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# ID Southern ID_2018_D19 WUID 300277

## Report Produced for U.S. Geological Survey

USGS Contract: G16PC00020

Task Order: D01-GPSC3 140G0219F0356

Report Date: September 6, 2023

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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 WUID 300277 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 were produced for the project, providing approximately 42,120 sq. miles of coverage. A total of one (1) tile was produced for WUID 300277, providing approximately 0.87 sq. miles of coverage. Dewberry identified a void covering a portion of one tile of the Southern Idaho QL1 data during project production. This tile was withheld from delivery, pending re-flights of the affected area. Dewberry re-flew the affected area in June 2023 to provide full data coverage for the Southern Idaho project AOI, and this tile is included in WUID 300277.

## 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 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.

Dewberry and Leading Edge Geomatics (LEG) completed lidar data acquisition, and Dewberry performed data calibration and processing for entire project area.

## 1.2 Project Area

The work unit area is shown in figure 1. WUID 300277 contains one 1,500 m by 1,500 m tile. The project area tile grid contains 54,482 1,500 m by 1,500 m tiles.

**ID Southern ID_2018_D19 Lidar Project**

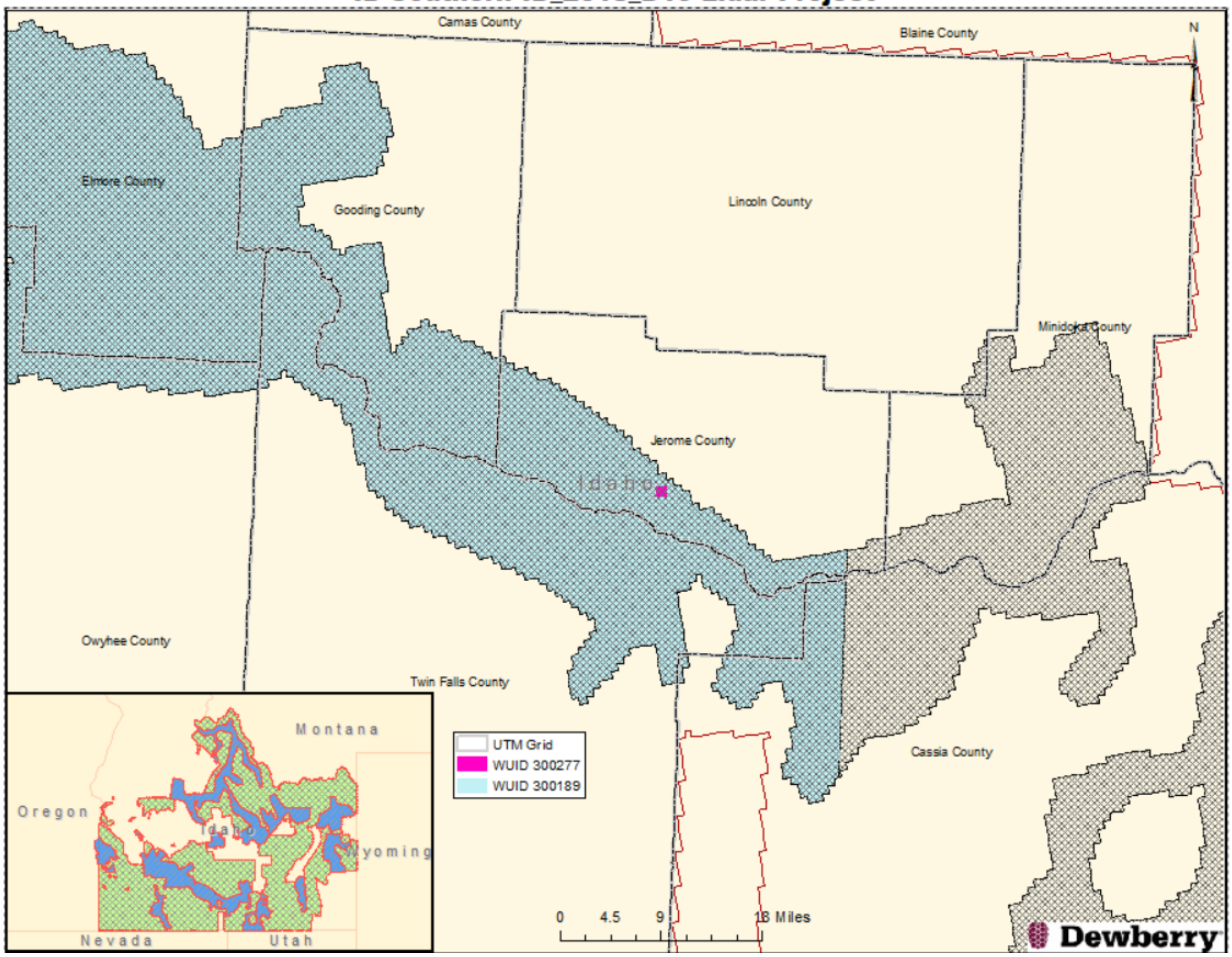


**Figure 1. Project map and tile grid**

## 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 |
| **Horizontal Units:** | Meters |
| **Vertical Units:** | Meters |

## 1.4 Project Deliverables

The deliverables for the project are as follows:

1. Project Extents (Esri SHP)

2. Classified Point Cloud (tiled LAS)
3. Intensity Images (tiled, 8-bit gray scale, GeoTIFF format)
4. Bare Earth Surface (tiled raster DEM, GeoTIFF format)
5. Swath Separation Images
6. Metadata (XML)
7. Work Unit Report
8. Flightline Extents GDB
9. Maximum Surface Height Rasters (tiled raster MSHRs, GeoTIFF format)

