Dewberry

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

813.225.1325
813.225.1385 fax
www.dewberry.com

FL Peninsular 2018 Lidar Project - Desoto County

Report Produced for U.S. Geological Survey

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

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

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ATTACHMENTS

Appendix A: GPS Processing Reports

1. EXECUTIVE SUMMARY

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy light detection and ranging (lidar) technology for the FL Peninsular 2018 Lidar Project-Desoto County 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 5,000 ft by 5,000 ft. A total of 39,217 tiles will be produced for the project, providing approximately 34,950 sq. miles of coverage. A total of 759 tiles were produced for Desoto County, providing approximately 680 sq. miles of coverage.

1.1 Project Team

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

Dewberry completed the ground survey for the project and delivered surveyed checkpoints. The 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. The GPS base station coordinates used during lidar data acquisition were verified.

Leading Edge Geomatics and Dowe Gallagher completed lidar data acquisition and data calibration for the project area.

1.2 Project Area

The block area is shown in figure 1. Desoto County contains 759 5,000 ft by 5,000 ft tiles. The project tile grid contains 39,217 5,000 ft by 5,000 ft tiles.

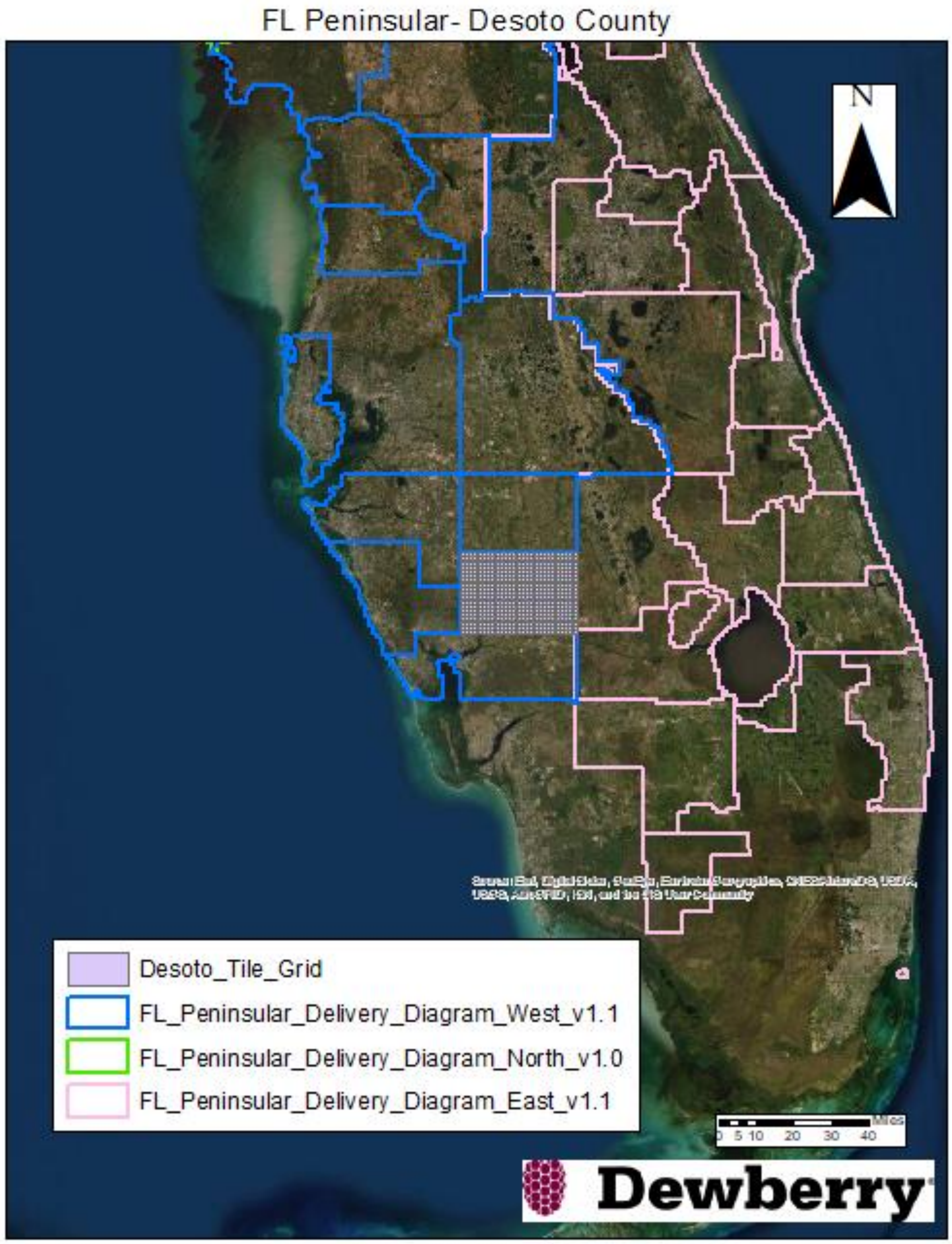

Figure 1. Project map and tile grid.

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:	FL State Plane Zone West

Horizontal Units:	U.S. Survey Feet
Vertical Units:	U.S. Survey Feet

1.4 Project Deliverables

The deliverables for the block are as follows:

1. Project Extents (Esri SHP)
2. Calibration Points (coordinates, Esri shapefile)
3. Classified Point Cloud (tiled LAS)
4. Independent Survey Checkpoint Data (report, photos, coordinates, Esri shapefiles)
5. Intensity Images (tiled, 8-bit gray scale, GeoTIFF format)
6. Breakline Data (file GDB)
7. Bare Earth Surface (tiled raster DEM, IMG format)
8. Interswath Raster
9. Interswath Polygons
10. Intraswath Polygons
11. Metadata (XML)
12. Swath Separation images (GeoTIFF Format)
13. Block Report

