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NE Northeast Phase2 QL2-Block

Report Produced for U.S. Geological Survey

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Appendix A: GPS Processing Reports

1. 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 NE Northeast Phase 2 project area.

Lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models were produced for the project area. Project components were formatted based on a tile grid with each tile covering an area 1,000 m by 1,000 m. A total of 20,121 tiles were produced for the project, providing approximately 7,406 sq. miles of coverage.

Lidar data, and derivative products produced in compliance with this task order are based on Geological Survey National Geospatial Program Lidar Base Specification, 2022 rev. A.

1.1 Project Team

Ahtna Solutions, LLC 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.

The ground survey was completed for the project and delivered surveyed checkpoints by Merrick. The task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the lidar-derived surface model and to acquire surveyed ground control points for use in calibration activities. Merrick also verified the GPS base station coordinates used during lidar data acquisition.

Ahtna Solutions, LLC completed lidar data acquisition and data calibration for the project area.

1.2 Project Area

The block area is shown in

figure 1. The project tile grid contains 20,121 1,000 m by 1,000 m tiles.

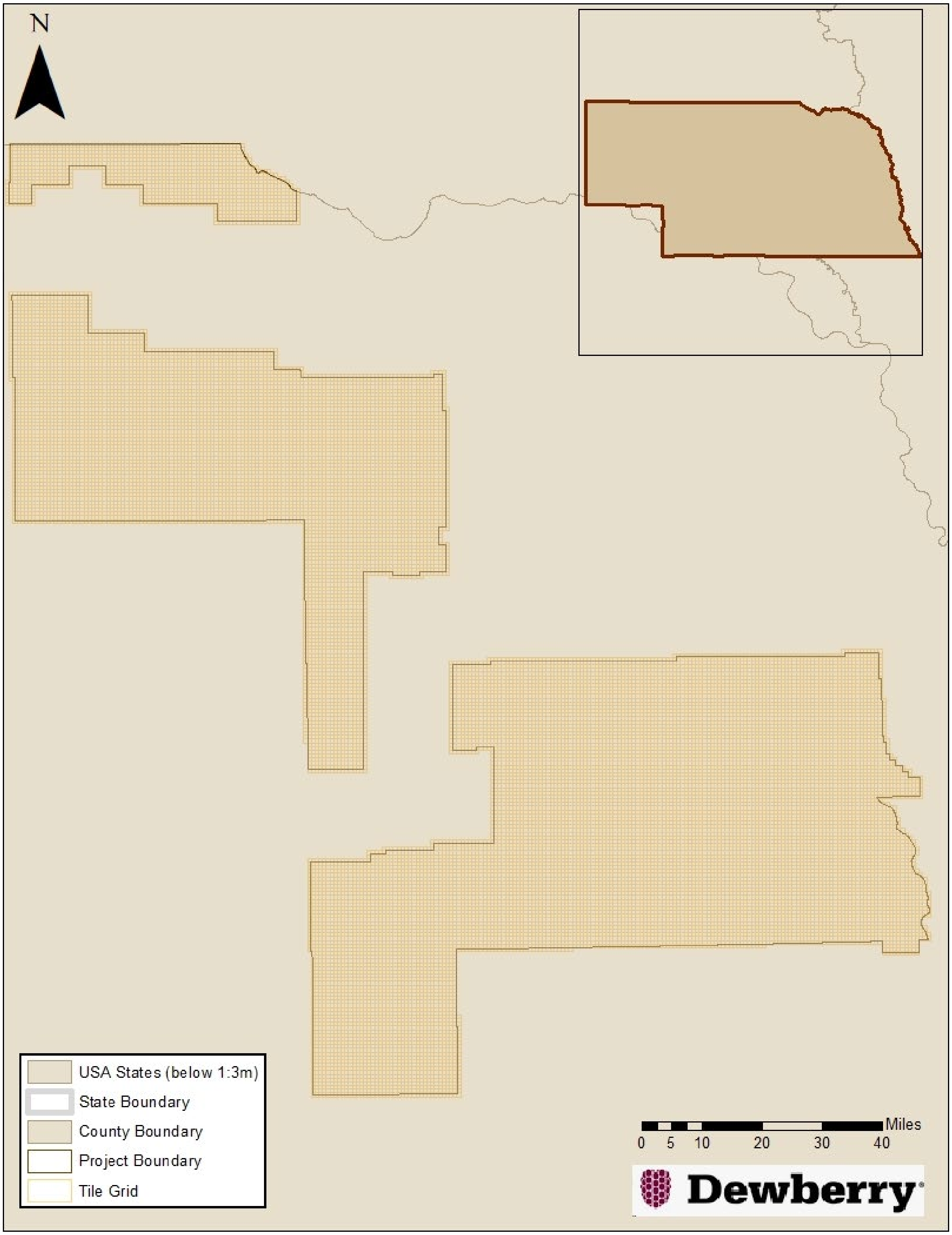

Figure 1. Project map and tile grid.

1.3 Coordinate Reference System

Data produced for the project are delivered in the following spatial reference system:

Horizontal Datum:	North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum:	North American Vertical Datum of 1988 (NAVD88)
Geoid Model:	Geoid18
Coordinate System:	UTM Zone 14N
Horizontal Units:	Meters
Vertical Units:	Meters

1.4 Lidar Vertical Accuracy

For the NE Northeast Phase 2 Lidar Project, the tested RMSEz of the classified lidar data for checkpoints in non-vegetated terrain equaled 4**.1 cm** compared with the 10 cm specification; and the NVA of the classified lidar data computed using RMSEz x 1.9600 was equal to **8.1 cm**, compared with the 19.6 cm specification.

For the NE Northeast Phase 2 Lidar Project, the tested VVA of the classified lidar data computed using the 95th percentile was equal to **17.1 cm**, compared with the 30 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.

1.5 Project Deliverables

The deliverables for the block are as follows:

1. Project Extents (Esri SHP)
2. Calibration Points (coordinates, Esri shapefile)
3. Classified Point Cloud (tiled LAS)
4. Independent Survey Checkpoint Data (report, photos, coordinates, Esri shapefiles)
5. Intensity Images (tiled, 8-bit gray scale, GeoTIFF format)
6. Breakline Data (file GDB)
7. Bare Earth Surface (Mosaic and tiled raster DEMs, IMG format)
8. First Return Digital Surface Model (Mosaic and tiled raster DSMs, IMG format)
9. Hillshade (Mosaic and tiled raster DEMs, IMG format)
10. Contours
11. Swath Separation Images
12. Interswath Polygons
13. Intraswath Polygons
14. Metadata (XML)
15. Project Report

1.6 Dewberry Production Workflow Diagram

The diagram below outlines Dewberry's standard lidar production workflow.

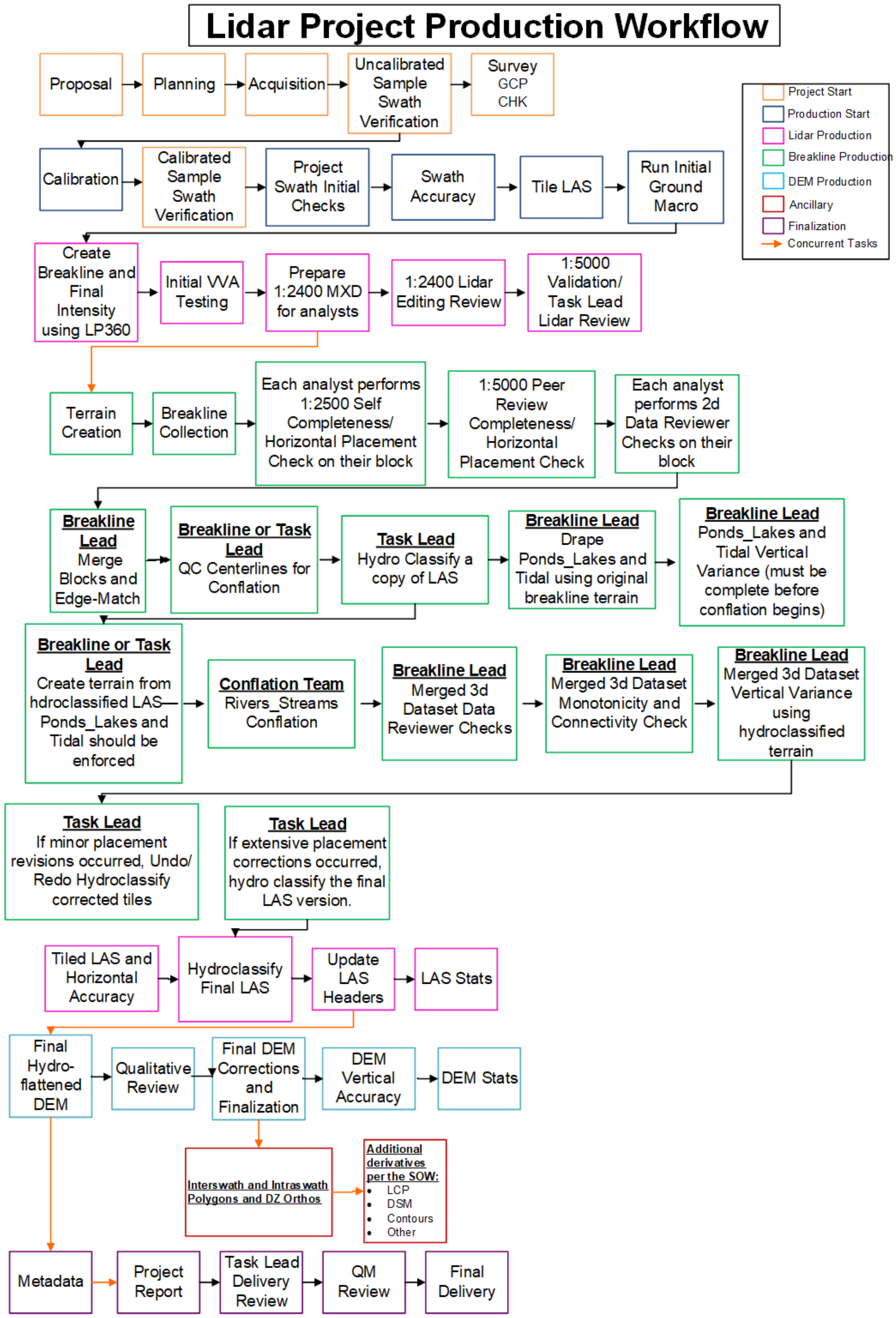

Figure 2. Dewberry's Lidar Production Workflow Diagram

2. LIDAR ACQUISITION REPORT

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

The lidar aerial acquisition for the north, central and south blocks were conducted between November 16th, 2020 thru December 9th, 2020.

