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UT FEMA Flaming Gorge 2020 B20 WUID300176

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 UT FEMA Flaming Gorge - WUID300176 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 16,794 tiles were produced for the project, providing approximately 13,681 sq. miles of coverage. A total of 10,300 tiles were produced for WUID300176, providing approximately 8,609 sq. miles of coverage. Originally, the project contained 16,795 tiles and WUID300176 contained 10,301 tiles. However, one (1) set of raster files and LAS were not delivered due to the tile being smaller than one pixel and not being able to generate raster files. The project tile grid and DPA were updated to remove this tile.

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.

Aero-Graphics Inc. completed lidar data acquisition and data calibration for the project area.

1.2 Project Area

The block area is shown in figure 1. WUID300176 contains 10,300 1,500 m by 1,500 m tiles. The project tile grid contains 16,794 1,500 m by 1,500 m tiles.

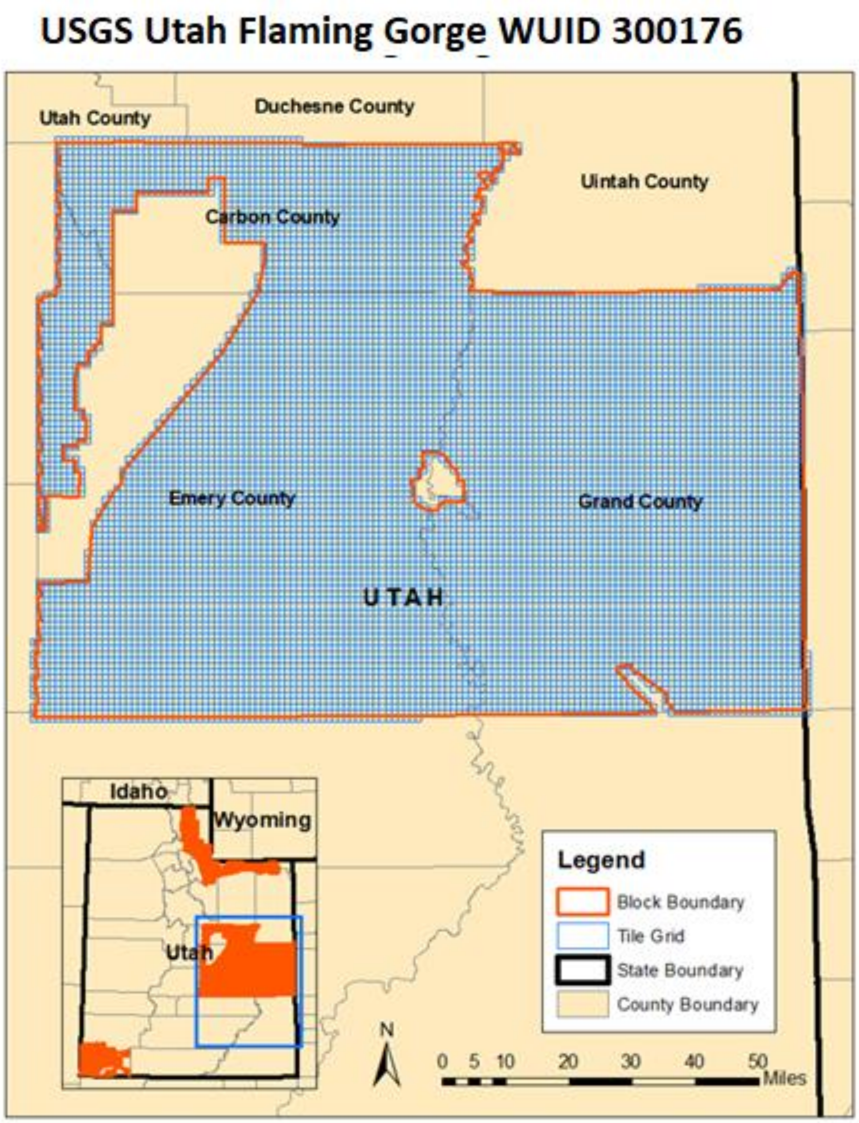


Figure 1. Project map for WUID300176.

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 (NAD83 (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.