## 1.5 Dewberry Production Workflow Diagram

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

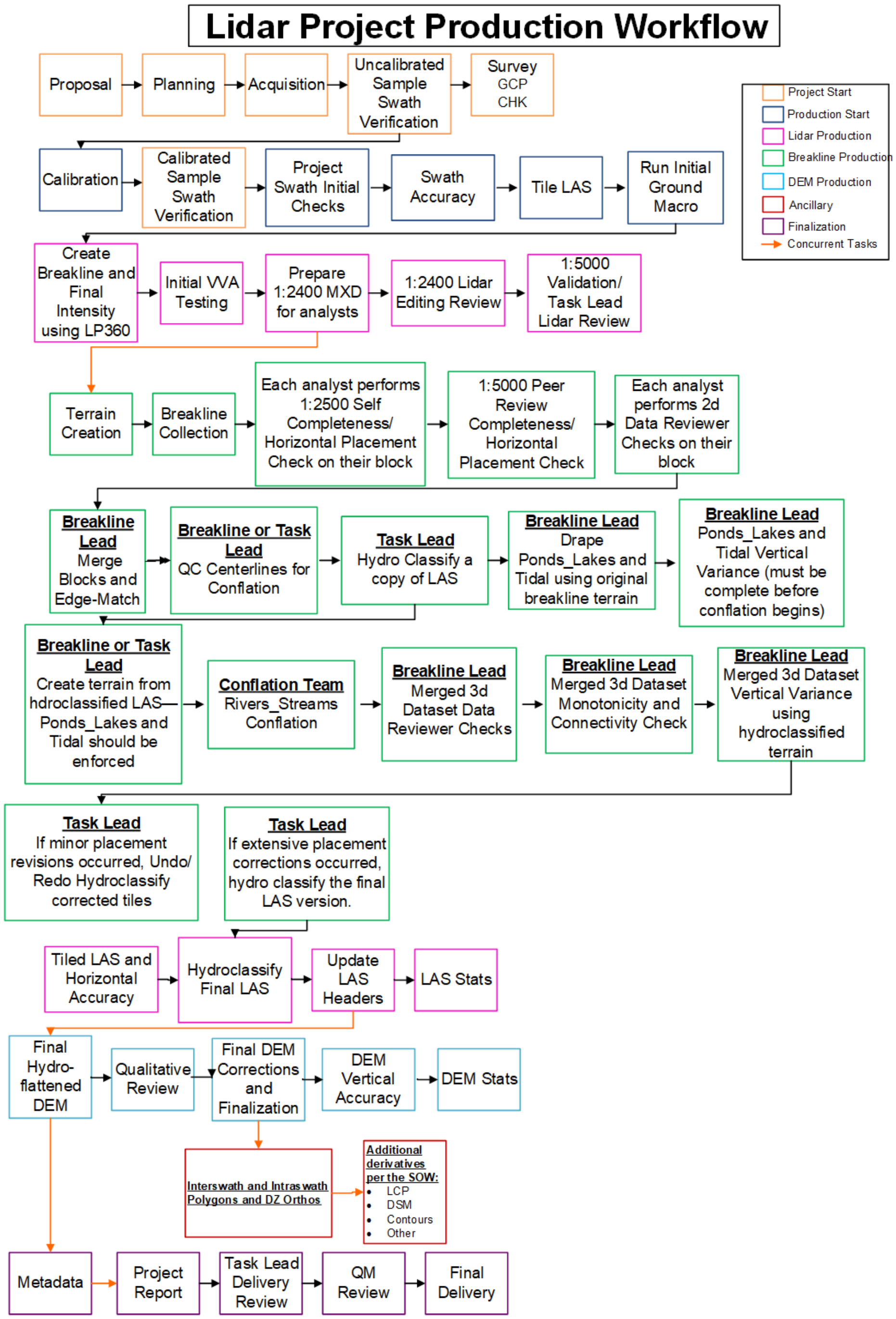


**Figure 2. Dewberry's Lidar Production Workflow Diagram**

# 2. LIDAR ACQUISITION REPORT

Dewberry and LEG were responsible for lidar acquisition, raw data conversion from sensors, and delivery of lidar data files for WUID 300277.

## 2.1 Acquisition Extents

The figure below shows flightline vectors by lift.