1.5 Dewberry Production Workflow Diagram

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

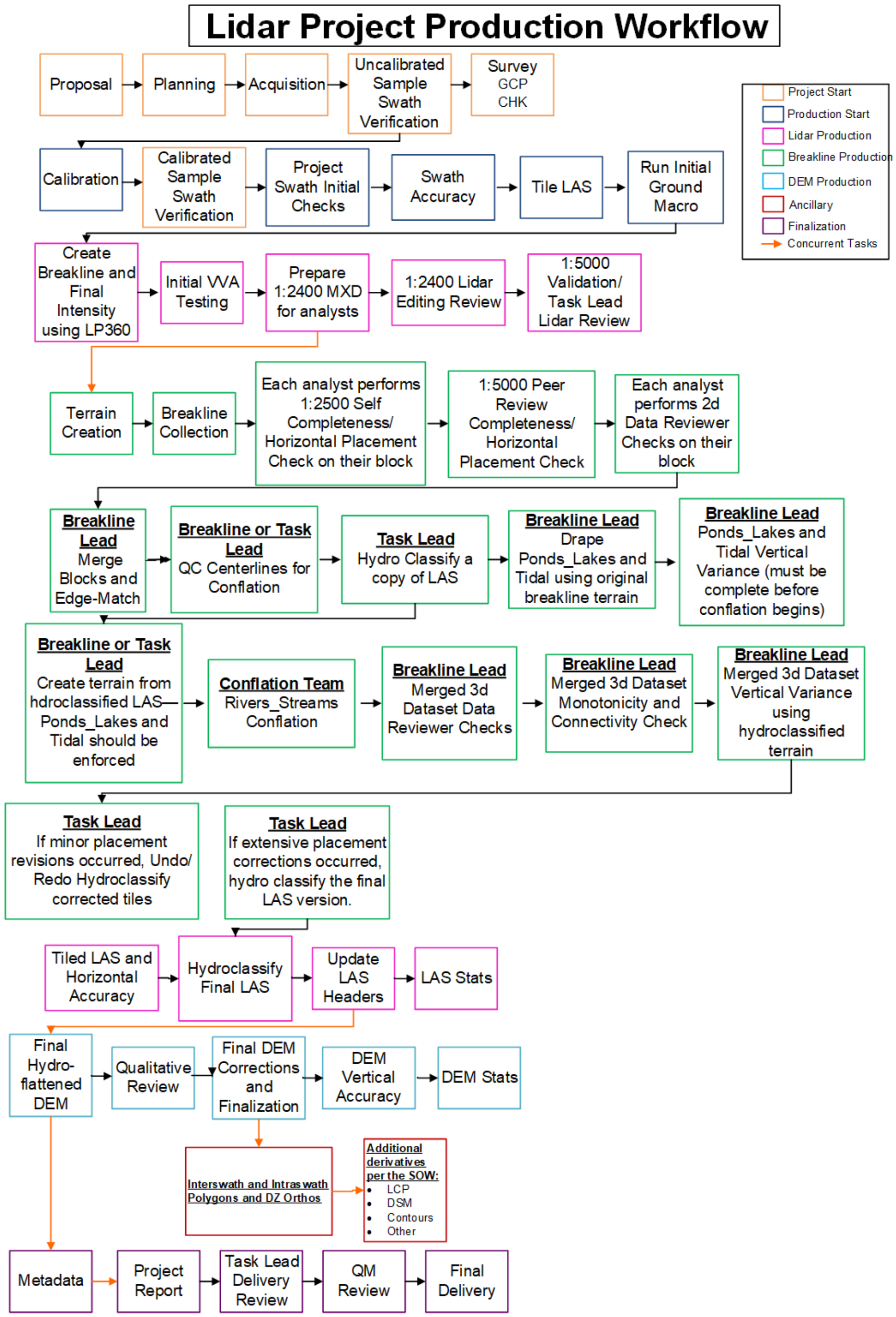

Figure 2- Dewberry's Lidar Production Workflow Diagram

2. LIDAR ACQUISITION REPORT- LEADING EDGE GEOMATICS

Dewberry elected to subcontract the lidar acquisition and calibration activities to Leading Edge Geomatics. Leading Edge Geomatics was responsible for providing lidar acquisition, calibration, and delivery of lidar data files to Dewberry.

The lidar aerial acquisition for Desoto County was conducted between November 30, 2018 to January 10, 2019.

2.1 Lidar Acquisition Details

Leading Edge Geomatics lidar sensors are calibrated at designated sites in the United States and are periodically checked and adjusted to minimize corrections at project sites.

Leading Edge Geomatics planned 162 passes 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 as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Leading Edge Geomatics followed FEMA’s Appendix A “guidelines” for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Track Air 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.

Leading Edge Geomatics 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. Leading Edge Geomatics 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, Leading Edge Geomatics 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

Leading Edge Geomatics operated three aircraft, each equipped with a Riegl VQ-1560i laser lidar system during data collection. Table 1 details the lidar system parameters used during acquisition for all three sensors used for this project.

Parameter	Value
System	Riegl VQ-1560i
Altitude (m above ground level)	1300
Nominal flight speed (kts)	120
Scanner pulse rate (kHz)	2000
Scan frequency (Hz)	160
Pulse duration of the scanner (ns)	3
Pulse width of the scanner (m)	0.9
Central wavelength of the sensor laser (nm)	1064
Multiple pulses in the air	Yes
Beam divergence (mrad)	0.25
Swath width (m)	1400
Nominal swath width on the ground (m)	1400
Swath overlap (%)	20
Total sensor scan angle (degrees)	60
Computed down track spacing per beam (m)	0.37
Computed cross track Spacing per beam (m)	0.37
Nominal pulse spacing (NPS) (single swath) (m)	0.29
Nominal Pulse Density (NPD) (single swath) (points per sq m)	11.9
Aggregate NPS (m) (if NPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.29
Aggregate NPD (m) (if NPD was designed to be met through single coverage, ANPD and NPD will be equal)	11.9
Maximum Number of Returns per Pulse	7

Table 1. Leading Edge Geomatics lidar system parameters.

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.

