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NV EastCentral 2021 D21 WUID 300260

Report Produced for U.S. Geological Survey

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TABLE OF CONTENTS

ATTACHMENTS

Appendix A: AGI 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 NV EastCentral 2021 D21 WUID 300260 project area.

Lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models were produced for the project area. Project components were formatted based on a tile grid with each tile covering an area of 1,000 m by 1,000 m for QL1 data, and 1,500 m by 1,500 m for QL2 data. A total of 36,665 tiles were produced for the project, providing approximately 29,800 sq. miles of coverage. A total of 2,875 tiles were produced for WUID 300260, providing approximately 1,072 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.

Aero-Graphics, Inc. (AGI) completed the ground survey for the project and delivered surveyed checkpoints. Ground control points and checkpoints were surveyed for the project. Ground control points were used in calibration activities and checkpoints were used in independent testing of the vertical accuracy of the lidar-derived surface model.

Acquisition provider AGI completed lidar data acquisition, and Dewberry performed data calibration and processing for entire project area.

1.2 Project Area

The block area is shown in figure 1. WUID 300260 contains 2,875 1,000 m by 1,000 m tiles. The project tile grid contains 2,875 1,000 m by 1,000 m tiles and 33,790 1,500 m by 1,500 m tiles.

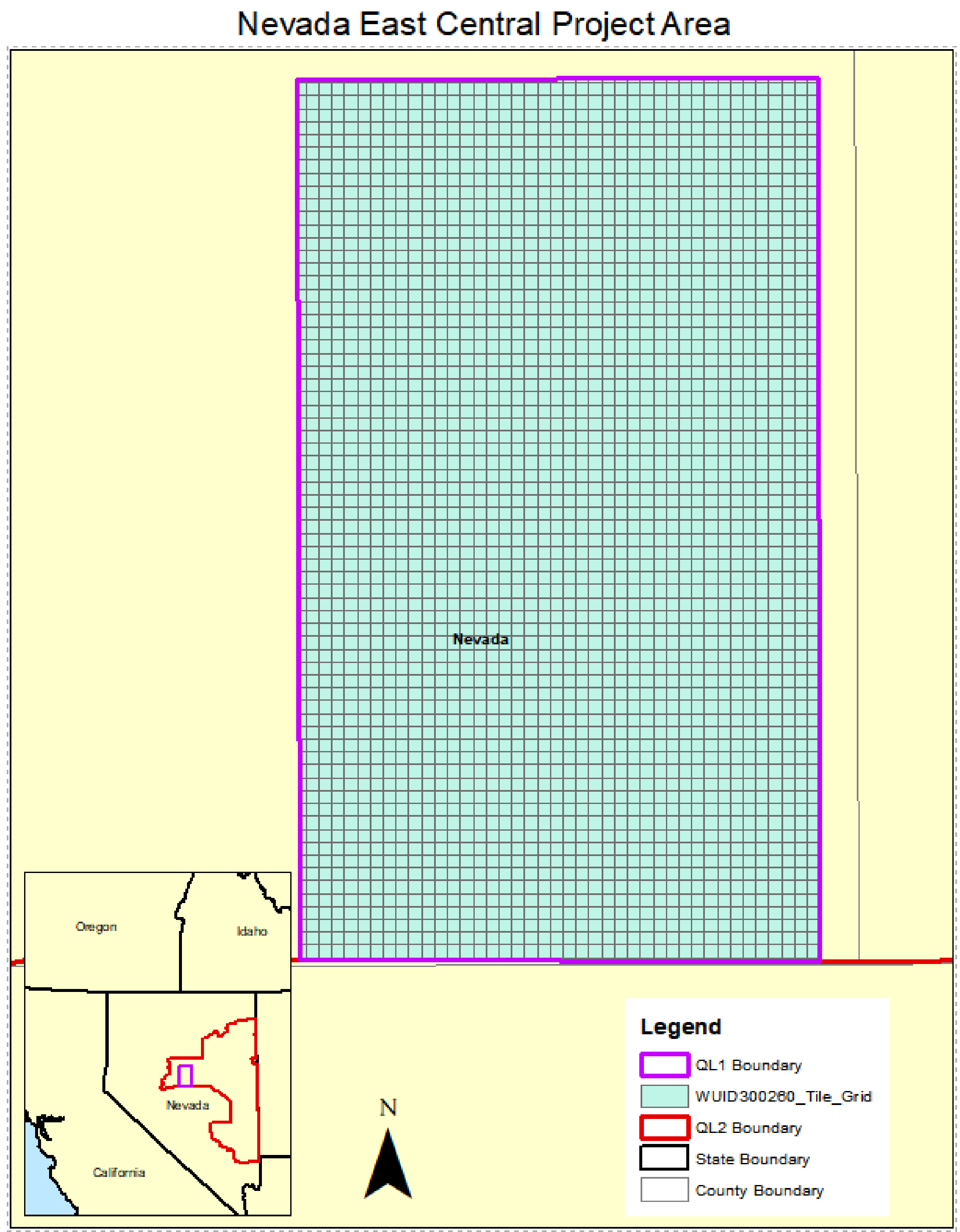


Figure 1. Project map and tile grid

1.3 Coordinate Reference System

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

Horizontal Datum:	North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum:	North American Vertical Datum of 1988 (NAVD88)
Geoid Model:	Geoid18
Coordinate System:	UTM Zone 11
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. Breakline Data (file GDB)
4. Bare Earth Surface (tiled raster DEM, IMG format)
5. Swath Separation Images
6. Metadata (XML)
7. Block Report
8. Flightline Extents GDB
9. Maximum Surface Height Rasters (tiled raster MSHRs, GeoTIFF format)
10. Snow Polygons (Esri SHP)

1.5 Dewberry Production Workflow Diagram

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

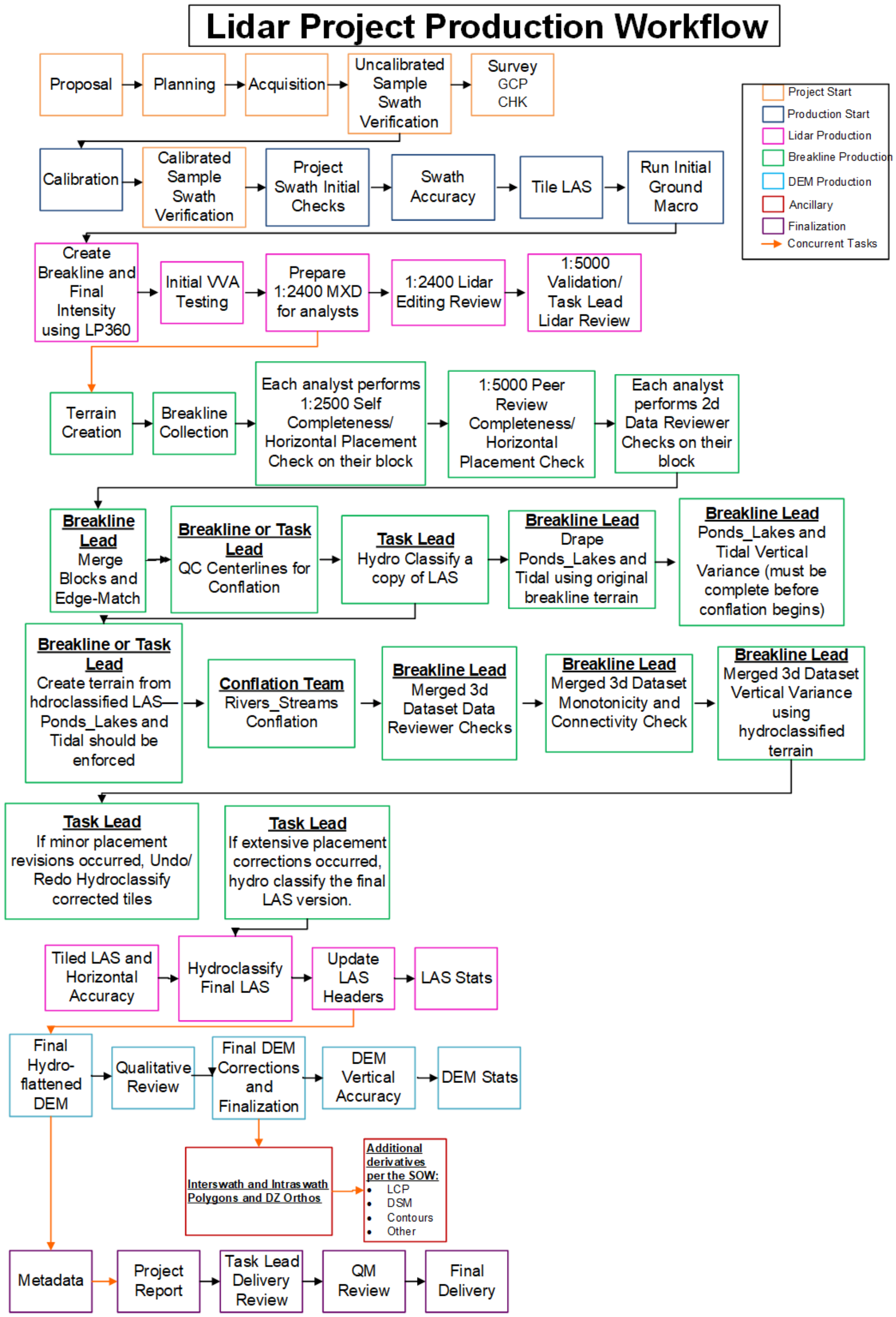


Figure 2. Dewberry's Lidar Production Workflow Diagram

2. LIDAR ACQUISITION REPORT

Dewberry elected to subcontract the lidar acquisition activities to AGI. AGI was responsible for providing lidar acquisition, raw data conversion from sensors and delivery of lidar data files to Dewberry for WUID300260.

2.1 Acquisition Extents

Figure 3 shows flightline swaths.

