Dewberry

Dewberry Engineers Inc.
1000 North Ashley Drive, Suite 801
Tampa, FL 33602

813.225.1325
813.225.1385 fax
www.dewberry.com

UT_FEMA_Flaming_Gorge_2020_B20-195625

Report Produced for U.S. Geological Survey

USGS Contract: G16PC00020

Task Order: 140G0220F0147

Report Date: November 16, 2021

SUBMITTED BY:
Dewberry
1000 North Ashley Drive Suite 801
Tampa, FL 33602
813.225.1325

SUBMITTED TO:
U.S. Geological Survey
1400 Independence Road
Rolla, MO 65401
573.308.3810

TABLE OF CONTENTS

ATTACHMENTS

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 UT_FEMA_Flaming_Gorge-195625 project.

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 1,500 m by 1,500 m. A total of 16,795 tiles were produced for the project, providing approximately 13,681 sq. miles of coverage. A total of 2355 tiles were produced for block 195625, providing approximately 1816 sq. miles of coverage.

1.1 Project Team

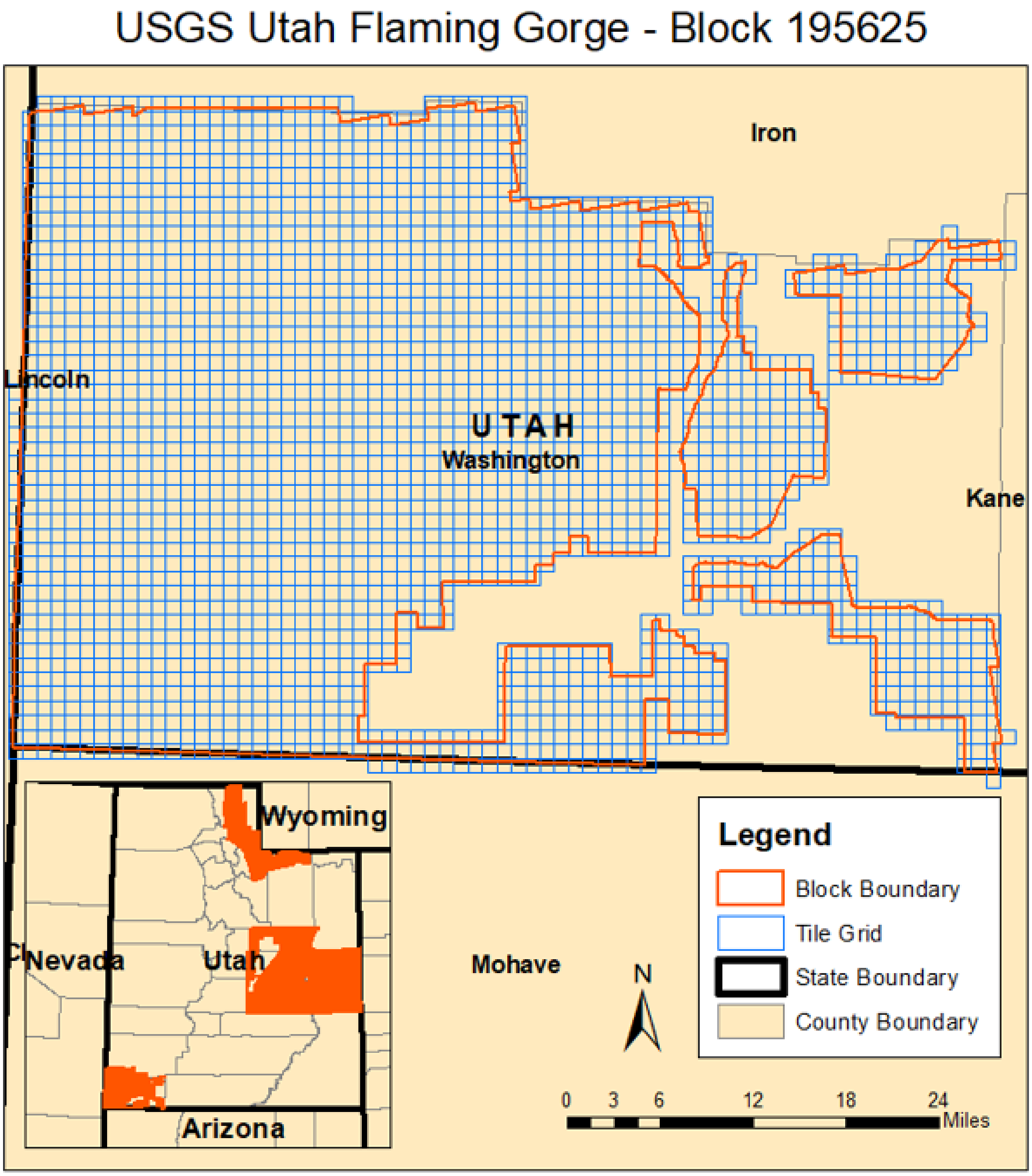
Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for LAS classification, all lidar products, breakline production, digital elevation model (DEM) production, and quality assurance.

