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Northeast Illinois Lidar

Report Produced for U.S. Geological Survey

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EXECUTIVE SUMMARY

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (lidar) technology for the Northeast Illinois Lidar Project Area.

The lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 2500ft by 2500ft. A total of 14,829 tiles were produced for the project encompassing an area of approximately 3,324 sq. miles.

THE PROJECT TEAM

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for LAS classification, all lidar products, breakline production, Digital Elevation Model (DEM) production, and quality assurance.

Dewberry's Gary D. Simpson completed ground surveying for the project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the lidar-derived surface model. He also verified the GPS base station coordinates used during lidar data acquisition to ensure that the base station coordinates were accurate. Please see Appendix A to view the separate Survey Report that was created for this portion of the project.

Harris Corporation completed lidar data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report falls within the Illinois counties of Cook, Kane, McHenry, and Lake.

DATE OF SURVEY

The lidar aerial acquisition was conducted from April 16, 2017 through May 7, 2017.

COORDINATE REFERENCE SYSTEM

Data produced for the project were delivered in the following reference system.

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 15
Units: Horizontal units are in U.S. Survey Feet, Vertical units are in U.S. Survey Feet.
Geiod Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the Northeast Illinois Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **5.1 cm (0.17 ft)** compared with the 10 cm specification; and the NVA of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to **10.1 cm (0.33 ft)**, compared with the 19.6 cm specification.

For the Northeast Illinois Lidar Project, the tested VVA of the classified lidar data computed using the 95^{th} percentile was equal to **10.2 cm (0.34 ft),** compared with the 29.4 cm specification.

Additional accuracy information and statistics for the classified lidar data, raw swath data, and bare earth DEM data are found in the following sections of this report.

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (Raster DEM – IMG Format)
3. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
4. Breakline Data (File GDB)
5. Independent Survey Checkpoint Data (Report, Photos, & Points)
6. Calibration Points
7. Metadata
8. Project Report (Acquisition, Processing, QC)
9. Project Extents, including a shapefile derived from the lidar deliverable

PROJECT TILING FOOTPRINT

Fourteen thousand eight hundred twenty nine (14,829) tiles were delivered for the project. Each tile's extent is 2,500 feet by 2,500 feet (see Appendix B for a complete listing of delivered tiles).

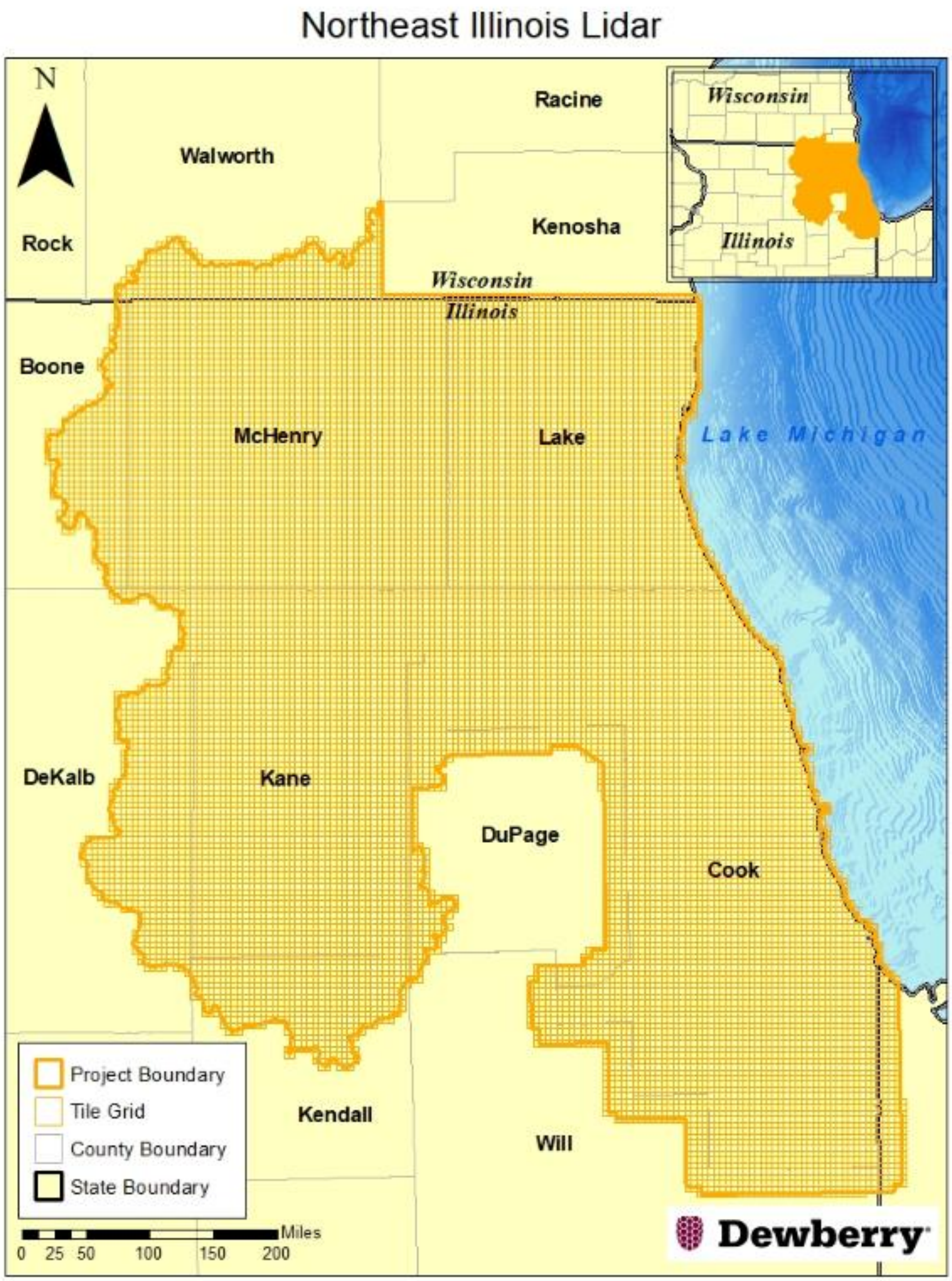


Figure 1 - Project Map

Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities to Harris Corporation. Harris Corporation was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry.

Dewberry received calibrated swath data from Harris Corporation on June 19, 2017.

LIDAR ACQUISITION DETAILS

Harris Corporation planned 254 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Harris Corporation followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Harris' custom Mission Planner flight design software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Harris Corporation will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Harris Corporation monitored weather and atmospheric conditions and conducted lidar missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Harris Corporation accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, Harris Corporation closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

Harris Corporation lidar sensors are calibrated at a designated site located at the Kenosha Regional Airport in Kenosha, WI and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Harris Corporation operated a Beechcraft King Air 200 (Tail #(s) N40R, N46L and N49R) outfitted with a Harris GmAPD lidar system during the collection of the study area. Table 1 illustrates Harris Corporation's system parameters for lidar acquisition on this project.

Item	Parameter
System	Harris GmAPD Mapping LiDAR Sensor
Altitude (AGL meters)	7620
Approx. Flight Speed (knots)	240
Scanner Pulse Rate (kHz)	50
Scan Frequency (hz)	17.7
Pulse Duration of the Scanner (nanoseconds)	0.46
Pulse Width of the Scanner (m)	0.138
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	0.05
Nominal Swath Width on the Ground (m)	3810
Swath Overlap (%)	55
Total Sensor Scan Angle (degree)	30
Computed Down Track spacing (m) per beam	N/A
Computed Cross Track Spacing (m) per beam	N/A
Nominal Pulse Spacing (single swath), (m)	N/A
Nominal Pulse Density (single swath) (ppsm), (m)	5
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	N/A
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	10
Maximum Number of Returns per Pulse	1 per detector (4096 detectors)

Table 1: Harris Corporation lidar system parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The Acquisition Manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 2 shows the combined trajectory of the flightlines.

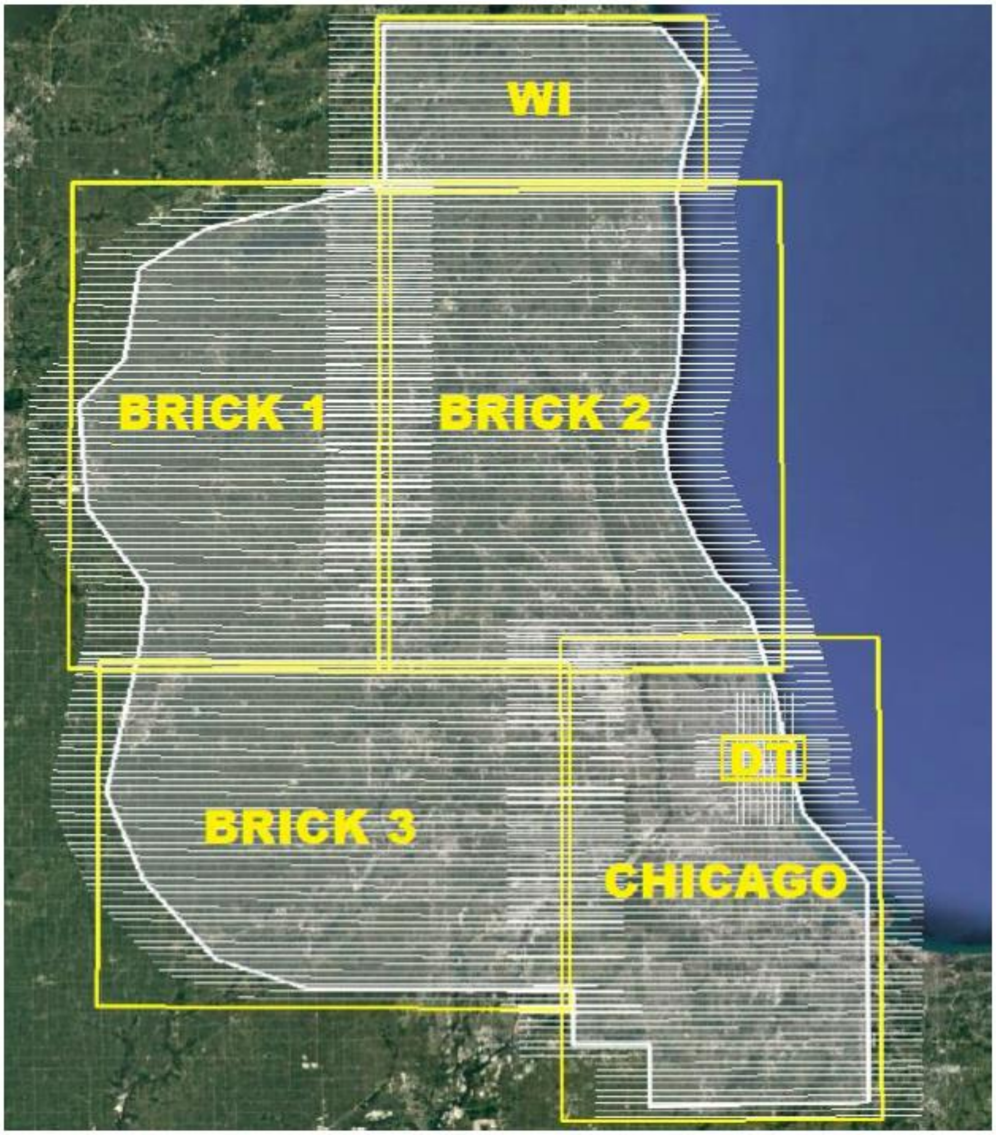


Figure 2: Trajectories as flown by Harris Corporation

LIDAR CONTROL

Forty-three existing NGS monuments and sixty-two newly established base stations were used to control the lidar acquisition for the Northeast Illinois lidar project area. The coordinates of all used base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

Design Name	As-Staked Name	Code	Design Northing	Design Easting	Design Elevation	Δ Northing	Δ Easting	Δ Elevation
NG0793	10000	CK NG0793	2158060.918	1085908.831	729.23	0.01	-0.03	-0.02
NG0793	10001	CK NG0793	2158060.918	1085908.831	729.23	0.05	-0.03	0.11
DG4959	10002	CK DG4959 VRSnow	2122386.616	874205.634	972.30	0.04	-0.04	-0.01
DG4959	10003	CK DG4959	2122386.616	874205.634	972.30	0.02	-0.03	0.00
DE7312	10004-1	CK DE7312	2078125.624	819973.070	915.61	-0.02	-0.01	0.13
DE7312	10005	DE7312 WISCORS	2078125.624	819973.070	915.61	-0.05	0.00	0.17
AE2581	10006	CK AE2581	1749857.706	1117320.102	785.05	-0.02	-0.01	0.10
ME1440	10007	CK ME1440	1760987.003	1196577.410	632.90	0.07	0.07	0.89
ME2498	10008	CK ME2498	1799165.879	1238223.151	592.86	-0.06	-0.20	0.00
AJ2766	10009	CK AJ2766	1781124.270	1020782.835	609.35	-0.05	0.05	0.12
DP5459	10010	CK DP5459	1791299.172	1080832.604	741.35			0.15
MF1248	10011	CK MF1248	1833569.176	1073614.049	747.64	0.03	0.02	0.36
MF1248	10012	CK MF1248	1833569.176	1073614.049	747.64	-0.02	0.00	0.24
MF1257	10013	CK MF1257	1836376.486	1073522.767	754.27			0.07
NGO793	20000-1	NGO793	2158060.918	1085908.831	842.88	0.00	-0.04	113.69
AJ2862	20001-1	AJ2862	2027352.668	1044313.982	854.99	0.01	-0.01	-0.04
ME1657	20003-1	ME1657	1915624.457	1125627.880	641.61	0.02	0.01	0.04
DF7926	20005-1	DF7926	1853207.717	1064114.342	757.54	0.00	0.05	0.11
DF0963	20006-1	DF0963	1866953.905	1064778.653	692.42			0.09
DF9847	20007	DF9847	2250453.030	1037204.261	772.36	0.02	-0.01	0.04
DF9847	20008	DF9847	2250453.030	1037204.261	772.36	0.00	-0.04	0.01
AJ2823	23000	AJ2823	1940246.119	1085054.521	673.15	0.02	-0.04	0.00
ME2498	10100	CK ME2498	1799165.879	1238223.151	592.86	-0.05	-0.17	0.12
ME1825	10101	CK ME1825	1819560.309	1196119.932	584.92	-0.08	-0.08	0.13
ME1604	10102	CK ME1604	1757277.198	1143654.948	736.16	0.01	0.09	-0.23
ME1944	10103	CK ME1944	1781751.133	1143317.004	696.68			0.04
AE2559	10104	CK AE2559	1813187.605	1099403.680	687.53	0.00	0.07	0.21
AE2559	10105	CK AE2559	1813187.605	1099403.680	687.53	0.01	0.05	0.21
ME2724	10106	CK ME2724	1874274.525	1174903.934	594.03	0.12	0.03	0.12
DG4988	21000	DG4988	2227812.532	1138436.414	592.88	0.04	-0.02	0.11
DF9473	21001	DF9473	2127904.270	1122030.680	627.61	-0.01	-0.03	0.07
AJ2897	21002	AJ2897	2112292.391	1097492.924	725.45	-0.04	0.03	0.04
AJ2897	21003	AJ2897	2112292.391	1097492.924	725.45	-0.05	0.04	0.02
DM3884	21004	DM3884	2071149.548	1102811.003	719.20			0.01
AJ2864	21005	AJ2864	2027532.434	1113944.684	678.80	0.01	-0.02	0.10
ME1695	21006	ME1695	1926434.852	1085860.552	694.50	0.05	0.02	0.00
NG0793	22000	NG0793	2158060.918	1085908.831	729.23	0.01	-0.03	0.05
AJ2897	22001	AJ2897	2112292.391	1097492.924	725.45	-0.04	0.04	0.06
ME1921	22002	ME1921	1942510.036	1163108.580	619.00	0.02	0.01	0.05
DF9473	22003	DF9473	2127904.270	1122030.680	627.61	0.01	-0.03	0.07
DF9473	22004	DF9473	2127904.270	1122030.680	627.61	0.01	-0.02	0.03
DG4988	22005	DG4988	2227812.532	1138436.414	592.88	-0.03	-0.02	0.15
DF9472	22006	DF9472	2131709.704	994474.696	859.59	0.01	-0.07	0.04

Table 2 – Base stations used to control lidar acquisition

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the PosPac kinematic Mobile Mapping Suite 8.0 software suite. Flights were flown with a minimum of 6 satellites in view (10° above the horizon) and with a PDOP of 3 or less. Distances from base station to aircraft were kept to a maximum of 40 km.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3 cm average or better but no larger than 10 cm being recorded.