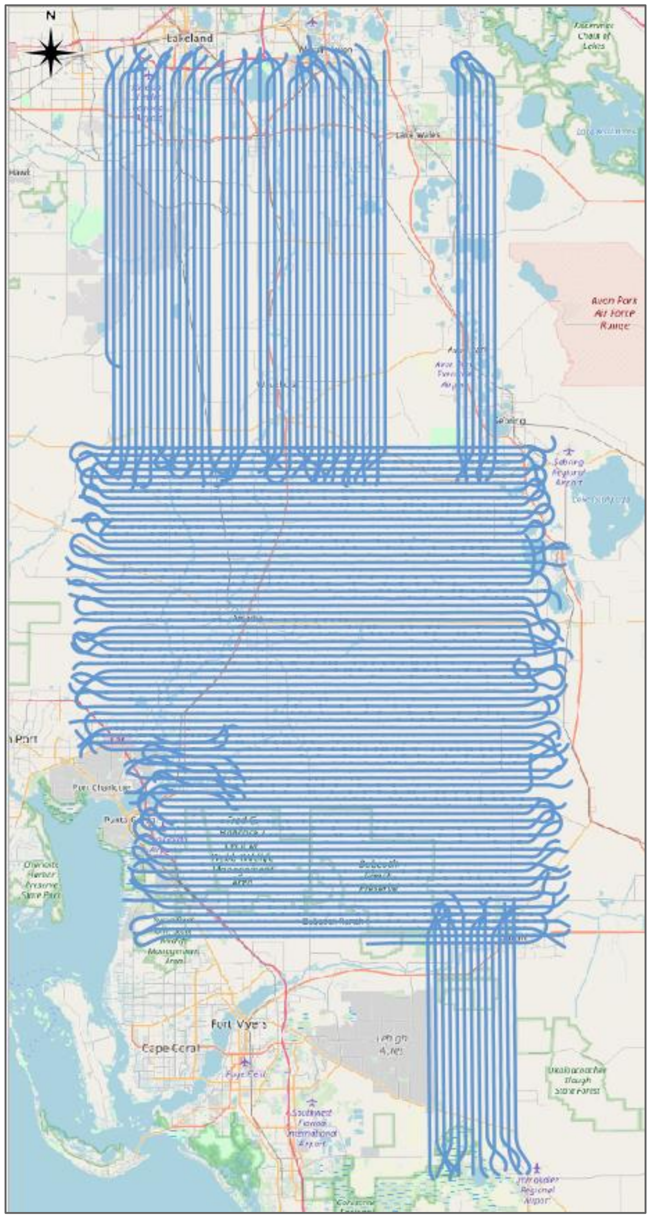

Figure 3. Trajectories of flight lines flown

2.4 Acquisition Static Control

Leading Edge Geomatics utilized 22 permanent static GNSS CORS base stations for the FL Peninsular lidar project area. The coordinates of all base stations used are provided in table 2. All control and calibration points are also provided in shapefile format as part of is delivery.

Name	NAD83(2011) FL State Plane West, ft		NAD83(2011), ft	NAVD88 Geoid12B, ft
	Easting (X)	Northing (Y)	Ellipsoid Height	Orthometric Height
CCV6	1502756.7	1123547.44	18.4	-22.7
DLND	1717517.94	891572.71	93.03	0.26
FMYR	820515.86	700558.13	35.7	-13.28
MCD5	1278477.27	484154.9	34.86	-14.17
MTNT	558398.95	1015584.6	17.7	-18.93
NAPL	659778.24	729553.24	19.87	-17.46
OKCB	1067579.57	1028027.57	42.21	-13.76
WACH	1156103.62	694286.02	117.21	10.72
ZEFR	1415483.53	603153.9	86.06	0.02
AVON	1185841.3	810004.54	156.52	21.78
FLCC	1367751.91	890171.93	92	0.34
FLD7	1321805.4	538656.81	40.39	-12.83
FLDC	1465759.4	595768.54	128.55	12.69
FLGR	1253011.34	603723.52	139.16	17.36
FLLP	1082035.6	862982.9	160.37	23.52
FLSI	778280.5	604221.13	21.05	-17.11
GSPS	1145619.72	542303.52	62.57	-5.65
HULK	1440285.17	837556.03	96.36	1.59
LAUD	681221.25	1255287.68	24.6	-18.14
LBLL	877803.4	834543	25.89	-16.58
PBCH	917372.92	1236855.84	36.73	-15.3
RCDA	1049344.4	697069.44	40.91	-12.04

Table 2. Base stations used to control lidar acquisition.

2.5 Airborne Kinematic Control

Airborne GNSS data was processed using the Applanix POSPac MMS software suite and Novatel's GrafNav software. Flights were flown with a minimum of six satellites in view (13° above the horizon) and with a PDOP of better than four. Distances from at least one base station to aircraft were kept to a maximum of 40 km (25 miles). For all flights, the GNSS data can be classified as excellent, with GNSS residuals of 3 cm average or better but no larger than 10 cm being recorded.

GPS processing reports for each mission are included in the Appendix A 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 Riegl's RiProcess initially with default values from Riegl 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.