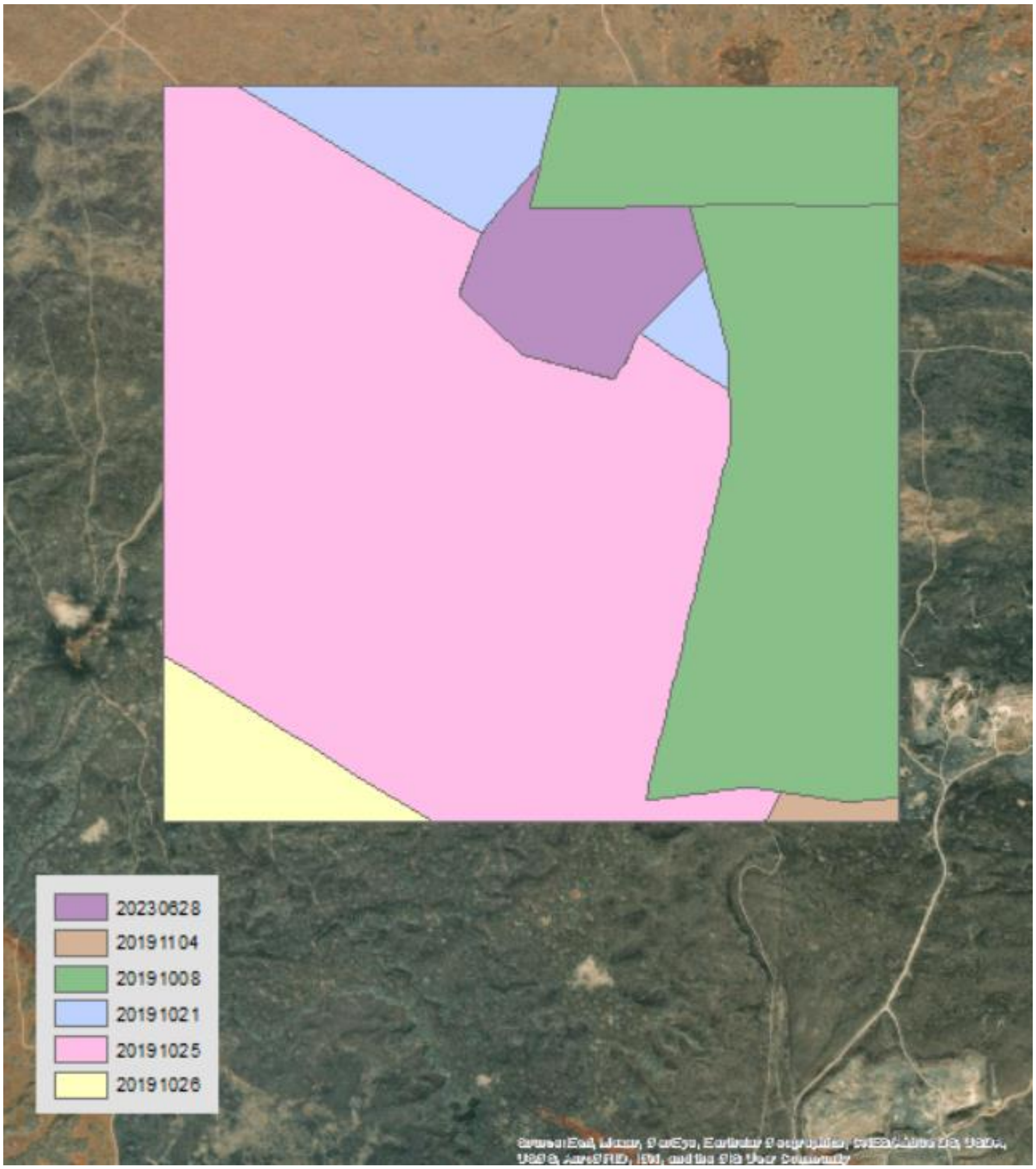


Figure 3. WUID 300277 swaths

## 2.2 Acquisition Summary

Dewberry and LEG were responsible for providing lidar acquisition, raw data conversion from sensors and delivery of lidar data files for WUID 300277. LEG acquired QL1 lidar data using a Riegl VQ1560i lidar sensor, and Dewberry used a Riegl VQ-1560II-S lidar sensor by monitoring suitable ground and weather conditions according to 3DEP lidar base specifications.

LEG and Dewberry planned eight passes over WUID 300277 for Quality Level 1 data acquisition as a series of parallel flight lines with cross flight lines for the purposes of quality control. LEG planned six passes and Dewberry planned two. 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 Riegl RiParameter, and Topoflight Mission Planner flight design software for direct integration into the aircraft flight navigation system;
- Planned flight lines, flight line numbers, and coverage area;
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables;
- Investigation of local restrictions related to air space and any controlled areas so that required permissions can be obtained in a timely manner with respect to project schedule; and
- Filed flight plans as required by local Air Traffic Control (ATC) prior to each mission.

LEG and Dewberry monitored weather and atmospheric conditions and conducted lidar missions only when no conditions existed below the sensor that would affect the collection of data. LEG and Dewberry accessed reliable weather sites and indicators (webcams) to establish the highest probability for successful data acquisition.

## 2.3 Sensor Calibration and Boresight

Prior to the ID_SouthernID project acquisition, LEG completed a sensor boresight on 10/07/19 in Salt Lake City, UT and Dewberry completed a sensor boresight in Apopka, Fl on 10/05/2022. 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 Riegl RiProcess. The boresight was calibrated and then analyzed. All deemed necessary corrections are then applied to the senor orientation internal files.