2.1 Summary

Acquisition needed to be timed so majority of the crops in the AOI were plowed and before snow began to fall. Dewberry and Ahtna Solutions communicated with USGS and NRCS for environmental conditions in the field and awaited approval from NRCS based on the percentage of plowed fields before beginning acquisition. Acquisition began on November 16, 2020. There were several days we were grounded due to weather conditions and acquisition wrapped up on December 9, 2020. There were several factories within the AOI that had persistent small patches of vented exhaust that may be reflected in the dataset.

In the south portion of the AOI vented exhaust is present in the dataset. Consisting of approximately 0.00077 sq miles located near south portion of the AOI. The name of the shapefile is Low_Confidence_Polygons.shp and can be found in the Low_Confidence_Polygons folder of the deliverables.

2.2 Lidar Acquisition Details

Ahtna Solutions, LLC lidar sensors are calibrated at a designated site located and are periodically checked and adjusted to minimize corrections at project sites.

Ahtna Solutions, LLC planned 200 passes for the project area as a series of parallel flight lines with cross flight lines for the purposes of quality control. The flight plan included zigzag flight line collection to compensate for the drift commonly associated with onboard inertial measurement unit (IMU) systems. In order to reduce potential errors in the data attributable to flight planning, Ahtna Solutions, LLC followed FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Survey.* The guidance includes the following minimum criteria:

- A digital flight line layout using Optech's FMS 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;
- Investigation of local restrictions related to air space and any controlled areas so that required permissions can be obtained in a timely manner with respect to project schedule; and
- Filed flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Ahtna Solutions, LLC monitored weather and atmospheric conditions and conducted lidar missions only when no conditions existed below the sensor that would affect the collection of data. Good lidar collection conditions include leaf-off for hardwoods and no snow, rain, fog, smoke, mist, or low clouds. Lidar systems are active sensors that do not require active light, thus allowing missions to be conducted during night hours if weather restrictions do not prevent collection. Ahtna Solutions, LLC accessed reliable weather sites and indicators (webcams) to establish the highest probability for successful data acquisition.

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

2.3 Lidar System Parameters

Ahtna Solutions, LLC operated a fixed wing aircraft outfitted with a Galaxy Prime T2000 lidar system during data collection. Table 1 details the lidar system parameters used during acquisition for this project.

Table 1. Ahtna Solutions, LLC lidar system parameters.

Parameter	Value
System	Galaxy Prime T2000 – SN5060449
Altitude (m above ground level)	2750
Nominal flight speed (kts)	170
Scanner pulse rate (kHz)	1000
Scan frequency (Hz)	93
Pulse duration of the scanner (ns)	3.5
Pulse width of the scanner (m)	1.375
Central wavelength of the sensor laser (nm)	1064
Multiple pulses in the air	Yes
Beam divergence (mrad)	0.25
Swath width (m)	1974.01
Nominal swath width on the ground (m)	2002
Swath overlap (%)	30
Total sensor scan angle (degrees)	40
Computed down track spacing per beam (m)	0.47
Computed cross track Spacing per beam (m)	0.47
Nominal pulse spacing (NPS) (single swath) (m)	0.58
Nominal Pulse Density (NPD) (single swath) (points per sq m)	3
Aggregate NPS (m) (if NPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.58
Aggregate NPD (m) (if NPD was designed to be met through single coverage, ANPD and NPD will be equal)	3
Maximum Number of Returns per Pulse	8

2.4 Acquisition Status Report and Flight Lines

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 course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the lidar sensor, the position dilution of precision (PDOP), and performed the first quality control review during acquisition. The flight crew 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 3 shows the combined flight line trajectories.

Figure 3. Trajectories of flight lines flown by Ahtna Solutions, LLC .

2.5 Airborne Kinematic Control

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

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

GNSS processing reports for each mission are included in Appendix A.

2.6 Generation and Calibration of Raw Lidar Data

Availability and status of all required GPS and laser data were verified against field reports and any data inconsistencies were addressed.

Subsequently the mission points were output using Optech's Lidar Mapping Suite (LMS) processor, initially with default values from Optech or the last mission calibrated for the system. The initial point generation for each mission calibration was verified within Microstation/TerraScan for calibration errors. If a calibration error greater than specification was observed, the appropriate roll, pitch and scanner scale corrections were calculated. The point data were then regenerated with the new calibration values and validated internally again to ensure that the errors were fully addressed.

Data collected by the lidar unit was reviewed for completeness, acceptable density, and to make sure all data were captured without errors or corrupted values. All GPS, aircraft trajectory, mission information, and ground control files were reviewed and logged. A supplementary coverage check was carried out (figure 4) to ensure that there were no unreported gaps in data coverage.

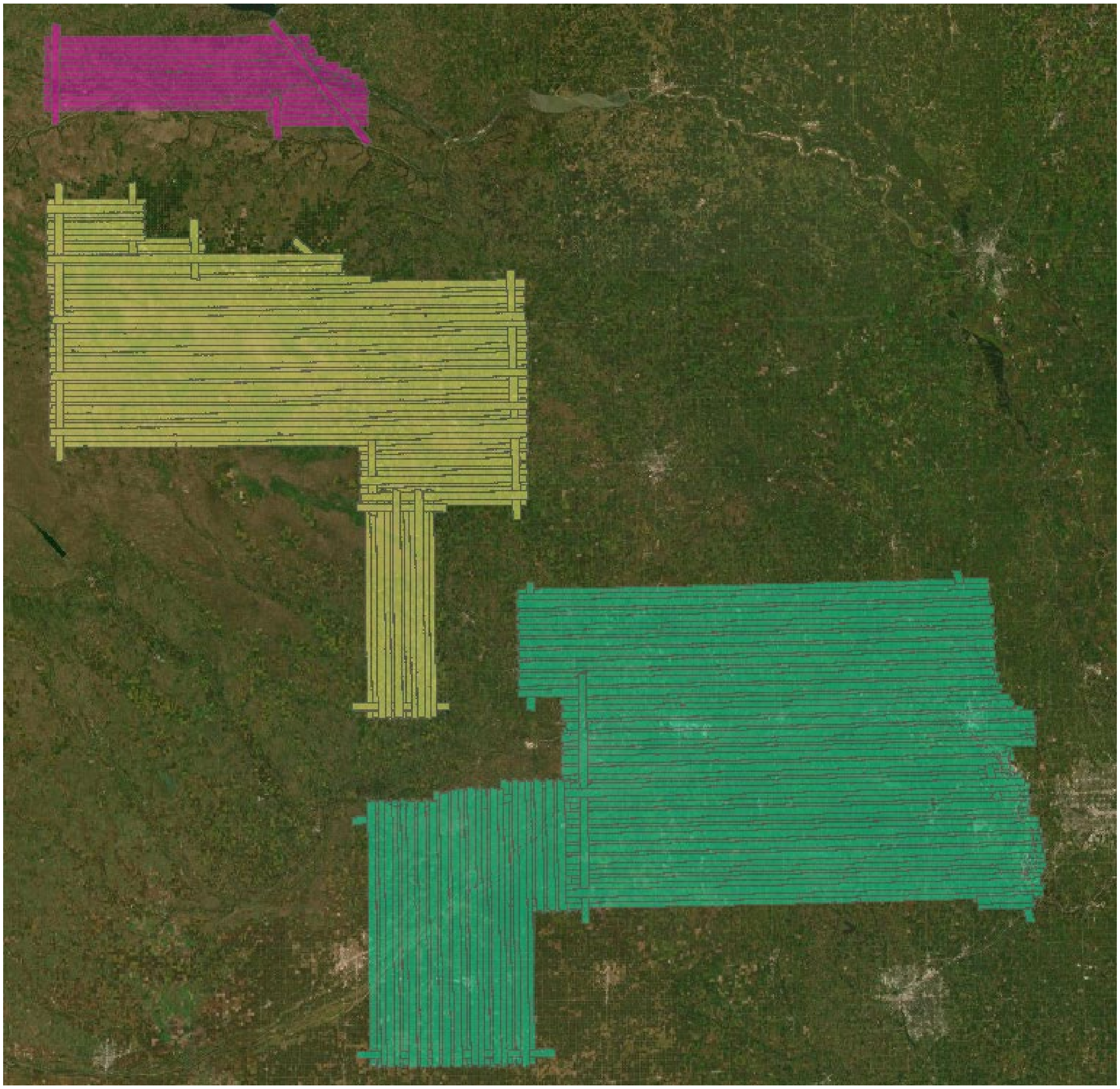

Figure 4. Lidar swath output showing complete coverage.