GPS processing reports for each mission are included in Appendix C.

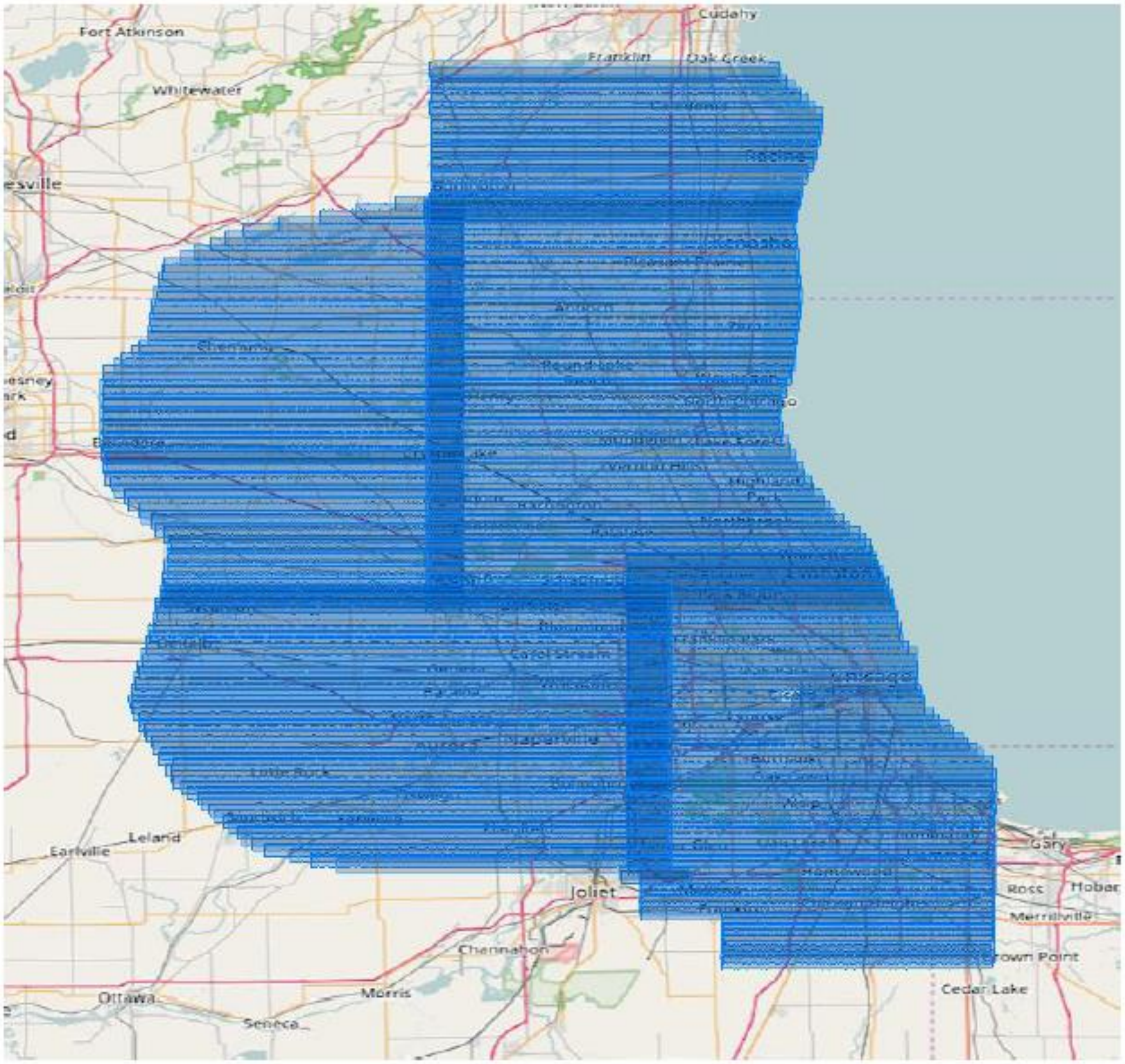
GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Subsequently the mission points are output using Applanix, initially with default values from Applanix or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the lidar unit is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.


Fort Atkinson
Whitewater
Cudahy
Franklin
Oak Creek
Leland
Earlville
Joliet
Channahon
Ottawa
Morris
Seneca
Gary
Ross
Merrillville
Cedar Lake

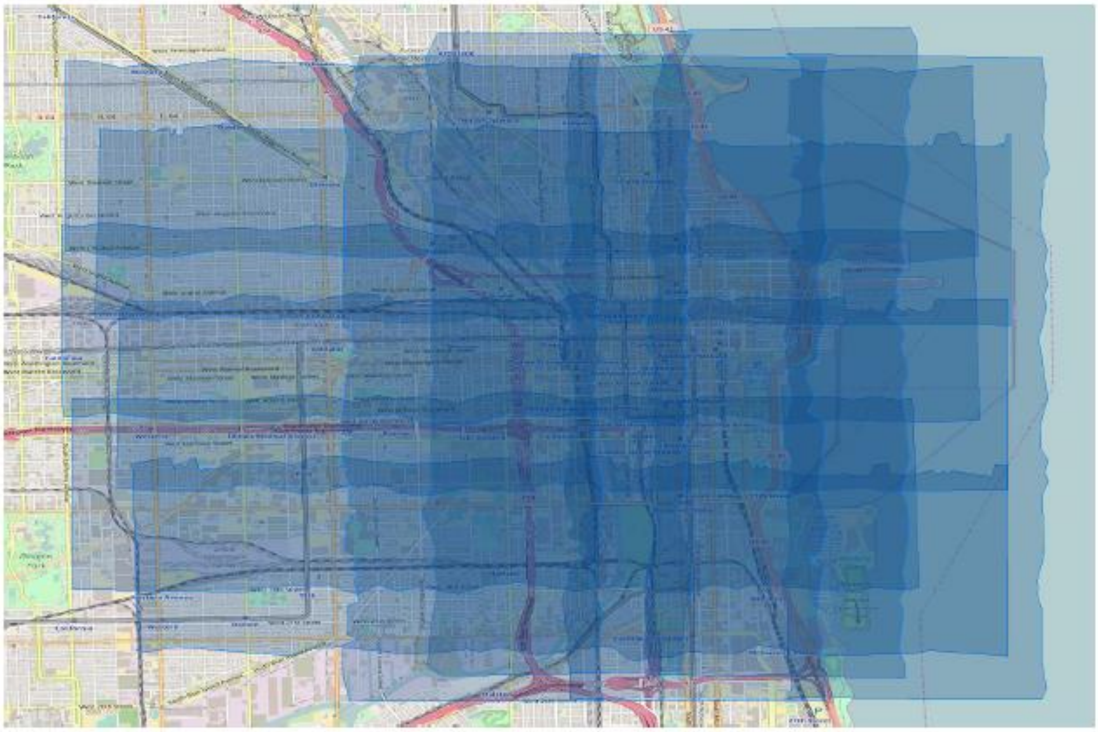


Figure 3 – Lidar swath output showing complete coverage.

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check is performed by Harris Corporation at this stage of the project life cycle in the raw lidar dataset against GPS static and kinematic data and compared to $RMSE_z$ project specifications. The lidar data is examined in non-vegetated, flat areas away from breaks. Lidar ground points for each flight line generated by an automatic classification routine are used.

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met Non-vegetated Vertical Accuracy (NVA) requirements ($RMSE_z \leq 10$ cm and $Accuracy_z$ at the 95% confidence level ≤ 19.6 cm) when compared to static and kinematic GPS checkpoints.

Lidar Processing & Qualitative Assessment

INITIAL PROCESSING

Once Dewberry receives the calibrated swath data from the acquisition provider, Dewberry performs several validations on the dataset prior to starting full-scale production on the project. These validations include vertical accuracy of the swath data, inter-swath (between swath) relative accuracy validation, intra-swath (within a single swath) relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allows Dewberry to determine if the data are suitable for full-scale production. Addressing issues at this stage allows the data to be corrected while imposing the least disruption possible on the overall production workflow and overall schedule.

Final Raw Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Harris, Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the 114 non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 cm (0.64 ft) based on the $RMSE_z$ (10 cm) x 1.96. The dataset for the Northeast Illinois Lidar Project satisfies this criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm (0.33 ft) $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 8.8 cm (0.29 ft), equating to +/- 17.3 cm (0.57 ft) at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec= 0.33 ft	NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec= 0.64 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Min (ft)	Max (ft)	Kurtosis
Non-Vegetated Terrain	114	0.29	0.57	-0.10	-0.08	-4.23	0.27	-2.04	0.41	27.56

Table 3: NVA at 95% Confidence Level for Raw Swaths

Two checkpoints (220A and 406A) were removed from the swath vertical accuracy testing for the unclassified lidar due to their proximity to artifacts in the terrain – one falling under a power line, and the other under a tree. Only non-vegetated terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation, structures, and other above ground features from the ground classification. While these points are located in open terrain, the overhead power line and trees are modeled by the lidar point cloud. These high points caused erroneous high values during the swath vertical accuracy testing so these points were removed from the final calculations. Once the data underwent the classification process, the power lines and trees were removed from the final ground classification and these points could be used in the final vertical accuracy testing for the fully classified lidar data. Table 4, below, provides the coordinates for this checkpoint and the vertical accuracy results from the raw swath data. The differences in the tables show how above ground features can cause erroneous vertical accuracy results in the raw swath data. Figures 4 and 5, below, show 3D models of the lidar point cloud and the location of the checkpoint beneath near embankments and/or ditches.

Point ID	NAD83(2011) State Plane VA		NAVD88 (Geoid 12B)	Lidar Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
220A	944927.67	1924848.87	956.92	942.86	-14.06	14.06
406A	1113316.66	2066036.70	671.35	627.83	-43.52	43.52

Table 4: Checkpoints removed from vertical accuracy testing due to their location near surrounding objects in the terrain

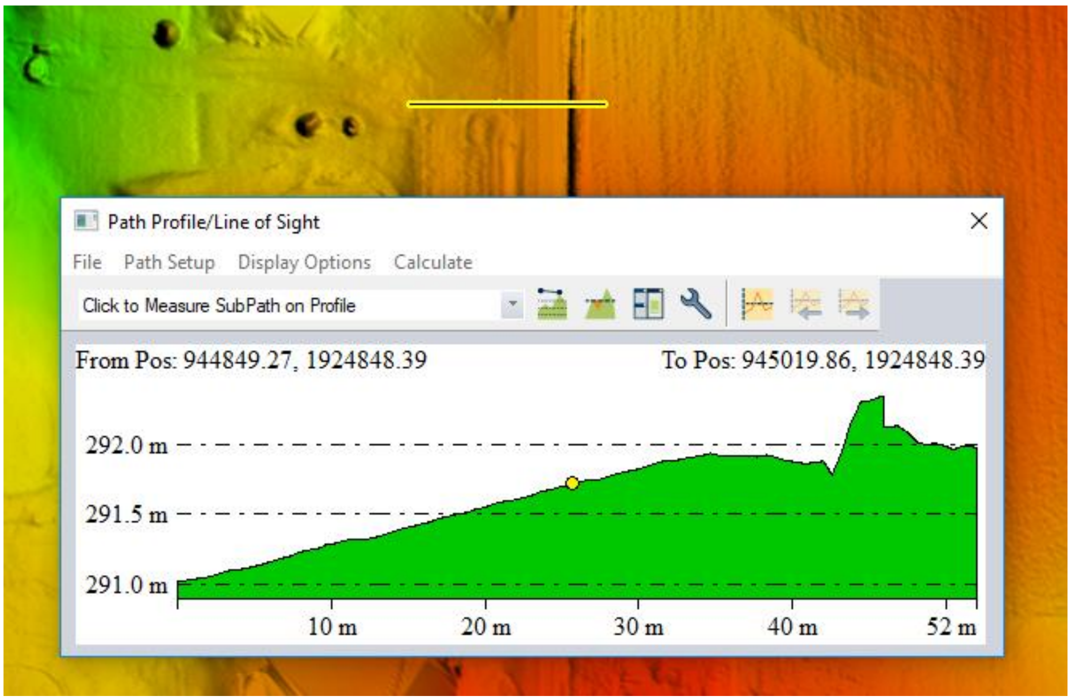


Figure 4 – Checkpoint 220A, shown as the yellow circle in the profile, is located on a steep road embankment. This checkpoint was removed from all vertical accuracy calculations due to its proximity to breaks in the terrain.