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

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

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

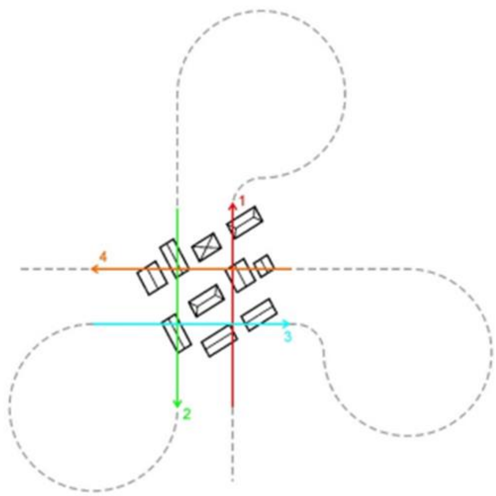


**Figure 4. A typical calibration and boresight flight plan where above ground features are acquired from all four cardinal directions, any offsets of the above ground features between overlapping and other directional flight lines are analyzed, and corrections are applied as necessary to ensure proper 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 WUID 300277. The data for WUID 300277 were acquired in Albers Equal Area and reprojected to NAD83 (2011) UTM Zone 11 for the final project deliverables.

**Table 1. Lidar acquisition details**

| Parameter | Value |
|---|---|
| Number of Flight lines | 8 |
| Approximate Area | 0.87 sq. miles |
| Acquisition Dates WUID 300277 | October 8, 2019 – June 28, 2023 |
| Horizontal Datum | North American Datum of 1983 (NAD83) |
| Vertical Datum | North American Vertical Datum of 1988 (NAVD88) |
| Geoid Model | Geoid12B |
| Coordinate Reference System | Albers Equal Area |
| Horizontal Units | Meters |
| Vertical Units | Meters |
| Kinematic Solution Processing Software: | Applanix Pospac |
| Point Cloud Generation Software | Riegl RiProcess |
| Calibration Software | BayesMap StripAlign |

## 2.5 Lidar System parameters

Acquisition Provider LEG operated a Piper Aztec outfitted with a Riegl VQ1560i lidar system during data collection, and Dewberry operated a Cessna 208 Caravan outfitted with a Riegl VQ-1560II-S lidar system. Table 2 details the lidar system parameters used during acquisition for WUID 300277.

**Table 2. Dewberry and LEG lidar system parameters.**

| Parameter | Value – LEG QL1 | Value – Dewberry QL1 |
|---|---|---|
| System | VQ1560i | VQ1560II-S |
| Altitude (m above ground level) | 1200 | 1836 |
| Nominal flight speed (kts) | 130 | 140 |
| Scanner pulse rate (kHz) | 1000 | 2690 |
| Scan frequency (Hz) | 180 | 312 |
| Pulse duration of the scanner (ns) | 3 | 3 |
| Pulse width of the scanner (m) | 0.8994 | 0.9 |
| Central wavelength of the sensor laser (nm) | 1064 | 1064 |
| Multiple pulses in the air | Yes | Yes |
| Beam divergence (mrad) | </= 0.5 | 0.17 |
| Swath width (m) | 1064 | 2057 |
| Nominal swath width on the ground (m) | 1330 | 2057 |
| Swath overlap (%) | 20 | 25 |
| Total sensor scan angle (degrees) | 58 | 58.5 |
| Computed down track spacing per beam (m) | 0.38 | 0.45 |
| Computed cross track Spacing per beam (m) | 0.42 | 0.37 |
| Nominal pulse spacing (NPS) (single swath) (m) | 0.33 | 0.32 |
| Nominal Pulse Density (NPD) (single swath) (points per sq m) | 9.0 | 10 |
| Maximum Number of Returns per Pulse | unlimited | 7 |

## 2.6 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 Appendices A and B: GPS Processing Reports.

## 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.

Appendices A and B contain 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 | Geoid12B |
| Coordinate Reference System | Albers Equal Area |
| Horizontal Units | Meters |
| Vertical Units | Meters |

## 2.8 Calibration Process (Project Mission Calibration)

Lidar mission flight trajectories were combined with raw point files in Riegl RiProcess. 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.

