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Suwannee River Lidar Project

Report Produced for U.S. Geological Survey

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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 USGS Suwannee River Lidar, Florida Project Area.

The lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area.

Data was formatted according to tiles with each tile covering an area of 5000 ft by 5000 ft. A total of 1378 tiles were produced for the project encompassing an area of approximately 921 sq. miles.

THE PROJECT TEAM

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

Dewberry's William D. Donley completed ground surveying for the project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the lidar-derived surface model. He also verified the GPS base station coordinates used during lidar data acquisition to ensure that the base station coordinates were accurate. Please see Appendix A to view the separate Survey Report that was created for this portion of the project.

Digital Aerial Solutions LLC completed lidar data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report falls within the Florida counties of Alachua, Baker and Levy.

DATE OF SURVEY

The lidar aerial acquisition was conducted from January 14, 2017 to February 10, 2017.

COORDINATE REFERENCE SYSTEM

Data produced for the project were delivered in the following reference system.

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: State Plane Florida North FIPS 0903 (AOI 3 is also delivered in State Plane Florida West FIPS 0902)
Units: Horizontal units are in U.S Survey Feet, Vertical units are in U.S Survey Feet.
Geoid Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the FL Suwannee River Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **0.18 ft (5.5 cm)** compared with the 0.33 ft (10 cm) specification; and the NVA of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to **0.35 ft (10.7 cm)**, compared with the 0.64 ft (19.6 cm) specification.

For the FL Suwannee River Lidar Project, the tested VVA of the classified lidar data computed using the 95^{th} percentile was equal to **0.54 ft (16.5 cm),** compared with the 0.96 ft (29.4 cm) specification.

Additional accuracy information and statistics for the classified lidar data, raw swath data, and bare earth DEM data are found in the following sections of this report.

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Raw Point Cloud Data (Swaths)
2. Classified Point Cloud Data (Tiled)
3. Bare Earth Surface (Raster DEM – Grid Format)
4. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
5. Breakline Data (File GDB)
6. Independent Survey Checkpoint Data (Report, Photos, & Points)
7. Calibration Points
8. Metadata
9. Project Report (Acquisition, Processing, QC)
10. Project Extents, Including a shapefile derived from the lidar deliverable

PROJECT TILING FOOTPRINT

One thousand three hundred and seventy-eight (1378) tiles were delivered for the project. Each tile's extent is 5,000 feet by 5,000 feet (see Appendix B for a complete listing of delivered tiles).

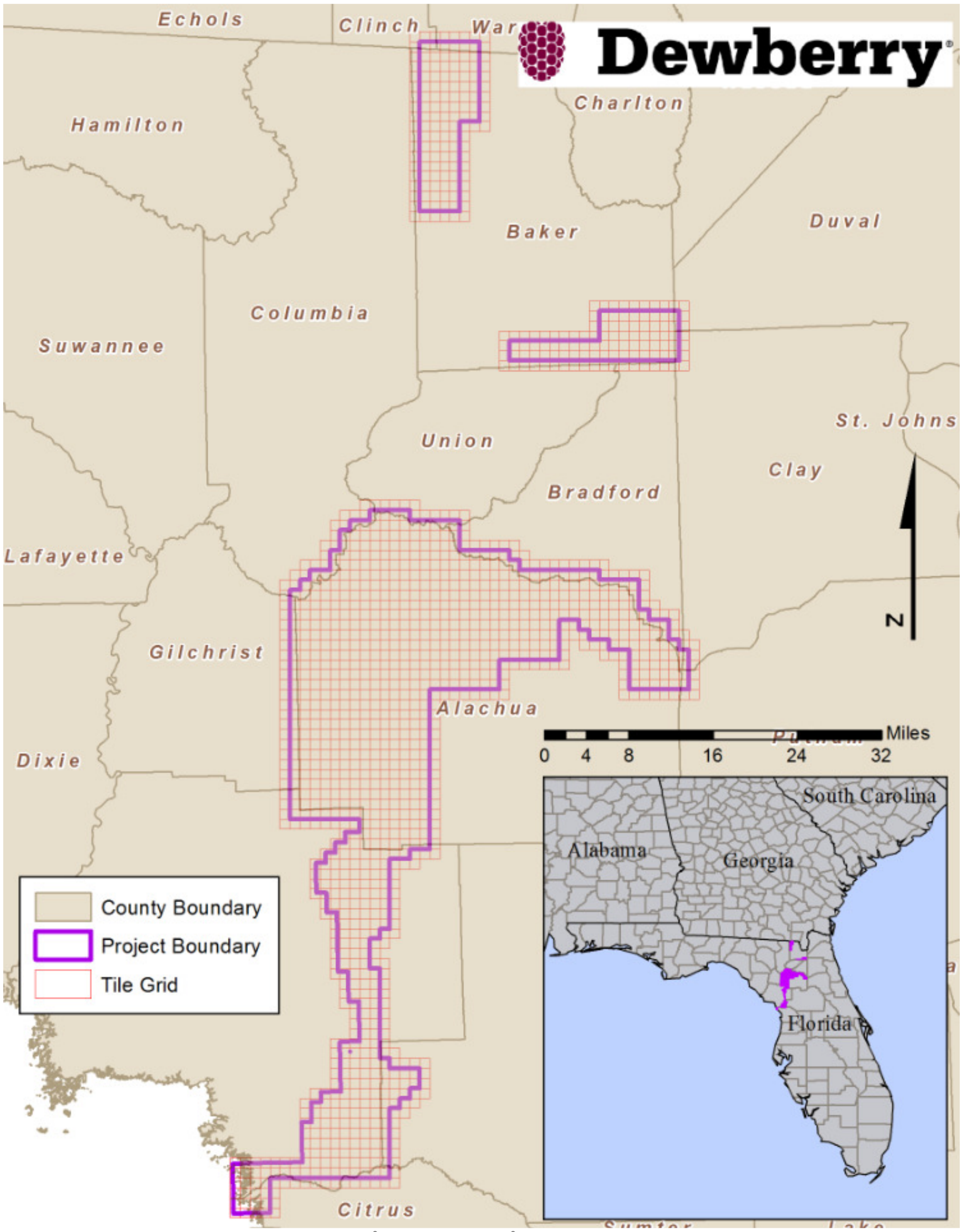


Figure 1 - Project Map

Lidar Acquisition Report

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

Dewberry received calibrated swath data from Digital Aerial Solutions on April 21, 2017.

LIDAR ACQUISITION DETAILS

Digital Aerial Solutions planned 285 passes for the FL Suwannee River Lidar of the project area as a series of parallel flight lines with cross flightlines 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, Digital Aerial Solutions followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using LEICA MISSION PRO 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.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Digital Aerial Solutions will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Digital Aerial Solutions monitored weather and atmospheric conditions and conducted lidar missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Digital Aerial Solutions accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

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

Digital Aerial Solutions lidar sensors are calibrated at a designated site located at the Plant City Airport in Plant City, Florida and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Digital Aerial Solutions operated a CESSNA 421 (Tail # N112MJ) outfitted with a LEICA ALS80 HP LiDAR system during the collection of the FL Suwannee River Lidar. Table 1 illustrates Digital Aerial Solutions system parameters for lidar acquisition on the project.

Item	Parameter
System	Leica ALS80 HP
Altitude (AGL meters)	1129
Approx. Flight Speed (knots)	150
Scanner Pulse Rate (kHz)	240.6
Scan Frequency (hz)	56.7
Pulse Duration of the Scanner (nanoseconds)	2.5
Pulse Width of the Scanner (m)	0.05
Swath width (m)	647.4
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in the air? (yes/no)	Yes 1
Beam Divergence (milliradians)	0.15-0.25
Nominal Swath Width on the Ground (m)	647.4
Swath Overlap (%)	32.45
Total Sensor Scan Angle (degree)	32
Computed Down Track spacing (m) per beam	0.68
Computed Cross Track Spacing (m) per beam	0.68
Nominal Pulse Spacing (single swath) (m)	0.50
Nominal Pulse Density (single swath) (ppsm) (m)	4
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.50
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	4
Maximum Number of Returns per Pulse	8

Table 1: Digital Aerial Solutions lidar system parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

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 aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly 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.

Figures 2 and 3 show the combined trajectory of the flightlines.

