Hamilton Co., IN 2016 Digital Orthoimagery LiDAR, and Planimetrics Project Report

County of Hamilton Indiana

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Project Report

2016 Hamilton County
Digital Orthoimagery, LiDAR, and Planimetrics

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Hamilton County, IN 2016 Digital Orthoimagery, LiDAR, and Planimetric Project task order, issued by Hamilton County, Indiana. The task order yielded a project area covering approximately 434 square miles over Hamilton County, Indiana. 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 / m^2	2,000 m	40°	10%	≤ 10 cm

High resolution 24-bit, 4-band RGB-IR digital imagery was acquired and used for digital orthophoto production. Ortho data collection was planned using the specifications listed below in Table 2.

Table 2. Originally Planned Ortho Specifications

GSD	Flight Altitude (AGL)	Min. Sun Angle	Side Overlap
0.5 ft	6,170 ft	30°	30% (+/- 5%)

1.3. Coverage

The project boundary covers approximately 434 square miles and encompasses the entirety of Hamilton County, Indiana. A buffer of 2,250 feet was created in order to complete the County's tile grid. Project extents are shown in Figure 1 on the following page.

1.4. Duration

LiDAR data was acquired from March 21, 2016 to March 22, 2016 in two total lifts. Imagery was acquired in three lifts from March 21, 2016 through March 22, 2016. See "Section: 2.6. Time Period" for more details.

1.5. Issues

There were no issues to report with this project

1.6. Deliverables

The following products were produced and delivered:

LiDAR
- Raw point cloud data, swaths in LAS 1.4 format
- Classified point cloud data, tiled, in LAS 1.4 format
- 3.125-foot bare earth hydro-flattened DEM, tiled, in IMG format
- Breaklines in Esri file geodatabase format
- 3.125-foot intensity imagery, tiled, in GeoTIFF format

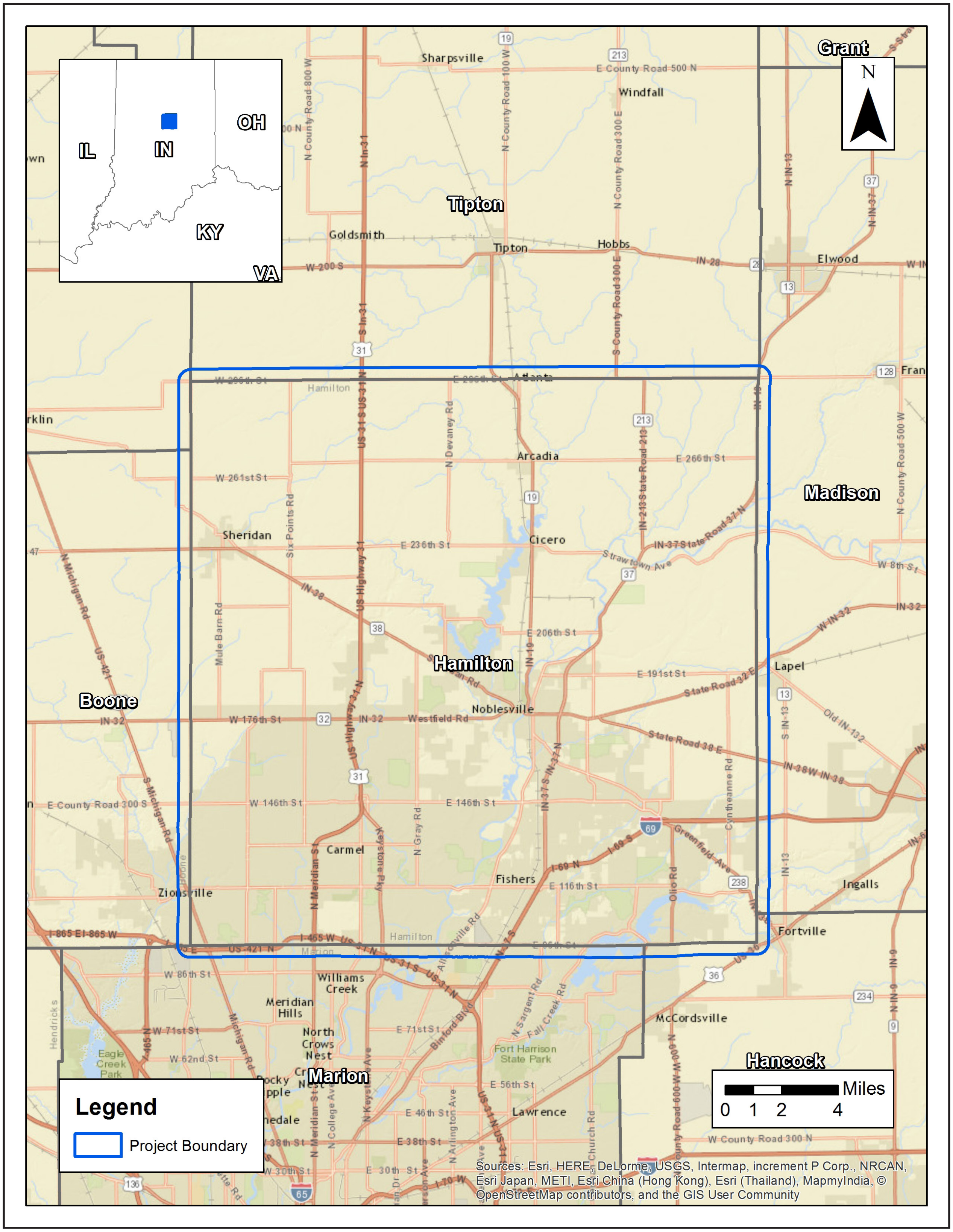
Ortho
- 6-inch color (RGB-IR) orthoimages, tiled, in GeoTIFF format
- Seamlines in Esri shapefile format
- Tile index in Esri shapefile format

Planimetrics
- Planimetric and topographic data, in Esri file geodatabase format
- Impervious surface data
- Digital elevation model data in Esri grid format
- Digital Terrain Model in Esri grid format

Other Deliverables
- Deliverable-level metadata, in .XML metadata

All geospatial deliverables were produced in NAD83 State Plane Coordinate System Indiana East Zone, US survey feet; NAVD (Geoid 12B), US survey feet. Tiled deliverables have a tile size of 2,500 ft x 2,500 ft. Tile names follow the naming convention of the tile index provided by Hamilton County.

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 37 planned flight lines measuring approximately 798.92 total flight line miles for the LiDAR acquisition (Figure 2) and 18 planned flight lines measuring approximately 451.34 miles for orthoimagery acquisition (Figure 4). See the flight diagrams in Appendices A and B.

2.2. LiDAR Sensor

Quantum Spatial utilized a Leica ADS 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 3.

2.3. Orthoimagery Camera

Quantum Spatial also utilized a Leica ADS 100 (Figure 5), serial number 10542. The ADS100 is a "push broom" style sensor, collecting imagery with linear CCD lines in a continuous manner along a given flight line. The ADS sensor used simultaneously collected 13 CCD lines at a swath width of 20,000 pixels each and cross track Field of View (FOV) angle of 77 degrees. The ADS100 CCDs have pixel dimensions of 5.0 microns x 5.0 microns, and the sensor's calibrated focal length is 62.5mm.

The multi-spectral channels at nadir are 'optically' co-registered through the use of a tetrachroid beam splitter. The focal plane and optics of the ADS100 permit all image channels to be collected at the native GSD. No multi-spectral image channels are "pan-sharpened" to obtain final resolution multi-spectral images. The current sensor calibration report is attached in Appendix C, Sensor Calibration Report.

A brief summary of the aerial acquisition parameters for the project are shown in the Camera System Specifications in Table 4.