2.6.1 Boresight and Relative accuracy

The initial points for each mission calibration were inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the lidar unit or GPS. Roll, pitch and scanner scale were optimized during the calibration process until relative accuracy requirements were met (figure5).

Relative accuracy and internal quality were checked using at least 3 regularly spaced QC blocks in which points from all lines were loaded and inspected. Vertical differences between ground surfaces of each line were displayed. Color scale was adjusted to flag errors that were not within project specifications (figure 6). Cross sections were visually inspected across each block to validate point to point, flight line to flight line, and mission to mission agreement.

The following relative accuracy specifications were used for this project:

- ≤ 6 cm maximum difference within individual swaths (intra-swath); and
- ≤ 8 cm RMSDz between adjacent and overlapping swaths (inter-swath).

A different set of QC blocks were generated for final review after any necessary transformations were applied.

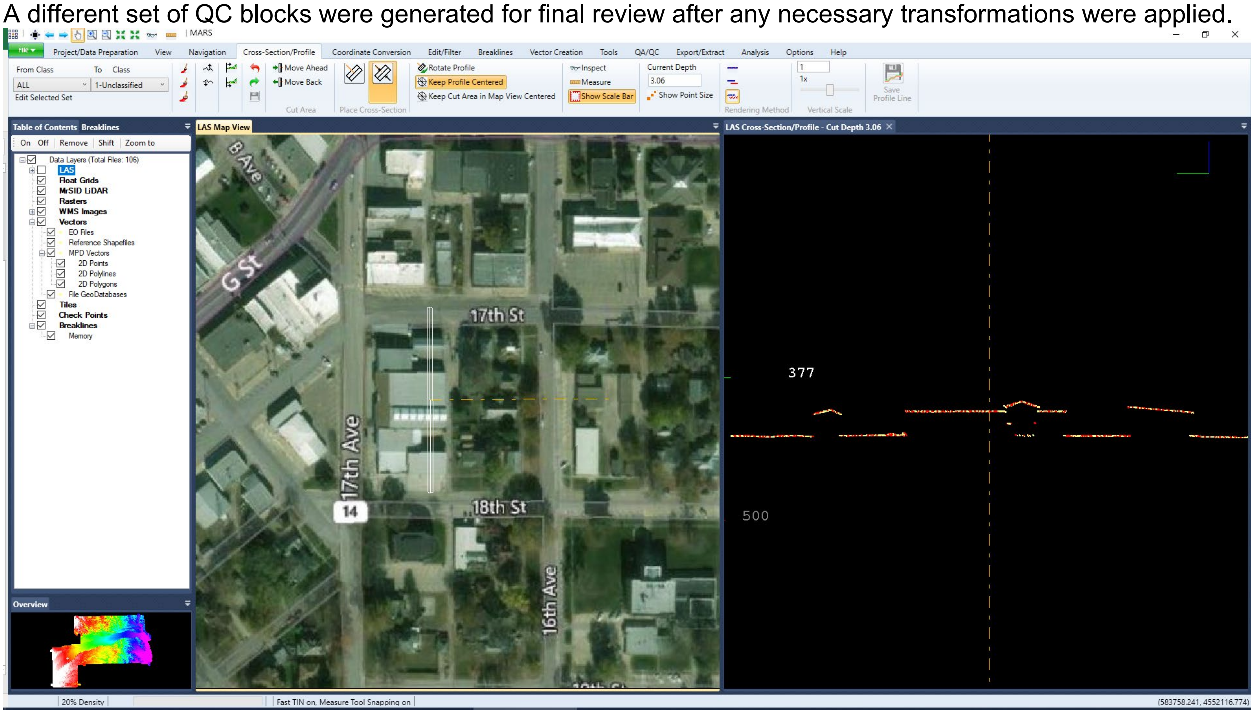

Figure 5. Profile views showing results of roll and pitch adjustments.

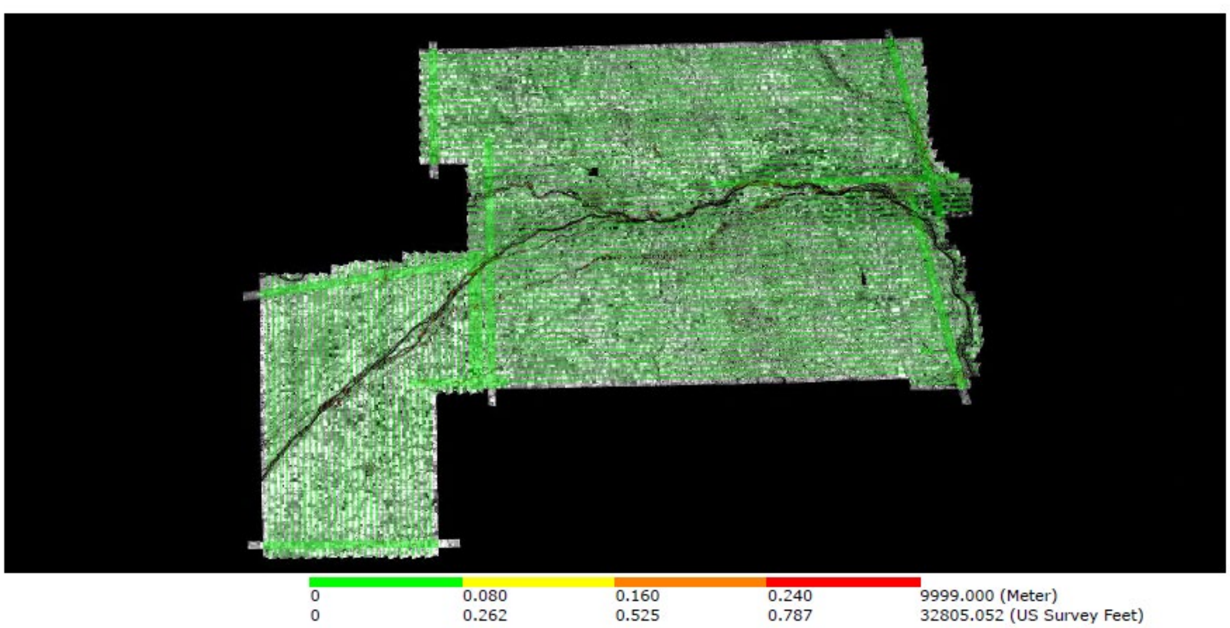

Figure 6. QC block colored by vertical difference between swaths to check accuracy at swath edges.

2.7 Final Calibration Verification

Ahtna Solutions, LLC conducted the survey for 80 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 80 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 2 and the accuracy results from testing the calibrated swath data against the GCPs is provided in table 3; no further adjustments to the swath data were required based on the accuracy results of the GCPs.

This project must meet Non-vegetated Vertical Accuracy (NVA) ≤ 8.2 cm at the 95% confidence level based on $RMSE_z$ ≤ 4.2 cm x 1.9600.

Table 2. NE Northeast Phase 2 surveyed ground control points (GCPs).

Point ID	NAD83 (2011), UTM Zone 14N, Meters		NAVD88 (Geoid 18)	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
3001	596998.512	4526851.048	533.926	533.95
3002A	680616.188	4588684.443	394.451	394.45
3003	698986.596	4580440.313	389.551	389.53
3004	675787.485	4620154.119	444.213	444.18
3005	611227.87	4574227.836	473.626	473.61
3006	684227.954	4563945.588	414.814	414.84
3007	584293.926	4534026.493	552.192	552.21
3008	666830.157	4592547.386	408.996	408.97
3009	569926.008	4540971.478	540.597	540.65
3010	601674.12	4547871.434	532.164	532.14
3011	597598.6	4505944.223	526.043	526.05
3012	670142.272	4571665.157	459.454	459.47
3013	708007.064	4558086.996	343.644	343.68
3014	720976.004	4545220.994	333.537	333.57
3015	621535.573	4560281.888	506.418	506.39
3016	610661.116	4583454.111	477.667	477.68
3017A	627554.013	4583754.503	451.618	451.64
3018	695850.036	4591806.596	376.889	376.85
3019	591648.802	4567846.294	499.663	499.63
3020	562164.194	4507144.074	571.399	571.37
3021	577166.37	4568498.78	528.618	528.6
3022	698308.42	4547333.548	365.282	365.32
3023	571714.4	4518516.299	559.708	559.61
3024	627952.741	4601504.238	508.539	508.53
3025	700851.258	4569205.951	373.291	373.31