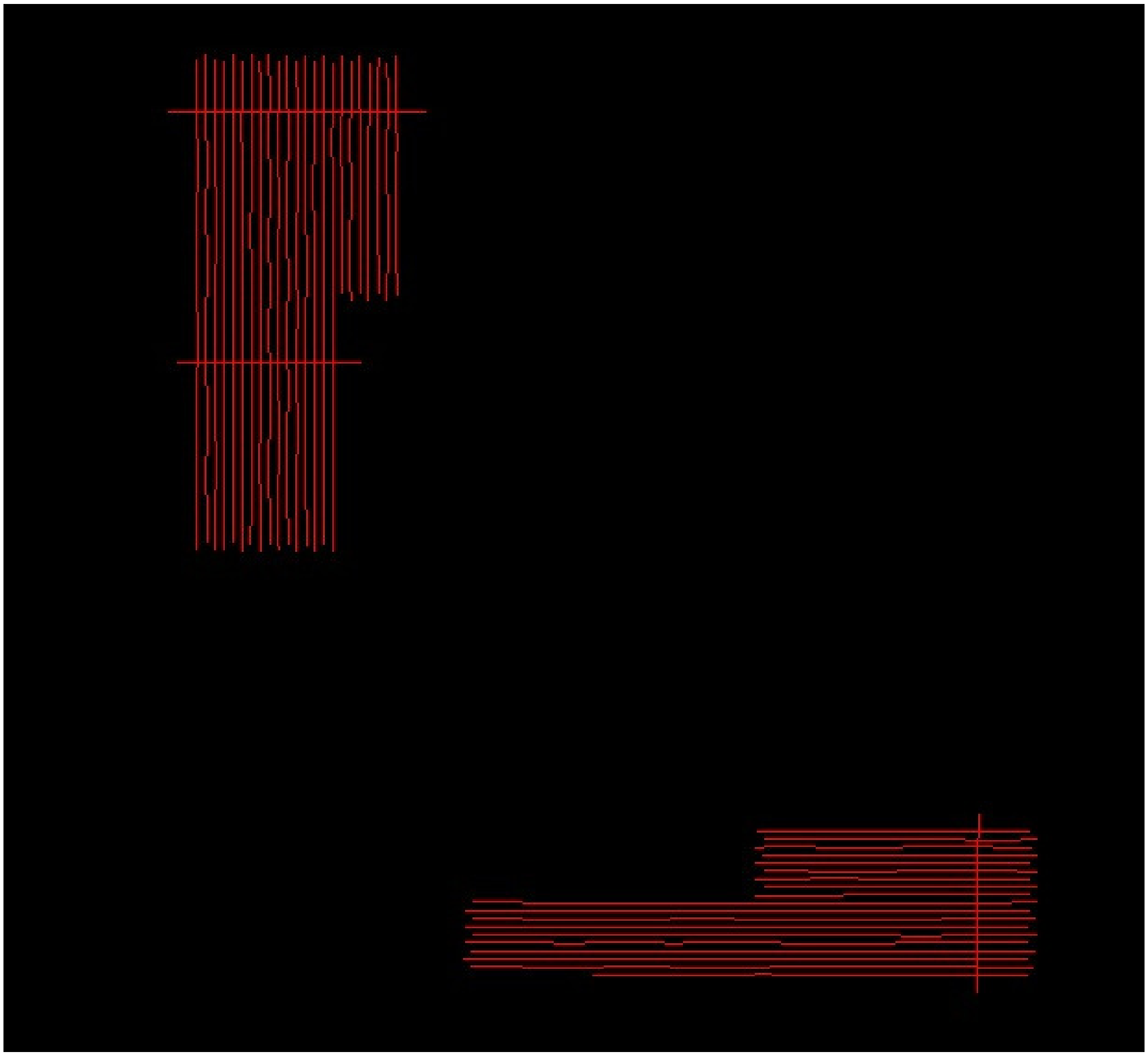


Figure 2: Area 1 & 2 Trajectories as flown by Digital Aerial Solutions

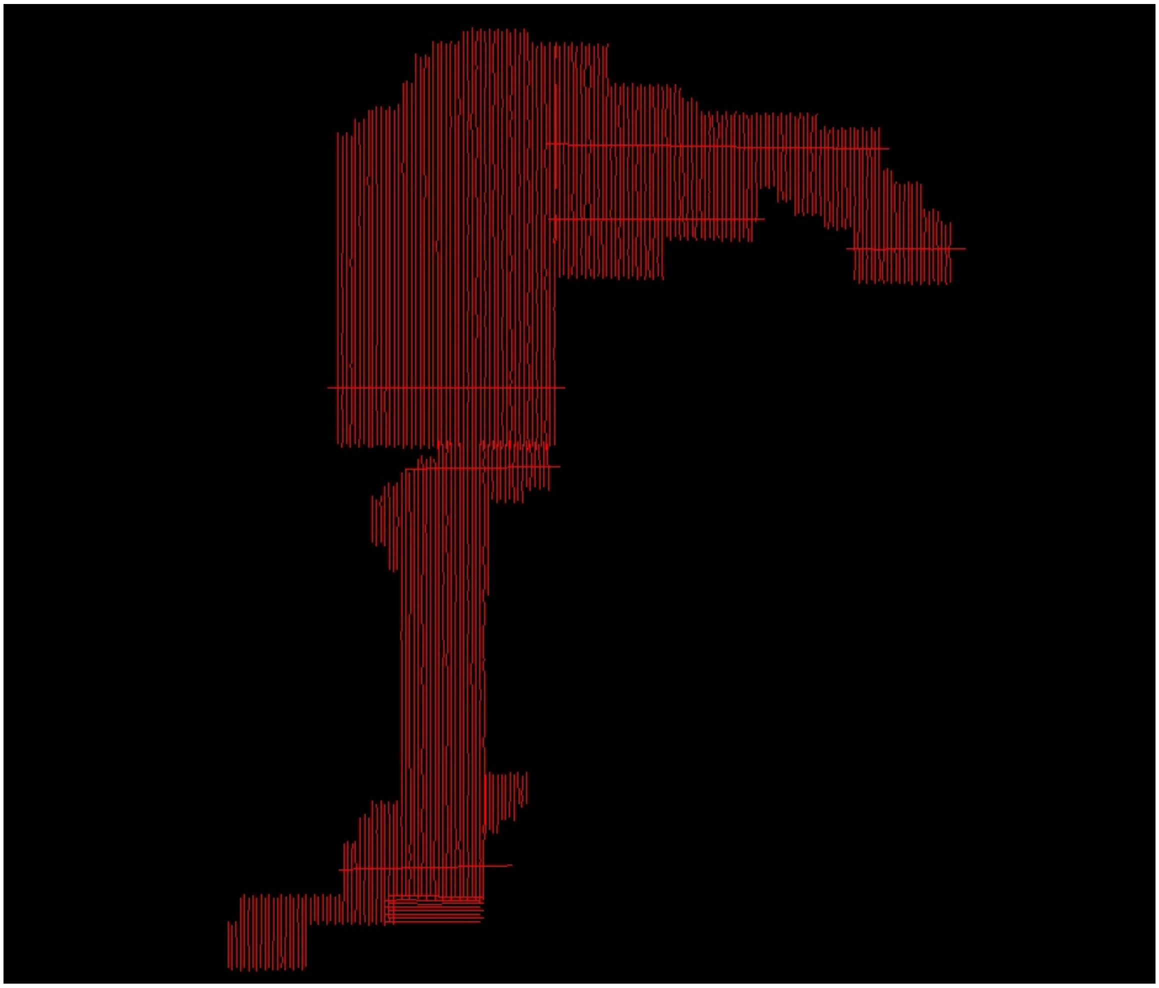


Figure 3: Area 3 Trajectories as flown by Digital Aerial Solutions

LIDAR CONTROL

Digital Aerial Solutions conducted the survey which provided the two (2) newly established base stations and eight (8) established CORS Stations that were used to control the lidar acquisition for the FL Suwannee River Lidar project area. The coordinates of all used base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

Name	North American Datum 1983 (2011) State Plane Florida North, U.S. Survey Feet		Orthometric Ht (NAVD88, ft)
	Northing	Easting	
lcq01	436418.8969	2574772.9573	200.1941
X6001	136678.2026	2614397.3560	67.3001
BKVL	136785.2721	2620389.8556	74.4486

DUNN	28955.2621	2648767.6018	69.8091
GNVL	256559.5018	2674388.1342	23.933
ORMD	116436.8079	2730678.8929	31.2773
PLTK	252266.8907	2861623.1929	34.0623
PRRY	393156.6906	2261189.2551	48.8118
XCTY	232178.5717	2410704.2221	45.7482
ZJX1	627098.2608	2783067.9282	103.3570

Table 2 – Base stations used to control lidar acquisition

AIRBORNE GPS KINEMATIC

Airborne GPS data was processed using the Inertial Explorer software suite. Flights were flown with a minimum of 6 satellites in view (10° above the horizon) and with PDOP of better than 4. Distances form base stations to aircraft were kept to a maximum of 55 km. For all flights, the GPS data can be classified as excellent, with GPS residuals of 3 cm average or better but not larger than 10 cm being recorded. GPS Processing reports for each mission are included Appendix C.

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Subsequently the mission points are output using Leica CloudPro, initially with default values from CloudPro or the last mission calibrated from the system. The initial point generation for each mission calibrated is verified within Microstation/Terrascan for calibration errors. If a calibration greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.
Data collected by the lidar unit is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

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

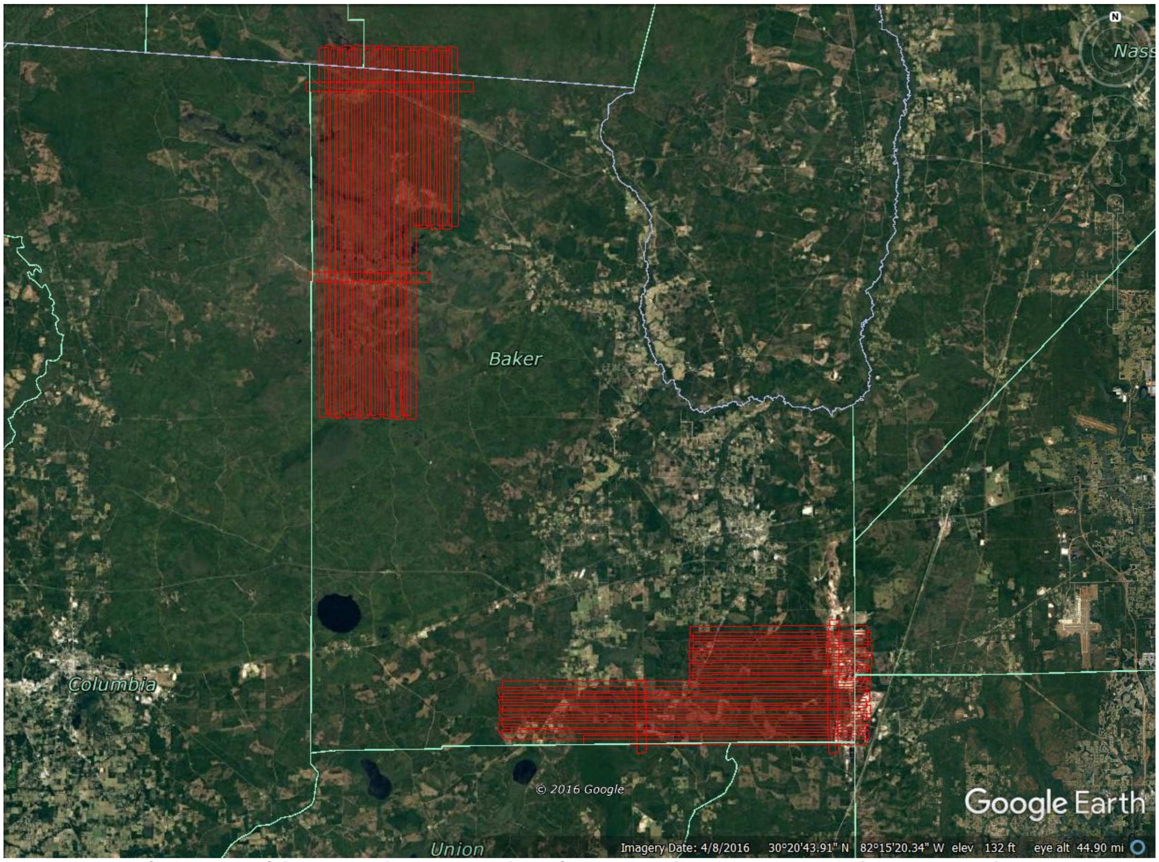


Figure 4: Lidar Swath output showing complete coverage of Area 1 and 2.

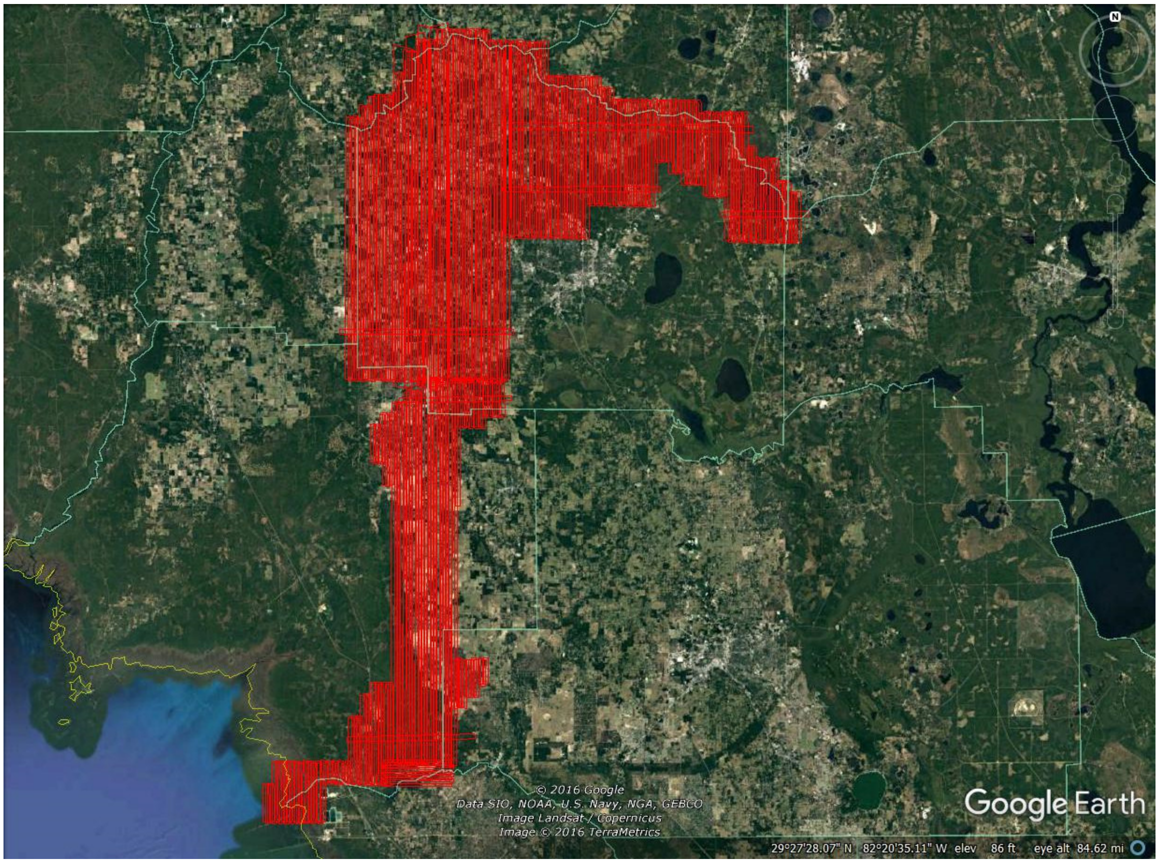


Figure 5: Lidar Swath output showing complete coverage of Area 3.

BORESIGHT AND RELATIVE ACCURACY

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.

Relative accuracy and internal quality are checked using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

For this project the specifications used are as follow:
Relative accuracy <= 6 cm maximum difference within individual swaths and <=8 cm RMSDz between adjacent and overlapping swaths.

Figure 6 – Profile views showing correct roll and pitch adjustments.

Figure 7: Area 1 & 2 QC block colored by distance to ensure accuracy at swath edges.

