Preliminary IL_LaSalle County QL2+ Lidar 2017

Report Produced for U.S. Geological Survey

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Overview

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 USGS Il_LaSalle County QL2+ Lidar 2017 project Area. LaSalle County, Illinois is the focus of this report and is one area of interest (AOI) from a lidar survey that was collected over two (2) areas of interest in Illinois identified as LaSalle and Expansion Counties. Expansion counties consisted of Grundy, Kendall, and DeKalb County, Illinois, covering approximately 1388 square miles. Grundy, Kendall, and DeKalb County Counties are a QL2 project and the second AOI for this lidar survey. Acquisition of LiDAR was planned for and executed as a combined collection. LaSalle and Expansion Counties cover a total of approximately 2,563 square miles.

The LiDAR data was processed and classified according to project specifications. Detailed breaklines, bare earth Digital Elevation Models (DEMs), and Intensity Images were produced for the project area. Data was formatted according to tiles with each tile covering an area of 2,000 feet by 2000 feet. A total of 8241 LAS tiles, 8241 DEMs, and 8241 Intensity Images were produced for the project encompassing an area of approximately 1,148 square miles. Thirty LAS tiles contain flagged withheld points due to an isolated anomaly found in the lidar data.

PROJECT TEAM

Aerial Services, Inc. (ASI) served as the prime contractor for the project. In addition to project management ASI was responsible for LiDAR acquisition and calibration, LAS classification, LiDAR products, Digital Elevation Model (DEM) production, Intensity Image production, and quality assurance. Subcontractor: GRW Aerial Surveys, Inc. (GRW) preformed LAS classification, and breakline production. Subcontractor: Survey And Mapping, LLC (SAM) preformed LAS classification breakline production, and DEM production.

GRW Aerial Surveys, Inc. completed ground surveying for the project and delivered surveyed checkpoints. GRW was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. Please see 2474-047 SURVEY REPORT to view the separate Survey Report that was created for this portion of the project.

SURVEY AREA

The project area address by this report falls within LaSalle County, Illinois.

DATE OF SURVEY

LiDAR acquisition was conducted from November 19, 2017 to November 23, 2017, with one re-flight flown April 12, 2018.

COORDINATE REFERENCE SYSTEM

Data produced for the project was 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: Illinois East State Plane (FIPS 1201)

Units: Horizontal units are in US Survey Feet, Vertical units are in US Survey feet.
Geoid Model: Geoid12B

LIDAR VERTICAL ACCURACY

For the IL_LaSalle County project, the tested RMSEz of the classified LiDAR data for checkpoints in non-vegetated terrain equaled 4.5 cm (0.148 ft) compared with the 10 cm (0.33 ft) specification: and the NVA of the classified LiDAR data computed using RMSEz x 1.96 was equal to 8.82 cm (0.29 ft), compared with the 19.6 cm (0.64 ft) specification.

For the IL_LaSalle County project, the tested VVA of the classified LiDAR data computed using the 95th percentile was equal to 23.5 cm (0.77 ft), compared with the 29.4 cm (0.96 ft) specification.

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

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Raw Point Cloud Data (Swaths)
2. Classified Point Cloud Data (Tiled)
3. Bare Earth Surface (Raster DEM – IMG format)
4. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
5. Breakline Data (File DGB)
6. Independent Survey Checkpoint Data
7. Calibration Points
8. Metadata
9. Project Report (Acquisition, Processing, QC)
10. Project Extent (Included in DGB)

PROJECT TILING FOOTPRINT

Eight thousand two hundred forty one (8421) LAS tiles, Eight thousand two hundred forty one (8421) DEM tiles, and Eight thousand two hundred forty one (8421) Intensity Image tiles were delivered for the project Thirty tiles contain flagged withheld. Each tile's extent is 2,000 feet by 2000 feet. (See Appendix A for a complete listing of delivered tiles and Appendix B for a list of tiles containing flagged withheld.)

IL_LaSalle QL2+ LiDAR

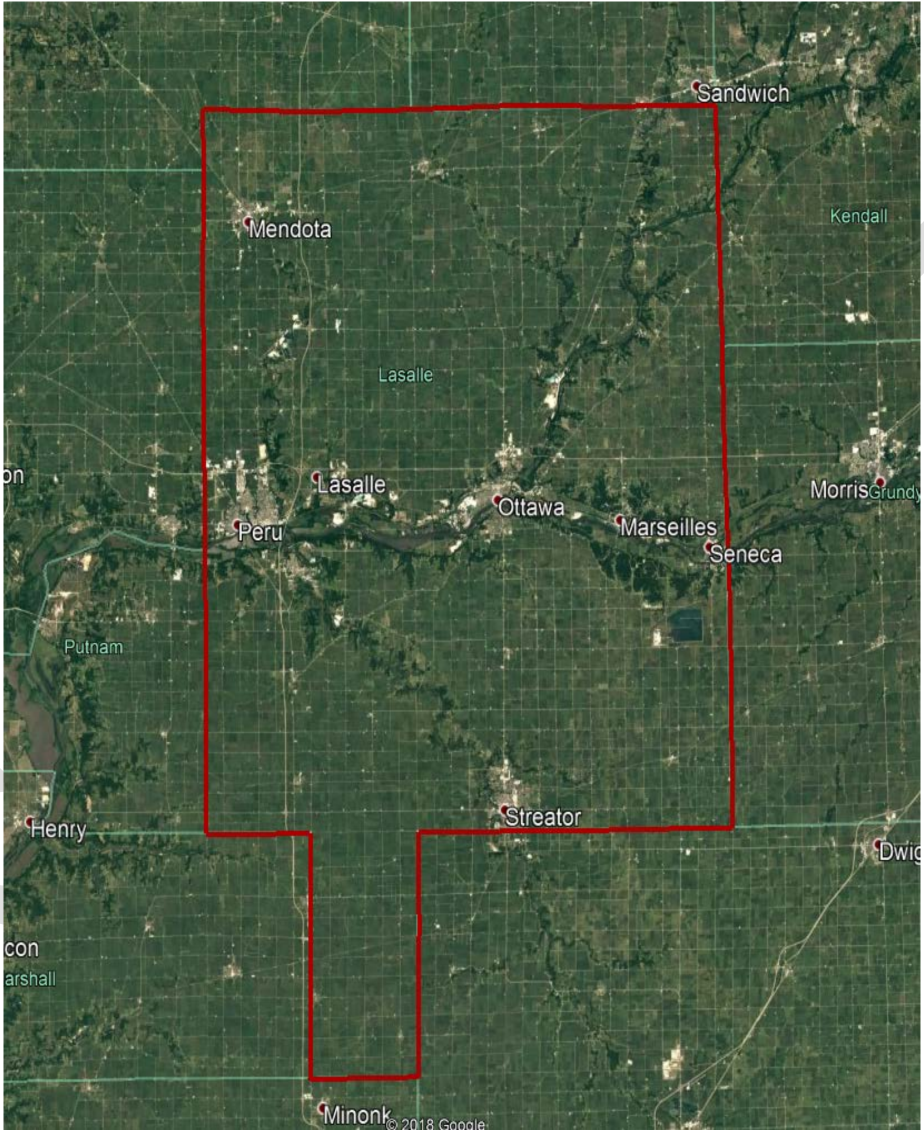


Figure 1 – Area of Interest

Lidar Acquisition Details

Aerial Services, Inc. served as prime contractor for the Il_LaSalle QL2+ and expansion counties QL2 project and preformed the LiDAR Acquisition and Calibration.

Aerial Services, Inc. planned 145 passes for the project area as well a series of 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, Aerial Services, Inc. followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using LEICA MISSION PRO 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, Aerial Services, Inc. will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Aerial Services, Inc. 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. Aerial Services, Inc. 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, Aerial Services, Inc. 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.

Aerial Services, Inc. lidar sensors are calibrated at a designated site located at the Waverly Municipal Airport in Waverly, Iowa and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Aerial Services, Inc. operated a Piper Navajo PA-31 (Tail # N35AS) outfitted with a LEICA ALS70-HP lidar system during the collection of the study area. Table 1 illustrates Aerial Services, Inc. system parameters for lidar acquisition on this project.

Item	Parameter
System	Leica ALS-70 HP
Maximum Number of Returns per Pulse	4
Nominal Pulse Spacing (single swath), (m)	0.5
Nominal Pulse Density (single swath) (ppsm), (m)	4
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.5
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	4
Altitude (AGL meters)	1100
Approx. Flight Speed (knots)	150
Total Sensor Scan Angle (degree)	50
Scan Frequency (hz)	47
Scanner Pulse Rate (kHz)	240
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Nominal Swath Width on the Ground (m)	1025
Swath Overlap (%)	30
Max. Point Spacing Along Track (m)	1.64
Max. Point Spacing Across Track (m)	0.56

Table 1: Aerial Services, Inc. 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.