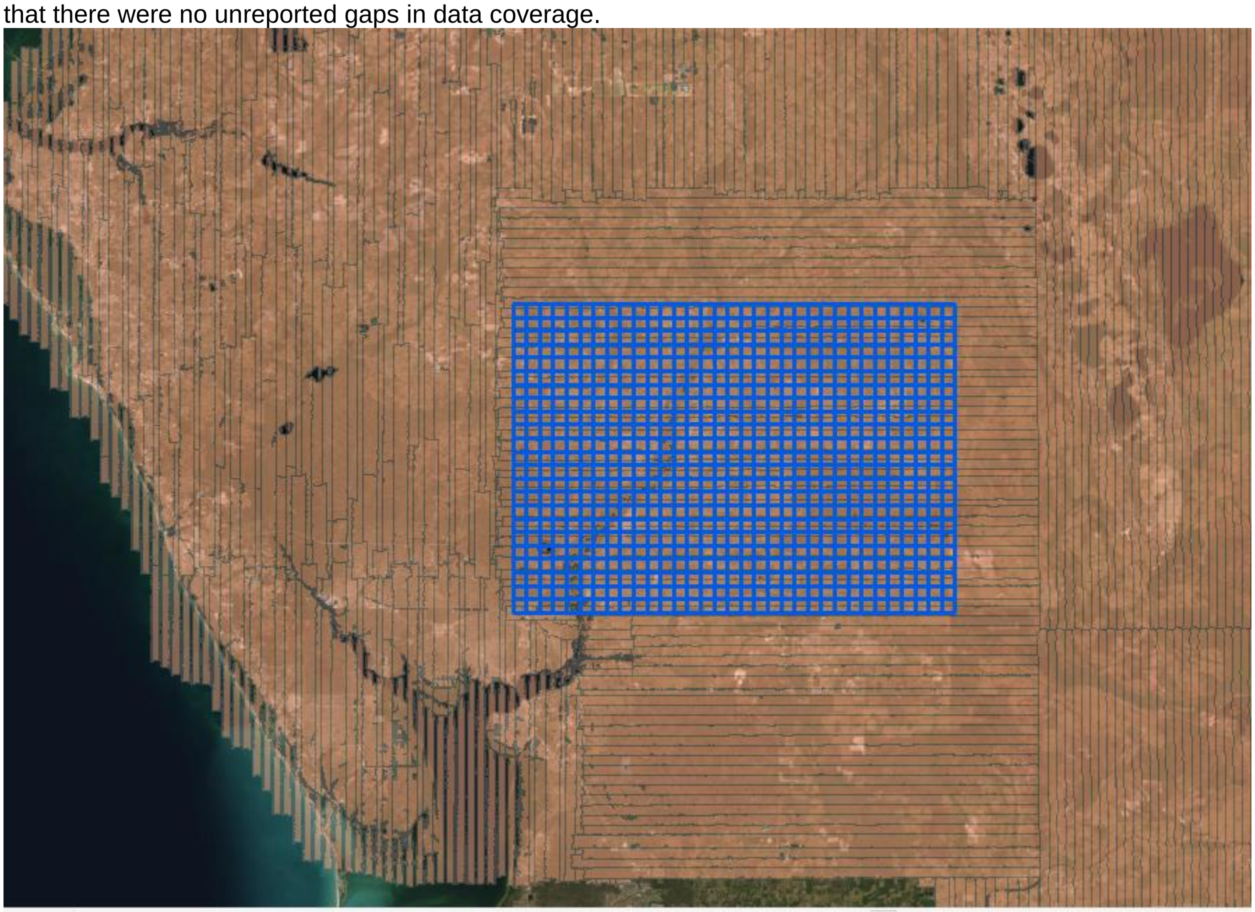

Figure 4. Lidar swath output showing complete coverage.

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 (Figure 5).

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 (Figure 6). 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).

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

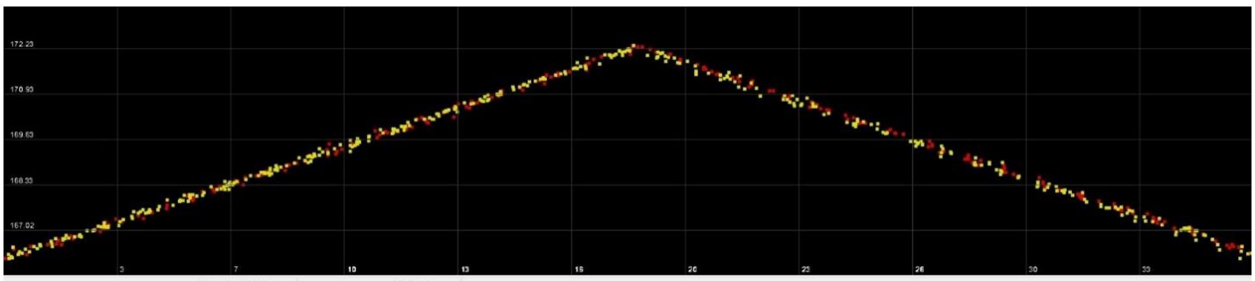

Figure 5. Profile views showing results of roll and pitch adjustments for Leading Edge Geomatics.

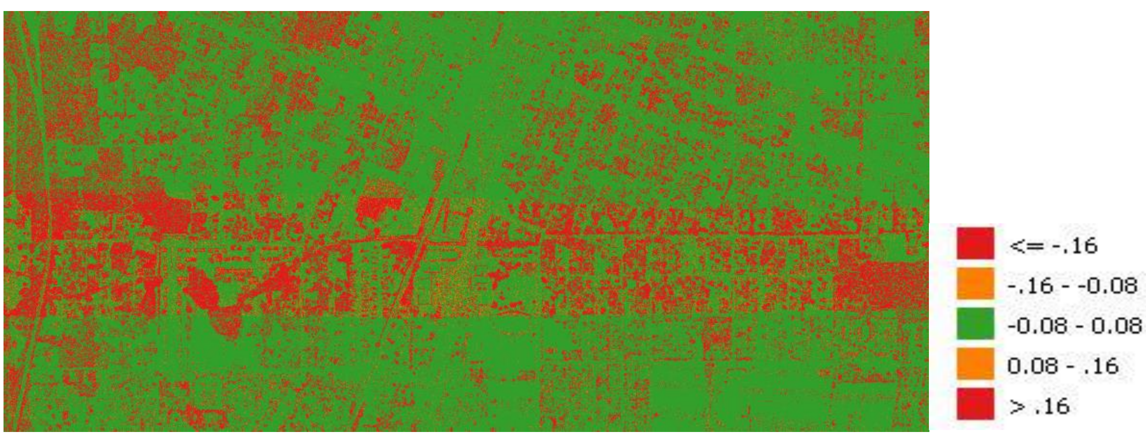

Figure 6. QC block colored by vertical difference between swaths to check accuracy at swath edges for Leading Edge Geomatics.

2.7 Final Calibration Verification

A preliminary RMSEz error check was performed by Leading Edge Geomatics at this stage of the project life cycle in the raw Lidar dataset against GNSS static and kinematic data and compared to RMSEz project specifications. The Lidar data was examined in non-vegetated, flat areas away from breaks. Lidar ground points for each flight line generated by an automatic classification routine were used. Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met Non-Vegetated Vertical Accuracy (NVA) requirements (RMSEz ≤ 10 cm and Accuracy at the 95% confidence level ≤ 19.6 cm) when compared to kinematic GNSS checkpoints.