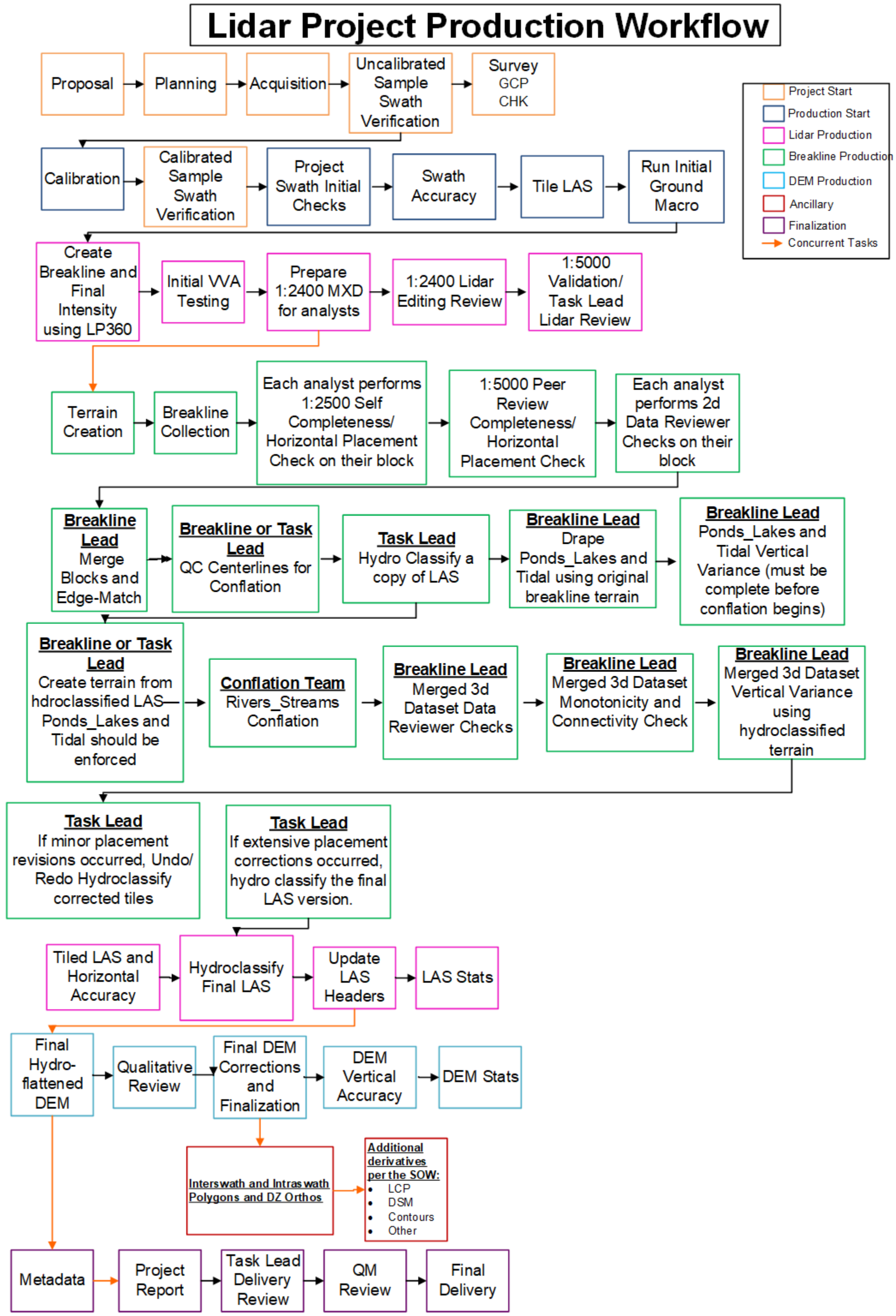


Figure 2. Dewberry's Lidar Production Workflow Diagram.

2. LIDAR ACQUISITION REPORT

Dewberry elected to subcontract the lidar acquisition and calibration activities to Aero-Graphics Inc. Aero-Graphics Inc. was responsible for providing lidar acquisition, calibration, and delivery of lidar data files to Dewberry.

The lidar aerial acquisition for WUID300176 was conducted between August 14, 2020 through November 20, 2020.

Localized horizontal and vertical offsets were identified in the Middle AOI (WUID300176) during final deliverable creation. These issues were not easily identifiable due to the sloped terrain and dense vegetation throughout the AOI. After a thorough review, it was determined the best course of action to correct the offsets were to recalibrate the data rather than perform localized shifts. This resulted in re-editing the data and reproducing the final deliverables.

2.1 Lidar Acquisition Details

Aero-Graphics planned 711 passes for the WUID300176 project area as a series of parallel flight lines, with cross flight lines for the purpose of quality control. The flight plan included zigzag flight line collection for improved inter-swath data accuracy. To reduce any margin for error in the flight plan, Aero-Graphics followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, adhered to 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 (940 m) 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, Aero-Graphics checked airspaces prior to each mission.

Aero-Graphics monitored weather and atmospheric conditions and conducted lidar missions only when no conditions that would interfere with data collection were present. 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 some missions were conducted during night hours when weather restrictions did not prevent collection. Aero-Graphics accessed reliable weather sites and indicators (webcams) to establish the highest probability for successful collection to position the sensors to maximize successful data acquisition.

Within the 72-hours prior to acquisition days, Aero-Graphics 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.

Aero-Graphics' lidar sensors were calibrated at a designated site located in Salt Lake City, UT and were periodically checked and adjusted to minimize corrections at project sites.

2.2 Lidar System Parameters

Aero-Graphics operated a Cessna 206 (Tail # N7269T) outfitted with an Optech Galaxy Prime lidar system, as well as a Cessna 206 (Tail # N27DV) outfitted with an Optech Galaxy T2000 lidar system during the collection over the study area. Table 1 illustrates Aero-Graphics' system parameters for lidar acquisition on this project.

Table 1. Aero-Graphics Inc. lidar system parameters.

Item	Parameter	Parameter
System	Optech Galaxy PRIME	Optech Galaxy T2000
Maximum Number of Returns per Pulse	8	8
Nominal Pulse Spacing (single swath), (m)	0.49	0.49
Nominal Pulse Density (single swath) (ppsm), (m)	4.23	4.23
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.49	0.49
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	4.23	4.23
Altitude (AGL meters)	1600	1600
Approx. Flight Speed (knots)	120	120
Total Sensor Scan Angle (degree)	46	46
Scan Frequency (hz)	63.5	63.5
Scanner Pulse Rate (kHz)	400	400
Pulse Duration of the Scanner (nanoseconds)	3	3
Pulse Width of the Scanner (m)	0.40	0.38
Central Wavelength of the Sensor Laser (nanometers)	1064	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes	Yes
Beam Divergence (milliradians)	0.25 mrad (1/e)	0.16 mrad (1/e)
Nominal Swath Width on the Ground (m)	1358	1358
Swath Overlap (%)	20	20
Computed Down Track spacing (m) per beam	0.49	0.49
Computed Cross Track Spacing (m) per beam	0.49	0.49
GNSS positional error (radial, in cm)	2-5	2-5
IMU error (in decimal degrees)	0.015	0.015
Line Spacing (m)	1386.66	1165

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. 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 continually 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 QC review during acquisition. The flight crew reviewed weather conditions and cloud locations in real time. 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 Trajectory of the flightlines:

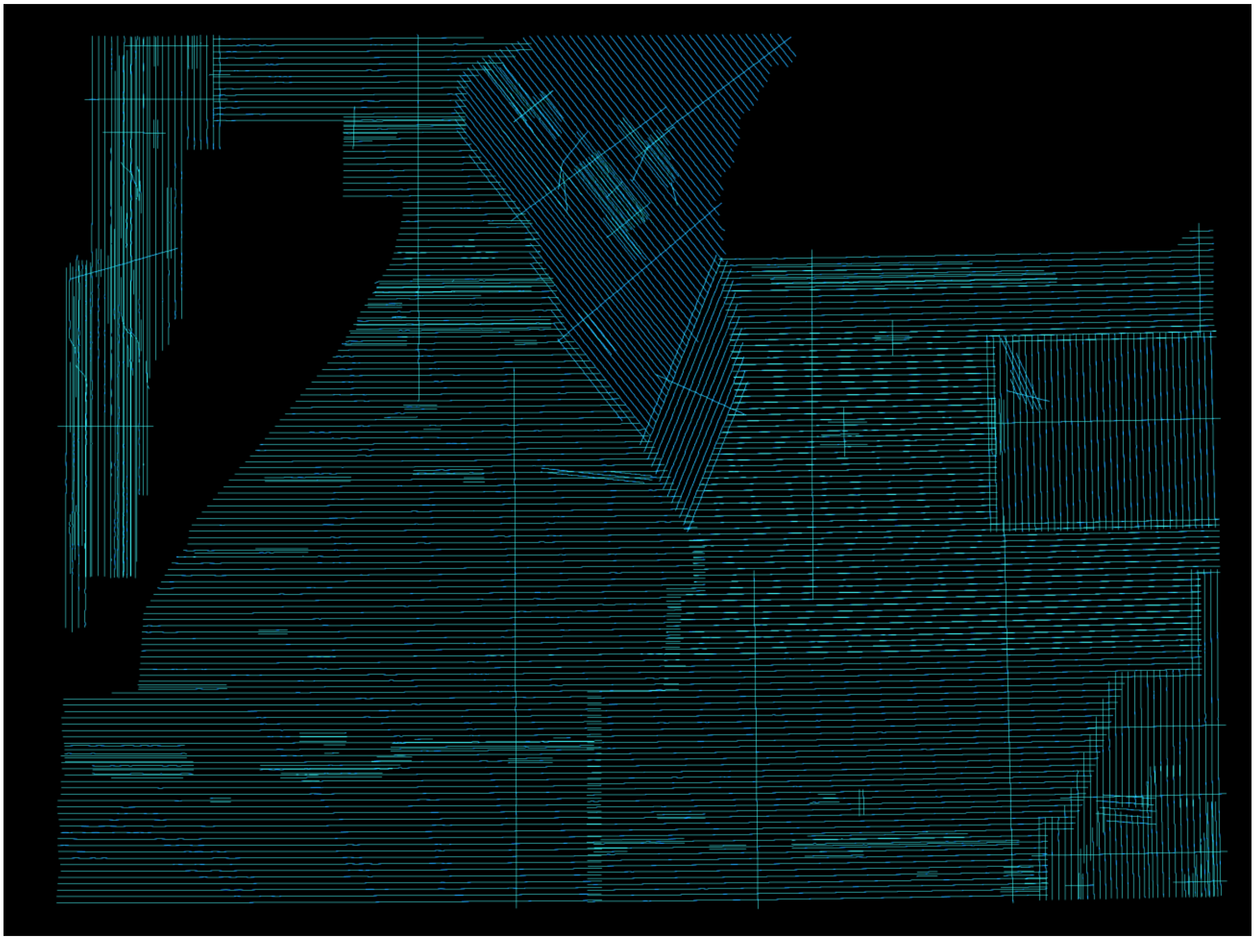


Figure 3. Trajectories as flown by Aero-Graphics

2.4 Acquisition Static Control

Aero-Graphics Inc. 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 Applanix's POSPac MMS GNSS Inertial software (PP-RTX) to post-process the 1-second airborne GPS positions with 1/200-second IMU (roll, pitch, and yaw) data through development of a smoothed best estimate of trajectory (SBET).

GPS processing reports for each mission will be added to the deliverables.

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.

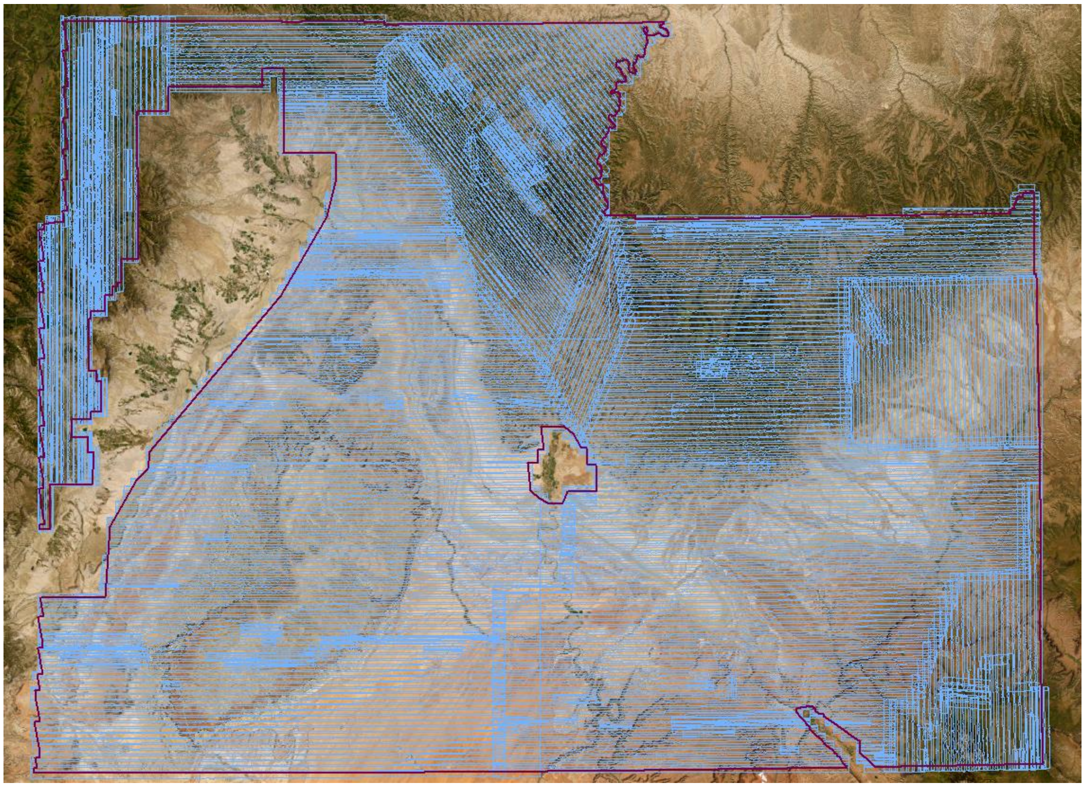


Figure 4. Lidar swath output showing complete coverage over the WUID300176 project area.