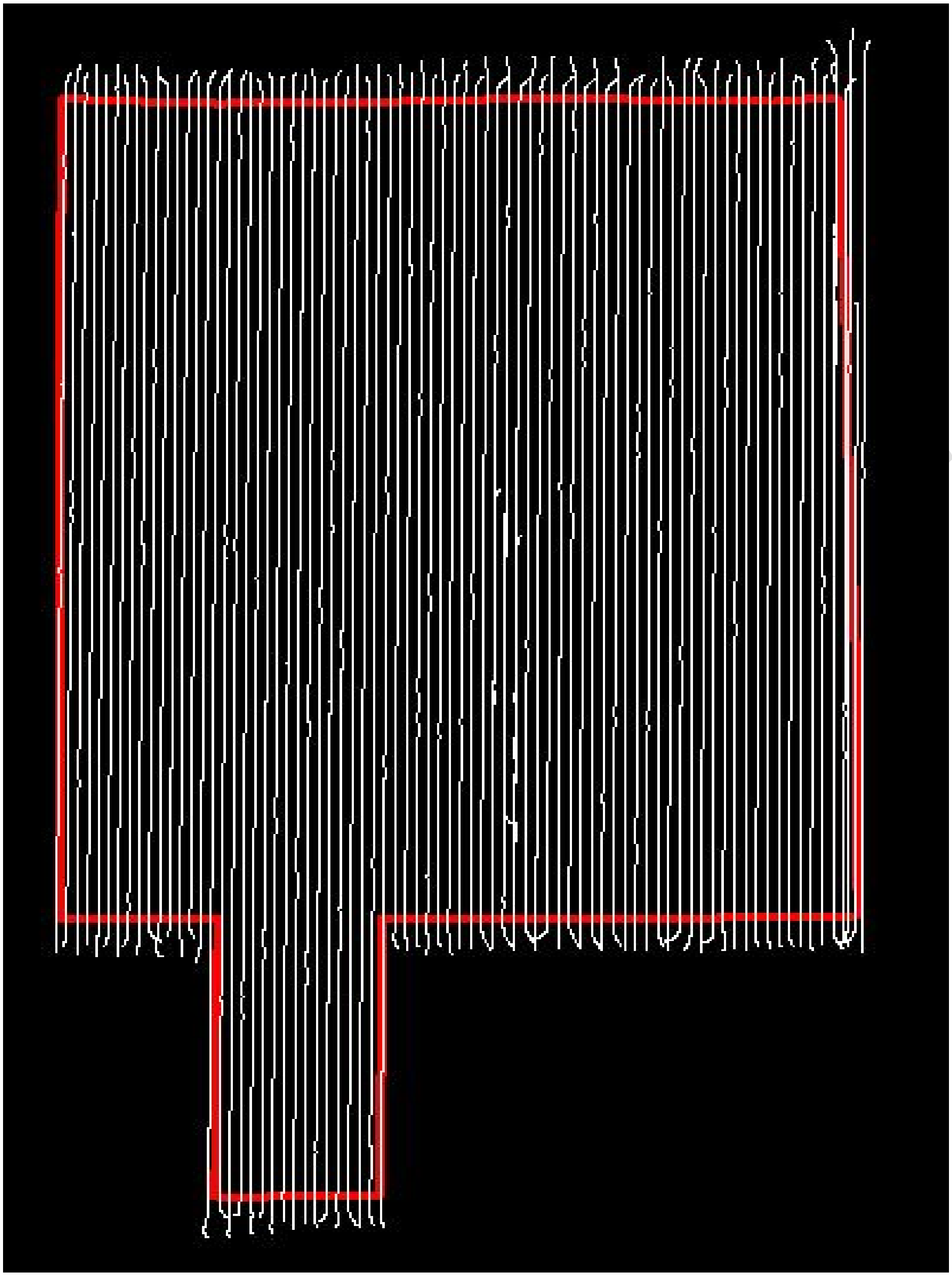


Figure 2: Trajectories as flown by Aerial Services, Inc.

ACQUISITION CONTROL

Aerial Services, Inc. conducted the survey which provided the established base stations that were used to control the lidar acquisition for the IL_LaSalle County project area. The coordinates of the base stations are provided in the table below.

Name	NAD83(2011) UTM 16		Ellipsoid Ht (WGS84, m)
	Easting X (m)	Northing Y (m)	
MF1461_Serena	412903.654	884512.146	159.010
MF1468_Utica	412136.087	885708.535	158.048

Table 2 – Base station used to control lidar acquisition for the Project.

AIRBORNE GPS KINEMATIC

Airborne GPS data was processed using Waypoint's Inertial Explorer version 8.60 software suite. All flights were flown with PDOP less than or equal to 3.0 and with at least 6 satellites in common view of both a stationary reference receiver and the airborne GPS. Distances from base station to aircraft were kept to a maximum of 50 km.

For all flights, the GPS data can be classified as excellent, with GPS residuals no larger than 10 cm being recorded.

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

FIGURE 3 – IL_LASALLE COUNTY PROJECT BASESTATIONS AND SWATHS

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

After processing the GNSS/GPS and IMU data in Inertial Explorer, the data is then exported to raw LAS files using Leica's CloudPro software. CloudPro combines the raw data collected with the ALS 70 HP sensor, combines it with the airborne trajectory data, applies the sensor's calculated boresite correction angles, and then outputs the point cloud to the specified coordinate reference system and file format.

The initial step of calibration is to verify the complete coverage of the AOI with the 100 meter buffer with no internal voids present, as well as ensuring that minimum point density of 4.0 ppsm has been achieved.

