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Upper Saint Johns 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 Puzzle Lake project area in East Central Florida Project Area to support natural resources

conservation programs, water use and quality monitoring and improved flood mitigation, preparedness, response and recovery programs.

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 973 tiles were produced for the project encompassing an area of approximately 687 square 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, 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 collected ground control points for use in lidar calibration and processing. Please see Appendix A to view the separate checkpoint Survey Report that was created for this portion of the project and the survey data folder in the deliverables for all survey materials.

Leading Edge Geomatics (LEG) completed lidar data acquisition and data calibration for the project area.

Earth Data, Inc completed breakline production for the project area.

SURVEY AREA

The project area addressed by this report is near the city of Orlando, Florida, covering an area of approximately 687 square miles.

DATE OF SURVEY

The lidar aerial acquisition was conducted between March 21, 2018 and June 13, 2018.

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:** Florida State Plane East
> **Units:** Horizontal units are in U.S. survey feet, Vertical units are in feet.
> **Geiod Model:** Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the Upper Saint Johns Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled 0.26 ft (7.9 cm) compared with the 10 cm specification; and the NVA of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to 0.51 ft (15.5 cm), compared with the 19.6 cm specification.

For the Upper Saint Johns Lidar Project, the tested VVA of the classified lidar data computed using the 95^{th} percentile was equal to 0.52 ft (15.8 cm), compared with the 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. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (Raster DEM – IMG Format)
3. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
4. Breakline Data (File GDB)
5. Tie Difference Grid
6. Tie Difference Report
7. Independent Survey Checkpoint Data (Report, Photos, & Points)
8. Calibration Points
9. Metadata
10. Project Report (Acquisition, Processing, QC)
11. Project Extents, Including a shapefile derived from the lidar deliverable

PROJECT TILING FOOTPRINT

Nine hundred seventy three (973) tiles (766 full tiles plus 207 buffer 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).

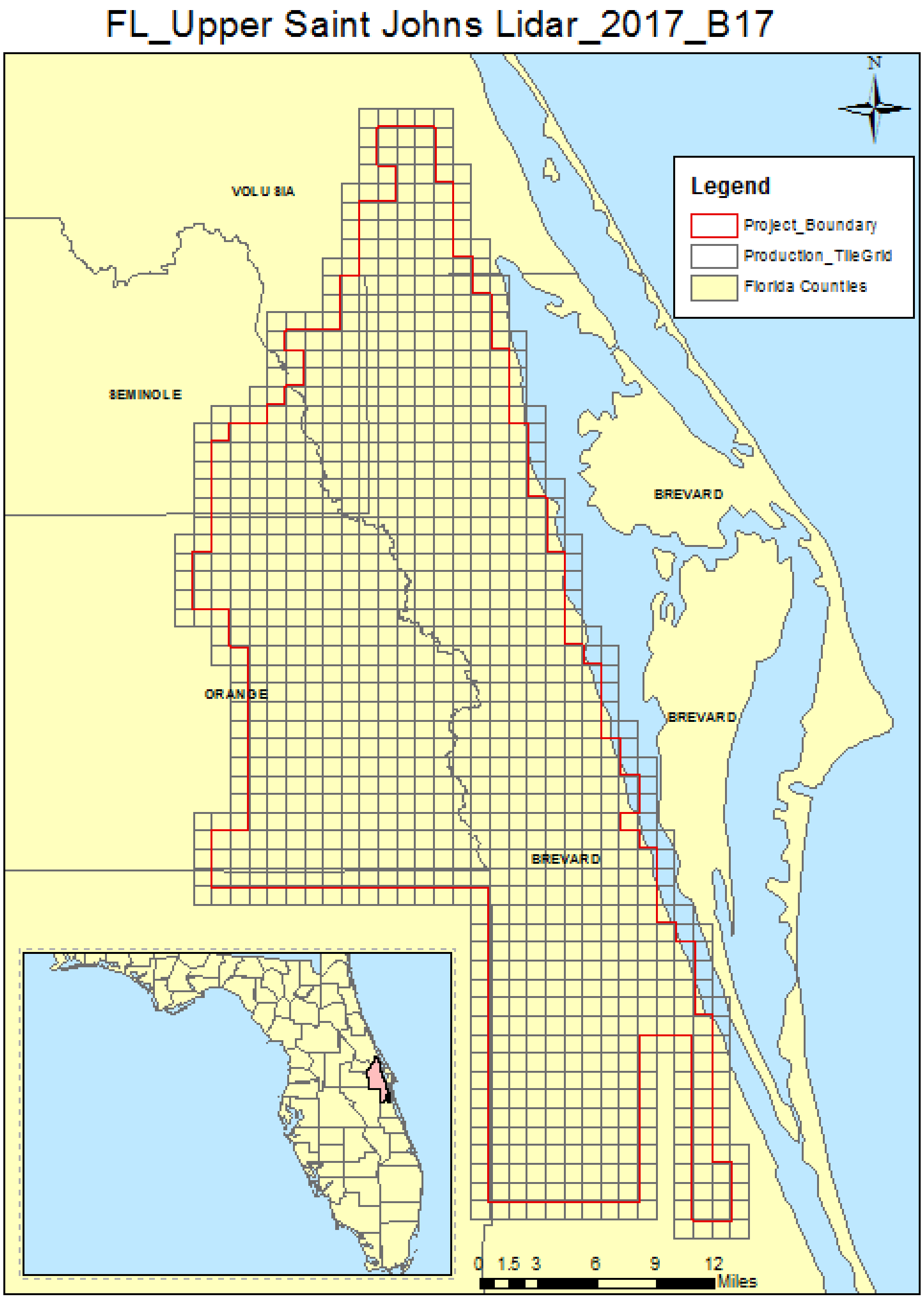


Figure 1 - Project Map.

Lidar Acquisition Report

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

Dewberry received calibrated swath data from Leading Edge Geomatics on July 16, 2018.

LIDAR ACQUISITION DETAILS

Leading Edge Geomatics planned a total 141 passes to complete the entire project area. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. Due to large changes in terrain height, the project area was broken down into three areas based of height above sea level. This was required to maintain the project accuracy specification. 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.
- 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, Leading Edge Geomatics will file our 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 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. Leading Edge Geomatics 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, 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, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

Leading Edge Geomatics lidar sensors are calibrated at a designated site located in downtown Fredericton, New Brunswick and are periodically checked and adjusted to minimize corrections at project sites. Both systems were calibrated before departing for the project area.

LIDAR SYSTEM PARAMETERS

Leading Edge Geomatics operated two different aircraft with the same aircraft for this project. The project was started with a Piper Navajo (C-GKCN) and finished with a Piper Aztec (N6645A).

A Riegl VQ1560i (2223065) was used in both aircraft. Table 1 illustrates Leading Edge Geomatics system parameters for LiDAR acquisition on this project.

Item	Parameter
System	Riegl VQ1560i
Altitude (AGL meters)	1300
Approx. Flight Speed (knots)	120
Scanner Pulse Rate (kHz)	2 x 1000
Scan Frequency	74
Pulse Duration of the Scanner (nanoseconds)	3
Pulse Width of the Scanner (m)	0.8994
Swath width (m)	1412
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	0.25
Nominal Swath Width on the Ground (m)	1412
Swath Overlap (%)	55
Total Sensor Scan Angle (degree)	57
Computed Down Track spacing (m) per beam	0.36
Computed Cross Track Spacing (m) per beam	0.36
Nominal Pulse Spacing (single swath), (m)	0.26
Nominal Pulse Density (single swath) (ppsm), (m)	14.8
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.20
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	25
Maximum Number of Returns per Pulse	infinite

Table 1 - Leading Edge Geomatics 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.

Figure 2 shows the combined trajectory of the flightlines.

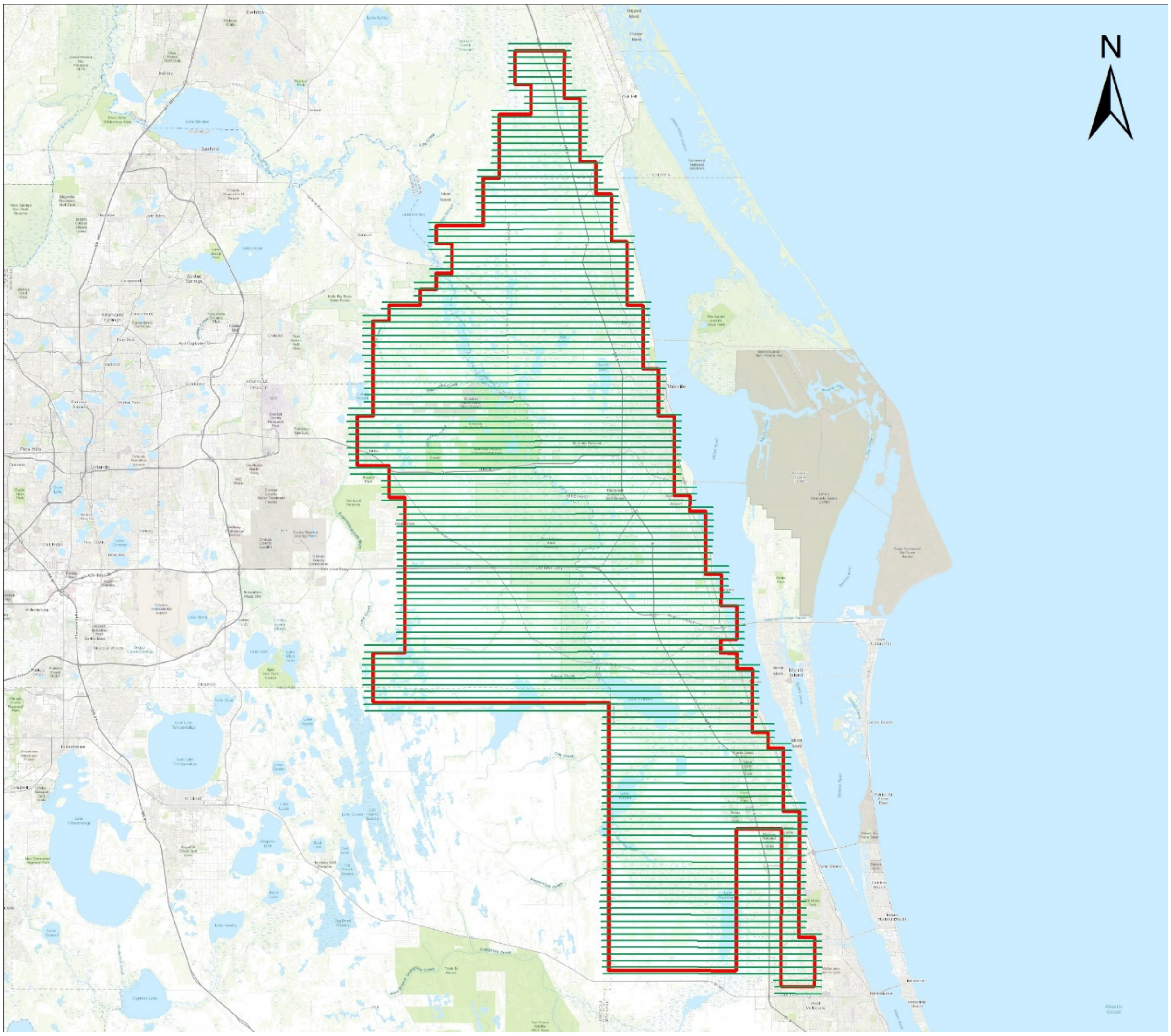


Figure 2 - Trajectories as flown by Leading Edge Geomatics.