## 2.9 Final Calibration Verification

No GCPs fall within WUID 300277. A full list of GCPs used for accuracy testing is included in the GCP Survey Report provided with project deliverables.

# 3. LIDAR PROCESSING & QUALITATIVE ASSESSMENT

## 3.1 Initial Processing

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

### 3.1.1 Post Calibration Lidar Review

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

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

| Requirement | Description of Deliverables | Additional Comments |
|---|---|---|
| Non-vegetated vertical accuracy (NVA) of the swath data meet required specifications of 19.6 cm at the 95% confidence level based on RMSEz (10 cm) x 1.96 | The swath NVA was tested and passed specifications. | None |
| The NPD/NPS (or Aggregate NPD/Aggregate NPS) meets required specification of 8 ppsm or 0.35 m NPS. The NPD (ANPD) is calculated from first return points only. | The average calculated (A)NPD of this project is 26.7 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. | 99.46% 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 | No sensor anomalies were present. | None |

| Requirement | Description of Deliverables | Additional Comments |
|---|---|---|
| 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 may be 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. The withheld bit was set on points classified as noise (classes 7 and 18) after manual clean-up.

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

### 3.2.1 Qualitative Review

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

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

**Table 5. Lidar editing and review guidelines**

| Category | Editing Guideline | Additional Comments |
|---|---|---|
| No Data Voids | The SOW for the project defines unacceptable data voids as voids | No unacceptable voids were identified in this dataset |

| Category | Editing Guideline | Additional Comments |
|---|---|---|
| | greater than 4 x $ANPS^2$, or 1.96 $m^2$, that are not related to water bodies or other areas of low near-infrared reflectivity and are not appropriately filled by data from an adjacent swath. The LAS files were used to produce density grids based on Class 2 (ground) points for review. | |
| Artifacts | Artifacts in the point cloud are typically caused by misclassification of points in vegetation or man-made structures as ground. Low-lying vegetation and buildings are difficult for automated grounding algorithms to differentiate and often must be manually removed from the ground class. Dewberry identified these features during lidar editing and reclassified them to Class 1 (unassigned). Artifacts up to 0.3 m above the true ground surface may have been left as Class 2 because they do not negatively impact the usability of the dataset. | None |
| Bridge Saddles | The DEM surface models are created from TINs or terrains. TIN and terrain models create continuous surfaces from the input points, interpolating surfaces beneath bridges where no lidar data was acquired. The surface model in these areas tend to be less detailed. Bridge saddles may be created where the surface interpolates between high and low ground points. Dewberry identifies problems arising from bridge removal and resolves them by reclassifying misclassified ground points to class 1 and/or adding bridge saddle breaklines where applicable due to interpolation. | 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 | None |

| Category | Editing Guideline | Additional Comments |
|---|---|---|
| | where it is difficult to determine whether the feature was a culvert or bridge, Dewberry errs on the side of culverts, especially if the feature is on a secondary or tertiary road. | |
| In-Ground Structures | In-ground structures typically occur on military bases and at facilities designed for munitions testing and storage. When present, Dewberry identifies these structures in the project and includes them in the ground classification. | No in-ground structures 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 0.8 hectare, 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 0.8 hectare size criteria were not collected. | Standing water within agricultural areas not present in the data |
| Wetland/Marsh Areas | Vegetated areas within wetlands/marsh areas are not considered water bodies and are not hydroflattened in the final DEMs. However, it is sometimes difficult to determine 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 | No marshes present in the data |

| Category | Editing Guideline | Additional Comments |
|---|---|---|
| | greater than or equal to 0.8 hectare 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 differences 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 | No Laser Shadowing is present in the data |

| Category | Editing Guideline | Additional Comments |
|---|---|---|
| | structures are taller. Data are edited to the fullest extent possible within the point cloud. As long as data meet other project requirements (density, spatial distribution, etc.), no additional action taken. | |