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 the relative accuracy was met.

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 so that errors greater than the specifications were flagged. Cross sections were visually inspected across each block to validate point to point, flight line to flight line, and mission to mission agreement.

For this project, the specifications used are as follows:

Relative accuracy ≤6 cm maximum differences within individual swaths and ≤8 cm RMSDz between adjacent and overlapping swaths.

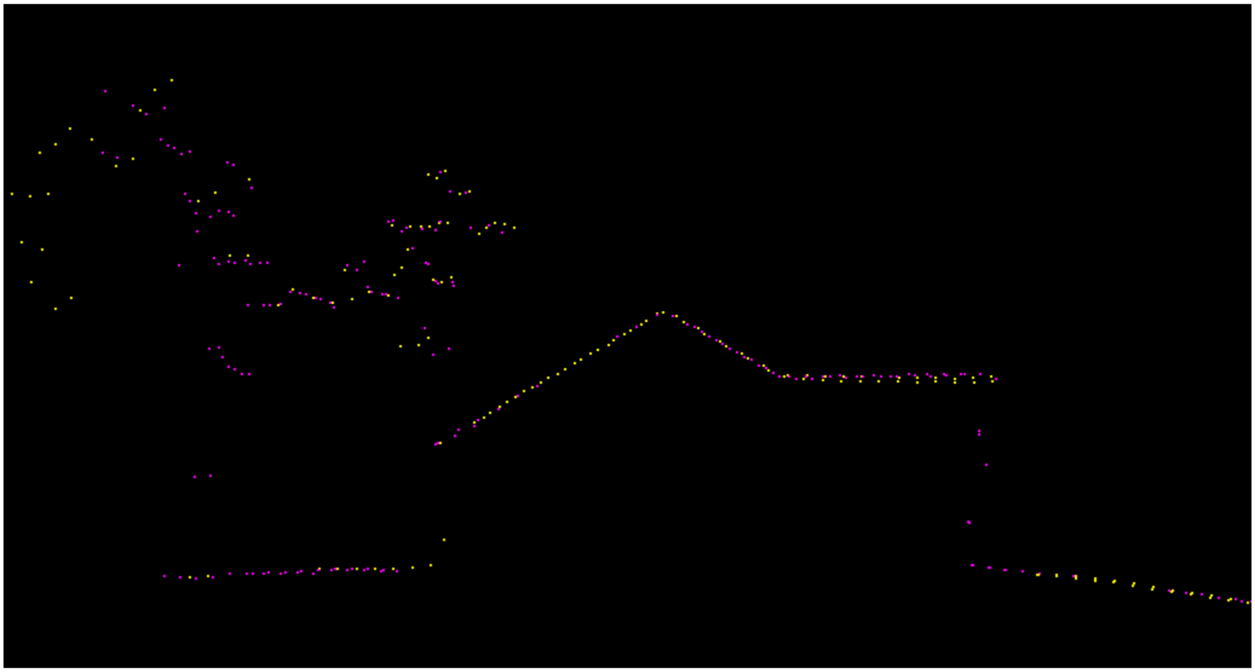
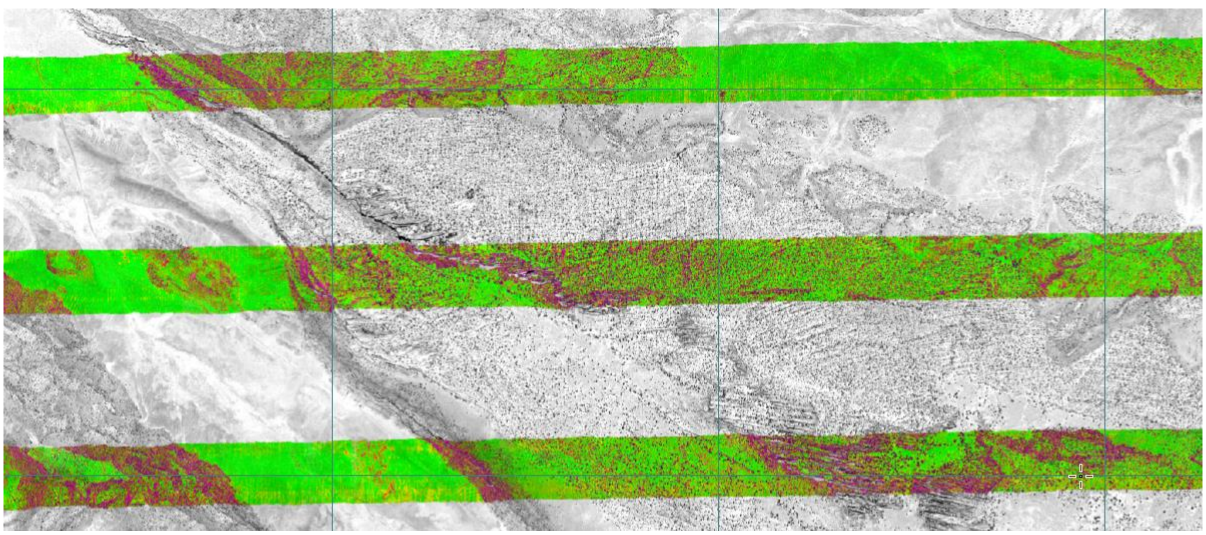


Figure 5. Profile views showing correct roll and pitch adjustments.



Intervals: 5 | Interval Size: 0.037 | Unit: metre | ☑ Absolute Values

Range	Color
> 0.148	Magenta
0.111 to 0.148	Red
0.074 to 0.111	Orange
0.037 to 0.074	Yellow
0 to 0.037	Green

Figure 6. QC block colored by distance to ensure accuracy at swath edges.