LIDAR CONTROL

NGS CORS Base Stations were used to control the lidar acquisition for the Upper Saint Johns 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.

Number	NAD83 (2011) State Plane Florida East FIPS 0901 US Feet		NAVD88 (Geoid 12B)
	Easting X (USft)	Northing Y (USft)	Known Z (USft)
TITU	719315.053	1516617.445	11.61
ORMO	621458.221	1804732.027	10.12

Number	NAD83 (2011) State Plane Florida East FIPS 0901 US Feet		NAVD88 (Geoid 12B)
	Easting X (USft)	Northing Y (USft)	Known Z (USft)
ORLA	533246.547	1490893.066	37.157
VIER	740758.42	1422460.35	19.398
FLWE	626424.44	1492936.613	24.573
KISS	515746.054	1440115.68	29.356
SEBA	820756.102	1265125.725	7.988
SANF	575006.273	1616016.905	21.837
DELA	572080.654	1716876.57	28.334

Table 2 - Base stations used to control lidar acquisition.

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the POSPac kinematic On-The-Fly (OTF) software suite using Applanix Smartbase processing. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 40 km.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3 cm average or better but no larger than 10 cm being recorded.

GPS processing reports for each mission are included in 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 Riegl's RiProcess application. System calibration was conducted prior to the aircraft departing for the project and the initial calibration values are used to position the point cloud. If a calibration error 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.

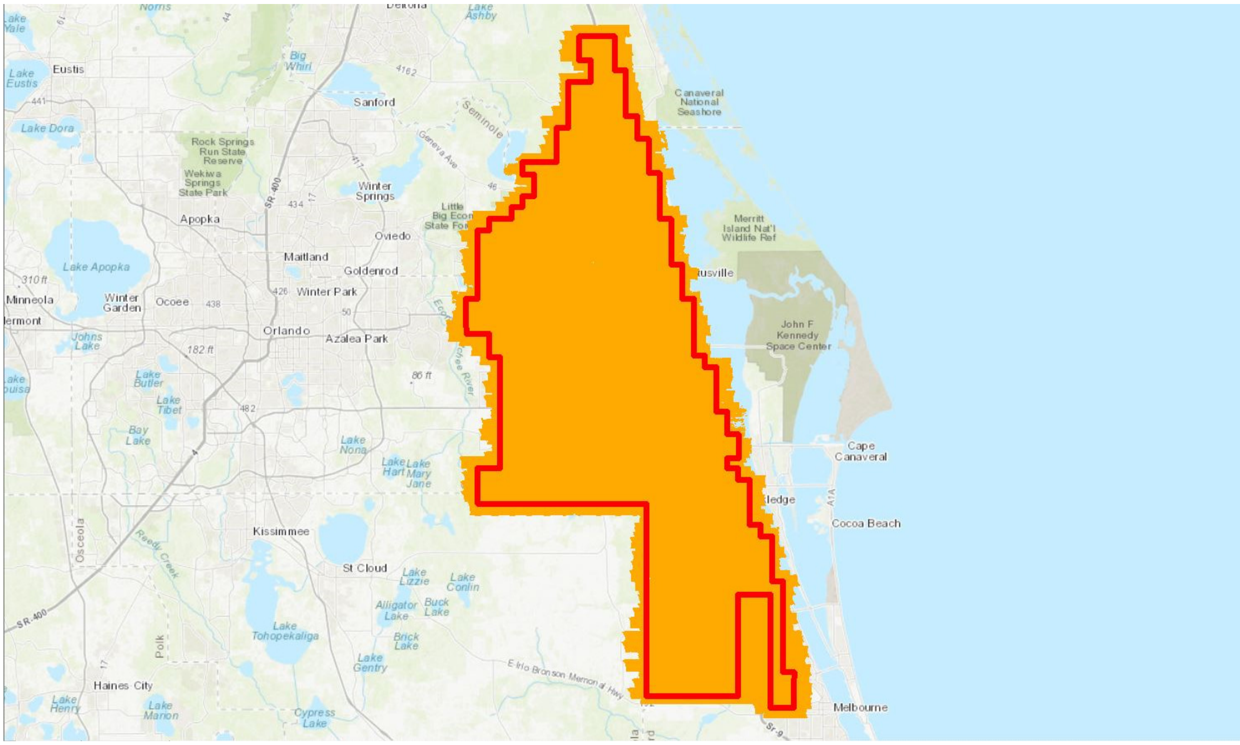


Figure 3 - Lidar swath output showing complete coverage.

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:
Absolute Vertical Accuracy <=10 cm RMSEZ in non-vegetated open areas.
Absolute Horizontal Accuracy = 0.6m RMSE
Relative Swath Accuracy ≤ 6cm within a single swath and ≤ 8cm RMSDz within swath overlap.

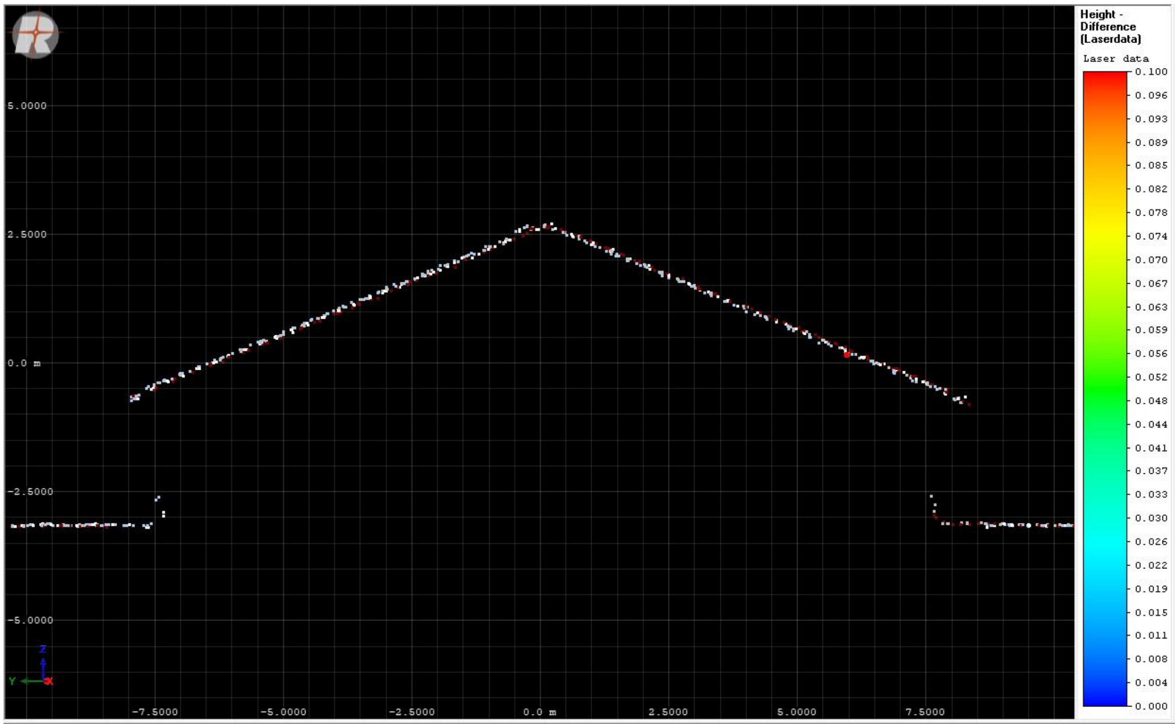


Figure 4 - Profile views showing correct roll and pitch adjustments.

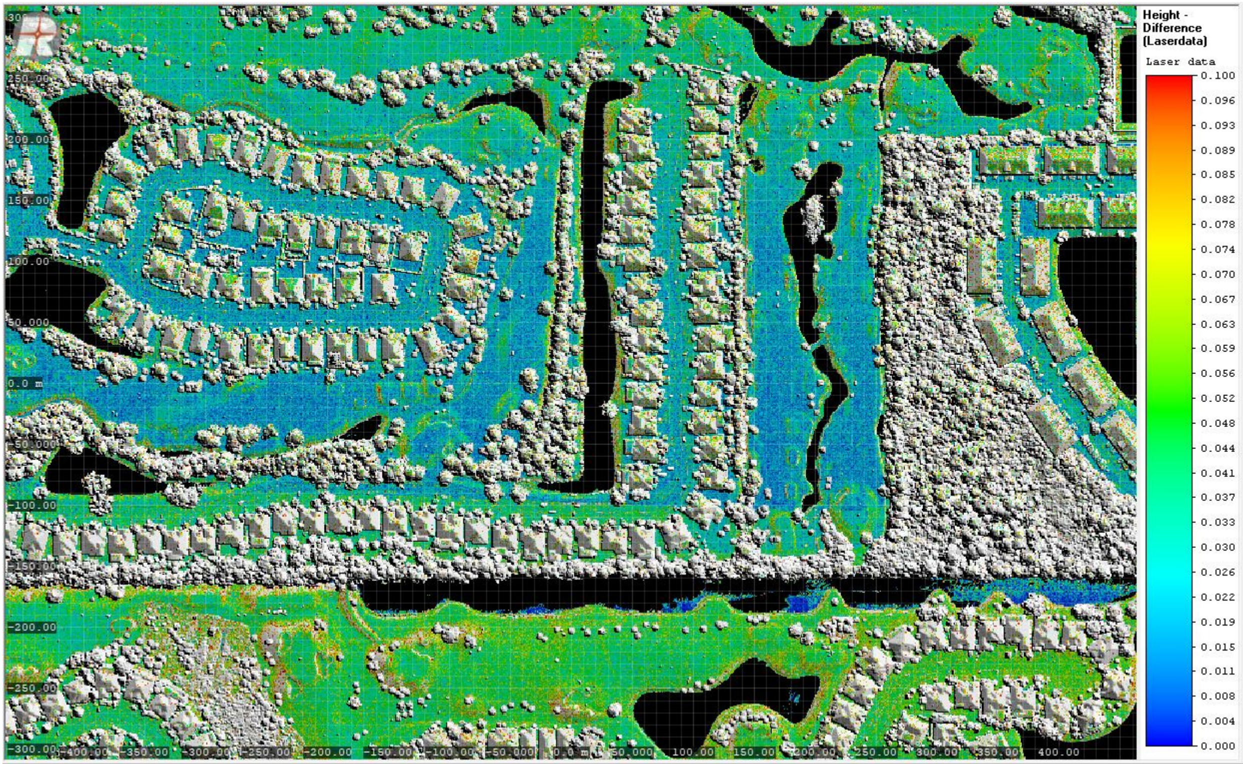


Figure 5 - QC block colored by distance to ensure accuracy at swath edges.

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

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check is performed by Leading Edge Geomatics at this stage of the project life cycle in the raw LiDAR dataset against GPS static data and compared to $RMSE_z$ project specifications. The LiDAR data is examined in open, flat areas away from breaks. Ground control points were collected by Real-Time Kinematic (RTK) survey and compared against the LiDAR ground points and statistics are generated.

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met project accuracy requirements (vertical accuracy <=10 cm RMSEz) or better in open, non-vegetated terrain) when compared to static GPS checkpoints. Below is a summary for the test:

The calibrated Upper Saint John's lidar dataset was tested to 0.173 m (0.567 ft) vertical accuracy at 95% confidence level based on consolidated $RMSE_z$ (0.0883m x 1.9600) when compared to 482 independently collected RTK check points.

The following are the final statistics for the GPS static checkpoints used by Leading Edge Geomatics to internally verify vertical accuracy.

Average dz	0.0883 m
Root mean square	0.0824 m
Std deviation	0.0318 m

Overall the calibrated lidar data products collected by Leading Edge Geomatics meet or exceed the requirements set out in the Statement of Work. The quality control requirements of Leading Edge Geomatics quality management program were adhered to throughout the acquisition stage for this for this project to ensure product quality.