3026	659829.694	4619760.401	474.472	474.45
3027	670864.18	4549108.477	449.476	449.48
3028	608463.745	4612452.888	536.576	536.56
3029	684063.767	4612269.984	418.364	418.3
3030	649047.219	4596627.997	450.855	450.82
3031	652033.89	4548717.378	462.713	462.78
3032	634933.085	4577431.864	449.995	449.96
3033	661763.665	4606119.861	472.312	472.3
3034	570808.265	4560332.114	532.999	533.03
3035	561950.92	4536106.694	552.095	552.12
3036	646470.848	4561593.983	476.635	476.68
3037	694621.67	4614981.528	381.348	381.28
3038	710771.462	4601618.185	367.596	367.6
3039	721601.825	4589019.385	351.638	351.62
3040	707830.809	4623125.806	399.766	399.75
3041	715431.851	4576124.739	390.812	390.79
3042	602021.719	4620354.54	559.93	559.87
3043	632307.164	4548507.588	502.286	502.3
3044	618530.745	4592478.662	462.675	462.67
3045	562714.329	4565084.106	533.199	533.22
3046	637297.364	4619388.382	499.851	499.79
3047	600240.383	4597893.519	510.829	510.83
3048	553790.853	4678752.249	566.361	566.28
3049	547455.445	4701624.413	592.777	592.82
3050	593377.123	4649130.213	568.032	568.15
3051	560703.212	4598715.236	612.098	612.22
3052	504001.692	4707218.42	639.924	640
3053A	592976.623	4673174.612	535.896	535.9
3054	578076.098	4655256.955	584.061	584.09
3055	562115.988	4614885.468	610.784	610.81
3056	494274.819	4661190.773	710.26	710.22
3057	513660.431	4702980.069	619.556	619.56
3058	528828.33	4661284.34	629.938	629.89
3059	569535.179	4638336.848	593.941	594
3060	527944.193	4672572.346	626.083	626.09
3061	488281.879	4715788.407	655.432	655.48
3062	591073.777	4695684.667	510.434	510.39
3063	528689.468	4690295.441	614.324	614.32
3064	567687.866	4668833.984	546.147	546.11

3065	483100.32	4706080.08	679.987	680.02
3066	486980.223	4682819.234	708.269	708.3
3067C	559848.924	4648623.664	629.799	629.81
3068	594395.02	4689435.96	536.714	536.6
3069A	503011.523	4689323.033	673.376	673.32
3070	580138.195	4682641.387	590.613	590.59
3071	544887.075	4687171.849	579.936	579.98
3072	556173.626	4667916.706	604.592	604.59
3073	514331.289	4664453.497	668.876	668.88
3074	572211.995	4600461.023	535.739	535.76
3075	543398.455	4741499.885	427.09	427.09
3076	482458.301	4756155.024	626.958	626.93
3077	522418.417	4759896.928	556.992	557.02
3078	481393.142	4746327.514	584.619	584.64
3079	521035.985	4748234.438	519.168	519.14
3080	543168.773	4753163.474	468.389	468.35

Table 3. Ground control points (GCPs) vertical accuracy results.

100 % of Totals	# of Points	RMSEz (m) Spec=0.100 m	NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
GCP	80	0.042	0.082	-0.001	0	0.168	0.042	-0.114	0.122	0.976

3. LIDAR PRODUCTION & QUALITATIVE ASSESSMENT

3.1 Initial Processing

Following receipt of the calibrated swath data from the acquisition provider, Dewberry performed vertical accuracy validation of the swath data, inter-swath relative accuracy validation, intra-swath relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allowed Dewberry to determine whether the data was suitable for full-scale production.

3.1.1 Post Calibration Lidar Review

The table below identifies requirements verified by Dewberry prior to tiling the swath data, running initial ground macros, and starting manual classification.

Table 4. Post calibration and initial processing data verification steps.

Requirement	Description of Deliverables	Additional Comments
Non-vegetated vertical accuracy (NVA) of the swath data meet required specifications of 19.6 cm at the 95% confidence level based on RMSEz (10 cm) x 1.96	The swath NVA was tested and passed specifications.	None
The NPD/NPS (or Aggregate NPD/Aggregate NPS) meets required specification of 2 ppsm or 0.7 m NPS. The NPD (ANPD) is calculated from first return points only.	The average calculated (A)NPD of this project is 2 ppsm. Density raster visualization also passed specifications.	None
Spatial Distribution requires 90% of the project grid, calculated with cell sizes of 2*NPS, to contain at least one lidar point. This is calculated from first return points only.	98% of cells (2*NPS cell size) had at least 1 lidar point within the cell.	None
Within swath (Intra-swath or hard surface repeatability) relative accuracy must meet ≤ 6 cm maximum difference	Within swath relative accuracy passed specification.	None
Between swath (Inter-swath or swath overlap) relative accuracy must meet 8 cm RMSDz/16 cm maximum difference. These thresholds are tested in open, flat terrain.	Between swath relative accuracy passed specification, calculated from single return lidar points.	None
Horizontal Calibration-There should not be horizontal offsets (or vertical offsets) between overlapping swaths that would negatively impact the accuracy of the data or the overall usability of the data. Assessments made on rooftops or other hard planar surfaces where available.	Horizontal calibration met project requirements.	None
Ground Penetration-The missions were planned appropriately to meet project density requirements and achieve as much ground penetration beneath vegetation as possible	Ground penetration beneath vegetation was acceptable.	None
Sensor Anomalies-The sensor should perform as expected without anomalies that negatively impact the usability of the data, including issues such as excessive sensor noise and intensity gain or range-walk issues	No sensor anomalies were present.	None

Requirement	Description of Deliverables	Additional Comments
Edge of Flight line bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath acquired, regardless of which type of sensor is used	Edge of Flight line bits were populated correctly	None
Scan Direction bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath acquired with sensors using oscillating (back-and-forth) mirror scan mechanism. These fields should show a minimum and maximum of 0 for each swath acquired with Riegl sensors as these sensors use rotating mirrors.	Scan Direction bits were populated correctly	None
Swaths are in LAS v1.4 formatting	Swaths were in LAS v1.4 as required by the project.	None
All swaths must have File Source IDs assigned (these should equal the Point Source ID or the flight line number)	File Source IDs were correctly assigned	None
GPS timestamps must be in Adjusted GPS time format and Global Encoding field must also indicate Adjusted GPS timestamps	GPS timestamps were Adjusted GPS time and Global Encoding field were correctly set to 17	None
Intensity values must be 16-bit, with values ranging between 0-65,535	Intensity values were 16-bit	None
Point Source IDs must be populated and swath Point Source IDs should match the File Source IDs	Point Source IDs were assigned and match the File Source IDs	None

3.1.2 Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Ahtna Solutions, LLC , 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 one hundred fifty seven (157) 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 based on the $RMSE_z$ (10 cm) x 1.96. The dataset for the NE Northeast Phase 2 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 $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = **5.9 cm**, equating to **+/- 11.5 cm** at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

Table 5. NVA at 95% Confidence Level for Raw Swaths

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.10 m	NVA –Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Non-Vegetated Terrain	157	0.059	0.115	0.007	0.008	2.311	0.059	-0.104	0.430	16.324

3.2 Data Classification and Editing

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, Dewberry utilized proprietary and TerraScan software for processing. The acquired 3D laser point clouds were tiled according to the project tile grid using proprietary software. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classified 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 were geometrically unusable were flagged as withheld and classified to a separate class so that they would be excluded from the initial ground algorithm. After points that could negatively affect the ground were removed from class 1, the ground layer was extracted from this remaining point cloud using an iterative surface model.

This surface model was generated using four main parameters: building size, iteration angle, iteration distance, and maximum terrain angle. The initial model was based on low points being selected by a "roaming window" with the assumption that these were the ground points. The size of this roaming window was determined by the building size parameter. The low points were triangulated and the remaining points were evaluated and subsequently added to the model if they met the iteration angle and distance constraints. This process was repeated until no additional points were added within iterations. Points that did not relate to classified ground within the maximum terrain angle were not captured by the initial model.

After the initial automated ground routine, each tile was 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. Dewberry analysts employed 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points were removed from the ground classification. Bridge decks were classified to class 17 and bridge saddle breaklines were used where necessary. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilized breaklines to automatically classify hydro features. The water classification routine selected ground points within the breakline polygons and automatically classified them as class 9, water. During this water classification routine, points that were within 1 NPS distance or less of the hydrographic feature boundaries were moved to class 20, ignored ground, to avoid hydro-flattening artifacts along the edges of hydro features.

The withheld bit was set on class 7, class 18, and the withheld points previously identified in TerraScan before the ground classification routine was performed.

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

3.2.1 Qualitative Review

Dewberry's qualitative assessment of lidar point cloud data utilized a combination of statistical analyses and visual interpretation. Methods and products used in the assessment included profile- and map view-based point cloud review, pseudo image products (e.g., intensity orthoimages), TINs, DEMs, DSMs, and point density rasters. This assessment looked for incorrect classification and other errors sourced in the LAS data. Lidar data are peer reviewed, reviewed by task leads (senior level analysts), and verified by an independent QA/QC team at key points within the lidar workflow.

The following table describes Dewberry's standard editing and review guidelines for specific types of features, land covers, and lidar characteristics.

Table 6. Lidar editing and review guidelines.