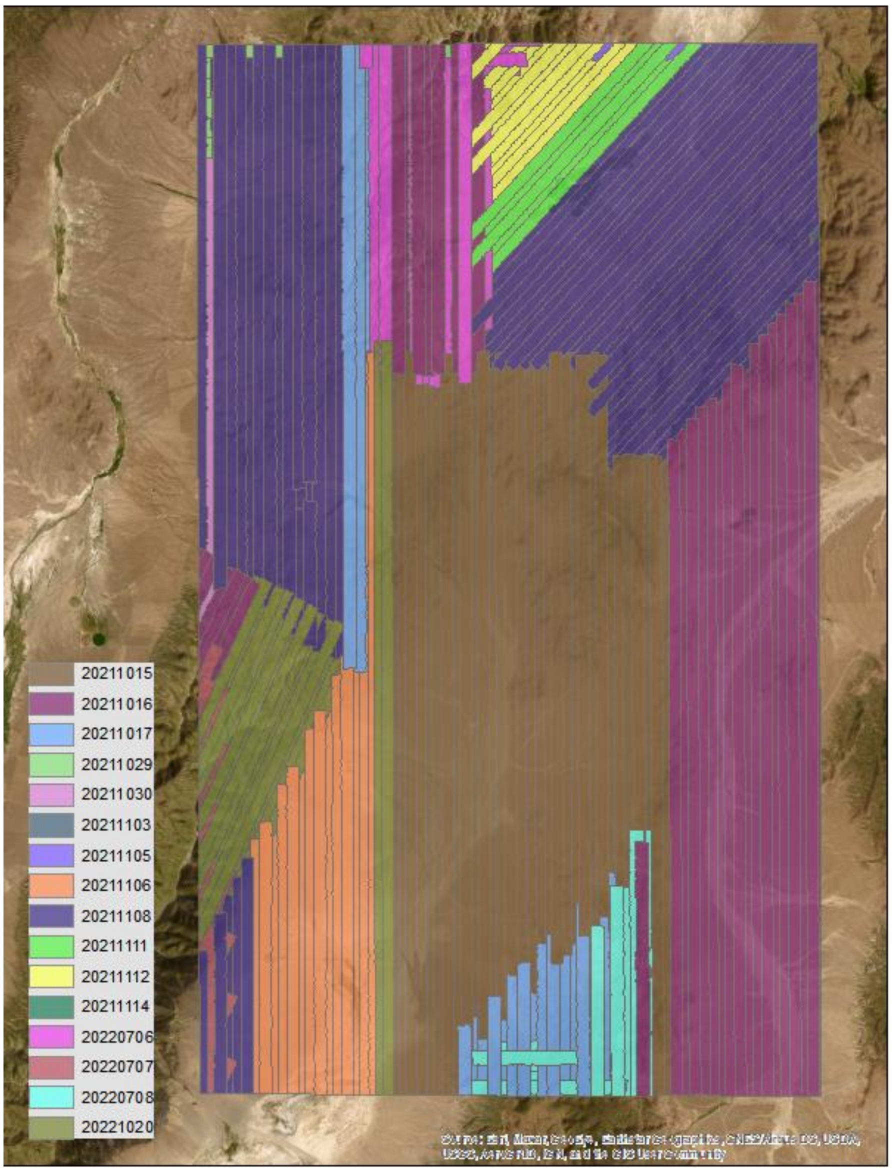


Figure 3. WUID300260 swaths

2.2 Acquisition Summary

AGI planned 246 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. In order to reduce any margin for error in the flight plan, AGI 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 (617m) 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.

AGI monitored weather, atmospheric, and ground conditions closely using a wide variety of sources and conducted lidar missions only when conditions were conducive to the goals of the project. These conditions included leaf-off for hardwoods, no rain, fog, smoke, mist, and low clouds. Lidar systems are active sensors, not requiring light, thus some missions were conducted during night or early morning hours when weather restrictions did not prevent collection.

Seventy-two hours prior to acquisition days, AGI closely monitored the weather, checking all reliable sources for forecasts at least twice daily as well as local traffic webcams to observe current ground conditions. This information was used to guide the aerial crew to areas with the highest probability for successful collection. 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 and ground condition analysis.

Snow cover or traces of snow often exist on higher elevations in the project area throughout the year. During acquisition in 2021, areas of snow were observed in these higher elevation areas. In an attempt to minimize the amount of snow that is present in the dataset, reflights for these areas were carried out earlier in the year in 2022. However, trace amounts of snow remain in the dataset. Dewberry appropriately classified the point cloud over the identifiable snow patches to Class-21 and provided low confidence polygons to delineate the snow-covered areas.

2.3 Sensor Calibration and Boresight

Prior to the NV EastCentral 2021 D21 acquisition, AGI completed a sensor boresight on October 14, 2021 in Salt Lake City, Utah. The boresight consisted of multiple opposing lines in an E-W direction as well as multiple opposing lines in a N-S direction. The swaths have a large overlap (>60%) with neighbors. The trajectory (.sbet) was processed using Applanix PosPac and raw swath data (.las) was produced using Optech's Lidar Mapping Suite. The boresight was calibrated and then analyzed. All deemed necessary corrections are then applied to the senor orientation internal files.

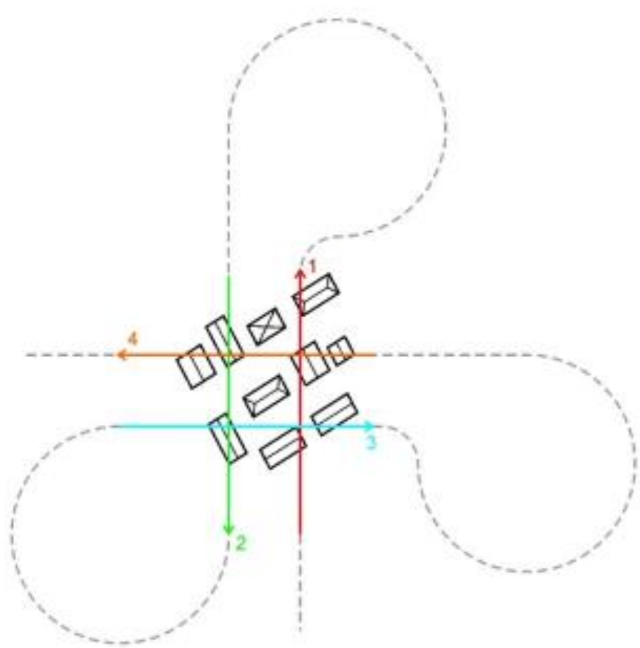


Figure 4. A typical calibration and boresight flight plan where above ground features are acquired from all four cardinal directions, any offsets of the above ground features between overlapping and other directional flight lines is analyzed, and corrections are applied as necessary to ensure proper configuration of the sensor

2.4 Lidar Acquisition and Processing Details

Table 1 outlines lidar acquisition details, including the project spatial reference system, and processing software used for this project.

Table 1. Lidar acquisition details

Parameter	Value
Number of Flight lines	245
Approximate Area	1,072 sq. miles
Acquisition Dates	October 15, 2021 – October 20, 2022

Parameter	Value
Horizontal Datum	North American Datum of 1983 (NAD83)
Vertical Datum	North American Vertical Datum of 1988 (NAVD88)
Geoid Model	Geoid18
Coordinate Reference System	UTM Zone 11
Horizontal Units	Meters
Vertical Units	Meters
Kinematic Solution Processing Software:	Applanix Pospac
Point Cloud Generation Software	Optech Lidar Mapping Suite
Calibration Software	BayesMap StripAlign

2.5 Lidar System Parameters

Aero-Graphics operated a Cessna T206 (Tail # N65474) outfitted with an Optech Galaxy T2000 lidar system and a Cessna T206 (Tail # N27DV) outfitted with an Optech Galaxy PRIME system during data collection. Table 2 details the lidar system parameters used during acquisition for this project.

Table 2. AGI lidar system parameters.

Parameter	Value – QL1	Value – QL1
System	Optech Galaxy T2000	Optech Galaxy PRIME
Altitude (m above ground level)	5000	4000
Nominal flight speed (kts)	120	120
Scanner pulse rate (kHz)	700	650
Scan frequency (Hz)	100	96
Pulse duration of the scanner (ns)	3	3
Pulse width of the scanner (m)	0.24	0.3
Central wavelength of the sensor laser (nm)	1064	1064
Multiple pulses in the air	Yes	Yes
Beam divergence (mrad)	0.25	0.16
Swath width (m)	806	690
Nominal swath width on the ground (m)	806	690
Swath overlap (%)	20	20
Total sensor scan angle (degrees)	30	32
Nominal pulse spacing (NPS) (single swath) (m)	0.31	0.32
Nominal Pulse Density (NPD) (single swath) (points per sq m)	10.43	11.55
Aggregate NPS (m) (if NPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.31	0.32

Aggregate NPD (m) (if NPD was designed to be met through single coverage, ANPD and NPD will be equal)	10.43	11.55
Maximum Number of Returns per Pulse	8	8

2.6 Acquisition Static Control

AGI 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.

2.7 ABGNSS-Inertial Processing

ABGNSS-Inertial processing was performed using the software identified in Table 1. The reference frame used for this processing does not always match the project spatial reference system and is shown in Table 3.