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 Leading Edge Geomatics, 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 fifty 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 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96. The dataset for the Upper Saint Johns Lidar Project satisfies this criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 0.28 ft (8.5 cm), equating to +/- 0.54 ft (16.5 cm) at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

Swath Vertical Accuracy Results										
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)	Median (ft)	Skew	Std Dev (ft)	Min (ft)	Max (ft)	Kurtosis
NVA	50	0.28	0.54	0.16	0.16	-0.15	0.23	-0.32	0.56	-0.81

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 QL1+ 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 Upper Saint Johns Lidar are shown in the figure below; this project meets inter-swath relative accuracy specifications.

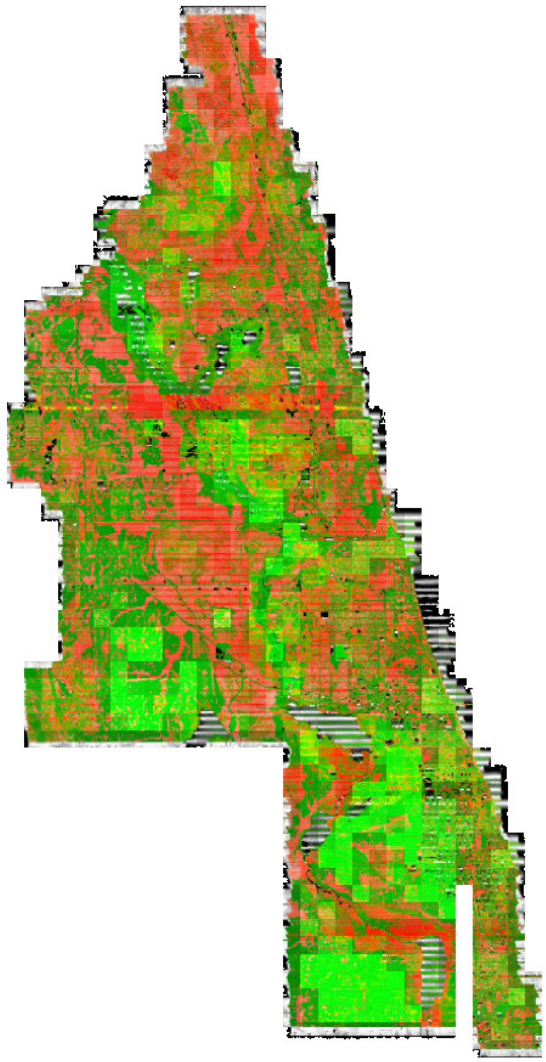


Figure 6 - Single return DZ Orthos for the Upper Saint Johns Lidar . Inter-swath relative accuracy passes specifications.

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 QL1+ 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 Upper Saint Johns Lidar; this project meets intra-swath relative accuracy specifications.

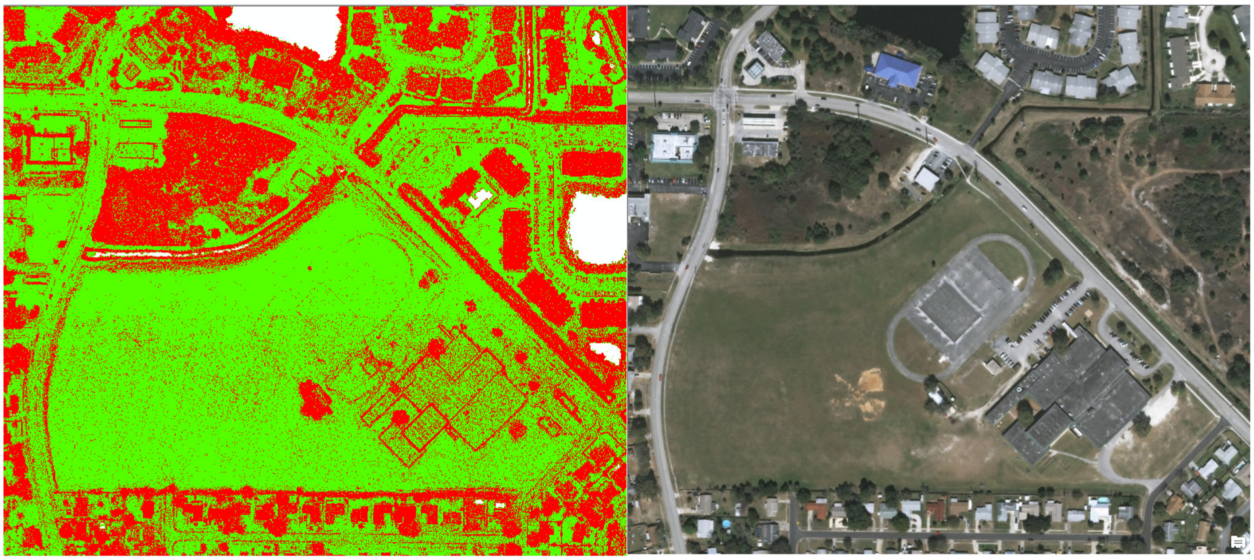


Figure 7 - Intra-swath relative accuracy. The left image is a close-up of a flat area. With the exception of trees and a few buildings (shown in red as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. The right image shows aerial image of the same area. 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 Upper Saint Johns Lidar
; no horizontal alignment issues were identified.

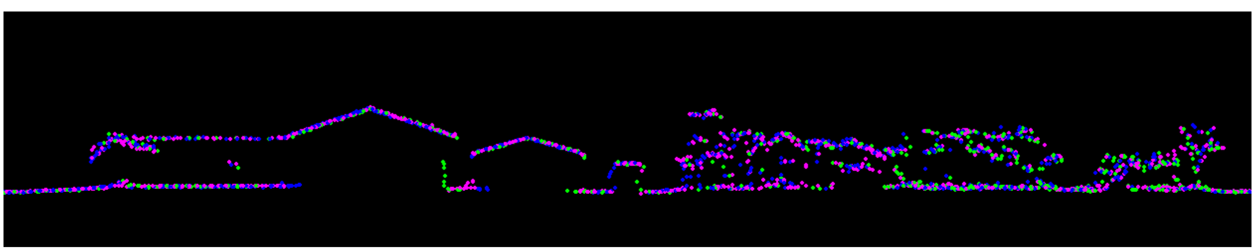


Figure 8 - Horizontal Alignment. Three separate flight lines differentiated by color (Blue/Purple/Green) are shown in this profile. There is no visible offset between these flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.25 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 16 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 0.21 meters or an ANPD of 23 points per square meter which satisfies the project requirements. A visual review of a 1-square m density grid (figure below) shows that there are some 1-meter cells that do not contain 16 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 16 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.

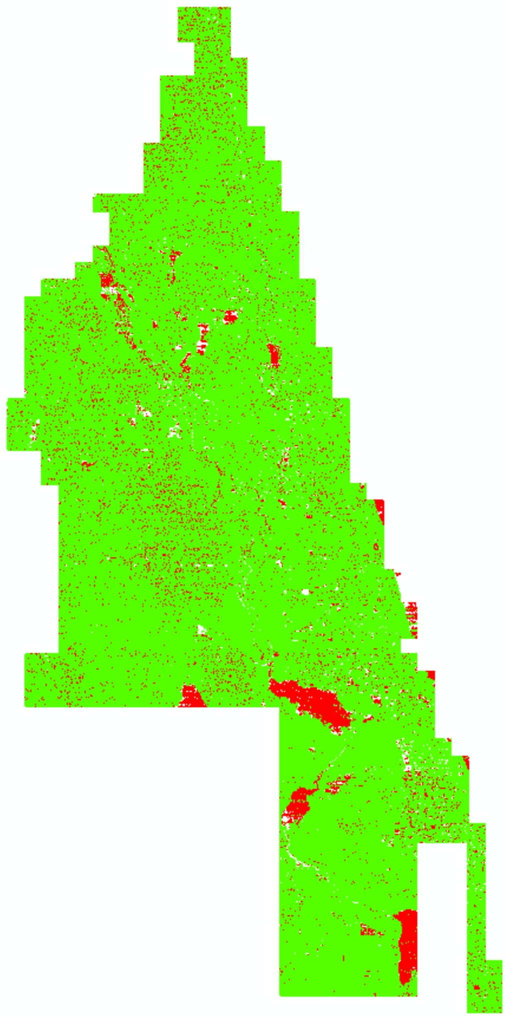


Figure 9 - 1-square meter density grid. There are some 1-meter cells that do not contain 16 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 16 points per square meter (green areas) showing there are no systematic density issues. When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues.

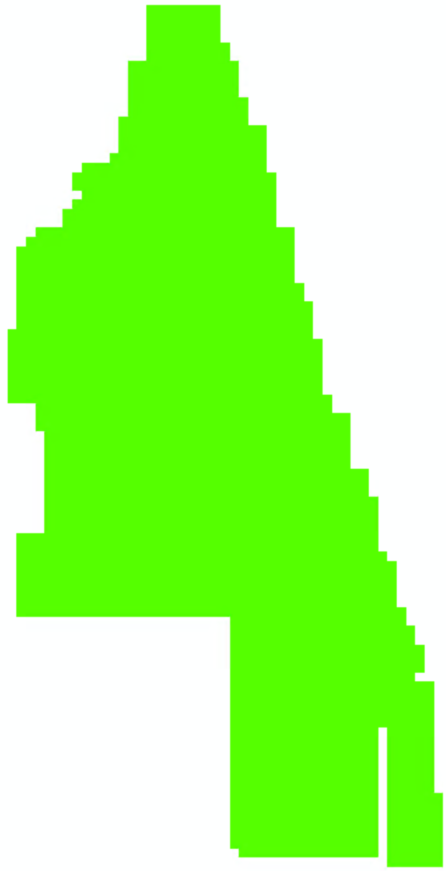


Figure 10 – When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues with every 1 km cell averaging 16 ppsm or greater (green cells).

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 11 - Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored purple. Cells that do not contain a lidar point, including water bodies which are acceptable NoData area, are colored green. Without removing acceptable NoData areas due to water, 97.4% 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 Upper Saint Johns 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 Upper Saint Johns Lidar project.

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 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

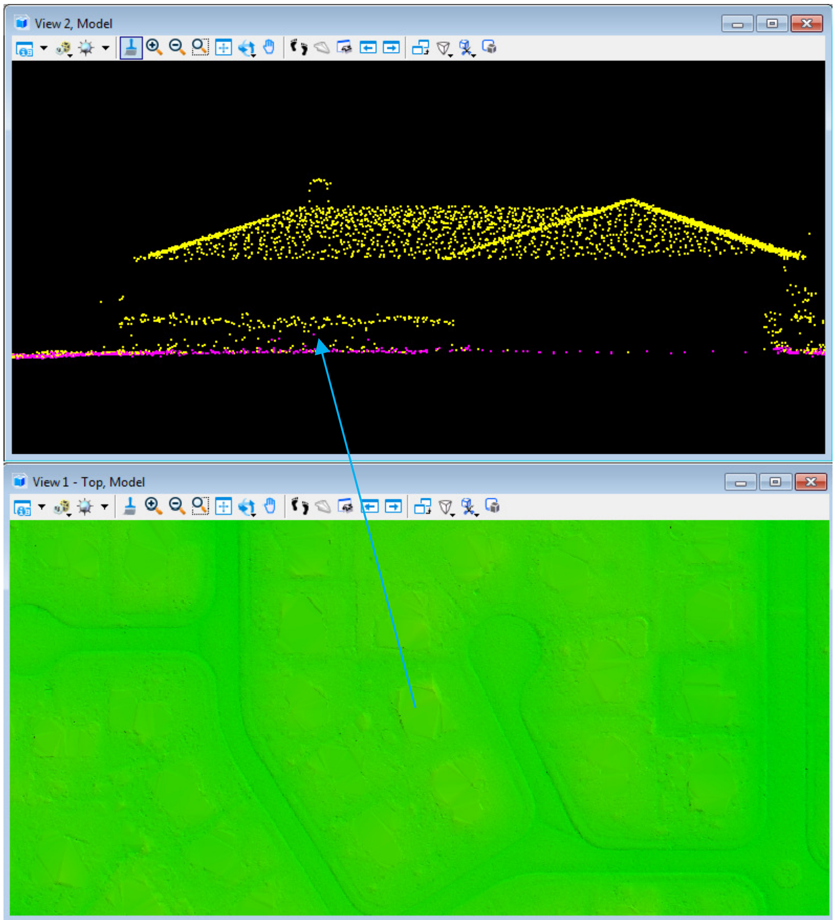


Figure 12 - Tile number 262615. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but do 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.

