University of Illinois
LiDAR 2018-Data Acquisition & Processing Boone & Winnebago Counties (U18049)
Lidar Mapping Report

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Submitted By:

MERRICK®

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Glossary of Terms

Term	Description
AGL	Above Ground Level
AGPS	Airborne Global Positioning System
ANPD	Aggregate Nominal Pulse Density
ANPS	Aggregate Nominal Pulse Spacing
ASPRS	American Society of Photogrammetry and Remote Sensing
AT	Aerial Triangulation
CD	Compact Disk
CMS	Certified Mapping Scientist
CORS	Continuous Operating Reference Station
CP	Certified Photogrammetrist
CVA	Consolidated Vertical Accuracy
DACS™	Digital Airborne Camera System
DEM	Digital Elevation Model
DFIRM	Digital Flood Insurance Rate Maps
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVD	Digital Versatile Disk / Digital Video Disk
DXF	Data Exchange Format / Drawing Interchange
FIRM	Flood Insurance Rate Maps
FEMA	Federal Emergency Management
FGDC	Federal Geographic Data Committee
FVA	Fundamental Vertical Accuracy
FY	Fiscal Year
GIS	Geographic Information System
GISP	Geographic Information System Professional
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSD	Ground Sample Distance
HARN	High Accuracy Reference Network
HDD	Hard Drive Disk
HPGN	High Precision Geodetic Network
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
LAS	(or .las) – industry accepted LIDAR data exchange file format
LB	License Business
LS	Land Surveyor
LiDAR	(or Lidar) Light Detection And Ranging
MARS®	Merrick Advanced Remote Sensing
Merrick	Merrick & Company
MSL	Mean Sea Level
NAD	North American Datum
NDEP	National Digital Elevation Program
NGP	National Geospatial Program
NGS	National Geodetic Survey
NMAS	National Map Accuracy Standards
No.	Number
NPS	Nominal Point Spacing

NSRS	National Spatial Reference System
NSSDA	National Standard for Spatial Data
NVA	Non-vegetated Vertical Accuracy
OPUS	Online Positioning User Service
PDOP	Positional Dilution Of Precision
PLS	Professional Land Surveyor
PLSS	Public Land Survey System
ppsm	Points (or pulses) per square meter
PSM	Professional Surveyor and Mapper
QL1	Quality Level One
QL2	Quality Level Two
RLS	Registered Land Surveyor
RGB	Red, Green, Blue (i.e., three-band image)
RGBNIR	Red, Green, Blue, Near Infra-Red (i.e., four-band image)
RMSE	Root Mean Square Error
SBET	Smoothed Best Estimated Trajectory
SHA	Secured Hash Standard
SPCS	State Plane Coordinate System
SVA	Supplemental Vertical Accuracy
TIN	Triangular Irregular Network
USGS	United State Geological Survey
VVA	Vegetated Vertical Accuracy
XML	eXtensible Markup Language

Project Summary

Merrick was awarded the Data Acquisition & Processing Boone & Winnebago Counties (U18049) project to provide high fidelity lidar mapping for Boone and Winnebago Counties commencing in the Spring of 2018. The area that comprises Boone and Winnebago Counties is approximately 860 square miles. Services included lidar acquisition, ground control survey, lidar post-processing, lidar classification, hydro-flattening, QA/QC, and development of derivative deliverable products.

The lidar mapping requirements and deliverables meet Quality Level Two (QL2) standards for final deliverables as outlined in the USGS-NGP Lidar Base Specifications, Techniques and Methods 11–B4, Version 1.3, November 2014 (TM11-B4) (http://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). QL2 lidar specifications suggest a pulse density of greater than or equal to two pulses per square meter (≥2ppsm) Aggregate Nominal Pulse Density (ANPD), and pulse spacing of less than or equal to seventy-one centimeters (≤0.71m) Aggregate Nominal Pulse Spacing (ANPS). For this project, the point density specification was modified to produce an Aggregate Nominal Point Density (ANPD) of greater than or equal to four points per square meter (≥4ppsm), or less than or equal to five-tenths of a meter (≤0.50m) Aggregate Nominal Point Spacing (ANPS).

The vertical accuracy requirements of the lidar data meets or exceeds the following:

> Absolute Vertical Accuracy
> - ≤10cm RMSEz
> - ≤19.6cm Non-vegetated Vertical Accuracy (NVA) at the 95% confidence level
> - ≤29.4cm Vegetated Vertical Accuracy (VVA) at the 95% percentile

Project Boundary Parameters
- Winnebago County, IL
  - Full extent of Esri shapefile *Winn_TileIndex*
  - Approximately 554.55 square miles
  - 3,865 tiles formatted as 2,000' x 2,000'
- Boone County, IL
  - Full extent of Esri shapefile *Boone_TileIndex*
  - Approximately 303.03 square miles
  - 2,112 tiles formatted as 2,000' x 2,000'

Project Spatial Reference
- Horizontal Datum – North American Datum of 1983 (NAD 83)
- Epoch – National Adjustment of 2011 (NA2011) (epoch 2010.00)
- Geoid – GEOID 12B
- Vertical Datum – North American Vertical Datum of 1988 (NAVD 88)
- Projection – Illinois State Plane Coordinate System, East Zone (Boone County) and West Zone (Winnebago County)
- Units – U.S. Survey Foot

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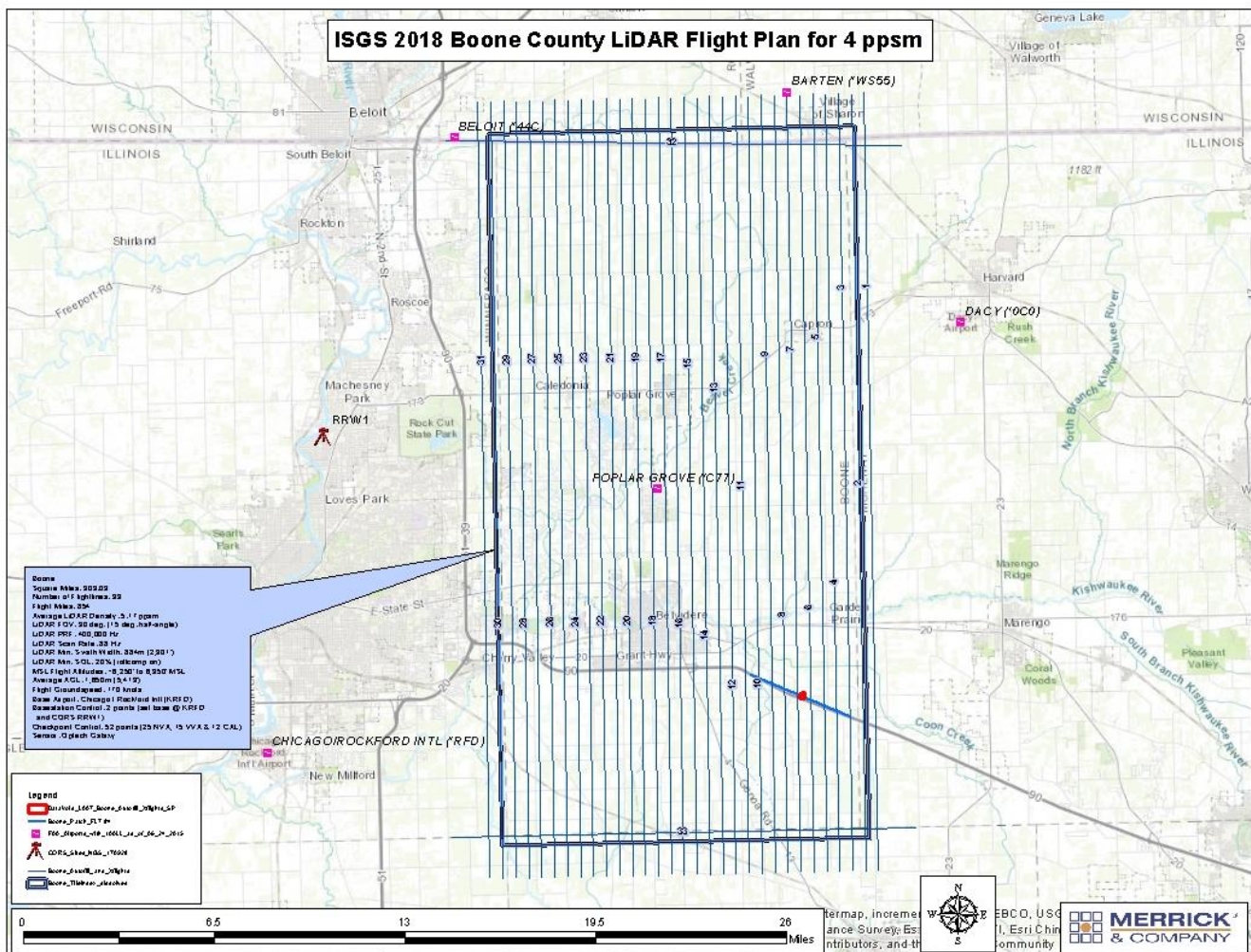> Doug.jacoby@merrick.com

The contents of this report summarize the methods used to calibrate and classify the lidar data as well as the results of these methods for the project U18049.
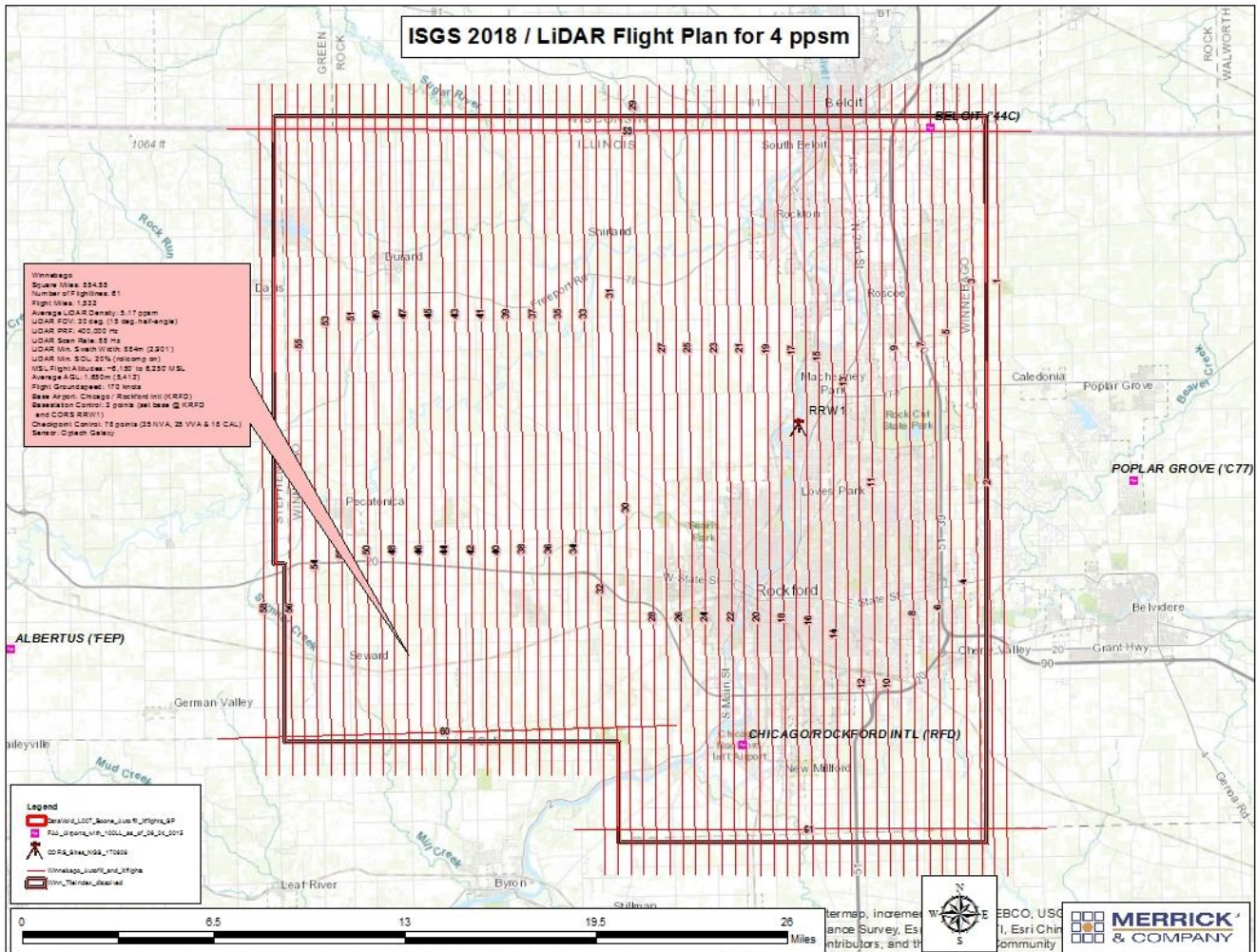
Lidar Flight Information

The acquisition area for the U18049 project is delineated by the extent of the client-approved Esri shapefiles and cover full tiles. Merrick acquired the lidar point cloud utilizing an Optech Galaxy lidar sensor. The Galaxy is a high performance 550 kHz lidar sensor capable of collecting large areas efficiently.

Merrick planned an acquisition area to include a proper flight line orientation and numbers for accurate sensor calibration. See below illustration of the proposed lidar flight plan.

Boone County

ISGS 2018 Boone County LiDAR Flight Plan for 4 ppsm

Winnebago County

ISGS 2018 / LiDAR Flight Plan for 4 ppsm

Winnebago
Square Miles: 554.55
Number of Flightlines: 61
Flight Miles: 1,532
Average LiDAR Density: 3.17 ppsm
LiDAR FOV: 20 deg. (13 deg. half-angle)
LiDAR PRF: 400,000 Hz
LiDAR Scan Rate: 55 Hz
LiDAR Min. Swath Width: 554m (2,901')
LiDAR Min. SOL 20% (rollcomp on)
MSL Flight Altitudes: ~6,150 to 6,250 MSL
Average AGL: 1,650m (5,413')
Flight Groundspeed: 172 knots
Base Airport: Chicago / Rockford Intl (KRFD)
Basestation Control: 2 points (set base @ KRFD and CORS RRW1)
Checkpoint Control: 78 points (35 NVA, 25 VVA & 18 CAL)
Sensor: Optech Galaxy

Airports of Operation

Centennial airport was used for the collection of this project. See below for a list of the airports used as well as an image of the project area with airport(s) displayed.