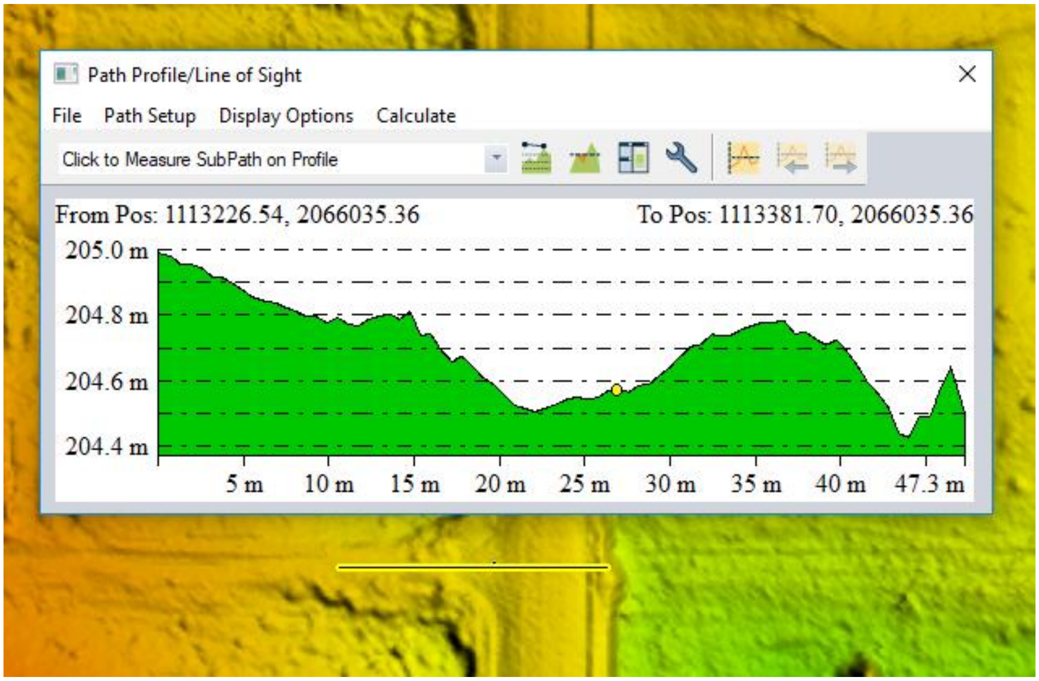


Figure 5 – Checkpoint 406A, shown as the yellow circle in the profile, is located very near to a ditch and steep embankments along a road. This checkpoint was removed from all vertical accuracy calculations due to its proximity to breaks in the terrain.

Inter-Swath (Between Swath) Relative Accuracy

The Northeast Illinois Lidar project was collected using a Geiger-Mode lidar sensor. Geiger mode sensors do not collect data in “swaths” so inter-swath relative accuracy does not apply to this dataset.

Intra-Swath (Within a Single Swath) Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using Quick Terrain Modeler (QTM) scripting and visual reviews. QTM scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry analysts then identify planar surfaces acceptable for repeatability testing and analysts review the QTM results in those areas. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet intra-swath relative accuracy of 6 cm maximum difference or less. The intra-swath relative accuracy of Northeast Illinois Lidar project met intra-swath relative accuracy specifications.

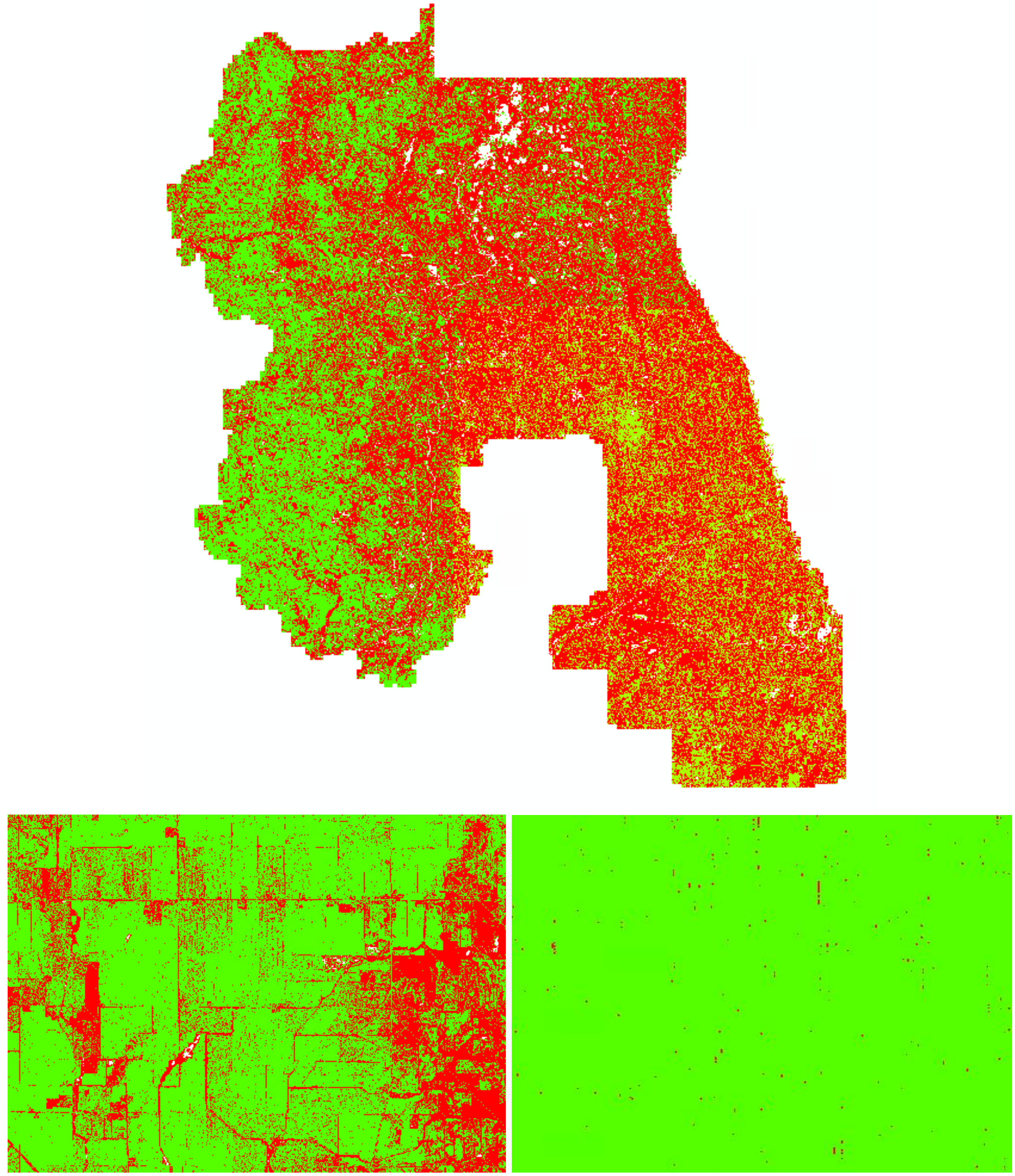


Figure 6 – Intra-swath relative accuracy. The top image shows the full project area; areas where the maximum difference is ≤0.2 ft per pixel within each swath are colored green and areas exceeding 0.2 ft are colored red. The bottom left image shows a large portion of the dataset; flat, open areas are colored green as they are within 0.2 ft whereas sloped terrain is colored red because it exceeds 0.2 ft maximum difference, as expected, due to actual slope/terrain change. The right image is a close-up of a flat area. With the exception of few trees (shown in red as the elevation/height difference in vegetated areas will exceed 0.2 ft) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.224 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 20 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.224 meters or an ANPD of 20 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 20 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.

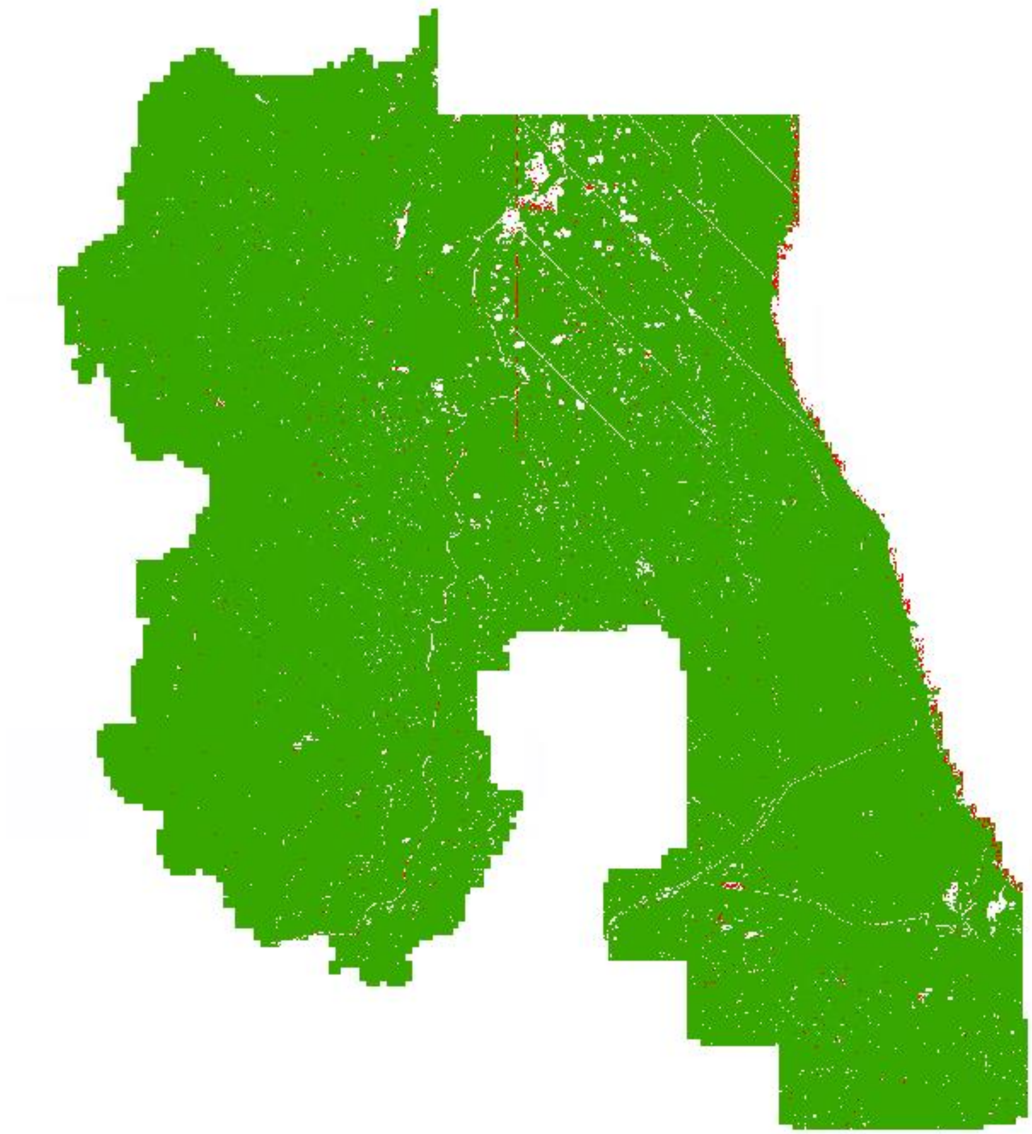


Figure 7 – 1-square meter density grid. There are some 1- meter cells that do not contain 20 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1- square meter cells contain at least 20 points per square meter (green areas) showing there are no systematic density issues. When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues.

The spatial distribution of points must be uniform and free of clustering. This specification is tested by creating a grid with cell sizes equal to the design NPS*2. ArcGIS tools are then used to calculate the number of first return points of each swath within each grid cell. At least 90% of the cells must contain 1 lidar point, excluding acceptable void areas such as water or low NIR reflectivity features, i.e. some asphalt and roof composition materials. This project passes spatial distribution requirements, as shown in the image below.

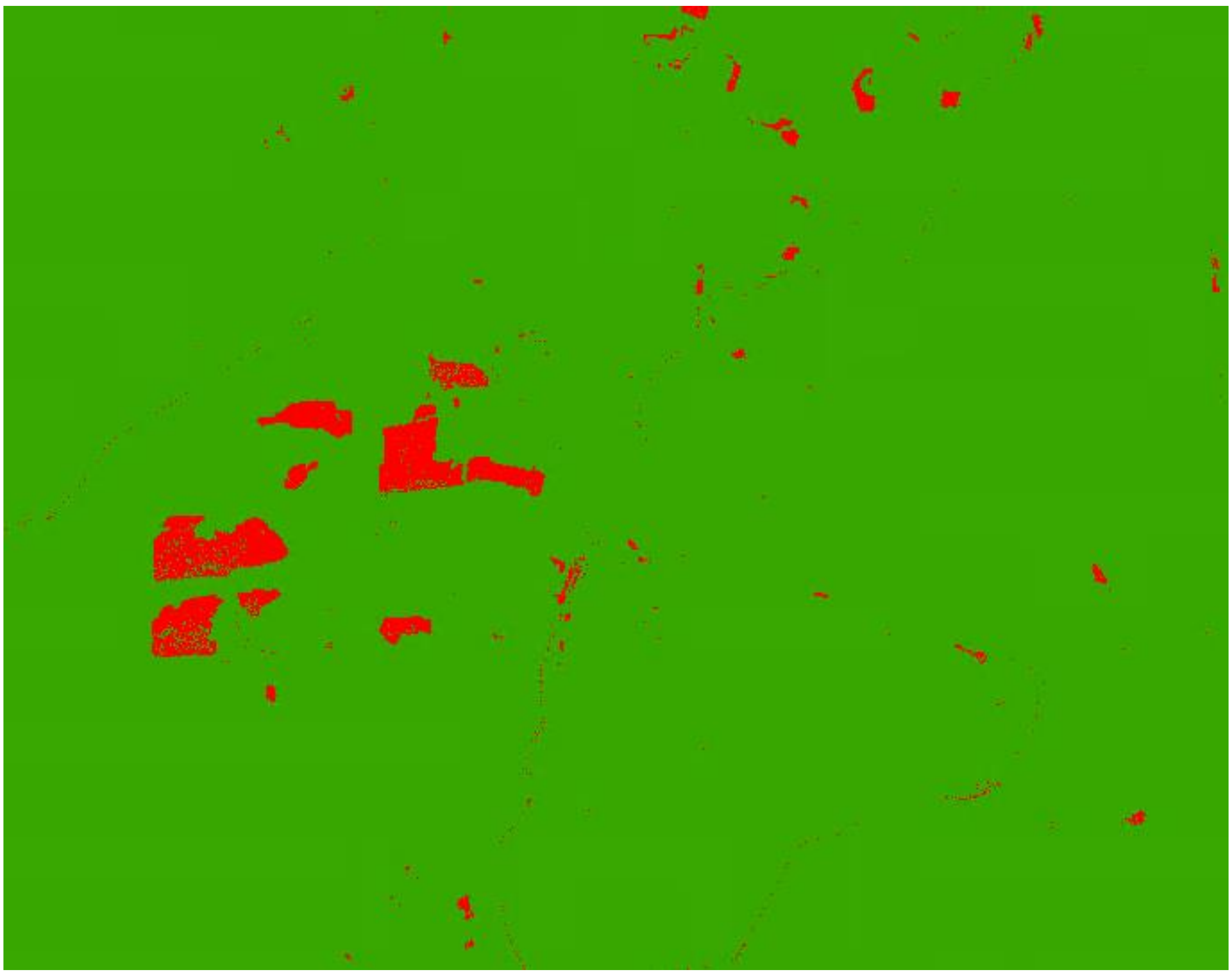


Figure 8 – Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies which are acceptable NoData area, are colored red. Without removing acceptable NoData areas due to water, 98.46% of cells contain at least one lidar point.