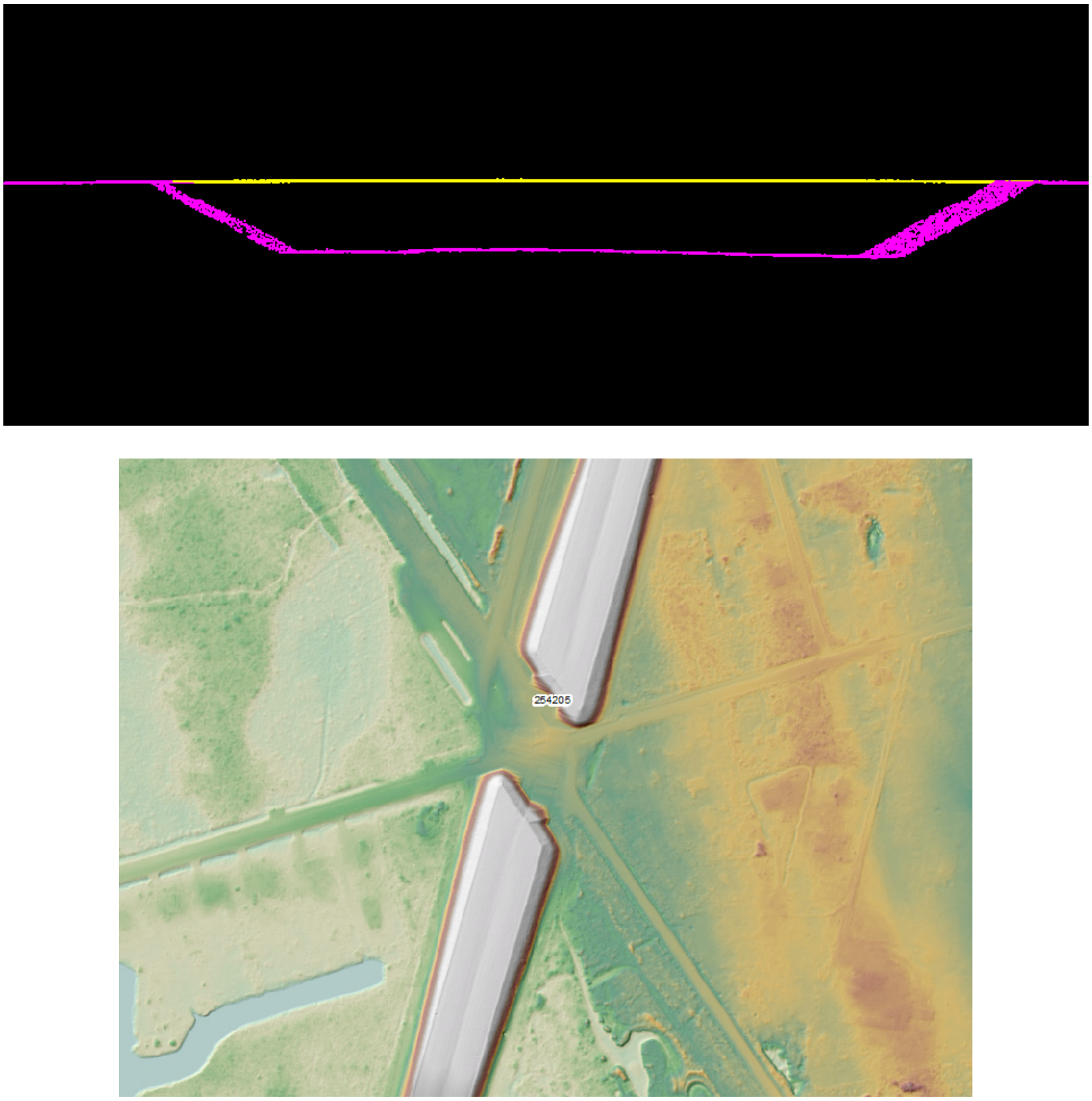


Figure 13 - Tile number 254205. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (pink) and classified to 17 (yellow).

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.

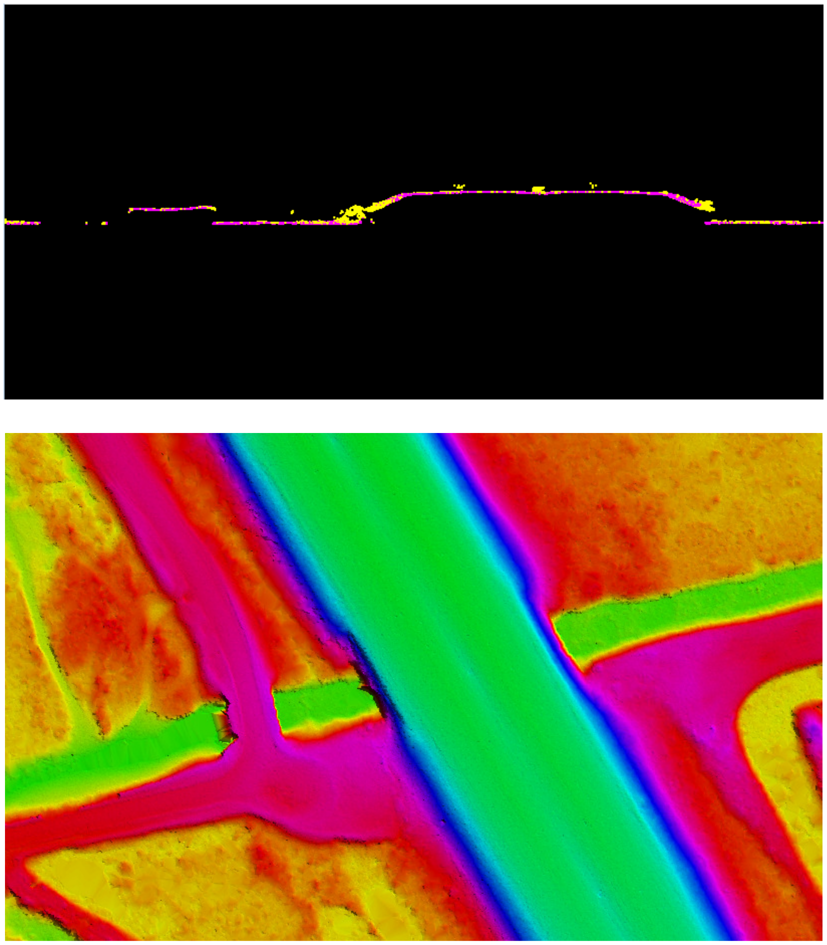
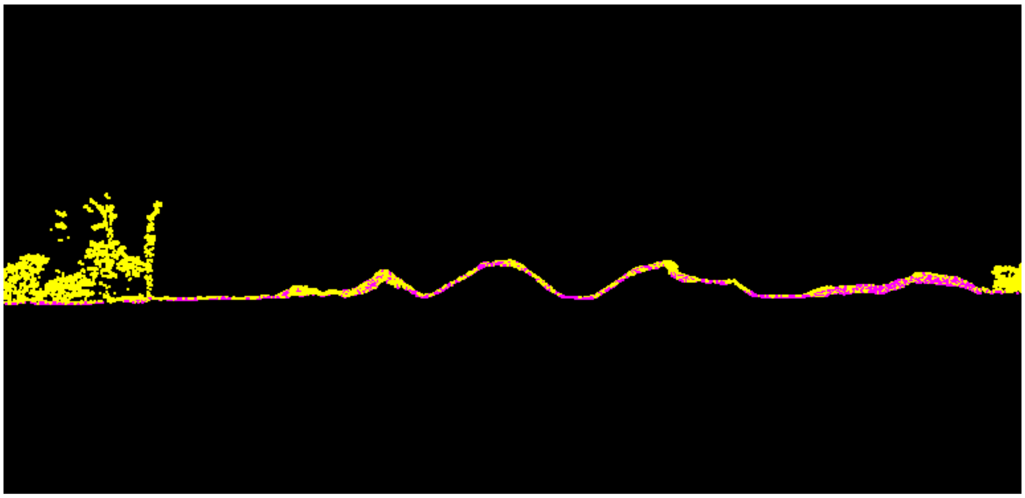


Figure 14 - Tile number 262912. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

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.



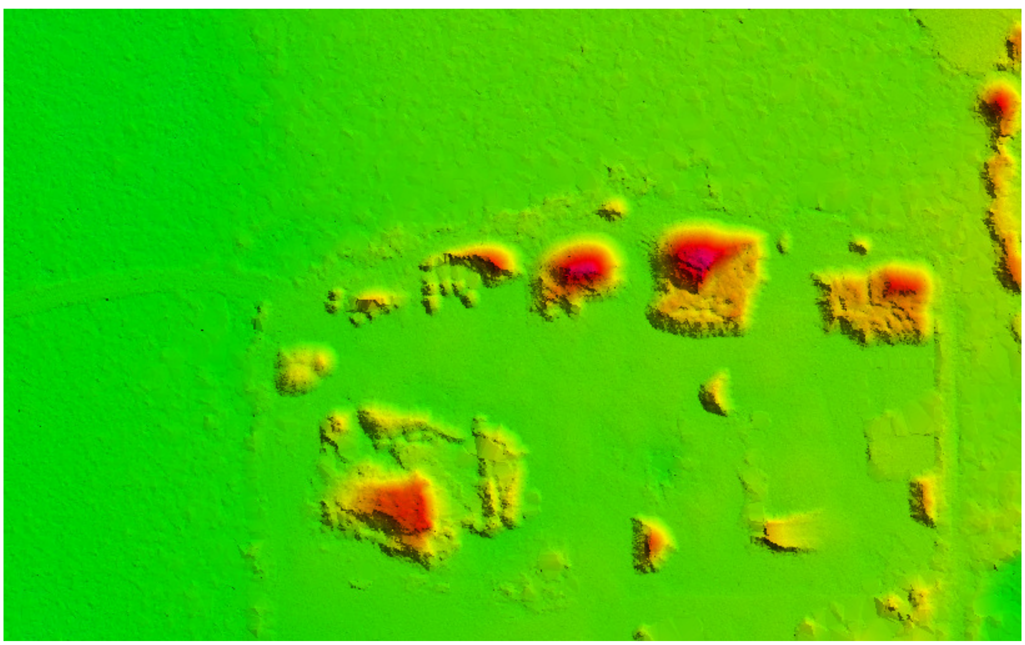


Figure 15 - Tile 261113. Profile with the points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

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 16 - Tile number 266513. Elevation change has been stair stepped. The steps are flat from bank to bank and flow consistently downhill. The aerial image on the right shows the hydro control structure that lead to change in elevation as demonstrated in the profile view on left image.