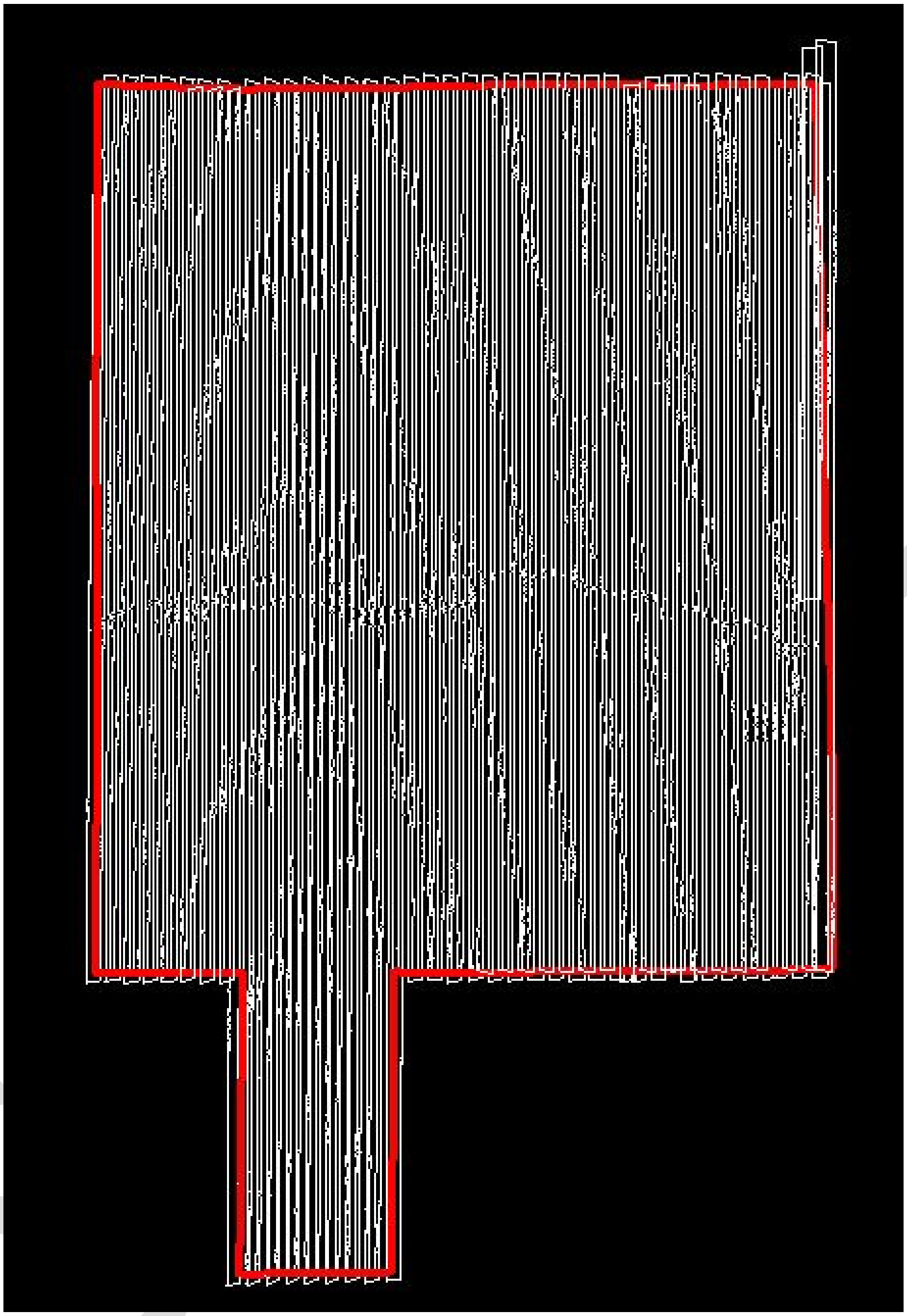


Figure 4 – Lidar swath coverage over Block 1.

Boresight and Relative accuracy

Subsequently, the project's data is then loaded into Microstation/TerraScan for viewing and post-processing of calibration errors. Roll, pitch, and heading corrections are calculated to produce the best relative accuracy that can be achieved, and at minimum 8 cm RMSDz with a 16 cm maximum difference. Tested interswath RMSDz was 4.511 cm.

The relative accuracy of every swath is checked and QC'd at 3 different points along its length. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement to verify that the project meet the specifications.

For this project the specifications used are as follow
Relative accuracy <= 6 cm maximum differences within individual swaths and <=8 cm RMSDz between adjacent and overlapping swaths.

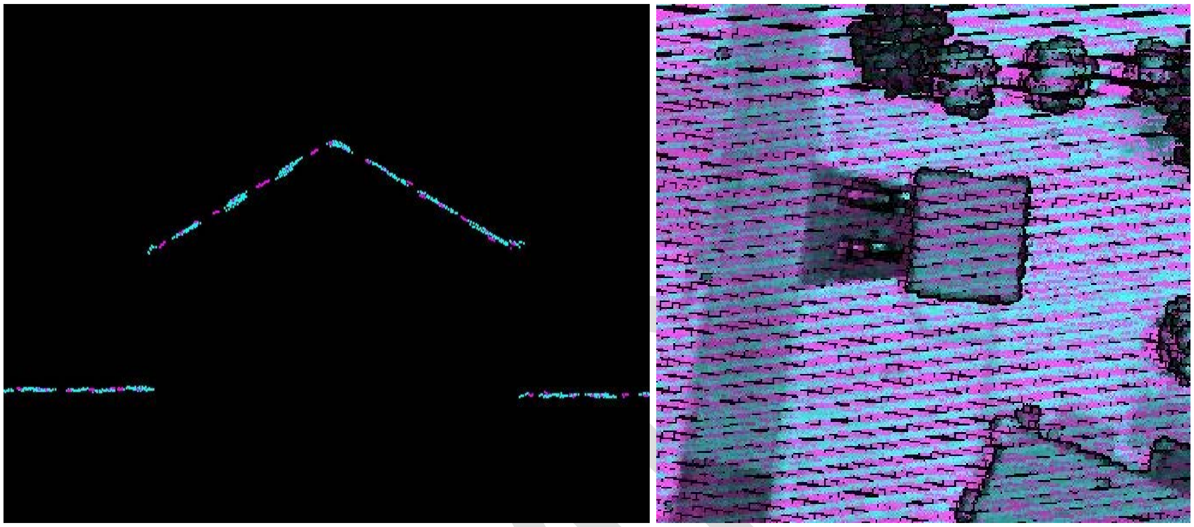


Figure 5 – Profile and top views showing proper interswath calibration.

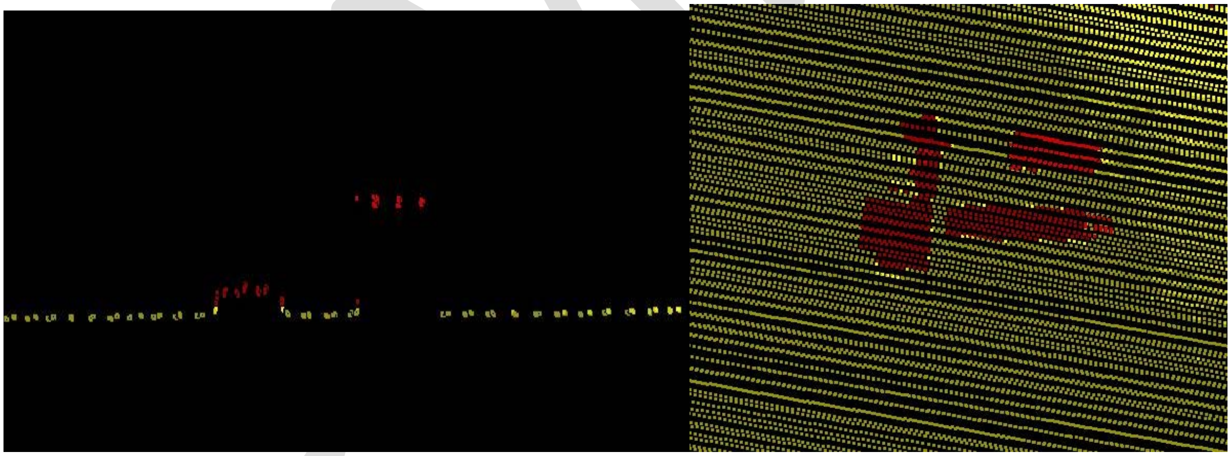


Figure 6 – Top view showing a parking lot with a car and raised feature on a single swath demonstrating intraswath accuracy. Yellow color is scaled to a range of 6 cm in elevation. Points are within 6 cm of variation until the raised curb and car. Also shown is a profile view showing low variability of ranges within the swath.

Final Calibration Verification

GRW Aerial Surveys, Inc. conducted the survey for 53 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 53 GCPs were available to use as control in case the swath data exhibited any biases which would need to be adjusted or removed. The coordinates of all GCPs are provided in table 3 and the accuracy results from testing the calibrated swath data against the GCPs is provided in table 4; no further adjustments to the swath data were required based on the accuracy results of the GCPs. Accuracy of Block 1 raw point cloud against GCP: 0.144 ft (4.389 cm) with a 95% confidence value of 0.28 ft (8.534 cm).

Point ID	NAD83 (2011 adj) UTM Zone 14		NAVD88 (Geoid 12B)		
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)	Dz
ASI-01	757730.212	1807820.903	846.397	846.420	+0.023
ASI-02	771270.016	1703616.174	617.140	617.400	+0.260
ASI-03	760852.184	1622517.018	650.284	650.440	+0.156
ASI-04	782013.266	1749628.284	649.924	650.070	+0.146
ASI-05	796053.875	1711608.620	615.042	615.140	+0.098
ASI-06	824809.747	1712642.272	628.614	628.480	-0.134
ASI-07	792955.388	1600032.641	681.177	681.220	+0.043
ASI-08	814497.844	1563048.613	669.315	669.510	+0.195
ASI-09	819396.568	1653359.599	613.428	613.320	-0.108
ASI-10	803090.503	1788880.333	707.821	707.920	+0.099
ASI-11	843211.602	1632054.680	627.437	627.610	+0.173
ASI-12	835147.699	1752535.984	653.722	653.840	+0.118
ASI-13	820129.834	1807415.883	722.042	722.260	+0.218
ASI-14	856867.368	1808564.379	703.906	704.130	+0.224
ASI-15	885186.762	1808485.169	684.171	684.320	+0.149
ASI-16	902684.988	1808496.457	665.718	665.860	+0.142
ASI-17	870014.355	1776555.722	628.321	628.350	+0.029
ASI-18	911943.262	1755476.757	699.127	699.090	-0.037
ASI-19	892093.494	1738438.937	728.826	728.760	-0.066
ASI-20	781321.912	1672967.002	661.067	661.130	+0.063
ASI-21	867732.054	1722232.031	614.324	614.350	+0.026
ASI-22	898507.662	1693798.314	520.782	520.880	+0.098
ASI-23	860671.749	1675594.493	622.297	622.500	+0.203
ASI-24	882543.658	1643914.910	701.472	701.220	-0.252
ASI-25	914467.287	1617765.4957	688.966	688.950	-0.016
ASI-47	914260.898	1666768.744	669.775	669.940	+0.165

Table 3 – Project X surveyed ground control points (GCPs).