Appendix A contains additional mission GPS and IMU processing covering:

- Pospac graphics and processing
- Graphics of any reference stations used for differential correction
- Graphics of processing interface to show trajectory data and labeled reference stations for each lift (only graphics of trajectory when precise point position is used).
- Graphics of processed plots for each mission/flight/lift to include:
    1. Forward/reverse separation of trajectory
    2. Estimated accuracy of trajectory
    3. Any additional plots used in the analyses of trajectory quality

Table 3. Spatial reference system used for ABGNSS-Inertial processing

Parameter	Value
Horizontal Datum	North American Datum of 1983 (NAD83)
Vertical Datum	North American Vertical Datum of 1988 (NAVD88)
Geoid Model	Geoid18
Coordinate Reference System	UTM Zone 11
Horizontal Units	Meters
Vertical Units	Meters

2.8 Calibration Process (Project Mission Calibration)

Lidar mission flight trajectories were combined with raw point files in Optech LMS. The initial points (.las) for each mission calibration were inspected for flight line errors, spatial distribution, data voids, density, or issues with the lidar sensor. If a calibration error greater than specification was observed within the mission, the necessary roll, pitch, and scanner scale corrections were calculated and corrections were applied to each individual swath using the BayesMap StripAlign software. In addition, all GPS, aircraft trajectory, mission information, and ground control files were reviewed and logged into a database. The missions with the new calibration values were regenerated and validated internally once again to ensure quality.

The methodology and assessment for the spatial distribution, density, and sensor anomaly reviews are outlined further in the Post Calibration Lidar Review table.

2.9 Final Calibration Verification

AGI surveyed 15 ground control points (GCPs) in flat, non-vegetated areas to test the accuracy of the calibrated swath data in WUID 300260. GCPs were located in open, non-vegetated terrain. To assess the accuracy of calibration, the heights of the ground control points were compared with a surface derived from the calibrated swath lidar. A full list of GCPs used for accuracy testing is included in the GCP Survey Report provided with project deliverables.

Table 4. Summary of calibrated swath vertical accuracy tested with ground control points.

Land Cover Type	# of Points	$RMSE_z$ (m)	NVA (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Ground Control Points (GCPs)	15	0.021	0.042	0.005	0.014	-0.700	0.021	-0.041	0.034	-0.092

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.

The methodology and assessment for the absolute and relative accuracy, density, and spatial distribution reviews performed are outlined further in the Post Calibration Lidar Review table.

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.

Methodology and Requirement	Description of Deliverables	Additional Comments
Using proprietary software it was determined the 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
Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing density mean statistics output by proprietary tool, the project area was determined to meet the required specification of 8 ppsm or 0.35 m NPS. A visual review of a 1-square meter density grid is also performed to confirm most 1-square meter cells satisfies the project requirements. Density is also viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds) to confirm density passes with no issues.	The average calculated (A)NPD of this project is 21.8 ppsm. Density raster visualization also passed specifications.	None
The spatial distribution of points must be uniform and free of clustering. This specification is tested by creating a grid with cell sizes equal to the design NPS*2. Proprietary tools are then used to calculate the number of first return points of each swath within each grid cell. At least 90% of the cells must contain 1 lidar point, excluding acceptable void areas such as water or low NIR reflectivity features, i.e. some asphalt and roof composition materials.	99.9% of cells (2*NPS cell size) had at least 1 lidar point within the cell.	None

Methodology and Requirement	Description of Deliverables	Additional Comments
This project passes spatial distribution requirements, as shown in the image below.		
Within swath (Intra-swath or hard surface repeatability) relative accuracy must meet ≤ 6 cm maximum difference. Dewberry verifies the intra-swath or within swath relative accuracy by using proprietary scripting to output intra-swath rasters. Proprietary scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry performs a visual review of planar surfaces and ensures the data passes specification.	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. Dewberry verifies the inter-swath or between swath relative accuracy by using proprietary scripting to output inter-swath rasters and LP360 generated Swath Separation Images which are both reviewed visually at multiple stages of production to ensure the data passes specification.	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	No sensor anomalies were present.	None

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

3.2 Data Classification and Editing

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, Dewberry utilized proprietary and TerraScan software for processing. The acquired 3D laser point clouds were tiled according to the project tile grid using proprietary software. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classified any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that were geometrically unusable were flagged as withheld and classified to a separate class so that they would be excluded from the initial ground algorithm. After points that could negatively affect the ground were removed from class 1, the ground layer was extracted from this remaining point cloud using an iterative surface model.

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

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

The withheld bit was set on the withheld points previously identified in TerraScan before the ground classification routine was performed.

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

3.2.1 Qualitative Review

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

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

Table 6 – Lidar editing and review guidelines.

Category	Editing Guideline	Additional Comments
No Data Voids	The SOW for the project defines unacceptable data voids as voids greater than 4 x $ANPS^2$, or 1.96 m^2, that are not related to water bodies or other areas of low near-infrared reflectivity and are not appropriately filled by data from an adjacent swath. The LAS files were used to produce density grids based on Class 2 (ground) points for review.	No unacceptable voids were identified 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 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	None

Category	Editing Guideline	Additional Comments
	breaklines where applicable due to interpolation.	
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 present in this dataset
Dirt Mounds	Irregularities in the natural ground, including dirt piles and boulders, are common and may be misinterpreted as artifacts that should be removed. To verify their inclusion in the ground class, Dewberry checked the features for any points above or below the surface that might indicate vegetation or lidar penetration and reviews ancillary layers in these locations as well. Whenever determined to be natural or ground features, Dewberry edits the features to class 2 (ground)	No dirt mounds or other irregularities in the natural ground were present in this dataset
Irrigated Agricultural Areas	Per project specifications, Dewberry collected all areas of standing water greater than or equal to 2 acres, including areas of standing water within agricultural areas and not within wetland or defined waterbody, hydrographic, or tidal boundaries. Areas of standing water that did not meet the 2 acre size criteria were not collected.	Standing water within agricultural areas not present in the data
Wetland/Marsh Areas	Vegetated areas within wetlands/marsh areas are not considered water bodies	No marshes present in the data

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

Category	Editing Guideline	Additional Comments
	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.	
Snow Cover	If snow cover present in the dataset, classify the points to Class 21 and the areas shall be identified with a shapefile.	Dewberry observed traces of snow cover which is sometimes present throughout the year on high elevations in the project area. Lidar points are appropriately classified to Class 21 and snow polygons provided to delineate the snow cover extents and represent low confidence bare-earth data.

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 11, meters in WKT format	Pass

Parameter	Project Specification	Pass/Fail
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 Class 9: Water Class 17: Bridge Decks Class 18: High Noise Class 20: Ignored Ground Class 21: Snow	Pass
Withheld Points	Withheld bits set	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Recorded for each pulse	Pass

3.3 Positional Accuracy Validation

3.3.1 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 and boresight adjustment of the data in each lift. Dewberry reviews the overlap consistency of the lidar dataset during multiple stages of production. Each review is performed by an initial reviewer and then reviewed by a second reviewer to verify the overlap consistency meets expectations. After calibration, Dewberry uses a proprietary software to generate a point statistics interswath raster. The interswath raster is reviewed for any systematic interswath errors that should be considered of concern. If issues are identified it will be corrected by the calibration team. The interswath rasters are symbolized by the following ranges:

- +/- 0-8 cm: **Green**
- +/- 8-16 cm: **Yellow**
- +/- 16 cm: **Red**

Once the initial ground macro has been run on the dataset, Dewberry uses LP360 to generate swath separation images. The swath separation images are generated using the same settings as the final deliverable swath separation images outlined in 6.1 Swath Separation Images (SSIs) and in accordance with USGS Lidar Base Specification v2023 Rev A. If the lidar dataset is heavily vegetated, Dewberry will generate swath separation images using the last return of ground points only to better confirm no offsets are present in the bare earth DEM. If issues are identified, dependent on the cause of the issue, it will be corrected by recalibrating the affected data or classifying the impacting points to withheld.

Lastly, the final deliverable swath separation images are generated using LP360. A final review is performed by the final product producer and then verified by a member of the quality management team prior to sending to USGS.

There were 12 instances of potential relative accuracy issues that appeared to coincide with re-flights, flown a year later, due to snow coverage. While areas of snow coverage do have discernible elevation differences in the point cloud (and have been addressed, as outlined in section 3.2 Snow Polygons), Dewberry did not identify calibration offsets between swaths, re-flights or otherwise, even though the appearance of the SSIs would suggest offsets are present as the “yellow” and “red” areas, representing elevation differences of 8-16 cm and >16cm, respectively, appear to follow flight line edges. Please see Figures 5-9 for examples of well aligned lidar point cloud profiles within areas that the SSI would suggest have calibration offsets.

When Dewberry could not identify calibration offsets within the point cloud, we investigated further. This WU includes some very mountainous and very vegetated areas (see Figures 10-12 for examples of the bare earth DEM, MSHR, and a slope map). These factors accounted for the “red” pixels in the SSIs, which are consistent across the WU, but alone do not account for the “red” SSI pixels which follow flight line edges and appear to be inconsistent with the surrounding area (see Figure 13).

As USGS noted, the visual patterns identified in the SSIs also coincide with re-flights. Again, in the point cloud, the re-flights are calibrated well to the other flight lines. However, many of the re-flights were flown in a different direction or heading compared to the original flights. And in areas with the most visible geometric patterning in the SSIs, original flights and re-flights were flown in opposite and perpendicular cardinal directions so that there are N-S flights and perpendicular E-W flights. In the locations of re-flights, all data were used to achieve maximum coverage. The result is that in the re-flight areas, and along flight line edges where more overlap exists, there are significantly higher densities.

The re-flights were due to snow present in higher elevations and as the slope map, DEM, and MSHR corroborate, this also means re-flights occurred in areas of high slope (often >30 degrees) which are heavily vegetated.

Dewberry looked at the density in more detail. The geometric patterns visible in the SSIs mainly occur on vegetated, steep slopes, in re-flight areas where overlap between these flight lines results in 3-4 swath coverages compared to two swath coverages elsewhere. The resulting density follows this trend with point density averaging 2-3x as many points (see Figures 14-15). Not only are more points present, but due to the different flight directions/headings of the re-flights, we’re achieving multiple look angles as well. This increased density has resulted in more vegetation points being present, expanding the “red” pixels in the SSIs in the overlap areas (see Figures 16-18). This is further confirmed by the SSIs and MSHRs, which show small pockets of “green” in between the vegetation all throughout these areas and same swaths in the SSIs. Additionally, the few non-vegetated, flat (0-10 degrees) areas of terrain present in this WU all show good alignment in the SSIs (see Figure 19).