- Chicago/Rockford International Airport – Chicago/Rockford, Illinois
    - FAA Identifier: RFD
    - Lat/Long: 42-11-43.3000N / 089-05-50.0000W
    - Elevation: 742 ft. / 226.2 m (surveyed)
    - From City: 68 miles NW of central business district of the associated city
    - Zip Code: 61109
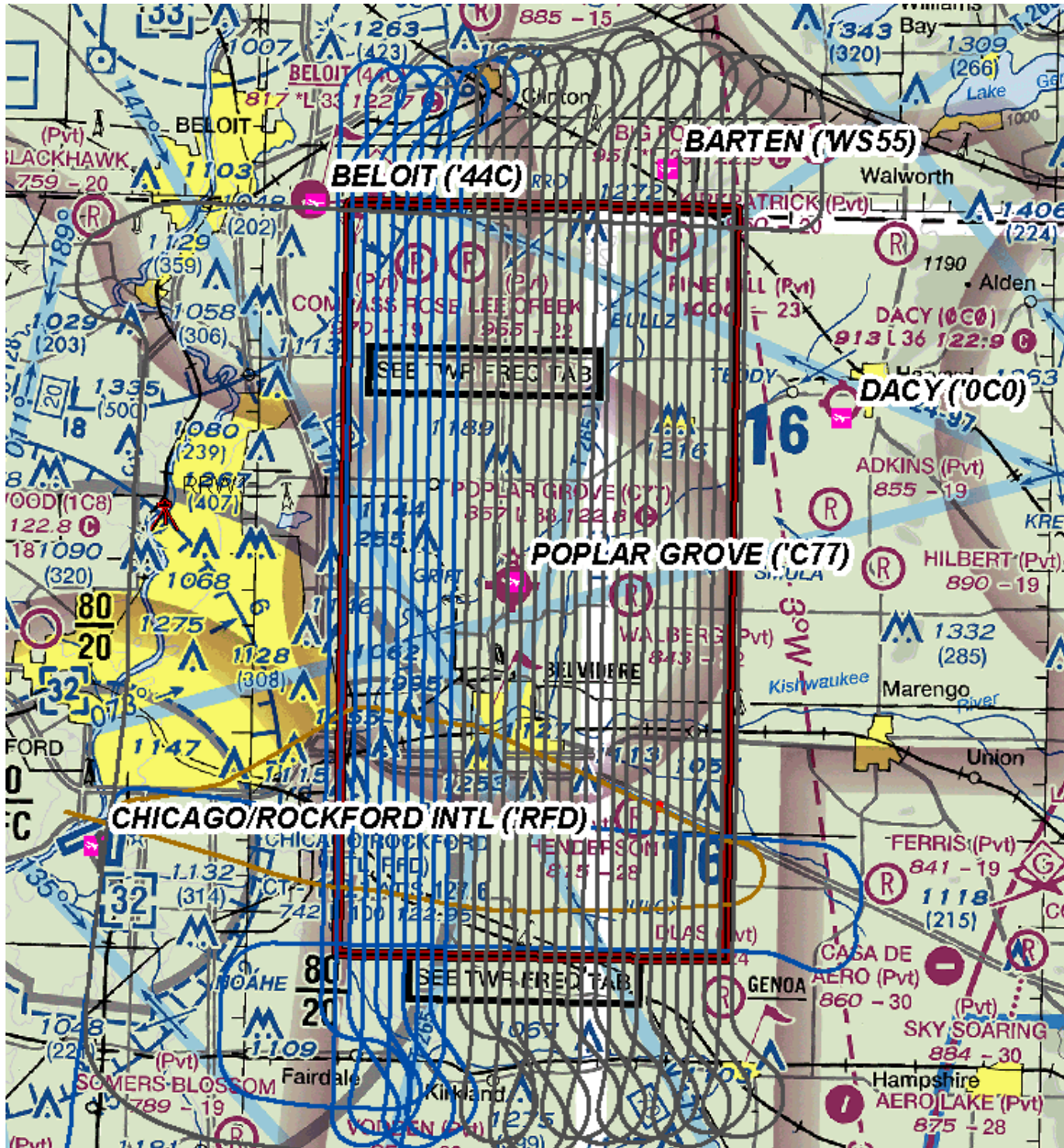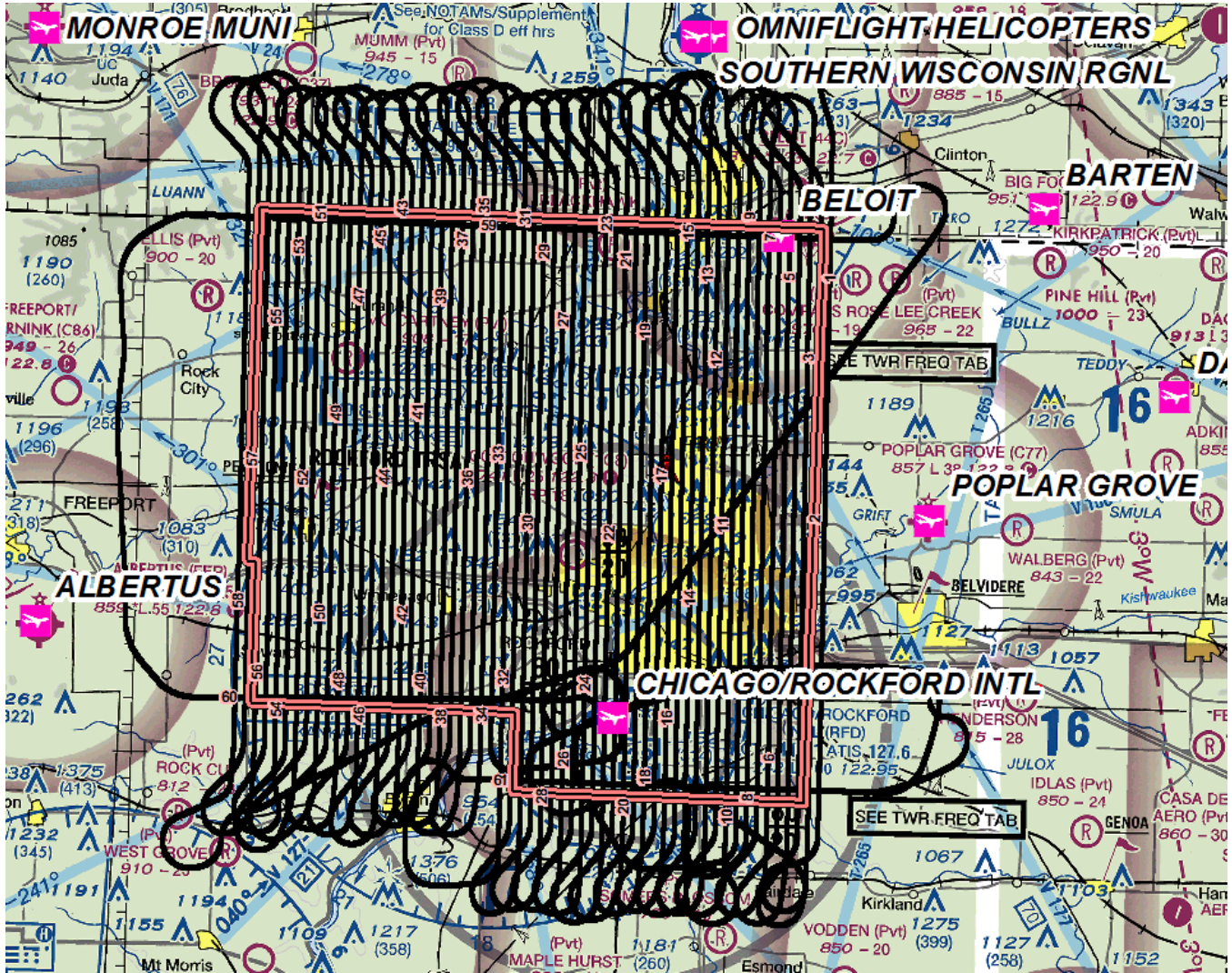
Aerial Mission(s) Duration / Time

Merrick's lidar acquisition was collected using a fixed wing aircraft and an Optech Galaxy lidar sensor. Data collection for the project was accomplished between April 22, 2018 and April 28, 2018. Each mission represents a lift of the aircraft and system from the ground, collects data, and lands again. Multiple lifts within a day are represented by Mission A, B, C, and D. The table below relates each mission to the date collected, the sensor and serial number used, the start/end time and the actual average MSL in meters. The time is shown in GPS seconds of the week.

Boone County

Mission(s)	Date	Sensor S/N	Start Time GPS sec.	End Time GPS sec.	Actual Avg. MSL (ft)
180424_A	April 24, 2018	5060385	224847	243452	6266
180425_A	April 25, 2018	5060385	308366	318920	6289
180428_A	April 28, 2018	5060385	569985	571836	6168

<u>Winnebago County</u>

Mission(s)	Date	Sensor S/N	Start Time GPS sec.	End Time GPS sec.	Actual Avg. MSL (ft)
180422_A	April 22, 2018	5060385	51110	73144	6266
180423_A	April 23, 2018	5060385	136437	156944	6184
180423_B	April 23, 2018	5060385	159206	167426	6250

GNSS / IMU Data

A five-minute INS initialization is conducted on the ground, with the aircraft engines running, prior to flight, to establish fine-alignment of the INS. GPS ambiguities are resolved by flying within ten kilometers of the base stations. During the data collection, the operator recorded information on log sheets which includes weather conditions, lidar operation parameters, and flight line statistics. Near the end of the mission, GPS ambiguities were again resolved by flying within ten kilometers of the base stations to aid in post-processing. Data is sent back to the main office for preliminary processing to check overall quality of GPS / INS data and to ensure sufficient overlap between flight lines. Any problematic data may be re-flown immediately as required.

The airborne GPS data was post-processed using Applanix POSPac Mobile Mapping Suite version 8.x. A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. Whenever practical, lidar acquisition was limited to periods when the PDOP was less than 4.0. PDOP indicates satellite geometry relating to position. Generally, PDOP's of 4.0 or less result in a good quality solution, however PDOP's between 4.0 and 5.0 can still yield good results most of the time. PDOP's over 6.0 are of questionable results and PDOP's of over 7.0 usually result in a poor solution. Usually as the number of satellites increase the PDOP decreases. Other quality control checks used for the GPS include analyzing the combined separation of the forward and reverse GPS processing from one base station and the results of the combined separation when processed from two different base stations. An analysis of the number of satellites, present during the flight and data collection times, is also performed.

The GPS trajectory was combined with the raw IMU data and post-processed using POSPac Mobile Mapping Suite version 8.x. The SBET and refined attitude data are then utilized in the LMS Post Processor to compute the laser point-positions – the trajectory is combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points. Up to four return values are produced within the Optech LMS processor software for each pulse which ensures the greatest chance of ground returns in a heavily forested area.

GPS Controls

Ground GNSS Base Stations were set up to control the lidar airborne flight lines. In addition, CORS are at times used to further enhance the airborne solution. The ground GNSS Base Stations coordinates were obtained from NGS OPUS solutions. CORS coordinates were obtained from NGS datasheets.

Lidar Calibration – see appendix 1 for a more detailed workflow description

Merrick takes great care to ensure all lidar acquisition missions are carried out in a manner conducive to post-processing an accurate data set. This begins in the flight-planning stage with attention to GPS baseline distances and GPS satellite constellation geometry and outages. Proper AGPS surveying techniques are always followed including pre- and post-mission static initializations. In-air IMU alignments (figure-eights) are performed both before and after on-site collection to ensure proper calibration of the IMU accelerometers and gyros.
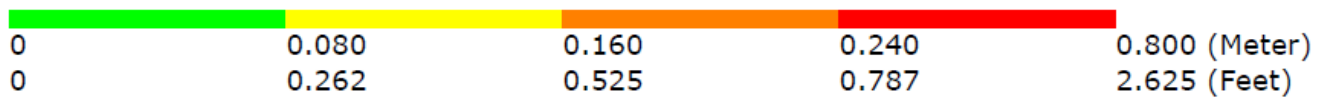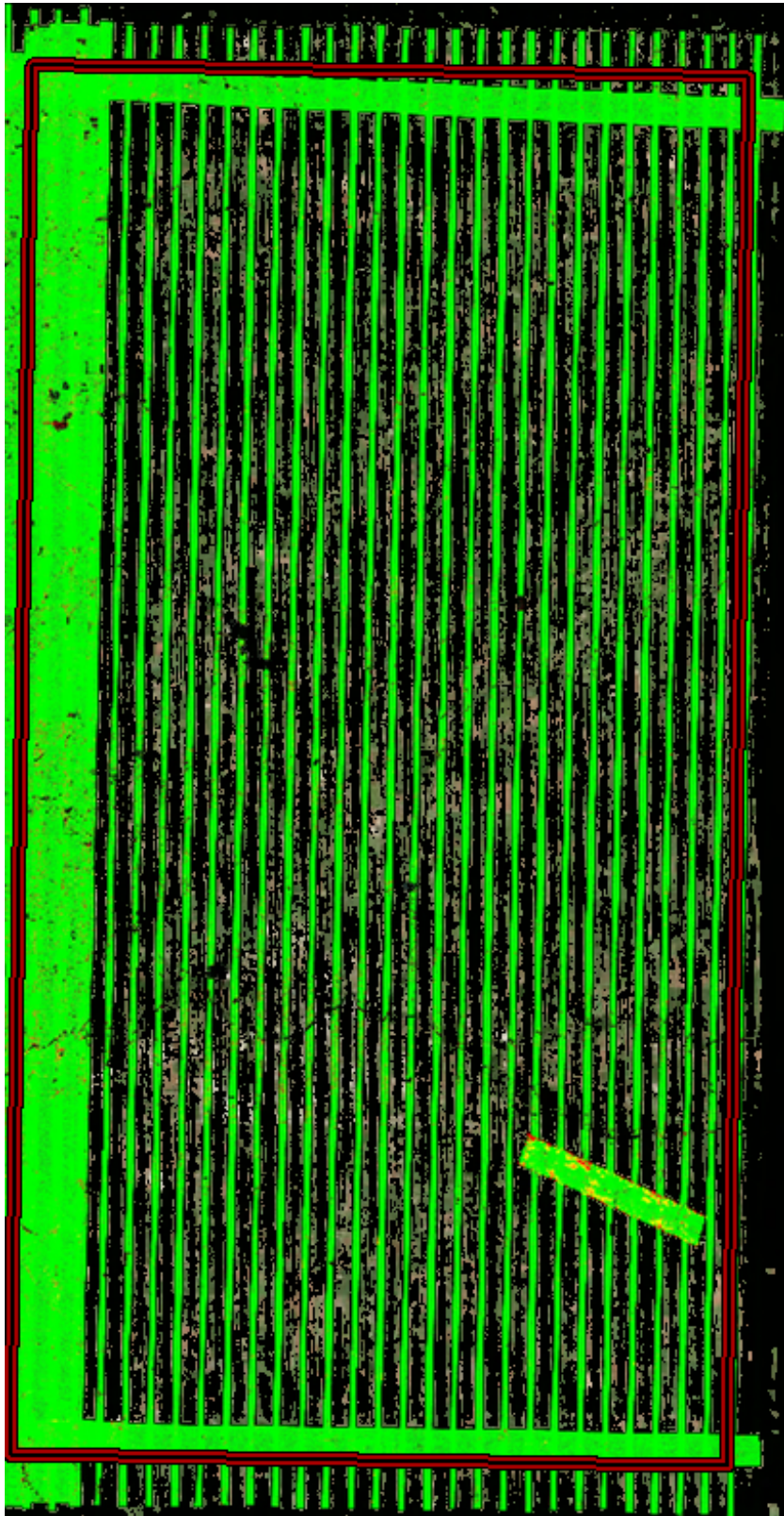
A minimum of one cross-flight is planned throughout the project area across all flightlines and over roadways where possible. The cross-flight provides a common control surface used to remove any vertical discrepancies in the lidar data between flightlines. The cross-flight is critical to ensure flightline ties across the project area. The areas of overlap between flightlines are used to boresight (calibrate) the lidar point cloud to achieve proper flightline to flightline alignment in all three axes. This includes adjustment of both IMU and scanner-related variables such as roll, pitch, heading, timing interval (range), and torsion. Each lidar mission flown is accompanied by a hands-on boresight in the office.
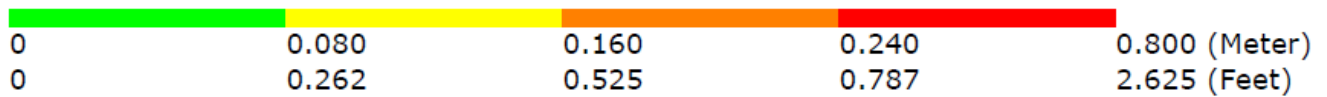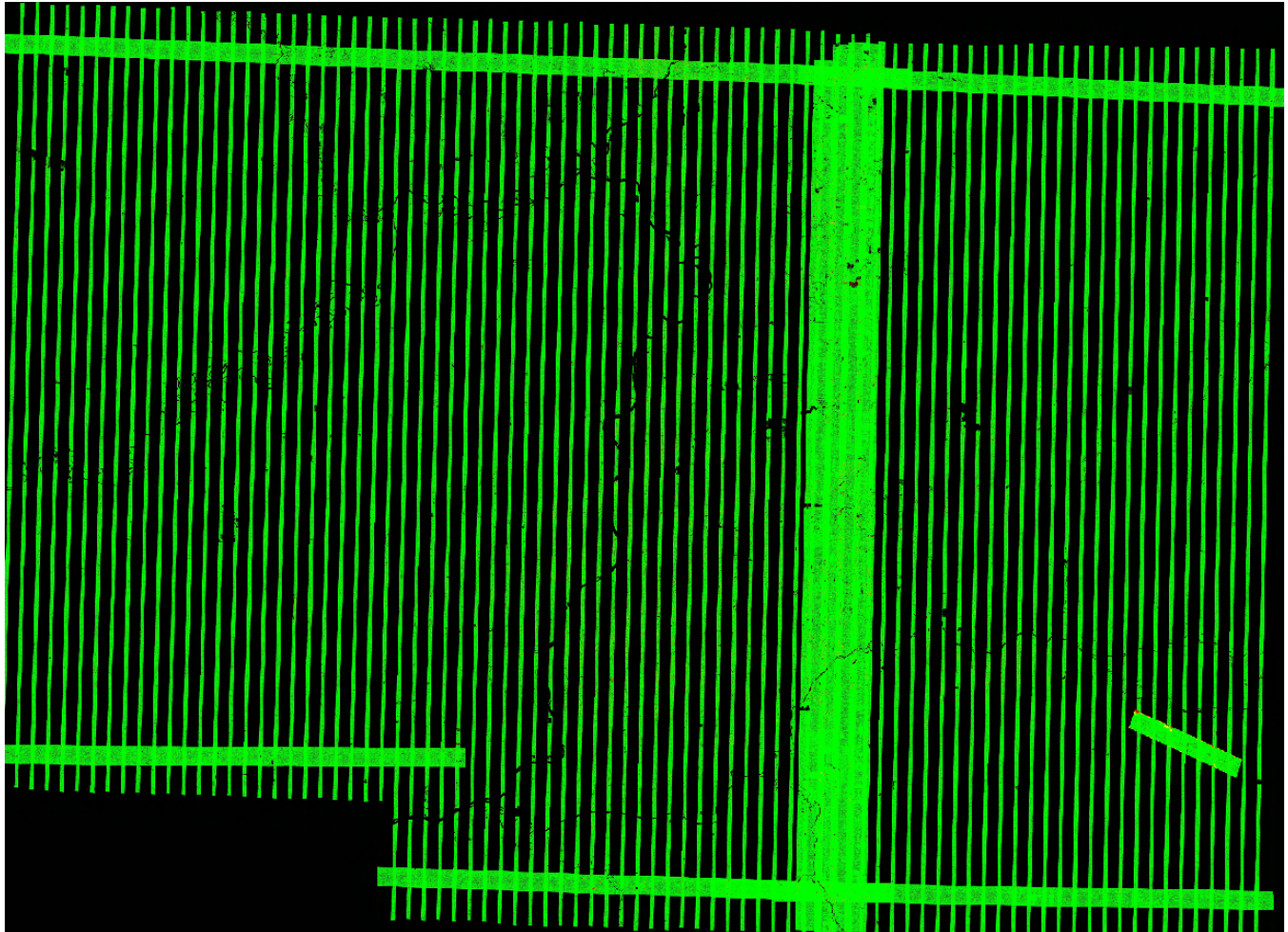
After boresighting is complete a detailed statistical report is generated to check relative and absolute accuracies before filtering of lidar begins.