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model. Additional classification routines were applied to the Northeast Illinois Lidar project. Northeast Illinois Lidar project required buildings to be assigned to class 6 and Low vegetation, medium vegetation, and high vegetation were classed to class 3, 4, 5 respectively based on height parameters provided by the client.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

Each tile was then imported into Terrascan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. Bridge decks are classified to class 17 using bridge breaklines compiled by Dewberry. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that are within 1x NPS or less of the hydrographic features are moved to class 10, an ignored ground due to breakline proximity. Overage points are then identified in Terrascan and GeoCue is used to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 10, 17, or 18, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 3 = Low Vegetation
- Class 4 = Medium Vegetation

- Class 5 = High Vegetation
- Class 6 = Buildings
- Class 7 = Low Noise
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity
- Class 17 = Bridge Decks
- Class 18 = High Noise

After manual classification, the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections, all headers, appropriate point data records, and variable length records, including spatial reference information, are updated in GeoCue software and then verified using proprietary Dewberry tools.

Lidar Qualitative Assessment

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a bare-earth digital terrain model (DTM). This includes creating pseudo image products such as lidar orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models as well as reviewing the actual point cloud data. This process looks for anomalies in the data, areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model, and other classification errors. This report will present representative examples where the lidar and post processing had issues as well as examples of where the lidar performed well.

VISUAL REVIEW

The following sections describe common types of issues identified in lidar data and the results of the visual review for Northeast Illinois.

Data Voids

The LAS files are used to produce density grids using the commercial software package QT Modeler (QTM) which creates a 3-dimensional data model derived from Class 2 (ground) points in the LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. Acceptable voids (areas with no lidar returns in the LAS files) that are present in the majority of lidar projects include voids caused by bodies of water. No unacceptable voids are present in the Northeast Illinois lidar project.

Artifacts

Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

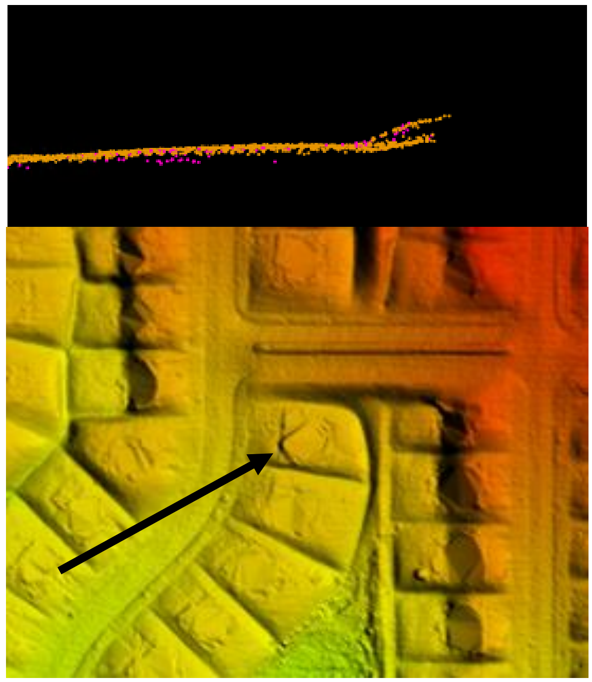


Figure 9 – Tile 10251000. Profile with points colored by class (class 1=pink, class 2=orange) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies a low porch. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

Bridge Removal Artifacts

The DEM surface models are created from TINs or Terrains. TIN and Terrain models create continuous surfaces from the inputs. Because a continuous surface is being created, the TIN or Terrain will use interpolation to continue the surface beneath the bridge where no lidar data was acquired. Locations where bridges were removed will generally contain less detail in the bare-earth surface because these areas are interpolated.

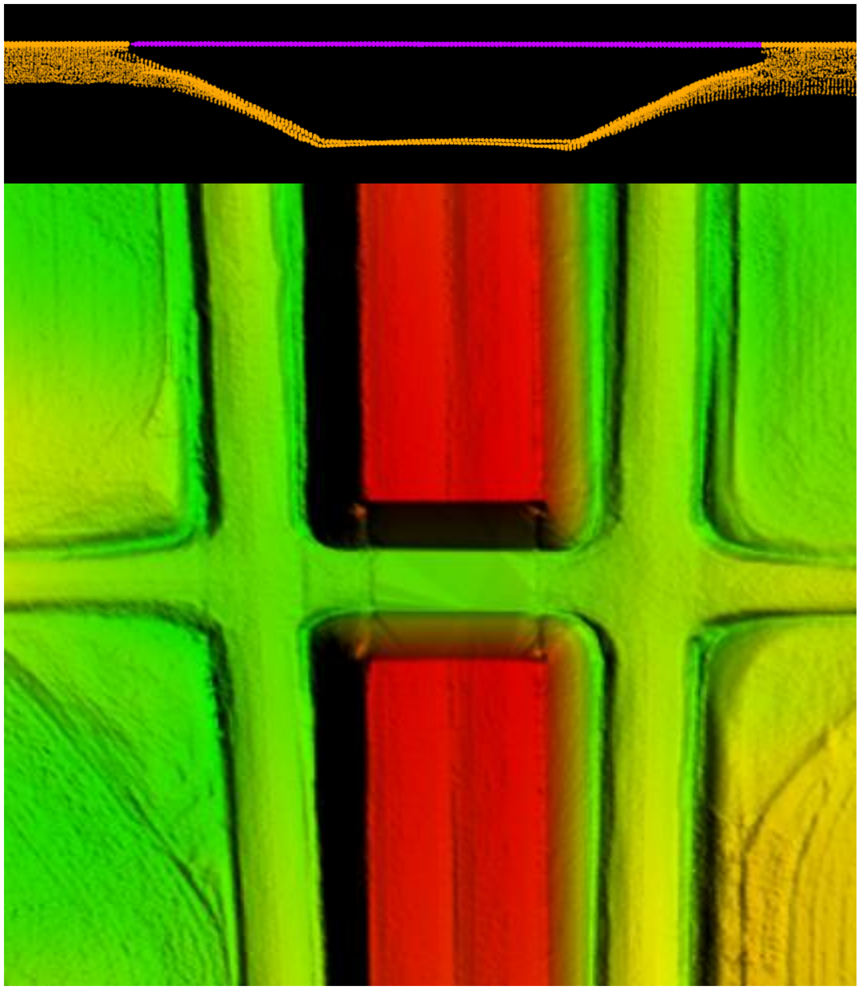


Figure 10 – Tile 08501900. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (orange) and are class 17 bridge deck (purple).

Buckshot

The anomaly known as "buckshot" – noise points surrounding retro-reflective targets – was found throughout the NEIL Lidar AOI. The noise was inconsistent and required manual editing to both class 7 low noise and class 18 high noise. Some buckshots created a visible void in the DEM, but many were not visible in the delivery DEM. Below is an example of a buckshot call from USGS with the appropriate classes assigned in the point cloud.

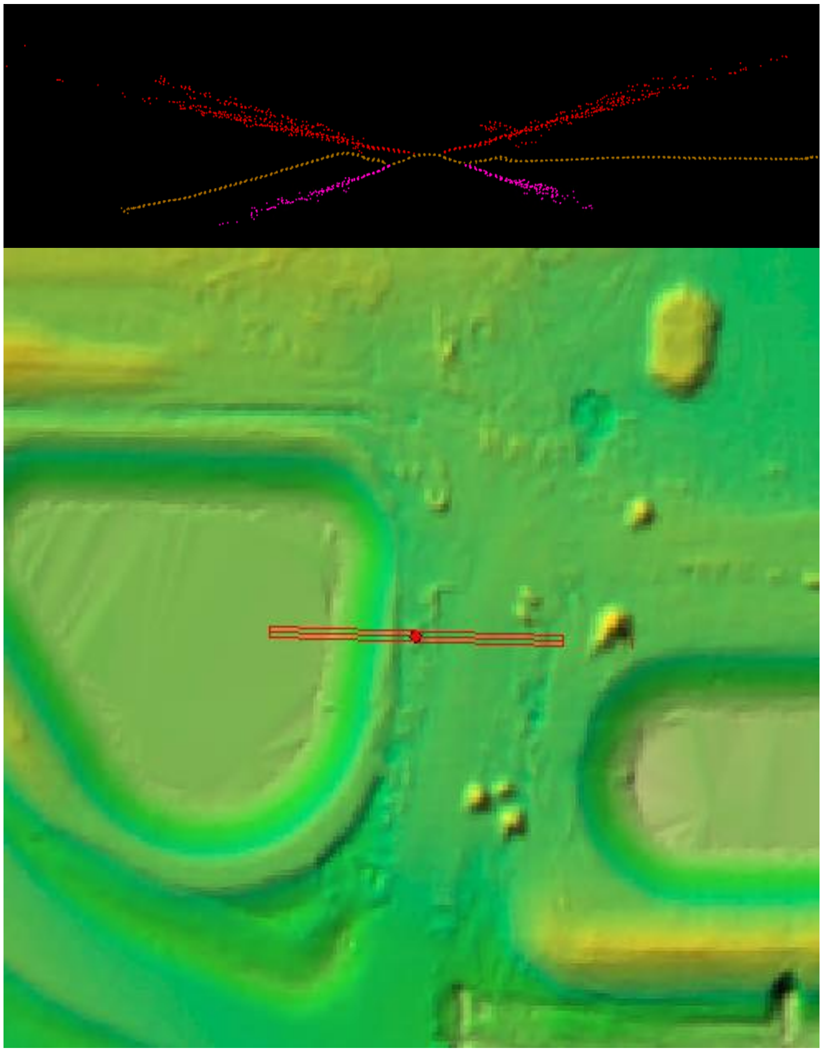


Figure 11 – Tile 08752250. The DEM in the bottom view shows a cross section drawn across the buckshot call. The buckshot is not visible in the DEM, but is visible in the cross section above at a scale is 1:1250. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. Orange represents Class 2 (ground), pink represents Class 7 (low noise), and red represents Class 18 (high noise).

Culverts and Bridges

Bridges have been removed from the bare earth surface while culverts remain in the bare earth surface. In instances where it is difficult to determine if the feature is a culvert or bridge, such as with some small bridges, Dewberry erred on assuming they would be culverts especially if they are on secondary or tertiary roads. Below is an example of a culvert that has been left in the ground surface.

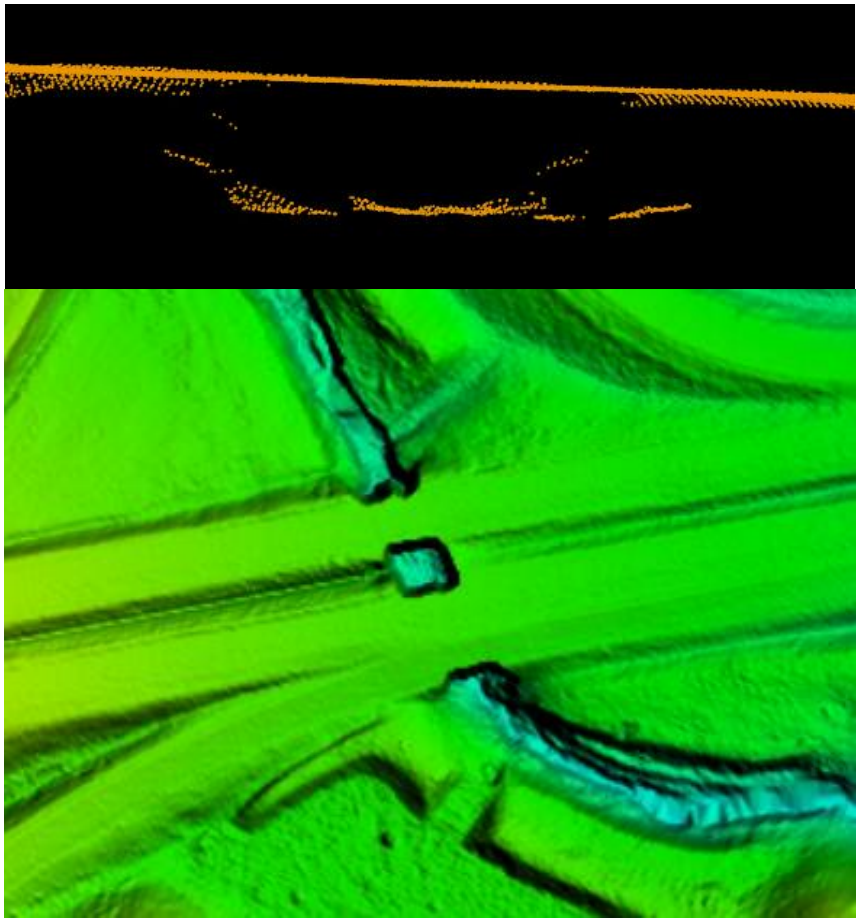


Figure 12 – Tile 08750675. Profile with points colored by class (Class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

In Ground Structures

In ground structures exist within the project area. These types of structures occur mainly on military bases and in facilities designed for munitions testing and storage. These features are correctly included in the ground classification.