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.

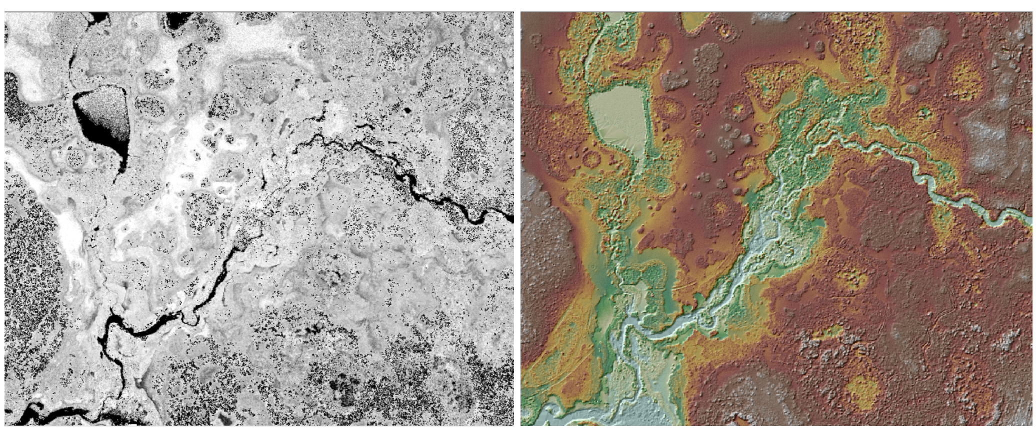


Figure 17 - Tiles 254798. The intensity on the left shows a marsh area that was not included in the collected breaklines. The same area is shown in the DEM on the right. Due to wet soils and broken terrain, the point density in marsh areas is sparser than surrounding areas and there is more variation in the low points representing ground.

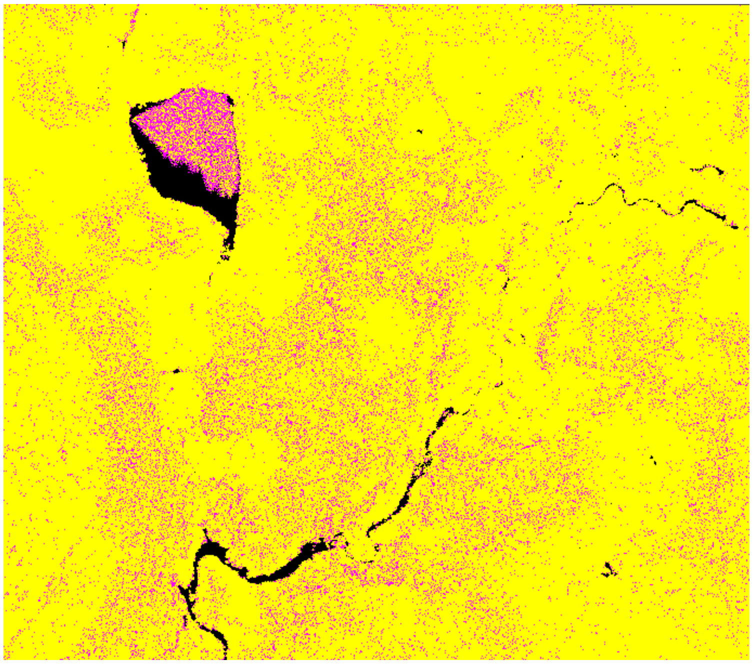


Figure 18 - Tile 254798. The same marsh area shown in the figure above is shown in this image with the points colored by class (class 1=yellow, class 2=pink). Though ground points are sparse they are present, indicating that the area is wet but should not be classified as water (class 9). Doing so would strip the detail from this area and result in incorrectly flattening ground as part of the hydro mask.

Flight line Ridges

Ridges occur when there is a difference between the elevations of adjoining flight lines or swaths. Some flight line ridges are visible in the final DEMs but they do not exceed the project specifications, with the exception of temporal differences. There are a limited number of locations within marsh areas where adjacent and overlapping flight lines show differing water levels within the marsh. Some of these flight line ridges exceed the 8cm RMSDz for flat, open, hard surface areas due to the temporal differences and varying environmental conditions of each flight line. The overall relative accuracy requirements for the project area have been met. Examples of visible ridges are shown below.

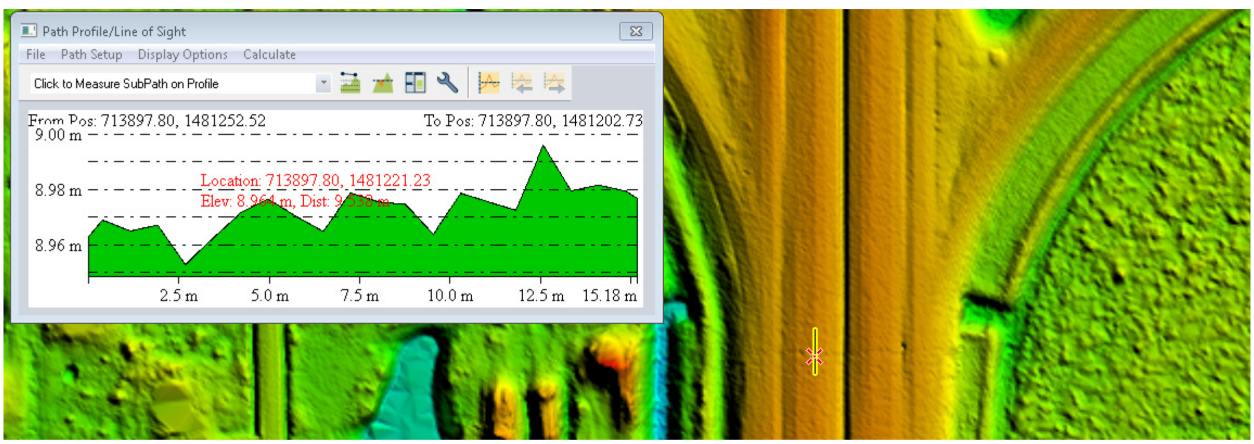


Figure 19 - Tile 261109. The flight line ridge is less than 8 cm. Overall, the Upper Saint Johns Lidar data meets the project specifications for 8 cm RMSDz relative accuracy.

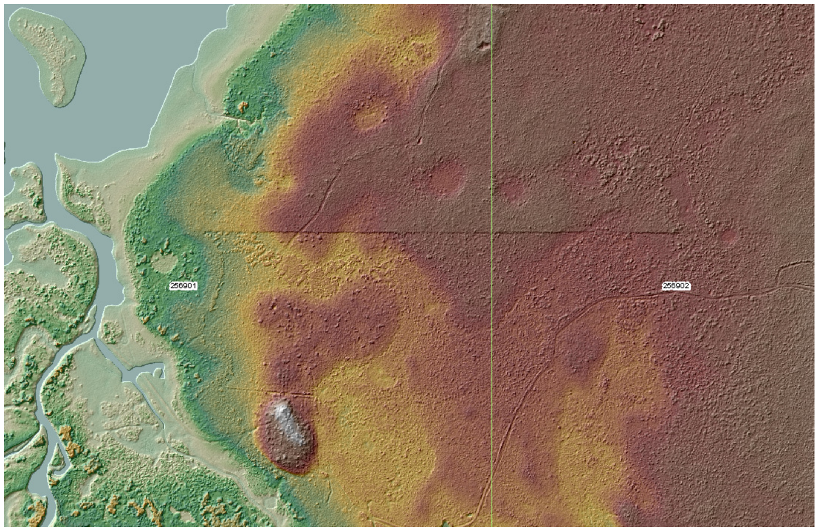


Figure 20 - Tiles 256901 and 256902. The image show a flight line ridge artifact that is due to temporal differences in marsh areas.

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) State Plane Florida East, FIPS 0901 US Survey Feet and NAVD88 (Geoid 12B), US Survey 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 Class 9: Water	Pass

	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, ninety (90) 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 FL East		NAVD88 (Geoid 12B)
	Easting X (ft)	Northing Y (ft)	Elevation (ft)
NVA1	677246.51	1591340.14	12.69
NVA2	684105.97	1635445.10	29.62
NVA3	700210.33	1591838.89	29.21
NVA4	689854.38	1612966.26	29.75
NVA5	703570.63	1575031.45	21.29
NVA6	666774.15	1628257.13	27.10
NVA7	680969.73	1657267.77	27.44
NVA8	649453.24	1590555.31	11.69
NVA9	631932.04	1550358.79	56.80
NVA10	631627.79	1527733.25	71.22
NVA11	650335.12	1505519.19	62.06
NVA12	662142.79	1579571.19	15.60
NVA13	676794.03	1530383.81	15.88
NVA14	728879.56	1508917.96	12.64
NVA15	684396.04	1505321.35	14.69
NVA16	693275.40	1545702.53	18.48
NVA17	712684.00	1556471.04	19.58
NVA18	693733.25	1532997.94	13.03
NVA19	650417.13	1527899.95	44.04
NVA20	719184.84	1534859.41	20.87
NVA21	706896.45	1513343.76	16.72
NVA22	685101.34	1558592.04	12.28
NVA23	646045.28	1562818.36	15.97
NVA24	672954.76	1636938.97	25.92
NVA25	694643.50	1524393.23	8.48
NVA26	636316.83	1497448.03	74.38
NVA27	669455.34	1487740.19	43.44
NVA28	635426.19	1488131.08	74.01
NVA29	644681.61	1465128.43	70.84
NVA30	655548.08	1475823.03	60.53
NVA31	653736.43	1456040.75	64.05
NVA32	708193.65	1375910.25	19.69
NVA33	732020.04	1370116.45	13.93
NVA34	735857.19	1416168.75	25.78
NVA35	761726.14	1364915.68	26.00

NVA36	755251.82	1369302.39	22.51
NVA37	763225.77	1379651.10	26.83
NVA38	709150.11	1490114.88	19.13
NVA39	756710.00	1382228.30	24.76
NVA40	749615.26	1419312.54	29.03
NVA41	758869.94	1419406.22	24.99
NVA42	711703.80	1463793.74	21.30
NVA43	737825.16	1479363.24	3.16
NVA44	757135.92	1405224.98	36.48
NVA45	738783.72	1442686.96	16.90
NVA46	710397.95	1424722.68	18.39
NVA47	684433.62	1472781.14	16.50
NVA48	726681.92	1429607.59	16.82
NVA49	717100.84	1408310.54	17.35
NVA50	690050.15	1455519.48	17.73
VVA1	679841.28	1627603.63	23.08
VVA2	666055.56	1639005.26	25.80
VVA3	661236.02	1618312.44	22.49
VVA4	673437.96	1651189.35	23.90
VVA5	692859.43	1620428.03	24.86
VVA6	660886.79	1598303.80	14.58
VVA7	634359.85	1574471.59	14.69
VVA8	626836.57	1558173.30	58.65
VVA9	626210.54	1532374.77	65.80
VVA10	636339.46	1510016.95	69.63
VVA11	669612.98	1506465.05	21.20
VVA12	726209.34	1506372.52	21.84
VVA13	704673.59	1535703.22	16.49
VVA14	700344.87	1564453.98	24.76
VVA15	691385.73	1590376.47	16.02
VVA16	698009.99	1518570.48	8.81
VVA17	647444.61	1532987.59	50.74
VVA18	668988.35	1574755.71	7.27
VVA19	670259.41	1606317.11	19.87
VVA20	664601.20	1552273.12	4.14
VVA21	760081.43	1371617.67	23.24
VVA22	759216.91	1402060.35	31.16
VVA23	731170.22	1372110.96	14.95
VVA24	709769.46	1372261.93	17.31
VVA25	718507.06	1387201.36	13.20
VVA26	701610.74	1399464.98	11.70
VVA27	731981.08	1411056.11	19.45
VVA28	707325.61	1421955.97	13.77
VVA29	736339.17	1437597.80	15.47
VVA30	708112.18	1442969.38	12.73
VVA31	722783.63	1462209.49	16.95
VVA32	732592.98	1485561.29	29.25

VVA33	705727.41	1484741.49	14.93
VVA34	694898.39	1465752.99	10.53
VVA35	664970.29	1456418.76	50.52
VVA36	631390.31	1456102.61	75.30
VVA37	639337.60	1475766.02	74.23
VVA38	671894.66	1476062.73	42.64
VVA39	647433.82	1496859.64	61.30
VVA40	685759.86	1497170.91	10.75

Table 4 - Upper Saint Johns Lidar surveyed accuracy checkpoints.