This project must meet Non-vegetated Vertical Accuracy (NVA) ≤ 0.64 ft (19.6 cm) at the 95% confidence level based on $RMSE_z$ ≤ 0.33 ft (10 cm) x 1.9600.

100 % of Totals	# of Points	RMSEz (ft) NVA ft	NVA-Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Min (ft)	Max (ft)	Kurtosis
GCP	37	0.148	0.39	0.035	-0.022	-0.369	0.145	-0.491	0.336	2.041

Table 4 - Ground control points (GCPs) vertical accuracy results.

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, ASI utilized TerraScan software for data processing. The acquired 3D laser point clouds, in LAS binary format, were imported into the 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. 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. 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.

Once the ground surface had been deduced through the filtering process a vegetation class was then extracted by distance from ground from remaining class 1. With Building size parameters set, extraction of buildings from the vegetation class occurs. Once building had been deduced the remaining vegetation points were re-filtered by distance into Low Vegetation is 0.5-5 feet, Medium Vegetation is 5-20 feet, High Vegetation is >20 feet.

In TerraScan surface models for each tile was created to examine the ground classification. ASI analysts visually reviewed the ground surface model for artifacts left in the ground classification. Theses artifacts consist of vegetation, buildings, and bridges that were still present in the ground after initial processing. ASI analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that errant points are removed from the ground classification. Bridge decks are manually classified to class 17. Building rooftops were manually reviewed to ensure that popper classification had occurred. After the ground classification and building corrections completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by subcontractors GRW Aerial Surveys as well as Survey And Mapping, LLC (SAM) 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 2x NPS or less of the hydrographic features are moved to class 10, and ignored ground due to breakline proximity. Overage points are then identified in TerraScan and used to set the overlap bit for those points. The withheld points identified during the classification routine are used to set the withheld bit. The LiDAR tiles were classified to the following classification schema:

- Class 1 – Default, Processed, but unclassified
- Class 2 – Ground, Bare-earth
- Class 3 – Low Vegetation is 0.5-5 feet
- Class 4 – Medium Vegetation is 5-20 feet
- Class 5 – High Vegetation is >20 feet
- Class 6 – Buildings
- Class 7 – Low Noise (low and manually identified)
- Class 9 – Water
- Class 10 – Ignored Ground (Breakline Proximity – 1.5 feet)
- Class 17 – Bridge Decks
- Class 18 – High Noise (high, manually identified)

After manual classification, the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections, the LAS files were then converted from LAS v1.2 to LAS v1.4 using TerraScan software to flag the overlap bit and withheld bit. LAStools by Rapidlasso GmbH was used, to set the LAS header to the appropriate point data records, variable length records, and spatial reference information (WKT).

LIDAR QUALITATIVE ASSESSMENT

ASI'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. Bare earth DEMs for the south central ⅓ of the project area were provided by subcontractor SAM, the remainder were produced in-house by ASI. 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 IL_LaSalle County project.

Data Voids

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 IL_LaSalle county project.

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. 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 bridge deck (blue).

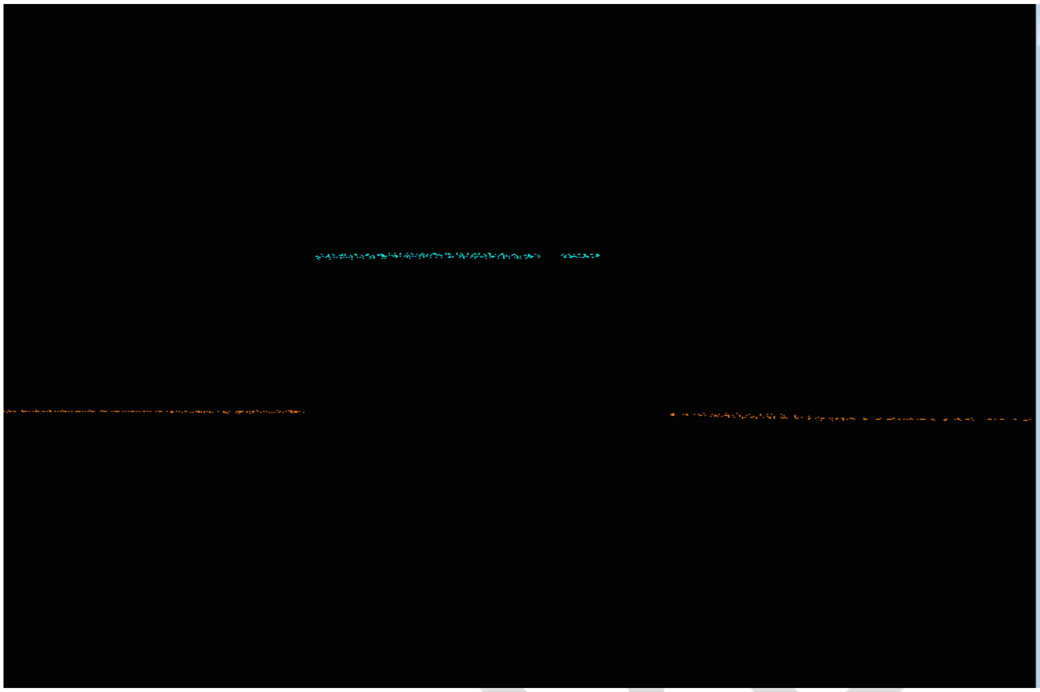


Figure 7: Profile view of a classified bridge deck (blue) and ground (orange).

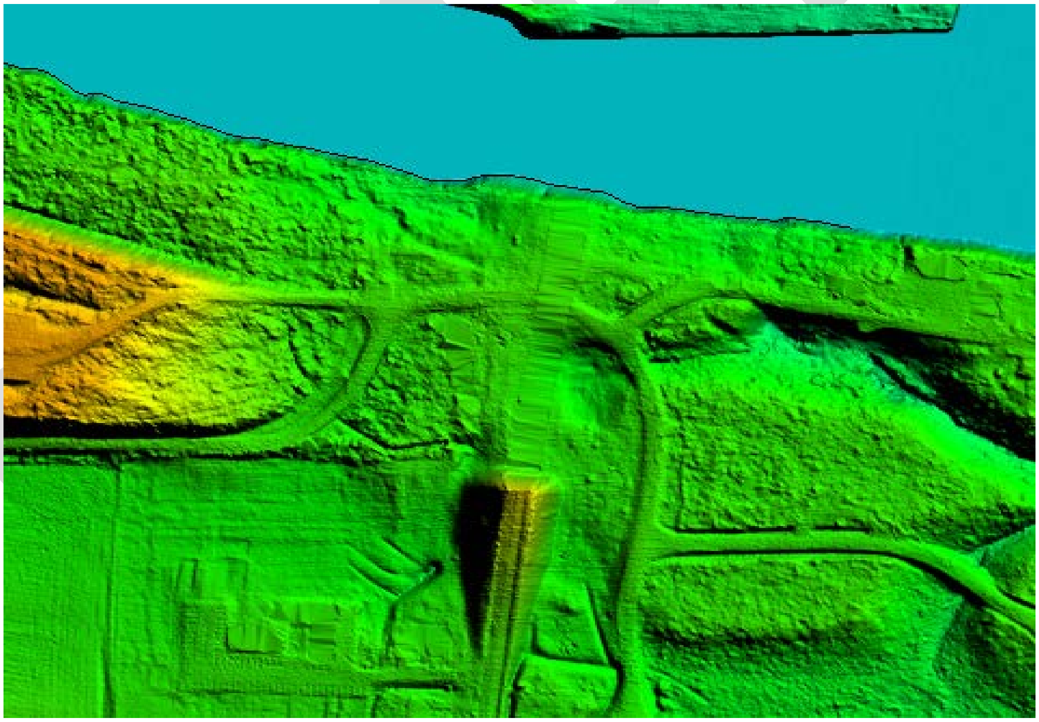


Figure 8: DEM with bridge removed from surface model.

Culverts

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, ASI 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.