2.7 Final Calibration Verification

Dewberry conducted the survey for 26 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 26 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.

Table 2. WUID300176 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)
CA2001	486153.973	4397408.763	2345.831	2346.040
CA2002	476459.610	4350613.635	2138.463	2138.720
CA2003	518425.977	4405426.122	2173.894	2173.990
CA2004	548873.091	4379465.043	1792.761	1792.880
CA2005	550811.893	4377797.159	1937.344	1937.540
CA2006	548873.091	4362499.485	1660.870	1661.000
CA2007	529545.031	4303707.057	2018.168	2018.360
CA2007-CK	529545.036	4303707.028	2018.204	2018.360
CA2008	554145.536	4308132.007	1299.631	1299.820
CA2008-CK	554145.517	4308131.998	1299.631	1299.820
CA2009	592284.358	4308634.256	1409.959	1410.050
CA2009-CK	592284.430	4308634.259	1409.965	1410.050
CA2010	661830.850	4337692.069	1485.067	1485.290
CA2011	637970.699	4311224.851	1360.161	1360.300
CA2011-CK	637970.699	4311224.848	1360.157	1360.300
CA2012	640298.792	4285236.798	1263.461	1263.580
CA2013	602550.458	4311131.002	1489.513	1489.620
CA2014	531417.128	4263075.022	1456.967	1457.190
CA2015	537694.666	4275885.766	1515.308	1515.530
CA2016	604475.528	4276406.811	1669.606	1669.700
CA2017	482155.870	4295301.865	1739.920	1740.140
CA2018	525375.629	4270812.924	1499.104	1499.280
CA2019	614137.234	4281261.773	1372.948	1372.950
CA2020	620072.800	4311394.050	1473.297	1473.380
CA2020-CK	620072.808	4311394.607	1473.261	1473.380

CA2021	495492.804	4308294.607	1831.550	1831.690

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 3. 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	26	0.025	0.049	0.020	0.019	-1.003	0.025	-0.070	0.039	0.897

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	The average calculated (A)NPD of this project is 6.582 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
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	Scan Direction bits were populated correctly.	None

Requirement	Description of Deliverables	Additional Comments
mechanism. These fields should show a minimum and maximum of 0 for each swath acquired with Riegl sensors as these sensors use rotating mirrors.		
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 5. 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.	No unacceptable voids are present in this dataset.
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	None

Category	Editing Guideline	Additional Comments
	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
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,	No dirt mounds or other irregularities in the natural ground were present in this dataset.

Category	Editing Guideline	Additional Comments
	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)	
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 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.	No marshes were present in this dataset.
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.	There are temporal offsets 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	No low NIR reflectivity were present in this dataset.

Category	Editing Guideline	Additional Comments
	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.	
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 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.	Laser shadowing is present in this dataset.
Vertical Cliff Faces	Overhanging ground points near the tops of cliffs and mesas were left as Class 1 – Unclassified. Ground points in the same pixel with large differences in vertical elevations will average the elevation for that single pixel and cause the overall terrain to be mis-represented. In order to model the most accurate terrain delineation, Dewberry classifies ground points above and below the extremely vertical cliff faces.	Vertical cliff faces exist in this dataset and are classified accordingly.

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 6. 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 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 Class 22: Temporal	Pass
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 7. 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 ~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	No tidally influenced features are present in this dataset so no tidal breaklines were collected.

	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.	
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

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 8. 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 9. 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	Pass

	deliverables are .tif format	
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

Dewberry verified inter-swath or between swath relative accuracy of the dataset by generating swath separation images in conjunction with interswath polygons. Color-coding is used to help visualize elevation differences between overlapping swaths. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values.

The swath separation images are symbolized by the following ranges:

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

Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across one raster pixel) are expected to appear yellow or red in the SSIs. Flat, open areas are expected to be green in the SSIs. Large or continuous sections of yellow or red pixels following flight line patterns and not the terrain or vegetation can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data.

Dewberry generated swath separation images using LP360 software. These images were created from the last return of all points except points classified as noise and/or flagged as withheld. Point Insertion was used as the Surface Method and the cell size was set to 2x the deliverable DEM cell size. The three interval bins used are bulleted above and the parameter to “Modulate source differences by Intensity” was set to 50%. The output GeoTIFF rasters are tiled to the project tile grid, clipped to the master DPA, and formatted (including defining the CRS which matches the project CRS) using GDAL software, version 2.4.0. The image below shows the generated SSIs for this work unit.