The lidar point cloud shows good alignment between all swaths, including the re-flights. The SSIs show good alignment and “green” pixels in non-vegetated, flat areas and typically even in sloped terrain where vegetation does not exist. There are visible patterns of “red” pixels in the SSIs, which appear to follow flight line edges, but represent higher density and multiple look angles, primarily on vegetation, in areas of higher overlap (overlap from 3+ swaths).

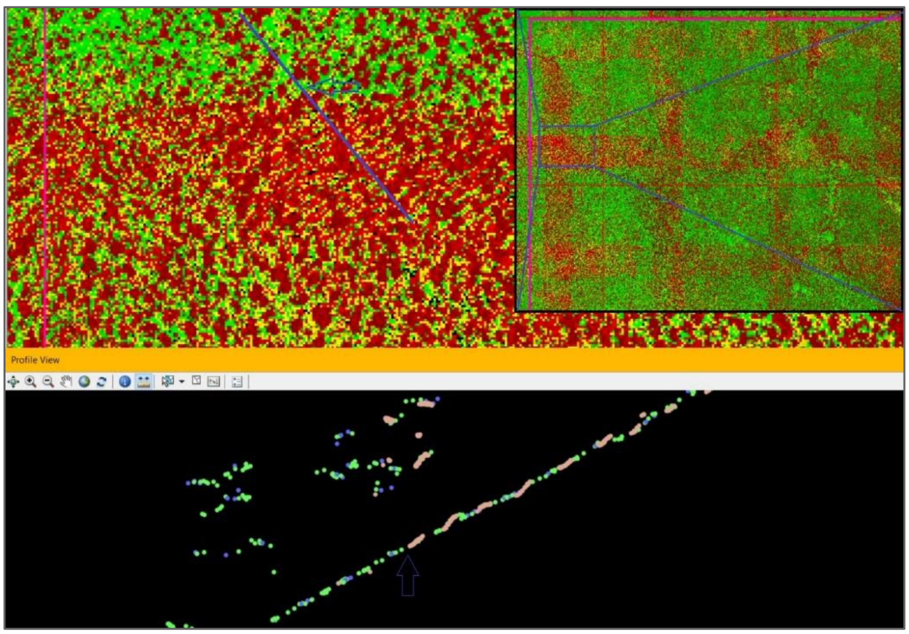


Figure 5. Top image shows a closeup of the SSI (0-8cm green, 8-16cm yellow, >16cm red) in an area identified by USGS as having potential relative accuracy issues, along with an inset showing the SSIs at a larger scale. The bottom image shows a lidar point cloud profile, taken at the location of the blue line and arrow in the top image, colored by Point Source ID. The lidar profile shows that all swaths are in good alignment with each other, even those the SSI shows a “red” edge along a flight line edge.

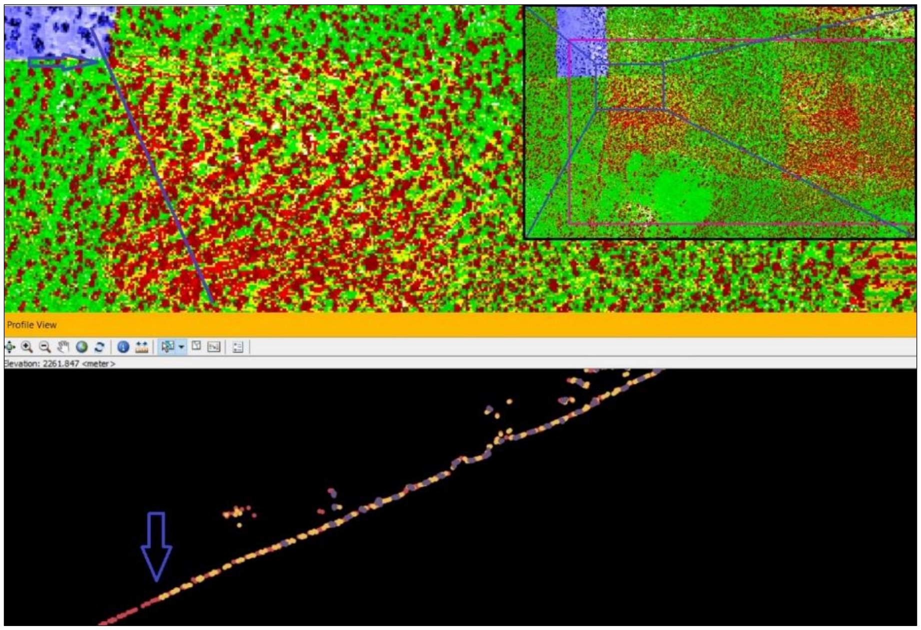


Figure 6. Top image shows a closeup of the SSI (0-8cm green, 8-16cm yellow, >16cm red) in an area identified by USGS as having potential relative accuracy issues, along with an inset showing the SSIs at a larger scale. The bottom image shows a lidar point cloud profile, taken at the location of the blue line and arrow in the top image, colored by Point Source ID. The lidar profile shows that all swaths are in good alignment with each other, even those the SSI shows a "red" edge along a flight line edge.

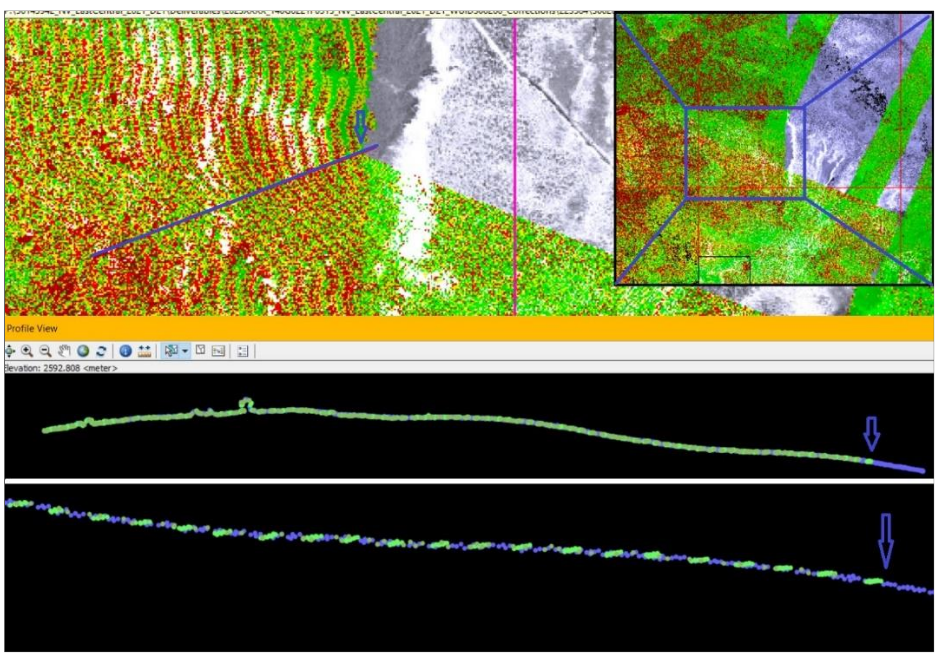


Figure 7. Top image shows a closeup of the SSI (0-8cm green, 8-16cm yellow, >16cm red) in an area identified by USGS as having potential relative accuracy issues, along with an inset showing the SSIs at a larger scale.

The middle image shows a lidar point cloud profile, taken at the location of the blue line and arrow in the top image, colored by Point Source ID and the bottom image is a closer view of a portion of the profile in the middle image. The lidar profile shows that all swaths are in good alignment with each other, even those the SSI shows a "red" edge along a flight line edge.

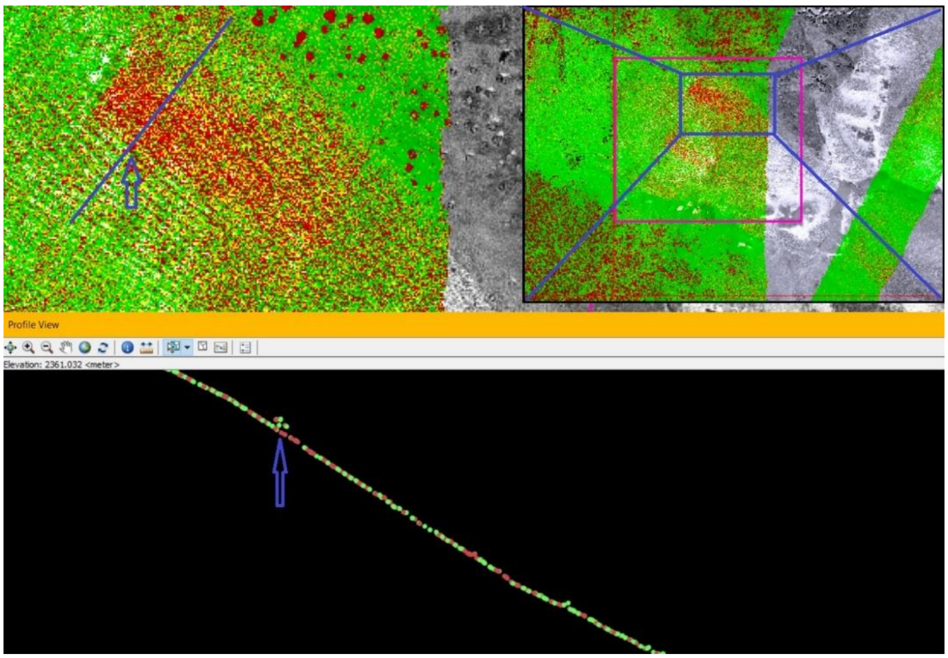


Figure 8. Top image shows a closeup of the SSI (0-8cm green, 8-16cm yellow, >16cm red) in an area identified by USGS as having potential relative accuracy issues, along with an inset showing the SSIs at a larger scale. The bottom image shows a lidar point cloud profile, taken at the location of the blue line and arrow in the top image, colored by Point Source ID. The lidar profile shows that all swaths are in good alignment with each other, even those the SSI shows a "red" edge along a flight line edge.