Ground survey was completed for the project. Survey tasks were 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. It was also verified the GPS base station coordinates used during lidar data acquisition.

Aerial Surveys International, LLC completed lidar data acquisition and data calibration for the project area.

1.2 Project Area

The block area is shown in figure 1. 195625 Block contains 2355 1,500 m by 1,500 m tiles. The project tile grid contains 16,795 1,500 m by 1,500 m tiles.



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 12N
Horizontal Units:	Meters
Vertical Units:	Meters

1.4 Project Deliverables

The deliverables for the block are as follows:

1. Project Extents (Esri SHP)
2. Classified Point Cloud (tiled LAS))
3. Intensity Images (tiled, 8-bit gray scale, GeoTIFF format)
4. Breakline Data (file GDB)
5. Bare Earth Surface (tiled raster DEM, TIF format)
6. Swath Separation Images
7. Interswath Polygons
8. Intraswath Polygons
9. Metadata (XML)
10. Block Report
11. Flightline Index

1.5 Dewberry Production Workflow Diagram

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

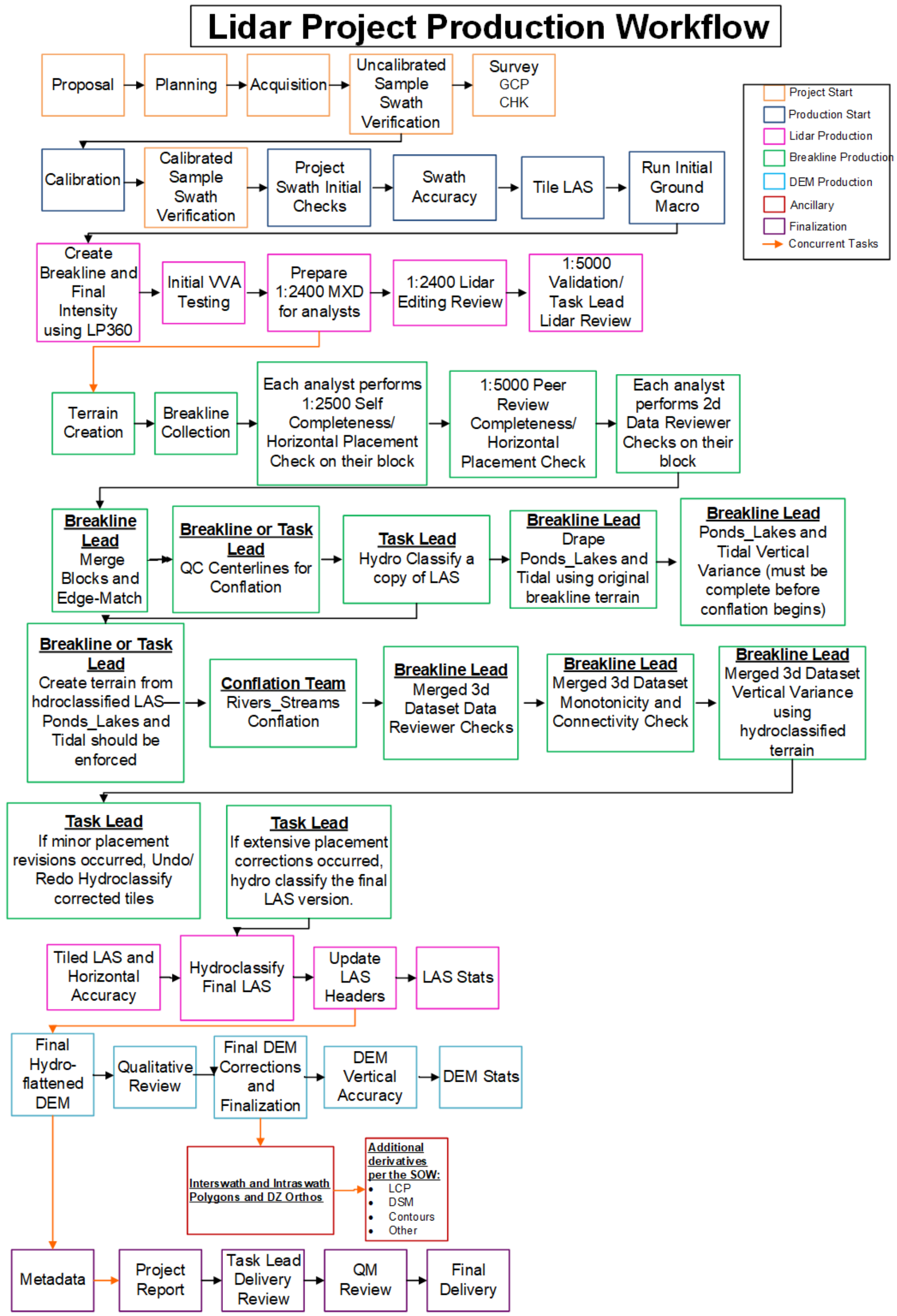


Figure 2. Dewberry's Lidar Production Workflow Diagram.

2. LIDAR ACQUISITION REPORT

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

The lidar aerial acquisition for the 195625 AOI and was conducted between September 14, 2020 thru November 5, 2020.

2.1 Lidar Acquisition Details

Aerial Surveys International, LLC planned 163 passes as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Aerial Surveys International, LLC followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Airborne Mission Manager 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 Surveys International, LLC will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Aerial Surveys International, LLC 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 Surveys International, LLC 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 Surveys International, LLC 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.

2.2 Lidar System Parameters

Aerial Surveys International, LLC operated a Cessna 310 (Tail # N7516Q) outfitted with an Optech T2000 lidar system during the collection of the project. Table 1 illustrates Aerial Surveys International, LLC system parameters for lidar acquisition on this project.

Table 1. Aerial Surveys International, LLC lidar system parameters.

Item	Parameter
System	Optech T2000

Item	Parameter
Maximum Number of Returns per Pulse	8
Nominal Pulse Spacing (single swath), (m)	0.62
Nominal Pulse Density (single swath) (ppsm), (m)	2.67
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.62
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2.67
Altitude (AGL meters)	1900
Approx. Flight Speed (knots)	160
Total Sensor Scan Angle (degree)	34
Scan Frequency (hz)	66
Scanner Pulse Rate (kHz)	500
Pulse Duration of the Scanner (nanoseconds)	10
Pulse Width of the Scanner (m)	3.04
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	0.23
Nominal Swath Width on the Ground (m)	1456
Swath Overlap (%)	30%
Computed Down Track spacing (m) per beam	0.62
Computed Cross Track Spacing (m) per beam	0.62

2.3 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 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 flight line trajectories.