The following summary shows the results comparing the final calibrated Lidar data to NVA ground check points provided by Leading Edge Geomatics.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33 ft	NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec=0.64 ft	Mean (ft)	Std Dev (ft)	Min (ft)	Max (ft)
GCP	1463	0.12	0.23	-0.08	0.09	-0.41	0.13

Table 3 - Ground control points (GCPs) vertical accuracy results.

3. LIDAR ACQUISITION REPORT- DOWE GALLAGHER

Dewberry elected to subcontract the lidar acquisition and calibration activities to Dowe Gallagher. Dowe Gallagher was responsible for providing lidar acquisition, calibration, and delivery of lidar data files to Dewberry.

The lidar aerial acquisition for Desoto County was conducted between November 30, 2018 to January 10, 2019.

3.1 Lidar Acquisition Details

Dowe Gallagher lidar sensors are calibrated at Tampa Bay Regional Airport and are periodically checked and adjusted to minimize corrections at project sites.

Dowe Gallagher planned 144 passes 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 as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Dowe Gallagher followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Track Air 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.

Dowe Gallagher 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. Dowe Gallagher 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, Dowe Gallagher 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.

3.2 Lidar System Parameters

Dowe Gallagher operated a Cessna Grand Caravan EX 208B (Tail # N256DG) outfitted with a Riegl VQ-15601i lidar system during data collection. Table 1details the lidar system parameters used during acquisition for this project.

Parameter	Value
System	Riegl VQ-1560i
Altitude (m above ground level)	1500
Nominal flight speed (kts)	140
Scanner pulse rate (kHz)	2000
Scan frequency (Hz)	375
Pulse duration of the scanner (ns)	3
Pulse width of the scanner (m)	0.9
Central wavelength of the sensor laser (nm)	1064
Multiple pulses in the air	Yes
Beam divergence (mrad)	0.25
Swath width (m)	1500
Nominal swath width on the ground (m)	1674
Swath overlap (%)	30
Total sensor scan angle (degrees)	60
Computed down track spacing per beam (m)	0.43

Computed cross track Spacing per beam (m)	0.42
Nominal pulse spacing (NPS) (single swath) (m)	0.35
Nominal Pulse Density (NPD) (single swath) (points per sq m)	8
Aggregate NPS (m) (if NPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.35
Aggregate NPD (m) (if NPD was designed to be met through single coverage, ANPD and NPD will be equal)	8
Maximum Number of Returns per Pulse	7

Table 3. Dowe Gallagher lidar system parameters.

3.3 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 7 shows the combined flight line trajectories.

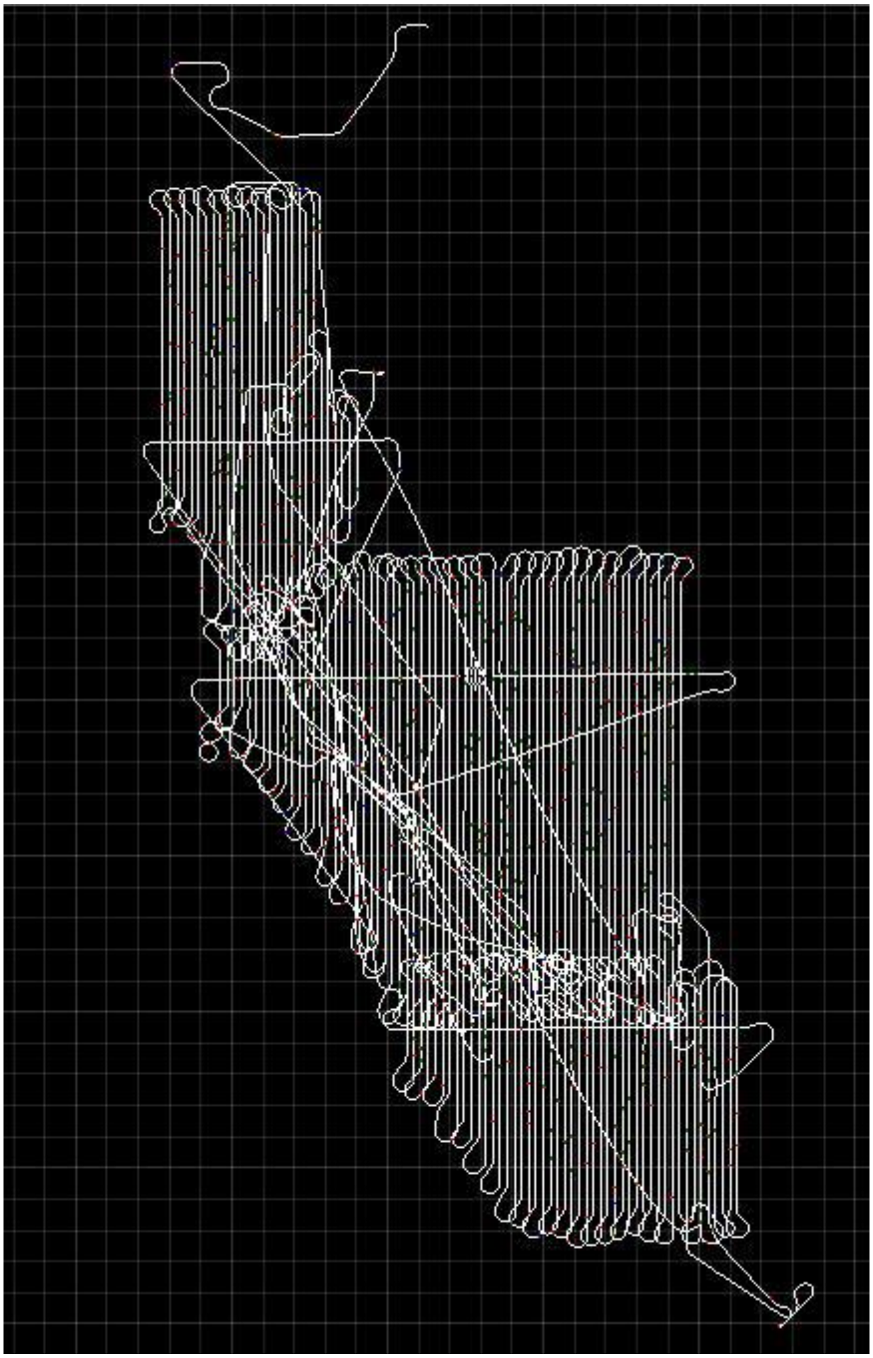

Figure 7. Trajectories of flight lines flown by Dowe Gallagher.