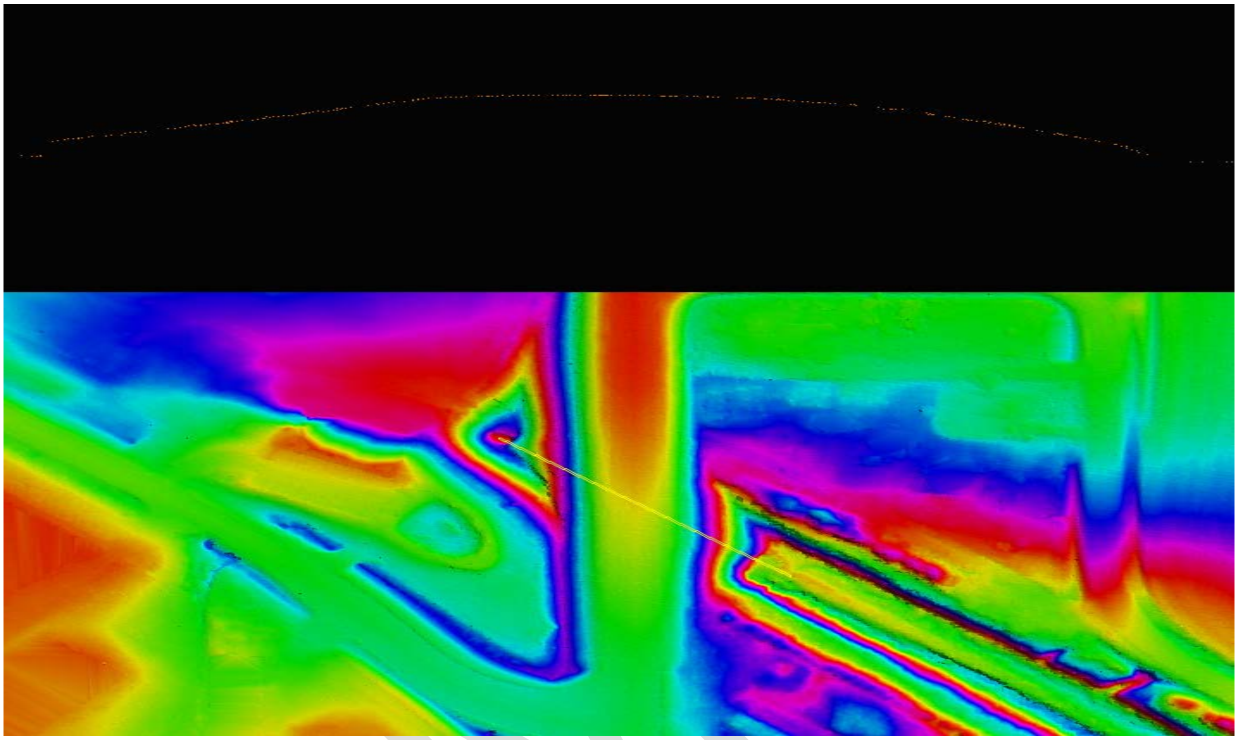


Figure 9: Profile with points colored by class (class 1=white, class 2=orange, model key point=red) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

Dirt Mounds

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

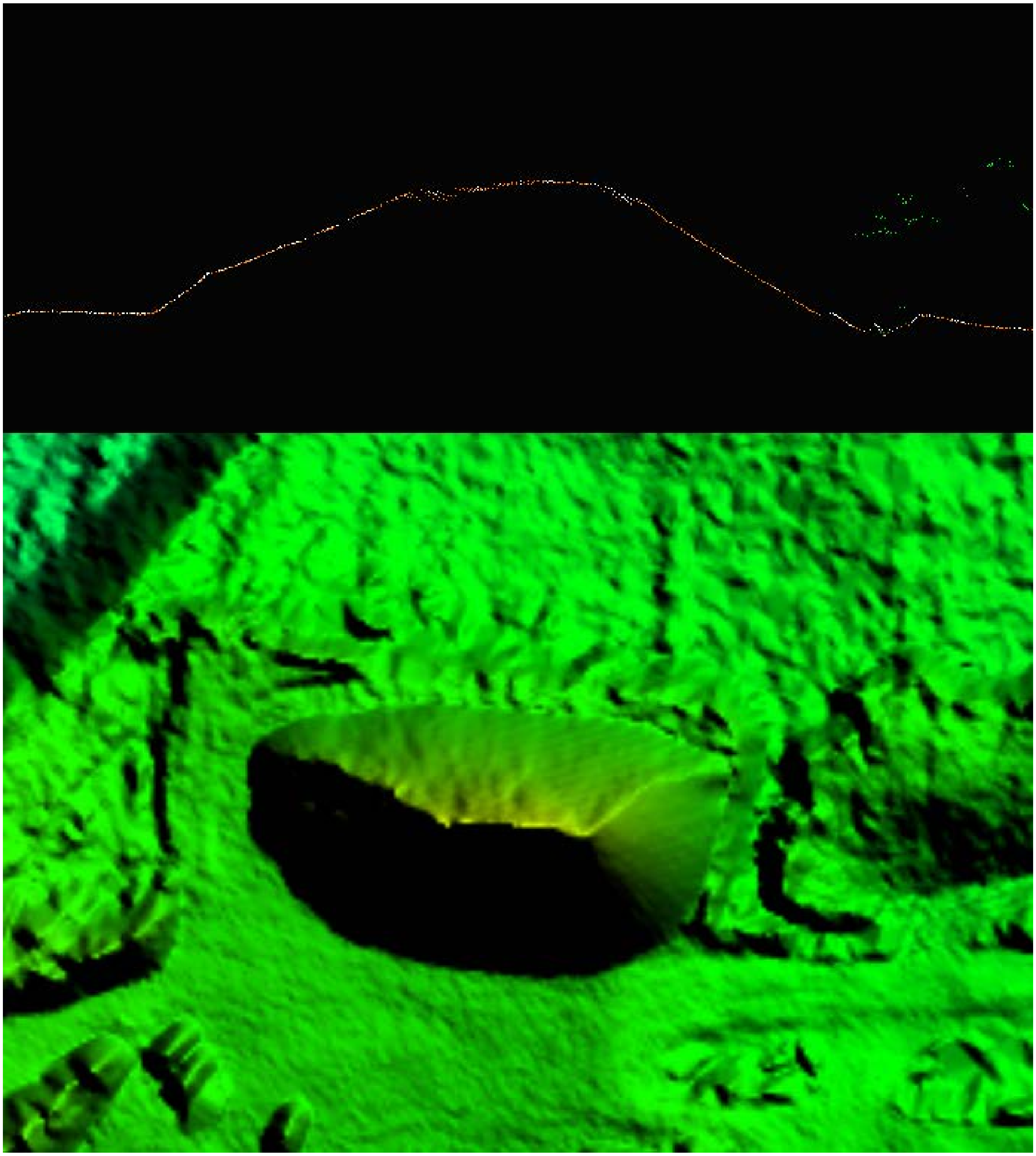
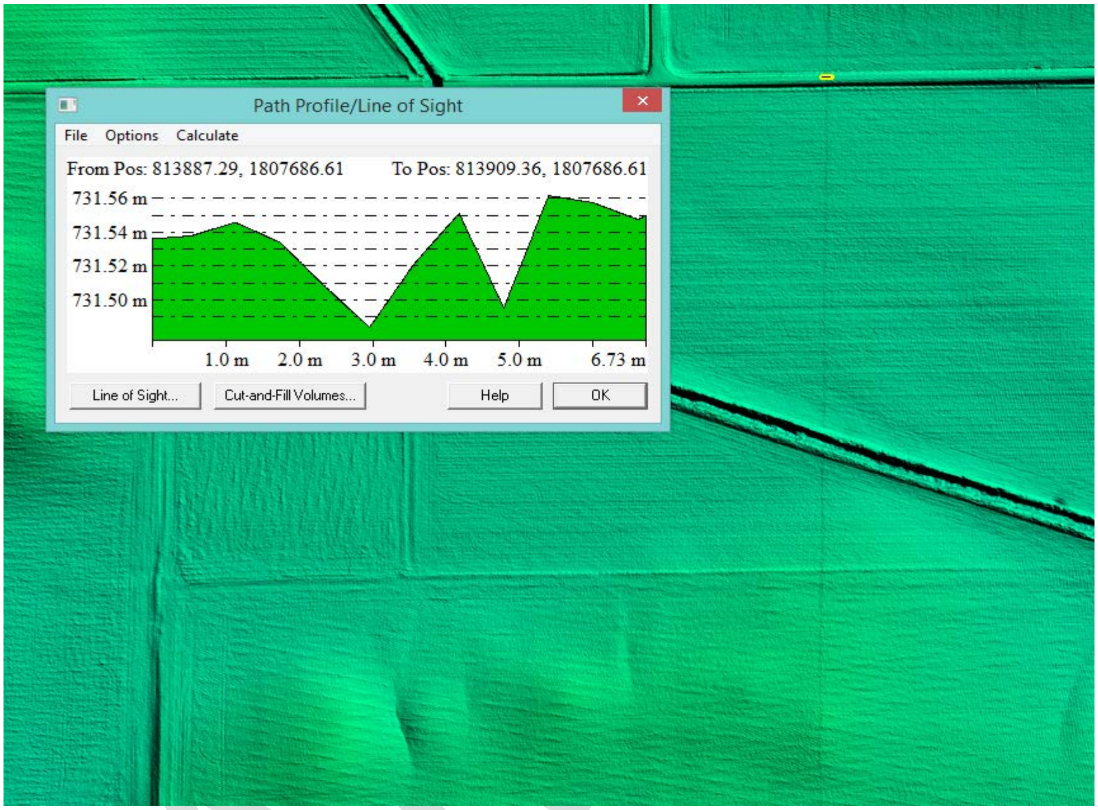