Category	Editing Guideline	Additional Comments
No Data Voids	The SOW for the project defines unacceptable data voids as voids greater than 4 x $ANPS^2$, or 1.96 m^2, that are not related to water bodies or other areas of low near-infrared reflectivity and are not appropriately filled by data from an adjacent swath. The LAS files were used to produce density grids based on Class 2 (ground) points for review.	Ground void for more information reference lidar acquisition summary in section 2.2. The shapefile named NE_Northeast_Phase2_Vented_Exhaust.shp
Artifacts	Artifacts in the point cloud are typically caused by misclassification of points in vegetation or man-made structures as ground. Low-lying vegetation and buildings are difficult for automated grounding algorithms to differentiate and often must be manually	None

Category	Editing Guideline	Additional Comments
	removed from the ground class. Dewberry identified these features during lidar editing and reclassified them to Class 1 (unassigned). Artifacts up to 0.3 m above the true ground surface may have been left as Class 2 because they do not negatively impact the usability of the dataset.	
Bridge Saddles	The DEM surface models are created from TINs or terrains. TIN and terrain models create continuous surfaces from the input points, interpolating surfaces beneath bridges where no lidar data was acquired. The surface model in these areas tend to be less detailed. Bridge saddles may be created where the surface interpolates between high and low ground points. Dewberry identifies problems arising from bridge removal and resolves them by reclassifying misclassified ground points to class 1 and/or adding bridge saddle breaklines where applicable due to interpolation.	None
Culverts and Bridges	It is Dewberry's standard operating procedure to leave culverts in the bare earth surface model and remove bridges from the model. In instances where it is difficult to determine whether the feature was a culvert or bridge, Dewberry errs on the side of culverts, especially if the feature is on a secondary or tertiary road.	None

Category	Editing Guideline	Additional Comments
In-Ground Structures	In-ground structures typically occur on military bases and at facilities designed for munitions testing and storage. When present, Dewberry identifies these structures in the project and includes them in the ground classification.	No in-ground structures present in this dataset
Dirt Mounds	Irregularities in the natural ground, including dirt piles and boulders, are common and may be misinterpreted as artifacts that should be removed. To verify their inclusion in the ground class, Dewberry checked the features for any points above or below the surface that might indicate vegetation or lidar penetration and reviews ancillary layers in these locations as well. Whenever determined to be natural or ground features, Dewberry edits the features to class 2 (ground)	No dirt mounds or other irregularities in the natural ground were present in this dataset
Irrigated Agricultural Areas	Per project specifications, Dewberry collected all areas of standing water greater than or equal to 2 acres, including areas of standing water within agricultural areas and not within wetland or defined waterbody, hydrographic, or tidal boundaries. Areas of standing water that did not meet the 2 acre size criteria were not collected.	Standing water within agricultural areas not present in the data
Wetland/Marsh Areas	Vegetated areas within wetlands/marsh areas are not considered water bodies and are not hydroflattened in the final DEMs. However, it is sometimes difficult to determine	No marshes present in the data

Category	Editing Guideline	Additional Comments
	true ground in low wet areas due to low reflectivity. In these areas, the lowest points available are used to represent ground, resulting in a sparse and variable ground surface. Open water within wetland/marsh areas greater than or equal to 2 acres is collected as a waterbody.	
Flight Line Ridges	Flight line ridges occur when there is a difference in elevation between adjacent flight lines or swaths. If ridges are visible in the final DEMs, Dewberry ensures that any ridges remaining after editing and QA/QC are within project relative accuracy specifications.	No flight line ridges are present in the data
Temporal Changes	If temporal differences are present in the dataset, the offsets are identified with a shapefile.	No temporal offsets are present in the data
Low NIR Reflectivity	Some materials, such as asphalt, tars, and other petroleum-based products, have low NIR reflectivity. Large-scale applications of these products, including roadways and roofing, may have diminished to absent lidar returns. USGS LBS allow for this characteristic of lidar but if low NIR reflectivity is causing voids in the final bare earth surface, these locations are identified with a shapefile.	No Low NIR Reflectivity is present in the data
Laser Shadowing	Shadows in the LAS can be caused when solid features like trees or buildings obstruct the lidar pulse, preventing data collection on one or more sides of these features. First return data is typically collected on the	No Laser Shadowing is present in the data

Category	Editing Guideline	Additional Comments
	side of the feature facing toward the incident angle of transmission (toward the sensor), while the opposite side is not collected because the feature itself blocks the incoming laser pulses. Laser shadowing typically occurs in areas of single swath coverage because data is only collected from one direction. It can be more pronounced at the outer edges of the single coverage area where higher scanning angles correspond to more area obstructed by features. Building shadow in particular can be more pronounced in urban areas where structures are taller. Data are edited to the fullest extent possible within the point cloud. As long as data meet other project requirements (density, spatial distribution, etc.), no additional action taken.	

3.2.2 Formatting Review

After the final QA/QC was performed and all corrections were applied to the dataset, all lidar files were updated to the final format requirements and the final formatting, header information, point data records, and variable length records were verified using proprietary tools. The table below lists the primary lidar header fields that are updated and verified.

Table 7. Classified lidar formatting parameters

Parameter	Project Specification	Pass/Fail
LAS Version	1.4	Pass
Point Data Record Format	6	Pass
Horizontal Coordinate Reference System	NAD83 (2011) UTM Zone 14N, meters in WKT format	Pass
Vertical Coordinate Reference System	NAVD88 (Geoid 18), meters in WKT format	Pass
Global Encoder Bit	17 for adjusted GPS time	Pass

Parameter	Project Specification	Pass/Fail
Time Stamp	Adjusted GPS time (unique timestamps)	Pass
System ID	Sensor used to acquire data	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 recorded for each pulse	Pass
Classification	Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 9: Water Class 17: Bridge Decks Class 18: High Noise Class 20: Ignored Ground	Pass
Withheld Points	Withheld bits set for geometrically unreliable points and for noise points in classes 7 and 18	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Recorded for each pulse	Pass

4. LIDAR POSITIONAL ACCURACY

4.1 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.

4.2 Survey Vertical Accuracy Checkpoints

For the vertical accuracy assessment, one hundred fifty seven (157) 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 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.

Table 8. NE Northeast Phase 2 lidar surveyed accuracy checkpoints

Point ID	NAD83 (2011), UTM Zone 14N		NAVD88 (Geoid 18)
	Easting X (m)	Northing Y (m)	Elevation (m)
1001	595701.2	4526524	536.471
1002	681488.9	4588866	394.102
1003A	690947.3	4581916	396.364
1004	562005.2	4523237	572.245
1005	584214.9	4542840	553.812
1006	657871.3	4553663	485.406
1007	712726.1	4616198	400.204
1008A	700604	4580469	389.529
1009	648615.9	4617948	491.714
1010	678998.3	4619411	415.679
1011	612566.3	4572211	473.363
1012	683340.8	4563936	424.409
1013	573251.3	4505638	557.43
1014	643177.7	4567972	495.239
1015A	683006.6	4578380	456.613
1016	561278	4555406	557.64
1017	584697.2	4508974	539.723
1018	657349.7	4577818	433.65
1019A	633933.2	4545190	498.401
1020	584310.1	4533145	551.876
1021	667303.6	4563565	514.329
1022	642319.2	4611396	477.481
1023	637643.8	4603278	502.989
1024	602289.4	4567149	487.084
1025A	668436.7	4592579	407.623

1026	570992.4	4541736	538.866
1027	627794.9	4612781	515.191
1028	598460.9	4547813	529.76
1029	596124.1	4505855	524.667
1030	663951.3	4571484	464.375
1031	709629	4558103	342.733
1032	669607.2	4610321	437.818
1033	606267.6	4559224	531.899
1034	720459.8	4544356	331.8
1035	622154.9	4560242	495.915
1036	627036.3	4569250	487.815
1037	718206.6	4563219	359.909
1038	611301.3	4548010	518.724
1039	609172.1	4583423	480.838
1040	646085.1	4577671	444.383
1041A	628352	4584382	449.957
1042	694251.7	4591875	379.215
1043	591627.7	4568617	504.686
1044	562157.5	4508748	578.748
1045	578794.3	4568511	531.09
1046	675518	4555660	457.727
1047	698275.8	4548120	365.536
1048	571690.3	4520141	562.225
1049	627971.9	4603125	499.441
1050	615019.6	4607728	487.462
1051	632099.9	4554828	482.609
1052	700888.5	4568014	372.53
1053	661456	4619797	494.408
1054	656641.6	4571411	498.998
1055A	671708.6	4581340	435.989
1056	669250.6	4549060	467.719
1057	608435.5	4614065	528.267
1058	684095.9	4610673	432.784
1059	597122.8	4539738	535.657
1060	649076	4595419	451.029
1061	571004.2	4552276	537.088
1062	650807.4	4547086	460.818
1063	637692.2	4595181	467.039
1064	636641.2	4577484	449.751
1065	674635.3	4602364	415.55
1066	707050.7	4593940	367.615
1067	709070.3	4575829	416.662

1068	627773.3	4616821	513.606
1069	708699	4585429	386.941
1070	661784	4605320	457.703
1071	574085	4560377	527.691
1072	641734.4	4555047	486.797
1073	561959.1	4534406	553.003
1074	649718.9	4561627	485.867
1075	698673.5	4606129	400.253
1076	693773.3	4615703	382.48
1077	620494	4579754	460.068
1078	711578.9	4601644	364.371
1079	688418.4	4555905	404.833
1080	586995.1	4554827	511.871
1081	598984.3	4607375	536.811
1082	721638.8	4587809	350.955
1083	707770	4622504	387.128
1084	717181.2	4572794	365.513
1085	598819	4620288	560.254
1086	626610.6	4548281	504.666
1087	574712.8	4532197	565.978
1089	620138.1	4592501	460.337
1090	562689.7	4566670	529.382
1091	637234.1	4620985	502.316
1092	611904.8	4602842	520.512
1093	709708.4	4548386	378.702
1094	599199	4599008	517.224
1095	550393	4681940	572.498
1096	547384.7	4703276	584.594
1097	594988.9	4649163	546.197
1098	559088.2	4614859	583.173
1099	559112.9	4598792	610.397
1100	499139.5	4717394	643.525
1101	572736.1	4640741	622.243
1102	557824.3	4663102	585.289
1103	594737.4	4663595	562.745
1104	517511.4	4672581	644.935
1105	498225.4	4668592	705.567
1106	504697.8	4661199	695.207
1107	578840.2	4655926	597.62
1108	556826.6	4675633	560.422
1109	560049.2	4630741	625.489
1110	494268.6	4661763	709.689