3.4 Acquisition Static Control

Dowe Gallagher utilized FPRN and USGS CORS for the FL Peninsular lidar project area. The coordinates of all base stations used are provided in table 4. All control and calibration points are also provided in shapefile format as part of is delivery.

Name	NAD83(2011) FL State Plane West, ft		NAD83(2011), ft	NAVD88 Geoid12B, ft
	Easting (X)	Northing (Y)	Ellipsoid Height	Orthometric Height
BKVL	510417.9763	1505238.078	-16.47	70.12
CHIN	387892.75	79689.73	-44.34	-27
DUNN	537666.4496	1719074.74	-20.79	69.87
FLAI	432312.1217	1133278.42	-35.49	44.27
FLD7	538656.8107	1321805.403	-42.1	40.39
FLEM	422824.4646	1438944.764	-53.26	30.61
FLGR	603723.5203	1253011.341	56.96	139.16
FLIB	383933.5751	1290000.048	-52.6	27.52
FLSI	604221.1278	778280.4981	-56.13	21.05
FMYR	700558.086	820515.8843	-43.55	35.72
GSPS	542303.5239	1145619.717	-18.53	62.57
NAPL	401512.5065	660475.4096	-57.26	19.89
PNTA	658530.9426	940469.1876	-43.8	35.22
RCDA	697069.4398	1049344.397	-39.49	40.91
STPT	453457.1812	1248625.8	-58.82	21.71
WACH	694285.979	1156103.638	35.19	117.24
ZEFR	603153.8606	1415483.549	-0.16	86.14

Table 4. Base stations used to control lidar acquisition.

3.5 Airborne Kinematic Control

Airborne GNSS data was processed using the Applanix POSPac MMS software suite and Novatel's GrafNav software. Flights were flown with a minimum of six satellites in view (13° above the horizon) and with a PDOP of better than four. Distances from at least one base station to aircraft were kept to a maximum of 40 km (25 miles). For all flights, the GNSS data can be classified as excellent, with GNSS residuals of 3 cm average or better but no larger than 10 cm being recorded.

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

3.6 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 Riegl's RiProcess initially with default values from Riegl 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 8) to ensure that there were no unreported gaps in data coverage.

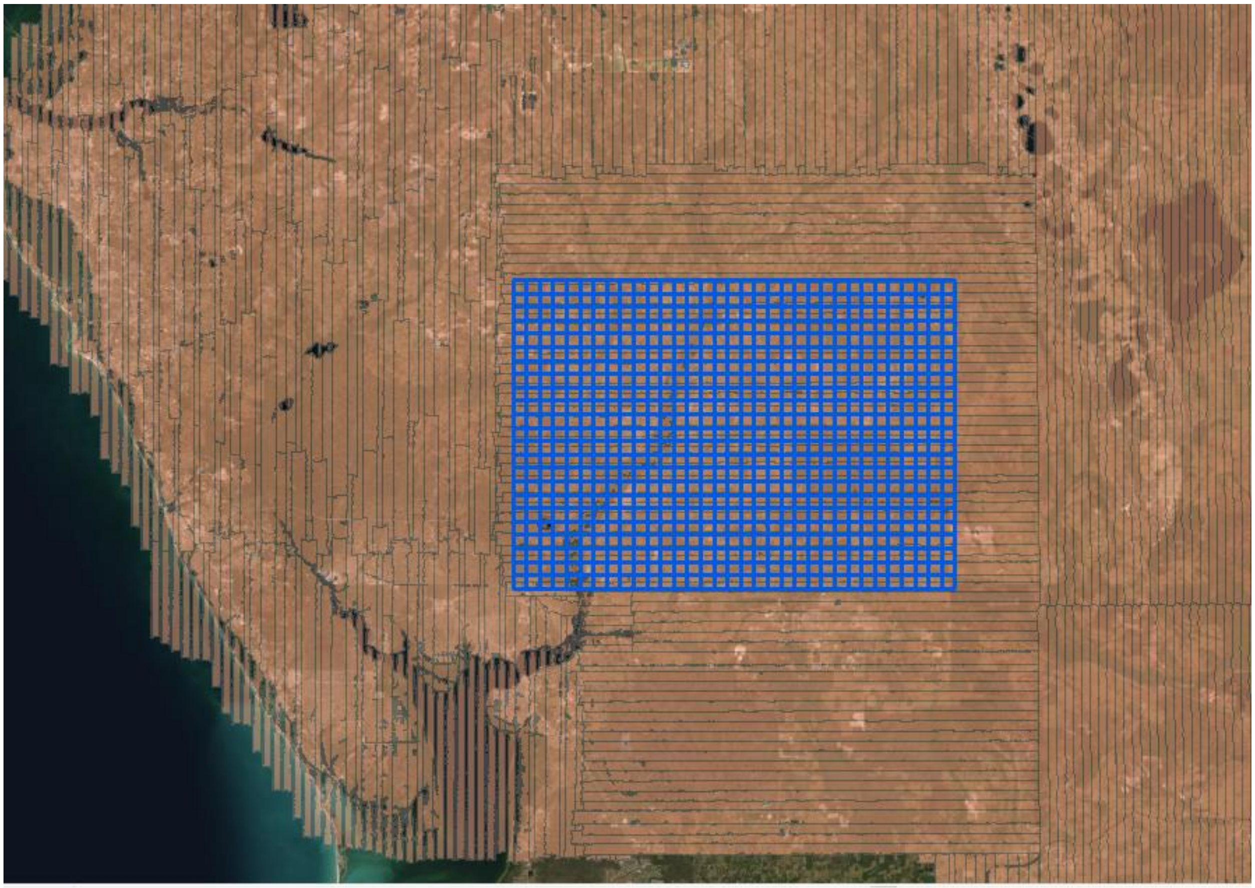

Figure 8. Lidar swath output showing complete coverage.