### 3.2.2 Formatting Review

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

**Table 6. Classified lidar formatting parameters**

| Parameter | Project Specification | Pass/Fail |
|---|---|---|
| LAS Version | 1.4 | Pass |
| Point Data Record Format | 6 | Pass |
| Horizontal Coordinate Reference System | NAD83 (2011) UTM Zone 11, meters in WKT format | Pass |
| Vertical Coordinate Reference System | NAVD88 (Geoid12B), 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<br>Class 2: Ground<br>Class 7: Low Noise<br>Class 18: High Noise | Pass |
| Withheld Points | Withheld bits set for geometrically unreliable points and for noise points in classes 7 and 18 | Pass |
| Scan Angle | Recorded for each pulse | Pass |
| XYZ Coordinates | Recorded for each pulse | Pass |

## 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 v2022 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.

### 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 intraswath rasters are symbolized by the following ranges:

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

# 4. BREAKLINE PROCESSING & 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 lidar point cloud. Subsequent processing was done on ponds/lakes to identify the minimum z-values within these features and re-applied that minimum elevation to all vertices of the breakline feature.

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

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

### 4.1.1 Breakline Collection Requirements

The table below outlines breakline collection requirements for this dataset.

**Table 7. Breakline collection requirements**

| Parameter | Project Specification | Additional Comments |
|---|---|---|
| Ponds and Lakes | Breaklines are collected in all inland ponds and lakes ~0.8 hectare or greater. These features are flat and level water bodies at a single elevation for each vertex along the bank. | No ponds or lakes exist in this dataset, so no ponds or lakes were collected. |
| Rivers and Streams | Breaklines are collected for all streams and rivers ~30 m 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. | No rivers or streams exist in this dataset, so no rivers or streams were collected. |

| Parameter | Project Specification | Additional Comments |
|---|---|---|
| Tidal | Breaklines are collected as polygon features depicting water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any significant water body that is affected by tidal variations. Tidal variations over the course of collection, and between different collections, can result in discontinuities along shorelines. This is considered normal and should be retained. Variations in water surface elevation resulting from tidal variations during collection should not be removed or adjusted. Features should be captured as a dual line with one line on each bank. Each vertex placed shall maintain vertical integrity. Parallel points on opposite banks of the tidal waters must be captured at the same elevation to ensure flatness of the water feature. The entire water surface edge is at or below the immediate surrounding terrain. | No tidally influenced features are in this dataset so no tidal breaklines were collected. |
| Islands | Donuts will exist where there are islands greater than 1 acre in size within a hydro feature. | None |
| Bridge Saddle Breaklines | Bridge Saddle Breaklines are collected where bridge abutments were interpolated after bridge removal causing saddle artifacts. | None |
| Soft Features | Soft Feature Breaklines are collected where additional enforcement of the modeled bare earth terrain was required, typically on hydrographic control structures or vertical waterfalls, due to large vertical elevation differences within a short linear distance on a hydrographic 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 8. Breakline verification steps.**

| Parameter | Requirement | Pass/Fail |
|---|---|---|
| Collection | Collect breaklines according to project specifications using lidar-derived data, including intensity imagery, bare earth ground models, density models, slope models, and terrains. | N/A |
| 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. | N/A |
| 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. | N/A |
| 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. | N/A |
| 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<br><br>Vertices should not have excessive min or max z-values when compared to adjacent vertices<br><br>Intersecting features should maintain connectivity in X, Y, Z planes<br><br>Dual line streams shall have the same elevation at any given cross-section of the stream | N/A |
| 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 | N/A |

| Parameter | Requirement | Pass/Fail |
|---|---|---|
| | interpolated lidar elevations to ensure there are no unacceptable discrepancies. | |
| 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<br><br>Features must not have unnecessary dangles or boundaries | N/A |
| 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. | N/A |
| Hydro-flattening | Perform hydro-flattening and hydro-enforcement checks. Tidal waters should preserve as much ground as possible and can be non-monotonic. | N/A |

