ID Southern ID_2018_D19

Work Package: 183648
Work Units: 230906, and 230909

Report Produced for U.S. Geological Survey

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Task Order: D01-GPSC3 140G0219F0356-ID

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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 ID SouthernID_2018_D19 – WUIDs 230906 and 230909 of the project area.

Lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models were produced for the project area. Project components were formatted based on a tile grid with each tile covering an area 1,500 m by 1,500 m. A total of 54,482 tiles were produced for the project, providing approximately 42,120 sq. miles of coverage. A total of 2,846 tiles were produced for WUIDs 230906 and 230909, providing approximately 2,327 sq. miles of coverage. Within WUID 230906, tile number 12TVP095060 is not delivered due to no lidar points falling within the tile boundary, none of the derivative products were able to be created.

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.

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

Acquisition providers Aerial Surveys International (ASI), Aero-graphics (AGI), Axis Geospatial (AXIS), Eagle Mapping (EMI), Leading Edge Geomatics (LEG) and Quantum Spatial (NV5) completed lidar data acquisition for the project area, and Dewberry performed data calibration and processing for entire project area.

1.2 Project Area

The block area is shown in figure 1. WUIDs 230906 and 230909 contain 2,846 1,500 m by 1,500 m tiles. The project area tile grid contains 54,482 1,500 m by 1,500 m tiles.
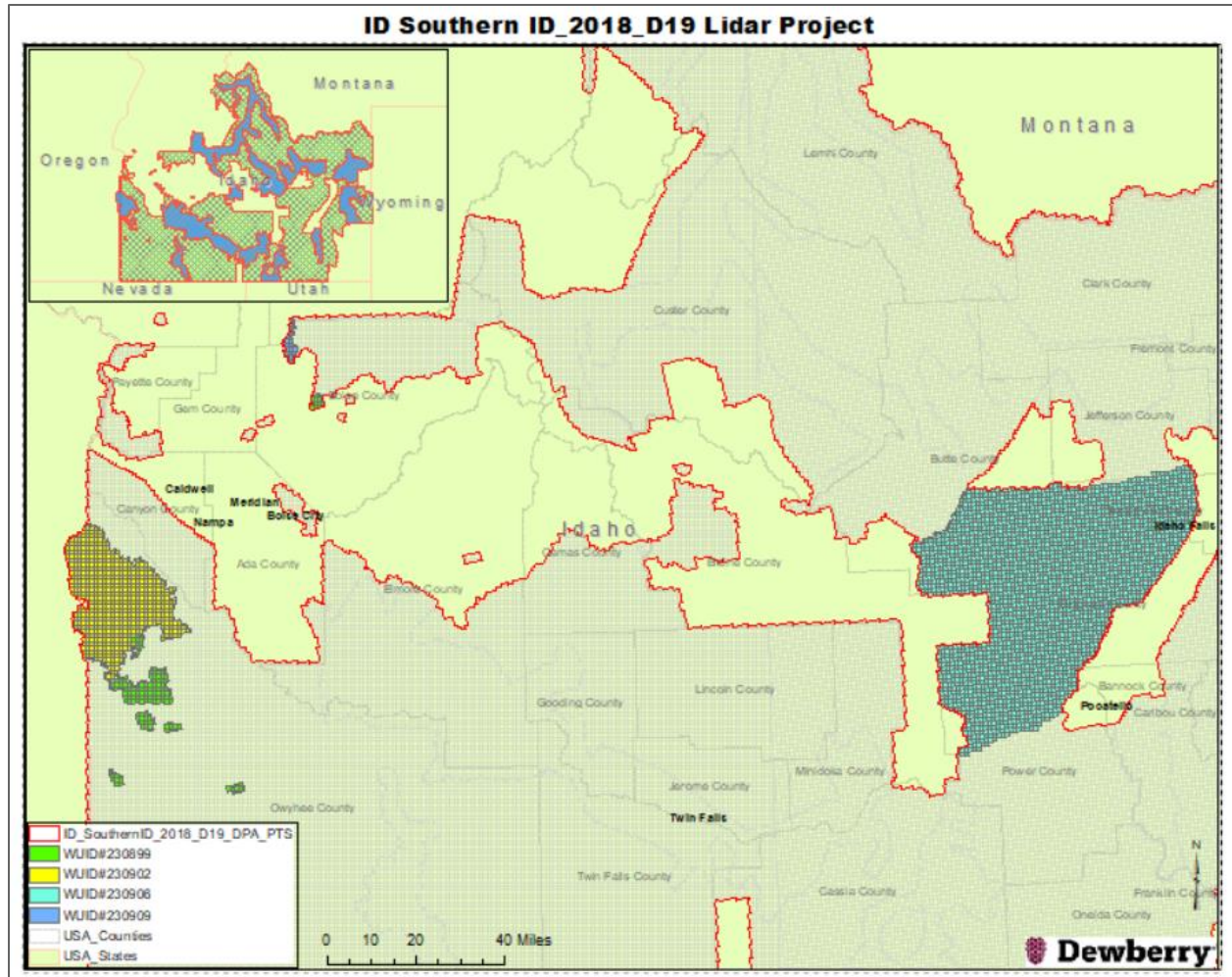
Figure 1. Project map and tile grid