3.6.1 Boresight and Relative accuracy

The initial points for each mission calibration were inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the lidar unit or GPS. Roll, pitch and scanner scale were optimized during the calibration process until relative accuracy requirements were met (Figure 9).

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 (Figure 10). 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).

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

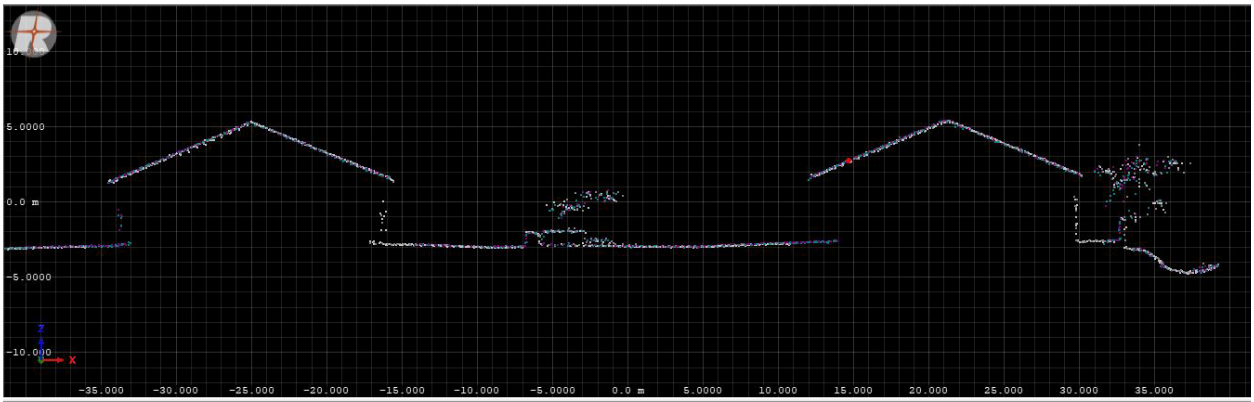

Figure 9. Profile views showing results of roll and pitch adjustments.

Figure 10. QC block colored by vertical difference between swaths to check accuracy at swath edges.

3.7 Final Calibration Verification

A preliminary RMSEz error check was performed by Dowe Gallagher at this stage of the project life cycle in the raw Lidar dataset against GNSS static and kinematic data and compared to RMSEz project specifications. The Lidar data was examined in non-vegetated, flat areas away from breaks. Lidar ground points for each flight line generated by an automatic classification routine were used. Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met Non-Vegetated Vertical Accuracy (NVA) requirements (RMSEz ≤ 10 cm and Accuracy at the 95% confidence level ≤ 19.6 cm) when compared to kinematic GNSS checkpoints.

The following summary shows the results comparing the final calibrated Lidar data to NVA ground check points provided by Dowe Gallagher.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33 ft	NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec=0.64 ft	Mean (ft)	Std Dev (ft)	Min (ft)	Max (ft)
GCP	19	0.11	0.22	0.01	0.12	-0.17	0.28

Table 3 - Ground control points (GCPs) vertical accuracy results.

4. LIDAR PRODUCTION & QUALITATIVE ASSESSMENT

4.1 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.

4.1.1 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.

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

Requirement	Description of Deliverables	Additional Comments
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 8 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 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	Scan Direction bits were populated correctly	None

Requirement	Description of Deliverables	Additional Comments
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.		
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

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

4.2 Data Classification and Editing

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

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

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

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

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

4.2.1 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.

Category	Editing Guideline	Additional Comments
No Data Voids	The SOW for the project defines unacceptable data voids as voids greater than 4 x $ANPS^2$, or 1.96 m^2, that are not related to water bodies or other areas of low near-infrared reflectivity and are not appropriately filled by data from an adjacent swath. The LAS files were used to produce density grids based on Class 2 (ground) points for review.	No unacceptable voids were identified in this dataset

Category	Editing Guideline	Additional Comments
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
In-Ground Structures	In-ground structures typically occur on military bases and at facilities designed for munitions testing and storage. When	No in-ground structures present in this dataset

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

Category	Editing Guideline	Additional Comments
	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.	If temporal offsets are present in the data, the areas are outlined in the temporal.shp
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

Table 5 – Post calibration and initial processing data verification steps.

4.2.2 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.

Parameter	Project Specification	Pass/Fail
LAS Version	1.4	Pass
Point Data Record Format	6	Pass
Horizontal Coordinate Reference System	NAD83 (2011) FL State Plane Zone West in WKT format	Pass
Vertical Coordinate Reference System	NAVD88 (Geoid 12B), feet 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 6: Buildings Class 7: Low Noise Class 9: Water Class 17: Bridge Decks Class 18: High Noise Class 20: Ignored Ground	Pass
Withheld Points	Withheld bits set	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Recorded for each pulse	Pass

Table 6. Classified lidar formatting parameters

4.2.3 Synthetic Points

Time of flight laser measurements have their maximum unambiguous range restricted by the maximum distance the laser can travel round-trip before the next laser pulse is emitted. One solution to this problem is to limit "valid" returns to a certain window between specified elevations, or a "range gate"; however, this technique can prevent some returns from being captured if there is terrain outside of the range gate. It can also cause some late returns to be georeferenced as part subsequent pulses.

The multiple time around (MTA) capabilities of Riegl sensors enable the recording of lidar returns any distance from the laser (within detection capabilities) without forcing range gate restrictions. However, there is still a possibility that a late return will occur simultaneously with a pulse emission. The backscatter energy from the laser optics and the atmosphere directly below the aircraft during this event can effectively blind the sensor, making it unable to discern information about the laser return. Because this occurs more consistently with later returns, this blind zone is typically found in a narrow band along the edges of the sensor's range. The result is a predictable geometry of voids (typically within project specifications) in the point cloud.