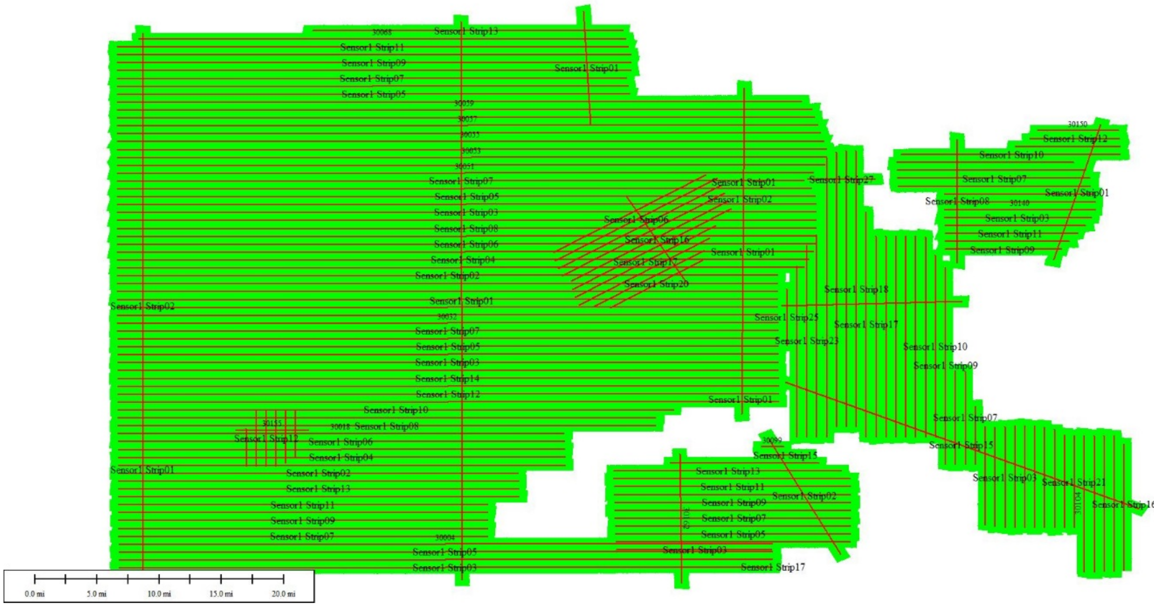


Figure 3. Trajectories of flight lines flown by Aerial Surveys International, LLC.

2.4 Acquisition Static Control

Aerial Surveys International, LLC utilized Applanix's PPRTX module for the static control. Using the precise data derived from the real-time CenterPoint RTX system, a new high-accuracy post-processed RTX-Aided inertial processing method has been developed for POSPac MMS, enabling robust, cm level positioning to be achieved for mobile mapping without reference stations. The Post-processed RTX (PP-RTX) implementation in POSPac is comprised of three components: 1. A web-based service that provides the CenterPoint RTX information along the rover trajectory to be post-processed. 2. A QC step that processes the information from the service with the raw rover observables in forward and reverse time to generate the convergence-free PPRTX GNSS solution 3. Generation of the final RTX-Aided Inertial navigation solution using a Kalman filter and optimal smoother processing.

2.5 Airborne Kinematic Control

Airborne GPS data was processed using the POSPac MMS version 8.5 and the PPRTX module. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4.

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

2.6 Generation and Calibration of Raw Lidar Data

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

Subsequently the mission points are output using Optech's LMS software, initially with default values from Optech or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within MARS 8 for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