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:	Geoid12B
Coordinate System:	UTM Zone 11N and 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)

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3. Intensity Images (tiled, 8-bit gray scale, GeoTIFF format)
4. Breakline Data (file GDB)
5. Bare Earth Surface (tiled raster DEM, GeoTIFF format)
6. Digital Surface Models (tiled Raster DSM, GeoTIFF format) (WUID 230909)
7. Swath Separation Images (tiled, GeoTIFF format)
8. SBET Shapefiles (WUID 230909)
9. Interswath Polygons
10. Intraswath Polygons
11. Metadata (XML)
12. Block Report

1.5 Dewberry Production Workflow Diagram

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

Lidar Project Production Workflow

Figure 2. Dewberry's Lidar Production Workflow Diagram

2. LIDAR ACQUISITION REPORT

Dewberry elected to subcontract the lidar acquisition activities to 6 Acquisition Providers ASI, AGI, AXIS, EMI, LEG and NV5. Acquisition Providers AGI and ASI were responsible for providing lidar acquisition, raw data conversion from sensors and delivery of lidar data files to Dewberry for these work units.

The lidar aerial acquisition for WUID 230906 was conducted between October 3, 2019 through November 3, 2019. WUID230909 was conducted between May 29, 2020 and May 30, 2020.
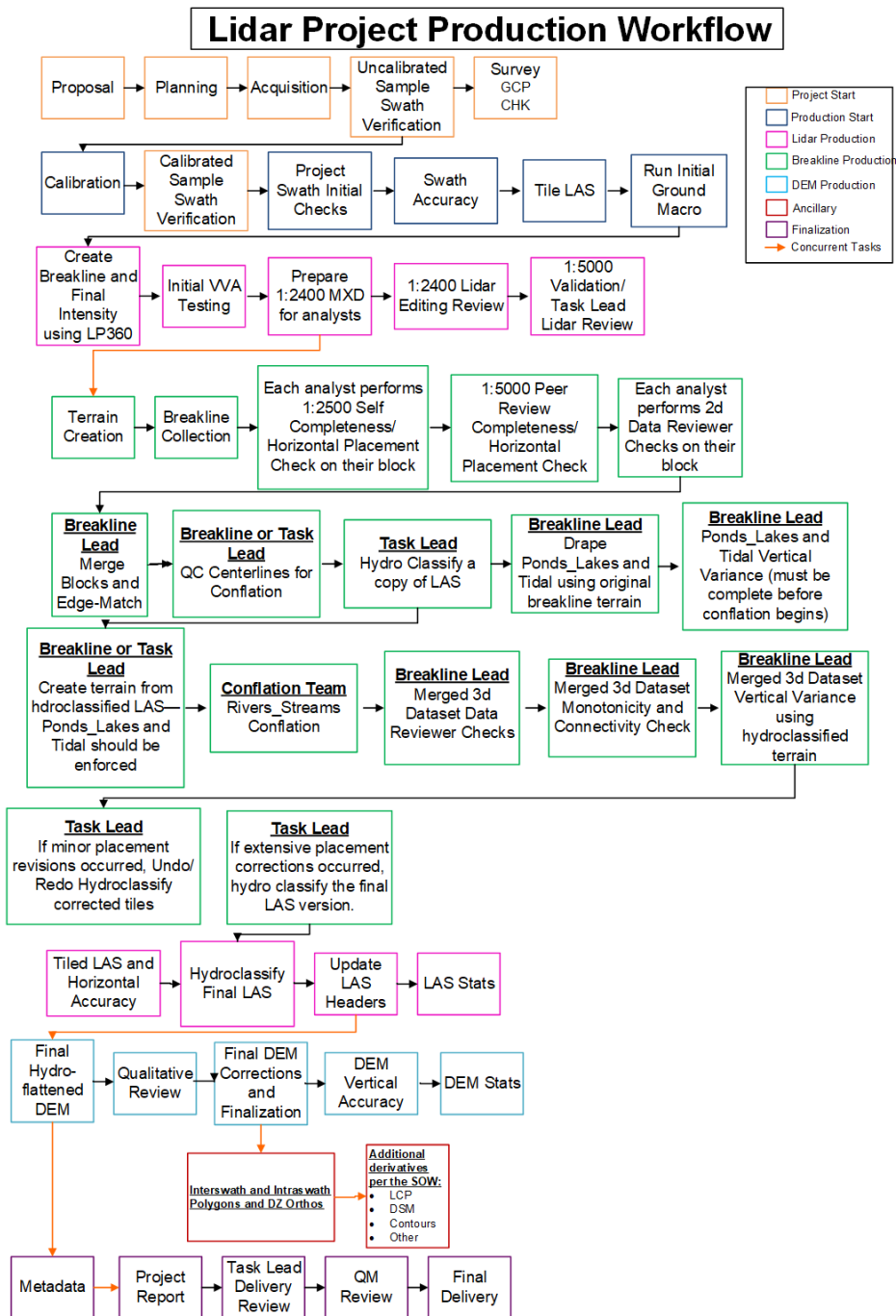
2.1 Lidar Acquisition Details