1111	516879.4	4702983	624.786
1112	491784	4691802	680.906
1113	543319.7	4662985	612.779
1114	511083.5	4672495	658.151
1115	528926.1	4662895	628.716
1116	523576.5	4680584	632.215
1117A	569086.3	4660021	594.461
1118	572641.5	4631120	570.314
1119A	528936.4	4674184	624.417
1120	488309.6	4717182	664.313
1121	555519.2	4698504	578.995
1123	528691.8	4691901	610.976
1124A	502965.1	4695667	658.184
1125	569737.5	4669314	541.64
1126	528113.2	4704683	613.689
1127	572042.8	4682529	588.894
1128	589772.8	4673178	545.474
1129	483077.5	4699675	689.861
1130	484226.3	4681223	717.015
1131	559889.1	4643823	622.102
1132C	591191.4	4689309	543.956
1133A	503017.6	4677488	675.103
1134A	580201.4	4677819	566.568
1135	512599.7	4690298	650.193
1136	579919.7	4692340	555.13
1137	538380.2	4683922	605.486
1138	571024.6	4606896	581.869
1139	548154.1	4693638	593.248
1140	492726.2	4706278	657.316
1141	567064.7	4621390	609.311
1142	568640.7	4693733	549.972
1143	563993.1	4687373	591.208
1144A	502996.5	4685487	668.978
1145	558520.3	4659889	608.987
1146	516089.3	4662860	668.745
1147	570298.6	4594039	581.048
1148	567860.4	4648846	595.628
1149	487883.7	4709324	662.982
1150	506555.6	4759452	568.951
1151	548368.7	4742085	424.026
1152	536710.4	4754728	535.249
1153	480850.8	4756274	648.951

1154	524232	4757563	593.003
1155	483712.8	4746328	589.379
1156	511386.4	4751402	545.191
1157	524368.5	4747421	505.272
1146B	520787.3	4659644	658.733
1063B	638547.6	4587658	439.188

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

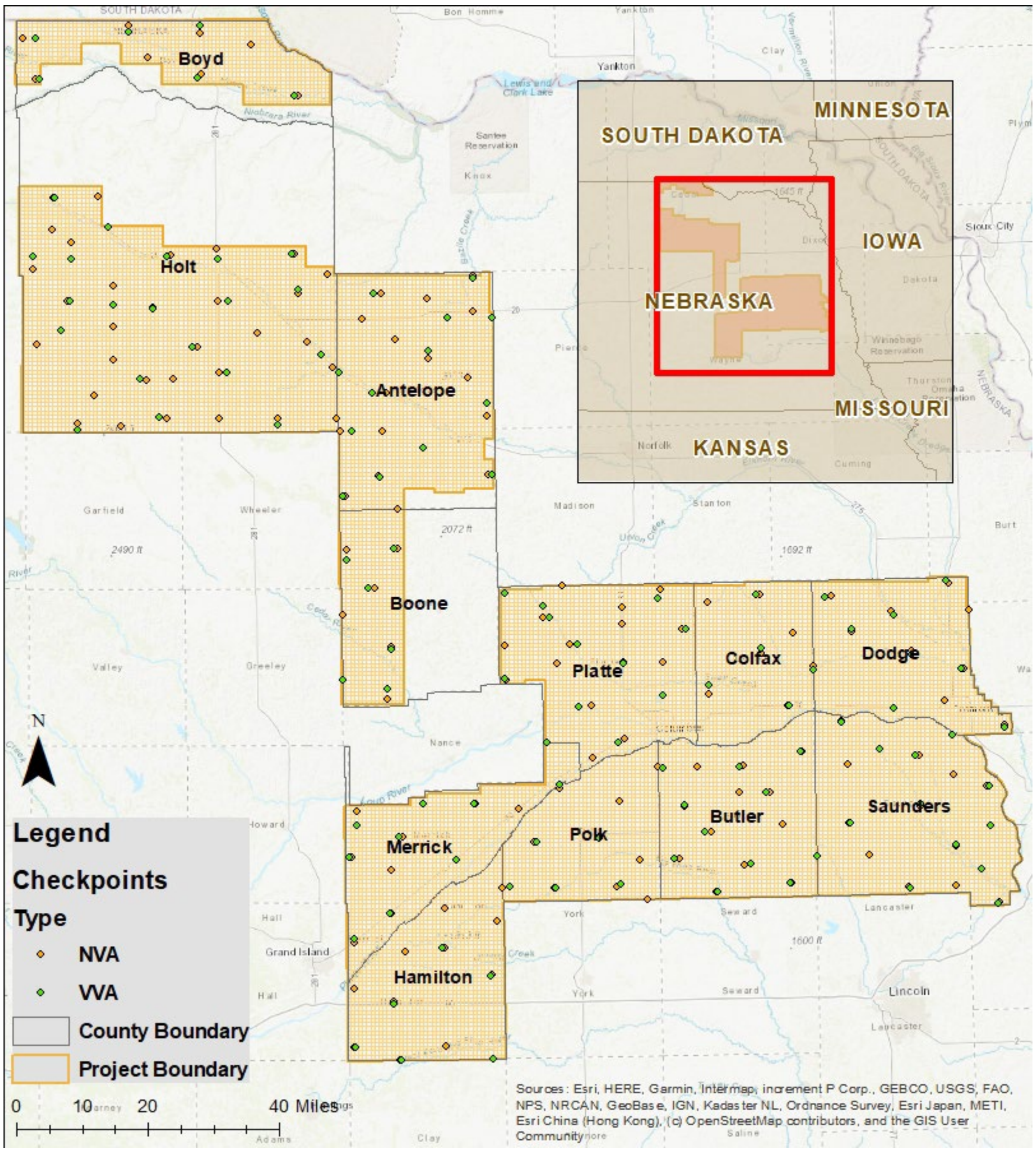

Figure 7. Location of QA/QC Checkpoints

4.3 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 (RMSEz) of the checkpoints x 1.9600. For the NE Northeast Phase 2 lidar project, vertical accuracy must be 19.6 cm or less based on an RMSEz 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 95th percentile error for all checkpoints in all vegetated land cover categories combined. The NE Northeast Phase 2 Lidar Project VVA standard is 30 cm based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, Accuracyz differs from VVA because Accuracyz 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 9.

Table 9. Acceptance Criteria

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	30 cm (based on combined 95th percentile)

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.

4.4 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.

Table 10. Tested NVA and VVA

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=30 cm
NVA	157	8.1	
VVA	113		17.1

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 **RMSEz =4.1 cm,** equating to **+/- 8.1 cm** at 95% confidence level. Actual VVA accuracy was found to be **+/- 17.1 cm** 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 checkpoint's elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +40 cm.

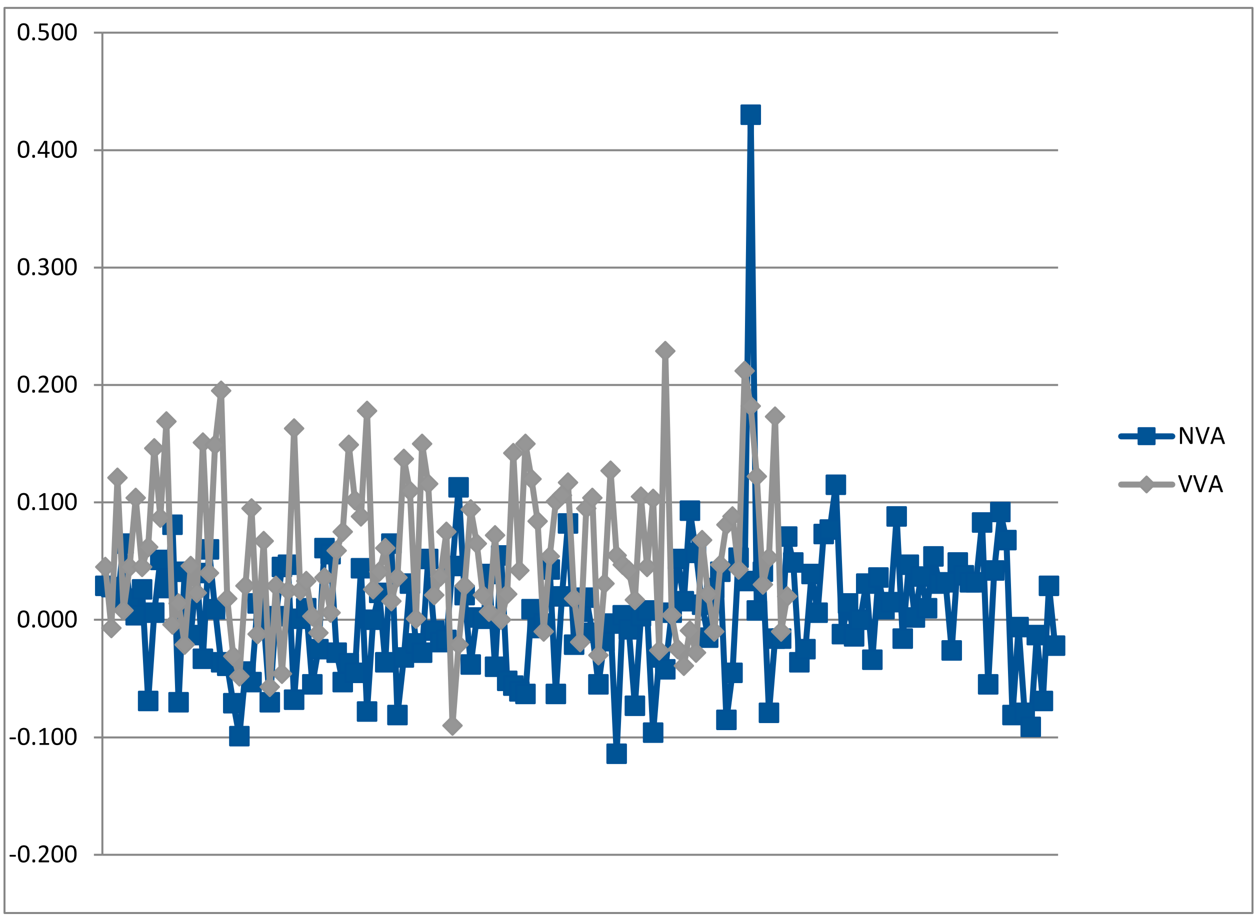

Figure 8. Magnitude of elevation discrepancies per land cover category

Table 11 lists the 5% outliers that are larger than the VVA 95th percentile.