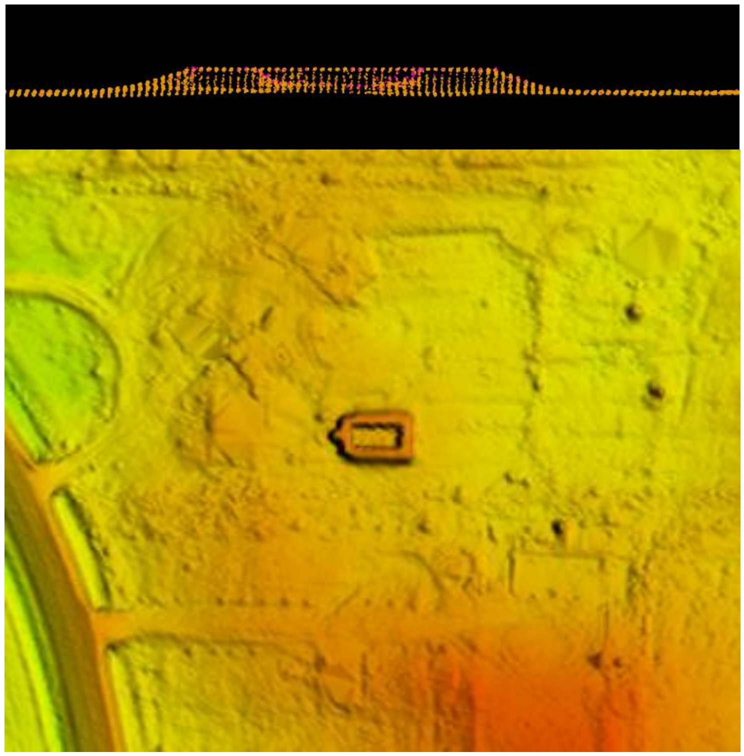


Figure 13 – Tile 91250075. Profile with the points colored by class (class 1=pink, class 2=orange) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

Dirt Mounds

Irregularities in the natural ground exist and may be misinterpreted as artifacts that should be removed. Small hills and dirt mounds are present throughout the project area. These features are correctly included in the ground.

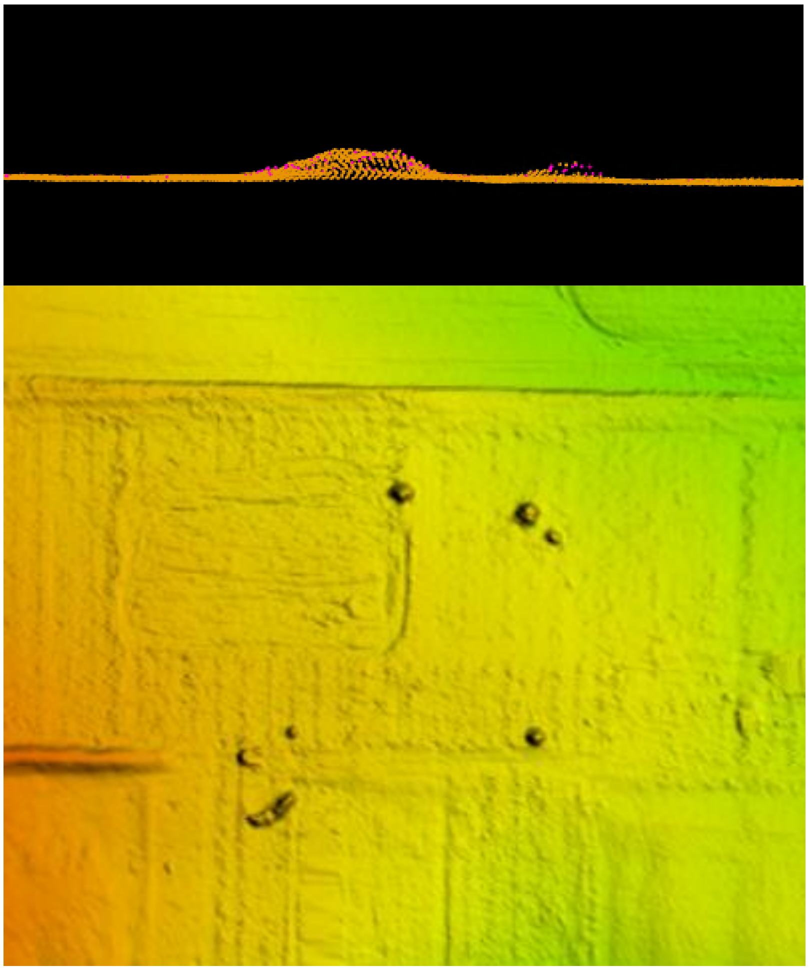


Figure 14 - Tile 88750575. Profile with the points colored by class (class 1=pink, class 2=orange) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

Elevation Change Within Breaklines

While water bodies are flattened in the final DEMs, other features such as linear hydrographic features can have significant changes in elevation within a small distance. In linear hydrographic features, this is often due to the presence of a structure that affects flow such as a dam or spillway. Dewberry has reviewed the DEMs to ensure that changes in elevation are shown from bank to bank. These changes are often shown as steps to reduce the presence of artifacts while ensuring consistent downhill flow. An example is shown below.

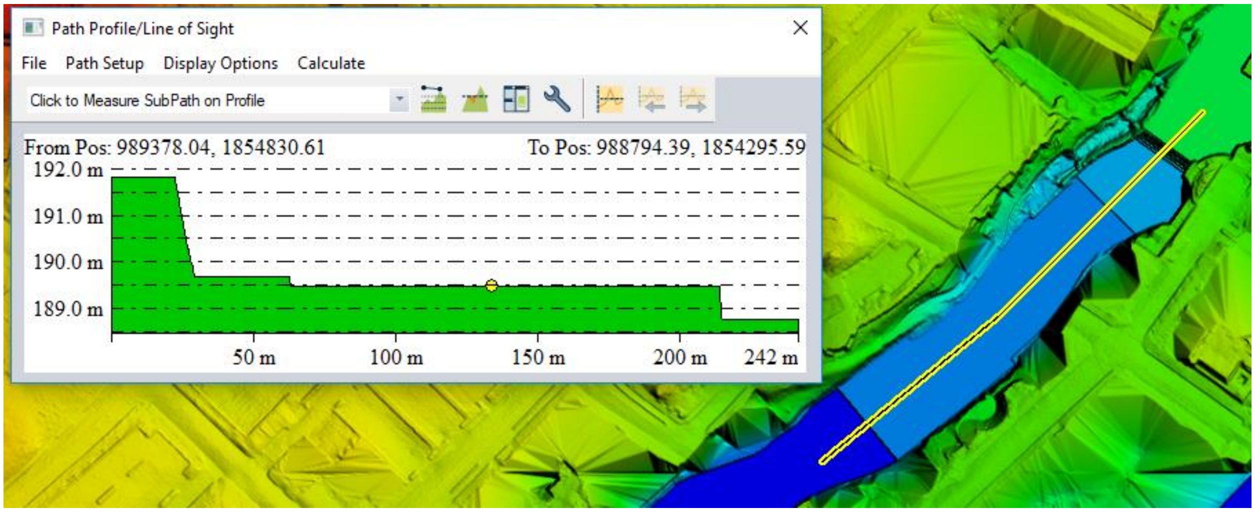


Figure 15 – Tile 98758525. Elevation change has been stair stepped. The steps are flat from bank to bank and flow consistently downhill.

Irrigated Agricultural Areas

The Illinois River Basin is a highly productive agricultural area. This is apparent throughout the project area due to the numerous small areas of standing water present at the time the lidar was acquired. Dewberry collected all areas of standing water greater than or equal to 2 acres. Areas of standing water that did not meet the 2 acre size criteria were not collected. Examples are shown below.

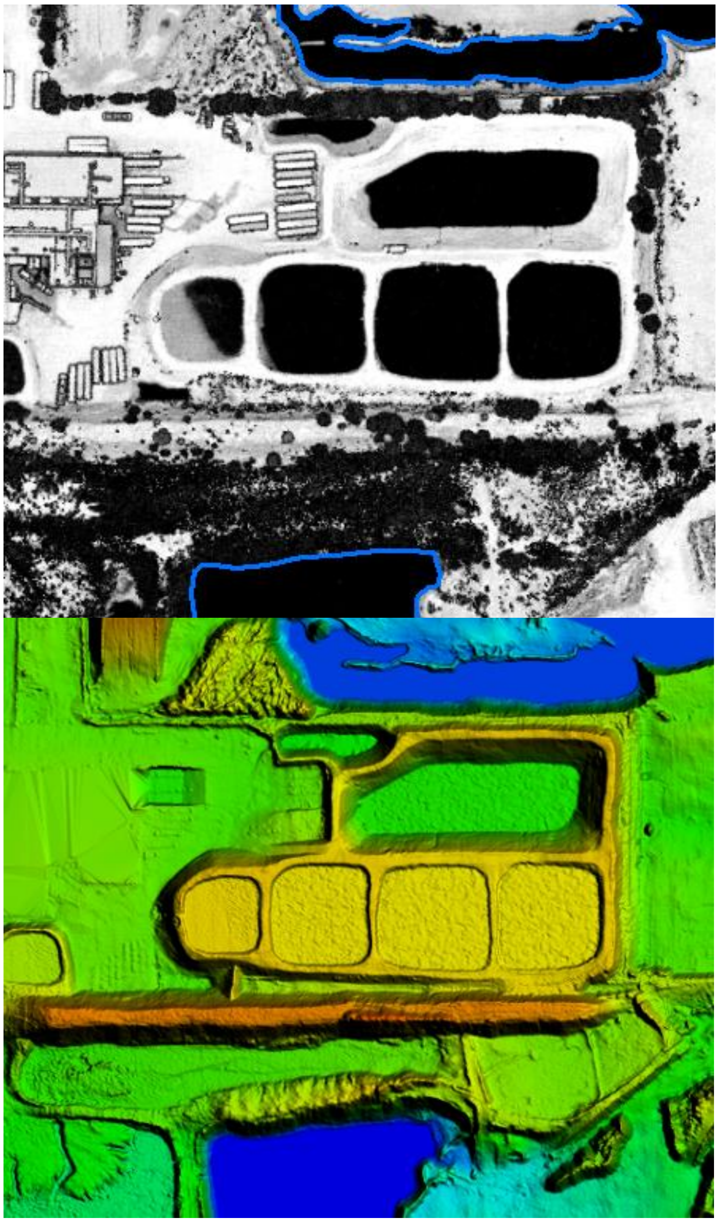
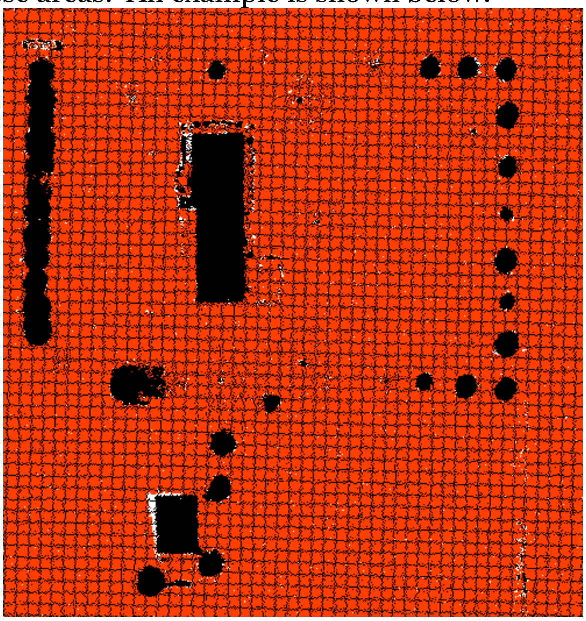


Figure 16 – Tiles 90500150 and 90750150. All lakes, ponds, irrigated agricultural fields, and other areas of standing water greater than or equal to 2 acres are included in the delivered breaklines.

Low NIR Reflectivity

Some areas of asphalt on roads and parking lots and some rooftops due to the roofing material composition have resulted in low NIR reflectivity. In these areas, the NIR lidar pulses are absorbed by the asphalt or roofing material, resulting in diminished to absent lidar returns for these areas. An example is shown below.



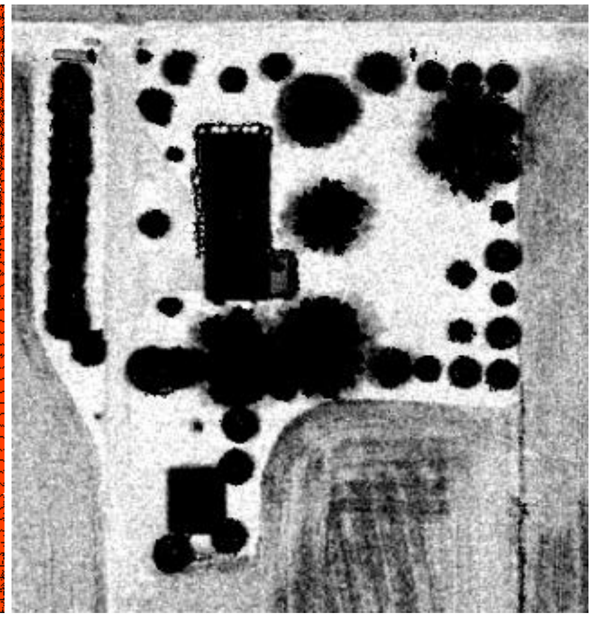


Figure 17 - Tile 87500050. Full lidar point cloud (white=unclassified, orange=ground) is shown in the left image and orthoimagery of the same location is shown in the right image. This rooftop is an area of low NIR reflectivity because the composition of the roofing materials result in the absorption of the NIR laser, reducing the number of lidar returns defining the building. Areas of low NIR reflectivity exist within this dataset.

FORMATTING

After the final QA/QC is performed and all corrections have been applied to the dataset, all lidar files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using Dewberry proprietary tools. The table below lists some of the main lidar header fields that are updated and verified.