Acquisition Provider ASI lidar sensors are calibrated at a designated site located at the Boise International Airport, Idaho and are periodically checked and adjusted to minimize corrections at project sites.

Acquisition Provider Aero-Graphics lidar sensors are calibrated at a designated site located at the Salt Lake City, UT and are periodically checked and adjusted to minimize corrections at project sites.

Acquisition Providers planned 4075 passes (1977 Quality Level 1 and 2098 Quality Level 2) for the project area as a series of parallel flight lines with cross flight lines for the purposes of quality control. The flight plan included zigzag flight line collection to compensate for the drift commonly associated with onboard inertial measurement unit (IMU) systems. In order to reduce potential errors in the data attributable to flight planning, Acquisition Providers followed FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Survey.* The guidance includes the following minimum criteria:

- A digital flight line layout using respective sensor Mission Management flight design software for direct integration into the aircraft flight navigation system;
- Planned flight lines, flight line numbers, and coverage area;
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables;
- Investigation of local restrictions related to air space and any controlled areas so that required permissions can be obtained in a timely manner with respect to project schedule; and
- Filed flight plans as required by local Air Traffic Control (ATC) prior to each mission.

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

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

2.2 Lidar System Parameters

Acquisition Provider ASI operated Cessna 310 (twin-piston) - N7516Q and Cessna T206 N989DE outfitted with an Optech Galaxy Prime lidar system during data collection. Acquisition Provider AGI operated Cessna 310 (twin-piston) - N310WJ and Cessna T206 N7269T outfitted with an Optech Galaxy Prime lidar system during data collection. Tables 1 and 2 detail the lidar system parameters used during acquisition for this project.

Table 1. Acquisition Provider ASI lidar system parameters

Parameter	Value – QL1
System	Galaxy – PRIME
Altitude (m above ground level)	1380
Nominal flight speed (kts)	150
Scanner pulse rate (kHz)	650
Scan frequency (Hz)	85
Pulse duration of the scanner (ns)	3
Pulse width of the scanner (m)	1
Central wavelength of the sensor laser (nm)	1064
Multiple pulses in the air	Yes
Beam divergence (mrad)	</= 0.5
Swath width (m)	740
Nominal swath width on the ground (m)	740
Swath overlap (%)	30
Total sensor scan angle (degrees)	30
Computed down track spacing per beam (m)	0.24
Computed cross track Spacing per beam (m)	0.45
Nominal pulse spacing (NPS) (single swath) (m)	0.33
Nominal Pulse Density (NPD) (single swath) (points per sq m)	9.09
Maximum Number of Returns per Pulse	7

Table 1. Acquisition Provider AGI lidar system parameters

Parameter	Value – QL2, 206	Value – QL2, 310
System	Galaxy – PRIME	Galaxy – PRIME
Altitude (m above ground level)	1600	1600
Nominal flight speed (kts)	120	170
Scanner pulse rate (kHz)	300	300
Scan frequency (Hz)	55.6	69.5
Pulse duration of the scanner (ns)	4	4
Pulse width of the scanner (m)	1.2	1.2
Central wavelength of the sensor laser (nm)	1064	1064
Multiple pulses in the air	Yes	Yes
Beam divergence (mrad)	</= 0.5	</= 0.5
Swath width (m)	1358	1165
Nominal swath width on the ground (m)	1358	1165
Swath overlap (%)	30	30
Total sensor scan angle (degrees)	46	40
Computed down track spacing per beam (m)	0.56	0.63
Computed cross track Spacing per beam (m)	0.56	0.63

Nominal pulse spacing (NPS) (single swath) (m)	0.55	0.63
Nominal Pulse Density (NPD) (single swath) (points per sq m)	3.24	2.53
Maximum Number of Returns per Pulse	7	7

2.3 Acquisition Status Report and Flight Lines

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The acquisition manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the lidar sensor, the position dilution of precision (PDOP), and performed the first quality control review during acquisition. The flight crew reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 3 shows the combined flight line trajectories.