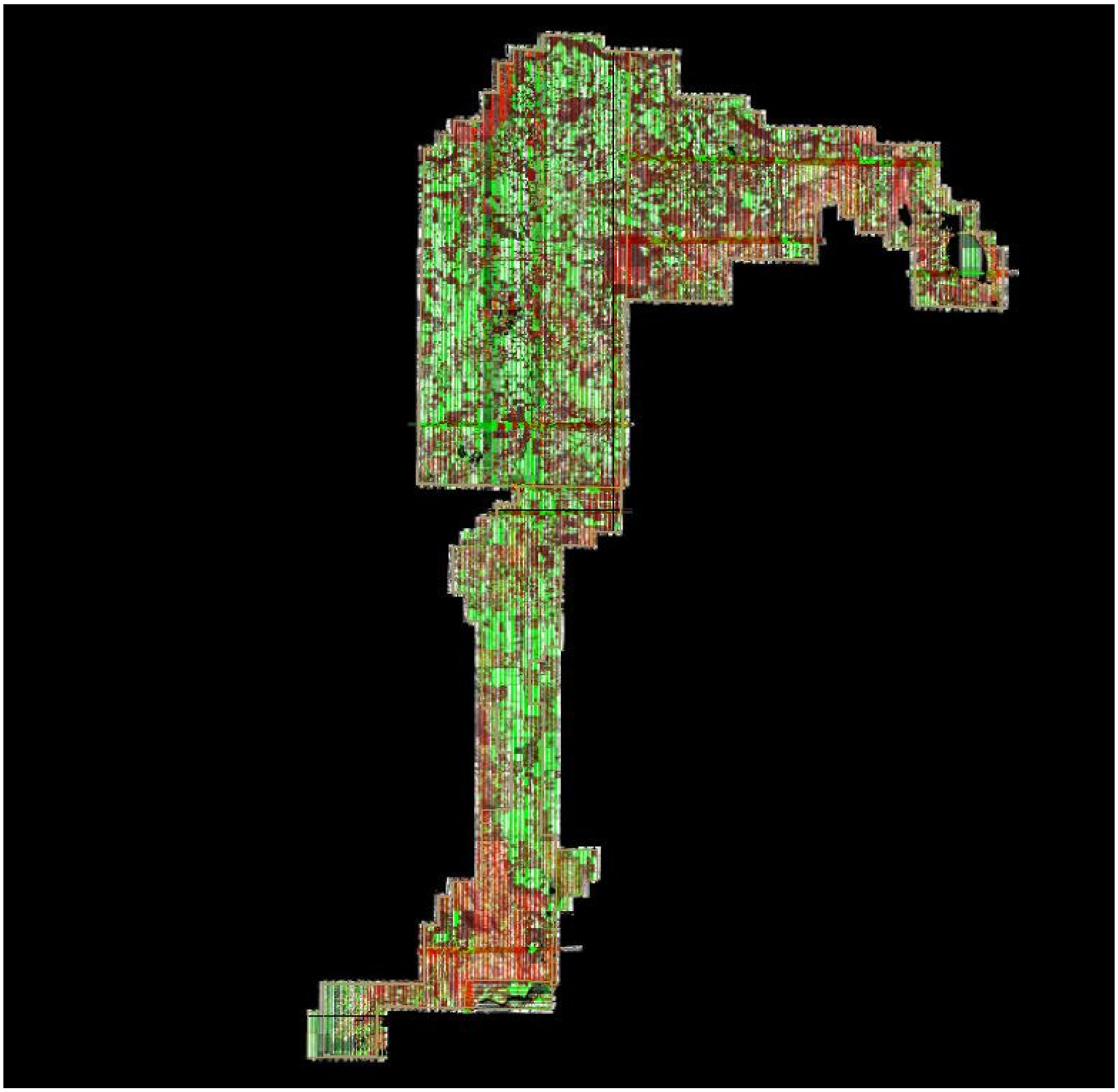


Figure 8: Area 3 QC block colored by distance to ensure accuracy at swath edges.

A different set of QC blocks are generated for final review after all transformations have been applied.

Lidar Processing & Qualitative Assessment

INITIAL PROCESSING

Once Dewberry receives the calibrated swath data from the acquisition provider, Dewberry performs several validations on the dataset prior to starting full-scale production on the project. These validations include vertical accuracy of the swath data, inter-swath (between swath) relative accuracy validation, intra-swath (within a single swath) relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allows Dewberry to determine if the data are suitable for full-scale production. Addressing issues at this stage allows the data to be corrected while imposing the least disruption possible on the overall production workflow and overall schedule.

Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Digital Aerial Solutions, Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the ninety-three non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 0.64 ft (19.6 cm) based on the $RMSE_z$ (0.33 ft/10 cm) x 1.96. The dataset for the Suwannee River lidar satisfies this criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.33 ft (10 cm) $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 0.18 ft (5.5 cm), equating to +/- 0.34 ft (10.4 cm) at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.33 ft	NVA –Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.64 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Min (ft)	Max (ft)	Kurtosis
Non-Vegetated Terrain	93	0.18ft	0.34	-0.03	-0.01	-0.25	0.17	-0.49	0.31	-0.47

Table 3: NVA at 95% Confidence Level for Raw Swaths

Inter-Swath (Between Swath) Relative Accuracy

Dewberry verified inter-swath or between swath relative accuracy of the dataset by creating Delta-Z (DZ) orthos. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet inter-swath relative accuracy of 8 cm RMSDz or less with maximum differences less than 16 cm. These measurements are to be taken in non-vegetated and flat open terrain using single or only returns from all classes. Measurements are calculated in the DZ orthos on 1-meter pixels or cell sizes. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored green, areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm to 16 cm are colored yellow, and areas in the dataset where overlapping flight lines have elevation differences in each pixel greater than 16 cm are colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across 1 linear meter) are expected to appear yellow or red in the DZ orthos. If the project area is heavily vegetated, Dewberry may also create DZ Orthos from the initial ground classification only, while keeping all other parameters consistent. This allows Dewberry to review the ground classification relative accuracy beneath vegetation and to ensure flight line ridges or other issues do not exist in the final classified data.

Flat, open areas are expected to be green in the DZ orthos. Large or continuous sections of yellow or red pixels can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data, especially when these yellow/red sections follow the flight lines and not the terrain or areas of vegetation. The DZ orthos for Suwannee River Lidar are shown in the figure below; this project meets inter-swath relative accuracy specifications.

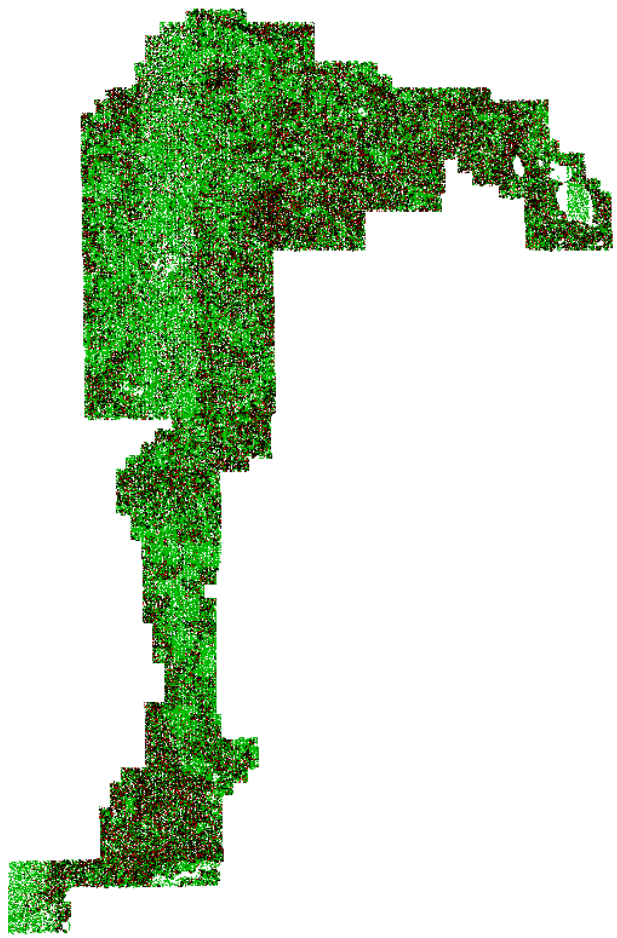
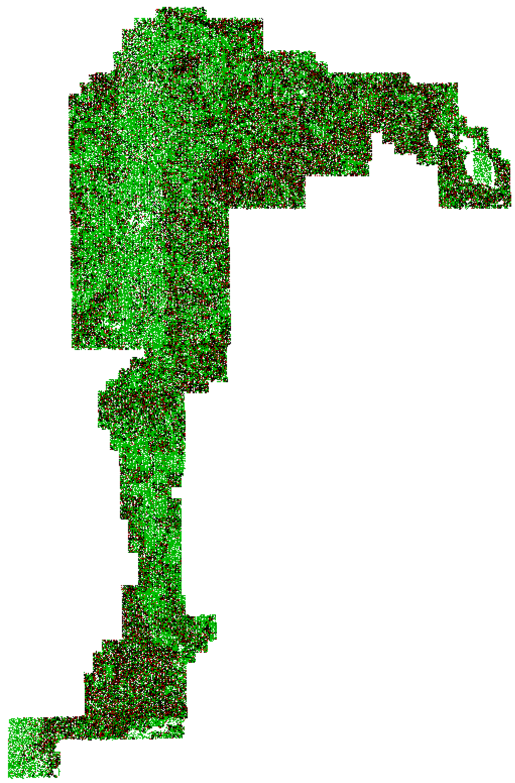


Figure 9- Single return DZ Orthos for the Suwannee River lidar Project (Block 3). Inter-swath relative accuracy passes specifications.

Intra-Swath (Within a Single Swath) Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using Quick Terrain Modeler (QTM) scripting and visual reviews. QTM scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry analysts then identify planar surfaces acceptable for repeatability testing and analysts review the QTM results in those areas. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet intra-swath relative accuracy of 6 cm maximum difference or less. The image below shows two examples of the intra-swath relative accuracy of Suwannee River lidar; this project meets intra-swath relative accuracy specifications.



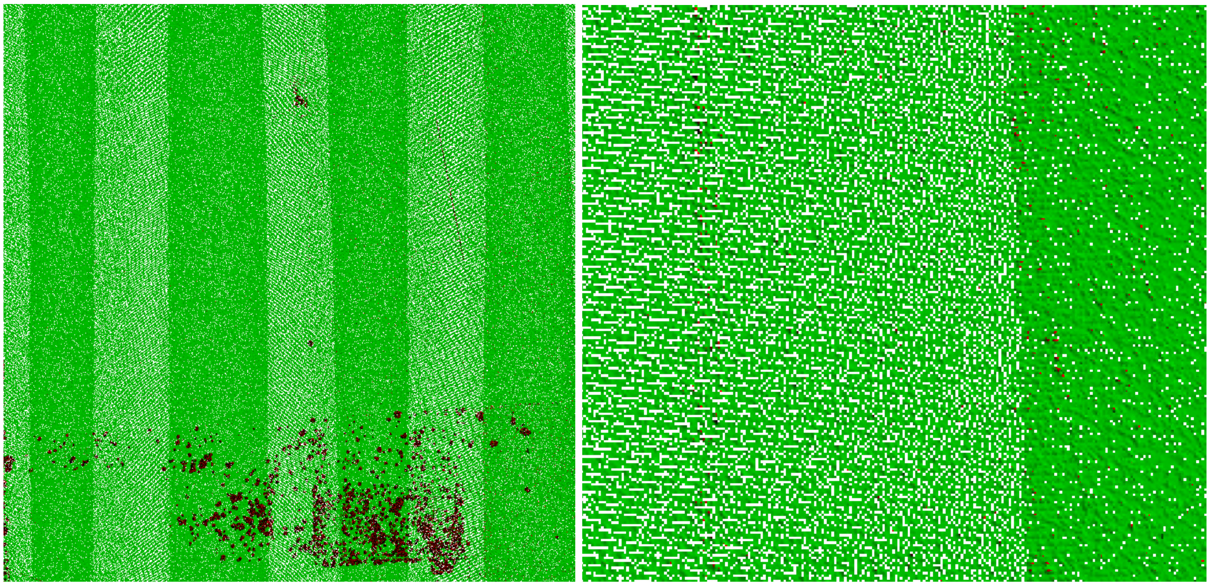


Figure 10–Intra-swath relative accuracy. The top image shows the full project area (block 3); areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The left image shows a large portion of the dataset; flat, open areas are colored green as they are within 6 cm whereas sloped terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change. The right image is a close-up of a flat area. With the exception of vegetation (shown in red in the bottom left image as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.

Horizontal Alignment

To ensure horizontal alignment between adjacent or overlapping flight lines, Dewberry uses QTM scripting and visual reviews. QTM scripting is used to create files similar to DZ orthos for each swath but this process highlights planar surfaces, such as roof tops. In particular, horizontal shifts or misalignments between swaths on roof tops and other elevated planar surfaces are highlighted. Visual reviews of these features, including additional profile verifications, are used to confirm the results of this process. The image below shows an example of the horizontal alignment between swaths for Suwannee River lidar; no horizontal alignment issues were identified.

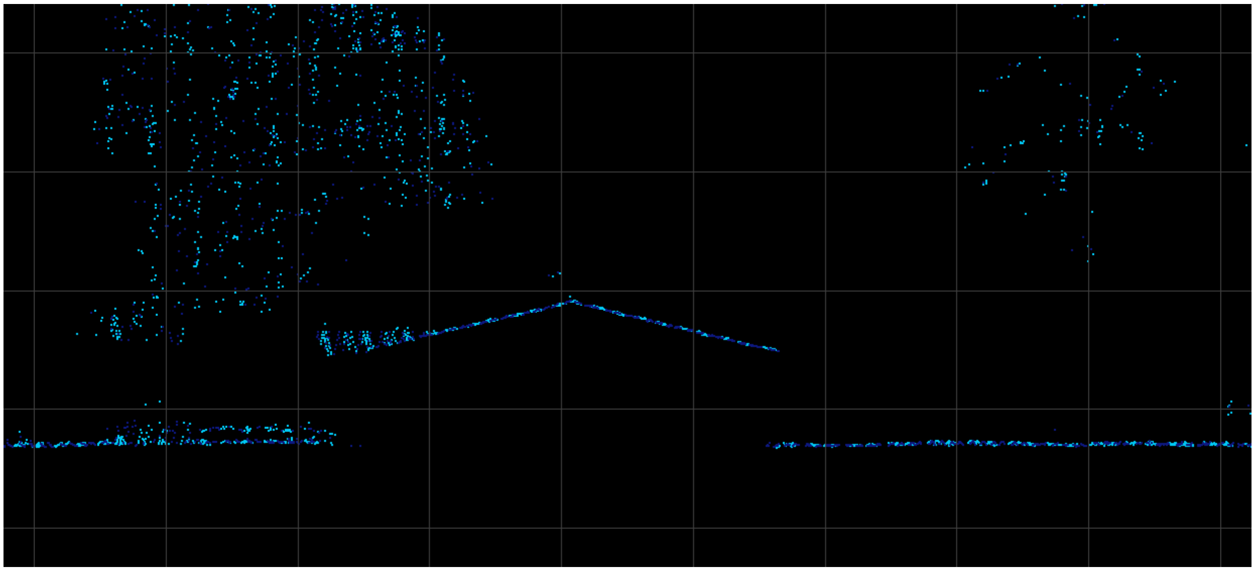


Figure 11– Horizontal Alignment. Two separate flight lines differentiated by color (Cyan/Blue) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.71 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 2 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.42 meters or an ANPD of 5.70 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) may result in some 1-meter cells which do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.