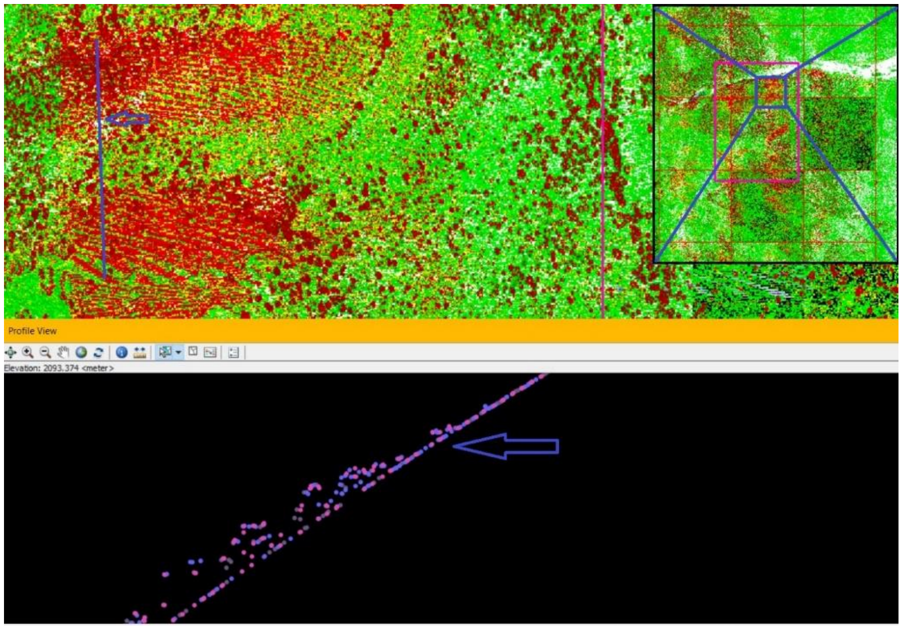


Figure 9. Top image shows a closeup of the SSI (0-8cm green, 8-16cm yellow, >16cm red) in an area identified by USGS as having potential relative accuracy issues, along with an inset showing the SSIs at a larger scale. The bottom image shows a lidar point cloud profile, taken at the location of the blue line and arrow in the top image, colored by Point Source ID. The lidar profile shows that all swaths are in good alignment with each other, even those the SSI shows a "red" edge along a flight line edge.

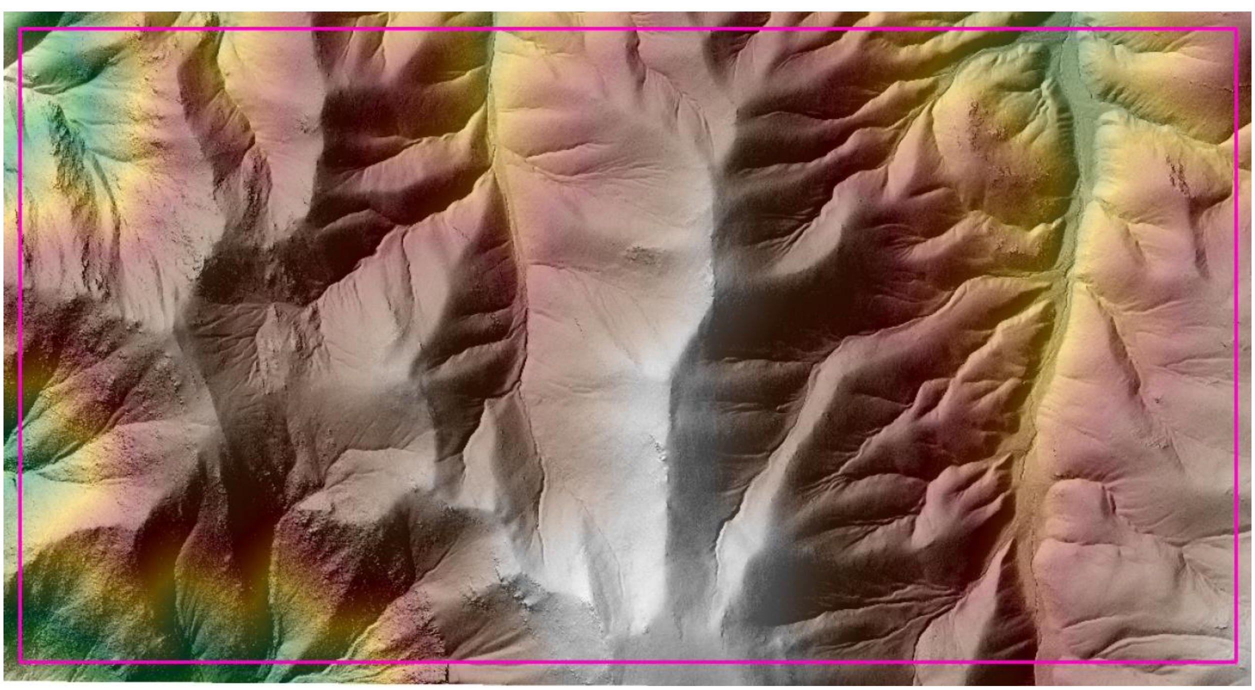


Figure 10. Bare earth DEM for the southernmost relative accuracy call placed by USGS. Some areas of this WU are very mountainous, with high slopes.

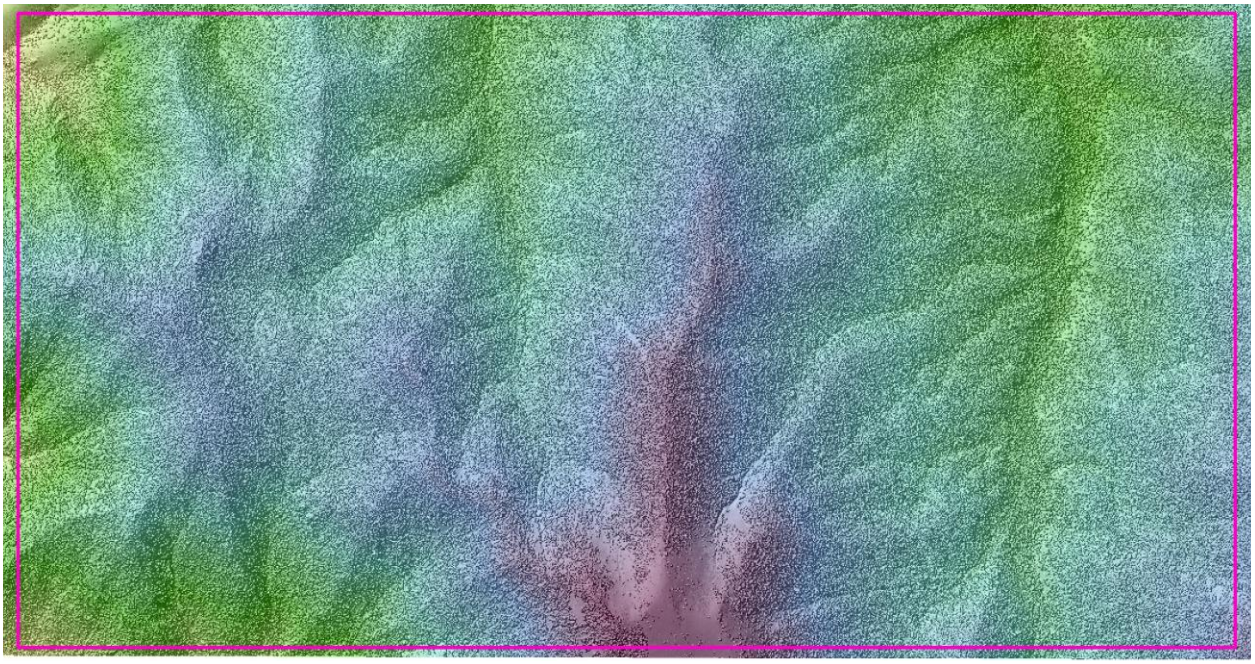


Figure 11. MSHR for the southernmost relative accuracy call placed by USGS. Some areas of this WU are very vegetated.