Table 11. 5% Outliers

Point ID	NAD83 (2011), UTM Zone 14N		NAVD88 (Geoid 18)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
2020	709633.126	4558454.309	343.445	343.640	0.195	0.195
2044	651116.428	4547096.698	458.542	458.720	0.178	0.178
2093	559282.789	4643831.865	611.891	612.120	0.229	0.229
2106	570298.196	4596695.698	557.958	558.170	0.212	0.212
2107	568324.944	4648719.506	596.788	596.970	0.182	0.182
2110	483861.549	4756220.096	618.967	619.020	0.173	0.173

Table 12 provides overall descriptive statistics.

Table 12. Overall Descriptive Statistics

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	157	0.041	0.005	0.004	2.365	0.058	16.869	-0.114	0.430
VVA	113	N/A	0.056	0.045	0.459	0.064	-0.229	-0.090	0.229

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 -0.15 meters and a high of +0.27 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 -0.03 meters to +0.03 meters.

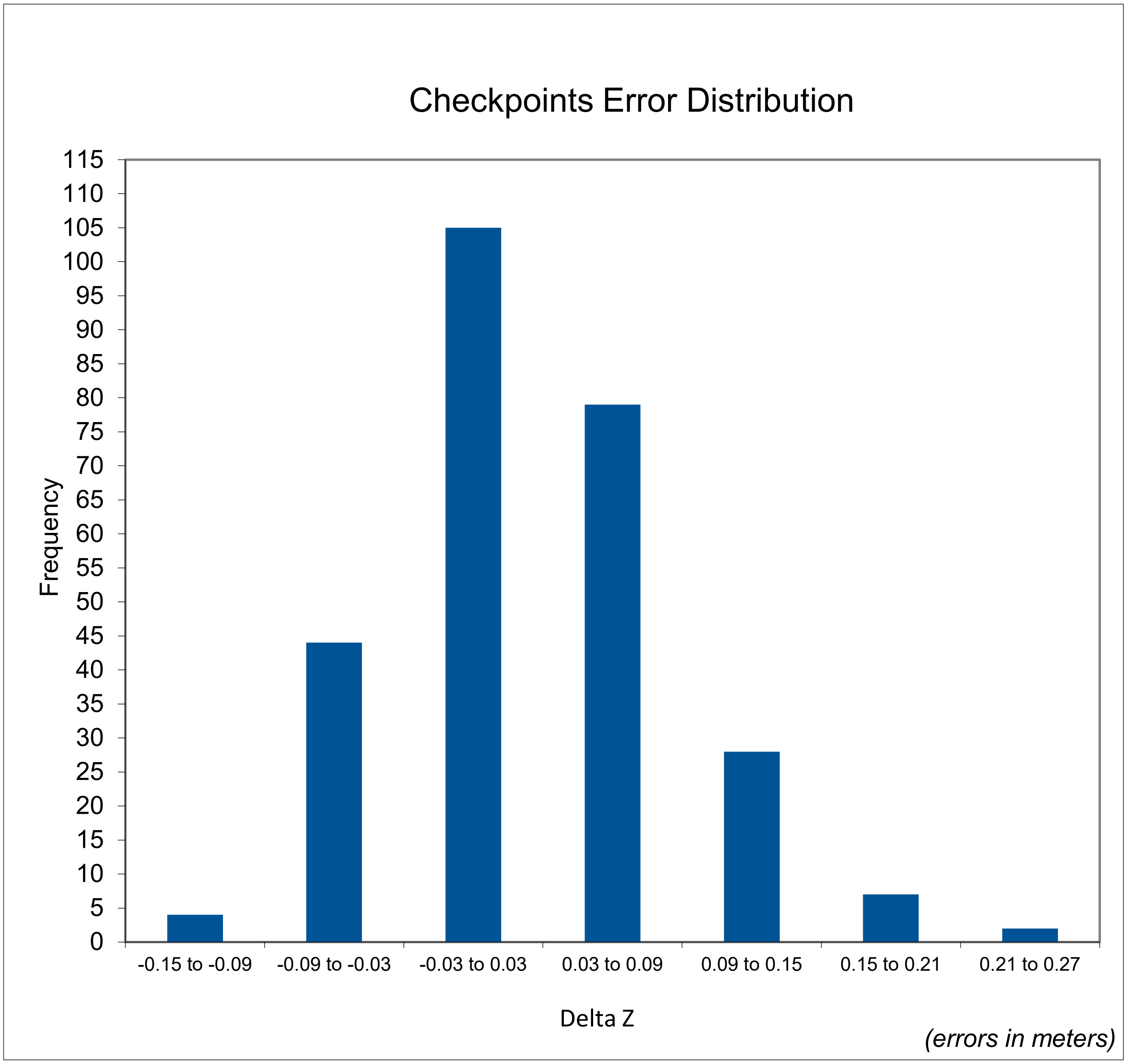

Figure 9. Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the NE Northeast Phase 2 Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

4.5 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.

4.6 Horizontal Accuracy Results

Four 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 four (4) 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 at the 95% confidence level.

Table 13. Tested horizontal accuracy at the 95% confidence level

# of Points	$RMSE_x$ (Target=41 cm)	$RMSE_y$ (Target=41 cm)	$RMSE_r$ (Target=58 cm)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=100 cm
4	17.1	29.1	33.7	58.4

This data set was produced 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. Four (4) checkpoints were photo-identifiable but do not produce a statistically significant tested horizontal accuracy value. Using this small sample set of photo-identifiable checkpoints, positional accuracy of this dataset was found to be RMSEx = **17.1 cm** and RMSEy = **29.1 cm** which equates to **+/- 58.4 cm** at 95% confidence level. While not statistically significant, the results of the small sample set of checkpoints are within the produced to meet horizontal accuracy.

5. BREAKLINE PRODUCTION & QUALITATIVE ASSESSMENT

5.1 Breakline Production Methodology

Breaklines were manually digitized within an Esri software environment, using full point cloud intensity imagery, bare earth terrains and DEMs, the lidar point cloud, and ancillary ortho imagery where appropriate.

When data characteristics are suitable, Dewberry may use eCognition software to generate initial, automated water polygons, which are then manually reviewed and refined where necessary.

Breakline features with static or semi-static elevations (ponds and lakes, bridge saddles, and soft feature breaklines) were converted to 3D breaklines within the Esri environment where breaklines were draped on terrains or the las point cloud. Subsequent processing was done on ponds/lakes to identify the minimum z-values within these features and re-applied that minimum elevation to all vertices of the breakline feature.

Linear hydrographic features show downhill flow and maintain monotonicity. These breaklines underwent conflation by using a combination of Esri and LP360 software. Centerlines were draped on terrains, enforced for monotonicity, and those elevations were then assigned to the bank lines for the final river/stream z-values.

Tidal breaklines may have been converted to 3D using either method, dependent on the variables within each dataset.

5.1.1 Breakline Collection Requirements

The table below outlines breakline collection requirements for this dataset.

Table 14. Breakline collection requirements

Parameter	Project Specification	Additional Comments
Ponds and Lakes	Breaklines are collected in all inland ponds and lakes ~0.8 hectare or greater. These features are flat and level water bodies at a single elevation for each vertex along the bank.	None
Rivers and Streams	Breaklines are collected for all streams and rivers ~30 meter nominal width or wider. These features are flat and level bank to bank, gradient will follow the surrounding terrain and the water surface will be at or below the surrounding terrain. Streams/river channels will break at culvert locations however not at elevated bridge locations.	None

Tidal	Breaklines are collected as polygon features depicting water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any significant water body that is affected by tidal variations. Tidal variations over the course of collection, and between different collections, can result in discontinuities along shorelines. This is considered normal and should be retained. Variations in water surface elevation resulting from tidal variations during collection should not be removed or adjusted. Features should be captured as a dual line with one line on each bank. Each vertex placed shall maintain vertical integrity. Parallel points on opposite banks of the tidal waters must be captured at the same elevation to ensure flatness of the water feature. The entire water surface edge is at or below the immediate surrounding terrain.	No tidally influenced features are in this dataset so no tidal breaklines were collected.
Islands	Donuts will exist where there are islands greater than 1 acre in size within a hydro feature.	None
Bridge Saddle Breaklines	Bridge Saddle Breaklines are collected where bridge abutments were interpolated after bridge removal causing saddle artifacts.	None
Soft Features	Soft Feature Breaklines are collected where additional enforcement of the modeled bare earth terrain was required, typically on hydrographic control structures or vertical waterfalls, due to large vertical elevation differences within a short linear distance on a hydrographic features.	None

5.2 Breakline Qualitative Assessment

Dewberry performed both manual and automated checks on the collected breaklines. Breaklines underwent peer reviews, breakline lead reviews (senior level analysts), and final reviews by an independent QA/QC team. The table below outlines high level steps verified for every breakline dataset.