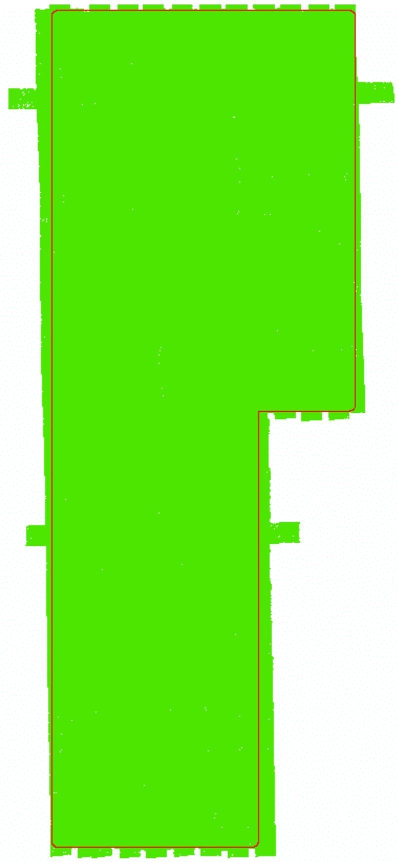


Figure 12– 1-square meter density grid. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) showing there are no systematic density issues. When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues.

The spatial distribution of points must be uniform and free of clustering. This specification is tested by creating a grid with cell sizes equal to the design NPS*2. ArcGIS tools are then used to calculate the number of first return points of each swath within each grid cell. At least 90% of the cells must contain 1 lidar point, excluding acceptable void areas such as water or low NIR reflectivity features, i.e. some asphalt and roof composition materials. This project passes spatial distribution requirements, as shown in the image below.

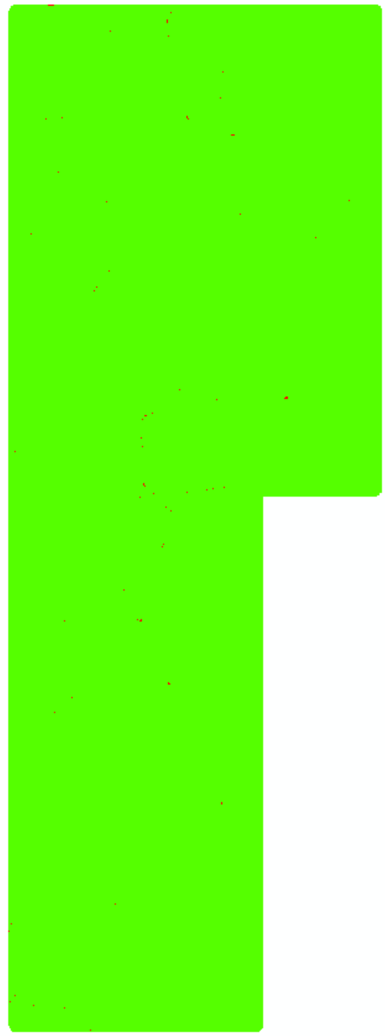


Figure 13– Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies which are acceptable NoData area, are colored red. Without removing acceptable NoData areas due to water, 99.5% of cells contain at least one lidar point.

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies 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 are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud.

The ground extraction process encompassed in this routine takes place by building an iterative surface model.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

Each tile was then 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 conducted by Dewberry. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. Bridge decks are classified to class 17 using bridge breaklines compiled by Dewberry. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that are within 1x NPS or less of the hydrographic features are moved to class 10, an ignored ground due to breakline proximity. Overage points are then identified in Terrascan and GeoCue is used to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 10, 17, or 18, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity
- Class 17 = Bridge Decks
- Class 18 = High Noise

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

Lidar Qualitative Assessment

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a bare-earth digital terrain model (DTM). This includes creating pseudo image products such as lidar orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models as well as reviewing the actual point cloud data. This process looks for anomalies in the data, areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model, and other classification errors. This report will present representative examples where the lidar and post processing had issues as well as examples of where the lidar performed well.

VISUAL REVIEW

The following sections describe common types of issues identified in lidar data and the results of the visual review for Suwannee River lidar.

Data Voids

The LAS files are used to produce density grids using the commercial software package QT Modeler (QTM) which creates a 3-dimensional data model derived from Class 2 (ground) points in the LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. Acceptable voids (areas with no lidar returns in the LAS files) that are present in the majority of lidar projects include voids caused by bodies of water. No unacceptable voids are present in the Suwannee River lidar project.

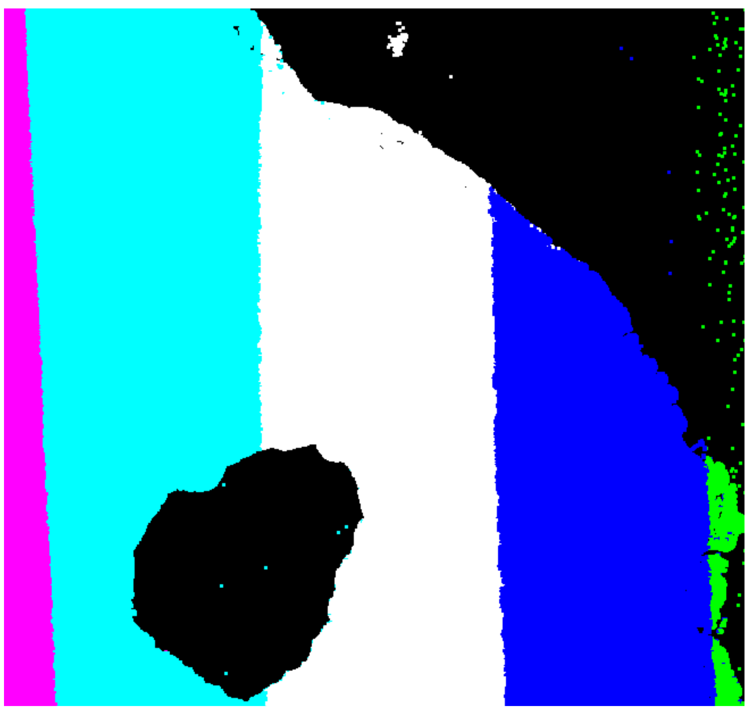


Figure 14 – Tile number LID2017675437_N. Plan view of points (colored by flightlines) in an area of acceptable voids (water bodies).

Artifacts

Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 1 foot or less above the actual ground surface, and should not negatively impact the usability of the dataset.

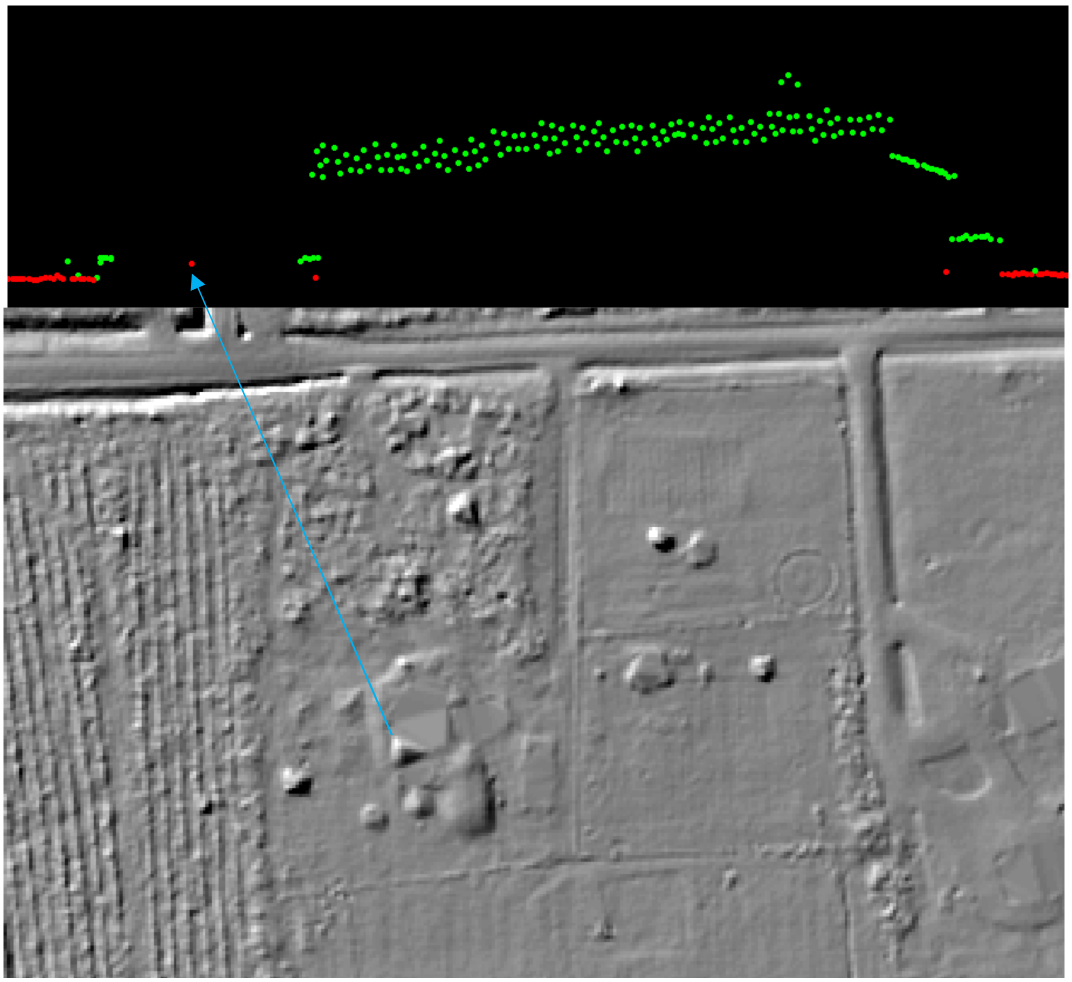


Figure 15 – Tile number LID2017_673260_N. Profile with points colored by class (class 1=green, class 2=red) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies an errant ground point. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

Bridge Removal Artifacts

The DEM surface models are created from TINs or Terrains. TIN and Terrain models create continuous surfaces from the inputs. Because a continuous surface is being created, the TIN or Terrain will use interpolation to continue the surface beneath the bridge where no lidar data was acquired. Locations where bridges were removed will generally contain less detail in the bare-earth surface because these areas are interpolated.

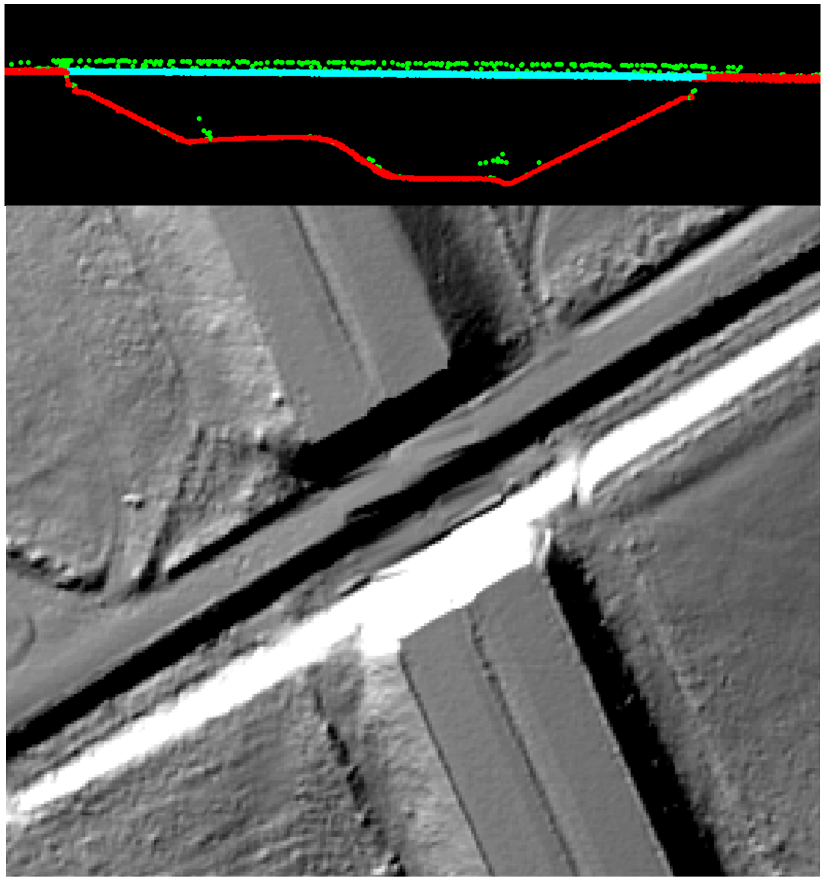


Figure 16 – Tile number LID2017_673790_N. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (red) and are classified to bridge deck (cyan).