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) State Plane Illinois East, feet and NAVD88 (Geoid 12B), feet in WKT Format	Pass
Global Encoder Bit	Should be set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass

System ID	Should be set to the processing system/software and is set to NIIRS10 for GeoCue software	Pass
Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16 bit intensity values are recorded for each pulse	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 3: Low Vegetation Class 4: Medium Vegetation Class 5: High Vegetation Class 6: Buildings Class 7: Low Noise Class 9: Water Class 10: Ignored Ground Class 17: Bridge Decks Class 18: High Noise	Pass
Overlap and Withheld Points	Overlap (Overage) and Withheld points are not present in Geiger-Mode Lidar	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Lidar Positional Accuracy

BACKGROUND

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to that of the interpolated value within the three closest lidar points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the lidar data is actually tested. However there is an increased level of confidence with lidar data due to the relative accuracy. This relative accuracy in turn is based on how well one lidar point "fits" in comparison to the next contiguous lidar measurement, and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Dewberry also tests the horizontal accuracy of lidar datasets when checkpoints are photo-identifiable in the intensity imagery. Photo-identifiable checkpoints in intensity imagery typically include checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90 degree corners of different reflectivity, e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints, as defined in the intensity imagery, are compared to surveyed XY coordinates for each photo-identifiable checkpoint. These differences are used to compute the tested horizontal accuracy of the lidar. As not all projects contain photo-identifiable checkpoints, the horizontal accuracy of the lidar cannot always be tested.

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, one hundred ninety five (195) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see appendix A to view the survey report which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area so as to cover as many flight lines as possible using the “dispersed method” of placement.

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table.

Point ID	NAD83(2011) Illinois State Plane East		NAVD88 (Geoid 12B)
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)
NVA-1	1009909.06	2224212.72	816.58
NVA-2	1085885.69	2218698.66	770.39
NVA-4	1060126.94	2165684.26	735.43
NVA-5	1120709.15	2181108.50	608.26
NVA-6	1104679.38	2123135.92	707.21
NVA-7	1025897.55	2098618.73	741.36
NVA-8	959650.79	2142001.61	880.56
NVA-10	998861.56	2052880.31	819.40
NVA-11	1081473.39	2046010.37	702.57
NVA-12	1127023.03	1981181.72	636.29
NVA-13	1036587.32	1978237.09	863.61
NVA-14	973737.88	1987539.67	897.61
NVA-16	948465.03	1939080.72	1002.86
NVA-17	1080465.26	1935067.50	714.52
NVA-18	1145263.03	1888653.92	602.77
NVA-19	1185344.78	1832701.72	589.20
NVA-20	1173208.15	1751424.00	712.21
NVA-21	1105023.03	1812708.41	733.51

NVA-22	995130.72	1908446.60	758.42
NVA-23	905982.68	1899011.91	860.12
NVA-24	988973.17	1866673.42	664.75
NVA-25	957215.18	1819179.12	642.93
NVA-26	926916.81	2056698.76	849.77
NVA-27 (Harris Pt 63A)	1164780.54	1760782.87	698.94
101A	997117.19	2240124.86	839.70
102A	1002110.09	2186118.42	764.76
103A	1007806.45	2133223.70	860.66
105A	912525.89	2123110.67	954.00
106A	954637.13	2083901.88	858.22
107A	1018198.94	2045263.61	758.80
108A	909750.94	2034247.49	820.64
109A	1055779.95	2004462.25	815.61
110A	1128623.13	1998403.84	638.40
111a	1033421.67	2056107.71	784.46
112a	1097023.78	2044982.32	704.11
113A	1071701.28	2093582.55	753.54
114A	1121590.30	2133212.28	628.94
115A	1060291.79	2163060.36	733.73
116A	1138516.44	2227865.74	592.20
117A	1070363.12	2241736.50	752.18
119A	971322.36	2006930.04	894.27
122A	897516.12	1858396.94	745.16
123A	948688.97	1957443.78	966.85
124A	928880.76	1904854.18	870.12
125A	941948.15	1820299.91	637.66
126A	1017916.07	1946847.00	797.12
127A	1089704.15	1960162.29	664.66
128A	1151351.34	1947594.09	600.42
129A	988854.43	1893051.97	714.25
131A	1118859.11	1902446.25	627.23
132A	1176811.10	1887116.96	592.54
134A	1090258.00	1852621.53	720.37
135A	1146008.28	1841358.06	617.50
136A	1101605.67	1784039.07	678.32
137A	1211834.49	1826852.98	584.38

138A	1176442.00	1740969.51	729.75
201A	999256.33	2246962.49	846.89
202A	995535.63	2192255.58	780.79
204a	885987.16	2128067.18	979.16
205A	998488.55	2133456.20	867.44
206A	919652.36	2077949.56	1022.53
207A	851766.71	2039035.11	761.58
208A	996841.86	2035505.72	905.02
209A	1087467.52	2245253.09	730.77
210A	1057343.83	2191060.08	800.92
211A	1113674.58	2198495.59	713.01
212A	1053189.04	2128647.72	837.24
213A	1112313.25	2142166.81	656.39
214A	1047942.88	2062269.12	816.68
215A	1109389.06	2061352.38	723.26
217A	948026.41	1996459.73	881.64
218A	1025840.41	1981344.23	868.37
219A	885987.53	1916976.07	892.46
220A	944927.67	1924848.87	956.92
222A	926039.66	1820440.49	656.08
223A	988822.36	1835941.45	662.15
224A	1089455.63	1996638.47	676.19
225A	1153878.12	1971112.13	611.40
226A	1070972.11	1932021.76	683.75
227A	1157152.04	1907886.06	597.08
228A	1094109.17	1810957.60	682.29
229A	1181627.46	1777131.97	629.43
230A	1181846.45	1842108.72	590.34
301	1001257.72	2248738.14	820.96
401A	853393.95	2038522.22	757.33
402A	1049297.18	2227757.66	785.83
403A	1120666.55	2241156.15	674.65
405A	998400.90	2068525.89	752.80
406A	1113316.66	2066036.70	671.35
408A	891344.88	1914493.57	879.40
409A	927403.05	1813623.03	630.78
410A	950346.11	1885365.84	785.39

411A	1001338.37	1864468.10	719.44
412A	1078417.63	1954345.53	709.13
414A	1176204.34	1883264.21	592.34
415	1111052.78	1859113.91	644.26
416A	1203858.73	1830213.30	585.71
417A	1168146.28	1810308.35	595.65
418A	1096908.25	2189339.00	720.51
419A	1047332.90	2150023.22	819.49
420A	1121683.03	2130769.96	628.25
421A	1069954.47	2098474.46	773.92
422A	1047867.49	2037662.21	877.21
423A	982721.04	2140859.58	855.58
424A	1010992.35	2208151.49	830.91
425A	893906.51	2125923.64	957.07
426A	944164.08	2093634.73	980.15
427A	988335.26	1981471.53	860.51
429A	1088464.87	1808303.16	729.33
430A	1134069.90	1998816.49	647.18
430A	1134069.97	1998816.55	647.13
431A	1132875.10	1763331.71	726.52
432A	894090.94	1859201.30	745.94
433A	1118880.88	1914022.63	624.20
434A	1202866.43	1756189.58	654.19
900A	911873.26	2046410.91	910.55
901A	911859.67	2046556.69	910.74
902A	853727.80	2038532.23	759.63
904A	998112.14	2068345.73	758.55
VVA-1	1202032.93	1758548.12	645.66
VVA-2	1136308.20	1812319.59	643.21
VVA-3	1083015.68	1826694.27	612.39
VVA-3A	1002564.19	2182403.51	774.80
VVA-4	1114787.01	1885533.16	622.82
VVA-5	990881.25	1823050.23	681.66
VVA-6	900321.48	1869395.94	764.27
VVA-7	959636.03	1900916.54	799.64
VVA-8	905789.83	1937885.24	902.05
VVA-9	1009037.12	1927748.99	752.18
VVA-9A	883664.49	2067526.60	837.43
VVA-10	1074654.17	1956437.93	724.44
VVA-11	1137112.88	1964882.50	621.80

VVA-12	1054723.62	1995601.98	826.52
VVA-13	962284.22	1981109.60	908.92
VVA-14	918925.47	2016076.60	895.36
VVA-15	878180.48	2051836.40	797.25
VVA-15A	914997.17	1992923.01	835.06
VVA-16	945431.45	2047569.34	887.31
VVA-17	1035176.56	2051042.76	792.65
VVA-18	1094806.36	2022713.12	648.05
VVA-19	1096546.14	2121566.37	675.78
VVA-20	987700.83	2096286.58	803.96
VVA-21	1154528.46	1826736.65	616.40
VVA-22	949435.39	2131604.42	993.36
VVA-23	1010580.17	2159667.86	784.01
VVA-24	1084462.94	2186894.52	752.97
VVA-25	1033566.24	2232366.17	772.29
VVA-26	1109325.52	2237283.67	679.00
CP317	1113391.06	2066427.41	673.78
CP345A	1173913.35	1930046.00	588.17
302	998042.11	2193486.79	777.21
304	898073.21	2136305.03	945.07
306	853474.57	2038451.29	755.63
307	1049237.95	2227733.93	786.63
308	1120675.64	2241060.70	669.48
309	1096961.85	2189380.98	712.87
310	1115631.34	2135429.62	652.08
311	1043201.07	2155101.76	815.80
312A	994532.55	2132299.68	858.69
313	944216.64	2093698.26	977.30
314	911860.91	2046709.01	914.53
315	1069890.44	2098382.61	771.65
316	998470.65	2068534.32	751.79
317	1113167.22	2066083.97	673.35
318	1046762.89	2038233.46	845.90
320	970763.54	2009145.05	882.36
321	891453.10	1914385.04	876.67
322	936686.06	1946765.22	906.69
323	897086.99	1858131.76	746.84
324	927573.73	1813426.60	625.31
325	950585.74	1885667.94	781.82
326	1099429.72	2009396.17	656.85
327	1031155.75	1982709.42	875.56
328	1002046.26	1936930.31	756.29
329	1001314.01	1864649.58	718.25

331	1078373.44	1954457.04	706.41
332	1151593.47	1975023.54	613.05
334	1119409.17	1912654.80	626.99
335	1176472.47	1883239.36	593.68
335A	1176325.28	1883252.62	595.47
338	1111078.45	1859218.52	648.11
339	1104835.36	1804761.27	699.25
340	1203954.53	1830184.93	584.96
341	1132587.15	1755250.21	744.70
342	1168152.98	1810485.83	595.85
343	1202907.80	1756054.25	645.51
344A	1123147.72	2105752.51	594.16
345	1173837.06	1930081.89	588.81
346	1189589.80	1865349.25	583.89
347	942131.20	1981412.23	992.22
348	999735.85	1905803.01	794.50
349	1040957.27	2201991.88	819.08
350	1084089.75	2163128.61	740.71
351	952039.36	2051165.35	934.90
352	1139070.11	1927014.54	614.74

Table 5 - Northeast Illinois Lidar surveyed accuracy checkpoints

The figure below shows the location of the QA/QC checkpoints used to test the positional accuracy of the dataset.

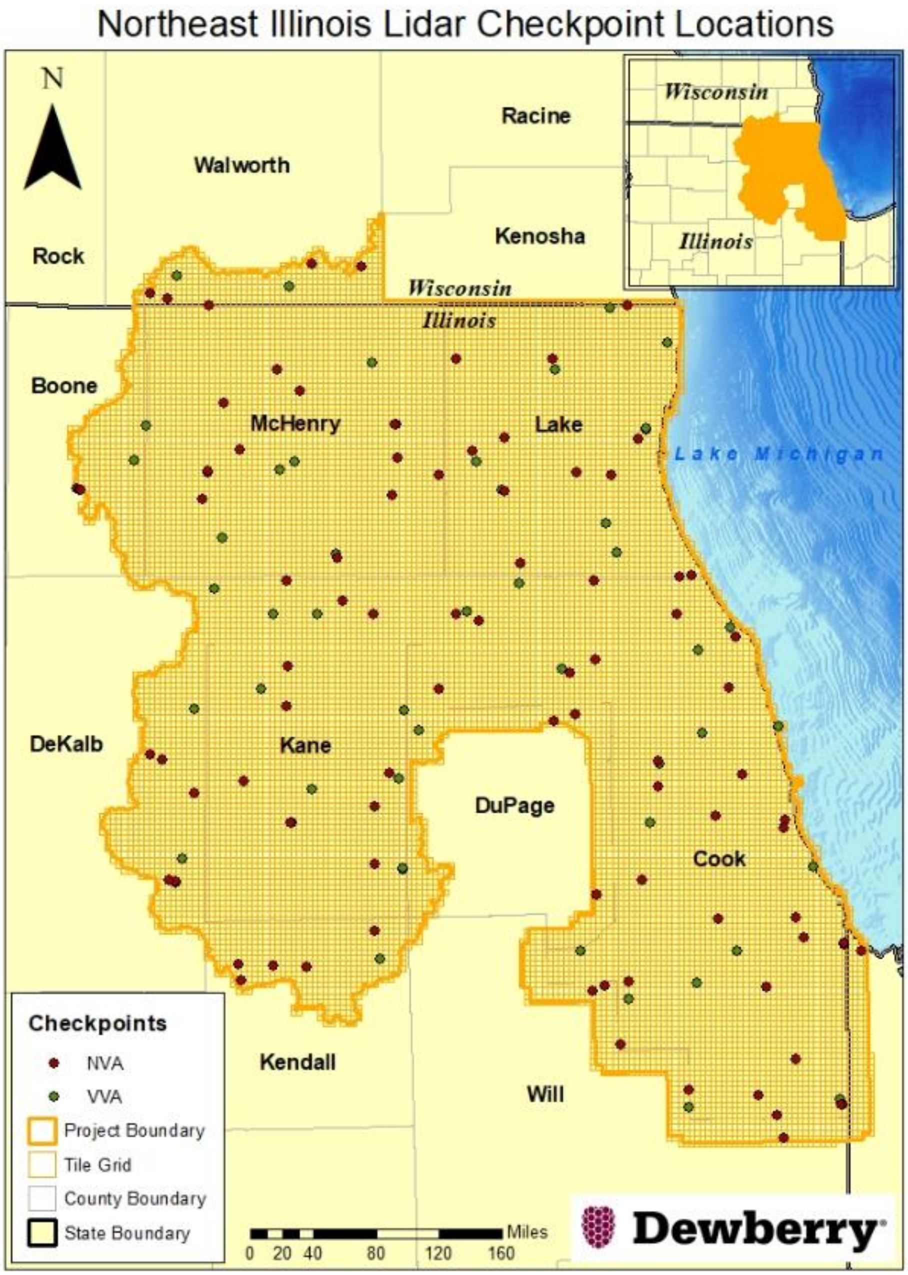


Figure 18 – Location of QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, where there is a very high probability that the lidar sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The NVA determines how well the calibrated lidar sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the Northeast Illinois lidar project, vertical accuracy must be 19.6 cm or less based on an $RMSE_z$ of 10 cm x 1.9600.