Figure 2. Planned LiDAR Flight Lines

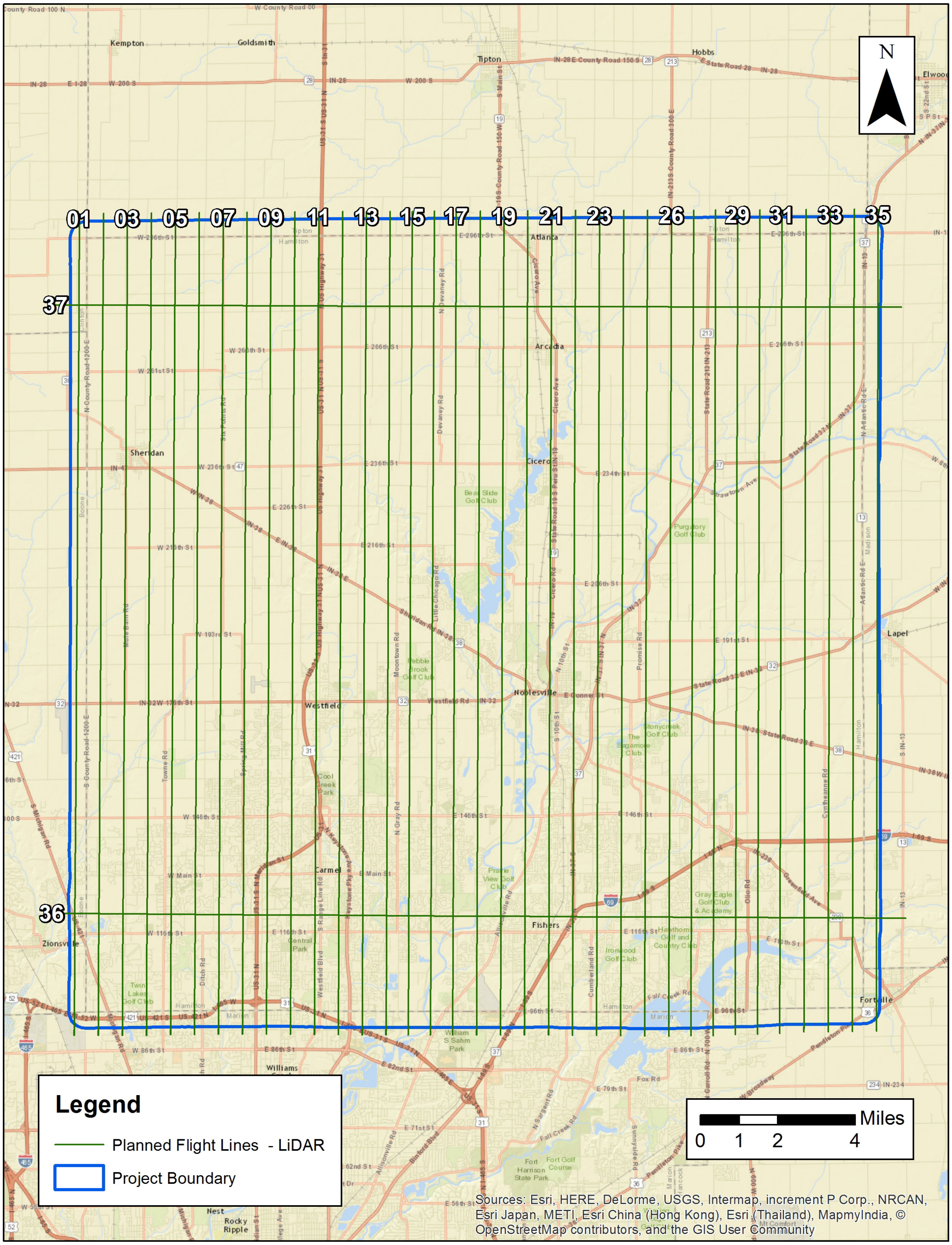


Table 3. Lidar System Specifications

Terrain and Aircraft Scanner	Flying Height	2,000 m
	Recommended Ground Speed	170 kts
Scanner	Field of View	40.0°
	Scan Rate Setting Used	53.4 Hz
Laser	Laser Pulse Rate Used	273 kHz
	Multi Pulse in Air Mode	Enabled
Coverage	Full Swath Width	1,455.88 m
	Line Spacing	1,296.65 m
Point Spacing and Density	Maximum Point Spacing Along Track	1.24 m
	Maximum Point Spacing Along Track (in phase)	1.64 m
	Maximum Point Spacing Along Track (out of phase)	0.82 m
	Average Point Density	2.14 pts / m^2

Figure 3. Leica ALS 70 LiDAR Sensor

Figure 4. Planned Ortho Flight Lines

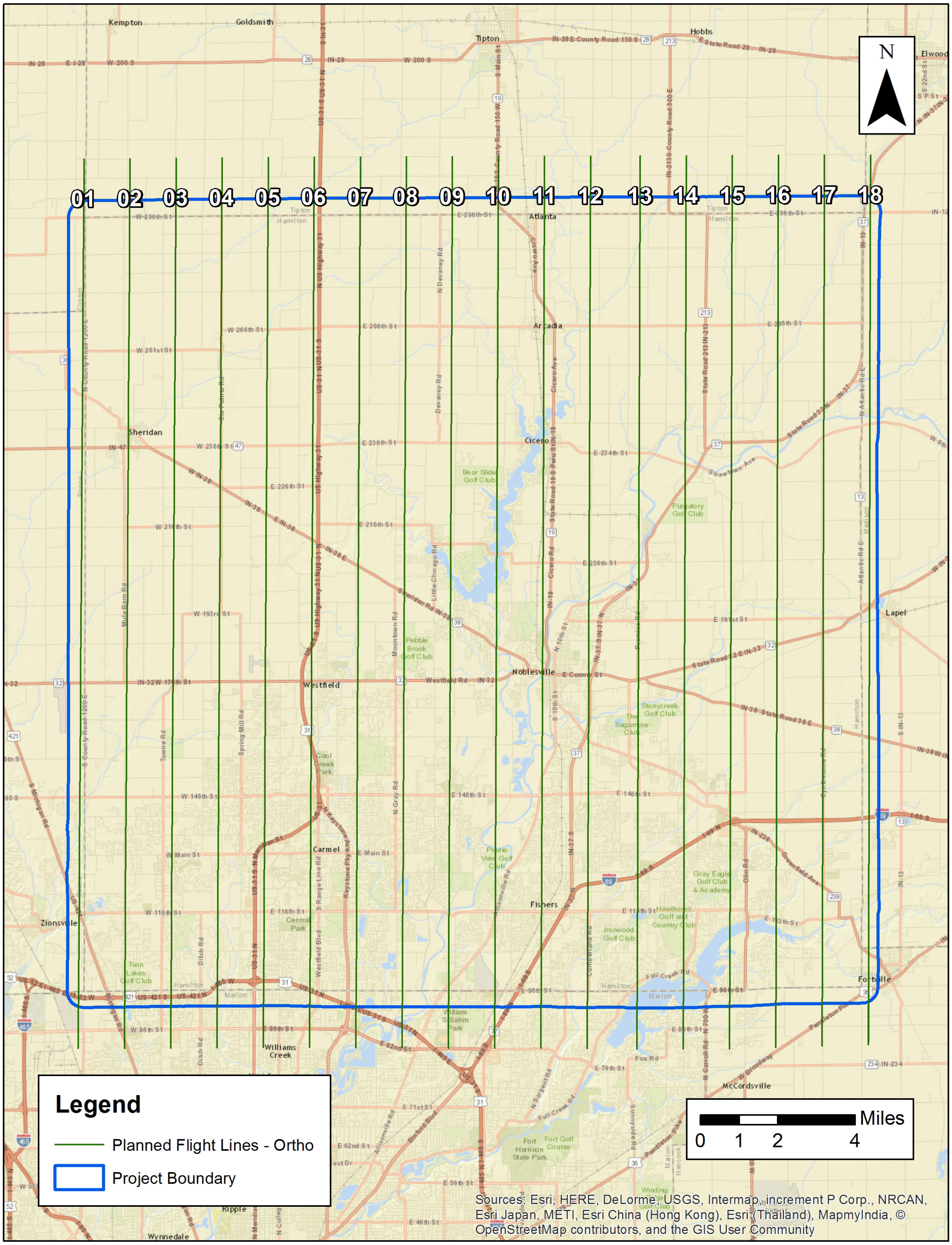


Table 4. Camera System Specifications

Terrain and Aircraft	Flying Height AGL	6,750 ft
	Recommended Ground Speed (GS)	130 kts
Overlap	Forward Overlap	100%
	Side Overlap	30%
Coverage	Strip Width	9,500 ft
Resolution	GSD	0.5 feet