Culverts and Bridges

Bridges have been removed from the bare earth surface while culverts remain in the bare earth surface. In instances where it is difficult to determine if the feature is a culvert or bridge, such as with some small bridges, Dewberry erred on assuming they would be culverts especially if they are on secondary or tertiary roads. Below is an example of a culvert that has been left in the ground surface.

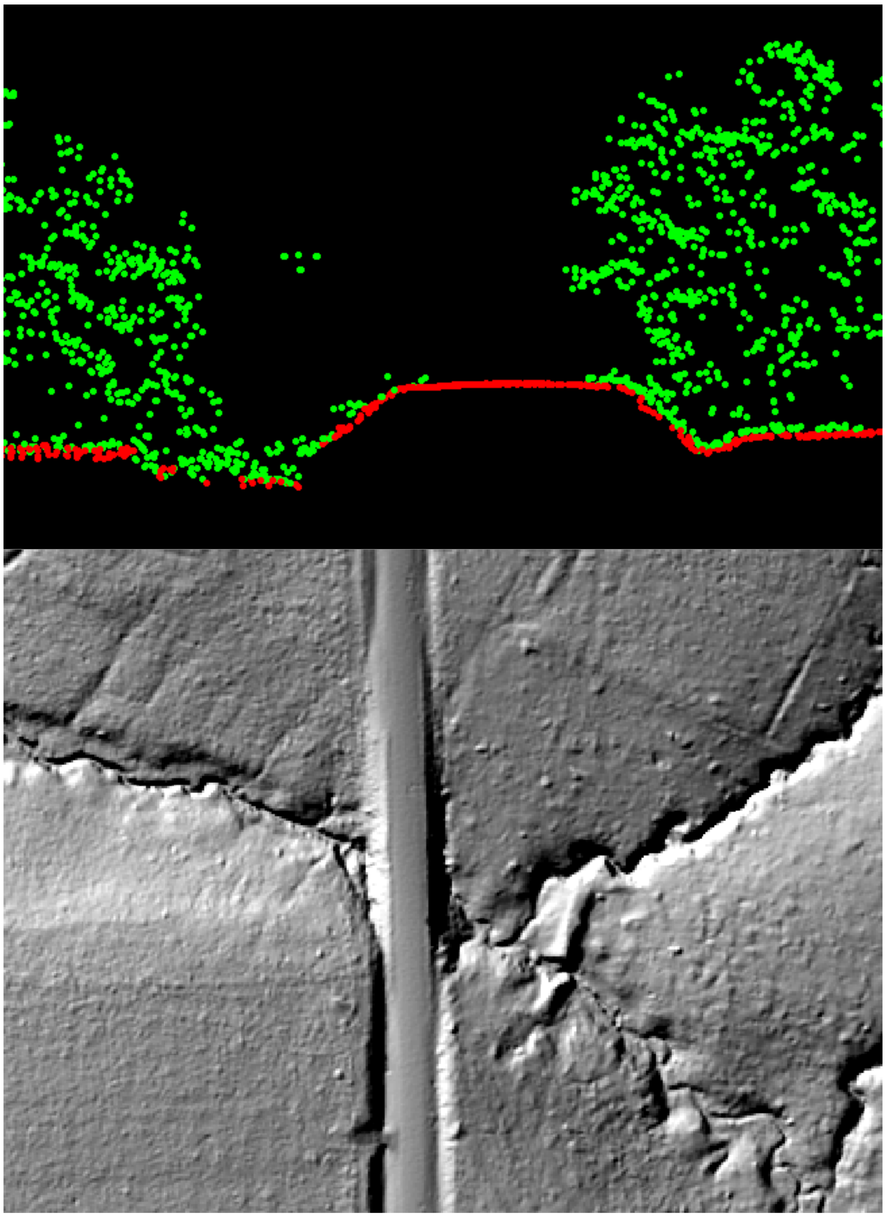


Figure 17– Tile number LID2017_671091_N. Profile with points colored by class (class 1=green, class 2=red) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface.

Dirt Mounds

Irregularities in the natural ground exist and may be misinterpreted as artifacts that should be removed. Small hills and dirt mounds are present throughout the project area. These features are correctly included in the ground.

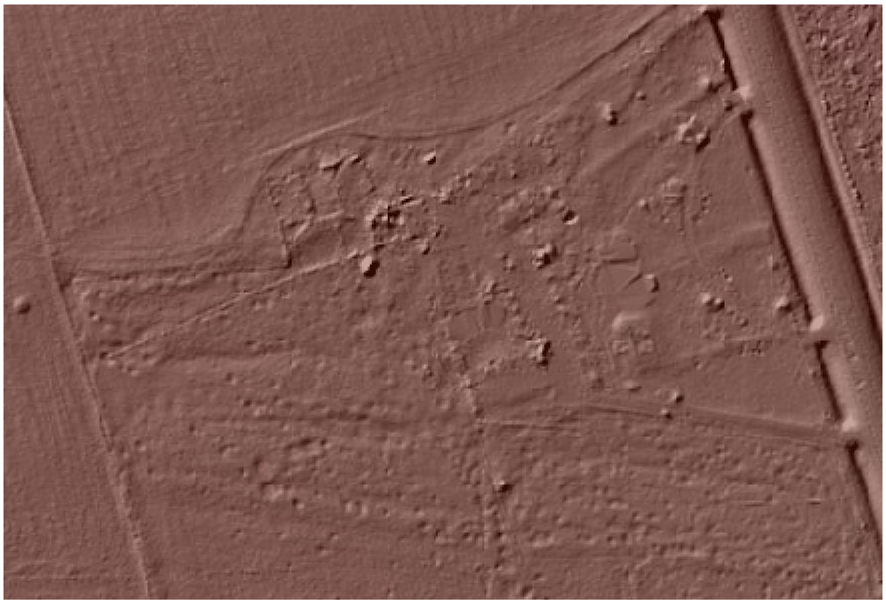


Figure 18 - Tile LID2017_670017_N. DEM of the surface is shown in the view. These features are correctly included in the ground classification.

Elevation Change Within Breaklines

While water bodies are flattened in the final DEMs, other features such as linear hydrographic features can have significant changes in elevation within a small distance. In linear hydrographic features, this is often due to the presence of a structure that affects flow such as a dam or spillway. Dewberry has reviewed the DEMs to ensure that changes in elevation are shown from bank to bank. These changes are often shown as steps to reduce the presence of artifacts while ensuring consistent downhill flow. An example is shown below.

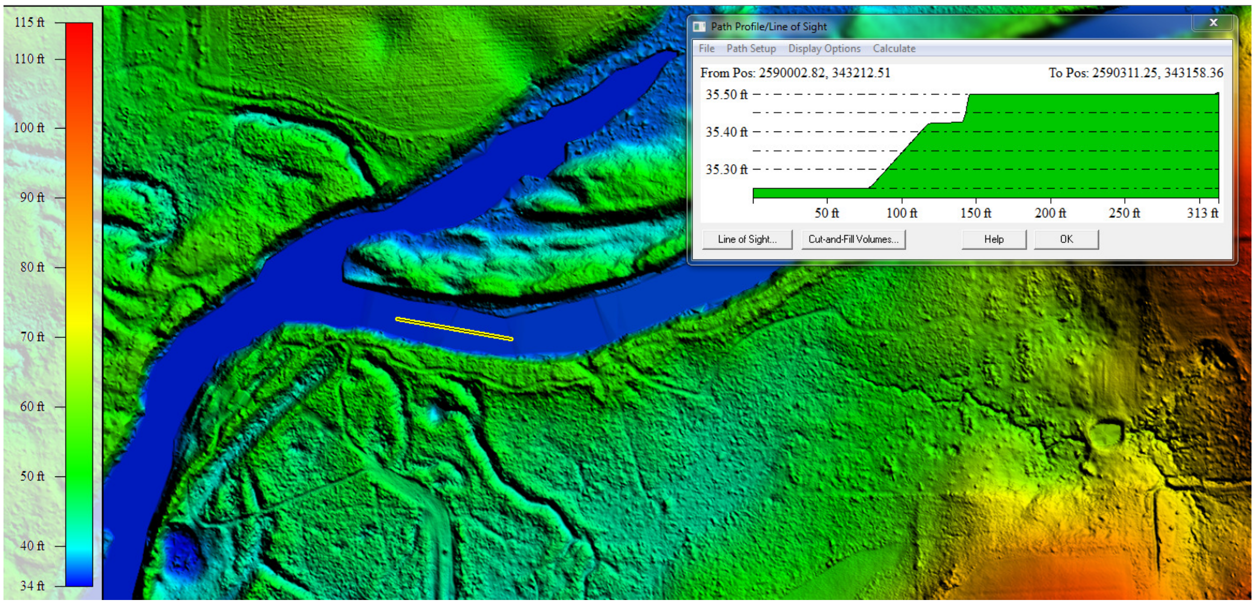


Figure 19 – Tile number LID2017_667849_N. Elevation change has been stair stepped. The steps are flat from bank to bank and flow consistently downhill.

Marsh Areas

It is sometimes difficult to determine true ground in low wet areas; the lowest points available are used to represent ground. Marsh areas are present within the project area and were not collected with breaklines as they are not open bodies of water. As these areas are not included in the collected breaklines, marsh areas were not flattened in the final DEMs. While low points are used to determine ground in marsh areas, there is often greater variation within the low points due to wet soils that cause greater interpolation between points, and undulating or uneven ground. An example is shown below.

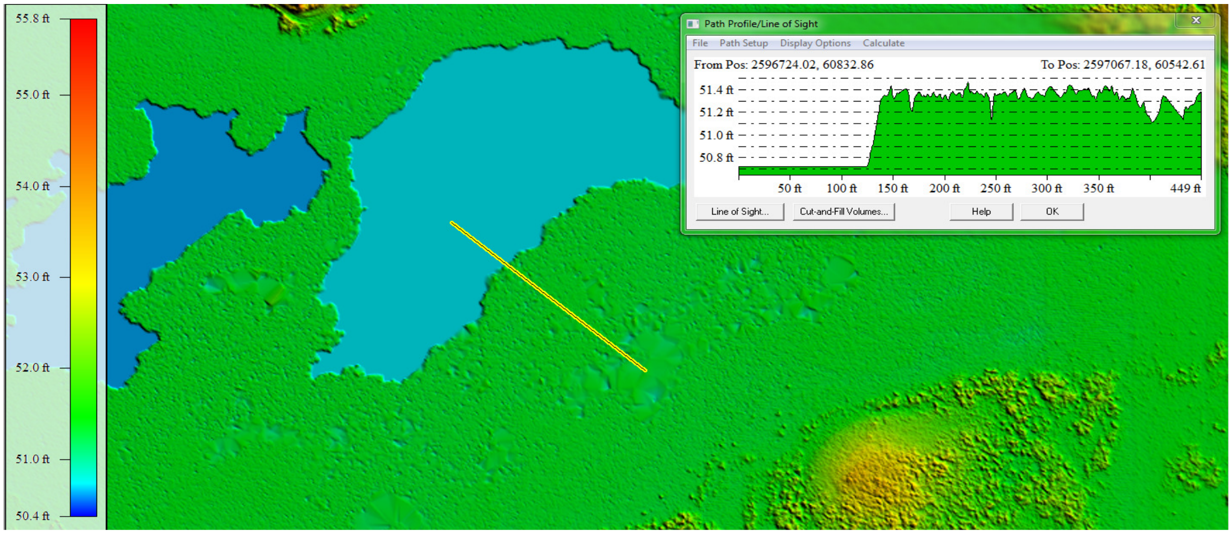


Figure 20 - Tile LID2017_698090_N. The area on the right shows a marsh area that was not included in the collected breaklines. Due to wet soils and broken terrain, the point density in marsh areas is sparser than surrounding areas and there is more variation in the low points representing ground.

FORMATTING

After the final QA/QC is performed and all corrections have been applied to the dataset, all lidar files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using Dewberry proprietary tools. The table below lists some of the main lidar header fields that are updated and verified.

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) Florida State Plane North and West, US Survey feet and NAVD88 (Geoid 12B), feet in WKT Format	Pass
Global Encoder Bit	Should be set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Should be set to the processing system/software and is set to NIIRS10 for GeoCue software	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 are recorded for each pulse	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 7: Low Noise	Pass

	Class 9: Water Class 10: Ignored Ground Class 17: Bridge Decks Class 18: High Noise	
Overlap and Withheld Points	Overlap (Overage) and Withheld points are set to the Overlap and Withheld bits	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Lidar Positional Accuracy

BACKGROUND

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to that of the interpolated value within the three closest lidar points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the lidar data is actually tested. However there is an increased level of confidence with lidar data due to the relative accuracy. This relative accuracy in turn is based on how well one lidar point "fits" in comparison to the next contiguous lidar measurement, and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Dewberry also tests the horizontal accuracy of lidar datasets when checkpoints are photo-identifiable in the intensity imagery. Photo-identifiable checkpoints in intensity imagery typically include checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90 degree corners of different reflectivity, e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints, as defined in the intensity imagery, are compared to surveyed XY coordinates for each photo-identifiable checkpoint. These differences are used to compute the tested horizontal accuracy of the lidar. As not all projects contain photo-identifiable checkpoints, the horizontal accuracy of the lidar cannot always be tested.