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in all vegetated land cover categories combined. The Northeast Illinois Lidar Project VVA standard is 29.4 cm based on the 95^{th} percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 6.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm (based on $RMSE_z$ (10 cm) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	29.4 cm (based on combined 95^{th} percentile)

Table 6 — Acceptance Criteria

The primary QA/QC vertical accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications.
2. Next, Dewberry interpolated the bare-earth lidar DTM to provide the z-value for every checkpoint.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the lidar data and the ground truth survey checkpoints and computed NVA, VVA, and other statistics.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

VERTICAL ACCURACY RESULTS

The table below summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified lidar LAS files.

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec= 0.64 ft	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=0.96 ft
NVA	116	0.33 ft	
VVA	79		0.34 ft

Table 7 — Tested NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =5.1 cm (0.17 ft), equating to +/- 10.1 (0.33 ft) cm at 95% confidence level. Actual VVA accuracy was found to be +/- 10.2 cm (0.34 ft) at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within +/- 20 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +70 cm.

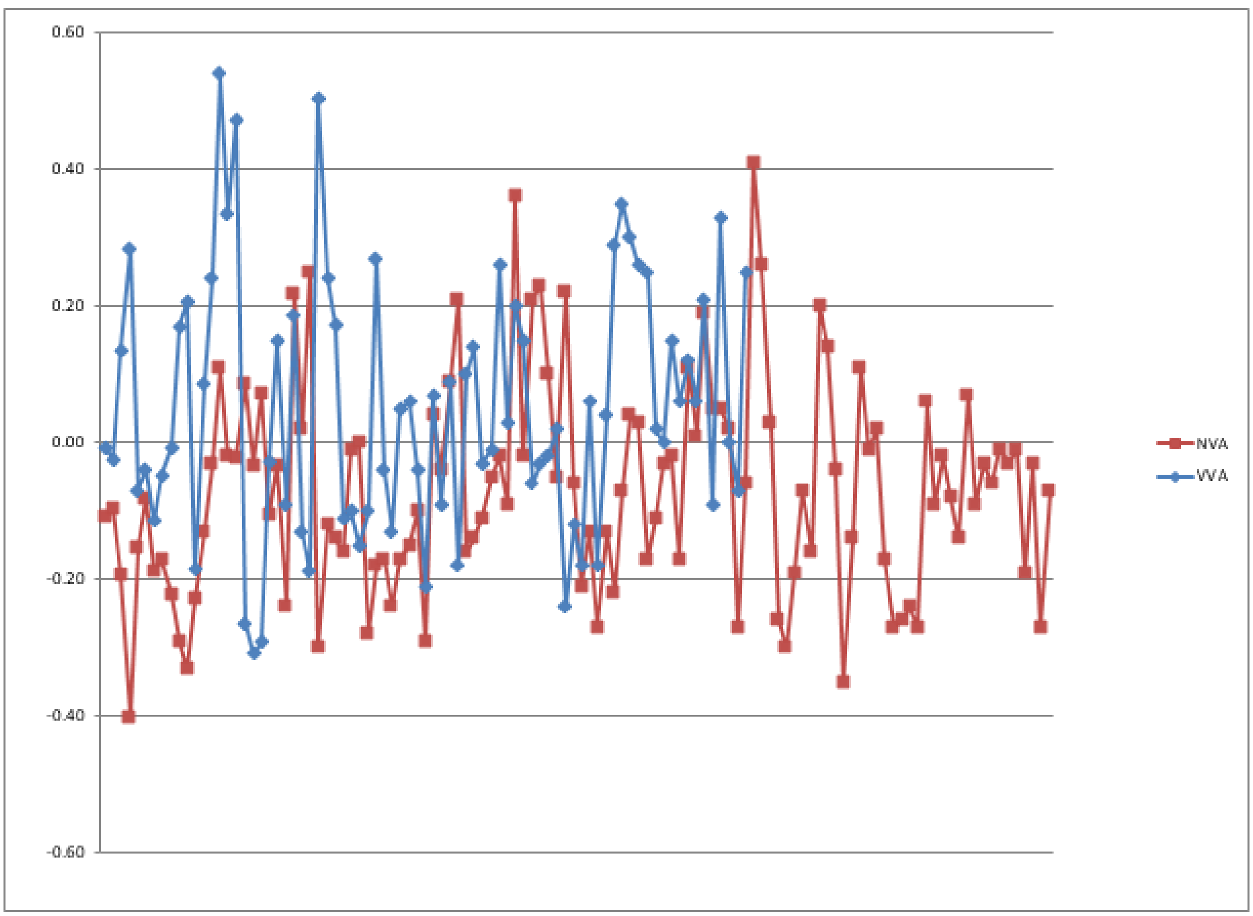


Figure 19 – Magnitude of elevation discrepancies per land cover category

Table 8 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83(2011) Illinois State Plane East		NAVD88 (Geoid 12B)	Lidar Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
VVA-7	959636.03	1900916.54	799.64	800.18	0.54	0.54
VVA-9	1009037.12	1927748.99	752.18	752.65	0.47	0.47
VVA-19	1096546.14	2121566.37	675.78	676.28	0.50	0.50
339	1104835.358	1804761.27	699.25	699.6	0.35	0.35

Table 8 — 5% Outliers

Table 9 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
NVA	116.00	0.17	-0.07	-0.07	0.52	0.16	0.29	-0.40	0.41
VVA	79.00	N/A	0.05	0.02	0.41	0.19	-0.18	-0.31	0.54

Table 9 — Overall Descriptive Statistics

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.40 meters and a high of +0.54 meters, the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the ranges of -0.05 meters to +0.05 meters.

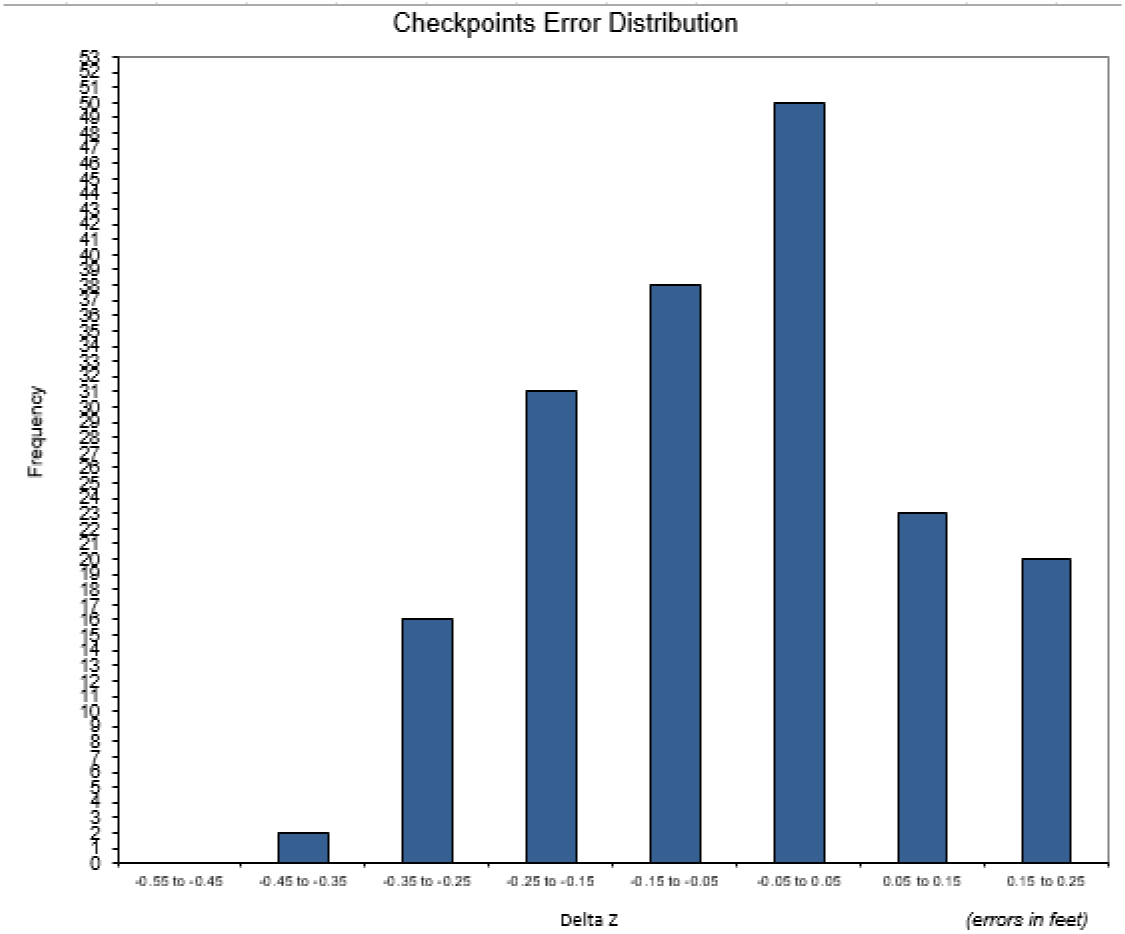


Figure 20 – Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the Northeast Illinois Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

HORIZONTAL ACCURACY TEST PROCEDURES

Horizontal accuracy testing requires well-defined checkpoints that can be identified in the dataset. Elevation datasets, including lidar datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. However, the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) recommends at least half of the NVA vertical check points should be located at the ends of paint stripes or other point features visible on the lidar intensity image, allowing them to double as horizontal check points.

Dewberry reviews all NVA checkpoints to determine which, if any, of these checkpoints are located on photo-identifiable features in the intensity imagery. This subset of checkpoints are then used for horizontal accuracy testing.

The primary QA/QC horizontal accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.
2. Next, Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the lidar intensity imagery and the ground truth survey checkpoints.
4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

HORIZONTAL ACCURACY RESULTS

Fifty-four checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset.

Using NSSDA methodology (endorsed by the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)), horizontal accuracy at the 95% confidence level (called ACCURACYr) is computed by the formula RMSEr * 1.7308 or RMSExy * 2.448.

# of Points	$RMSE_x$ (Target=1.34 ft)	$RMSE_y$ (Target=1.34 ft)	$RMSE_r$ (Target=1.9 ft)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=3.28 ft
54	1.34	1.17	1.78	3.08

Table 10 - Tested horizontal accuracy at the 95% confidence level

This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1 meter at a 95% confidence level. Actual positional accuracy of this dataset was found to be RMSEx = 41 cm (1.34 ft) and RMSEy = 35.6 cm (1.17 ft) which equates to +/- 93.9 cm (3.08 ft) at 95% confidence level.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop lidar stereo models of the project area so the lidar derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using lidargrammetry procedures with lidar intensity imagery, Dewbery used the stereo models to stereo-compile the three types of hydrographic breaklines in accordance with the project's Data Dictionary.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are at a constant elevation where the lowest elevation of the water body has been applied to the entire water body.

BREAKLINE QUALITATIVE ASSESSMENT

Dewberry completed breakline qualitative assessments according to a defined workflow. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.

Completeness and horizontal placement is verified through visual reviews against lidar intensity imagery. Automated checks are applied on all breakline features to validate topology, including the 3D connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies.

The next step is to compare the elevation of the breakline vertices against the ground elevation extracted from the ESRI Terrain built from the lidar ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations differ too much from the lidar.

After all corrections and edits to the breakline features, the breaklines are imported into the final GDB and verified for correct formatting.

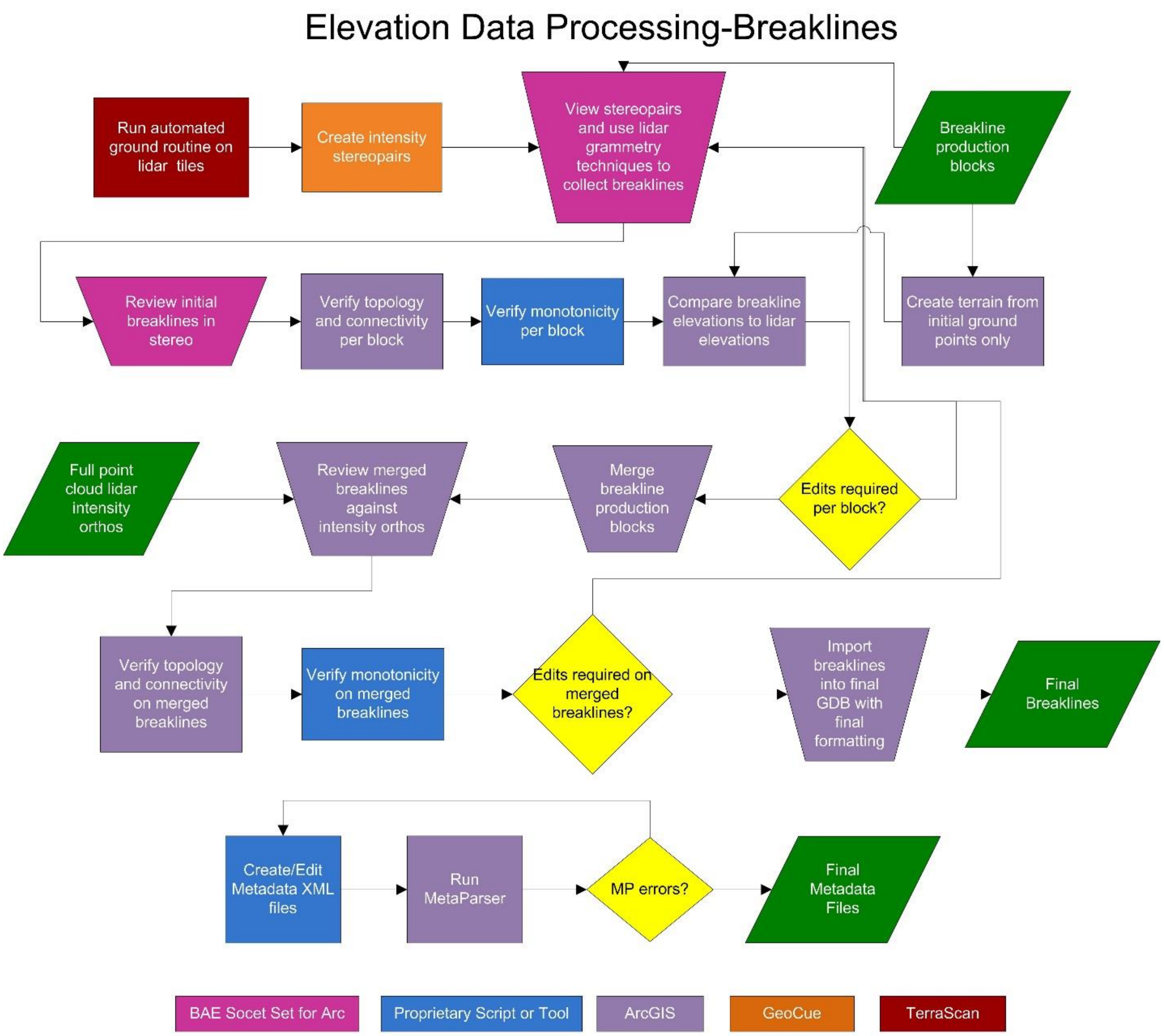


Figure 21 - Breakline QA/QC workflow

BREAKLINE CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's Production and QA/QC checklist that were performed for this project.