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

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

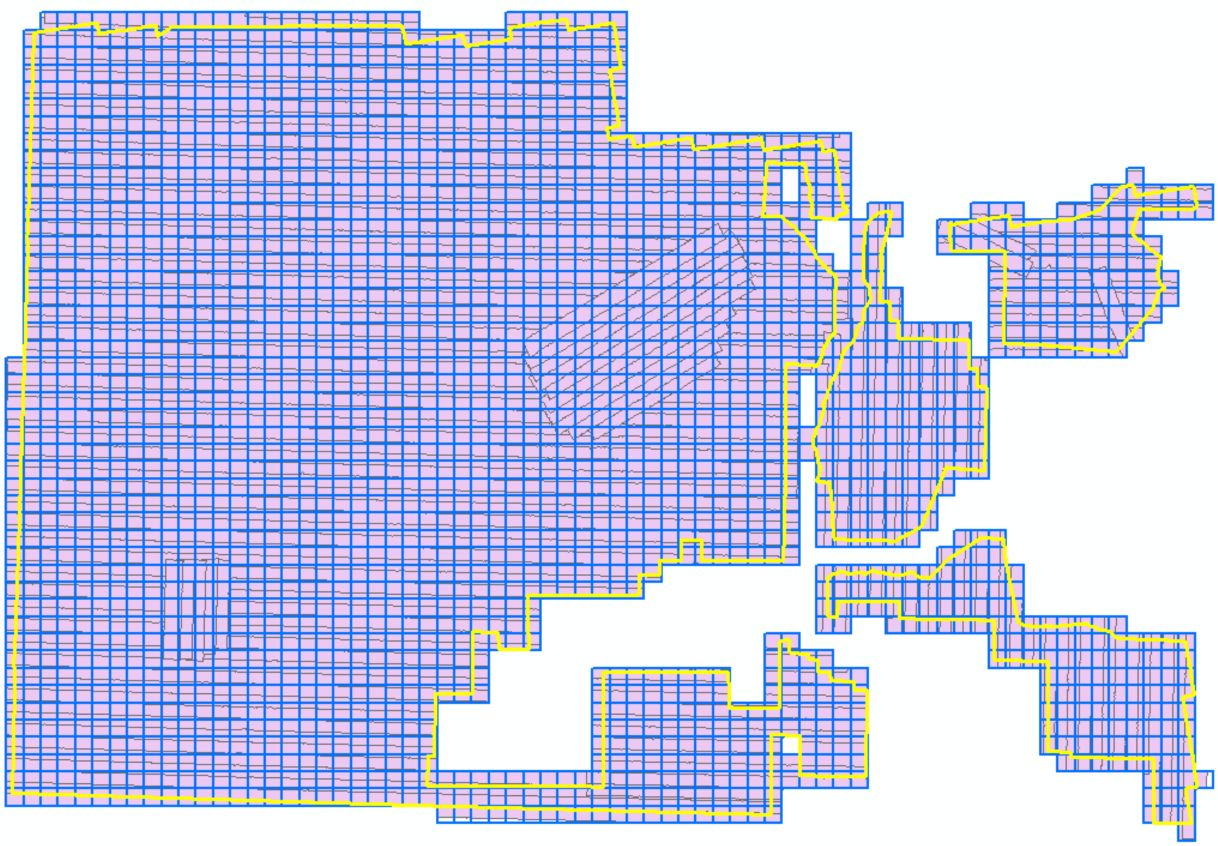


Figure 4. Lidar swath output showing complete coverage.

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 (figure 4).

The initial points for each mission calibration are 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 are optimized during the calibration process until the relative accuracy is met.

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.

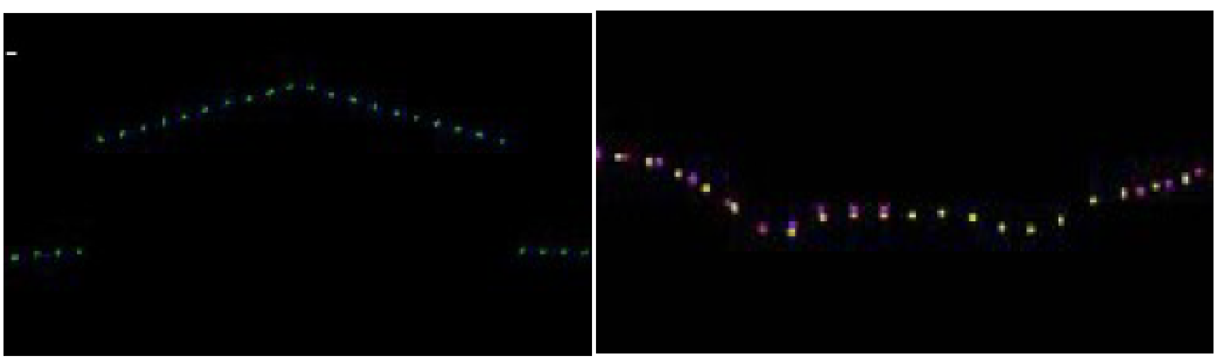


Figure 5. Profile views showing results of roll and pitch adjustments.

2.7 Final Calibration Verification

Dewberry conducted the survey for 34 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 34 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.

Table 3. Surveyed ground control points (GCPs).

Point ID	NAD83 (2011) UTM 12N	NAVD88 (Geoid 18)

	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
GCP-101	230707	4165231	1877.545	1877.51
GCP-102	264724	4154641	2177.924	2177.8
GCP-103	277524	4163885	1736.614	1736.63
GCP-104	299046.1	4153427	1728.91	1728.93
GCP-105	303089.4	4147534	1544.75	1544.77