Image Channel	Look Angle	Wave Length
Red Nadir	0 degrees	619 - 651 nm
Green Nadir	0 degrees	525 - 585 nm
Blue Nadir	0 degrees	435 - 495 nm
Near-infrared Nadir	0 degrees	808 - 882 nm

Figure 5. Leica ADS 100 Camera

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
- Piper Navajo (twin-piston), Tail Number: N73TM

Imagery Collection Planes
- Cessna 206 Stationair, Tail Number: N7266Z

These aircraft provided an ideal, stable aerial base for LiDAR and orthoimagery 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 LiDAR and imagery systems. Some of Quantum Spatial's operating aircraft can be seen in Figure 6 below.

Figure 6. Some of Quantum Spatial's Planes

2.5. Time Period

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

LiDAR Sorties
- Mar 21, 2016-A (N73TM, SN7178)
- Mar 22, 2016-A (N73TM, SN7178)

Ortho Sorties
- Mar 21, 2016-A (N7266Z, SN10548)
- Mar 22, 2016-A (N7266Z, SN10548)
- Mar 22, 2016-B (N7266Z, SN10548)

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

Similar information was also collected for imagery:

- Job / Project #
- System
- Flight Date / Lift Number
- Flight Line Number
- Flight Line Start Time
- Flight Line Stop Time
- Image Range
- F-Stop Setting
- Shutter Setting

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc). Project specific flight logs for each sortie are available in Appendices D and E.

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 D.

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 7 – Noise – Low or high points, manually identified above or below the surface that could be noise points in point cloud.
- Class 8 – Model Key Point – A thinned subset of the ground class created via an automated routine that takes into account changes in the terrain.
- 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.

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 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 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 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 Creation

All breaklines were collected through photogrammetric methods. The 2D breaklines were created using heads-up digitization of inland streams and rivers with a 30 meter nominal width and Inland Ponds and Lakes of 2 acres or greater surface area.

All ground (ASPRS Class 2) LiDAR data inside of the collected inland Lake/Pond breaklines were then classified to water (ASPRS Class 9). 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 10). Bridge breaklines were created from the LiDAR dataset using points in Class 17 (Bridge Decks).

The breakline files were then translated to Esri file geodatabase format using Esri conversion tools.

3.6. Contour Creation

Contours were created using automated scripting routines within TerraScan/TerraModeler. The Class 8 Model Key points were combined with the hydro-flattened breaklines to create the contours. These features were then translated to Esri shapefile for ingestion into the final deliverable format.

3.7. Spot Elevation Creation

Spots were created using automated methods for spotting found within TerraModeler to create this deliverable.

3.8. Imagery Processing Summary

There are several distinct processing steps. First, raw imagery is converted from the raw data collected in flight and post-processed to a "RAW" file that can be incorporated into orthophotography data. Next, Ground Control Points (GCPs) were collected and processed. Then, an additional set of raw data collected in flight from the Airborne GPS systems are processed to create an external orientation file. The processed RAW imagery, ground control and the external orientation file are used to create aerotriangulation data. Finally, the merging of all of these, along with a surface, is done in order to create a digital orthophotograph.

3.9. Raw Data Extraction

Leica Geosystems XPro version 6.2.1 was used to download the raw flight data from the MMU. Raw data for the ADS sensor consists of the un-rectified strip images in TIFF format, commonly referred to as L0 images in ADS workflows, and the raw ABGPS/IMU observables.

3.10. Airborne GPS and IMU Processing

ABGPS/IMU data was collected on the aircraft during the survey mission, providing sensor position and orientation information for geo-referencing the imagery data. ABGPS observations were collected at a frequency of 2Hz, and IMU observations were collected at a frequency of 200Hz. Precise lever arm measurements from the ABGPS/IMU measurement reference points to the principal point of the ADS focal plane are used in reducing the raw vehicle position/attitude observables to sensor exterior orientation. These lever arm measurements are measured during sensor installation in the survey aircraft.

GPS data was collected using two CORS base stations, providing corrections to support differential post-processing of the ABGPS. The two CORS stations used in the processing are INPD, and INTP. Differential correction of the ABGPS data using the ground base station data was performed in NovAtel Inertial Explorer software version 8.6. The NAD83 geodetic coordinates acquired through the CORS network were held as reference during differential correction. Corrected ABGPS data was combined with IMU data in Inertial Explorer through a Kalman filtering algorithm to arrive at a smoothed best estimate of the sensor's trajectory during the collection missions. This trajectory estimate along with precise exposure timing data provide initial EO estimates for the imagery in aero-triangulation.

3.11. Aerotriangulation

Aero-triangulation was performed using Leica Geosystems' XPro software version 6.2.1. XPro's automatic point matching algorithm was used to match image tie points in the side overlap between adjacent image strips. The tie point observations were used in a least squares bundle adjustment to solve for systematic errors in the smoothed best estimate of trajectory, including GPS drift and timing offsets. The bundle adjustment also identifies and eliminates measurement blunders in the tie points.

After solving for systematic navigation errors and removing measurement blunders, ground control points were manually measured in the imagery. Ground control points coordinates used had horizontal reference of NAD83 Indiana State Plane East Zone, US feet, and vertical reference of NAVD88 ellipsoid heights, US survey feet. AT for the ADS sensor is performed in the ellipsoid vertical reference to avoid systematic errors that geoid undulations cause in the pushbroom sensor model. The ground control point observations are used to solve for any remaining datum transformation required to determine EO in the project datum. Ground control points were assigned statistical weight, equivalent to their estimated accuracy, in the final least squares adjustment to solve for the control datum transformation.

For more information, see the Aerotriangulation Report in Appendix F.

3.12. Surface Model Creation

Quantum Spatial generated an elevation model utilizing LiDAR data collected under this task order.

3.13. Orthorectification Process

Orthorectification of imagery was accomplished with the XPro software version 6.2.1 rectification module, which provided a seamless workflow for block bundle adjustment and generation of orthoimages. The XPro rectification module used the block bundle adjustment solution developed in the bundle adjustment module and the L0 images as inputs.

Radiometric correction of the imagery included applying the manufacturer's calibration and a proprietary process to account for atmospheric and lighting effects. Two principal effects were considered in the proprietary correction; atmospheric haze and bi-directional reflectance. Atmospheric haze describes the effect of sunlight reflecting off of aerosols dispersed in the atmosphere, especially in the blue wavelength of the visible light spectrum. Bi-directional reflectance describes the non-uniform brightness of the ground scene in an aerial image caused by varied viewing and illumination angles. Due to the ADS sensor's consistent nadir geometry in the along-track flight direction of the image strip, haze and reflectance only affect the ADS sensor in the across track direction of the image strip. The algorithm works by sampling the pixel values throughout the image strip and calculating an average pixel value for each column of pixels across the sensor track. A polynomial function is used to normalize the samples to remove any anomalies, such as specular reflection on water, from the column averages. Mean brightness of the column averages are calculated, and a correction value determined to adjust the average pixel value of each column in the strip to the mean. The corrections were calculated and applied in the raw 12-bit dynamic range of the ADS sensor, permitting a more accurate correction than one applied after the imagery has been histogram stretched for 8-bit storage and viewing. Correction values were stored in separate files for each multi-spectral image and were applied by the orthorectification module during orthoimage output. The manufacturer's factory calibrated radiometric gain parameters were also applied during orthorectification, modeling the variable sensitivity of each CCD in the ADS sensor to the wavelength of light it is assigned to collect.