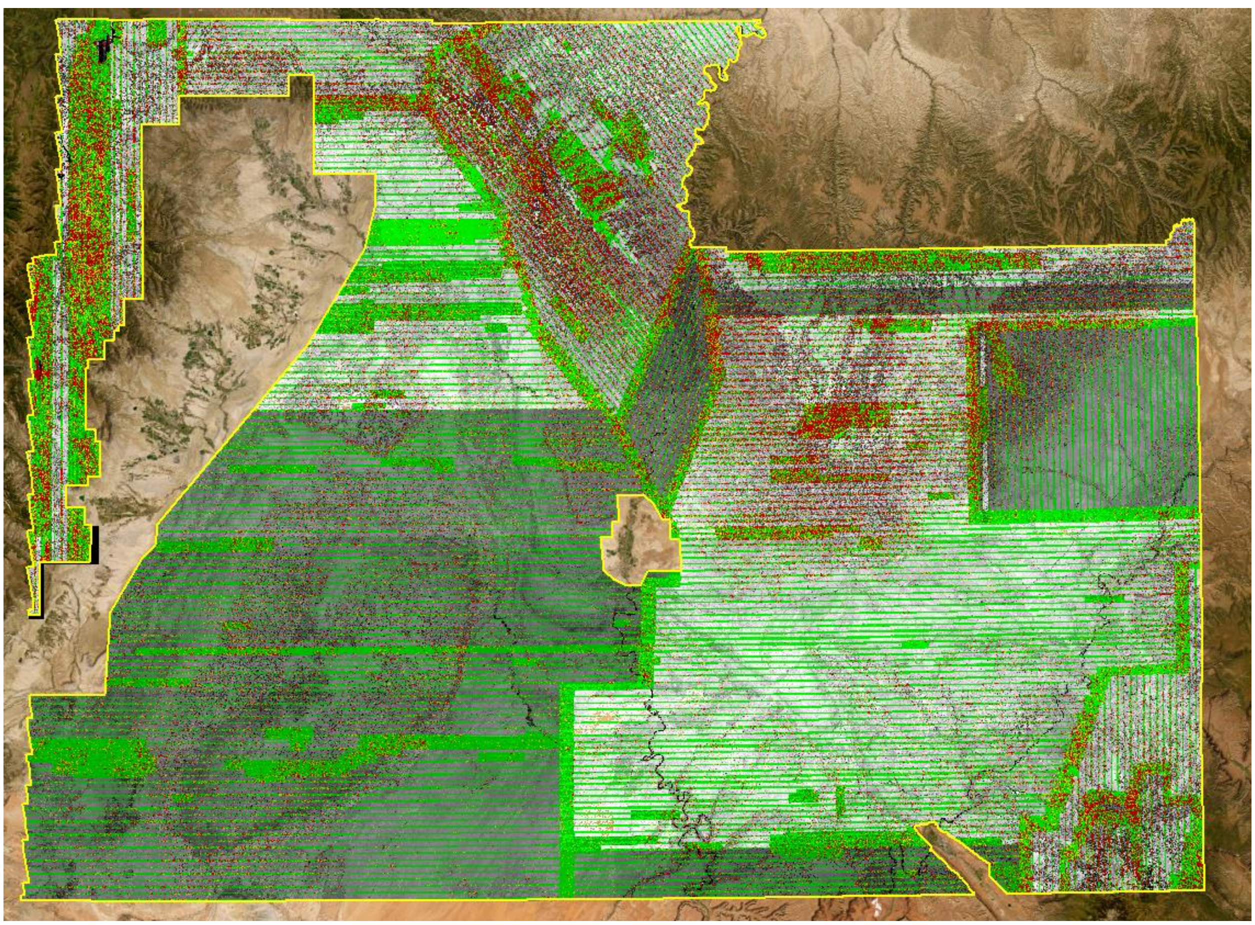


Figure 7. Swath Separation Images (SSIs) generated for WUID300176

6.2 Intensity Images

The intensity imagery was created from the point cloud intensity values of first returns from all point classes except for noise (classes 7 and 18) and points flagged as withheld were used to create the raster. The review of the intensity imagery included looking for anomalous intensity values, voids, and processing artifacts.

6.3 Interswath and Intraswath Polygons

6.3.1 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

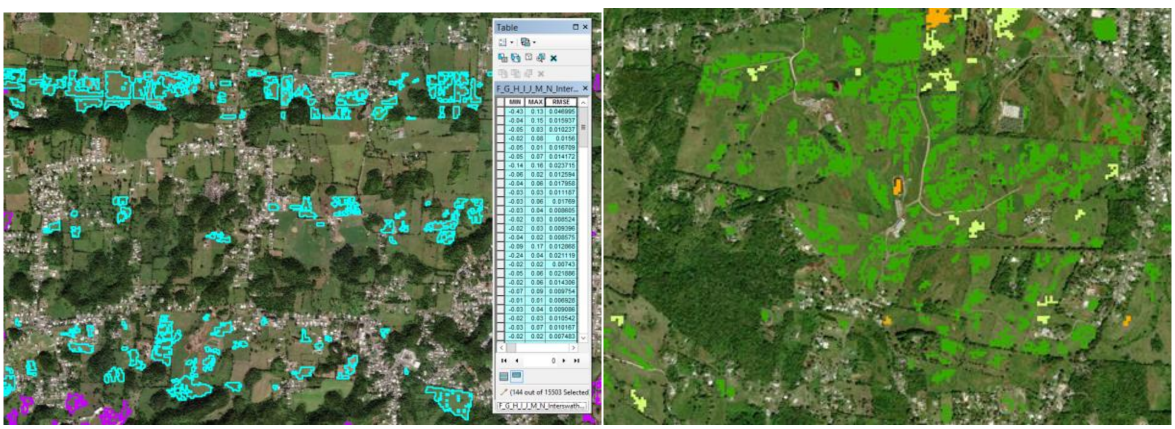


Figure 8. Left: Example interswath polygons and example statistics. Right: Example interswath polygons colored by RMSDz values.