GCP-106	318074.7	4146142	2476.515	2476.46
GCP-107	319050.3	4146649	2480.656	2480.63
GCP-108	325367.3	4141935	2054.825	2054.82
GCP-109	316808.8	4138646	2370.261	2370.3
GCP-110	300049.9	4140557	1518.655	1518.68
GCP-111	232774	4157160	1677.88	1677.74
GCP-112	234490.8	4133288	1092.212	1092.2
GCP-113	263562.7	4133902	1431.072	1431.01
GCP-114	306430.6	4127520	1723.535	1723.47
GCP-115	311633.1	4129169	1645.387	1645.37
GCP-116	314007.4	4111445	1430.412	1430.45
GCP-117	316518.6	4111563	1349.89	1349.95
GCP-118	301256.4	4116999	1149.503	1149.57
GCP-119	286738.4	4122325	973.382	973.425
GCP-120	263113.8	4112705	852.278	852.314
GCP-121	231471.6	4114220	884.546	884.61
GCP-122	240932.9	4100072	843.026	843.095
GCP-123	279645.9	4099285	860.497	860.454
GCP-124	280636.6	4108474	892.528	892.543
GCP-125	291309.2	4104866	1065.542	1065.6
GCP-126	293217.4	4099735	1002.87	1002.97
GCP-127	300450.1	4101453	1778.959	1778.9
GCP-128	299320.7	4108431	1326.486	1326.48
GCP-129	330703.4	4096747	1631.841	1631.78
GCP-130	259340.1	4162649	1629.538	1629.49
GCP-131	267466	4152257	1775.282	1775.23
GCP132	263975.4	4139118	1499.711	1499.67
GCP-133	268191.5	4125767	1382.138	1382.13
GCP-134	26824.3	4112921	884.719	884.742