Relative Accuracy – flight line to flight line

The project representative flight line separation raster examples (below) depict the vertical separation of flight lines by thematically coloring the separation magnitude on a color ramp based on relative distance.

| 0 | | 0.080 | | 0.160 | | 0.240 | | 0.800 (Meter) |
| 0 | | 0.262 | | 0.525 | | 0.787 | | 2.625 (Feet) |

Winnebago County

| 0 | 0.080 | 0.160 | 0.240 | 0.800 (Meter) |
| 0 | 0.262 | 0.525 | 0.787 | 2.625 (Feet) |

Unfiltered Lidar Control Point Report

The following tables illustrate the results of the lidar data compared to the lidar control points post-calibration. The listing is sorted by the Z Error column showing, in ascending order, the vertical difference between the lidar points and the twelve (12) surveyed ground points for Boone Count and seventeen (17) for Winnebago County used for lidar calibration.

Boone County

Project Data Unit: U.S. Survey Foot
Vertical Accuracy Class tested: 10.0-cm
Elevation Calculation Method: Interpolated from TIN
LiDAR Classifications Included: 0-255

Check Points in Report: 12
Check Points with LiDAR Coverage: 12
Check Points (NVA): 12
Check Points (VVA): 0
Average Vertical Error Reported: -0.023 U.S. Survey Foot
Maximum (highest) Vertical Error Reported: 0.138 U.S. Survey Foot
Median Vertical Error Reported: -0.033 U.S. Survey Foot
Minimum (lowest) Vertical Error Reported: -0.147 U.S. Survey Foot
Standard deviation of Vertical Error: 0.076 U.S. Survey Foot
Skewness of Vertical Error: 0.411
Kurtosis of Vertical Error: -0.024
Non-vegetated Vertical Accuracy (NVA) RMSE(z): 2.322cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/-: 4.551cm PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-: 4.551cm
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM): 2.917cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- (DEM): 5.717cm PASS

This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10.0-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 2.322cm, equating to +/- 4.551cm at the 95% confidence level.

Checkpoint Id	Checkpoint X	Checkpoint Y	Coverage	Checkpoint Z	Z from lidar	Z Error
1701	878216.298	2051862.416	Yes	802.587	802.542	-0.045
1702	844556.751	2106307.521	Yes	984.168	984.118	-0.05
1703	878294.244	2115207.6	Yes	994.194	994.235	0.041
1704	827200.679	2073970.266	Yes	930.438	930.452	0.014
1705	880934.847	2062311.178	Yes	858.895	859.033	0.138
1706	881174.874	2001440.504	Yes	839.84	839.82	-0.02
1707	853234.96	2027282.822	Yes	865.417	865.435	0.018
1708	839093.207	2001447.861	Yes	806.218	806.145	-0.073
1709	867665.682	2048855.805	Yes	813.934	813.787	-0.147
1710	867714.141	2060979.104	Yes	828.527	828.417	-0.11
1711	841570.664	2078251.699	Yes	925.934	925.872	-0.062
1712	822424.283	2037259.08	Yes	759.715	759.739	0.024

Winnebago County

Project Data Unit: U.S. Survey Foot
Vertical Accuracy Class tested: 10.0-cm
Elevation Calculation Method: Interpolated from TIN
LiDAR Classifications Included: 0-255

Check Points in Report: 17
Check Points with LiDAR Coverage: 17
Check Points (NVA): 17
Check Points (VVA): 0
Average Vertical Error Reported: 0.022 U.S. Survey Foot
Maximum (highest) Vertical Error Reported: 0.192 U.S. Survey Foot
Median Vertical Error Reported: 0.011 U.S. Survey Foot
Minimum (lowest) Vertical Error Reported: -0.092 U.S. Survey Foot
Standard deviation of Vertical Error: 0.081 U.S. Survey Foot
Skewness of Vertical Error: 0.471
Kurtosis of Vertical Error: -0.770
Non-vegetated Vertical Accuracy (NVA) RMSE(z): 2.492cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/-: 4.884cm PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-: 4.884cm
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM): 2.750cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- (DEM): 5.391cm PASS

This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10.0-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 2.492cm, equating to +/- 4.884cm at the 95% confidence level.

Checkpoint Id	Checkpoint X	Checkpoint Y	Coverage	Checkpoint Z	Z from lidar	Z Error
702	2533110.532	2121031.331	Yes	765.262	765.375	0.113
703	2515482.884	2033121.806	Yes	889.684	889.783	0.099
704	2543809.592	2074195.792	Yes	738.991	739.067	0.076
705	2504566.79	2110973.087	Yes	854.12	854.174	0.054
706	2564403.879	2096584.617	Yes	734.895	734.844	-0.051
707	2526234.772	2024355.091	Yes	878.654	878.846	0.192
708	2618573.658	2005409.968	Yes	772.475	772.486	0.011
709	2592555.401	2118016.771	Yes	774.148	774.097	-0.051
710	2614874.282	2115081.598	Yes	788.445	788.414	-0.031
711	2603308.791	2060859.911	Yes	751.48	751.388	-0.092
712	2618093.152	2028687.891	Yes	795.689	795.715	0.026
713	2591548.646	2078643.619	Yes	786.295	786.238	-0.057
714	2515481.441	2072721.842	Yes	852.668	852.8	0.132
715	2514916.186	2062187.265	Yes	743.398	743.407	0.009
716	2565576.381	2031710.34	Yes	838.115	838.074	-0.041
717	2573588.792	2004229.863	Yes	714.847	714.898	0.051
718	2623073.36	2087719.046	Yes	898.173	898.102	-0.071

Lidar Control Point Layout
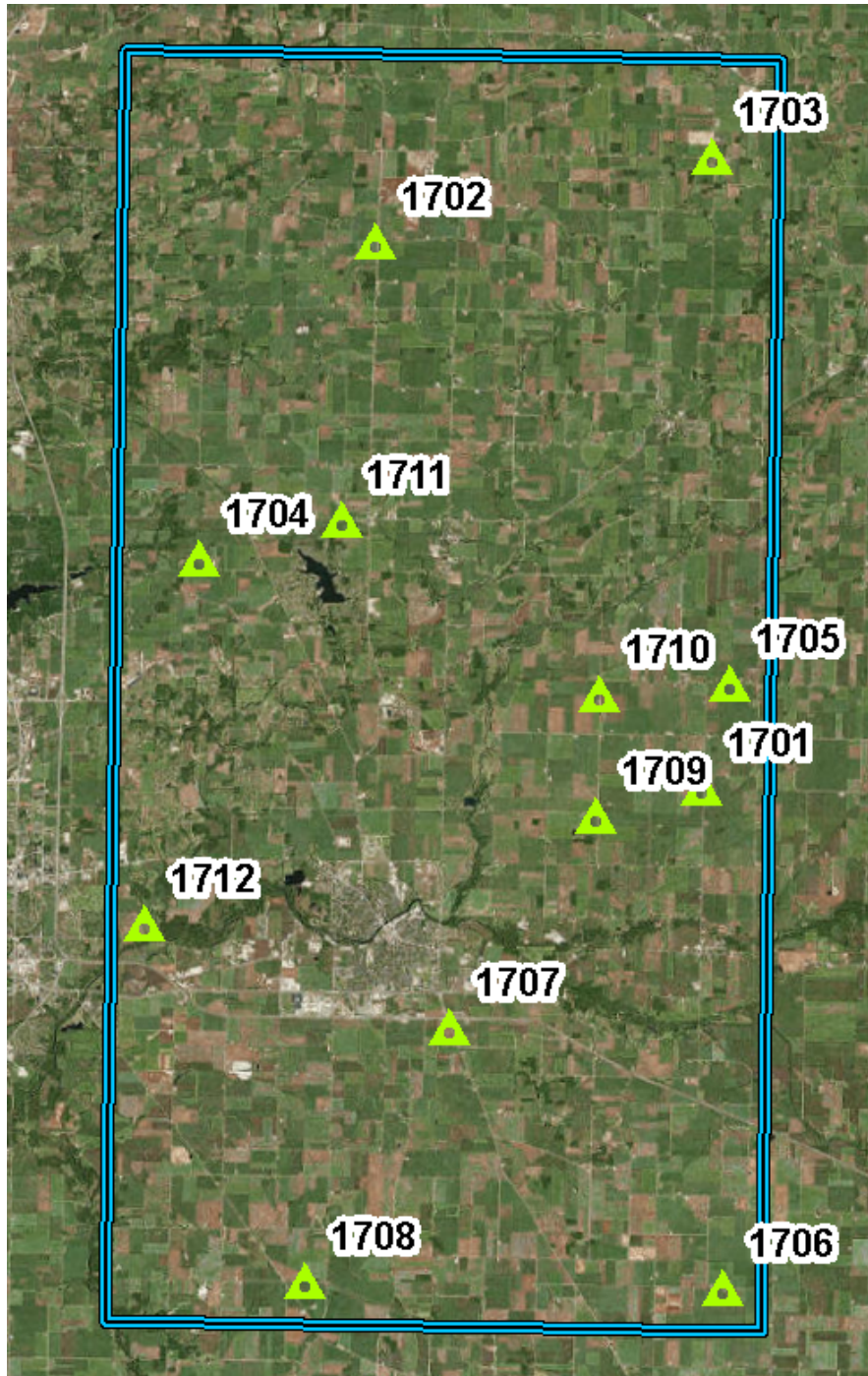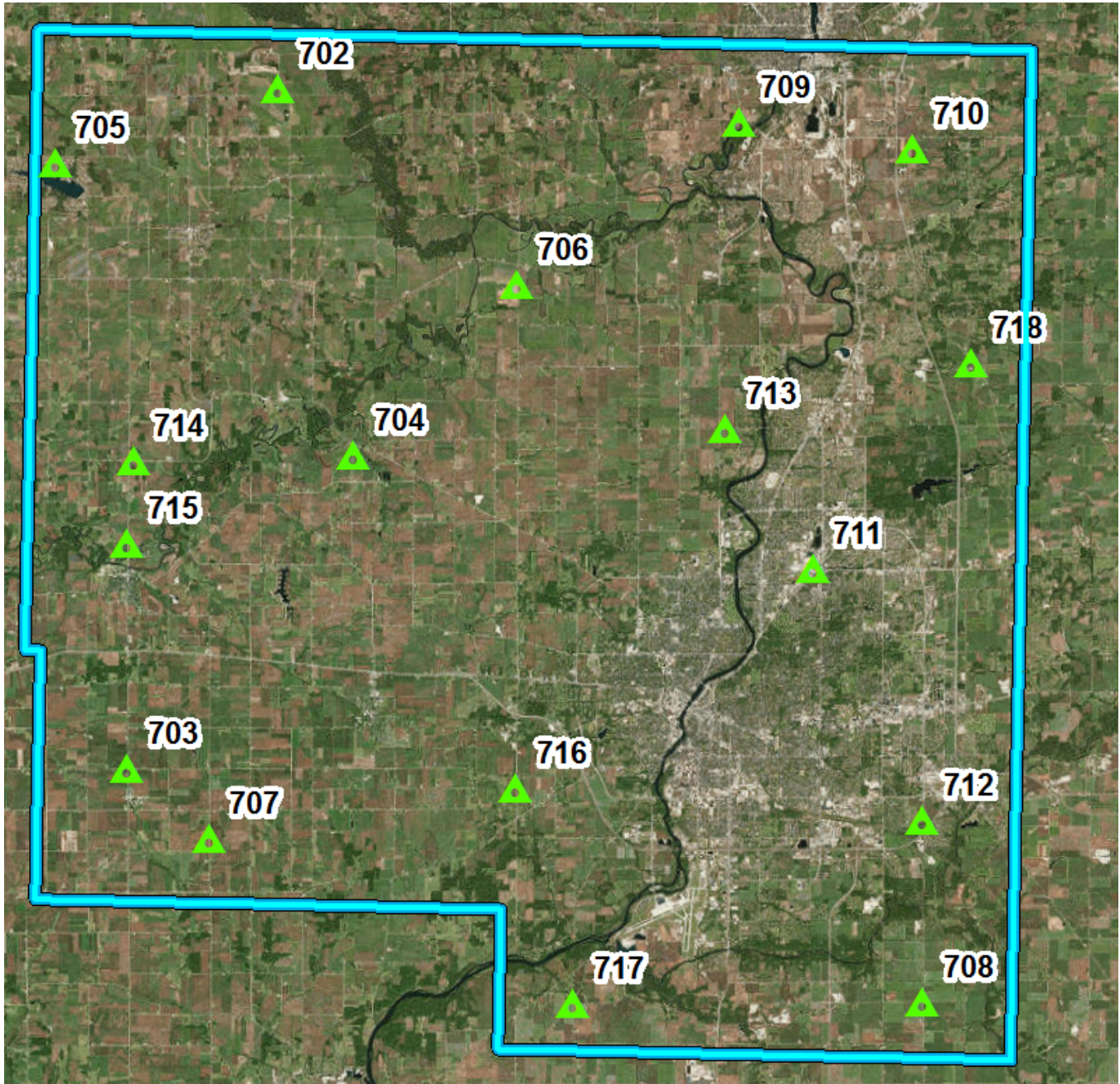
Lidar Filtering and Classification

The lidar filtering process encompasses a series of automated and manual steps to classify the boresighted point cloud data set. Each project represents unique characteristics in terms of cultural features (urbanized vs. rural areas), terrain type and vegetation coverage. These characteristics are thoroughly evaluated at the onset of the project to ensure that the appropriate automated filters are applied and that subsequent manual filtering yields correctly classified data. Data is most often classified by ground and "unclassified", but specific project applications can include a wide variety of classifications including but not limited to buildings, vegetation, power lines, etc. MARS® software is used for the auto-filtering, manual filtering and QC of the classified data.

Merrick used the ASPRS LAS Specification Version 1.4 – R13, 15 July 2013, Point Data Record Format 6 for this project and classified the lidar point cloud in accordance with the following classification classes and bitflags. The following outlines project specific requirements.

- Class 1 = Unclassified
- Class 2 = Bare-earth Ground
- Class 3 = Low Vegetation [0.5-5 feet]
- Class 4 = Medium Vegetation [5-20 feet]
- Class 5 = High Vegetation [>20 feet]
- Class 6 = Buildings
- Class 7 = Low point (noise)
- Class 9 = Water
- Class 10 = Ignored ground (near a breakline)
- Class 17 = Bridge decks
- Class 18 = High noise
- Bitflags
  - Withheld: Within the LAS file specification, a single bit flag indicating that the associated lidar point is geometrically anomalous or unreliable and should be ignored for all normal processes.
  - Model Keypoints: A thinned version of the ground while still retaining the terrain definition at a 2ft spacing plus or minus 0.2ft.

Merrick has developed several customized automated filters that are applied to the lidar data set based on project specifications, terrain, and vegetation characteristics. A filtering macro, which may contain one or more filtering algorithms, is executed to derive LAS files separated into the different classification groups as defined in the ASPRS classification table. The macros are tested in several portions of the project area to verify the appropriateness of the filters. Often, there is a combination of several filter macros that optimize the filtering based on the unique characteristics of the project. Automatic filtering generally yields a ground surface that is 85-90% valid, so additional editing (hand-filtering) is required to produce a more robust ground surface.

Lidar data is next taken into a graphic environment using MARS® to manually re-classify (or hand-filter) "noise" and other features that may remain in the ground classification after auto filter. A cross-section of the post auto-filtered surface is viewed to assist in the reclassification of non-ground data artifacts. The following is an example of re-classification of the non-ground points (elevated features) that need to be excluded from the true ground surface. Certain features such as berms, hilltops, cliffs and other features may have been aggressively auto-filtered and points will need to be re-classified into the ground classification. Data in the profile view displays non-ground (Unclassified, class 1) in grey and ground in brown/tan (Class 2). In figure 1, a small building was not auto-filtered and needs to be manually re-classified. Note that figure 2 has the building points reclassified to unclassified from the true ground surface.
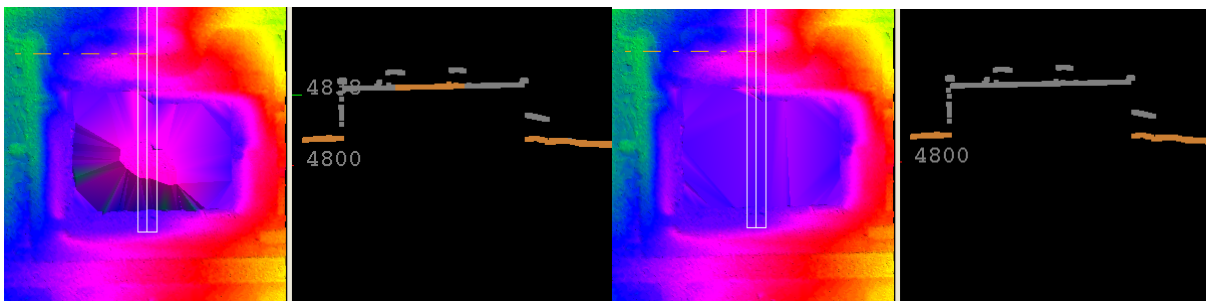

Figure 1   Figure 2

A combination of automated and semi-automated routines to classify buildings and vegetation. We expect that the classified buildings will meet a filtering criterion in the range of 90-95%.