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, one hundred (144) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see appendix A to view the survey report which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area so as to cover as many flight lines as possible using the "dispersed method" of placement.

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table.

Point ID	NAD83 (2011) State Plane Florida North		NAVD88 (Geoid 12B)
	Easting X (ft)	Northing Y (ft)	Elevation (ft)
NVA-101	2622995.07	576005.43	131.59
NVA-102	2630508.53	575387.95	125.35
NVA-103	2637852.85	572134.63	127.32
NVA-104	2636938.91	561319.31	125.67
NVA-105	2630976.91	560295.65	125.65
NVA-106	2621848.17	559827.75	124.70
NVA-107	2615316.89	546873.72	127.28
NVA-108	2627116.35	543881.74	125.12
NVA-109	2636199.42	548550.38	126.07
NVA-110	2644656.09	549437.57	126.26
NVA-112	2625224.17	533831.48	126.98
NVA-113	2616267.62	535939.19	126.43
NVA-114	2622265.48	522345.08	134.24
NVA-115	2634189.54	524806.55	131.36
NVA-116	2633223.03	512879.99	129.06
NVA-117	2623687.74	512157.96	131.90
NVA-118	2615608.02	512857.24	135.90
NVA-119	2615302.74	503316.59	134.26
NVA-120	2622748.61	583019.51	118.69
NVA-121	2660405.01	432566.73	132.58
NVA-122	2663133.76	425486.20	141.77
NVA-123	2673504.26	433475.56	133.36
NVA-124	2689010.29	433359.74	123.65
NVA-125	2687846.61	425651.80	137.33
NVA-126	2702732.07	434451.75	134.19
NVA-127	2699987.51	425944.43	136.02
NVA-128	2709880.50	449867.08	138.06
NVA-129	2707242.62	442377.45	134.52
NVA-130	2717047.29	448692.16	139.39
NVA-131	2716390.61	441447.13	150.54
NVA-132	2715077.29	433965.59	142.14
NVA-133	2715545.37	425252.84	138.51
NVA-134	2728599.71	449496.62	139.36
NVA-135	2725573.37	440398.99	142.38
NVA-136	2730803.55	433258.87	143.16
NVA-137	2726553.22	425541.38	144.75
NVA-138	2737027.61	449402.41	172.24

NVA-139	2743276.49	445167.43	149.26
NVA-140	2744356.92	425699.72	176.79
NVA-141	2524734.32	4866.85	5.12
NVA-142	2539959.11	15985.77	4.66
NVA-143	2555954.50	16483.98	16.77
NVA-144	2569457.63	15224.22	32.50
NVA-145	2561352.11	31495.71	43.45
NVA-146	2585690.98	20946.49	43.65
NVA-147	2600348.44	28438.54	59.24
NVA-148	2593252.45	36519.61	79.13
NVA-149	2586817.36	48444.80	72.38
NVA-150	2563619.90	48384.34	30.45
NVA-151	2574850.55	57982.67	55.85
NVA-152	2604834.33	51951.58	80.40
NVA-153	2605575.87	62500.41	136.04
NVA-154	2587126.44	65041.82	58.92
NVA-155	2580268.52	80971.23	58.81
NVA-156	2593822.39	81106.75	88.38
NVA-157	2585827.90	98808.48	83.64
NVA-158	2594822.15	100013.60	62.13
NVA-159	2581904.00	115612.07	84.48
NVA-160	2585268.92	126824.96	87.01
NVA-161	2569422.60	157925.59	70.07
NVA-162	2585128.44	160393.72	83.21
NVA-163	2607670.03	182331.14	65.97
NVA-164	2551410.10	206824.46	62.78
NVA-165	2583665.49	227397.00	86.22
NVA-166	2598886.14	226118.07	84.46
NVA-167	2605060.81	241803.51	85.57
NVA-168	2618654.94	240493.31	124.78
NVA-169	2618327.82	256393.38	89.65
NVA-170	2581897.84	259171.12	103.72
NVA-171	2553446.59	269018.04	92.06
NVA-172	2582380.68	268673.81	91.89
NVA-173	2583853.99	289782.37	85.41
NVA-174	2565177.18	303814.40	69.85
NVA-175	2581855.05	301030.39	96.24
NVA-176	2597047.19	304621.40	74.04
NVA-177	2581142.73	319396.33	58.30
NVA-178	2614444.60	291035.94	87.15
NVA-179	2600075.36	343753.87	75.27
NVA-180	2612582.45	336564.59	88.39
NVA-181	2625319.26	339187.90	79.61
NVA-182	2632604.85	311354.89	145.37
NVA-183	2654415.66	329857.27	118.14
NVA-184	2648502.48	281495.15	168.99
NVA-185	2674038.95	276906.03	166.64
NVA-186	2678335.11	311192.57	147.87
NVA-187	2691379.88	312005.73	136.66
NVA-188	2708309.62	295359.79	155.64
NVA-189	2716960.27	284099.02	168.66

NVA-190	2728463.67	267547.43	176.70
NVA-191	2630923.65	530839.71	132.92
NVA-192	2681680.78	429869.59	139.19
NVA-193	2638957.93	261094.79	172.92
NVA-194	2563969.82	165764.38	74.67
VVA-201	2618481.94	573058.93	128.16
VVA-202	2637306.30	566086.35	124.34
VVA-203	2623167.33	564693.56	123.81
VVA-204	2633722.73	554852.01	125.77
VVA-205	2619891.36	530402.80	133.41
VVA-206	2674289.21	426359.84	134.00
VVA-207	2705640.63	439316.97	129.62
VVA-208	2709674.09	429201.44	149.55
VVA-209	2737527.31	446491.79	173.52
VVA-210	2742063.87	433579.61	176.55
VVA-211	2554829.77	20107.88	14.19
VVA-212	2576920.69	142332.17	65.71
VVA-213	2592825.01	145300.81	95.33
VVA-214	2597507.53	161694.65	60.85
VVA-215	2569501.78	176830.82	95.75
VVA-216	2589180.23	177053.02	91.59
VVA-217	2586509.66	191976.94	94.60
VVA-218	2615785.93	192528.71	70.65
VVA-219	2559873.36	206292.51	74.59
VVA-220	2579676.79	211046.34	58.93
VVA-221	2599412.06	208658.51	74.45
VVA-222	2613463.61	212576.85	70.50
VVA-223	2554387.34	224066.23	93.72
VVA-224	2567243.44	226619.04	82.57
VVA-225	2612610.61	225459.16	73.65
VVA-226	2550760.78	237555.98	96.30
VVA-227	2585619.49	240562.32	89.79
VVA-228	2606625.89	253743.29	88.15
VVA-229	2553728.49	258000.04	82.27
VVA-230	2569436.89	256572.38	74.85
VVA-231	2568306.54	269461.48	74.77
VVA-232	2599916.31	270155.32	97.64
VVA-233	2638422.96	272778.58	186.82
VVA-234	2629983.88	286992.13	167.14
VVA-235	2598918.84	288958.55	92.87
VVA-236	2568845.28	288134.17	75.14
VVA-237	2553086.71	288137.47	80.35
VVA-238	2550579.17	303567.69	52.06
VVA-239	2566687.31	319545.24	52.99
VVA-241	2591260.18	324930.69	144.62
VVA-242	2597004.79	336373.94	139.57
VVA-243	2613323.17	306439.89	135.45
VVA-244	2617680.93	321517.09	169.50
VVA-245	2628509.42	325110.35	132.27
VVA-246	2651218.11	305830.74	147.27
VVA-247	2660065.29	316995.79	116.22

VVA-248	2662733.65	296753.44	162.76
VVA-249	2737060.97	289187.59	146.91
VVA-250	2743913.87	282192.78	151.91
VVA-251	2605040.98	316819.64	124.56
VVA-252	2565462.35	42195.37	34.32

Table 4- Suwannee River lidar surveyed accuracy checkpoints

The figure below shows the location of the QA/QC checkpoints used to test the positional accuracy of the dataset.

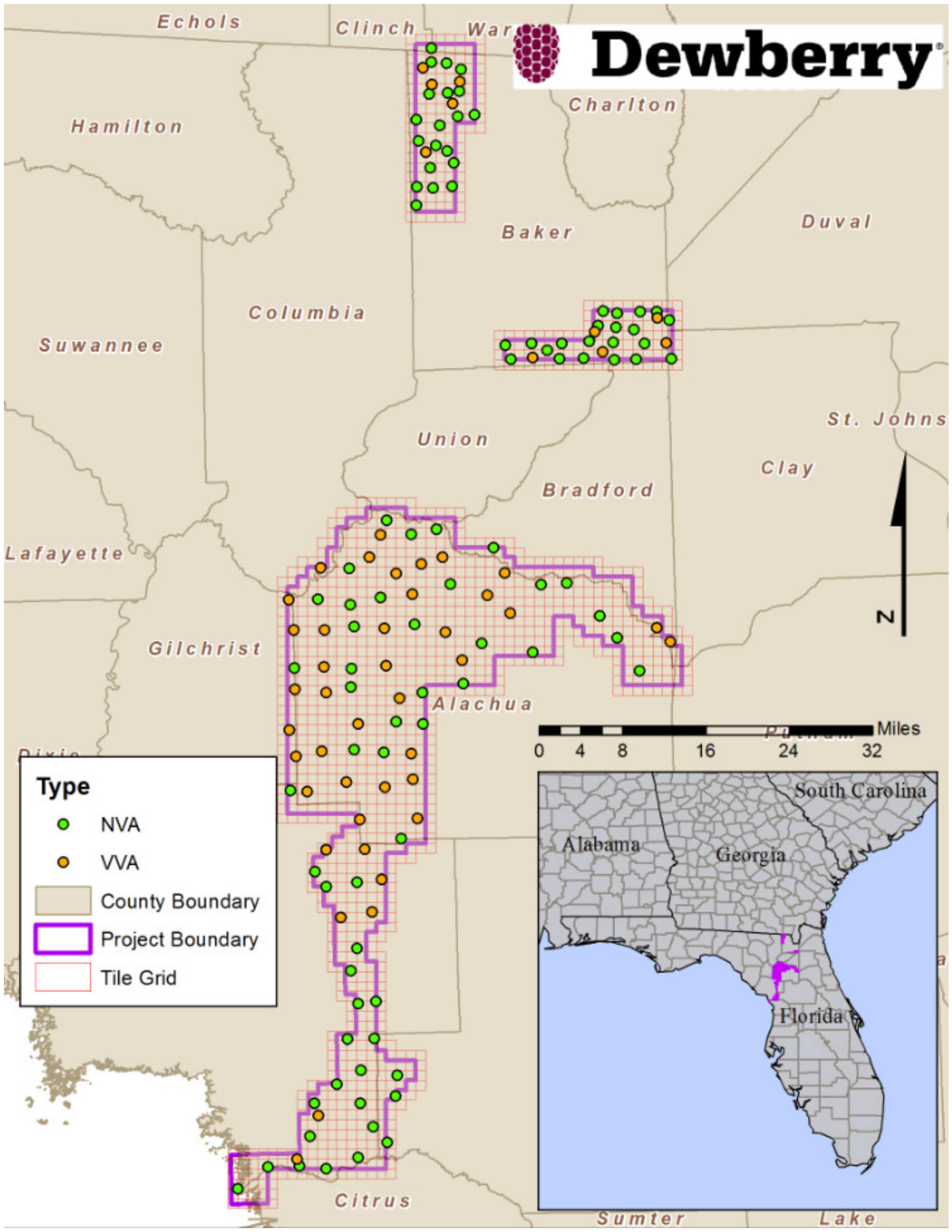


Figure 21 – Location of QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, where there is a very high probability that the lidar sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The NVA determines how well the calibrated lidar sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error

($RMSE_z$) of the checkpoints x 1.9600. For the Suwannee River lidar project, vertical accuracy must be 0.64 ft (19.6 cm) or less based on an $RMSE_z$ of 0.33 ft (10 cm) x 1.9600.

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in all vegetated land cover categories combined. The Suwannee River lidar Project VVA standard is 0.96 ft (29.4 cm) based on the 95^{th} percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 5.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	0.64 ft/19.6 cm (based on $RMSE_z$ (0.33 ft/10 cm) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	0.96 ft/29.4 cm (based on combined 95^{th} percentile)

Table 5 – Acceptance Criteria

The primary QA/QC vertical accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications.
2. Next, Dewberry interpolated the bare-earth lidar DTM to provide the z-value for every checkpoint.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the lidar data and the ground truth survey checkpoints and computed NVA, VVA, and other statistics.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

VERTICAL ACCURACY RESULTS

The table below summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified lidar LAS files.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.64 ft	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=0.96 ft

NVA	93	0.35	
VVA	51		0.54

Table 6 — Tested NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.33 ft (10 cm) RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSE$_z$ =0.18 ft (5.5 cm), equating to +/- 0.35 ft (10.7 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.54 ft (16.5 cm) at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within +/- 0.30 ft of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +0.80 ft.