# 5. DEM PROCESSING & 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 9. DEM verification steps**

| Parameter | Requirement | Pass/Fail |
|---|---|---|
| Digital Elevation Model (DEM) of bare-earth w/ breaklines | DEM of bare-earth terrain surface (0.5 m) 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. GDAL version 2.4.0 used for all DEM formatting. | Pass |
| DEM Extents | Load all tiled DEMs into Global Mapper and verify complete coverage within the | Pass |

| Parameter | Requirement | Pass/Fail |
|---|---|---|
| | (buffered) project boundary and verify that no tiles are corrupt | |

# 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**
- 16-24 cm: **Orange**
- >24: **Red**

## 6.2 Intensity Images

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

### 6.2.1 Intensity Quality Difference

Due to the data being acquired at different times of the year, the re-flown data has a higher ground density due to vegetation generally being more leaf-off. The re-flown data meets all required density and quality requirements.

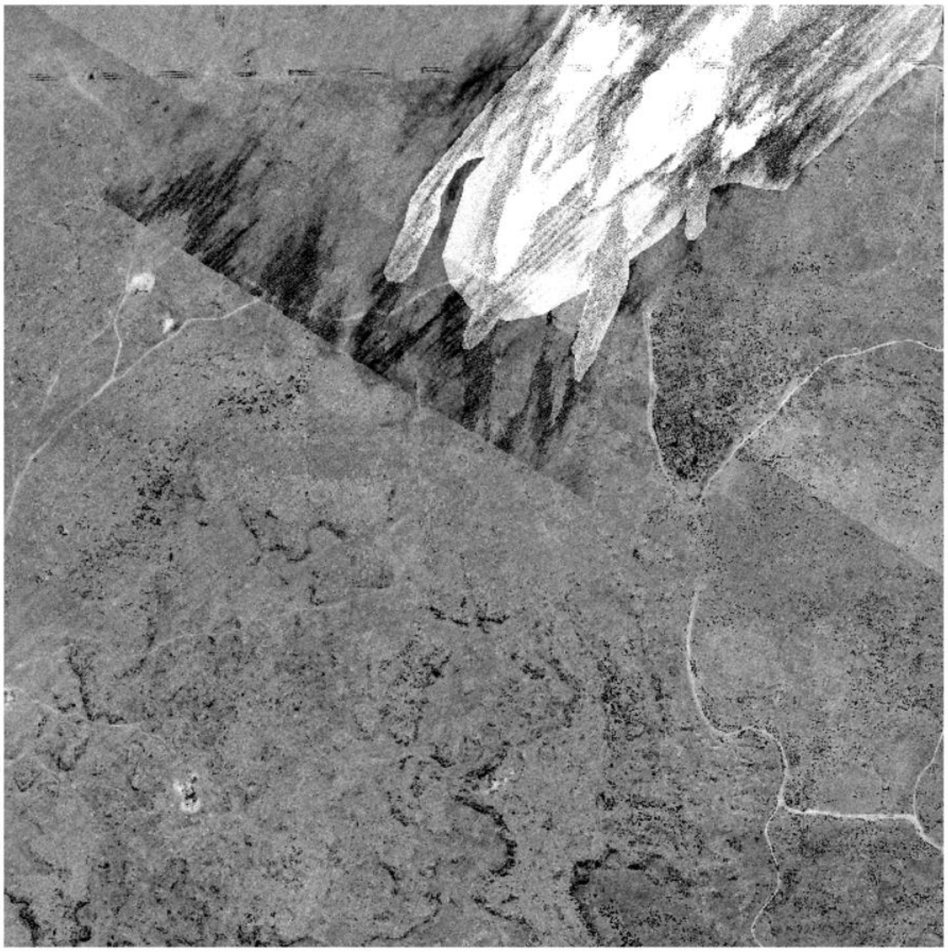

**Figure 5. Higher ground density is apparent in the re-flown portion of the redelivered tile.**

## 6.3 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 is 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.

## 6.4 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.