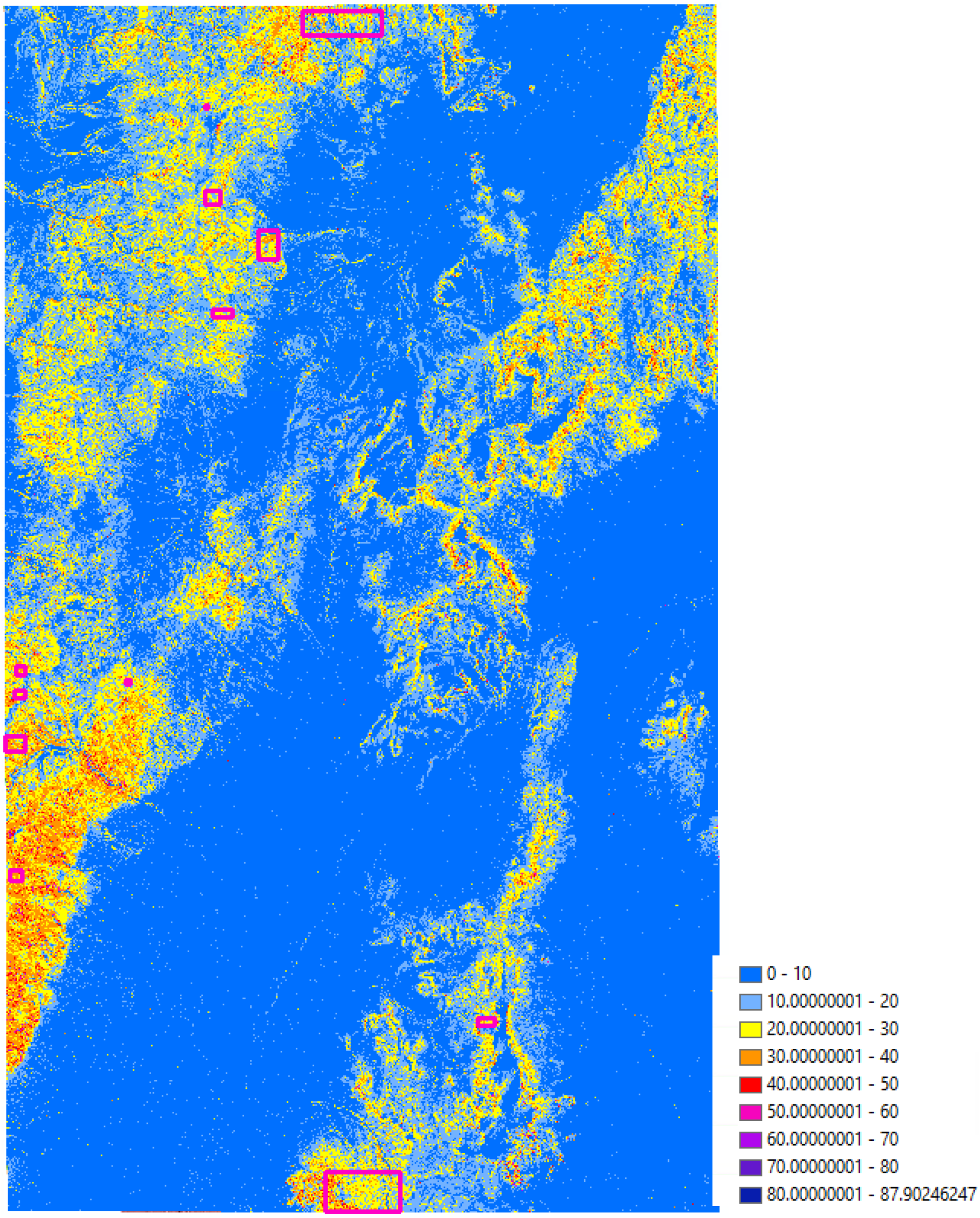


Figure 12. Slope map, by degrees, for this WU, with USGS relative accuracy calls outlined in pink. Relative accuracy calls placed by USGS and visible patterns in SSIs occur in areas of steep slope that are heavily vegetated and were flown with multiple coverages due to snow.

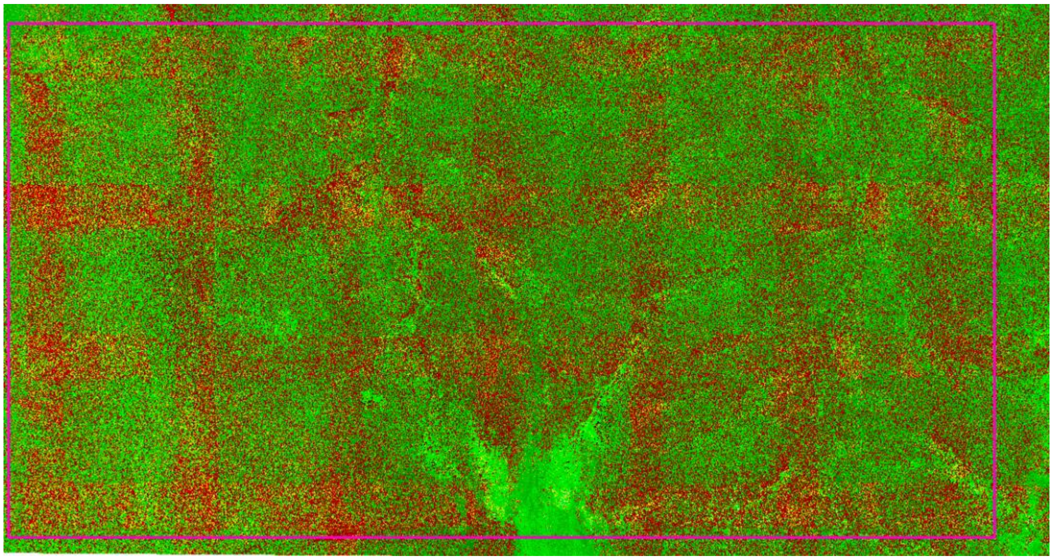


Figure 13. The SSI (0-8cm green, 8-16cm yellow, >16cm red) in an area identified by USGS as having potential relative accuracy issues. A geometric pattern, appearing to follow flight line edges, is visible in the SSIs.

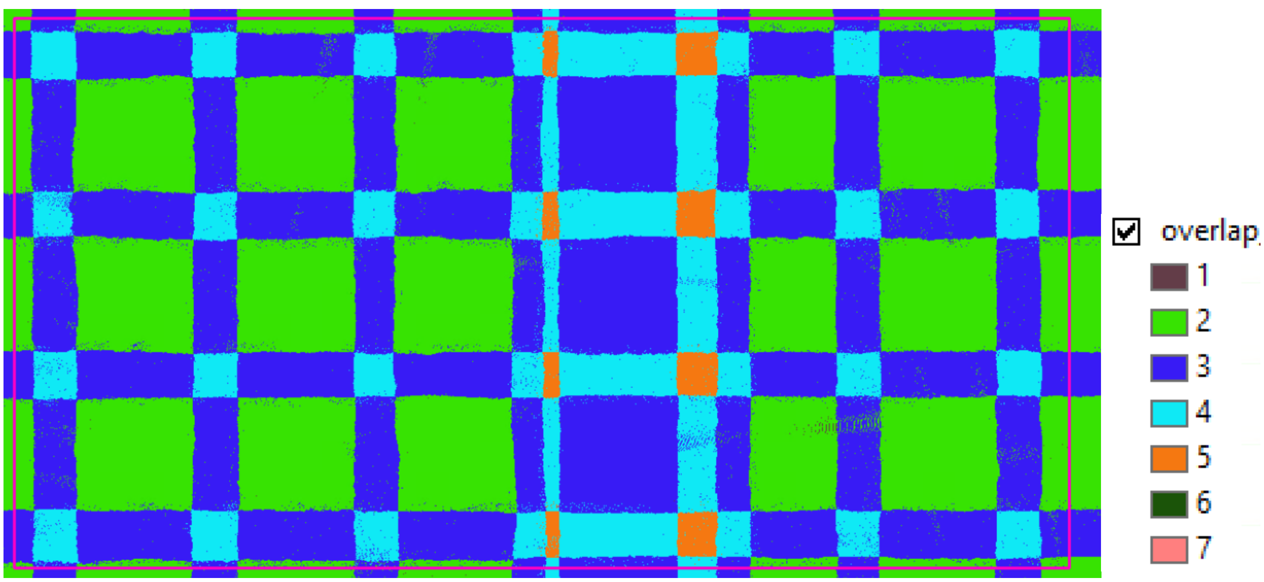


Figure 14. A raster showing the number of swath coverages over one of the relative accuracy areas identified by USGS. Original flights and re-flights are present here, resulting in both N-S flight lines and E-W flight lines. There are consistently 3-4 swath coverages in the overlap areas.

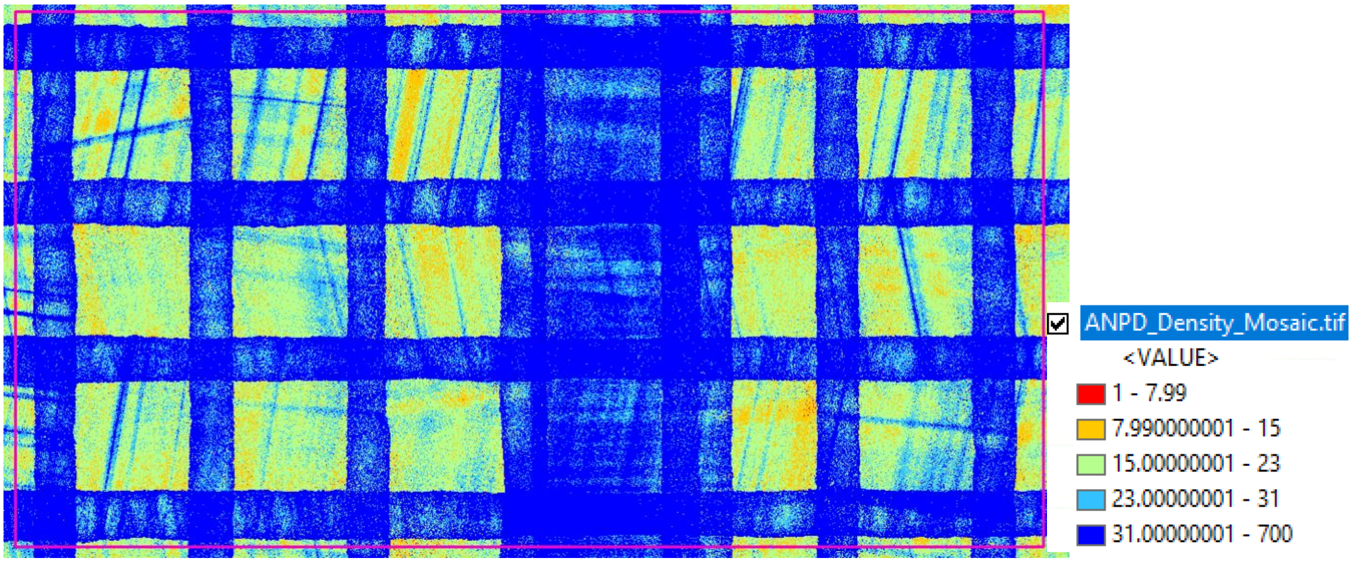


Figure 15. A density raster showing higher point density (2-3x or greater) in the overlap areas where 3-4 swath coverages are present.