At this point, individual lidar points from the original point cloud have now been parsed into separate classifications.

Filtered Lidar Checkpoint Report

After hand-filtering has been completed and quality checked, a Checkpoint Report is generated to validate that the accuracy of the ground surface is within the defined accuracy specifications. Each surveyed ground check point is compared to the lidar surface by interpolating an elevation from a Triangulated Irregular Network (TIN) of the surface. The MARS® derived report provides an in-depth statistical report, including an RMSE of the vertical errors; a primary component in most accuracy standards and a statistically valid assessment of the overall accuracy of the ground surface.

The below lidar check point reports provide statistics for the ground survey points used to validate the final filtered lidar surface. Please note that all input data per project specification are in U.S. Survey Foot however, UGSS vertical statistic reporting guidelines require reporting in meters so the below results are in meters – units are converted on the fly during the MARS® statistical processing.

Boone County

Units: Meter (/US Survey Feet)

Vertical Accuracy Class tested: 10-cm

Check Points in defined project area (DPA):	40
Check Points with Lidar Coverage	40
Check Points with Lidar Coverage (NVA)	25
Check Points with Lidar Coverage (VVA)	15
Average Z Error (NVA)	-0.014/-0.047
Maximum Z Error (NVA)	0.030/0.099
Median Z Error (NVA)	-0.009/-0.029
Minimum Z Error (NVA)	-0.047/-0.155
Standard deviation of Vertical Error (NVA)	0.020/0.065
Skewness of Vertical Error (NVA)	0.346
Kurtosis of Vertical Error (NVA)	-0.398
Non-vegetated Vertical Accuracy (NVA) RMSE(z) [1]	0.024/0.079 PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- [1]	0.047/0.155 PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-	0.047/0.155
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM) [2]	0.025/0.082 PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level (DEM) +/- [2]	0.049/0.160 PASS
Vegetated Vertical Accuracy (VVA) at the 95th Percentile (DEM) +/- [2]	0.059/0.193 PASS

This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 2.411cm, equating to +/- 4.725cm at the 95% confidence level. Actual VVA accuracy was found to be +/- 5.882cm at the 95th percentile.

[1] This value is calculated from TIN-based testing of the raw swath lidar point cloud data.

[2] This value is calculated from RAM-based grid testing of the classified tiled lidar data. The grid cells are sized according to the Quality Level selected, and are defined in the USGS NGP Lidar Base Specification Version 1.2 (page 15, Table 7).

Units: U.S. Survey Foot

Check Point Id	Check Point X	Check Point Y	Coverage	Check Point Z	Z from Lidar	Z Error	NVA or VVA
1501	878215.556	2053022.725	808.401	TRUE	808.429	0.028	NVA
1502	841919.122	2106072.131	965.819	TRUE	965.664	-0.155	NVA

1503	883451.347	2112564.366	943.124	TRUE	943.124	0.000	NVA
1504	829600.427	2072895.21	934.876	TRUE	934.746	-0.130	NVA
1505	883595.626	2067556.377	838.479	TRUE	838.454	-0.025	NVA
1506	883284.948	2001422.943	842.698	TRUE	842.776	0.078	NVA
1507	853991.475	2025362.855	850.475	TRUE	850.360	-0.115	NVA
1508	841068.65	2002103.238	801.108	TRUE	801.008	-0.100	NVA
1509	867663.873	2049828.139	832.046	TRUE	832.026	-0.020	NVA
1510	867721.37	2065028.708	818.783	TRUE	818.682	-0.101	NVA
1511	843116.661	2078264.15	917.993	TRUE	917.869	-0.124	NVA
1512	822953.243	2036943.158	758.035	TRUE	758.134	0.099	NVA
1513	858103.282	2122252.256	973.447	TRUE	973.420	-0.027	NVA
1514	869813.728	2087485.82	899.466	TRUE	899.429	-0.037	NVA
1515	841258.475	2023072.853	806.963	TRUE	806.959	-0.004	NVA
1516	832953.347	2099366.703	941.048	TRUE	940.917	-0.131	NVA
1517	878156.921	2029357.682	786.329	TRUE	786.232	-0.097	NVA
1518	835603.539	2051291.112	810.601	TRUE	810.581	-0.020	NVA
1519	832887.949	2123154.857	924.778	TRUE	924.709	-0.069	NVA
1520	855877.758	2072983.811	845.807	TRUE	845.737	-0.070	NVA
1521	830519.917	2011994.234	844.875	TRUE	844.846	-0.029	NVA
1522	867142.977	1999821.586	856.848	TRUE	856.755	-0.093	NVA
1523	865114.13	2014059.548	826.128	TRUE	826.109	-0.019	NVA
1524	844318.754	2088873.308	953.813	TRUE	953.790	-0.023	NVA
1525	830436.917	1998906.614	788.841	TRUE	788.850	0.009	NVA
1601	878148.451	2054300.998	809.727	TRUE	809.813	0.086	VVA
1602	841555.987	2106028.965	969.287	TRUE	969.254	-0.033	VVA
1603	881548.145	2112628.859	954.247	TRUE	954.138	-0.109	VVA
1604	830377.278	2072848.457	936.049	TRUE	936.004	-0.045	VVA
1605	883553.799	2066856.987	834.303	TRUE	834.352	0.049	VVA
1606	882611.311	2001387.337	842.144	TRUE	842.144	0.000	VVA
1607	855927.898	2025308.872	860.7	TRUE	860.722	0.022	VVA
1608	840963.534	2001254.217	794.98	TRUE	794.851	-0.129	VVA
1609	867714.411	2050471.909	837.833	TRUE	837.806	-0.027	VVA
1610	866402.796	2064983.386	816.945	TRUE	816.792	-0.153	VVA
1611	842878.39	2078382.03	920.882	TRUE	920.642	-0.240	VVA
1612	822606.523	2037285.291	757.96	TRUE	757.963	0.003	VVA
1613	861170.57	2122152.08	960.083	TRUE	959.994	-0.089	VVA
1614	870494.394	2087559.907	899.528	TRUE	899.513	-0.015	VVA
1615	841215.927	2023774.914	794.26	TRUE	794.233	-0.027	VVA

<u>Winnebago County</u>

Units: Meter (/US Survey Feet)

Vertical Accuracy Class tested: 10-cm

Check Points in defined project area (DPA):	60
Check Points with Lidar Coverage	60
Check Points with Lidar Coverage (NVA)	35
Check Points with Lidar Coverage (VVA)	25
Average Z Error (NVA)	0.006/0.019
Maximum Z Error (NVA)	0.052/0.171
Median Z Error (NVA)	0.005/0.017
Minimum Z Error (NVA)	-0.066/-0.217
Standard deviation of Vertical Error (NVA)	0.027/0.087
Skewness of Vertical Error (NVA)	-0.379
Kurtosis of Vertical Error (NVA)	-0.062
Non-vegetated Vertical Accuracy (NVA) RMSE(z) [1]	0.027/0.088 PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- [1]	0.052/0.172 PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-	0.052/0.172
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM) [2]	0.028/0.091 PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level (DEM) +/- [2]	0.054/0.178 PASS
Vegetated Vertical Accuracy (VVA) at the 95th Percentile (DEM) +/- [2]	0.076/0.250 PASS

This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 2.674cm, equating to +/- 5.241cm at the 95% confidence level. Actual VVA accuracy was found to be +/- 7.616cm at the 95th percentile.

[1] This value is calculated from TIN-based testing of the raw swath lidar point cloud data.

[2] This value is calculated from RAM-based grid testing of the classified tiled lidar data. The grid cells are sized according to the Quality Level selected, and are defined in the USGS NGP Lidar Base Specification Version 1.2 (page 15, Table 7).

Units: U.S. Survey Foot

| Check Point Id	Check Point X	Check Point Y	Coverage	Check Point Z	Z from Lidar	Z Error	NVA or VVA
501	2622486.132	2070265.592	896.015	TRUE	896.056	0.041	NVA
502	2533281.047	2120278.251	768.275	TRUE	768.227	-0.048	NVA
503	2510239.805	2032996.41	851.95	TRUE	852.101	0.151	NVA
504	2544606.091	2075161.772	738.575	TRUE	738.677	0.102	NVA
505	2505292.309	2111425.513	870.154	TRUE	870.223	0.069	NVA
506	2564362.667	2099051.392	731.606	TRUE	731.551	-0.055	NVA
507	2526151.529	2028058.413	898.068	TRUE	898.239	0.171	NVA
508	2597392.643	2004788.251	744.967	TRUE	745.058	0.091	NVA
509	2593339.043	2118425.727	776.574	TRUE	776.587	0.013	NVA
510	2613539.16	2116520.534	783.817	TRUE	783.836	0.019	NVA
511	2603540.108	2061147.153	752.885	TRUE	752.858	-0.027	NVA
512	2618093.668	2029778.034	788.655	TRUE	788.644	-0.011	NVA
513	2591238.703	2077873.532	795.934	TRUE	795.911	-0.023	NVA
514	2514772.046	2073443.42	873.997	TRUE	874.129	0.132	NVA
515	2514975.432	2059856.629	749.665	TRUE	749.787	0.122	NVA
516	2567054.845	2033172.673	813.475	TRUE	813.445	-0.030	NVA
517	2574010.237	1998422.361	733.228	TRUE	733.309	0.081	NVA
518	2622169.587	2088851.309	873.1	TRUE	873.044	-0.056	NVA

519	2558251.031	2116740.245	837.524	TRUE	837.428	-0.096	NVA
520	2583097.017	2022510.215	727.656	TRUE	727.673	0.017	NVA
521	2558090.637	2065906.875	867.761	TRUE	867.854	0.093	NVA
522	2584656.088	2048761.982	729.424	TRUE	729.303	-0.121	NVA
523	2542581.309	2054776.004	887.39	TRUE	887.379	-0.011	NVA
524	2605054.583	2044248.579	798.234	TRUE	798.159	-0.075	NVA
525	2549824.885	2033823.784	893.63	TRUE	893.688	0.058	NVA
526	2511898.749	2119742.456	862.539	TRUE	862.688	0.149	NVA
527	2626387.155	2000329.989	752.746	TRUE	752.798	0.052	NVA
528	2607704.408	2085220.18	739.575	TRUE	739.358	-0.217	NVA
529	2613008.176	2026422.348	814.846	TRUE	814.882	0.036	NVA
530	2625877.61	2043915.351	848.905	TRUE	848.901	-0.004	NVA
531	2545999.528	2096011.714	758.937	TRUE	759.025	0.088	NVA
532	2503886.893	2095926.236	938.64	TRUE	938.727	0.087	NVA
533	2562256.394	2055465.9	793.441	TRUE	793.445	0.004	NVA
534	2613091.665	2105901.327	779.946	TRUE	779.887	-0.059	NVA
535	2580098.892	2089001.411	837.303	TRUE	837.210	-0.093	NVA
601	2622384.025	2070204.817	898.693	TRUE	898.703	0.010	VVA
602	2534309.345	2120155.883	754.858	TRUE	754.964	0.106	VVA
603	2510299.264	2032730.844	849.426	TRUE	849.558	0.132	VVA
604	2545070.738	2074888.717	738.044	TRUE	738.228	0.184	VVA
605	2504947.374	2111113.655	835.489	TRUE	835.478	-0.011	VVA
606	2564429.142	2099392.569	730.338	TRUE	730.323	-0.015	VVA
607	2526219.203	2027457.847	884.616	TRUE	884.831	0.215	VVA
608	2596255.812	2004800.536	750.084	TRUE	750.162	0.078	VVA
609	2593364.78	2118279.169	778.24	TRUE	778.226	-0.014	VVA
610	2613121.235	2116616.971	781.944	TRUE	781.917	-0.027	VVA
611	2604093.565	2061113.689	760.005	TRUE	759.936	-0.069	VVA
612	2618014.828	2030488.28	774.471	TRUE	775.093	0.622	VVA
613	2590805.359	2077436.34	804.166	TRUE	804.265	0.099	VVA
614	2514679.17	2074312.356	855.094	TRUE	855.227	0.133	VVA
615	2514686.944	2059994.821	741.851	TRUE	741.933	0.082	VVA
616	2565921.943	2033084.024	836.448	TRUE	836.405	-0.043	VVA
617	2573744.587	1999308.632	720.035	TRUE	720.055	0.020	VVA
618	2621709.557	2089328.054	856.202	TRUE	856.102	-0.100	VVA
619	2558171.41	2116589.162	833.66	TRUE	833.726	0.066	VVA
620	2583018.699	2022561.222	726.854	TRUE	726.804	-0.050	VVA
621	2556863.316	2066096.87	840.63	TRUE	840.726	0.096	VVA
622	2584788.997	2048845.495	730.302	TRUE	730.238	-0.064	VVA
623	2542511.865	2055035.218	885.074	TRUE	885.080	0.006	VVA
624	2604613.222	2043949.384	812.229	TRUE	812.092	-0.137	VVA
625	2549887.78	2032976.189	912.796	TRUE	912.979	0.183	VVA

Lidar Check Point Layout

- Yellow = NVA
- Green = VVA

Boone County
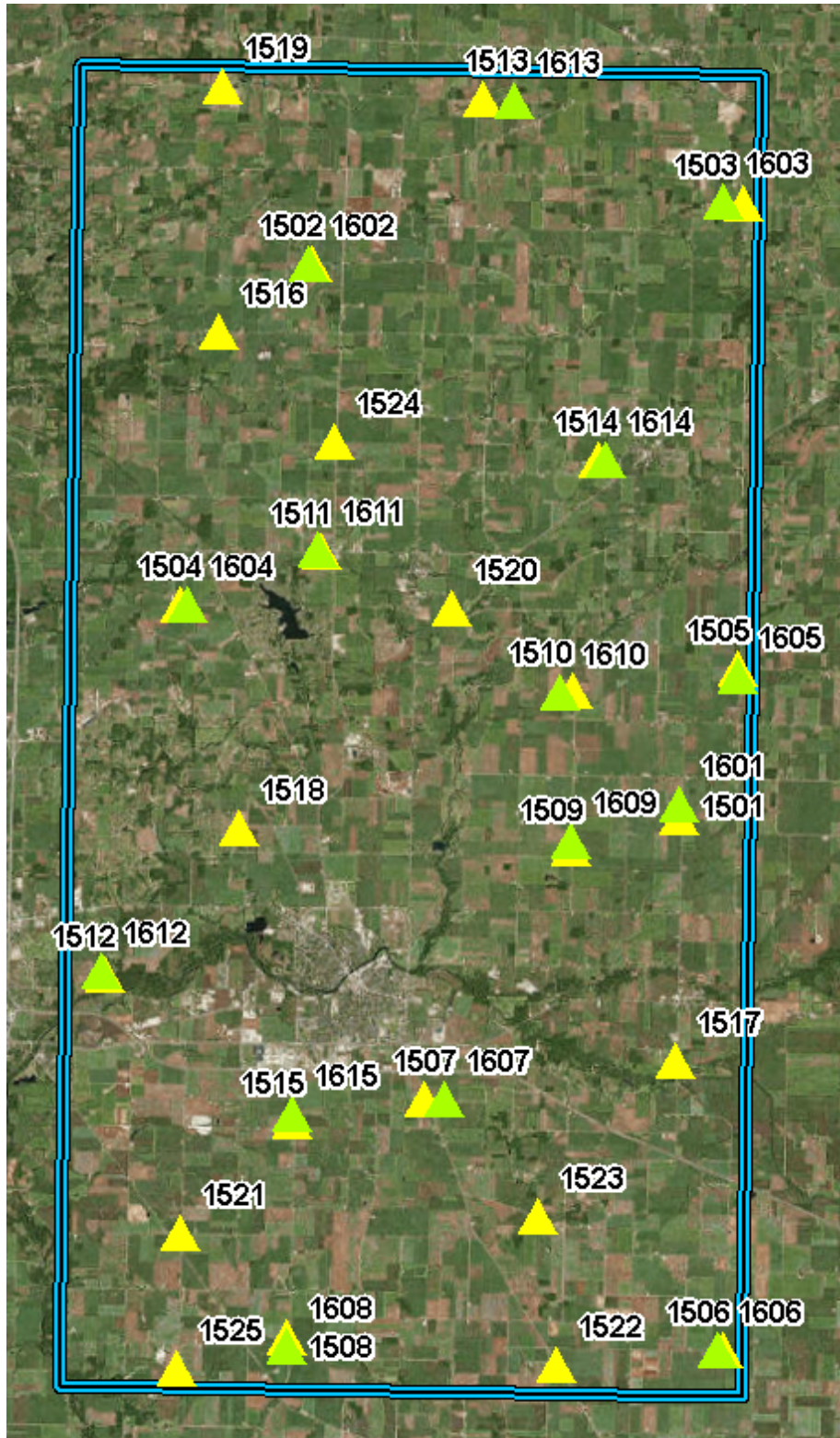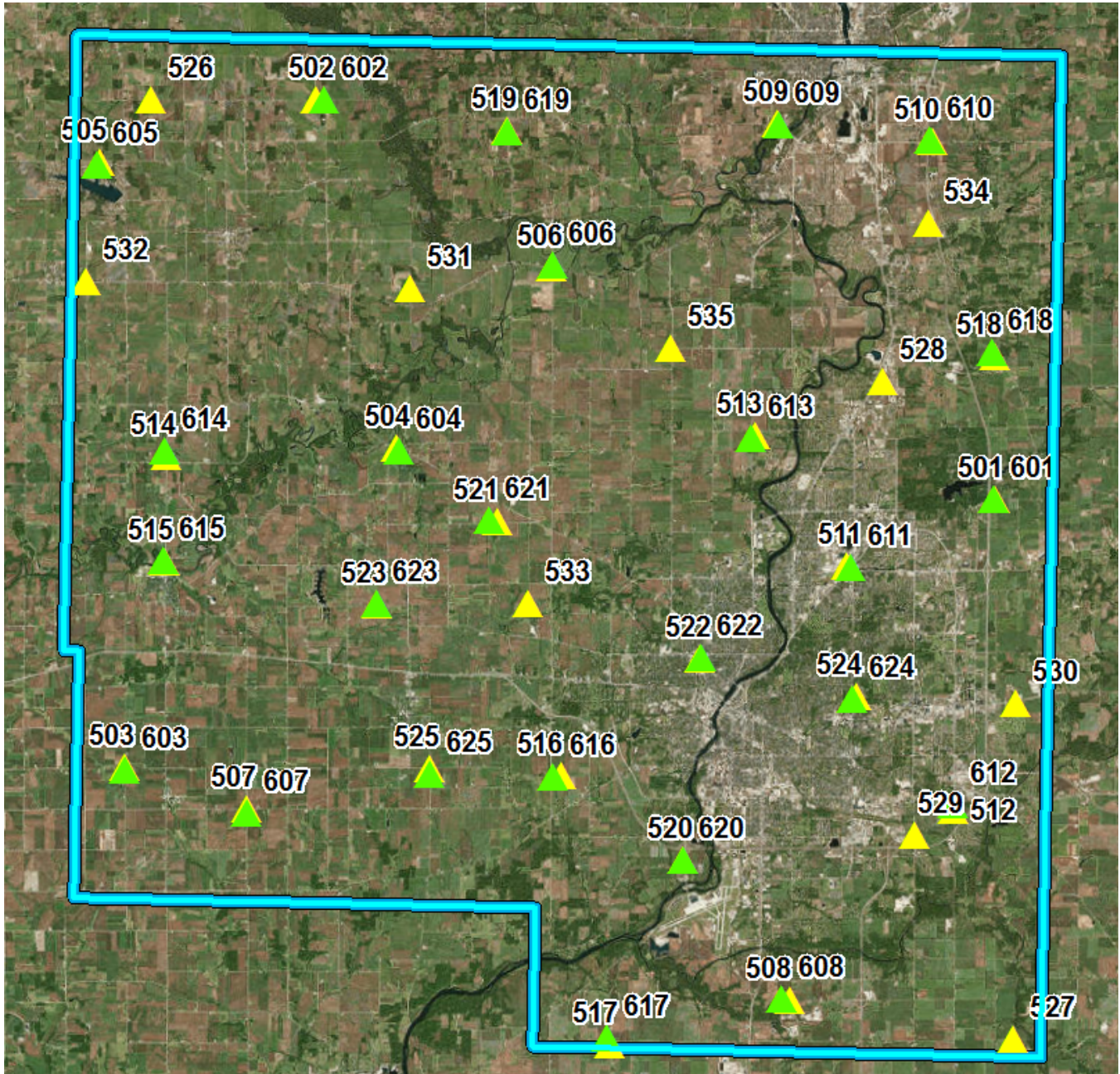
Hydro-flattening Breakline Collection