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

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

100 % of Totals	# of Points	RMSEz (m) NVA 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	34	0.055	0.108	-0.006	-0.007	-0.454	0.056	-0.144	0.099	0.086

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 confimation 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 5. 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	The average calculated (A)NPD of this project is 14.067 ppsm. Density raster	None

Requirement	Description of Deliverables	Additional Comments
specification of 2 ppsm or 0.7 m NPS. The NPD (ANPD) is calculated from first return points only.	visualization also passed specifications.	
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
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

Requirement	Description of Deliverables	Additional Comments
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

3.2 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, after classification, class 7 & 18 were flagged with the withheld bit. 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 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	No unacceptable voids are present in this dataset.

Category	Editing Guideline	Additional Comments
	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.	
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 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.	None
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.	There are bridge saddle breaklines in the breakline gdb.
Culverts and Bridges	It is Dewberry's standard operating procedure to leave culverts in the bare	None

Category	Editing Guideline	Additional Comments
	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.	
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 were 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 was not present in this dataset.
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 true ground in low wet areas due to low reflectivity. In these	No marshes were present in this dataset.

Category	Editing Guideline	Additional Comments
	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 were present in this dataset.
Temporal Changes	If temporal differences are present in the dataset, the offsets are identified with a shapefile.	No temporal offsets were present in this dataset.
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 were present in this dataset.
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 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	2 Voids present in the dataset caused by laser shadowing

Category	Editing Guideline	Additional Comments
	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 12N, 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
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	Pass

Parameter	Project Specification	Pass/Fail
	Class 7: Low Noise (Withheld bit applied) Class 9: Water Class 17: Bridge Decks Class 18: High Noise (Withheld bit applied) Class 20: Ignored Ground	
Withheld Points	Withheld bits set: Class 1 Withheld set in overlapping flightlines, and all Class 7 & 18 set as Withheld	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Recorded for each pulse	Pass

4. BREAKLINE PRODUCTION & QUALITATIVE ASSESSMENT

4.1 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.

4.1.1 Breakline Collection Requirements

The table below outlines breakline collection requirements for this dataset.

Table 8. Breakline collection requirements.

Parameter	Project Specification	Additional Comments
Ponds and Lakes	Breaklines are collected in all inland ponds and lakes ~2 acres 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 ~30meter 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.	Rivers and streams wider than ~30 m were not present in this dataset so no breaklines were collected.
Tidal	Breaklines are collected as polygon features depicting water bodies such as oceans, seas, gulfs, bays, inlets, slat 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 present 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.	No islands were present in this dataset so no breaklines were collected.
Bridge Saddle Breaklines	Bridge Saddle Breaklines are collected where bridge abutments were interpolated after bridge removal causing saddle artifacts.	Bridge Saddle Breaklines are in the final breakline GDB.
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.	Soft features were not applicable to this dataset so no breaklines were collected.

4.2 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 9. 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 direction of flow – some natural exceptions are allowed	Pass
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

5. DEM PRODUCTION & QUALITATIVE ASSESSMENT

5.1 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.

5.2 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 10. DEM verification steps.

Parameter	Requirement	Pass/Fail
Digital Elevation Model (DEM) of bare-earth w/ breaklines	DEM of bare-earth terrain surface (1 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. DERIVATIVE LIDAR PRODUCTS

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

6.1 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 .TIF format. The swath separation images are symbolized by the following ranges:

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

6.2 Interswath and Intraswath Polygons

6.2.1 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

6.2.2 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).