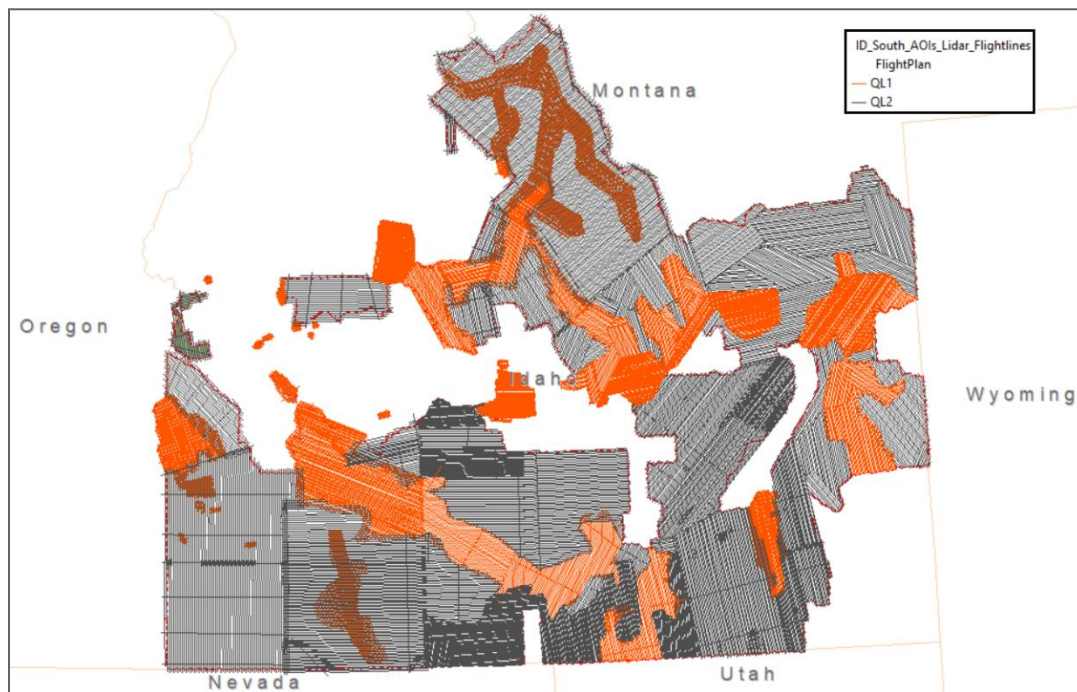**Figure 3. Trajectories of flight lines flown by Acquisition Providers**

2.4 Acquisition Static Control

The project area consists of limited number of operational CORS base stations operating at 1 Hz and many areas are not accessible by road to set up base stations. As a result, base stations were not setup to meet the 20-mile baseline requirement. Instead, Trimble PP-RTX solution for GPS/IMU data post-processing approach

was utilized during the lidar acquisition and adjustment of trajectories due to the lack of CORS network. PP-RTX uses Applanix POSPac MMS software leveraging near real- time atmospheric models from Trimble's extensive worldwide network of continuously operating base stations to produce highly accurate trajectories. Detailed parameters information is provided in Appendix-A, B, and C GPS Processing Reports.

2.5 Airborne Kinematic Control

Airborne GPS data was processed using the PosPac kinematic On-The-Fly (OTF) software suite. Flights were flown with a minimum of six satellites in view (13° above the horizon) and with PDOP less than 4.

The GPS average residuals for all flights were 3 cm or better, with no residuals greater than 10 cm recorded.

GPS processing reports for each mission are included in the Appendix A, B and C attachment.