Hydro- flattening breaklines are captured per the USGS National Geospatial Program Lidar Base Specification Version 1.2. Final hydro-flattened breaklines features are appropriately turned into polygons (flat elevations) and polylines (decreasing by elevation) and are used to reclassify ground points in water to Water (Class 9). The lidar points around the breaklines are reclassified to Ignored Ground (Class 10) based on predetermined buffer.

Linear hydrographic features

To collect hydrographic features, Merrick-Surdex JV uses a methodology that directly interacts with the lidar bare-earth data to collect drainage breaklines. To determine the alignment of a drainageway, the technician first views the area as a TIN of bare-earth points using a color ramp to depict varying elevations. In areas of

extremely flat terrain, the technician may need to determine the direction of flow based on measuring lidar bare-earth points at each end of the drain. The operator will then use the color ramped TIN to digitize the drainage in 2D with the elevation being attributed directly from the bare-earth LAS data. MARS® software has the capability of "flipping" views between the elevation TIN, Intensity and imagery, as necessary, to further assist in the determination of the drainage. All drainage breaklines are collected in a downhill direction. For each point collected, the software uses a five-foot (5') search radius to identify the lowest point within that proximity. Within each radius, if a bare-earth point is not found that is lower than the previous point, the elevation for subsequent point remains the same as the previous point. This forces the drain to always flow in a downhill direction. Waterbodies that are embedded along a drainageway are validated to ensure consistency with the downhill direction of flow.

This methodology may differ from those of other vendors in that Merrick-Surdex JV relies on the bare-earth data to attribute breakline elevations. As a result of our methodology, there is no mismatch between lidar bare-earth data and breaklines that might otherwise be collected in stereo 3D as a separate process. This is particularly important in densely vegetated areas where breaklines collected in 3D from imagery will most likely not match (either horizontally or vertically), the more reliable lidar bare-earth data.

Merrick-Surdex JV has the capability of "draping" 2D breaklines to a bare-earth elevation model to attribute the "z" as opposed to the forced downhill attribution methodology described above. However, the problem with this process is the "pooling "effect or depressions along the drainageway caused by a lack of consistent penetration in densely vegetated areas.

Criteria of linear hydrographic breaklines are as follows:

- Linear hydrographic features (e.g., visible streams, rivers, shorelines, canals, etc.) greater than one hundred feet (100') wide will be captured as a double-lined polygon
    - linear hydrographic features must be flat and level bank-to-bank (perpendicular to the apparent flow centerline) with gradient following the immediately surrounding terrain
    - water surface edge must be at or just below the immediately surrounding terrain
    - streams should break at road crossings (e.g., culverts), and streams and rivers should not break at bridges

Waterbodies

Waterbodies are digitized from the color ramped TIN, similar to the process described above. The elevation attribute is determined as the technician collects the hydro feature by using the lowest bare-earth point within the polygon.

Criteria of waterbody breaklines are as follows:

- Waterbodies (e.g., lakes, ponds, reservoirs) greater than two (2) acres in size are surrounded by a water breakline (i.e., closed polygon)
    - waterbodies must be flat and level with a single elevation for every bank vertex
    - water surface edge must be at or just below the immediately surrounding terrain
    - long impoundments, such as reservoirs or inlets, whose water surface elevations drop when moving downstream should be treated as rivers

Color cycles provide a clear indication of where breaklines are to be collected, especially hydrographic breaklines. Figure 3 demonstrates no breaklines, where Figure 4 is breakline enforced displayed using color cycles within the MARS® software environment.
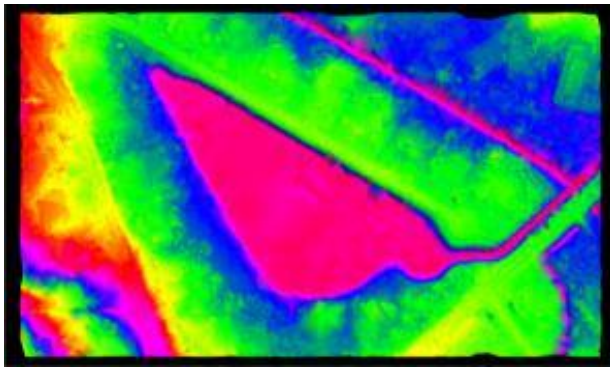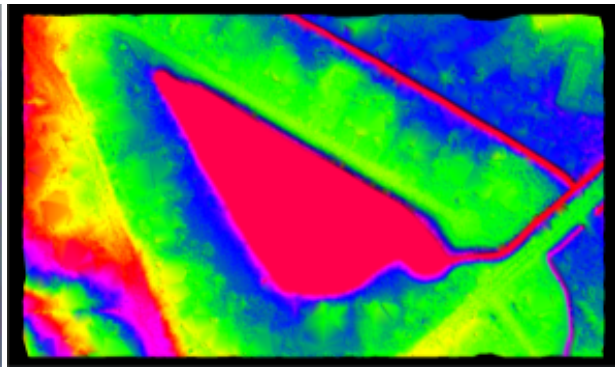
Figure 3

Figure 4

List of Deliverables

- Raw lidar point cloud
  - Fully compliant ASPRS LAS 1.4
  - Calibrated
  - By swath
  - Intensity values normalized (rescaled) to 16-bit
  - FGDC-compliant metadata
- Classified lidar point cloud
  - Fully compliant ASPRS LAS 1.4, point record format 6
  - By tile
  - Intensity values normalized (rescaled) to 16-bit
  - FGDC-compliant metadata
- Bare-earth DEM
  - 1m cell size 32-bit floating point raster in ERDAS IMG format
  - Bare-earth (hydro-flattened)
    - o Culverts will not be removed from the DEMs
    - o Bridges will be removed from the DEMs
  - By tile and by County
  - FGDC-compliant metadata
- Hydro-flattened breaklines
  - Project-wide Esri feature class(es) for insertion into file geodatabase

  - FGDC-compliant metadata
- Intensity Images
  - 1m cell size 8-bit, 256 color gray scale in ERDAS IMG format
  - By tile and by County
  - FGDC-compliant metadata
- Control
  - Survey report
  - Esri shapefile format
  - FGDC-compliant metadata
- FGDC-compliant metadata (project level)
- Detailed lidar Mapping / Project Report

Following is a more detailed lidar calibration workflow description.

LIDAR CALIBRATION AND BLOCK LAS OUTPUT

Note: All figures represented on the following pages are for general illustration purposes, and are not examples derived from the project.

Initial Processing

Lidar data is output as LAS point data using Optech's Lidar Mapping Suite (LMS). LMS matches ground and roof planes plus roof lines to self-calibrate and correct system biases. These biases occur within the hardware of the laser scanning systems, within the Inertial Measurement Unit (IMU) and because of environmental conditions which affect the refraction of light. The systemic biases that are corrected for include scale, roll, pitch, and heading.

In addition to the self-calibration mode LMS runs a "production" mode which applies the self-calibration parameters and then analyzes each individual flight line and applies small adjustments to each line to tie overlapping lidar points even more tightly together.

Boresight Self-Calibration Processing Procedures

An LMS boresight calibration is performed on an as-needed basis to correct scale, roll, pitch and heading biases. A minimum of three overlapping flights are flown in opposing directions with one cross flight.
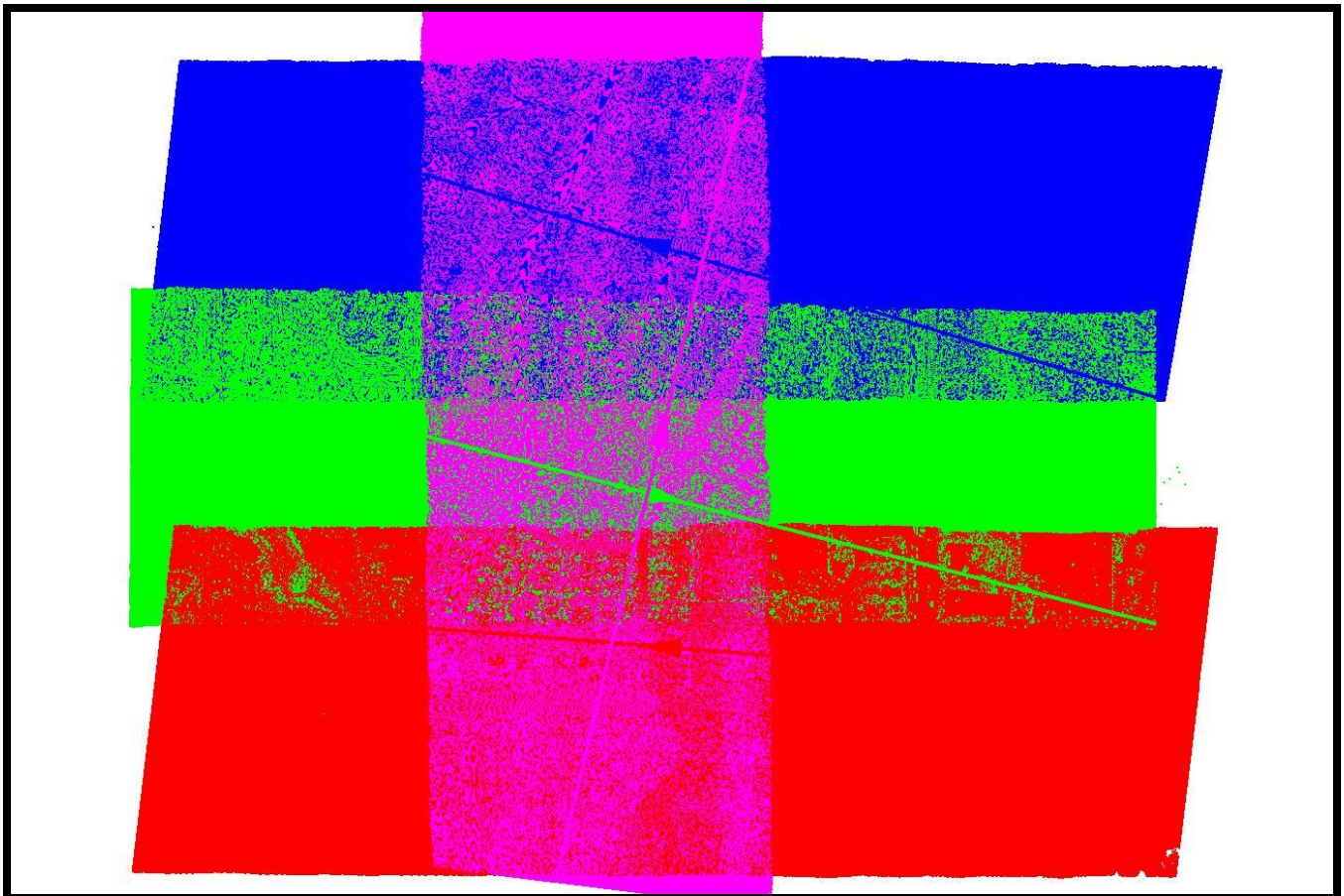
The Boresighting module frees scan angle scale, scan angle lag, XYZ boresight corrections and elevation position corrections while locking scan angle offset and XY position corrections.

The picked calibration site will have a good distribution of buildings for the self-calibration software to match ground planes, roof planes and roof lines.
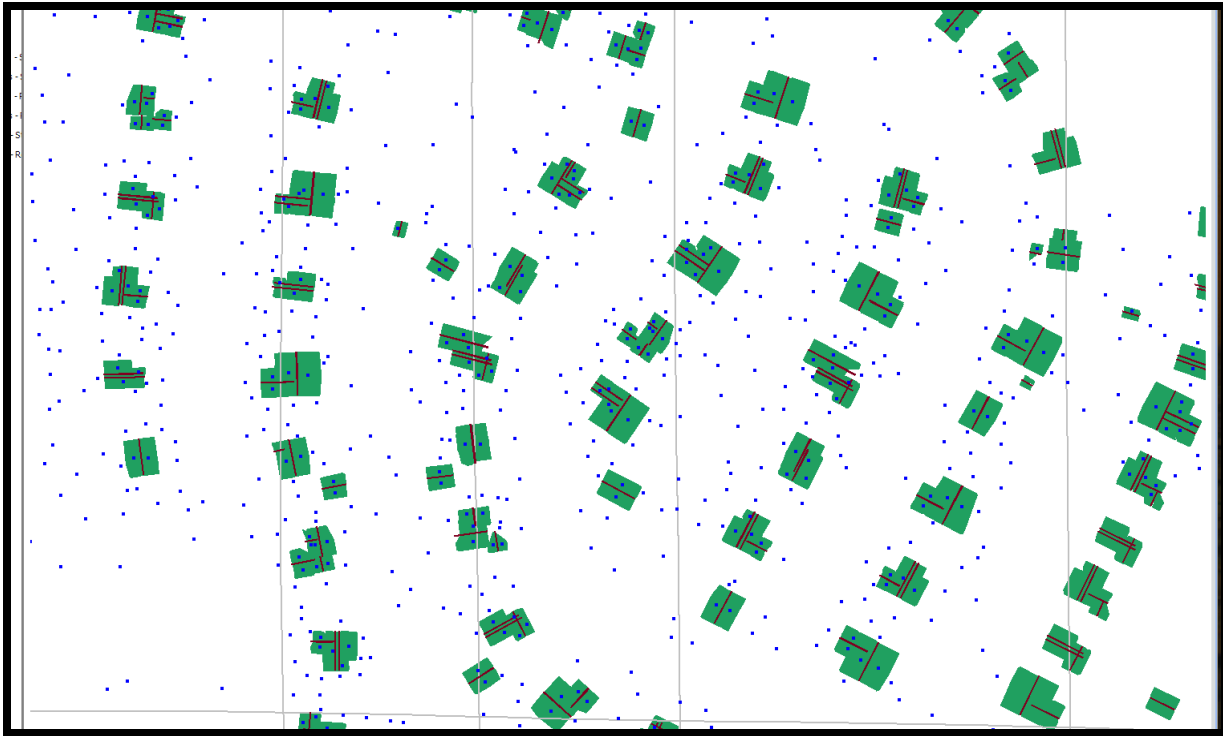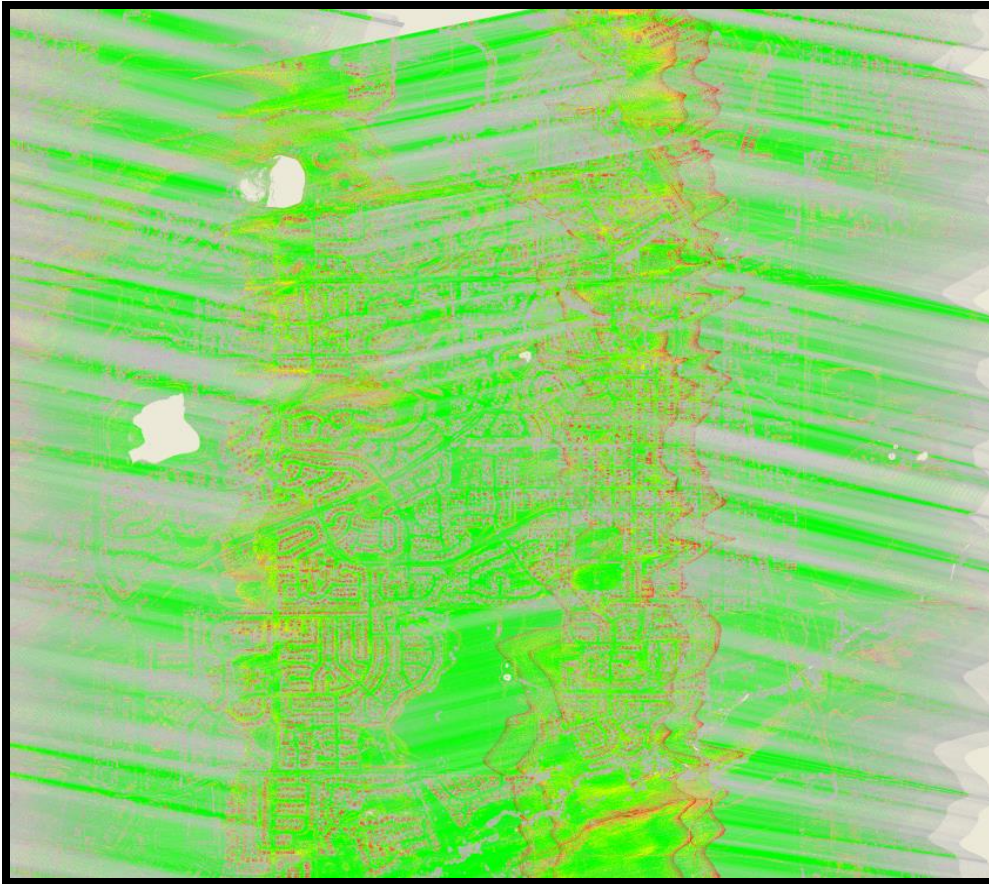