Figure 10 - Profile with the points colored by class (unclassified points are white, ground points are orange) is shown on the right and a DEM of the surface is shown to the left. These features are correctly included in the ground classification.

FLIGHTLINE RIDGES

Ridges occur when there is a difference between the elevations of adjoining flight lines or swaths. Some flightline ridges are visible in the final DEMs but they do not exceed the project specifications and the overall relative accuracy requirements for the project area have been met. An example of a visible flightline ridge that is within tolerance is shown below.



From Pos: 813887.29, 1807686.61 To Pos: 813909.36, 1807686.61

Figure 11 – The flight line ridge is less than 8 cm. Overall, the IL_LaSalle County project data meets the project specifications for 8 cm RMSDz relative accuracy requirement.

Dam and Lock system

Irregularities in the natural water flow exist in sections of river affected by Lock and Dam systems. Series of locks enable vessels to “step” up or down a river or canal from one water level to another. There are several Dam and Lock systems in the IL LaSalle Lidar project area.

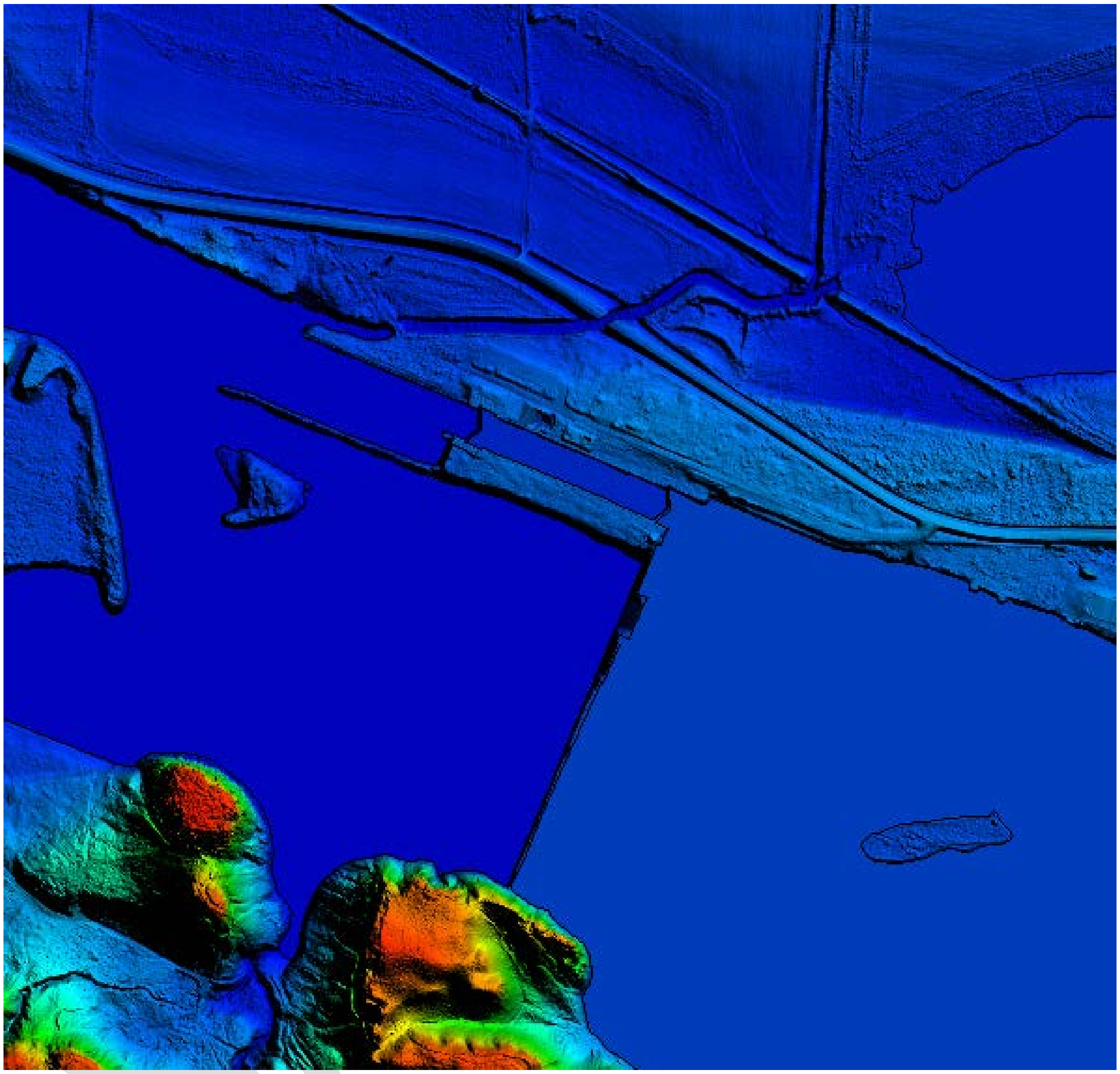


Figure 12 – DEM shows Large Dam structure that disrupts natural monotonic river flow, coupled with a lock system.

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 ASI proprietary tools. ASI routinely reviews for: proper LAS versions, Coordinate Reference System, Global Encoder Bit, Time Stamp, System ID, Multiple Returns, Intensity, Classification, Overlap and Withheld Points, Scan angle, XYZ Coordinates.

LiDAR Positional Accuracy

BACKGROUND

ASI 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. ASI 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 of the IL_LaSalle County project sixty eight check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, brush/low trees, 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) State Plane IL East	NAD83 (2011) State Plane IL East	NAVD88 (Geoid12B)
	Easting (ft)	Northing (ft)	Elevation (ft)
NVA_1025	761423.742	1805500	887.602
NVA_1026	814888.231	1797110	711.795
NVA_1027	863622.535	1797853	684.081
NVA_1034	890397.924	1776948	584.222

NVA_1035	845150.619	1770615	666.449
NVA_1036	803328.746	1770928	689.179
NVA_1037	765713.788	1766066	713.85
NVA_1038	789318.627	1750183	665.106
NVA_1039	828087.764	1749763	650.741
NVA_1040	887448.607	1747619	610.141
NVA_1044	766985.955	1728973	663.109
NVA_1045	805940.34	1728627	621.945
NVA_1046	859375.259	1723904	605.631
NVA_1047	901955.07	1723322	698.768
NVA_1050	776233.423	1708736	620.482
NVA_1051	814539.569	1707452	618.7
NVA_1052	856946.347	1703219	483.01
NVA_1053	882633.389	1703407	690.437
NVA_1057	759695.114	1682536	656.701
NVA_1058	798450.787	1686248	640.339
NVA_1059	846925.139	1685446	603.429
NVA_1060	909851.885	1684556	602.057
NVA_1066	877172.208	1669370	678.105
NVA_1067	816774.066	1667850	661.926
NVA_1068	779718.858	1665024	671.332
NVA_1069	761092.842	1643658	733.827
NVA_1070	806883.092	1643812	665.02
NVA_1071	850860.294	1654478	674.308
NVA_1072	903780.479	1646102	679.719