The assembled DEM and atmospheric correction files were added to the XPro block definition. The rectification module was used to generate a 4-band orthorectified image strip, commonly referred to as L2 images in ADS workflows. The band order of the L2 was Red in Band 1, Green in Band 2, Blue in Band 3, and Near-Infrared in Band 4. The L2 was stored in 16-bit GeoTIFF file format, and had the atmospheric corrected 12-bit dynamic range of the ADS sensor. The L2 images were validated for relative and absolute horizontal accuracy by visual inspection using the inpho OrthoVista software. Photogrammetric technicians manually measured common features in the sidelap region of adjacent images and photo-identifiable ground control points to validate relative and absolute accuracy of the L2s. The results of the horizontal accuracy assessment are outlined in the table below. With horizontal accuracy requirements validated, the imagery was moved into the mosaic phase.

3.14. Mosaic

The mosaicing of the L2 images was accomplished in the inpho OrthoVista Seam Editor (OrthoVista SE) software. Photogrammetric technicians manually placed seamlines using heads-up digitization techniques in OrthoVista SE. Use of OrthoVista SE allowed the technicians to see the resulting mosaic in real-time during editing, minimizing the number edits for seam placement required once tiles are clipped from the mosaic. Technicians placed the seams so as to utilize the most nadir portion of each orthoimage, while avoiding clipping of above ground features wherever possible. The manually placed seams were stored in seam definition files and applied during the tile clipping process in OrthoVista.

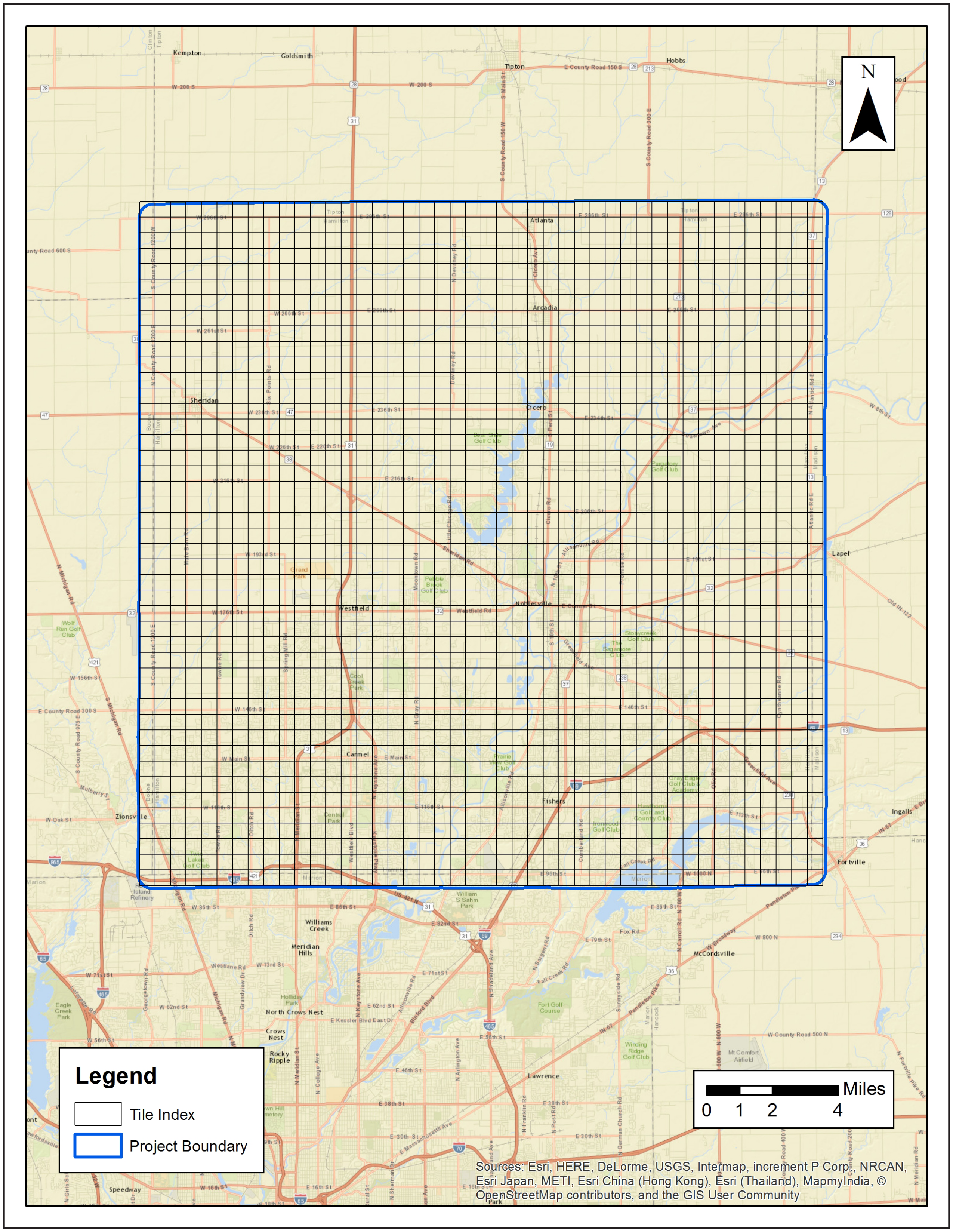
Color adjustment of the atmospherically corrected, 12-bit dynamic range L2 ADS strips, for storage and viewing as 8-bits per channel GeoTIFF images, was applied in the final processing step before individual orthoimages were clipped from the mosaic. The L2 strips generated from the PictoVera processing block were loaded into OrthoVista to perform the color adjustment, which allowed visual as well as numerical inspection of calculated color corrections in real-time, before the corrections were actually applied to the images. Color adjustments were calculated using the Radiometrix module in the OrthoVista software. The Radiometrix module was used to define a non-linear, splined curve histogram stretch to transform the 12-bit dynamic range of the L2 strip to the full dynamic range of the 16-bit GeoTIFF. The histogram stretch generally reflects a natural logarithm function; this is necessary to accommodate the way in which the human eye perceives light.

OrthoVista software was used to apply the seamlines and histogram stretch to generate the final 24-bit 4-band RGB-IR mosaics. The tiling scheme for the mosaic was a 2,500-foot x 2,500-foot grid shown in Figure 7.

3.15. Planimetric Feature Capture

Planimetric features are those that are typically independent of elevation, but must be horizontally accurate. These features include paved transportation surfaces (roads), structures, foundations, drainages, streams, ponds, lakes, rivers, culverts, and pipes. Planimetrics were collected in a 2D environment.

Figure 7. 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 8.

The AOI project area imagery frame coverage (see Figure 9) and content verification was performed and validated by visual review. This action was performed in the field by flight crew during the acquisition phase as well as by imagery QA technicians at our processing center. The ABGPS/IMU and base station data was uploaded to the company FTP site after each flight for the INS processing team in Lexington, Kentucky to verify accuracy of data collected.