At the conclusion of the self-calibration run the data is quality checked with LMS plots
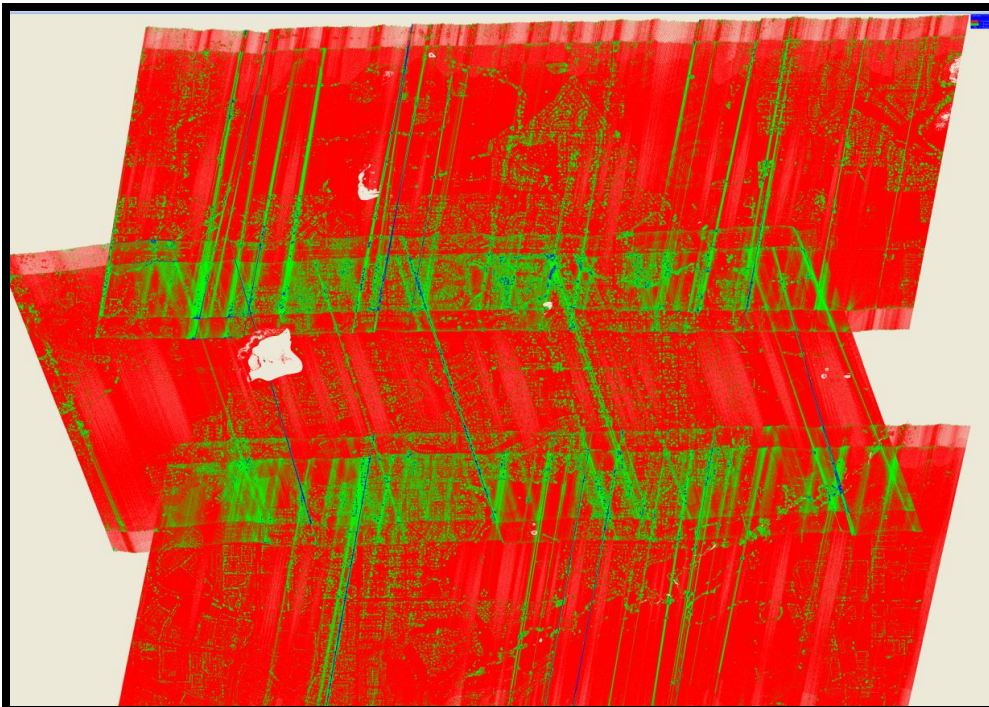
Plot of plane vertical distances from datum plane.
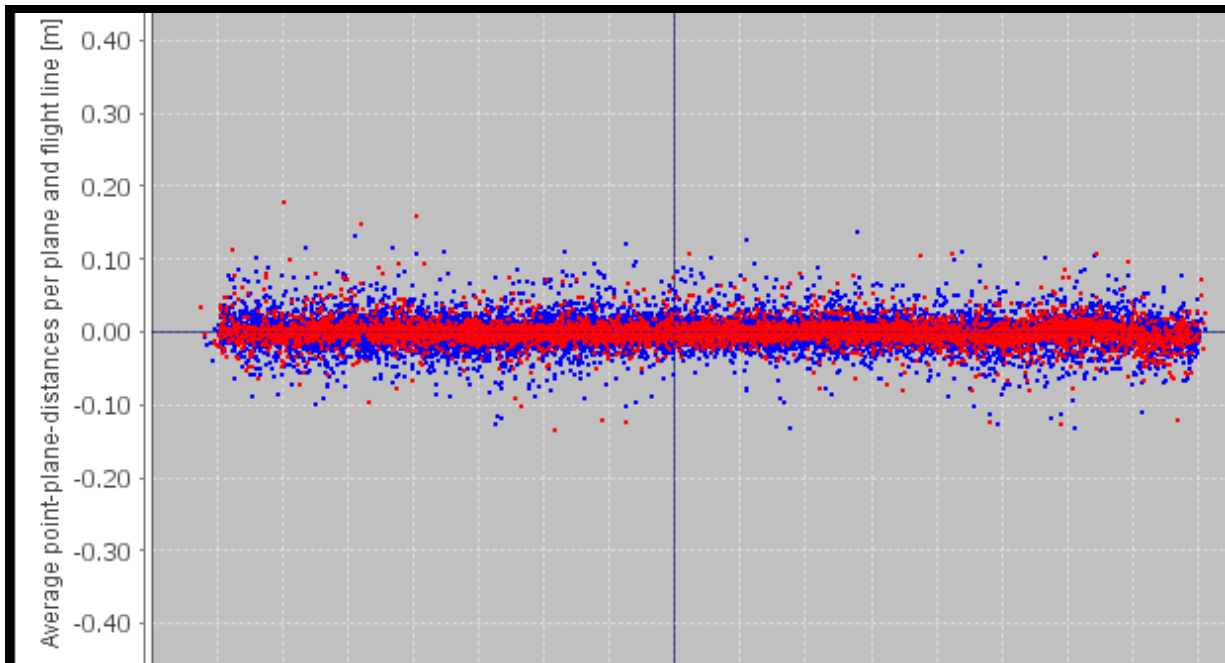
Plot of height differenced between flight lines. (Green=less than 5cm).

Plot of point densities. (Red=5-9 points per cell, green 10+ points per cell).

A Flight Line Separation Raster image is generated in Merrick Advanced Remote Sensing Software (MARS®), in this example ground returns from multiple flight lines that are fitting within 3 centimeters are colored green.
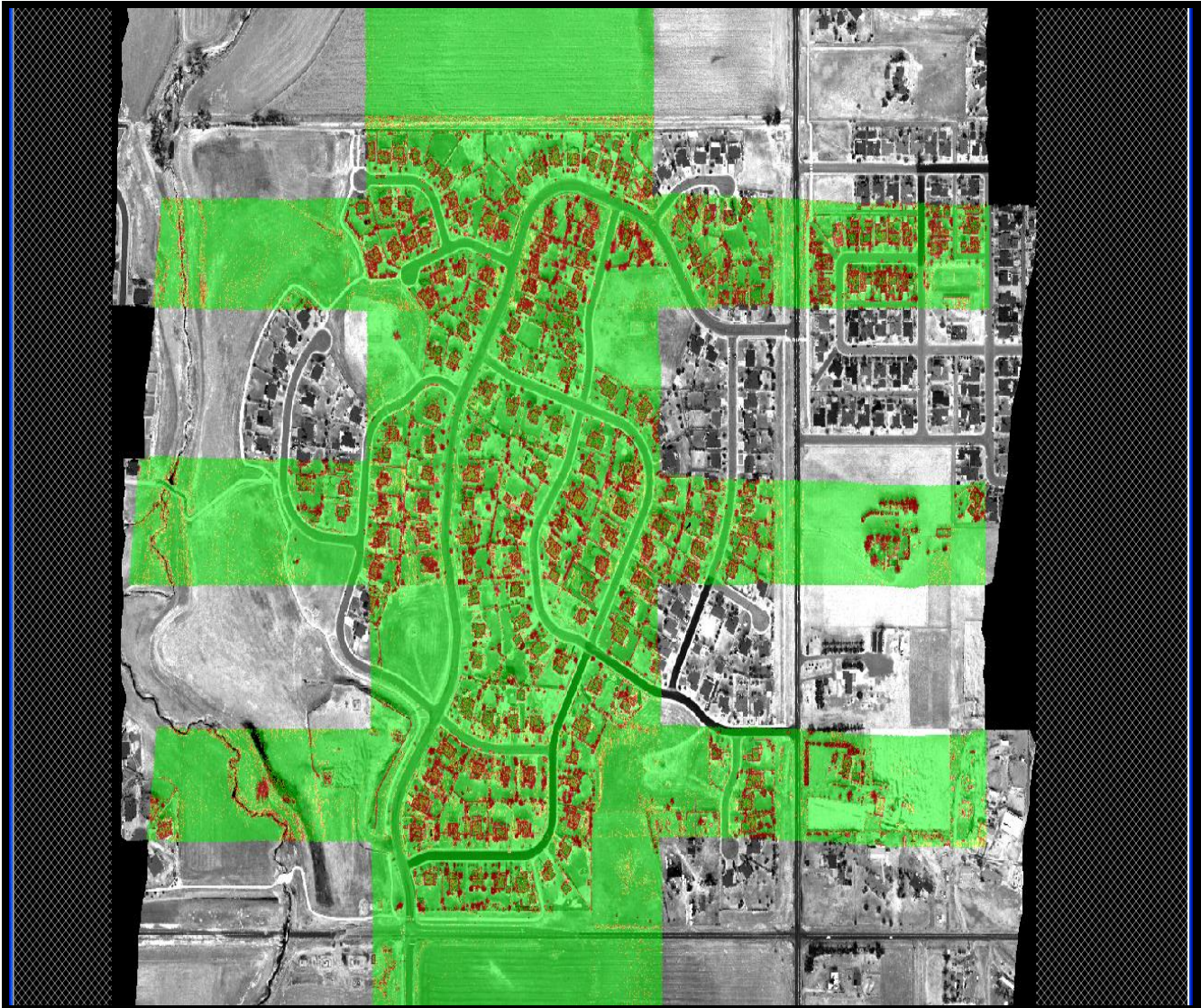
MARS® tests for internal relative vertical accuracy using inbound and outbound scan values. Again, Green is showing inbound and outbound scan data fitting to 3 centimeters.
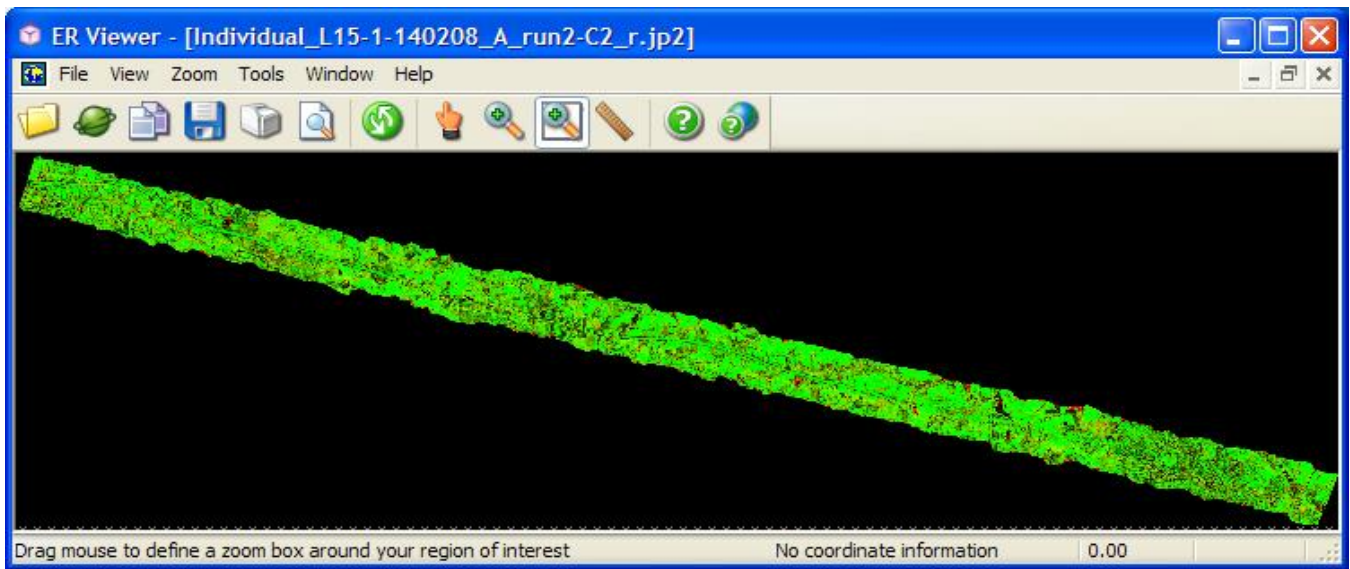
Building cross sections are checked for good alignment. Pitch and heading are checked on roof planes parallel to the flight direction.
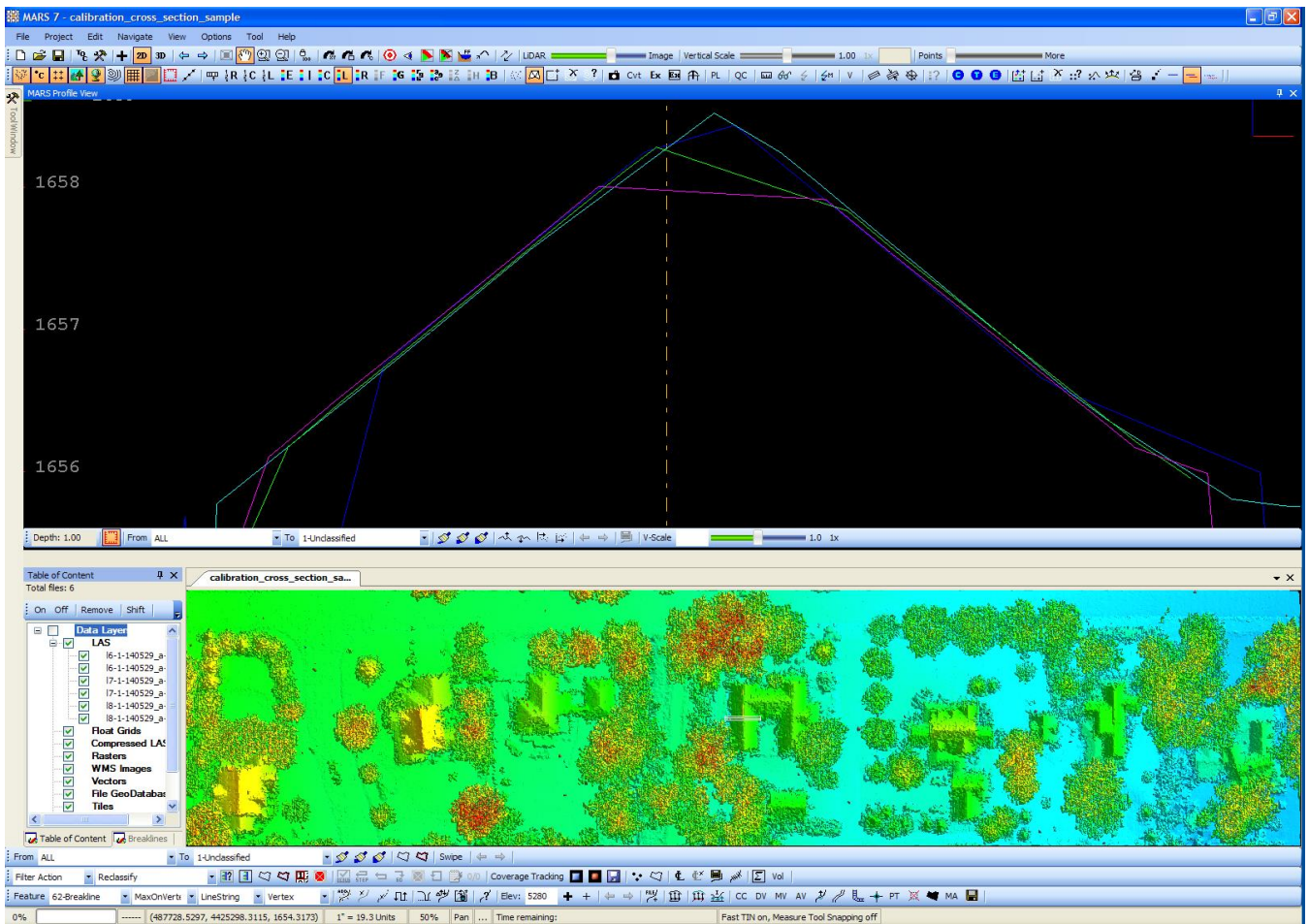
Roll and scale are checked on roof planes perpendicular to the flight direction.
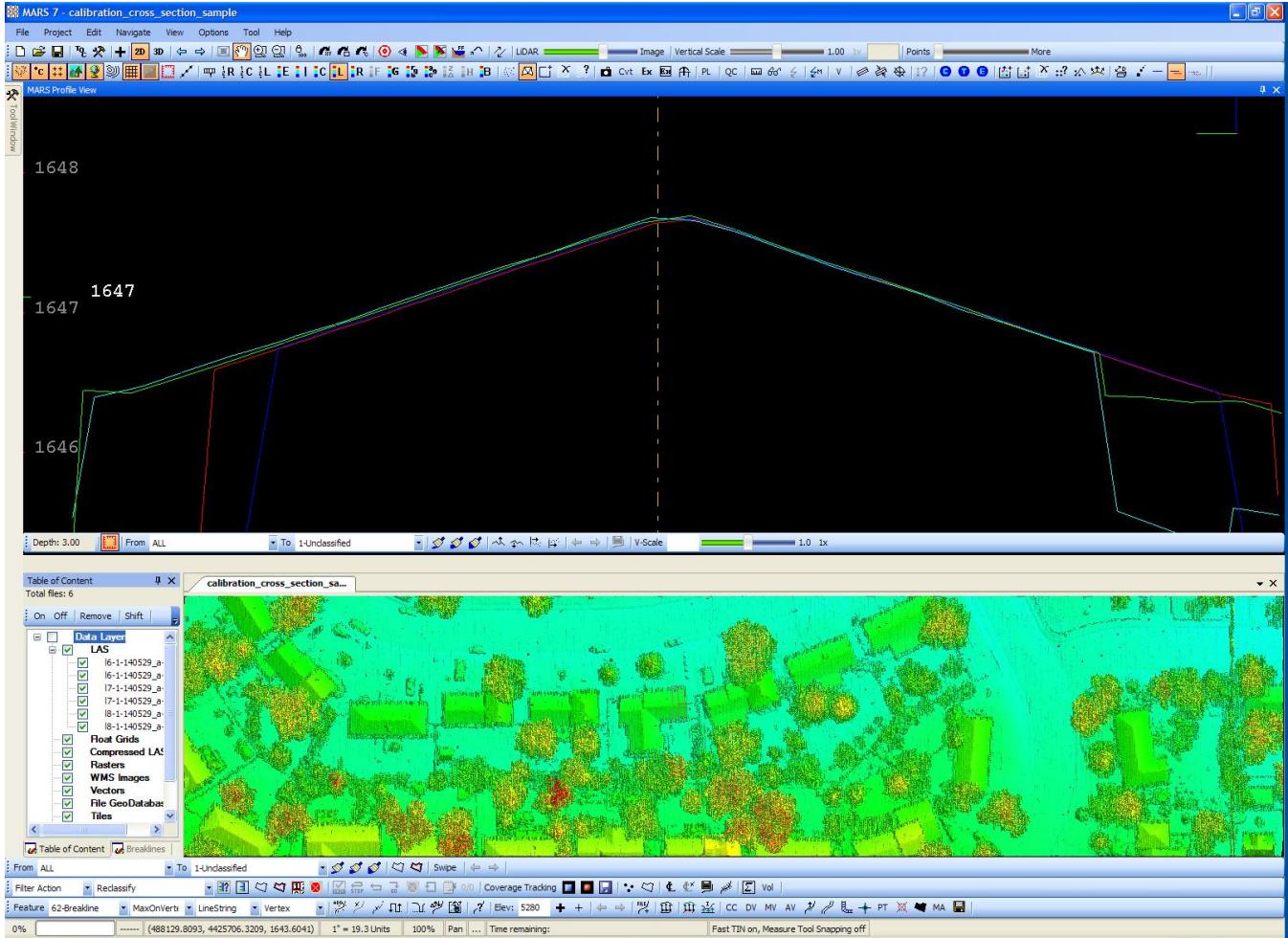