2.6 Generation and Calibration of Raw Lidar Data

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

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

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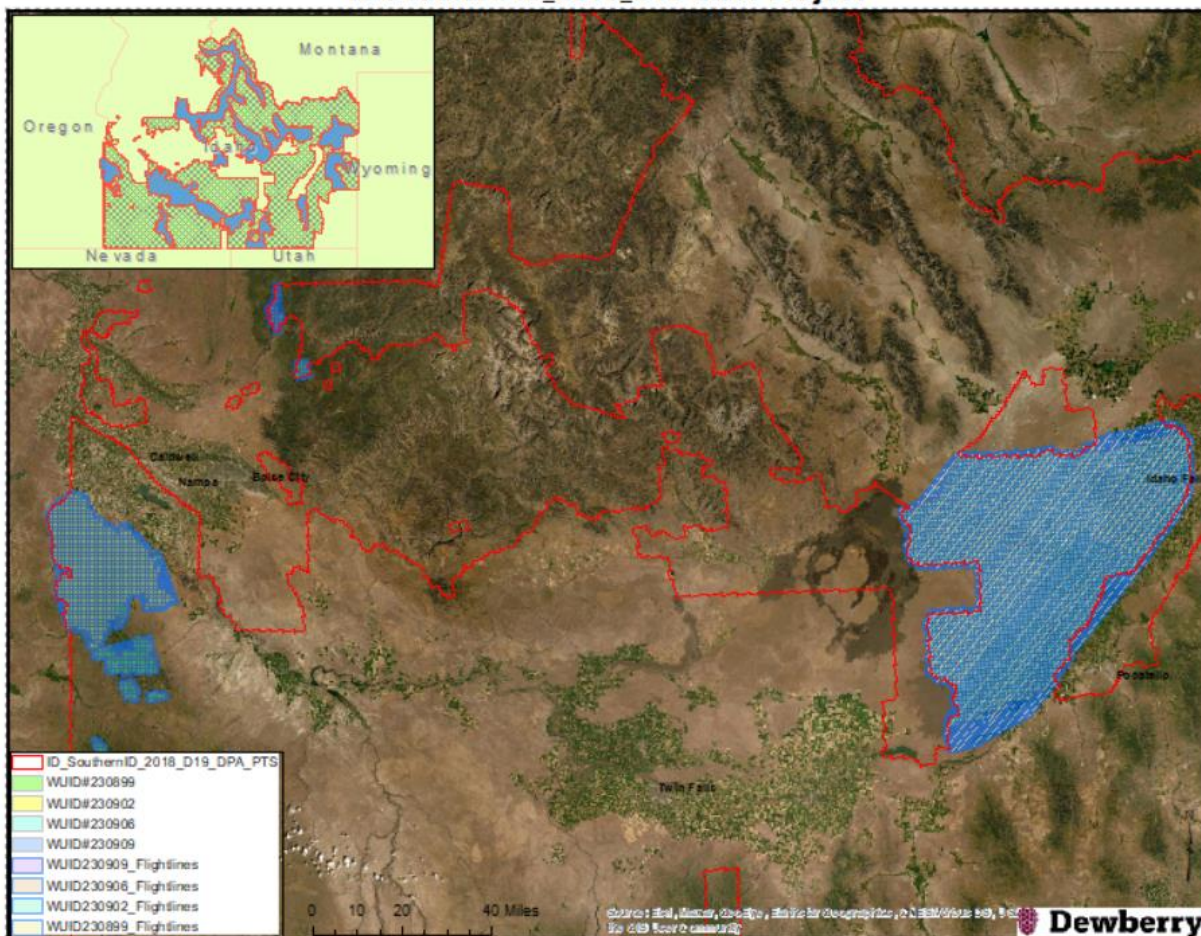
Figure 4. Lidar swath output showing complete coverage.

2.6.1 Boresight and Relative accuracy

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

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

The following relative accuracy specifications were used for this project:

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

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

Figure 5. Profile views showing results of roll and pitch adjustments.
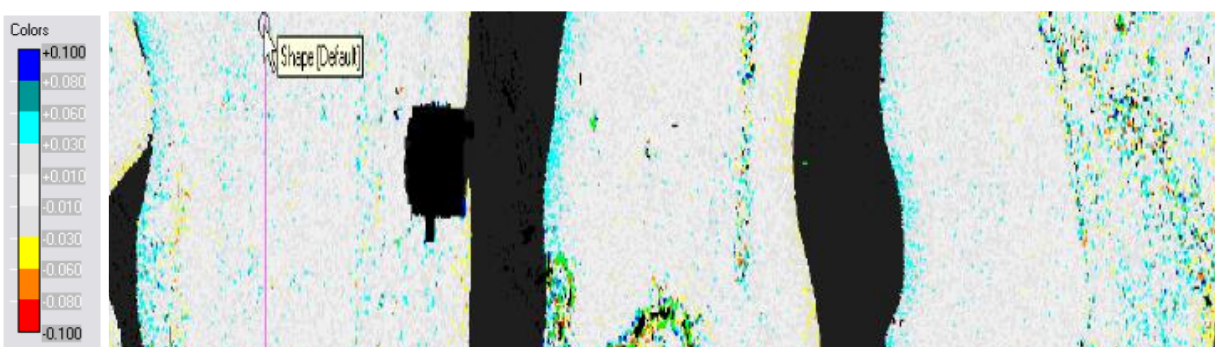
Figure 6. QC block colored by vertical difference between swaths to check accuracy at swath edges.