Figure 8. Flightline Swath LAS File Coverage

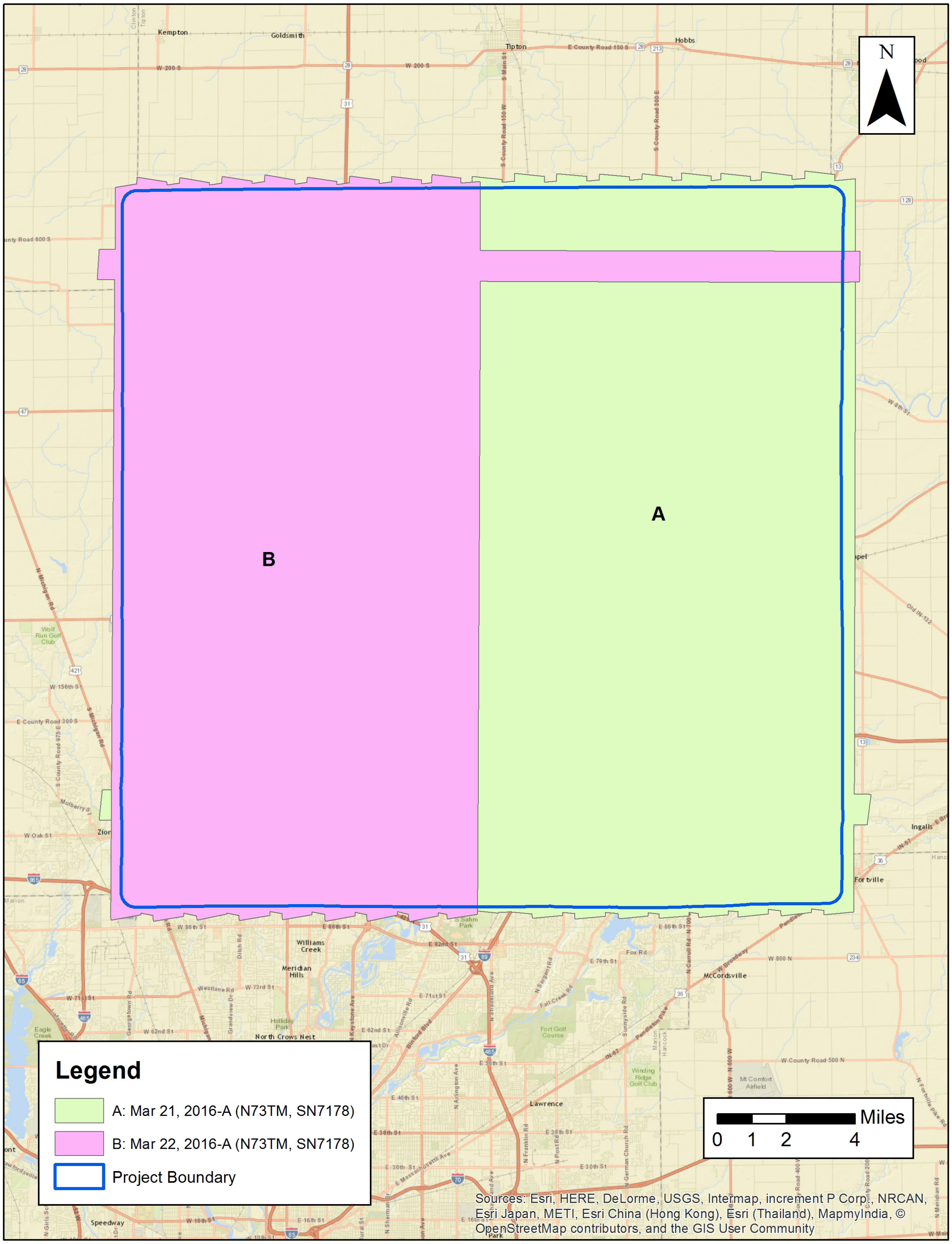
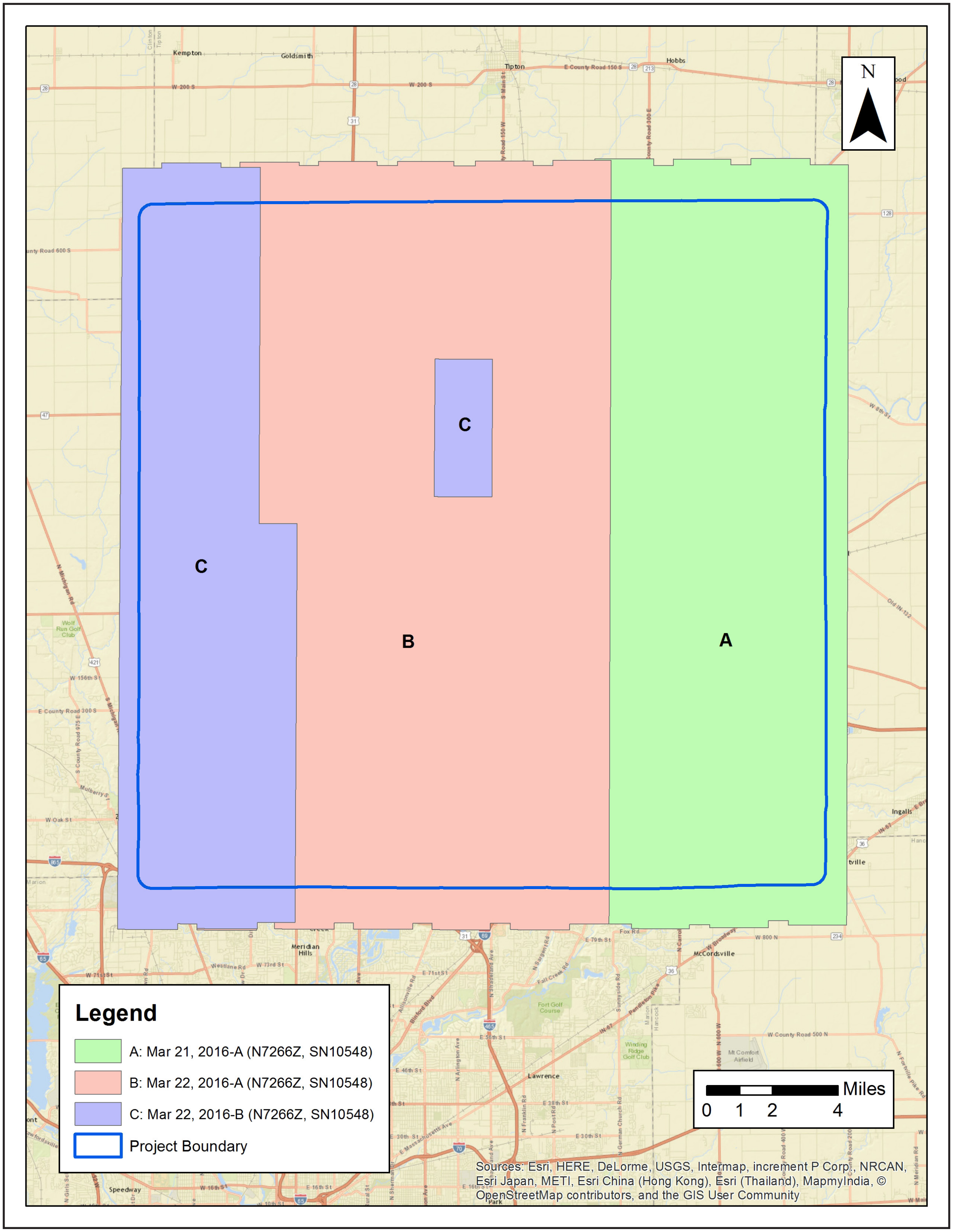


Figure 9. Ortho Frame Coverage



5. Ground Control and Check Point Collection

A field survey was completed of 39 ground control (calibration) points along with 53 blind QA points in Non-Vegetated and Vegetated land cover classifications (total of 92 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 1.2.

5.1. 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 32 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)/ASRPS Guidelines. See Figure 10.

5.2. 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 32 checkpoints located in bare earth and urban (non-vegetated) areas. See Figure 10.