Table 15. Breakline verification steps.

Parameter	Requirement	Pass/Fail
Collection	Collect breaklines according to project specifications using lidar-derived data, including intensity imagery, bare earth ground models, density models, slope models, and terrains.	Pass
Placement	Place the breakline inside or seaward of the shoreline by 1-2 x NPS in areas of heavy vegetation or where the exact shoreline is hard to delineate.	Pass
Completeness	Perform a completeness check, breakline variance check, and all automated checks on each block before designating that block complete.	Pass
Merged Dataset	Merge completed production blocks. Ensure correct horizontal and vertical snapping between all production blocks. Confirm correct horizontal placement of breaklines.	Pass
Merged Dataset Completeness Check	Check entire dataset for features that were not captured but that meet baseline specifications or other metrics for capture. Features should be collected consistently across tile boundaries.	Pass
Edge Match	Ensure breaklines are correctly edge-matched to adjoining datasets. Check completion type, attribute coding, and horizontal placement.	Pass
Vertical Consistency	Waterbodies shall maintain a constant elevation at all vertices Vertices should not have excessive min or max z-values when compared to adjacent vertices Intersecting features should maintain connectivity in X, Y, Z planes Dual line streams shall have the same elevation at any given cross-section of the stream	Pass
Vertical Variance	Using a terrain created from lidar ground (class 2, 8, and 20 as applicable) and water points (class 9) to compare breakline Z values to interpolated lidar elevations to ensure there are no unacceptable discrepancies.	Pass
Monotonicity	Dual line streams generally maintain a consistent down-hill flow and collected in the	Pass

	direction of flow – some natural exceptions are allowed	
Topology	Features must not overlap or have gaps Features must not have unnecessary dangles or boundaries	Pass
Hydro-classification	The water classification routine selected ground points within the breakline polygons and automatically classified them as class 9, water. During this water classification routine, points that were within 1 NPS distance or less of the hydrographic feature boundaries were moved to class 20, ignored ground, to avoid hydroflattening artifacts along the edges of hydro features.	Pass
Hydro-flattening	Perform hydro-flattening and hydro-enforcement checks. Tidal waters should preserve as much ground as possible and can be non-monotonic.	Pass

6. DEM PRODUCTION & QUALITATIVE ASSESSMENT

6.1 DEM Production Methodology

Dewberry utilized LP360 to generate DEM products and both ArcGIS and Global Mapper for QA/QC.

The final classified lidar points in all bare earth classes were loaded into LP360 along with the final 3D breaklines and the project tile grid. A raster was generated from the lidar data with breaklines enforced and clipped to the project tile grid. The DEM was reviewed for any issues requiring corrections, including remaining lidar misclassifications, erroneous breakline elevations, incorrect or incomplete hydro-flattening or hydro-enforcement, and processing artifacts. The formatting of the DEM tiles was verified before the tiles were loaded into Global Mapper to ensure that there was no missing or corrupt data and that the DEMs matched seamlessly across tile boundaries. A final qualitative review was then conducted by an independent review department within Dewberry.

6.2 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. Dewberry conducted the review in ArcGIS using a hillshade model of the full dataset with a partially transparent colorized elevation model overlaid. The tiled DEMs were reviewed at a scale of 1:5,000 to look for artifacts caused by the DEM generation process and to verify correct and complete hydro-flattening and hydro-enforcement. Upon correction of any outstanding issues, the DEM data was loaded into Global Mapper for its second review and to verify corrections.

The table below outlines high level steps verified for every DEM dataset.

Table 16. DEM verification steps.

Parameter	Requirement	Pass/Fail
Digital Elevation Model (DEM) of bare-earth w/ breaklines	DEM of bare-earth terrain surface (1.0 meter) is created from lidar ground points and breaklines. DEMs are tiled without overlaps or gaps, show no edge artifact or mismatch, DEM deliverables are .tif format	Pass
DEM Compression	DEMs are not compressed	Pass
DEM NoData	Areas outside survey boundary are coded as NoData. Internal voids (e.g., open water areas) are coded as NoData (-999999)	Pass
Hydro-flattening	Ensure DEMs were hydro-flattened or hydro-enforced as required by project specifications	Pass
Monotonicity	Verify monotonicity of all linear hydrographic features	Pass
Breakline Elevations	Ensure adherence of breaklines to bare-earth surface elevations, i.e., no floating or digging hydrographic feature	Pass
Bridge Removal	Verify removal of bridges from bare-earth DEMs and no saddles present	Pass
DEM Artifacts	Correct any issues in the lidar classification that were visually expressed in the DEMs. Reprocess the DEMs following lidar corrections.	Pass
DEM Tiles	Split the DEMs into tiles according to the project tiling scheme	Pass
DEM Formatting	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression is not applied to the tiled DEMs	Pass
DEM Extents	Load all tiled DEMs into Global Mapper and verify complete coverage within the (buffered) project boundary and verify that no tiles are corrupt	Pass

6.3 DEM Vertical Accuracy Results

The same 270 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 17 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Table 17. DEM tested NVA and VVA

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=30 cm
NVA	157	10.8	
VVA	113		18.7

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 RMSEz =5.5 cm, equating to +/- 10.8 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 18.7 cm at the 95th percentile.

Table 18 lists the 5% outliers that are larger than the VVA 95th percentile.

Table 18. 5% Outliers

Point ID	NAD83 (2011), UTM Zone 14N		NAVD88 (Geoid 12B)	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
2020	709633.126	4558454.309	343.445	343.680	0.235	0.235
2041	609835.160	4614058.699	499.191	499.394	0.203	0.203
2044	651116.428	4547096.698	458.542	458.738	0.196	0.196
2053	648089.717	4561623.427	482.500	482.691	0.191	0.191
2093	559282.789	4643831.865	611.891	612.140	0.249	0.249
2106	570298.196	4596695.698	557.958	558.187	0.229	0.229

Table 19 provides overall descriptive statistics.

Table 19. Overall Descriptive Statistics

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	157	0.055	0.002	0.002	2.671	0.055	19.504	-0.100	0.419
VVA	113	N/A	0.060	0.050	0.576	0.069	-0.035	-0.078	0.249

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the NE Northeast Phase 2 Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

7. DERIVATIVE LIDAR PRODUCTS

USGS required several derivative lidar products to be created. Each type of derived product is described below.

7.1 Swath Separation Images

Swath separation images representing interswath alignment have been delivered. These images were created from the last return of all points except points classified as noise or flagged as withheld. The images are in .TIFF format. The swath separation images are symbolized by the following ranges:

- 0-8 cm: **Green**
- 8-16 cm: **Yellow**
- > 16 cm: **Red**

7.2 Interswath and Intraswath Polygons

7.2.1 Interswath Accuracy

The Interswath accuracy, or overlap consistency, measures the variation in the lidar data within the swath overlap. Interswath accuracy measures the quality of the calibration or boresight adjustment of the data in each lift. Per USGS specifications, overlap consistency was assessed at multiple locations within overlap in non-vegetated areas of only single returns. As with precision, the interswath consistency was reported by way of a polygon shapefile delineating the sample areas checked and attributed with the following and using the cells within each polygon as sample values:

- Minimum difference in the sample area (numeric)
- Maximum difference in the sample area (numeric)
- RMSDz (Root Mean Square Difference in the vertical/z direction) of the sample area (numeric).
  Intraswath Accuracy

7.2.2 Intraswath Accuracy

The intraswath accuracy, or the precision of lidar, measures variations on a surface expected to be flat and without variation. Precision is evaluated to confirm that the lidar system is performing properly and without gross internal error that may not be otherwise apparent. To measure the precision of a lidar dataset, level or flat surfaces were assessed. Swath data were assessed using only first returns in non-vegetated areas.

Precision was reported by way of a polygon shapefile delineating the sample areas checked and attributed with the following and using the cells within each polygon as sample values:

- Minimum slope-corrected range (numeric)
- Maximum slope-corrected range (numeric)
- RMSDz of the slope-corrected range (numeric).

7.3 Contours

Dewberry created 2-foot contours for the full project area. The contour attributes include designation as either Index or Intermediate and an elevation value. The contours are also 3D, storing elevation values within their internal geometry. Some smoothing was applied to the contours to enhance their aesthetic quality. This task order required auto/machine generated contours so contours were reviewed for completeness and correct attribution but were not reviewed or edited for correct topology or correct behavior in regard to hydrographic crossings. Because of the density of the contours and their file size, the contours were tiled to the project tiles. The contour tiles are delivered in one file geodatabase (GDB) and are named according to the final project tile grid.

7.4 DSM

The creation of first return DSMs followed a similar workflow to the bare-earth DEMs, except that the first returns from all point classes except for noise (classes 7 and 18) and points flagged as withheld were used to create the raster and breaklines were not used to hydro-flatten or hydro-enforce the surface. The review of the DSMs included looking for spikes, divots, noise points not properly classified to the noise classes, other lidar misclassifications, and processing artifacts.