2.7 Final Calibration Verification

Dewberry conducted the survey for 42 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 42 GCPs were available to use as control in case the swath data exhibited any biases which would need to be adjusted or removed. The coordinates of all GCPs are provided in table 3 and the accuracy results from testing the calibrated swath data against the GCPs is provided in table 4; no further adjustments to the swath data were required based on the accuracy results of the GCPs.

Table 3. Surveyed ground control points (GCPs).

Point ID	NAD83 (2011) UTM Zone 11N		NAVD88 (Geoid 12B)	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
GCP-29	510923.716	4806054.404	1187.758	1187.740
GCP-30	497919.353	4788717.734	1266.253	1266.220
GCP-31	499224.09	4823177.763	761.547	761.635
GCP-32	499991.767	4803276.366	1316.538	1316.540
GCP-33	496516.59	4777013.934	1414.482	1414.530

Point ID	NAD83 (2011) UTM Zone 12N		NAVD88 (Geoid 12B)	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
GCP-35	521746.139	4762670.814	1885.785	1885.750
GCP-40	551470.408	4728710.253	1865.64	1865.600
GCP-56	501252.857	4794197.724	1324.935	1324.930
GCP-57	502418.564	4796775.139	1308.167	1308.180
GCP-58	506827.009	4802480.43	1217.572	1217.600
GCP-84	507162.182	4731878.975	2367.6	2367.530
GCP-181	335948.363	4745967.728	1393.851	1393.910
GCP-182	322349.742	4755104.602	1529.79	1529.880
GCP-183	335839.285	4758025.503	1468.684	1468.670
GCP-193	347228.272	4747305.173	1340.673	1340.750
GCP-194	349690.488	4755493.991	1342.777	1342.830
GCP-195	352683.176	4768289.768	1352.648	1352.680
GCP-196	328552.794	4768332.533	1595.841	1595.890
GCP-197	349489.586	4776462.795	1398.46	1398.470
GCP-266	369815.845	4774371.072	1354.255	1354.280
GCP-267	339985.538	4780032.562	1476.486	1476.460
GCP-269	366909.636	4766670.195	1335.743	1335.850
GCP-270	375325.753	4783867.093	1360.547	1360.560
GCP-272	359333.481	4784231.884	1387.715	1387.690
GCP-273	361498.950	4820908.462	1612.825	1613.080
GCP-276	388382.719	4786658.453	1369.928	1369.960
GCP-277	381499.943	4789915.586	1369.85	1369.860
GCP-279	352164.478	4791674.825	1454.062	1453.850
GCP-280	341128.835	4800969.578	1582.83	1582.990
GCP-281	324431.779	4796382.358	1573.908	1574.040
GCP-282	323871.329	4810678.411	1593.113	1593.320
GCP-283	353642.717	4811413.922	1529.644	1529.820
GCP-284	375227.566	4802752.282	1439.421	1439.450
GCP-285	361194.288	4800219.514	1453.266	1453.120
GCP-287	333971.405	4825749.162	1550.596	1550.570
GCP-289	392510.415	4799579.846	1420.558	1420.640
GCP-291	370792.543	4823585.198	1640.889	1640.630
GCP-292	342669.709	4819400.298	1508.93	1508.850
GCP-294	411055.992	4824365.835	1460.238	1460.230

GCP-295	394801.890	4823203.155	1545.603	1545.560
GCP-296	405220.060	4803323.637	1402.931	1402.940
GCP-297	412764.021	4816759.744	1438.648	1438.690

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

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

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec=0.195 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
GCP	42	0.097	0.189	0.019	0.013	-0.317	0.096	-0.259	0.255	1.900

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 5 – Post calibration and initial processing data verification steps.

Requirement	Description of Deliverables	Additional Comments
Non-vegetated vertical accuracy (NVA) of the swath data meet required specifications of 19.6 cm at the 95% confidence level based on RMSEz (10 cm) x 1.96	The swath NVA was tested and passed specifications.	None
Quality Level -1: The NPD/NPS (or Aggregate NPD/Aggregate NPS) meets required specification of 8 ppsm	The average calculated (A)NPD of this project is 27.8 ppsm. Density raster visualization also passed specifications.	None