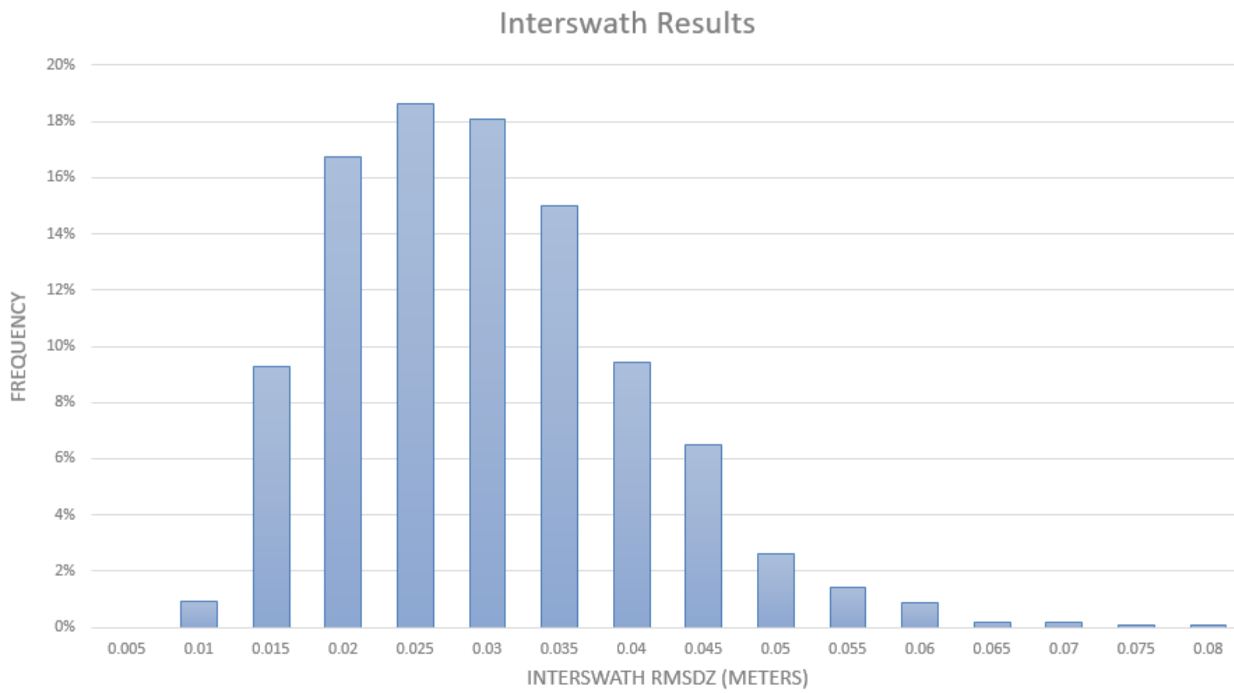


Figure 9. Frequency distribution of interswath RMSDz results for WUID300176

6.3.2 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. Several polygons are less than 400 sq. m in size due to the mountainous terrain and difficulty finding flat surfaces between polygons.

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).

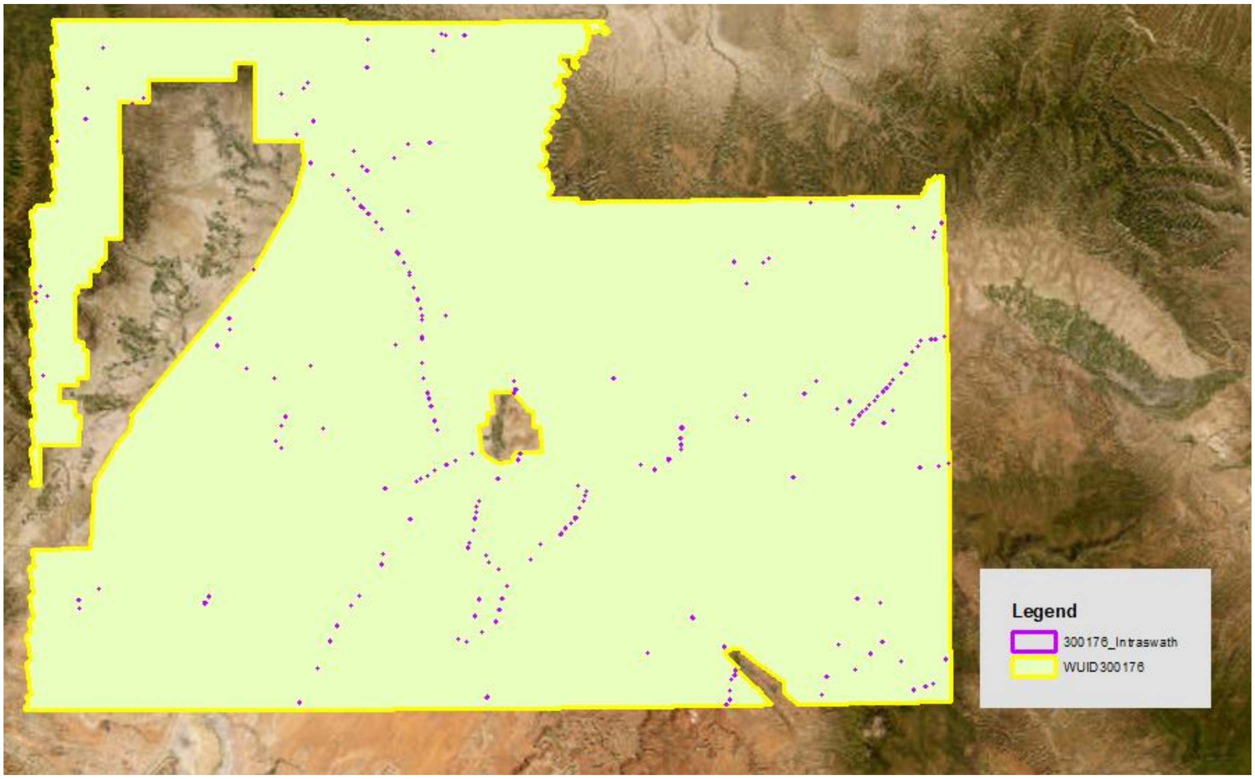


Figure 10. Intraswath polygons used to test intraswath vertical accuracy for WUID300176

