
| Maximum Dz | 0.960 |
| Root Mean Square | 0.403 |
| 95% Confidence | 0.846 |