Requirement	Description of Deliverables	Additional Comments
or 0.33 m NPS. The NPD (ANPD) is calculated from first return points only.		
Quality Level -2: The NPD/NPS (or Aggregate NPD/Aggregate NPS) meets required specification of 2 ppsm or 0.7 m NPS. The NPD (ANPD) is calculated from first return points only.	The average calculated (A)NPD of this project is 7.5 ppsm. Density raster visualization also passed specifications.	None
Spatial Distribution requires 90% of the project grid, calculated with cell sizes of 2*NPS, to contain at least one lidar point. This is calculated from first return points only.	98% of cells (2*NPS cell size) had at least 1 lidar point within the cell.	None
Within swath (Intra-swath or hard surface repeatability) relative accuracy must meet ≤ 6 cm maximum difference	Within swath relative accuracy passed specification.	None
Between swath (Inter-swath or swath overlap) relative accuracy must meet 8 cm RMSDz/16 cm maximum difference. These thresholds are tested in open, flat terrain.	Between swath relative accuracy passed specification, calculated from single return lidar points.	None
Horizontal Calibration-There should not be horizontal offsets (or vertical offsets) between overlapping swaths that would negatively impact the accuracy of the data or the overall usability of the data. Assessments made on rooftops or other hard planar surfaces where available.	Horizontal calibration met project requirements.	None
Ground Penetration-The missions were planned appropriately to meet project density requirements and achieve as much ground penetration beneath vegetation as possible	Ground penetration beneath vegetation was acceptable.	None
Sensor Anomalies-The sensor should perform as expected without anomalies that negatively impact the usability of the data, including issues such as excessive sensor noise and intensity gain or range-walk issues	No sensor anomalies were present.	None
Edge of Flight line bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath	Edge of Flight line bits were populated correctly	None

Requirement	Description of Deliverables	Additional Comments
acquired, regardless of which type of sensor is used		
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

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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. These work units were collected using Optech Galaxy sensors. These sensors are equipped with SwathTRAK to make FOV dynamic based on terrain, so withheld points may not be present in areas acquired using Galaxy sensors.

After manual classification, class 7 and class 18 were flagged with the withheld bit. Then, 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	No unacceptable voids were identified in this dataset

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

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

Category	Editing Guideline	Additional Comments
	ensures that any ridges remaining after editing and QA/QC are within project relative accuracy specifications.	
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 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.	No Laser Shadowing is present in the 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 and 12, meters in WKT format	Pass
Vertical Coordinate Reference System	NAVD88 (Geoid 12B), 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 22: Temporal Exclusion	Pass
Withheld Points	Withheld bits set	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.

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.	None
Tidal	Breaklines are collected as polygon features depicting water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any significant water body that is affected by tidal variations. Tidal variations over the course of collection, and between different collections, can result in discontinuities along shorelines. This is considered normal and should be retained. Variations in water surface elevation resulting from tidal variations during collection should not be removed or adjusted. Features should be captured as a dual line with	No tidally influenced features are in this dataset so no tidal breaklines were collected.

	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 feature.	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 9 – Breakline verification steps.

Parameter	Requirement	Pass/Fail
Collection	Collect breaklines according to project specifications using lidar-derived data, including intensity imagery, bare earth ground models, density models, slope models, and terrains.	Pass
Placement	Place the breakline inside or seaward of the shoreline by 1-2 x NPS in areas of heavy vegetation or where the exact shoreline is hard to delineate.	Pass
Completeness	Perform a completeness check, breakline variance check, and all automated checks on each block before designating that block complete.	Pass

Merged Dataset	Merge completed production blocks. Ensure correct horizontal and vertical snapping between all production blocks. Confirm correct horizontal placement of breaklines.	Pass
Merged Dataset Completeness Check	Check entire dataset for features that were not captured but that meet baseline specifications or other metrics for capture. Features should be collected consistently across tile boundaries.	Pass
Edge Match	Ensure breaklines are correctly edge-matched to adjoining datasets. Check completion type, attribute coding, and horizontal placement.	Pass
Vertical Consistency	Waterbodies shall maintain a constant elevation at all vertices Vertices should not have excessive min or max z-values when compared to adjacent vertices Intersecting features should maintain connectivity in X, Y, Z planes Dual line streams shall have the same elevation at any given cross-section of the stream	Pass
Vertical Variance	Using a terrain created from lidar ground (class 2, 8, and 20 as applicable) and water points (class 9) to compare breakline Z values to interpolated lidar elevations to ensure there are no unacceptable discrepancies.	Pass
Monotonicity	Dual line streams generally maintain a consistent down-hill flow and collected in the direction of flow – some natural exceptions are allowed	Pass
Topology	Features must not overlap or have gaps Features must not have unnecessary dangles or boundaries	Pass
Hydro-classification	The water classification routine selected ground points within the breakline polygons and automatically classified them as class 9, water. During this water classification routine, points that were within 1 NPS distance or less of the hydrographic feature boundaries were moved to class 20, ignored ground, to avoid hydroflattening artifacts along the edges of hydro features.	Pass
Hydro-flattening	Perform hydro-flattening and hydro-enforcement checks. Tidal waters should preserve as much ground as possible and can be non-monotonic.	Pass

5. DEM PRODUCTION & QUALITATIVE ASSESSMENT

5.1 DEM Production Methodology

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

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

5.2 DEM Qualitative Assessment

Dewberry performed a comprehensive qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. Dewberry conducted the review in ArcGIS using a hillshade model of the full dataset with a partially transparent colorized elevation model overlaid. The tiled DEMs were reviewed at a scale of 1:5,000 to look for artifacts caused by the DEM generation process and to verify correct and complete hydro-flattening and hydro-enforcement. Upon correction of any outstanding issues, the DEM data was loaded into Global Mapper for its second review and to verify corrections.