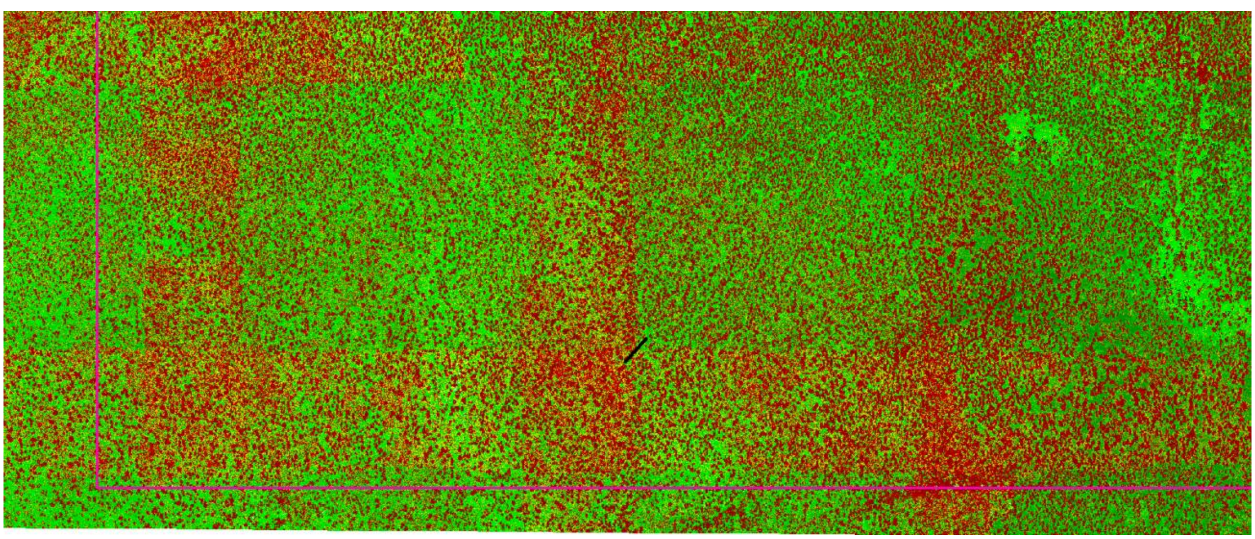


Figure 16. The SSI (0-8cm green, 8-16cm yellow, >16cm red) in an area identified by USGS as having potential relative accuracy issues. While a "red" pattern is visible, it primarily corresponds to vegetation in overlap areas where there is a higher point density from multiple look angles. Pockets of "green" are present all throughout these flight lines and occur in between the vegetation or in the non-vegetated pixels. The black line represents the location shown in Figure 14.

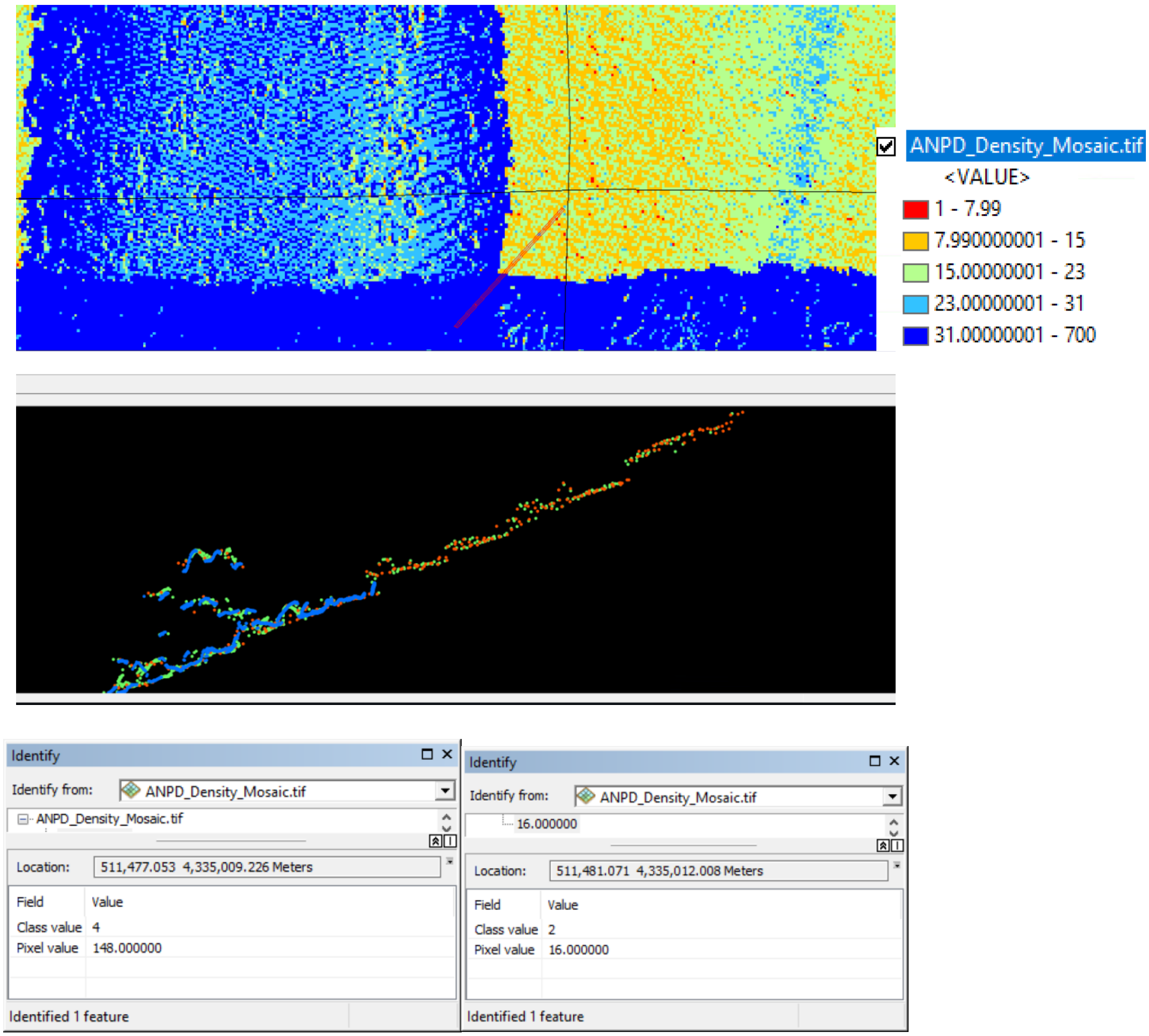


Figure 17. Top image is the density raster, middle image is the lidar point cloud profile colored by Point Source ID and bottom images are point counts from the density raster. The area on the left side of the profile has 3-4 swath coverages, and some pixels have >100 ppsm, whereas the right side of the profile only has 2 swath coverages and point densities are in the 8-23 ppsm range. As the profile shows, there are significantly higher numbers of returns in vegetation, which expand and solidify the "red" pixels in the SSIs.

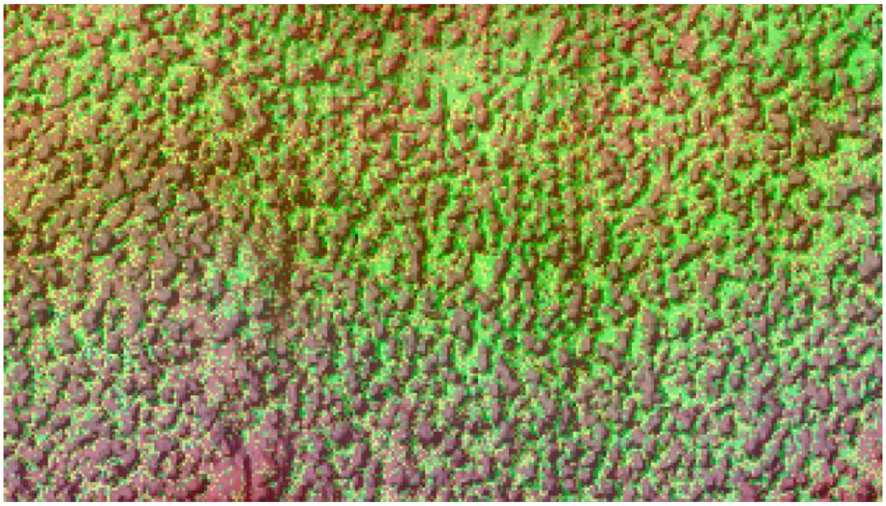


Figure 18. The SSIs (0-8cm green, 8-16cm yellow, >16cm red) are overlaid on the MSHR, illustrating alignment between vegetation in the MSHR and "red" pixels in the SSIs. This example is from an area identified by USGS for relative accuracy. Non-vegetated areas appear as green, corroborating the swath alignment verified in the lidar point cloud.