During post-processing of the lidar data, Riegl software interpolates coordinates within the blind zones between last returns on each side of the gap. These are flagged as "synthetic" points and are assigned a valid time stamp, though they do not have any waveform data or pulse width information. Amplitude and reflectance are averaged from surrounding points. The assignment of synthetic points does not change the original raw point cloud data.

This dataset contains flagged synthetic points. The images below show an example from a different dataset of synthetic points applied to the ground class of the lidar point cloud.

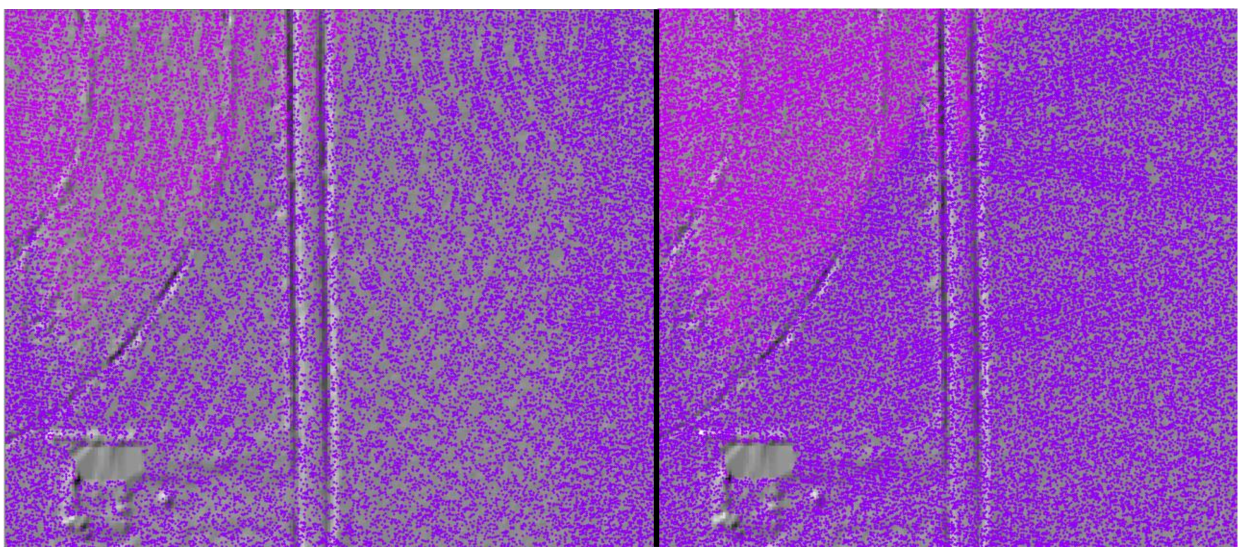

Figure 11 – The left image shows ground classified without synthetic points. The right image shows ground classified with synthetic points. Both images are overlaid on a hillshade of the example area.

5. BREAKLINE PRODUCTION & QUALITATIVE ASSESSMENT

5.1 Breakline Production Methodology

Breaklines were manually digitized within an Esri software environment, using full point cloud intensity imagery, bare earth terrains and DEMs, the lidar point cloud, and ancillary ortho imagery where appropriate.

When data characteristics are suitable, Dewberry may use eCognition software to generate initial, automated water polygons, which are then manually reviewed and refined where necessary.

Breakline features with static or semi-static elevations (ponds and lakes, bridge saddles, and soft feature breaklines) were converted to 3D breaklines within the Esri environment where breaklines were draped on terrains or the las point cloud. Subsequent processing was done on ponds/lakes to identify the minimum z-values within these features and re-applied that minimum elevation to all vertices of the breakline feature.

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

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

5.1.1 Breakline Collection Requirements

The table below outlines breakline collection requirements for this dataset.

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
Hydrographic Features	Breaklines are collected for all streams and rivers 8 ft nominal width or wider as dual line drains and single line drains for features <8 ft in nominal width but greater than 0.5 mi in length. The dual line drain 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
Coastal Feature	Breaklines are collected as polygon features depicting water bodies such as oceans, seas, gulfs, bays, inlets, slat marshes, very large lakes, etc.	None

	Includes any significant water body that is affected by tidal variations. Tidal variations over the course of collection, and between different collections, can result in discontinuities along shorelines. This is considered normal and should be retained. Variations in water surface elevation resulting from tidal variations during collection should not be removed or adjusted. Features should be captured as a dual line with one line on each bank. Each vertex placed shall maintain vertical integrity. Parallel points on opposite banks of the tidal waters must be captured at the same elevation to ensure flatness of the water feature. The entire water surface edge is at or below the immediate surrounding terrain.	
Islands	Donuts will exist where there are islands greater than 1 acre in size within a hydro feature.	None
Bridge Saddle Breaklines	Bridge Saddle Breaklines are collected where bridge abutments were interpolated after bridge removal causing saddle artifacts.	None
Soft Features	Soft Feature Breaklines are collected where additional enforcement of the modeled bare earth terrain was required, typically on hydrographic control structures or vertical waterfalls, due to large vertical elevation differences within a short linear distance on a hydrographic features.	None
Connectors	A CONNECTOR will be collected where a hydrographic feature is collected on either side of the road. The connector must snap to the adjoining hydrological features.	None

Table 7. Breakline collection requirements

5.2 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.

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	Pass

	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	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

Table 8 – Breakline verification steps.

6. DEM PRODUCTION & QUALITATIVE ASSESSMENT

6.1 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.

6.2 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.

Parameter	Requirement	Pass/Fail
Digital Elevation Model (DEM) of bare-earth w/ breaklines	DEM of bare-earth terrain surface (2.5’) is created from lidar ground points and breaklines. DEMs are tiled without overlaps or gaps, show no edge artifact or mismatch, DEM deliverables are .img 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	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

Table 9 – DEM verification steps.

7. DERIVATIVE LIDAR PRODUCTS

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

7.1 Interswath Raster

Interswath raster representing interswath alignment have been delivered. This raster was created from the last return of all points except points classified as noise or flagged as withheld. The images are in .TIFF format.

7.2 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**

7.3 Interswath and Intraswath Polygons

7.3.1 Interswath Accuracy

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

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

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).