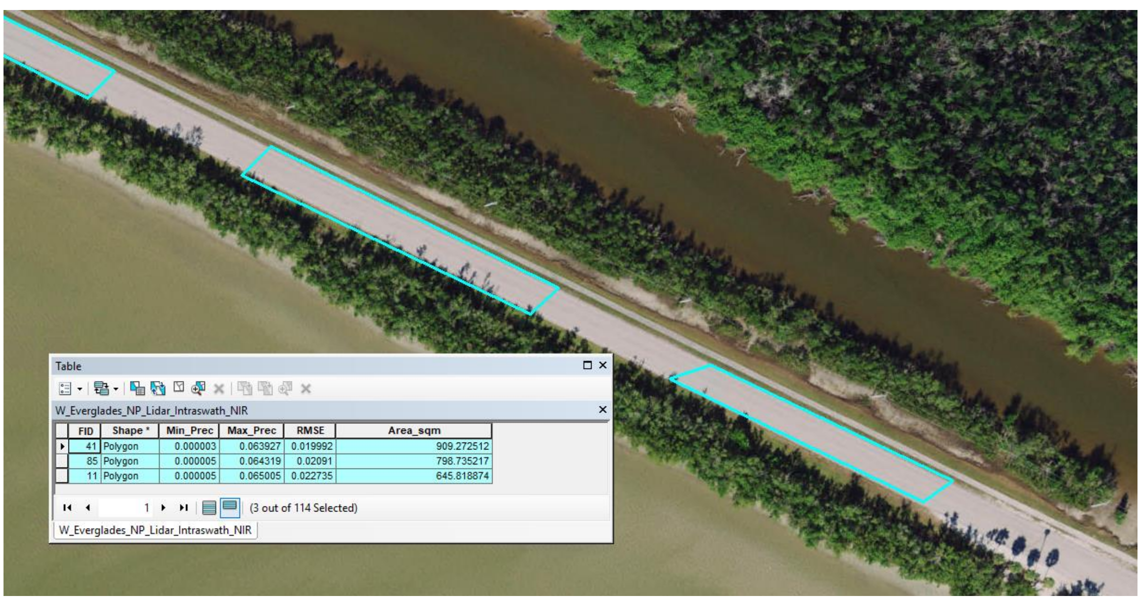


Figure 11. Example test polygon for intraswath testing, and its results.

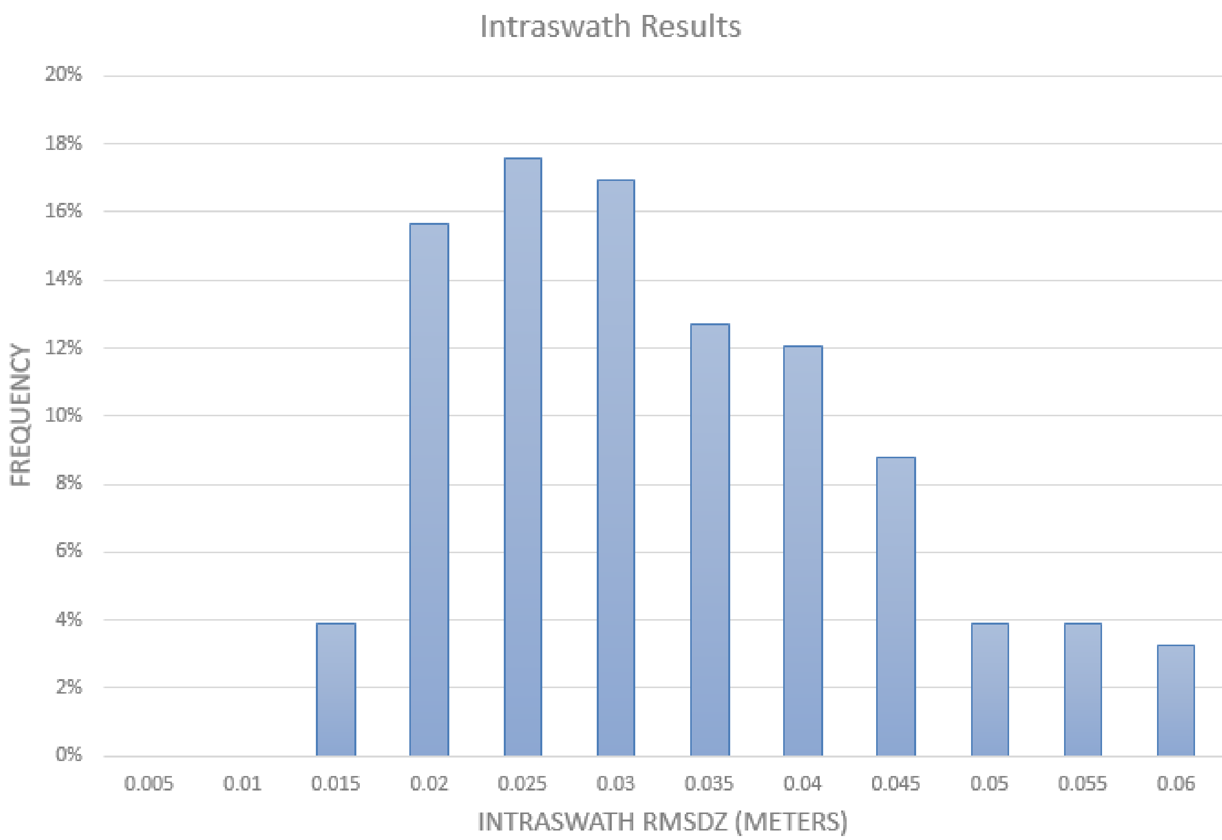


Figure 12. Frequency distribution of intraswath RMSDz results for WUID300176.

6.4 Maximum Surface Height Rasters (MSHRs)

MSHRs are delivered as tiled GeoTIFFs (32-bit, floating point), with the tile size and naming convention matching the project tile grid, tiled point cloud, and tiled DEM deliverables. MSHRs are provided as proof of performance that Dewberry's withheld bit flag has been properly set on all points, including noise, which are not deemed valid returns and which should be excluded from all derivative product development. All points, all returns, excluding points flagged as withheld, are used to produce MSHRs. The rasters are produced with a binning method in which the highest elevation of all lidar points intersecting each pixel is applied as the pixel elevation in the resulting raster. Final MSHRs are formatted using GDAL software version 2.4.0, spatially defined to match the project CRS, and the cell size equals 2x the deliverable DEM cell size (unless lidar density at the defined DEM cell size is insufficient for MSHR analysis and then a larger cell size for the MSHRs may be used). Prior to delivery, all MSHRs are reviewed for complete coverage, correct formatting, and any remaining point cloud misclassifications specifically in regard to the use of the withheld bit.

6.5 Flightline Extents GDB

Flightline extents are delivered as polygons in an Esri GDB, delineating actual coverage of each swath used in the project deliverables. Dewberry delivered this GDB using USGS's provided template so that each polygon contains the following attributes:

- Lift/Mission ID (unique per lift/mission)

- Point Source ID (unique per swath)
- Type of Swath (project, cross-tie, fill-in, calibration, or other)
- Start time in adjusted GPS seconds
- End time in adjusted GPS seconds

Prior to delivery, a final flightline GDB is created from the final, tiled point cloud deliverables to ensure all correct swaths are represented in the flightline GDB. The flightline GDB is then reviewed for complete coverage and correct formatting.