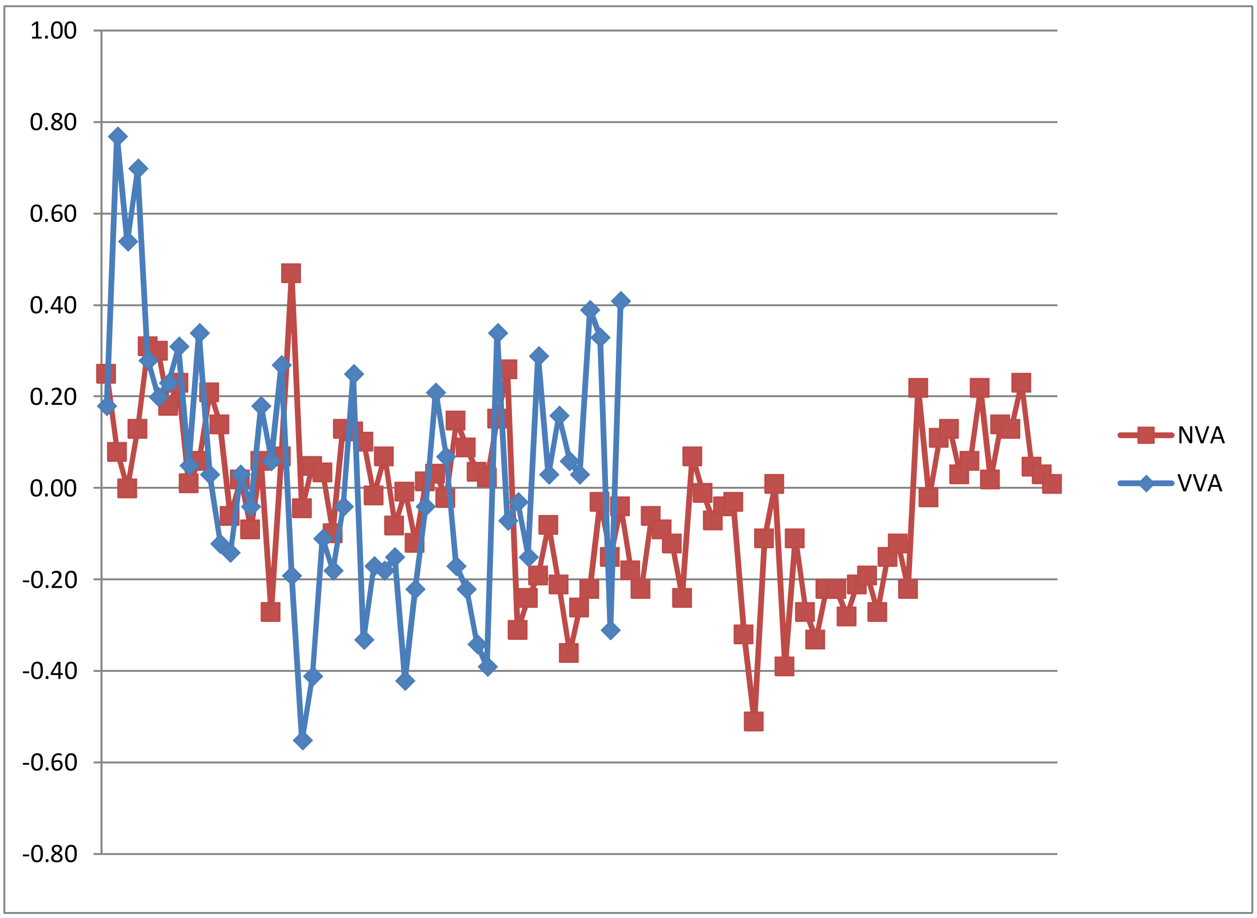


Figure 22 – Magnitude of elevation discrepancies per land cover category

Table 7 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83 (2011) Florida State Plane North		NAVD88 (Geoid 12B)	Lidar Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
VVA-202	2637306.30	566086.35	124.34	125.11	0.77	0.77
VVA-203	2623167.33	564693.56	123.81	124.35	0.54	0.54
VVA-204	2633722.73	554852.01	125.77	126.47	0.70	0.70
VVA-220	2579676.79	211046.34	58.93	58.38	-0.55	0.55

Table 7 — 5% Outliers

Table 8 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
NVA	93.00	0.18	-0.03	-0.01	-0.08	0.18	-0.02	-0.51	0.47
VVA	51.00	N/A	0.03	0.03	0.35	0.29	-0.01	-0.55	0.77

Table 8 — Overall Descriptive Statistics

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.55 feet and a high of +0.77 feet, the histogram shows that the majority of the lidar minus survey checkpoint elevation differences (DZ values) have a negative bias. The vast majority of points are within the ranges of -0.255 feet to +0.255 feet.

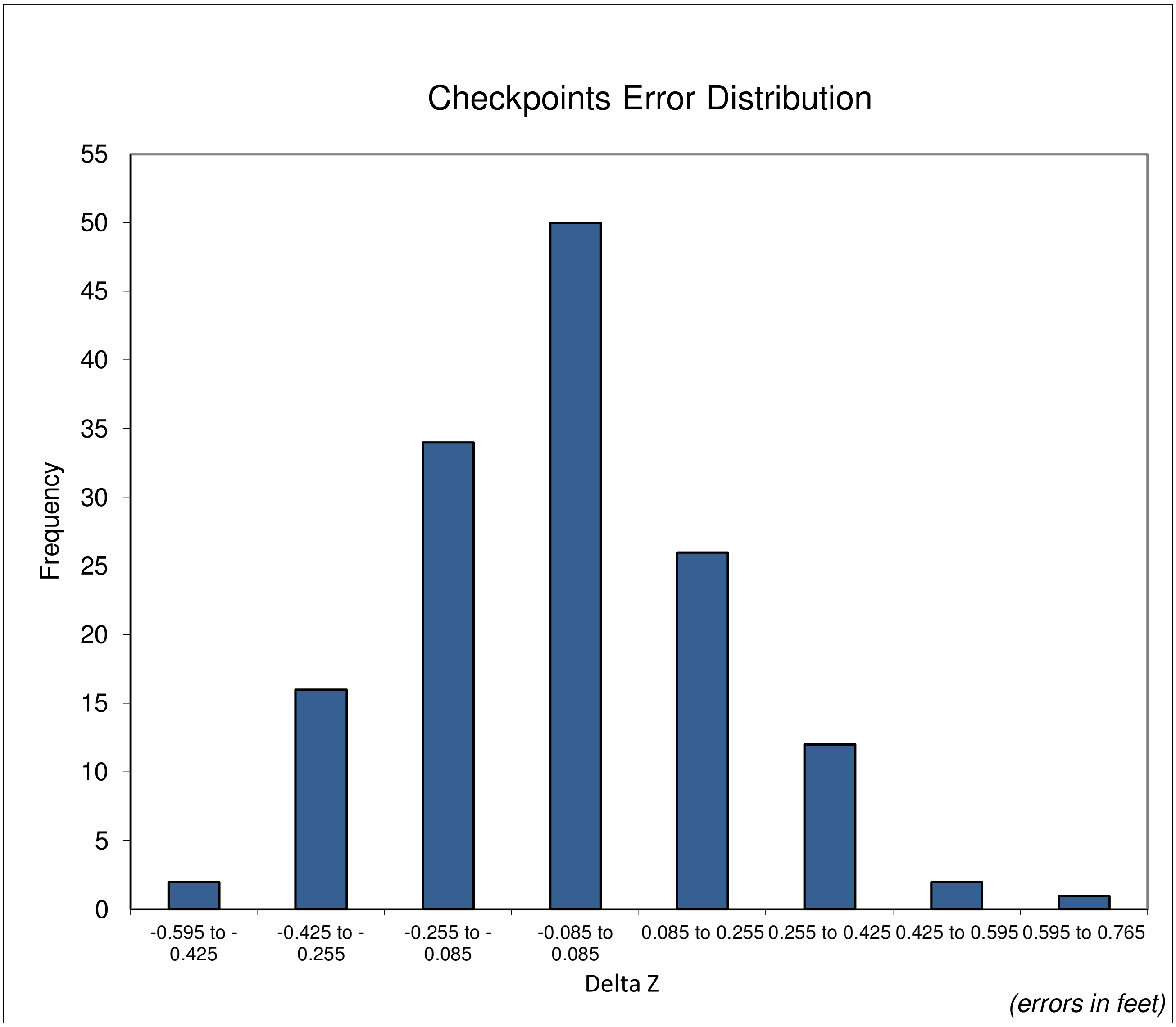


Figure 23 — Histogram of Elevation Discrepancies with errors in feet.

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the Suwannee River lidar satisfies the project's pre-defined vertical accuracy criteria.

HORIZONTAL ACCURACY TEST PROCEDURES

Horizontal accuracy testing requires well-defined checkpoints that can be identified in the dataset. Elevation datasets, including lidar datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. However, the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) recommends at least half of the NVA vertical check points should be located at the ends of paint stripes or other point features visible on the lidar intensity image, allowing them to double as horizontal check points.

Dewberry reviews all NVA checkpoints to determine which, if any, of these checkpoints are located on photo-identifiable features in the intensity imagery. This subset of checkpoints are then used for horizontal accuracy testing.

The primary QA/QC horizontal accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.
2. Next, Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the lidar intensity imagery and the ground truth survey checkpoints.
4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

HORIZONTAL ACCURACY RESULTS

Nineteen checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset. As only nineteen (19) checkpoints were photo-identifiable, the results are not statistically significant enough to report as a final tested value, but the results of the testing are still shown in the Table below.

Using NSSDA methodology (endorsed by the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)), horizontal accuracy at the 95% confidence level (called ACCURACYr) is computed by the formula RMSEr * 1.7308 or RMSExy * 2.448.

No horizontal accuracy requirements or thresholds were provided for this project. However, lidar datasets are generally calibrated by methods designed to ensure a horizontal accuracy of 3.28 feet (1 m) or less at the 95% confidence level.

# of Points	$RMSE_x$ (Target=1.34 ft)	$RMSE_y$ (Target=1.34 ft)	$RMSE_r$ (Target=1.90 ft)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=3.28 ft
19	1.34	0.75	1.53	2.65

Table 9-Tested horizontal accuracy at the 95% confidence level

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 1.34 ft (41 cm) RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 3.28 feet (1 m) at a 95% confidence level. Nineteen (19) checkpoints were photo-identifiable but do not produce a statistically significant tested horizontal accuracy value. Using this small sample set of photo-identifiable checkpoints, positional accuracy of this dataset was found to be RMSEx = 1.34 ft (40.8 cm) and RMSEy = 0.75 ft (22.9 cm) which equates to +/- 2.65 ft (80.8 cm) at 95% confidence level. While not statistically significant, the results of the small sample set of checkpoints are within the produced to meet horizontal accuracy.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

Dewberry produced full point cloud intensity imagery, bare earth ground models, density models, and slope models. These files were ingested into eCognition software, segmented into polygons, and training samples were created to identify water. eCognition used the training samples and defined parameters to identify water segments throughout the project area. Water segments were then reviewed for completeness. Segments identified as each type of required breakline type, lakes and ponds, streams and rivers, and tidal waters, were merged and smoothed. 3D elevations were then applied to the breakline features.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are at a constant elevation where the lowest elevation of the water body has been applied to the entire water body.

BREAKLINE QUALITATIVE ASSESSMENT

Dewberry completed breakline qualitative assessments according to a defined workflow. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.

Completeness and horizontal placement is verified through visual reviews against lidar intensity imagery. Automated checks are applied on all breakline features to validate topology, including the 3D connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies.

The next step is to compare the elevation of the breakline vertices against the ground elevation extracted from the ESRI Terrain built from the lidar ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations differ too much from the lidar.

After all corrections and edits to the breakline features, the breaklines are imported into the final GDB and verified for correct formatting.