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

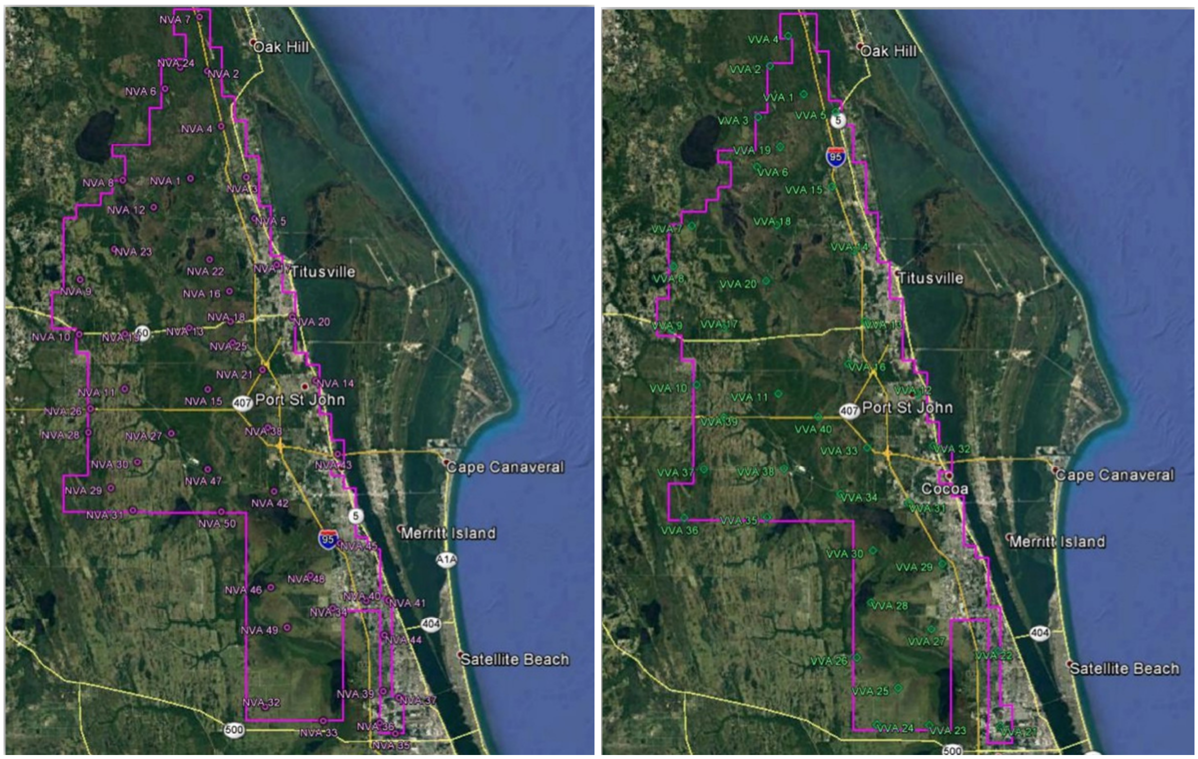


Figure 21 - Location of QA/QC Checkpoints.

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 Upper Saint Johns 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 95th percentile error for all checkpoints in all vegetated land cover categories combined. The Upper Saint Johns lidar project VVA standard is 0.96 ft (29.4 cm) based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th 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 95th 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	50	0.51	
VVA	40		0.52

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 $RMSE_z$ =0.26 ft (7.9 cm), equating to +/- 0.51 ft (15.5 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.52 ft (15.8 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 +0.66 ft.

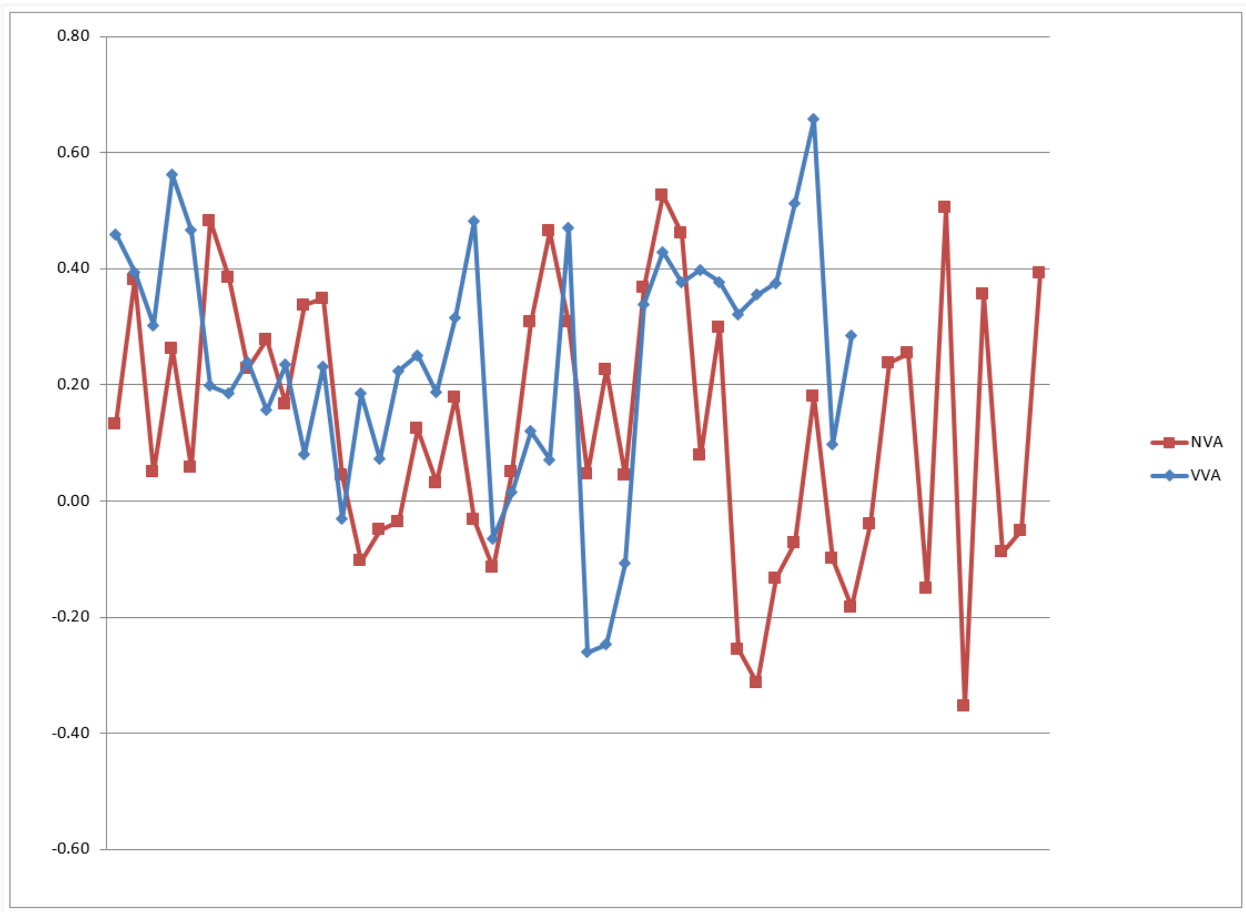


Figure 22 - Magnitude of elevation discrepancies per land cover category.

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

LiDAR 5% Outliers						
Point ID	NAD83(2011) FL State Plane East		NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
VVA4	673437.96	1651189.35	23.90	24.46	0.56	0.56

VVA38	671894.66	1476062.73	42.64	43.30	0.66	0.66

Table 7 - 5% Outliers

Table 8 provides overall descriptive statistics.

LiDAR Descriptive Statistics									
100 % of Totals	# of Points	RMSEz (ft) Spec=0.33 ft NVA	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
NVA	50.00	0.26	0.13	0.13	-0.12	0.23	-0.84	-0.35	0.53
VVA	40.00	N/A	0.24	0.25	-0.52	0.21	0.15	-0.26	0.66

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 -0.35ft and a high of +0.66 ft, the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the ranges of -0.3 ft to + 0.5 ft .

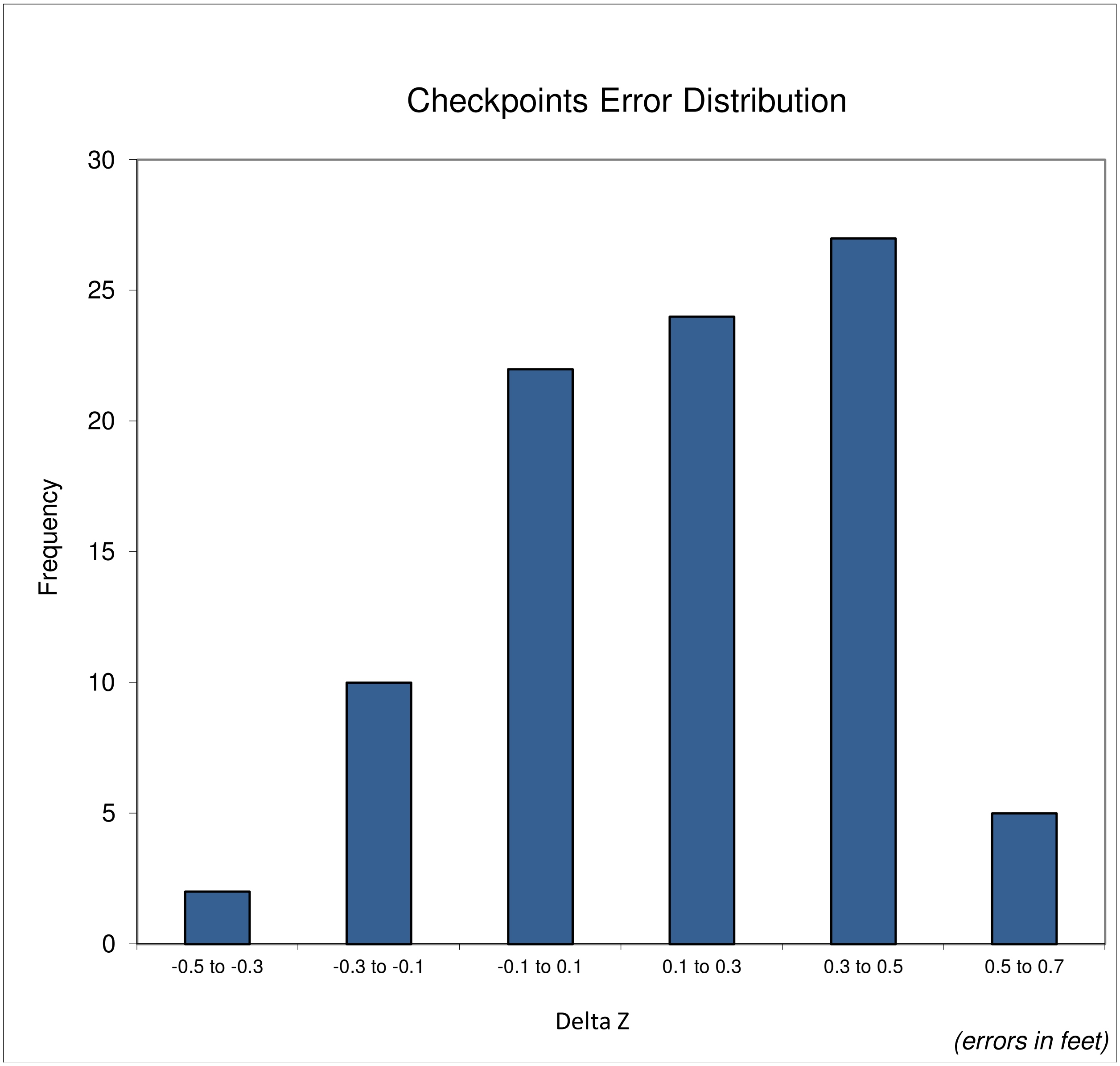


Figure 23 - Histogram of Elevation Discrepancies with errors in feet.