Pass/Fail	Validation Step
Pass	Use lidar-derived data, which may include intensity imagery, stereo pairs, bare earth ground models, density models, slope models, and terrains, to collect breaklines according to project specifications.
Pass	In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS).

Pass	After each producer finishes breakline collection for a block, each producer must perform a completeness check, breakline variance check, and all automated checks on their block before calling that block complete and ready for the final merge and QC
Pass	After breaklines are completed for production blocks, all production blocks should be merged together and completeness and automated checks should be performed on the final, merged GDB. Ensure correct snapping-horizontal (x,y) and vertical (z)-between all production blocks.
Pass	Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains
Pass	Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement.
Pass	Using a terrain created from lidar ground (all ground including 2, 8, and 10) and water points (class 9), compare breakline Z values to interpolated lidar elevations.
Pass	Perform all Topology and Data Integrity Checks
Pass	Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic.

Table 11 - A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.

DATA DICTIONARY

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983(2011), Units in Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Feet. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to State Plane Illinois East FIPS, Horizontal Units in U.S. Survey Feet and Vertical Units in U.S. Survey Feet.

Inland Streams and Rivers

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: STREAMS_AND_RIVERS
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall

		continue through the bridge. Islands: The double line stream shall be captured around an island if the island is greater than 1 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

Inland Ponds and Lakes

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: PONDS_AND_LAKES
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict closed water body features that are at a constant elevation.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. <u>The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body.</u> Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature that is 1 acre in size or greater will also have a "donut polygon" compiled. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water

		most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Tidal Waters

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: TIDAL_WATERS
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will outline the land / water interface at the time of lidar acquisition.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
TIDAL_WATERS	The coastal breakline will delineate the land water interface using lidar data as reference. In flight line boundary areas with tidal variation the coastal shoreline may show stair stepping as no feathering is allowed. Stair stepping is allowed to show as much ground as the collected	The feature shall be extracted at the apparent land/water interface, as determined by the lidar intensity data, to the extent of the tile boundaries. Differences caused by tidal variation are acceptable and breaklines delineated should reflect that change with no feathering. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the

	data permits.	negative direction will be defined for each project individually. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Breaklines shall snap and merge seamlessly with linear hydrographic features.

Beneath Bridge Breaklines

Feature Dataset: BREAKLINES
Feature Type: Polyline
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: Bridge_Breaklines
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polyline feature class is used to enforce terrain beneath bridge decks where ground data may not have been acquired. Enforcing the terrain beneath bridge decks prevents bridge saddles.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Bridge Breaklines	Bridge Breaklines should be used where necessary to enforce terrain beneath bridge decks and to prevent bridge saddles in the bare earth DEMs.	Bridge breaklines should be collected beneath bridges where bridge saddles exist or are likely to exist in the bare earth DEMs. Bridge breaklines should be collected perpendicular to the bridge deck so that the endpoints are on either side of the bridge deck. Typically two bridge breaklines are collected per bridge deck, one at either end of the bridge deck to enforce the terrain under the full bridge deck.

		The endpoints of the bridge breaklines will match the elevation of the ground at their xy position to enforce the ground/bare earth elevations beneath the bridge deck and prevent bridge saddles from forming.

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

Dewberry utilized ESRI software and Global Mapper for the DEM production and QC process. ArcGIS software is used to generate the products and the QC is performed in both ArcGIS and Global Mapper. The figure below shows the entire process necessary for bare earth DEM production, starting from the lidar swath processing.

The final bare-earth lidar points are used to create a terrain. The final 3D breaklines collected for the project are also enforced in the terrain. The terrain is then converted to raster format using linear interpolation. For most projects, a single terrain/DEM can be created for the whole project. For very large projects, multiple terrains/DEMs may be created. The DEM(s) is reviewed for any issues requiring corrections, including remaining lidar mis-classifications, erroneous breakline elevations, poor hydro-flattening or hydro-enforcement, and processing artifacts. After corrections are applied, the DEM(s) is then split into individual tiles following the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

Figure 22 - DEM Production Workflow

DEM QUALITATIVE ASSESSMENT

Dewberry performed a comprehensive qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. This process was performed in ArcGIS software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process and to review the hydro-flattened features. To perform this review Dewberry creates HillShade models and overlays a partially transparent colorized elevation model to review for these issues. All corrections are completed using Dewberry's proprietary correction workflow. Upon completion of the corrections, the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out, the final tiles are again loaded into Global Mapper to ensure coverage, extents, and that the final tiles are seamless.

The images below show an example of a bare earth DEM.

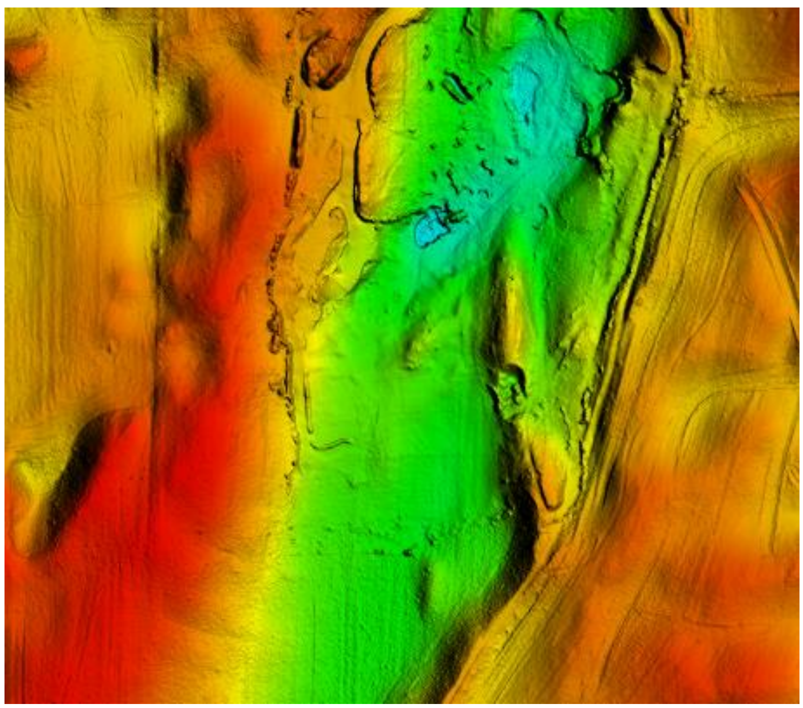


Figure 23 - Tile 97500700. The bare earth DEM is displayed above

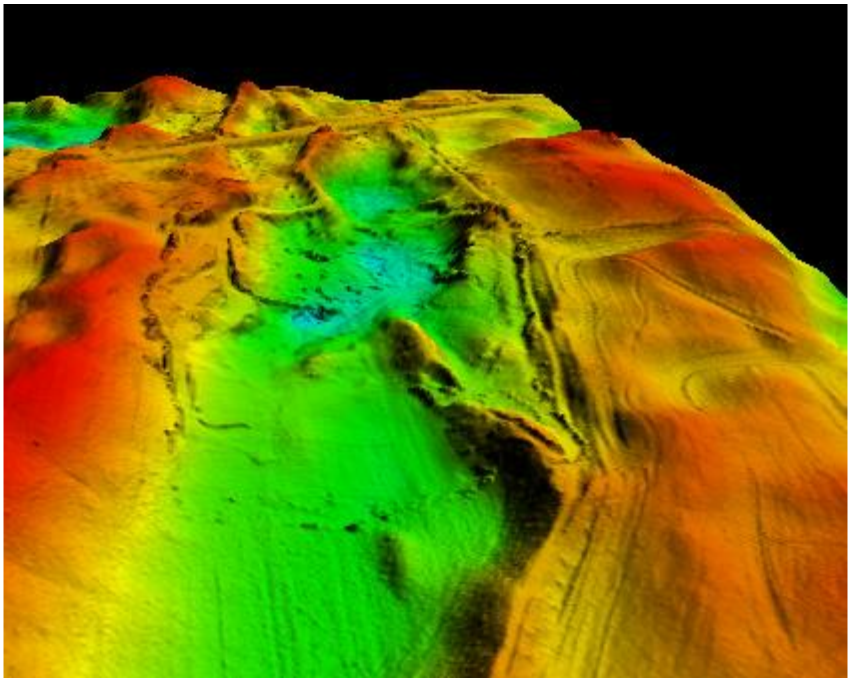


Figure 24 - Tile 97500700. 3D view of the bare earth DEM

When some bridges are removed from the ground surface, the distance from bridge abutment to bridge abutment is small enough that the DEM interpolates across the entire bridge opening, forming 'bridge saddles.' Dewberry collected 3D bridge breaklines in locations where bridge saddles were present and enforced these breaklines in the final DEM creation to help mitigate the bridge saddle artifacts. The image below on the left shows a bridge saddle while the image below on the right shows the same bridge after bridge breaklines have been enforced.

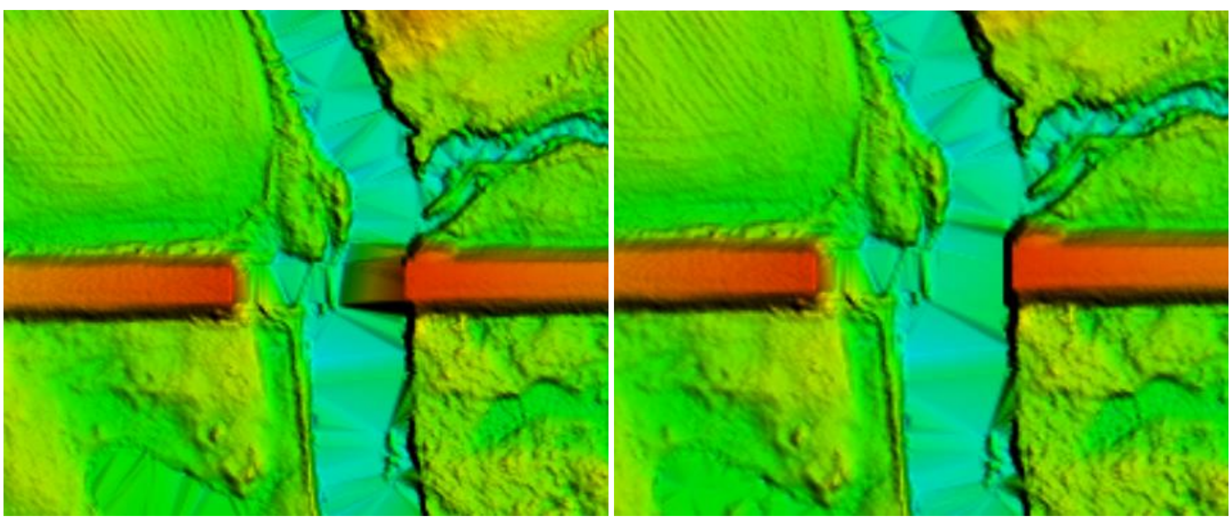


Figure 25 - Tile 88500825. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 195 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 12 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy (RMSEz x 1.9600) Spec=0.64 ft	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=0.96 ft
NVA	116	0.32	
VVA	76		0.33

Table 12 — DEM tested NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =4.9 cm (0.16 ft), equating to +/- 9.6 cm (0.32 ft) at 95% confidence level. Actual VVA accuracy was found to be +/- 10.2 cm (0.33 ft) at the 95th percentile.

Table 13 lists the 5% outliers that are larger than the VVA 95^{th} percentile.

Point ID	NAD83(2011) Illinois State Plane East		NAVD88 (Geoid 12B)	DEM Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
VVA-7	959636.03	1900916.54	799.64	800.20	0.56	0.56
VVA-9	1009037.12	1927748.99	752.18	752.62	0.44	0.44
VVA-19	1096546.14	2121566.37	675.78	676.24	0.47	0.47
351	952039.364	2051165.347	934.9	935.29	-0.03	0.03

Table 13 — 5% Outliers

Table 14 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSE z (ft) NVA Spec= 0.33 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
NVA	116.00	0.16	-0.09	-0.09	0.27	0.14	0.14	-0.41	0.33
VVA	79.00	N/A	0.03	0.00	0.60	0.18	-0.02	-0.29	0.56

Table 14 – Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the USGS Northeast Illinois Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

DEM CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's bare earth DEM Production and QA/QC checklist that were performed for this project.

Pass/Fail	Validation Step
Pass	Masspoints (LAS to multipoint) are created from ground points only (class 2 and class 8 if model key points created, but no class 10 ignored ground points or class 9 water points
Pass	Create a terrain for each production block using the final bare earth lidar points and final breaklines.
Pass	Convert terrains to rasters using project specifications for grid type, formatting, and cell size
Pass	Create hillshades for all DEMs
Pass	Manually review bare-earth DEMs in ArcMap with hillshades to check for issues
Pass	DEMs should be hydro-flattened or hydro-enforced as required by project specifications
Pass	DEMs should be seamless across tile boundaries
Pass	Water should be flowing downhill without excessive water artifacts present
Pass	Water features should NOT be floating above surrounding
Pass	Bridges should NOT be present in bare-earth DEMs.
Pass	Any remaining bridge saddles where below bridge breaklines were not used need to be fixed by adding below bridge breaklines and re-processing.
Pass	All qualitative issues present in the DEMs as a result of lidar processing and editing issues must be marked for corrections in the lidar These DEMs will need to be recreated after the lidar has been corrected.
Pass	Calculate DEM Vertical Accuracy including NVA, VVA, and other statistics
Pass	Split the DEMs into tiles according to the project tiling scheme
Pass	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression has not been applied to the tiled DEMs

Pass	Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt.

Table 15 - A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Appendix A: Survey Report

Please see the report included with this deliverable:
Appendix_A_Checkpoint_Survey_Report

Appendix B: Complete List of Delivered Tiles

Please see the report included with this deliverable:
Appendix_B_Complete_List_of_Delivered_Tiles

Appendix C: GPS Processing

Please see the report included with this deliverable:
Appendix_C_GPS_Processing