The LMS program outputs a "LCP" file with all the correction parameters. The calibration process may be run several times until the boresight adjustments are acceptable. When the boresight solution is acceptable the LCP file adjustments are saved and also applied to subsequent projects. Each new project is again analyzed and when the adjustment biases show too much drift a new boresight calibration is run. The LCP file may hold calibration tolerances for several projects.

Block LAS Production Processing Procedures

The LMS production mode is run on each flight line to further tie the final lidar LAS flight line files tightly together. Production settings allow scan angle scale, scan angle lag to float and allows elevation to move slightly during flight line to flight line comparison thus further tying flight lines together. A cross flight with locked elevation data is used for controlling flight line elevations.

A block of data is selected to process with LMS production settings. Data collected during turns at the ends of flight lines is deselected (light blue lines).
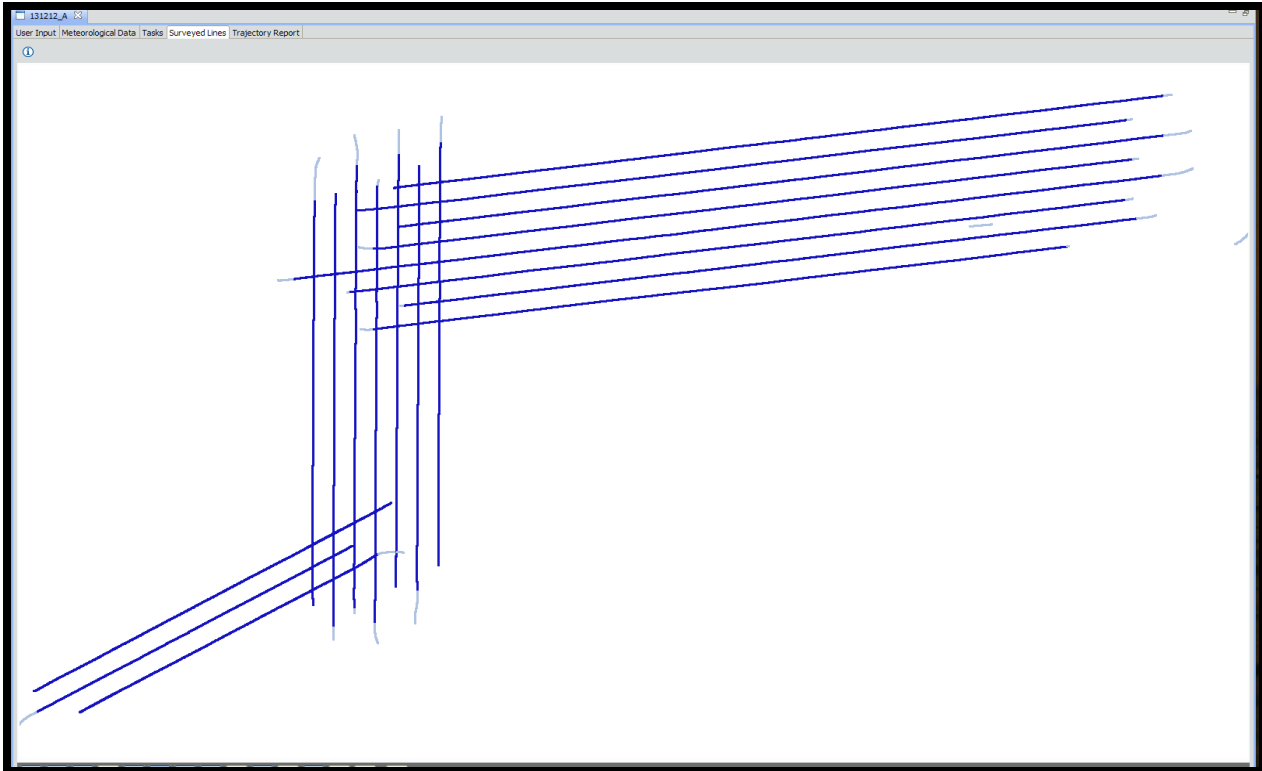
As in self-calibration the LMS production program analyses ground, roof planes and rooflines. One cross flight is locked in elevation and all other lines are adjusted to it. Unlike the calibration site the distribution of roof planes is usually much less dense. Here matched ground tie planes are blue.
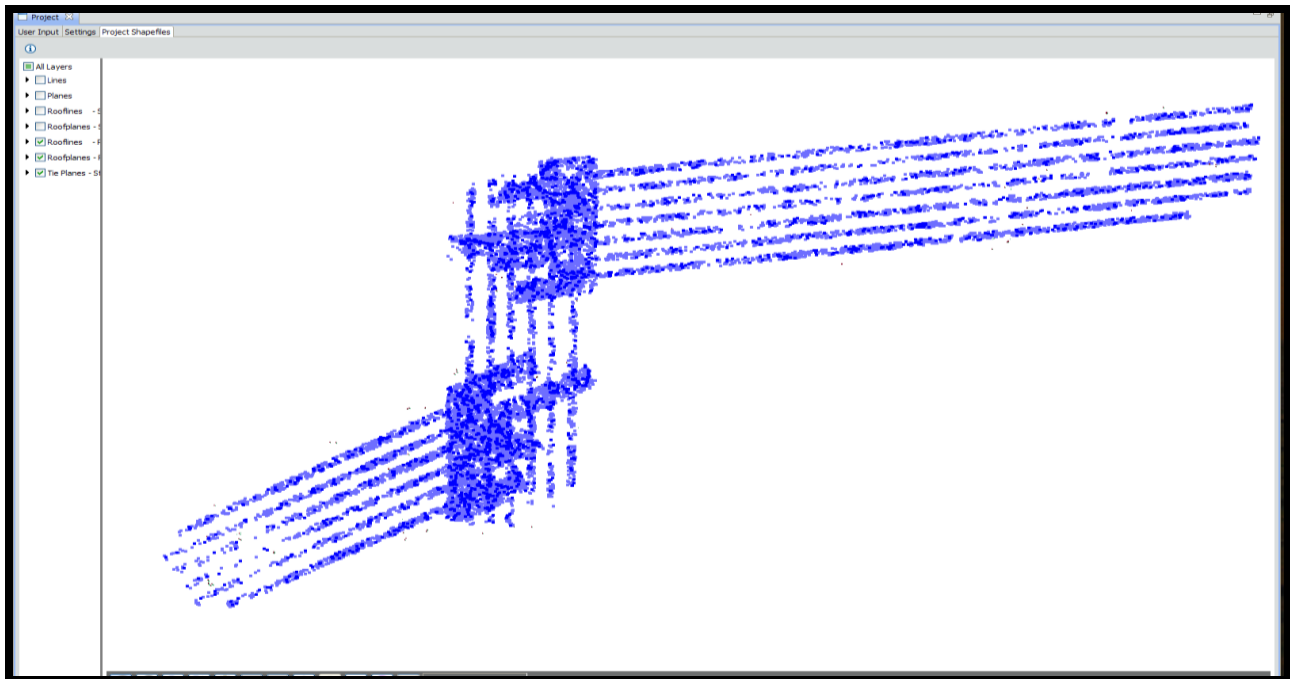

The same quality control outputs used to check self-calibrations are available to analyze the production run. Output plots are again available in LMS and cross sections plus a Flight Line Separation Raster are generated in MARS® to check coverage and quality.
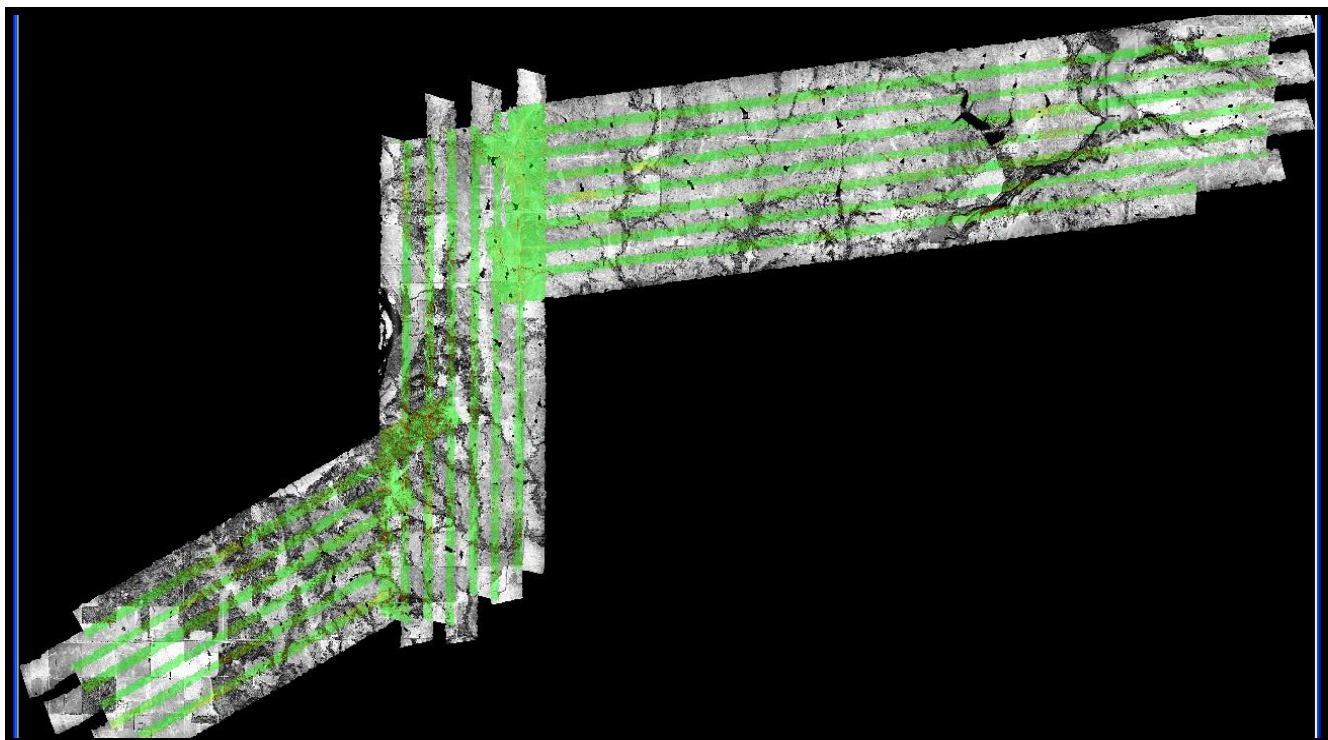
Correcting the Final Elevation

After all the lines are tied together a ground control network is imported into MARS®. The ground control network may be pre-existing or collected by a licensed surveyor.
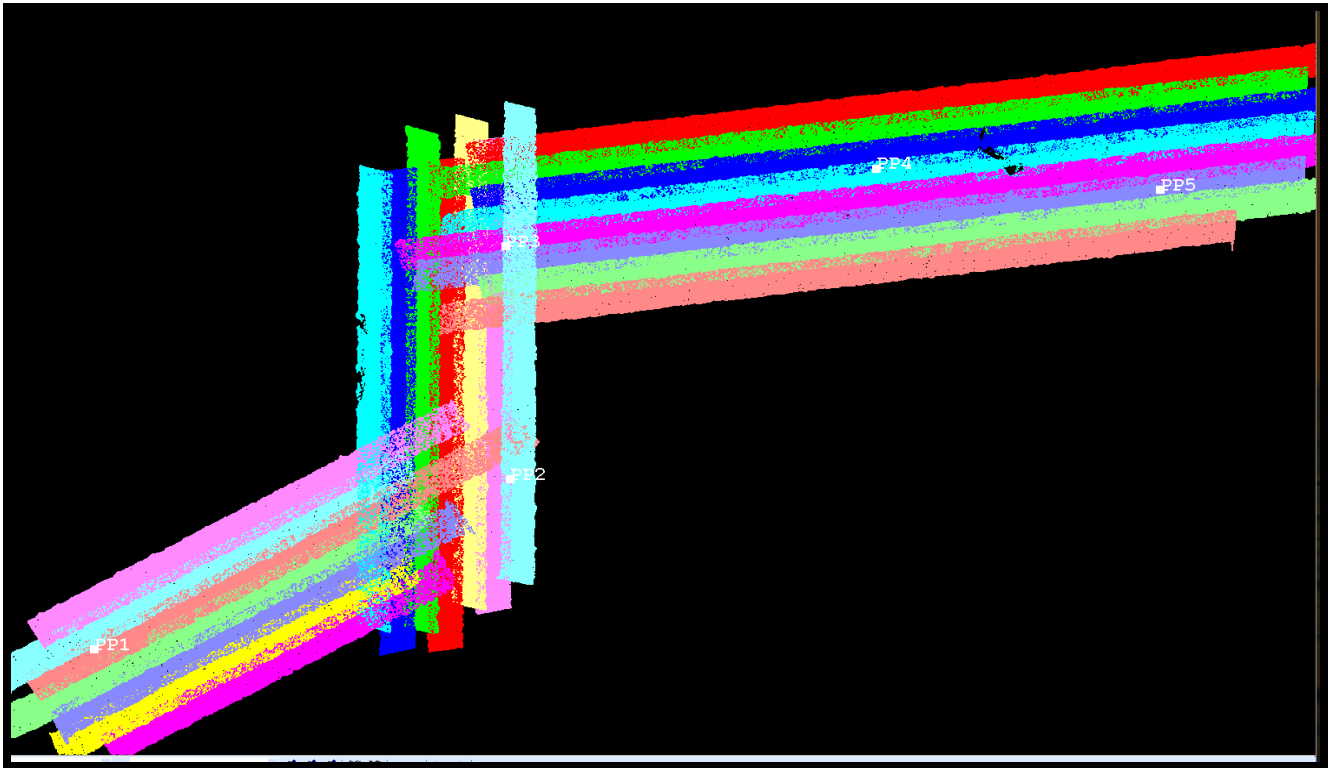
The next step is to match the ground control elevations to the lidar data set. A control report is run and the data set is shifted slightly to zero out the average elevation error and points checked for quality.