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the Upper Saint Johns Lidar Project 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 1 meter or less at the 95% confidence level.

LiDAR Horizontal Accuracy Results				
# of Points	$RMSE_x$ (Spec=1.34 ft)	$RMSE_y$ (Spec=1.34 ft)	$RMSE_r$ (Spec=1.9 ft)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Spec=3.28 ft
19	0.35	0.40	0.53	0.92

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 ft (1 meter) 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 = 0.35 ft (11 cm) and RMSEy = 0.40 ft (12 cm) which equates to +/- 0.92 ft (28 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

Earth Data Inc. used the terrain and intensity imagery to collect the Lakes and Ponds, Rivers and Streams, and Tidal in accordance with the project's Data Dictionary.

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.

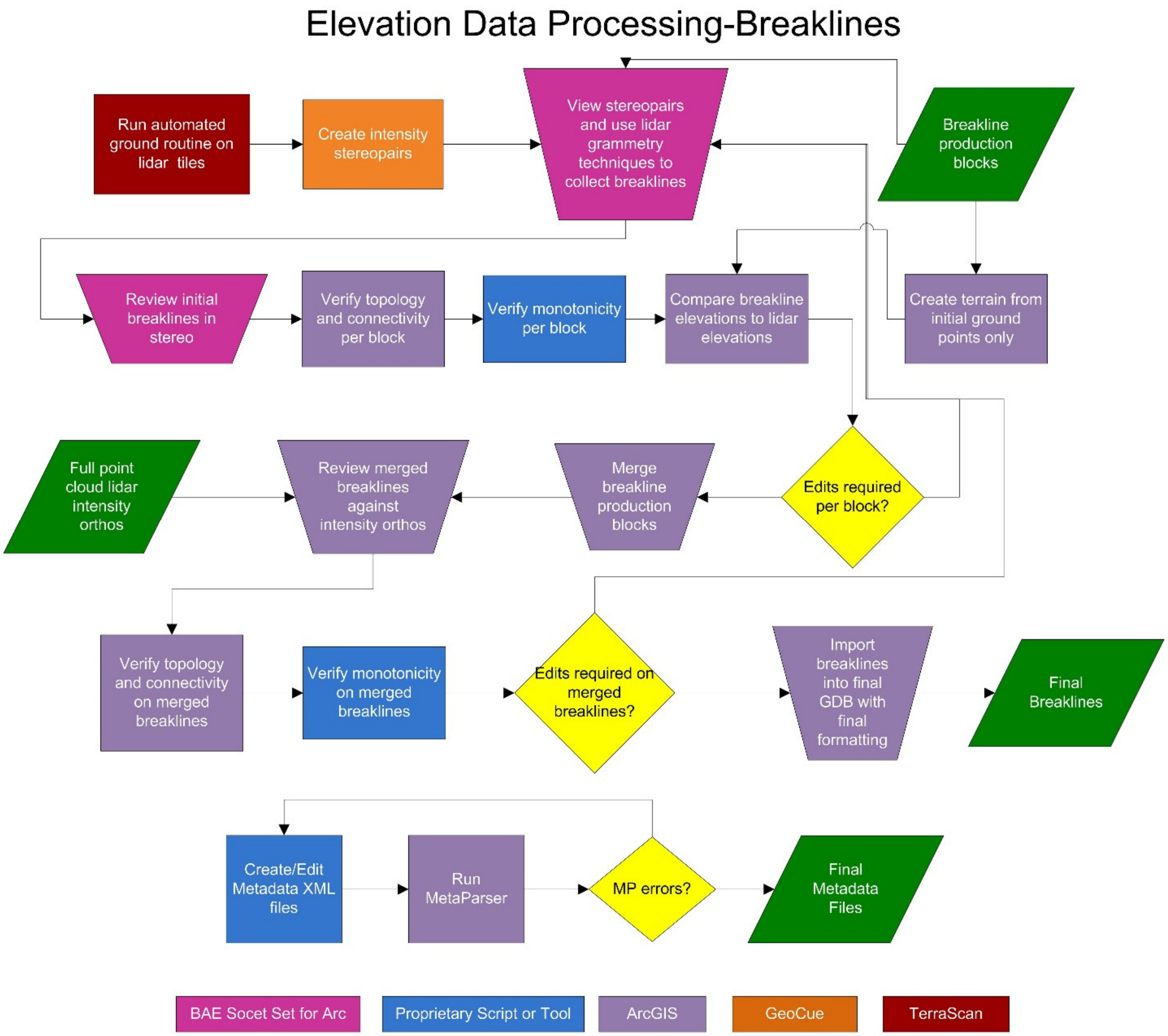


Figure 24-Breakline QA/QC workflow.

BREAKLINE CHECKLIST

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

Pass/Fail	Validation Step
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 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 U.S. Survey Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in U.S. Survey Feet. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to Nad83(20111) State Plane Florida East FIPS 0901, U.S. Survey Feet.

Inland Streams and Rivers

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

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

Description

This polygon feature class will depict linear hydrographic features with a width greater than 50 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 50 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 50 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. <u>The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body.</u> 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.

Beneath Bridge Breaklines

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

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

Description

This polyline feature class is used to enforce terrain beneath bridge decks where ground data may not have been acquired. Enforcing the terrain beneath bridge decks prevents bridge saddles.

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

Feature Definition

Description	Definition	Capture Rules
Bridge Breaklines	Bridge Breaklines should be used where necessary to enforce terrain beneath bridge decks and to prevent bridge saddles in the bare earth DEMs.	Bridge breaklines should be collected beneath bridges where bridge saddles exist or are likely to exist in the bare earth DEMs. Bridge breaklines should be collected perpendicular to the bridge deck so that the endpoints are on either side of the bridge deck. Typically two bridge breaklines are collected per bridge deck, one at either end of the bridge deck to enforce the terrain under the full bridge deck. The endpoints of the bridge breaklines will match the elevation of the ground at their xy position to enforce the ground/bare earth elevations beneath the bridge deck and prevent bridge saddles from forming.

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 images below show an example of a bare earth DEM.

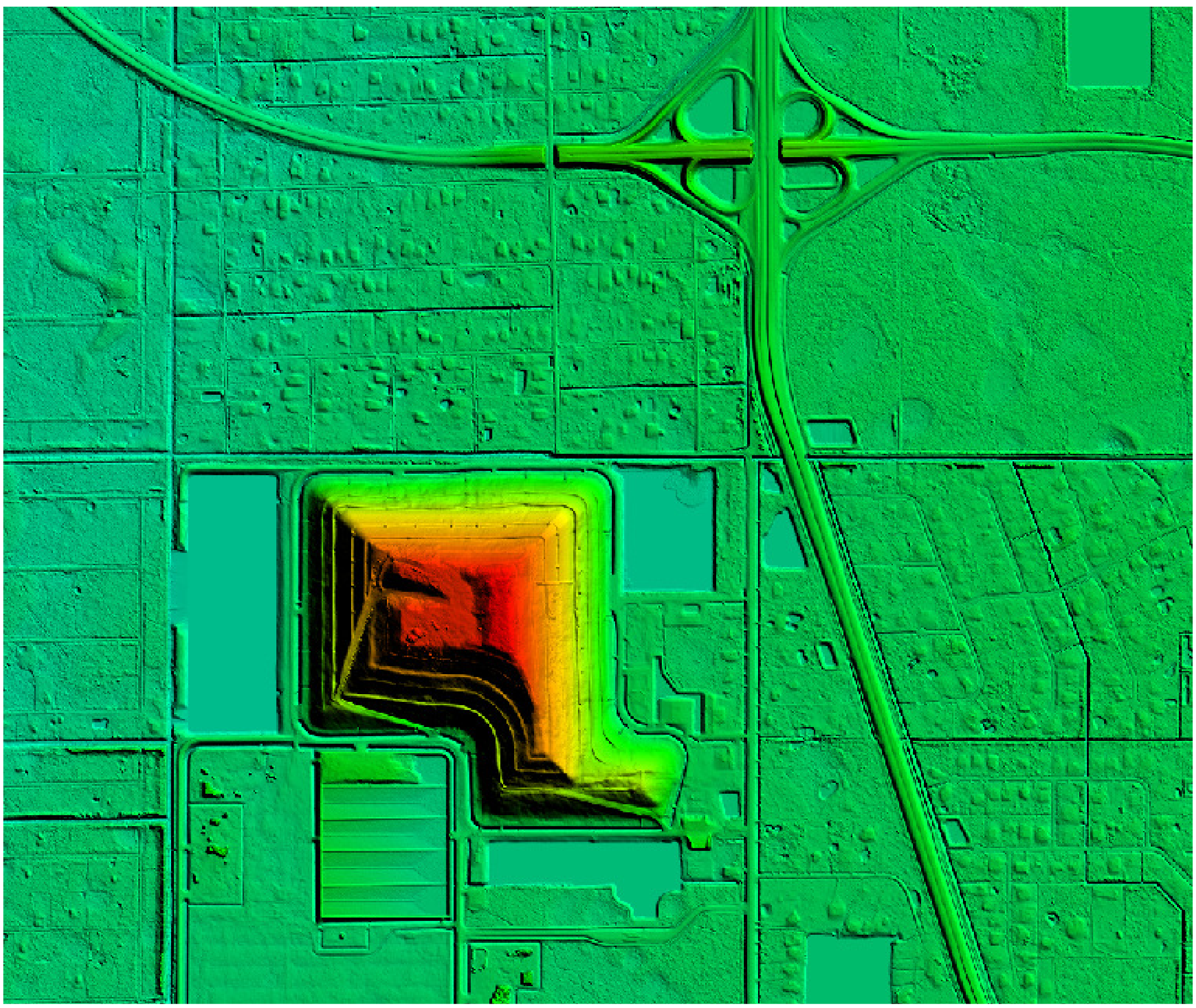


Figure 256-Tiles 261108, 261109, 261408 and 261409. The bare earth DEM is shown in the image above.