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

Table 10 – DEM verification steps.

Parameter	Requirement	Pass/Fail
Digital Elevation Model (DEM) of bare-earth w/ breaklines	DEM of bare-earth terrain surface (0.5/1m) is created from lidar ground points and breaklines. DEMs are tiled without overlaps or gaps, show no edge artifact or mismatch, DEM deliverables are .tif format	Pass
DEM Compression	DEMs are not compressed	Pass
DEM NoData	Areas outside survey boundary are coded as NoData. Internal voids (e.g., open water areas) are coded as NoData (-999999)	Pass
Hydro-flattening	Ensure DEMs were hydro-flattened or hydro-enforced as required by project specifications	Pass
Monotonicity	Verify monotonicity of all linear hydrographic features	Pass

Breakline Elevations	Ensure adherence of breaklines to bare-earth surface elevations, i.e., no floating or digging hydrographic feature	Pass
Bridge Removal	Verify removal of bridges from bare-earth DEMs and no saddles present	Pass
DEM Artifacts	Correct any issues in the lidar classification that were visually expressed in the DEMs. Reprocess the DEMs following lidar corrections.	Pass
DEM Tiles	Split the DEMs into tiles according to the project tiling scheme	Pass
DEM Formatting	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression is not applied to the tiled DEMs	Pass
DEM Extents	Load all tiled DEMs into Global Mapper and verify complete coverage within the (buffered) project boundary and verify that no tiles are corrupt	Pass

6. DERIVATIVE LIDAR PRODUCTS

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

6.1 Swath Separation Images

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

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

6.2 Interswath and Intraswath Polygons

6.2.1   Interswath Accuracy

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

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

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

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

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

6.3 DSM

DSMs were created for WUID 230909. The creation of first return DSMs followed a similar workflow to the bare-earth DEMs, except that the first returns from all point classes except for noise (classes 7 and 18) and points flagged as withheld were used to create the raster and breaklines were not used to hydro-flatten or hydro-enforce the surface. The review of the DSMs included looking for spikes, divots, noise points not properly classified to the noise classes, other lidar misclassifications, and processing artifacts.

6.4 Intensity Images

The lidar data for WUID 230909 were collected using two sensors. The intensity values between the two sensors were scaled differently in such a way that it caused the intensity to look incorrect when viewed as a raster mosaic. The intensity scaling is consistent when viewed tile-by-tile within each acquisition provider's area.
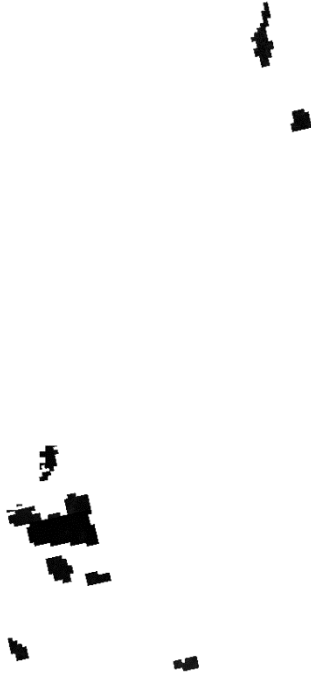
Figure 7. Intensity raster mosaic for WUIDs 230899 and 230909.

11TNJ700870

Figure 8. A closer look at Figure 7, showing the intensity values are scaled properly.

6.5 Contours

Dewberry created 1-meter contours for WUID 230909. The contour attributes include designation as either Index or Intermediate and an elevation value. The contours are also 3D, storing elevation values within their internal geometry. Some smoothing was applied to the contours to enhance their aesthetic quality. This task order required auto/machine generated contours so contours were reviewed for completeness and correct attribution but were not reviewed or edited for correct topology or correct behavior in regards to hydrographic crossings. Because of the density of the contours and their file size, the contours were tiled to the project tiles. The contour tiles are delivered in one file geodatabase (GDB) and are named according to the final project tile grid.

6.6 SBET

SBETs were created for WUID 230909. The position of the aircraft trajectory is created by combining aircraft attitude (roll, pitch and heading) recorded at 200 Hz with and differentially corrected GPS position at 1 Hz using Applanix POSPac MMS version 8.7. The processing output of a smoothed best estimate of trajectory (SBET) is generated by applying offsets to a common reference point to the processed kinematic solution.