2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for "brushlands/low trees" and "tall weeds/crops" land cover classes. The target VVA is: 29.4 cm at the 95th percentile, derived according to ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data, i.e., based on the 95th percentile error in all vegetated land cover classes combined. This is a target accuracy. The VVA was tested with 21 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 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	39
Raw NVA	0.196 m	0.104 m	32
NVA	0.196 m	0.095 m	32
VVA	0.294 m	0.206 m	21

5.3. Orthoimagery Calibration Control Point Testing

Figure 12 shows the location of each bare earth calibration point for the project area. Table 5 depicts the Control Report for the LiDAR bare earth calibration points, as computed in TerraScan as a quality assurance check.

The tested RMSEz was found to be 0.107 feet (0.033 meters). This meets the required RMSE value of 0.633 feet (0.100 meters) according to the National Standard for Spatial Database Accuracy (NSSDA), based on the final calibrated and controlled LiDAR swath data.

5.4. Orthoimagery Testing

Upon completion of all production activities and prior to delivery of the final orthophoto dataset, Quantum Spatial computed the overall accuracy of the orthophoto data set using 32 of the control points that were established for the project. The horizontal accuracy (RMSEr) was computed to be 0.32 feet (0.098 m). This meets the target of 2.20 feet (0.67 m).

Figure 10. QC Checkpoint Locations - NVA

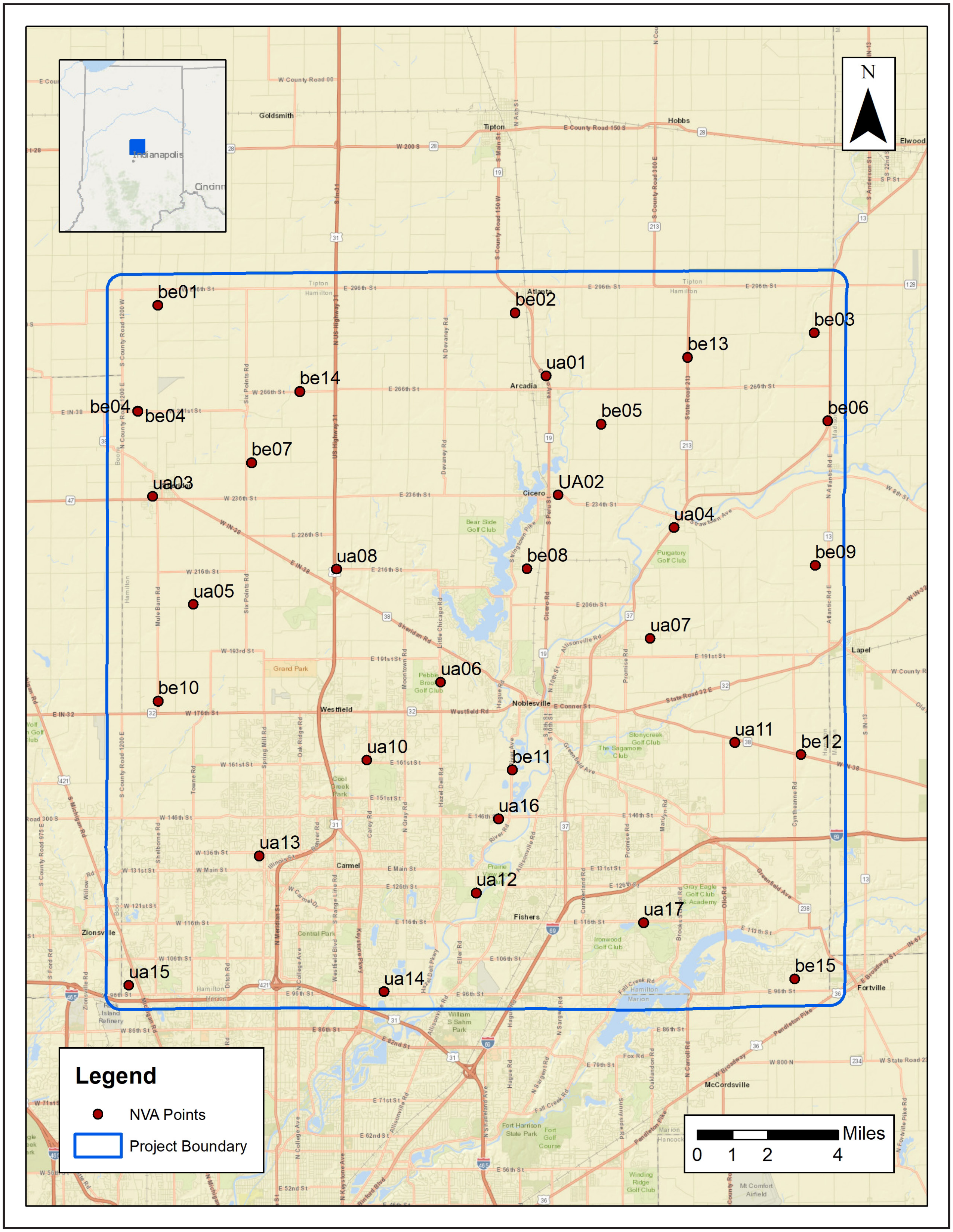


Figure 11. QC Checkpoint Locations - VVA

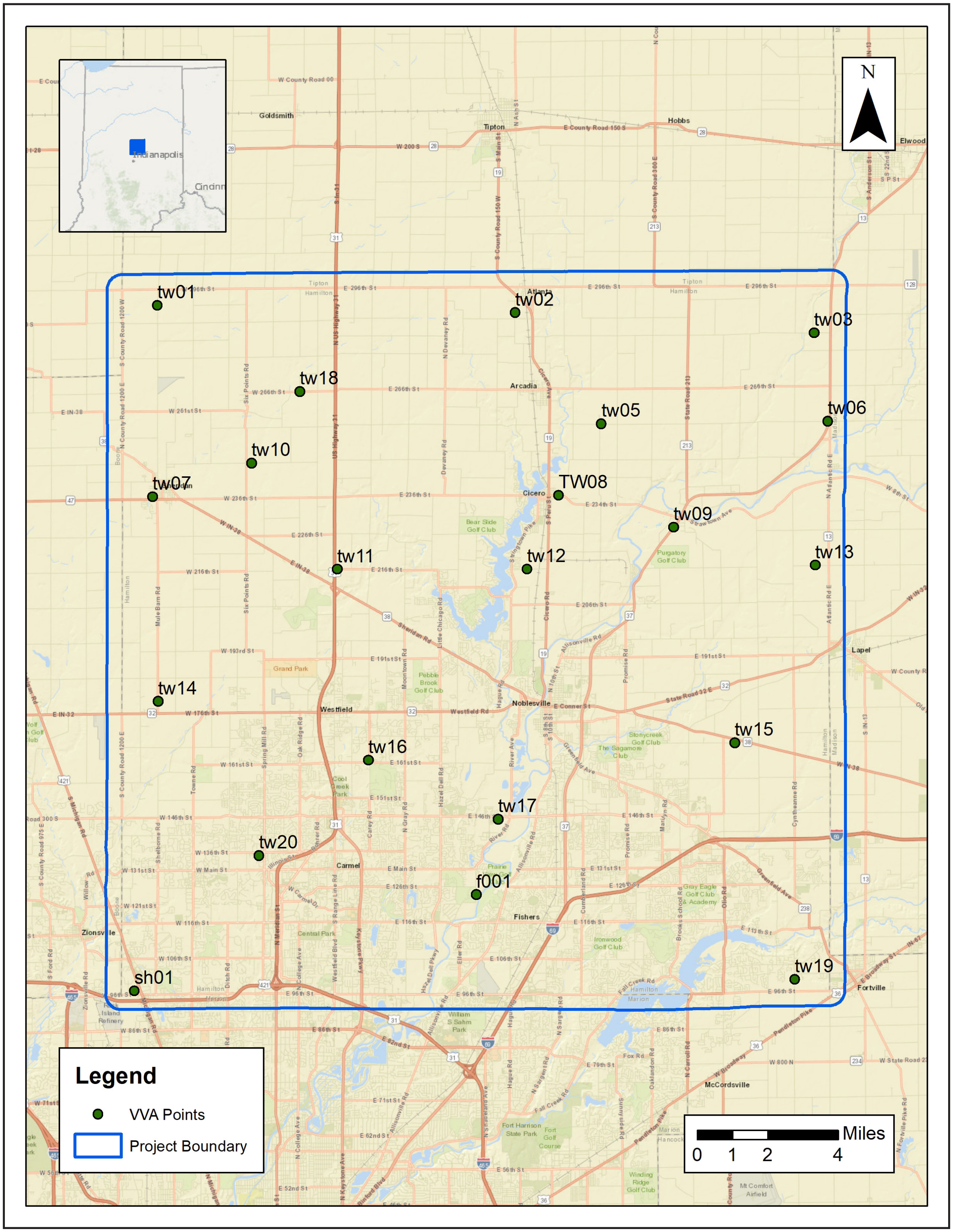