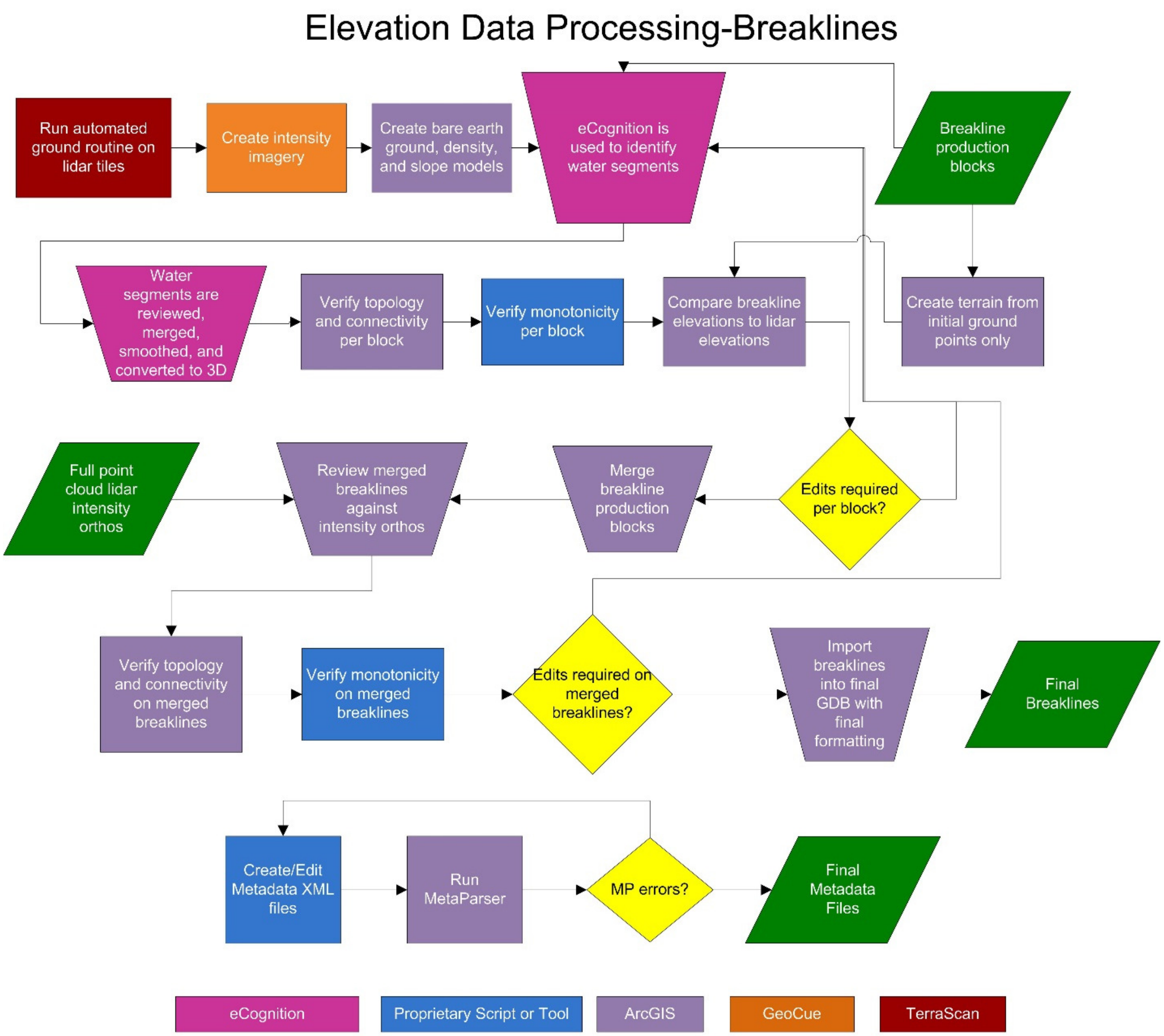


Figure 24-Breakline QA/QC workflow

BREAKLINE CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's Production and QA/QC checklist that were performed for this project.

Pass/Fail	Validation Step
Pass	Use lidar-derived data, which may include intensity imagery, stereo pairs, bare earth ground models, density models, slope models, and terrains, to collect breaklines according to project specifications.
Pass	In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS).
Pass	After each producer finishes breakline collection for a block, each producer must perform a completeness check, breakline variance check, and all automated checks on their block before calling that block complete and ready for the final merge and QC
Pass	After breaklines are completed for production blocks, all production blocks should be merged together and completeness and automated checks should be performed on the final, merged GDB. Ensure correct snapping-horizontal (x,y) and vertical (z)-between all production blocks.
Pass	Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains
Pass	Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement.
Pass	Using a terrain created from lidar ground (all ground including 2, 8, and 10) and water points (class 9), compare breakline Z values to interpolated lidar elevations.
Pass	Perform all Topology and Data Integrity Checks
Pass	Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic.

Table 10-A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.

DATA DICTIONARY

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983 (2011), Units in US Survey Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in US Survey Feet. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to Florida State Plane North (all blocks) and Florida State Plane West (Block 3), Horizontal Units in US Survey Feet and Vertical Units in US Survey Feet.

Inland Streams and Rivers

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
Feature Class: STREAMS_AND_RIVERS
Contains M Values: No
Annotation Subclass: None

XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

		Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the island is greater than 1 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

Inland Ponds and Lakes

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: PONDS_AND_LAKES
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict closed water body features that are at a constant elevation.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature that is 1 acre in size or greater will also have a "donut polygon" compiled. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath

		the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Tidal Waters

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: TIDAL_WATERS
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will outline the land / water interface at the time of lidar acquisition.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
TIDAL_WATERS	The coastal breakline will delineate the land water interface using lidar data as reference. In flight line boundary areas with tidal variation the coastal shoreline may show stair stepping as no feathering is allowed. Stair stepping is allowed to show as much ground as the collected data permits.	The feature shall be extracted at the apparent land/water interface, as determined by the lidar intensity data, to the extent of the tile boundaries. Differences caused by tidal variation are acceptable and breaklines delineated should reflect that change with no feathering. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Breaklines shall snap and merge seamlessly with linear hydrographic features.

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

Dewberry utilized ESRI software and Global Mapper for the DEM production and QC process. ArcGIS software is used to generate the products and the QC is performed in both ArcGIS and Global Mapper. The figure below shows the entire process necessary for bare earth DEM production, starting from the lidar swath processing.

The final bare-earth lidar points are used to create a terrain. The final 3D breaklines collected for the project are also enforced in the terrain. The terrain is then converted to raster format using linear interpolation. For most projects, a single terrain/DEM can be created for the whole project. For very large projects, multiple terrains/DEMs may be created. The DEM(s) is reviewed for any issues requiring corrections, including remaining lidar mis-classifications, erroneous breakline elevations, poor hydro-flattening or hydro-enforcement, and processing artifacts. After corrections are applied, the DEM(s) is then split into individual tiles following the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

Figure 25-DEM Production Workflow

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. This process was performed in ArcGIS software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process and to review the hydro-flattened features. To perform this review Dewberry creates HillShade models and overlays a partially transparent colorized elevation model to review for these issues. All corrections are completed using Dewberry's proprietary correction workflow. Upon completion of the corrections, the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out, the final tiles are again loaded into Global Mapper to ensure coverage, extents, and that the final tiles are seamless.

The image below shows an example of a bare earth DEM.

Figure 26-Tile LID2017_658698_N. The bare earth DEM

DEM VERTICAL ACCURACY RESULTS

The same 144 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 11 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.64 ft	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=0.96 ft
NVA	93.00	0.36	
VVA	51.00		0.51

Table 11 – DEM tested NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.33 ft (10 cm) RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =0.19 ft (5.8) cm, equating to +/- 0.36 ft (11 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.51 ft (15.5 cm) at the 95th percentile.

Table 12 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83 (2011) Florida State Plane North		NAVD88 (Geoid 12B)	DEM Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
VVA-202	2637306.30	566086.35	124.34	125.09	0.75	0.75
VVA-203	2623167.33	564693.56	123.81	124.35	0.54	0.54
VVA-204	2633722.73	554852.01	125.77	126.47	0.70	0.70

Table 12 – 5% Outliers

Table 13 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
NVA	93.00	0.19	-0.03	0.01	0.07	0.18	0.11	-0.46	0.55
VVA	51.00	N/A	0.05	0.03	0.26	0.29	-0.30	-0.48	0.75

Table 13 — Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the Suwannee River lidar satisfies the project's pre-defined vertical accuracy criteria.

DEM CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's bare earth DEM Production and QA/QC checklist that were performed for this project.

Pass/Fail	Validation Step
Pass	Masspoints (LAS to multipoint) are created from ground points only (class 2 and class 8 if model key points created, but no class 10 ignored ground points or class 9 water points)
Pass	Create a terrain for each production block using the final bare earth lidar points and final breaklines.
Pass	Convert terrains to rasters using project specifications for grid type, formatting, and cell size
Pass	Create hillshades for all DEMs
Pass	Manually review bare-earth DEMs in ArcMap with hillshades to check for issues
Pass	DEMs should be hydro-flattened or hydro-enforced as required by project specifications
Pass	DEMs should be seamless across tile boundaries
Pass	Water should be flowing downhill without excessive water artifacts present
Pass	Water features should NOT be floating above surrounding
Pass	Bridges should NOT be present in bare-earth DEMs.
Pass	Any remaining bridge saddles where below bridge breaklines were not used need to be fixed by adding below bridge breaklines and re-processing.
Pass	All qualitative issues present in the DEMs as a result of lidar processing and editing issues must be marked for corrections in the lidar These DEMs will need to be recreated after the lidar has been corrected.
Pass	Calculate DEM Vertical Accuracy including NVA, VVA, and other statistics
Pass	Split the DEMs into tiles according to the project tiling scheme
Pass	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression has not been applied to the tiled DEMs
Pass	Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt.

Table 14-A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Appendix A: Checkpoint Survey Report

See separate appendix document: ***Appendix A Checkpoint Survey Report.pdf***

Appendix B: Complete List of Delivered Tiles

LID2017_666768_N
LID2017_666769_N
LID2017_666770_N
LID2017_666771_N
LID2017_666772_N
LID2017_666773_N
LID2017_677020_N
LID2017_677021_N
LID2017_677022_N
LID2017_677023_N
LID2017_677024_N
LID2017_677025_N
LID2017_677026_N
LID2017_677027_N
LID2017_677028_N
LID2017_677029_N
LID2017_677030_N
LID2017_677031_N
LID2017_677032_N
LID2017_677033_N
LID2017_677034_N
LID2017_677035_N
LID2017_677036_N
LID2017_677037_N
LID2017_677038_N
LID2017_677039_N
LID2017_677040_N
LID2017_677041_N
LID2017_677042_N
LID2017_677054_N
LID2017_677055_N
LID2017_677056_N
LID2017_677057_N
LID2017_677058_N
LID2017_677059_N
LID2017_677060_N
LID2017_677061_N
LID2017_645173_N
LID2017_645174_N
LID2017_645175_N
LID2017_645176_N
LID2017_645177_N
LID2017_645178_N
LID2017_645179_N
LID2017_645180_N
LID2017_678640_N
LID2017_678641_N
LID2017_678642_N
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LID2017_678648_N
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LID2017_678650_N
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LID2017_668395_N
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LID2017_668397_N
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LID2017_647336_N
LID2017_647337_N
LID2017_647338_N
LID2017_659222_N
LID2017_659223_N
LID2017_659224_N
LID2017_659225_N
LID2017_659226_N
LID2017_659227_N
LID2017_659228_N
LID2017_659229_N
LID2017_659230_N
LID2017_659231_N
LID2017_659232_N
LID2017_659233_N
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LID2017_659235_N
LID2017_659236_N
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LID2017_659239_N
LID2017_659240_N
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LID2017_668927_N
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LID2017_668929_N
LID2017_668930_N
LID2017_668931_N
LID2017_668932_N
LID2017_668933_N
LID2017_668934_N
LID2017_668935_N

LID2017_668936_N	LID2017_671084_N	LID2017_672183_N	LID2017_671108_N
LID2017_668937_N	LID2017_671085_N	LID2017_672184_N	LID2017_671109_N
LID2017_668938_N	LID2017_671086_N	LID2017_672185_N	LID2017_671110_N
LID2017_668939_N	LID2017_671087_N	LID2017_672186_N	LID2017_671111_N
LID2017_668940_N	LID2017_671088_N	LID2017_672187_N	LID2017_671112_N
LID2017_668941_N	LID2017_671089_N	LID2017_672188_N	LID2017_671113_N
LID2017_668942_N	LID2017_671090_N	LID2017_672189_N	LID2017_671114_N
LID2017_668943_N	LID2017_671091_N	LID2017_672190_N	LID2017_671115_N
LID2017_687283_N	LID2017_671092_N	LID2017_672191_N	LID2017_671116_N
LID2017_687284_N	LID2017_671093_N	LID2017_672192_N	LID2017_678105_N
LID2017_687285_N	LID2017_671094_N	LID2017_672193_N	LID2017_692686_N
LID2017_687286_N	LID2017_671095_N	LID2017_672194_N	LID2017_692687_N
LID2017_687287_N	LID2017_671096_N	LID2017_672195_N	LID2017_692688_N
LID2017_687288_N	LID2017_671097_N	LID2017_672196_N	LID2017_692689_N
LID2017_687289_N	LID2017_671098_N	LID2017_672197_N	LID2017_692690_N
LID2017_687290_N	LID2017_671099_N	LID2017_671655_N	LID2017_642473_N
LID2017_687823_N	LID2017_671100_N	LID2017_671656_N	LID2017_642474_N
LID2017_687824_N	LID2017_671101_N	LID2017_678100_N	LID2017_642475_N
LID2017_687825_N	LID2017_671102_N	LID2017_678101_N	LID2017_642476_N
LID2017_687826_N	LID2017_671103_N	LID2017_678102_N	LID2017_642477_N
LID2017_687827_N	LID2017_671104_N	LID2017_678103_N	LID2017_642478_N
LID2017_687828_N	LID2017_672175_N	LID2017_678104_N	LID2017_642479_N
LID2017_687829_N	LID2017_672176_N	LID2017_682424_N	LID2017_642480_N
LID2017_687830_N	LID2017_672177_N	LID2017_682425_N	LID2017_682428_N
LID2017_687831_N	LID2017_672178_N	LID2017_682426_N	LID2017_682429_N
LID2017_671080_N	LID2017_672179_N	LID2017_682427_N	LID2017_682430_N
LID2017_671081_N	LID2017_672180_N	LID2017_671105_N	LID2017_682431_N
LID2017_671082_N	LID2017_672181_N	LID2017_671106_N	LID2017_682432_N
LID2017_671083_N	LID2017_672182_N	LID2017_671107_N	LID2017_682433_N

LID2017_682434_N	LID2017_641393_N	LID2017_699711_N	LID2017_701870_N
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Appendix C: GPS Processing

See separate appendix document: ***Appendix C GPS Processing.pdf***