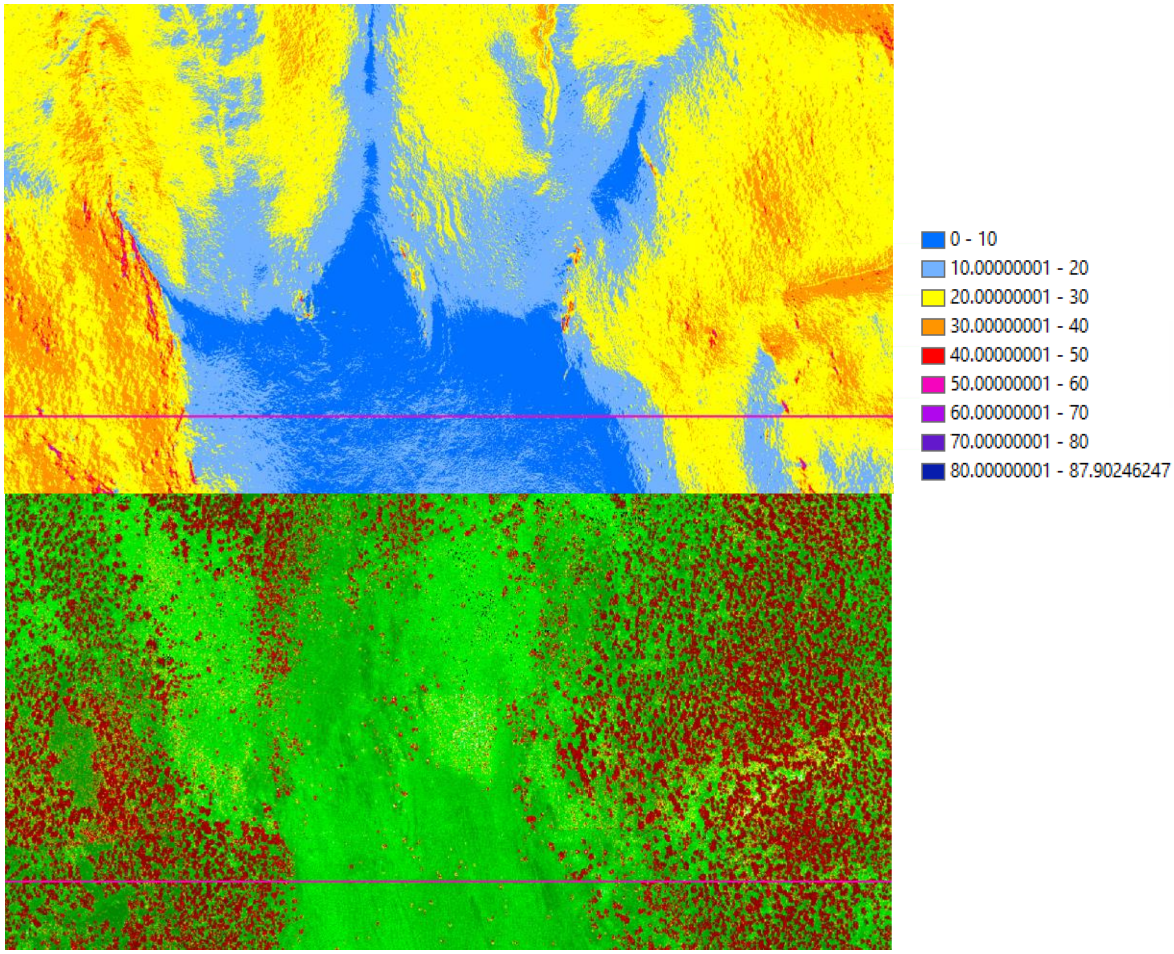


Figure 19. Top image shows a slope map, by degrees, for an area identified by USGS for relative accuracy and the bottom image shows the SSIs for the same location (0-8cm green, 8-16cm yellow, >16cm red). Flat (0-10 degrees), non-vegetated areas also align very well and appear green in the SSI.

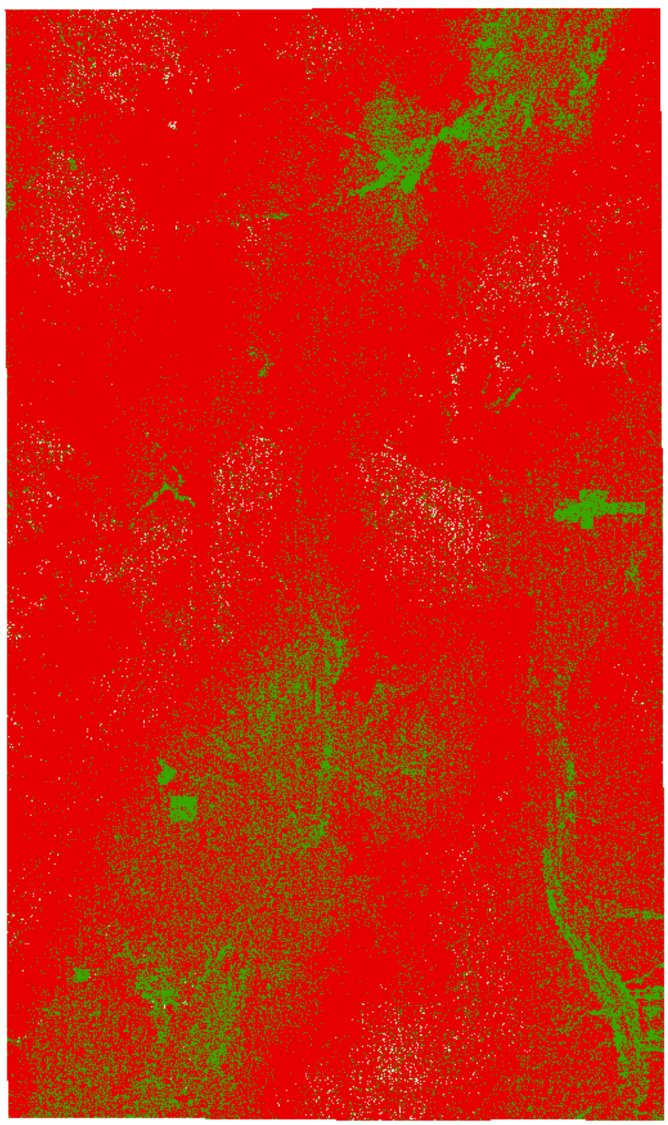
3.3.2 Intraswath Accuracy

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. Dewberry reviews the precision of the lidar dataset during multiple stages of production. Each review is performed by an initial reviewer and then reviewed by a second reviewer to verify the precision of the lidar meets expectations. Dewberry performs an intraswath accuracy review for each mission within 1-2 days of collection. The precision of the lidar dataset is then reviewed before calibration on the lidar dataset to ensure no systematic errors.

Dewberry uses a proprietary software to generate point statistics intraswath rasters. Swath data in non-overlap areas were assessed using only first returns in non-vegetated areas. To measure the precision of a lidar dataset, level or flat surfaces were assessed. If the lidar dataset is located in area with sloped or steep terrain, a slope raster will be used in conjunction with the intraswath raster to ensure only level or flat surfaces are being assessed. The intraswath raster is reviewed for any systematic intraswath errors that should be considered of concern. The images below show an example of the intraswath relative accuracy of WUID300260; this project meets intraswath relative accuracy specifications.

The intraswath rasters are symbolized by the following ranges:

- 0-6 cm: **Green**
- >6 cm: **Red**



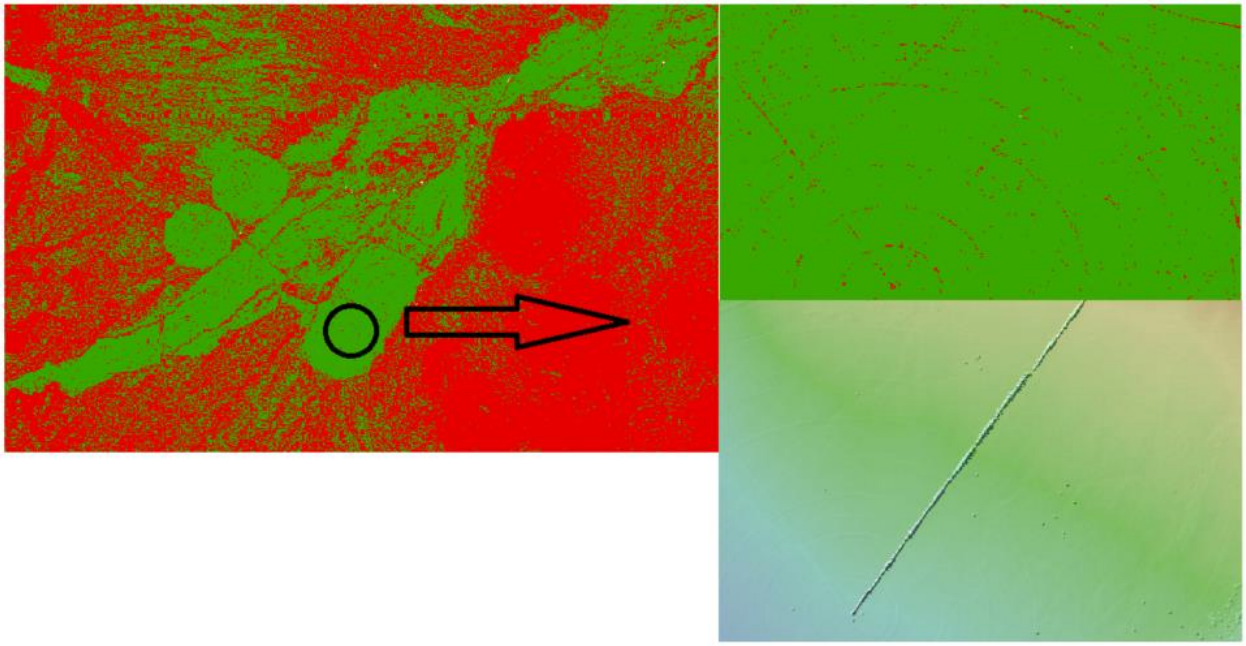


Figure 20. The top image shows the intraswath raster for the full project area; areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The left image shows a large portion of the dataset; flat, open areas are colored green as they are within 6 cm whereas sloped terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change. The right image is a close-up of a flat area, showing the intraswath raster and MSHR. With the exception of a few natural features, this open flat area is acceptable for repeatability testing. Intraswath relative accuracy passes specifications.

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 ~100' 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 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	No tidally influenced features are in this dataset so no tidal breaklines were collected.

	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.	Soft features were not applicable to this dataset so no soft feature 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	Pass

	intensity imagery, bare earth ground models, density models, slope models, and terrains.	
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	N/A
Topology	Features must not overlap or have gaps	Pass

	Features must not have unnecessary dangles or boundaries	
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 DEMs. LP360 uses TIN (Triangulated Irregular Network) as the interpolated surface method. A TIN divides a surface into a set of contiguous, non-overlapping, Delaunay triangles. The height of each triangle vertex interpolates together to construct the surface. Dewberry utilized 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 (0.5m) 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 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 .TIFF format. The swath separation images are symbolized by the following ranges:

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

6.2 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.

6.3 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.