The final step before boresighted, leveled LAS files are ready for filtering is to run the MARS® QC Module on the block data. The Boresighted lidar QC Report outputs individual reports on Point Density, Nominal Pulse Spacing, Data Voids, Spatial Distribution, Scan Angles, Control Report, Flight Line Separation, Flight Line Overlap, Buffered Boundary, LAS Formats, Datums and Coordinates.
These reports are checked with the required specifications in the Project Management Plan.

Survey Report.

Survey Report

1. Introduction

1.1   *Project Summary*

Juneau Associates, Inc., P.C. is under contract with Merrick & Company to provide 60 checkpoints and 18 calibration points in Winnebago County, Il. Further, to provide 40 check points and 12 calibration points in Boone County, Il. The ground survey was conducted March 12 to March 16, 2018.

Existing NGS monuments were located and surveyed to check the accuracy of RTK/GPS survey equipment with the results shown in section 2.4 of this report.

As an Internal procedure and to verify that the check points and calibration points meet the 95% confidence level all points were re-observed and are shown in section 5 of this report.

Final horizontal coordinates of points located in Winnebago county are referenced to US State Plane 1983, NAD 1983/ NA2011, Illinois West 1202. Final horizontal coordinates of points located in Boone county are referenced to US State Plane 1983, NAD 1983/ NA2011, Illinois East 1201. Final vertical elevations are referenced to NAVD 88 using Geoid12b model as requested. All final units are in U.S. survey feet.

1.2   *Points of Contact*

Questions regarding technical aspects of this survey report should be made to:

Juneau Associates, Inc., P.C.

Jeremy Dressel, P.L.S.

2100 State St Granite City, Illinois

(618) 844-1400

2. Project Details

2.1   *Survey Equipment*

The GPS observations were performed using Trimble R-10 GNSS receiver/antenna attached to a Trimble carbon fiber fixed tip GPS pole. A Trimble TSC3 data collector was used to store GPS raw data.

2.2   *Survey Field Note Information*

The 130 total points observed, in both Winnebago and Boone County, were well distributed throughout the project. Field notes were kept recording the internal point number used, the NVA, VVA, CAL code, and the time, date, and current weather for each observation of said checkpoints and calibration points.

2.3   *Network Design*

The GPS survey was performed using a RTK (Real-Time Kinematic) system managed by Trimble called VRS Now. VRS Now provides instant access to real-time kinematic (RTK) corrections using a network of fixed continuously operating reference stations. This system allows field crews to utilize a mobile hot spot via a cellular device which connects the data collector to the VRS Now network server, which then connects to the fixed reference stations to give the GPS readings corrections to selected coordinate system.

2.4   *Field Survey Procedure and Analysis*

Juneau Associates field survey crews used a Trimble R-10 GNSS receiver to collect data that was then corrected to the designated coordinate system by the process discussed in section 2.3

All locations were occupied twice for three minutes, 180 EPOCS, for each specified point at the time and date specified in the field notes utilizing the VRS network.

Seven existing NGS monuments with known horizonal and vertical coordinates were located to check the accuracy of the VRS network used to complete this project. Four total NGS monuments were observed in the Il-West coordinate system identified as, DE7265, DE7369, NH0504, NH0472. Also, three NGS monuments were observed in the Il-East coordinate system identified as, AH2885, AJ2947, NH0229. The "As Surveyed" vs. "Published" coordinate results are as follows on next page:

NGS PT. ID	As Surveyed (ft)			Published (ft)			Residual Errors		
	Northing (ft)	Easting (ft)	Elevation (ft)	Northing (ft)	Easting (ft)	Elev (ft)	Delta N	Delta E	Delta Elev
DE7265	2114091.374	2512246.451	878.371	2114091.34	2512246.54	N/A	0.034	-0.089	N/A
DE7369	2000306.975	2626576.682	752.531	2000307.03	2626576.66	N/A	-0.055	0.022	N/A
AH2885	2115257.731	844765.863	979.147	2115257.72	844765.87	979.07	0.011	-0.007	0.077
AJ2947	2009226.243	890000.427	823.967	2009226.32	890000.41	N/A	-0.077	0.017	N/A
NH0229	1977594.234	895189.995	832.81	1977594.26	895189.97	832.84	-0.026	0.025	-0.03
NH0504	1991140.868	2525732.865	772.743	1991140.86	2525732.87	772.77	0.008	-0.005	-0.027
NH0472	2050754.052	2525550.749	802.635	2050754.11	2525550.74	802.66	-0.058	0.009	-0.025
						Number of check points	7	7	4
						Mean Error	-0.0232857	-0.004	-0.00125
						Standard deviation	0.0419115	0.039501055	0.05220712
						RMSE(ft)	0.0535444	0.043529301	0.040454913
						RMSEr (ft)	0.0690058		
						RMSEr (cm)	2.1032967		
					Horizontal Accuracy (ACCr) at 95% Confidence Level (cm)		5.1488703		
					Horizontal Accuracy (ACCr) at 95% Confidence Level (ft)		0.1689262		
					Vertical Accuracy (ACCz) at 95% Confidence Level (cm)				2.379816904

Above indicates that the accuracies would meet the 2.5cm horizontal and vertical accuracy class of the ASPRS Positional Accuracy Standards.

2.5   *Data Processing Procedures*

After the Survey crew collects the field data, the information is uploaded from the data collectors to a FTP site, and then downloaded into the office software. The program used for this project is called Trimble Business Center (TBC).

Data is imported into this program to obtain the following reports; Point list reports and Point Derivation Report. This is completed to check the accuracy and precision of each individual report, as well as confirm that the proper coordinate systems were used while observing points in the field. After careful review, the points shot are exported out of TBC into a .csv file for the final product.

3. FINAL COORDINATES

Winnebago County, Illinois				
POINT #	NORTHING (FT)	EASTING (FT)	ELEV. (FT)	COORDINATE SYSTEM
CALIBRATION POINTS				
CAL 701	2070469.648	2625432.066	900.181	IL-WEST
CAL 702	2121031.331	2533110.532	765.262	IL-WEST
CAL 703	2033121.806	2515482.884	889.684	IL-WEST
CAL 704	2074195.792	2543809.592	738.991	IL-WEST
CAL 705	2110973.087	2504566.790	854.120	IL-WEST
CAL 706	2096584.617	2564403.879	734.895	IL-WEST
CAL 707	2024355.091	2526234.772	878.654	IL-WEST
CAL 708	2005409.968	2618573.658	772.475	IL-WEST
CAL 709	2118016.771	2592555.401	774.148	IL-WEST
CAL 710	2115081.598	2614874.282	788.445	IL-WEST
CAL 711	2060859.911	2603308.791	751.480	IL-WEST
CAL 712	2028687.891	2618093.152	795.689	IL-WEST
CAL 713	2078643.619	2591548.646	786.295	IL-WEST
CAL 714	2072721.842	2515481.441	852.668	IL-WEST
CAL 715	2062187.265	2514916.186	743.398	IL-WEST
CAL 716	2031710.340	2565576.381	838.115	IL-WEST
CAL 717	2004229.863	2573588.792	714.847	IL-WEST
CAL 718	2087719.046	2623073.360	898.173	IL-WEST
NVA CHECK POINTS				
NVA 501	2070265.592	2622486.132	896.015	IL-WEST
NVA 502	2120278.251	2533281.047	768.275	IL-WEST
NVA 503	2032996.410	2510239.805	851.950	IL-WEST
NVA 504	2075161.772	2544606.091	738.575	IL-WEST
NVA 505	2111425.513	2505292.309	870.154	IL-WEST
NVA 506	2099051.392	2564362.667	731.606	IL-WEST
NVA 507	2028058.413	2526151.529	898.068	IL-WEST
NVA 508	2004788.251	2597392.643	744.967	IL-WEST
NVA 509	2118425.727	2593339.043	776.574	IL-WEST
NVA 510	2116520.534	2613539.16	783.817	IL-WEST
NVA 511	2061147.153	2603540.108	752.885	IL-WEST
NVA 512	2029778.034	2618093.668	788.655	IL-WEST
NVA 513	2077873.532	2591238.703	795.934	IL-WEST
NVA 514	2073443.420	2514772.046	873.997	IL-WEST
NVA 515	2059856.629	2514975.432	749.665	IL-WEST
NVA 516	2033172.673	2567054.845	813.475	IL-WEST
NVA 517	1998422.361	2574010.237	733.228	IL-WEST

POINT #	NORTHING (FT)	EASTING (FT)	ELEV. (FT)	COORDINATE SYSTEM
NVA CHECK POINTS CONTINUED				
NVA 518	2088851.309	2622169.587	873.100	IL-WEST
NVA 519	2116740.245	2558251.031	837.524	IL-WEST
NVA 520	2022510.215	2583097.017	727.656	IL-WEST
NVA 521	2065906.875	2558090.637	867.761	IL-WEST
NVA 522	2048761.982	2584656.088	729.424	IL-WEST
NVA 523	2054776.004	2542581.309	887.390	IL-WEST
NVA 524	2044248.579	2605054.583	798.234	IL-WEST
NVA 525	2033823.784	2549824.885	893.630	IL-WEST
NVA 526	2119742.456	2511898.749	862.539	IL-WEST
NVA 527	2000329.989	2626387.155	752.746	IL-WEST
NVA 528	2085220.180	2607704.408	739.575	IL-WEST
NVA 529	2026422.348	2613008.176	814.846	IL-WEST
NVA 530	2043915.351	2625877.610	848.905	IL-WEST
NVA 531	2096011.714	2545999.528	758.937	IL-WEST
NVA 532	2095926.236	2503886.893	938.640	IL-WEST
NVA 533	2055465.900	2562256.394	793.441	IL-WEST
NVA 534	2105901.327	2613091.665	779.946	IL-WEST
NVA 535	2089001.411	2580098.892	837.303	IL-WEST
VVA CHECK POINTS				
VVA 601	2070204.817	2622384.025	898.693	IL-WEST
VVA 602	2120155.883	2534309.345	754.858	IL-WEST
VVA 603	2032730.844	2510299.264	849.426	IL-WEST
VVA 604	2074888.717	2545070.738	738.044	IL-WEST
VVA 605	2111113.655	2504947.374	835.489	IL-WEST
VVA 606	2099392.569	2564429.142	730.338	IL-WEST
VVA 607	2027457.847	2526219.203	884.616	IL-WEST
VVA 608	2004800.536	2596255.812	750.084	IL-WEST
VVA 609	2118279.169	2593364.780	778.240	IL-WEST
VVA 610	2116616.971	2613121.235	781.944	IL-WEST
VVA 611	2061113.689	2604093.565	760.005	IL-WEST
VVA 612	2030488.280	2618014.828	774.471	IL-WEST
VVA 613	2077436.340	2590805.359	804.166	IL-WEST
VVA 614	2074312.356	2514679.170	855.094	IL-WEST
VVA 615	2059994.821	2514686.944	741.851	IL-WEST
VVA 616	2033084.024	2565921.943	836.448	IL-WEST
VVA 617	1999308.632	2573744.587	720.035	IL-WEST
VVA 618	2089328.054	2621709.557	856.202	IL-WEST
VVA 619	2116589.162	2558171.410	833.660	IL-WEST
VVA 620	2022561.222	2583018.699	726.854	IL-WEST
VVA 621	2066096.870	2556863.316	840.630	IL-WEST
VVA 622	2048845.495	2584788.997	730.302	IL-WEST
VVA 623	2055035.218	2542511.865	885.074	IL-WEST

POINT #	NORTHING (FT)	EASTING (FT)	ELEV. (FT)	COORDINATE SYSTEM
VVA CHECK POINTS CONTINUED				
VVA 624	2043949.384	2604613.222	812.229	IL-WEST
VVA 625	2032976.189	2549887.780	912.796	IL-WEST
Boone County, Illinois				
POINT #	NORTHING (FT)	EASTING (FT)	ELEV. (FT)	COORDINATE SYSTEM
CALIBRATION POINTS				
CAL 1701	2051862.416	878216.298	802.587	IL-EAST
CAL 1702	2106307.521	844556.751	984.168	IL-EAST
CAL 1703	2115207.600	878294.244	994.194	IL-EAST
CAL 1704	2073970.266	827200.679	930.438	IL-EAST
CAL 1705	2062311.178	880934.847	858.895	IL-EAST
CAL 1706	2001440.504	881174.874	839.840	IL-EAST
CAL 1707	2027282.822	853234.960	865.417	IL-EAST
CAL 1708	2001447.861	839093.207	806.218	IL-EAST
CAL 1709	2048855.805	867665.682	813.934	IL-EAST
CAL 1710	2060979.104	867714.141	828.527	IL-EAST
CAL 1711	2078251.699	841570.664	925.934	IL-EAST
CAL 1712	2037259.080	822424.283	759.715	IL-EAST
NVA CHECK POINTS				
NVA 1501	2053022.725	878215.556	808.401	IL-EAST
NVA 1502	2106072.131	841919.122	965.819	IL-EAST
NVA 1503	2112564.366	883451.347	943.124	IL-EAST
NVA 1504	2072895.210	829600.427	934.876	IL-EAST
NVA 1505	2067556.377	883595.626	838.479	IL-EAST
NVA 1506	2001422.943	883284.948	842.698	IL-EAST
NVA 1507	2025362.855	853991.475	850.475	IL-EAST
NVA 1508	2002103.238	841068.650	801.108	IL-EAST
NVA 1509	2049828.139	867663.873	832.046	IL-EAST
NVA 1510	2065028.708	867721.370	818.783	IL-EAST
NVA 1511	2078264.150	843116.661	917.993	IL-EAST
NVA 1512	2036943.158	822953.243	758.035	IL-EAST
NVA 1513	2122252.256	858103.282	973.447	IL-EAST
NVA 1514	2087485.820	869813.728	899.466	IL-EAST
NVA 1515	2023072.853	841258.475	806.963	IL-EAST
NVA 1516	2099366.703	832953.347	941.048	IL-EAST
NVA 1517	2029357.682	878156.921	786.329	IL-EAST
NVA 1518	2051291.112	835603.539	810.601	IL-EAST
NVA 1519	2123154.857	832887.949	924.778	IL-EAST
NVA 1520	2072983.811	855877.758	845.807	IL-EAST
NVA 1521	2011994.234	830519.917	844.875	IL-EAST
NVA 1522	1999821.586	867142.977	856.848	IL-EAST
NVA 1523	2014059.548	865114.130	826.128	IL-EAST
NVA 1524	2088873.308	844318.754	953.813	IL-EAST

POINT #	NORTHING (FT)	EASTING (FT)	ELEV. (FT)	COORDINATE SYSTEM
NVA CHECK POINTS CONTINUED				
NVA 1525	1998906.614	830436.917	788.841	IL-EAST
VVA CHECK POINTS				
VVA 1601	2054300.998	878148.451	809.727	IL-EAST
VVA 1602	2106028.965	841555.987	969.287	IL-EAST
VVA 1603	2112628.859	881548.145	954.247	IL-EAST
VVA 1604	2072848.457	830377.278	936.049	IL-EAST
VVA 1605	2066856.987	883553.799	834.303	IL-EAST
VVA 1606	2001387.337	882611.311	842.144	IL-EAST
VVA 1607	2025308.872	855927.898	860.700	IL-EAST
VVA 1608	2001254.217	840963.534	794.980	IL-EAST
VVA 1609	2050471.909	867714.411	837.833	IL-EAST
VVA 1610	2064983.386	866402.796	816.945	IL-EAST
VVA 1611	2078382.030	842878.39	920.882	IL-EAST
VVA 1612	2037285.291	822606.523	757.960	IL-EAST
VVA 1613	2122152.080	861170.57	960.083	IL-EAST
VVA 1614	2087559.907	870494.394	899.528	IL-EAST
VVA 1615	2023774.914	841215.927	794.260	IL-EAST