NVA_1075	783813.562	1630554	706.139
NVA_1076	838409.13	1625651	626.511
NVA_1077	881823.382	1622493	715.932
NVA_1078	914542.29	1622295	659.791
NVA_1079	812379.231	1609610	666.758
NVA_1081	814136.681	1583982	661.254
NVA_1082	797830.876	1562870	694.289
NVA_1088	834654.245	1711660	610.77
VA_2016	769377.356	1794659	843.783
VA_2017	821380.752	1791882	695.91
VA_2018	887769.697	1791632	654.493
VA_2021	785261.358	1766096	689.689
VA_2022	858922.953	1764616	642.128
VA_2023	893171.57	1763176	619.103
VA_2026	773373.673	1734366	659.229
VA_2027	830746.201	1741722	627.961
VA_2028	877214.043	1736588	588.17
VA_2031	764100.035	1705160	637.683
VA_2032	816687.758	1707291	620.804
VA_2033	883582.825	1704226	680.784
VA_2037	784727.927	1685173	633.379
VA_2038	836682.43	1691410	593.843
VA_2039	895342.231	1680646	684.701
VA_2042	764012.442	1673276	659.483
VA_2043	815454.657	1655566	623.742

VA_2044	871861.8	1671513	641.929
VA_2045	891939.008	1654555	718.182
VA_2048	779570.797	1649146	675.151
VA_2049	852146.705	1638457	628.247
VA_2050	903801.256	1638937	667.439
VA_2053	835248.954	1627366	610.293
VA_2055	778596.72	1627712	676.713
VA_2056	814080.17	1600155	652.129
VA_2057	788715.293	1598559	686.431
VA_2058	796798.163	1584079	677.188
VA_2059	814121.82	1578179	649.782
VA_2060	789291.172	1562646	727.613
VA_2061	803857.391	1552332	693.469
VA_2068	856907.349	1805487	688.37

Table 5 – LaSalle Block 1 QL2+ LiDAR Checkpoints.

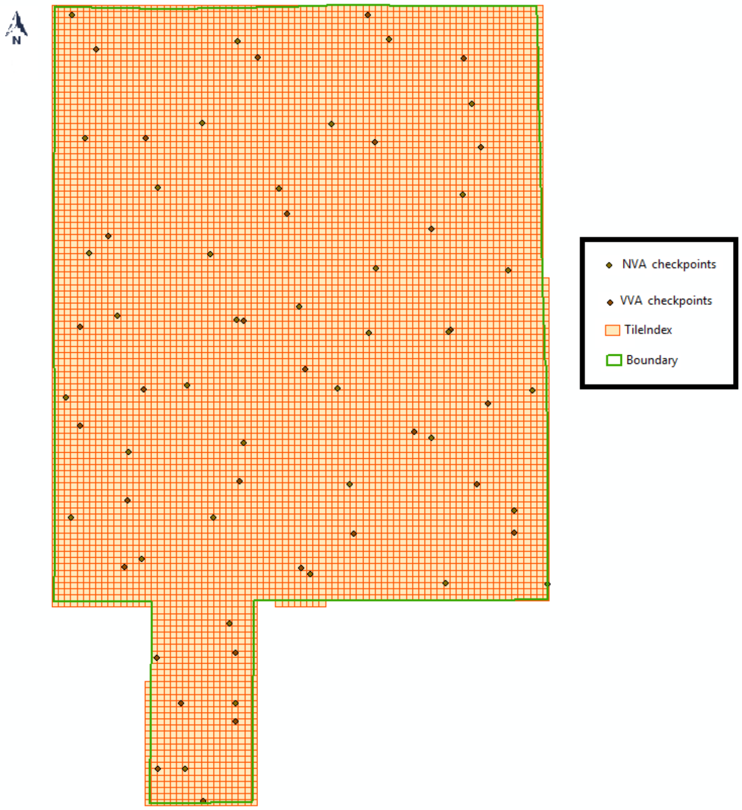


Figure 13 – Location of LaSalle LiDAR QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in nonvegetated 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 (RMSEz) of the checkpoints x 1.9600. For the IL_LaSalle County project, vertical accuracy must be 0.64 ft (19.6 cm) or less based on an RMSEz of 0.33 ft (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 95th percentile error for all checkpoints in all vegetated land cover categories combined. The LaSalle LiDAR Project VVA standard is 0.96 ft (29.4 cm) based on the 95th percentile.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using RMSEz *1.96	0..64 ft (based on RMSEz (0.33 ft)*1.96)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined and at the 95% confidence level	0.96 ft (based on combined 95 percentile)

Table 6 – Acceptance Criteria.

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

1. GRW surveyed QA/QC vertical checkpoints in accordance with the project's specifications.

2. Next, ASI interpolated the bare-earth LiDAR DTM to provide the z-value for every checkpoint.

3. ASI 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 ASI 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 (RMSEz x 1.96)Spec = 0.64 ft	VVA – Vegetated Vertical Accuracy (95th Percentile) spec = 0.96 ft
NVA	37	0.29	
VVA	31		0.77

Table 7 – Tested NVA and VVA.

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

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

1. GRW 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, ASI identified the well-defined features in the intensity imagery.

3. ASI 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 ASI 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

Eighteen checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the LiDAR dataset. As only eighteen (18) checkpoints were photo-identifiable, the results are not statistically significant enough to report as a final tested value, but the results of the testing are still shown in the table below. 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. No horizontal accuracy requirements or thresholds were provided for this project. However, LiDAR datasets are generally calibrated by methods designed to ensure a horizontal accuracy of 1 meter or less.

# of Points	RMSEx (ft)	RMSEy (ft)	RMSEr (ft)	ACCURACYr (RMSEr x 1.7308) (ft)
18	0.129	0.183	0.382	0.658

Table 8 – Tested horizontal accuracy at the 95% confidence level.

Actual positional accuracy of this dataset was found to be RMSEx = 0.129 ft (3.931 cm) and RMSEy = 0.183 (5.578 cm) which equates to +/- 0.658 ft (20.056 cm) at 95% confidence level.

BREAKLINE PRODUCTION METHODOLOGY

MicroStation, in conjunction with TerraSolid's TerraScan and TerraModeler was utilized for the collection of hydrologic breaklines, which occurred independently of manual edit. Collection was done using 2D information in the LAS format, intensity format, and ground surface. Breaklines are developed to the limit of the project boundary. Breaklines are in the same coordinate reference system and unit as the LiDAR point delivery. Hydrologic water-surface edges are set at or below the immediately surrounding terrain. Breaklines are developed to the limit of the project boundary.

BREAKLINE QUALITATIVE ASSESSMENT

Completeness and horizontal placement is verified through visual review against LiDAR intensity imagery, and bare earth surface. Breakline features are check for connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies.

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

FEATURE DEFINITION

Inland Streams and Rivers

Streams and Rivers with a nominal width of 30-m (100 feet), were collected to best fit the shoreline by using information in the LAS format; intensity format, ground surface TIN, and sometimes “quick guide” contours. Streams and rivers do not break at bridges, but they are closed ended breaks at culvert locations. Steams and Rivers breaklines have been delivered in PolylineZ format in the final GDB.

Inland Ponds and Lakes

Inland ponds and lakes of 2 acres (86,111 square feet/ ~350’ diameter for a round pond) or greater were collected. Inland pond and Lakes were collected to best fit the shoreline by using information in the LAS format; intensity format, ground surface TIN, and sometimes “quick guide” contours. Inland pond and Lakes Breaklines have been delivered in PolygonZ format in the final GDB.

Islands

Permanent island 4000m² (1 acre) or larger shall be delineated within all water bodies. Breaklines have been delivered in PolygonZ format in the final GDB

Bridge Breaklines

Breaklines were placed across the bottom of the bridge embankment when triangulation occurred due to bridge deck classification. Breaklines have been delivered in PolylineZ format in the final GDB.

INTENSITY IMAGERY PRODUCTION & QUALITATIVE ASSESSMENT

DEM PRODUCTION METHODOLOGY

ASI utilized MicroStation in conjunction with TerraSolid’s TerraScan for Intensity production. Global Mapper was used to format and QC the products. ArcGIS was used finalize the Intensity’s projection.

Intensity Images are created for each tile in the tiling schema. The Intensities are reviewed for any issues requiring corrections. Tiles are verified for final formatting and loaded into Global Mapper to ensure there are no missing, or corrupt tiles, and to check for seamlessness across tile boundaries.

DEM QUALITATIVE ASSESSMENT

ASI performed a qualitative assessment of the Intensity deliverables to ensure that all tiled Intensity products were delivered with the proper extents, and contained proper referencing information.

The image below show an example of an Intensity Image

Figure 14 – Intensity Image example.

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

ASI utilized MicroStation in conjunction with TerraSolid's TerraScan and TerraModeler for DEM production. Global Mapper was used to format and QC the products. ArcGIS was used finalize the DEMs projection.