Figure 12. Calibration Control Point Locations

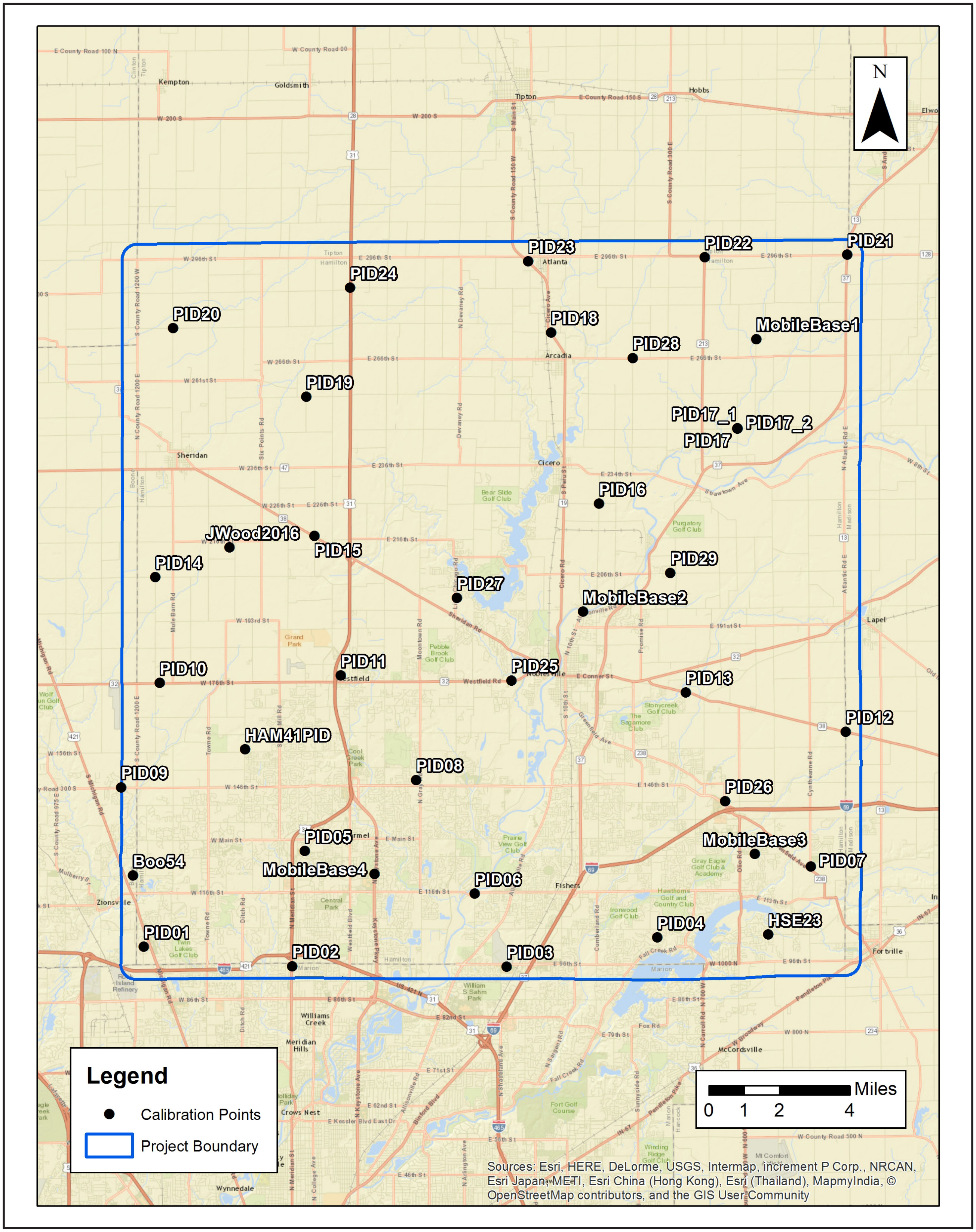


Table 5. Calibration Control Point Report

Units = US survey feet

Number	Easting	Northing	Known Z	Laser Z	Dz
Boo54	166570.37	1717602.27	900.76	900.85	0.09
HAM41PID	183372.71	1736478.86	915.19	915.11	-0.08
HSE23	261662.19	1708768.88	844.73	844.85	0.12
JWood2016	181014.21	1766688.76	949.07	949.10	0.03
MobileBase1	259926.05	1797905.00	823.28	823.41	0.13
MobileBase2	233975.19	1757108.71	759.18	759.15	-0.02
MobileBase3	259672.91	1720829.17	845.84	845.78	-0.06
MobileBase4	202771.62	1717832.65	829.49	829.48	-0.01
PID01	168205.39	1706936.33	889.59	889.61	0.02
PID02	190409.88	1704002.17	827.20	827.21	0.01
PID03	222525.29	1703936.57	810.97	810.99	0.02
PID04	245089.69	1708332.84	818.27	818.16	-0.11
PID05	192297.71	1721244.33	863.51	863.41	-0.10
PID06	217741.70	1714870.72	740.26	740.36	0.10
PID07	268079.23	1718960.70	849.46	849.51	0.05
PID08	208962.25	1731892.66	821.02	820.98	-0.04
PID09	164780.33	1730792.83	891.37	891.40	0.03
PID10	170589.65	1746410.06	915.39	915.34	-0.05
PID11	197699.78	1747530.49	893.68	893.62	-0.06
PID12	273322.59	1739112.55	867.01	867.27	0.26
PID13	249346.06	1745008.58	777.93	777.91	-0.02
PID14	169897.18	1762277.06	944.10	944.11	0.01
PID15	193758.05	1768425.59	927.93	927.90	-0.03
PID16	236332.52	1773261.29	810.73	810.77	0.04
PID17	257086.44	1784512.50	815.31	815.46	0.15
PID17_1	257097.15	1784537.70	816.06	816.16	0.10
PID17_2	257101.68	1784510.80	815.17	815.34	0.17
PID18	229180.35	1798905.42	863.01	862.83	-0.18
PID19	192500.37	1789264.99	910.61	910.76	0.15
PID20	172551.98	1799556.05	935.11	935.00	-0.11
PID21	273536.65	1810541.96	830.98	831.03	0.05
PID22	252161.43	1810134.55	857.12	857.11	-0.01