The final bare earth LiDAR points are used to create a terrain. The final 3D breaklines collected for the project are enforced in the terrain. The terrain is then converted to raster format using linear interpolation. DEMs are created for each tile in the tiling schema. The DEMs are reviewed for any issues requiring corrections, including remaining LiDAR mis-classifications, erroneous breakline elevations, poor hydro flattening, and processing artifacts. Tiles are verified for final formatting and loaded into Global Mapper to ensure there are no missing, or corrupt tiles, and to check for seamlessness across tile boundaries.

DEM QUALITATIVE ASSESSMENT

ASI performed a 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 proper referencing information. This process was performed using a scrip ASI developed to verify that the raster extents match those of the tile grid and contain the correct projection information.

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

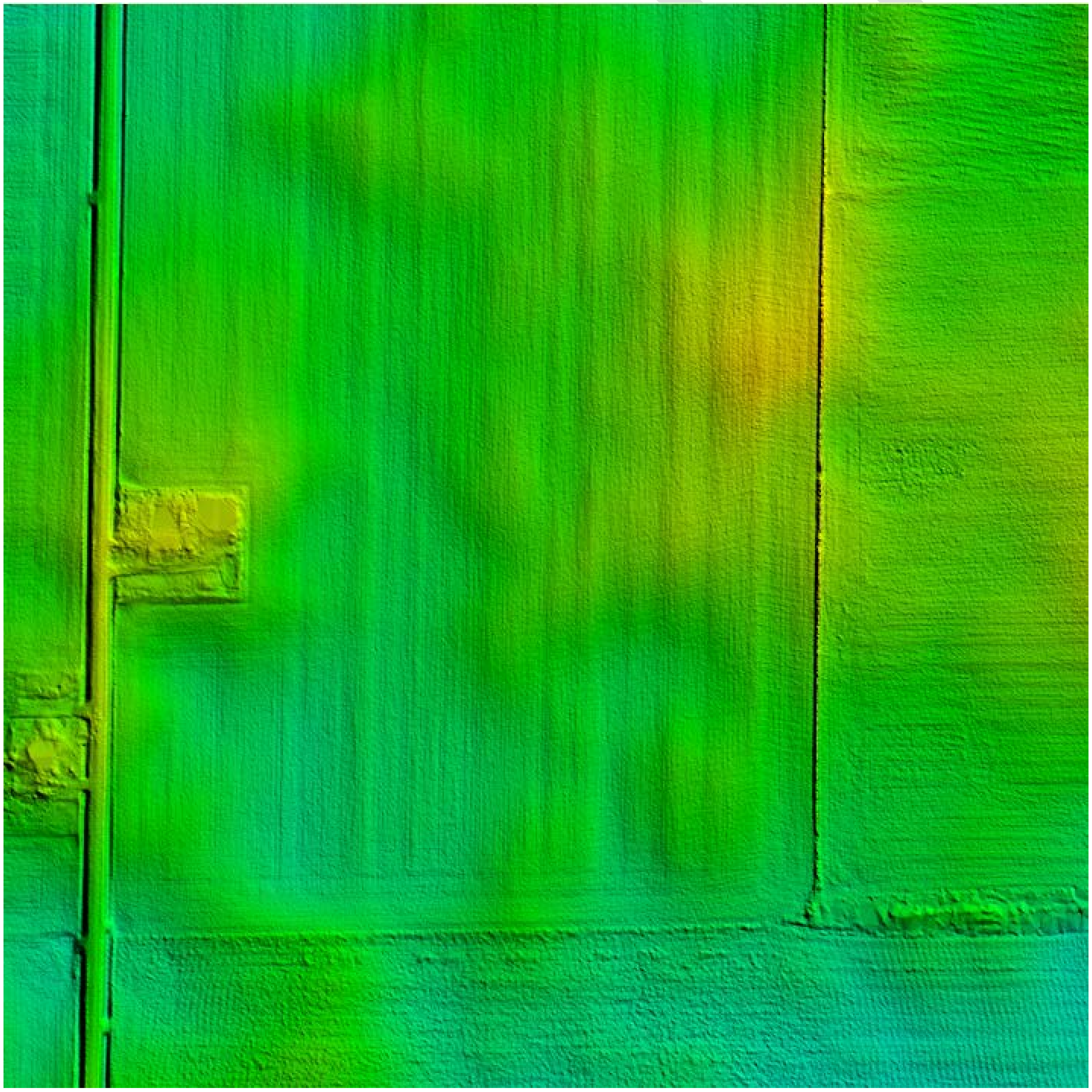


Figure 15 – IL_LaSalle County project bare earth DEM

DEM VERTICAL ACCURACY RESULTS

The same 68 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. The DEM pixel does not average several LiDAR point's together, it interpolates (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 survey elevations

Table 9. Summarizes the tested vertical accuracy result from a comparison of surveyed checkpoint to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy (RMSEz x 1.960)	VVA – Vegetated Vertical Accuracy (95th percentile)
NVA	37	0.13	
VVA	31		0.75

Table 9– DEM vertical accuracy summary

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.33 ft (10 cm) RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 0.13 ft (3.96 cm) equal to +/- 0.25 ft (7.62 cm) at 95 % confidence level. Actual VVA accuracy was found to be +/- 0.75 ft (22.86 cm) at the 95th percentile.

Based on the vertical acdcuracy testing conducted by ASI, the DEM dataset for the IL_LaSalle County project satisfies the project's pre-defined vertical accuracy criteria.

Appendix A: List of Delivered LAS Files

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Appendix B: List of Bit Set Withheld Tiles

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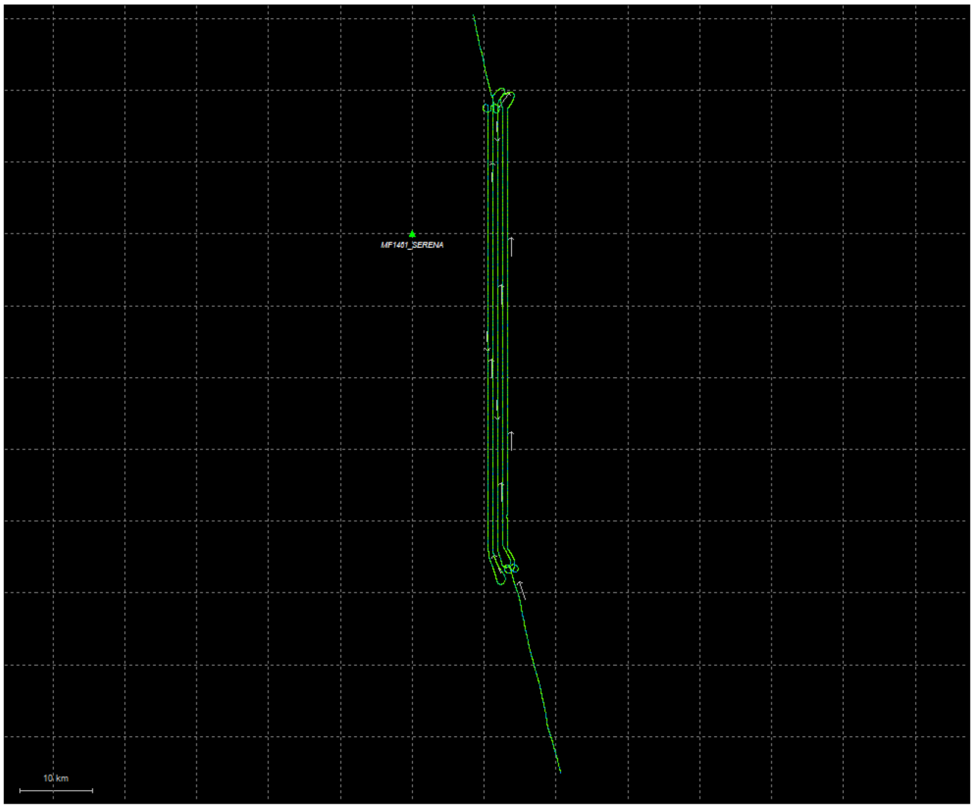
Appendix C: Sample Mission GPS and IMU Processing Report

Output Results for 3DEP_LaSalle_20171119_201531

Inertial Explorer Version 8.60.6717
06/07/2018

Figure 1: Smoothed TC Combined - Map



Process	3DEP_LaSalle_20171119_201531	by Unknown	on 11/23/2017	at 09:13:03

Figure 2: 3DEP_LaSalle_20171119_201531 [Smoothed TC Combined] - Estimated Position Accuracy Plot