Number	Easting	Northing	Known Z	Laser Z	Dz
PID23	225721.57	1809562.29	863.54	863.82	0.28
PID24	199098.75	1805609.36	911.69	911.54	-0.15
PID25	223244.08	1746787.39	788.36	788.22	-0.14
PID26	255271.96	1728727.47	830.64	830.58	-0.06
PID27	215063.62	1759131.75	832.24	832.20	-0.04
PID28	241398.19	1795061.95	849.47	849.30	-0.17
PID29	247049.94	1762898.24	807.98	808.02	0.04

Average Dz	0.01 ft
Minimum Dz	-0.176 ft
Maximum Dz	0.282 ft
Root Mean Square	0.107 ft
Std. Deviation	0.108 ft

Figure 13. Photo Checkpoint Locations

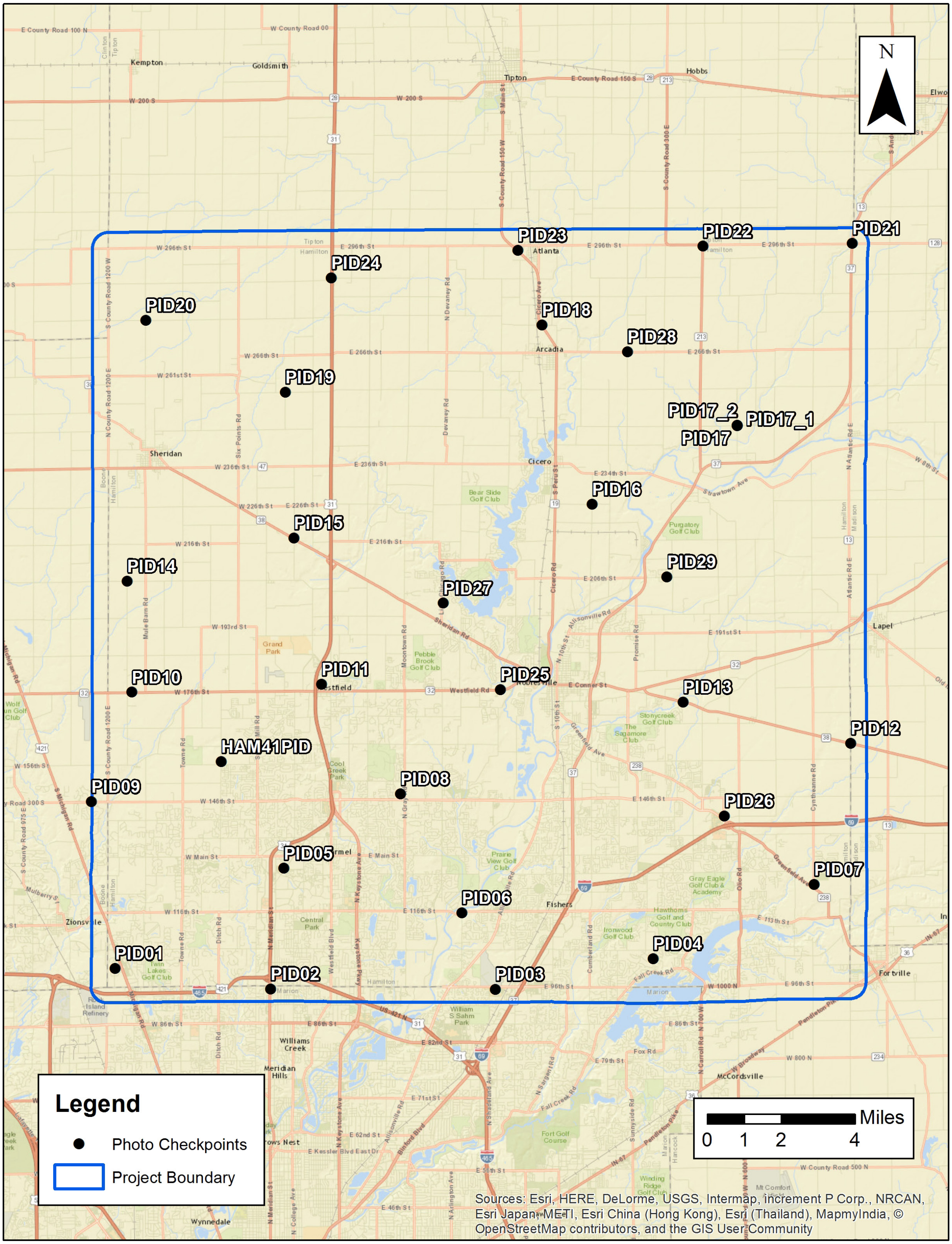


Table 6. Photo Checkpoint Report

Units = US survey feet

	Control		Image		Delta		
Number	Easting	Northing	Easting	Northing	East	North	Horiz
HAM41PID	183372.707	1736478.857	183372.52	1736478.7	0.19	0.16	0.24
PID01	168205.391	1706936.328	168205.57	1706936.13	-0.18	0.20	0.27
PID02	190409.876	1704002.174	190409.83	1704002.45	0.05	-0.28	0.28
PID03	222525.291	1703936.568	222525.04	1703936.77	0.25	-0.20	0.32
PID04	245089.688	1708332.844	245089.37	1708333.26	0.32	-0.42	0.52
PID05	192297.707	1721244.33	192297.31	1721244.62	0.40	-0.29	0.49
PID06	217741.696	1714870.715	217741.28	1714870.86	0.42	-0.15	0.44
PID07	268079.226	1718960.696	268079.12	1718960.72	0.11	-0.02	0.11
PID08	208962.25	1731892.66	208962.18	1731892.51	0.07	0.15	0.17
PID09	164780.326	1730792.829	N/A	N/A	-	-	-
PID10	170589.648	1746410.062	170589.43	1746409.95	0.22	0.11	0.25
PID11	197699.781	1747530.492	197699.43	1747530.45	0.35	0.04	0.35
PID12	273322.585	1739112.554	273322.81	1739112.61	-0.22	-0.06	0.23
PID13	249346.061	1745008.578	249346.4	1745008.65	-0.34	-0.07	0.35
PID14	169897.178	1762277.063	169897.07	1762277.27	0.11	-0.21	0.23
PID15	193758.054	1768425.589	193757.97	1768425.66	0.08	-0.07	0.11
PID16	236332.524	1773261.287	236332.19	1773260.98	0.33	0.31	0.45
PID17	257086.44	1784512.499	257086.74	1784512.65	-0.30	-0.15	0.34
PID17_1	257097.154	1784537.695	257097.12	1784537.76	0.03	-0.06	0.07
PID17_2	257101.68	1784510.802	257101.47	1784510.59	0.21	0.21	0.30
PID18	229180.348	1798905.419	229179.82	1798905.31	0.53	0.11	0.54
PID19	192500.372	1789264.994	192500.5	1789265.2	-0.13	-0.21	0.24
PID20	172551.979	1799556.048	172551.81	1799556.14	0.17	-0.09	0.19
PID21	273536.651	1810541.96	273536.78	1810542.08	-0.13	-0.12	0.18
PID22	252161.43	1810134.547	252161.17	1810134.83	0.26	-0.28	0.38
PID23	225721.567	1809562.294	N/A	N/A	-	-	-
PID24	199098.745	1805609.361	199098.35	1805609.52	0.39	-0.16	0.43
PID25	223244.08	1746787.39	223243.76	1746787.22	0.32	0.17	0.36
PID26	255271.964	1728727.465	255271.88	1728727.17	0.08	0.30	0.31
PID27	215063.622	1759131.751	215063.66	1759131.8	-0.04	-0.05	0.06

	Control		Image		Delta		
Number	Easting	Northing	Easting	Northing	East	North	Horiz
PID28	241398.186	1795061.952	241397.95	1795061.86	0.24	0.09	0.25
PID29	247049.935	1762898.235	247049.71	1762898.53	0.23	-0.29	0.37

RMSE Easting	0.26 ft
RMSE Northing	0.19 ft
RMSE r	0.32 ft
Accuracy r	0.55 ft