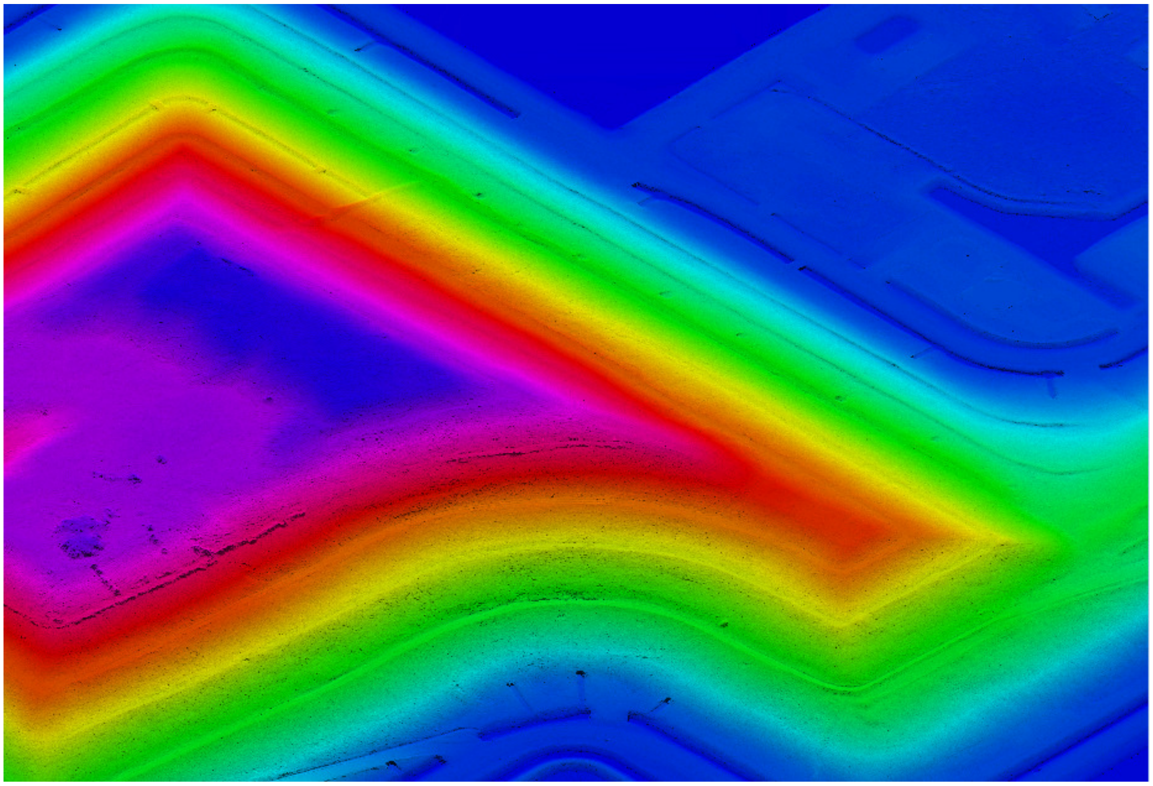


Figure 267 -Tile 261409. 3D Profile view of the bare earth DEM.

When some bridges are removed from the ground surface, the distance from bridge abutment to bridge abutment is small enough that the DEM interpolates across the entire bridge opening, forming 'bridge saddles.' Dewberry collected 3D bridge breaklines in locations where bridge saddles were present and enforced these breaklines in the final DEM creation to help mitigate the bridge saddle artifacts. The image below on the left shows a bridge saddle while the image below on the right shows the same bridge after bridge breaklines have been enforced.

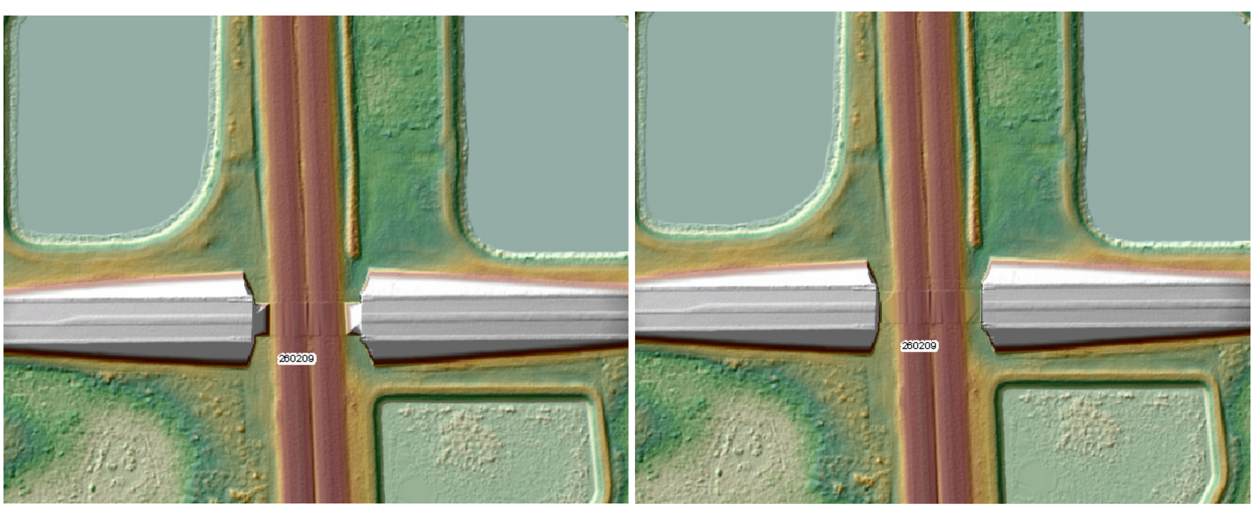


Figure 278 - The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 90 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	50.00	0.52	
VVA	40.00		0.54

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 $RMSE_z$ =0.27 ft (8.2 cm), equating to +/- 0.52 ft (15.8 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.54 ft (16.5) cm at the 95th percentile.

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

Point ID	NAD83(2011) FL State Plane East		NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Z-Survey (ft)	Z-LiDAR (ft)		
VVA4	673437.96	1651189.35	23.90	24.45	0.55	0.55
VVA38	671894.66	1476062.73	42.64	43.30	0.65	0.65

Table 12 - 5% Outliers

Table 13 provides overall descriptive statistics.

DEM Descriptive Statistics

100 % of Totals	# of Points	RMSEz (ft) Spec=0.33 ft NVA	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
NVA	50.00	0.27	0.14	0.13	0.00	0.23	-0.91	-0.32	0.54
VVA	40.00	N/A	0.25	0.26	-0.48	0.21	0.05	-0.25	0.65

Table 13 - Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the Upper Saint Johns Lidar Project 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.

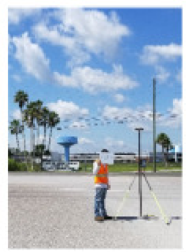
Table 14-A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Appendix A: Survey Report

Ground Control Point Survey Report Upper St. John's River Basin North LiDAR Project

USGS CONTRACT NUMBER: G16PC00020
TASK ORDER NUMBER: G17PD001256

PREPARED FOR:
USGS



Prepared By:
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1. INTRODUCTION

1.1 Project Summary

Dewberry Consultants LLC is under contract with the United States Geological Society (USGS) and St. John's River Water Management District (SJRWMD) to collect and process LiDAR for the Upper St. John's River Basin North (Puzzle Lakes), Florida. In support of this project Dewberry surveyed 30 Ground Control Points. Dewberry is tasked to complete the quality assurance of LiDAR products. As part of this work, Dewberry staff will complete a Control Survey of Ground Control Points that will be used to evaluate vertical and horizontal accuracy. The field work was conducted from April 24, 2018 –May 1, 2018.

Existing NGS Control Points were located and surveyed to check the accuracy of the RTK/GPS survey equipment with the results shown in Section 2.4 of this Report.

As an internal QA/QC procedure and to verify that the Ground Control Points meet the 95% confidence level approximately 50% of the points were re-observed and their corresponding coordinate differences are shown in Section 5 of this report.

Final horizontal coordinates are referenced to Florida State Plane Coordinate System, East Zone, NAD83 (2011 Adjustment) in U.S. Survey feet. Final vertical elevations are referenced to NAVD88 in U.S. Survey feet using Geoid model 2012B (Geoid12B).

1.2 Point of Contact

Questions regarding the technical aspects of this report should be addressed to:

Dewberry Engineers, Inc.

William D. Donley, PSM

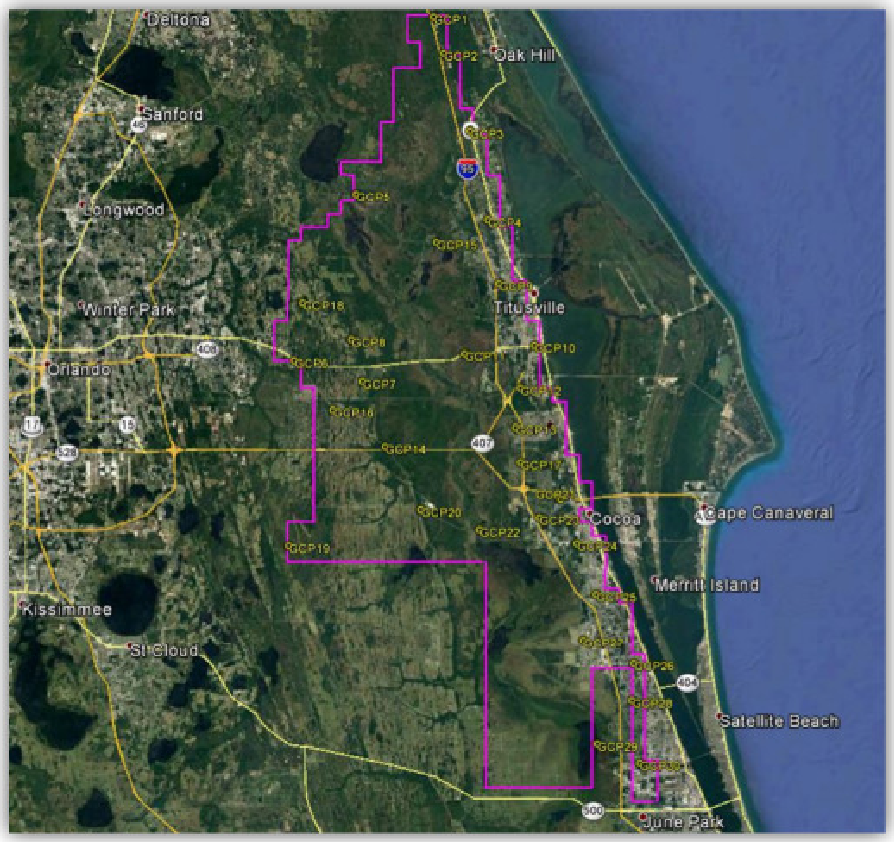
Associate Vice President

131 West Kaley Street

Orlando, Florida 32806

(321) 354-9834

1.3 Project Area



Project Limits and Ground Control Point Locations

2. PROJECT DETAILS

2.1 Survey Equipment

In performing the GPS observations, a Spectra Precision SP80 receiver/antenna attached to a two meter fixed height pole with a Spectra Precision Ranger 3 Data Collector were used. These receivers are geodetic quality dual frequency GPS receivers and were used to collect data at each surveyed location.

2.2 Survey Point Details

The 30 LiDAR Ground Control Points were well distributed throughout the project area. A sketch was made for each location and a nail & disk or iron rod & cap were set at the point where possible or at an identifiable point. The Ground Control Point locations are detailed on the "Ground Control Point Documentation Reports" sheets attached to this report.

2.3 Network Design

The GPS survey performed by Dewberry Engineers, Inc. office located in Orlando, FL was tied to VRS Now, a Real Time Network (RTN) managed by Trimble. Re-observation of select points (as described in Section 1.1 of this document) were tied to the Florida Permanent Reference Network, managed by the Florida Department of Transportation. Both networks are a series of "real-time" continuously operating, high precision GPS reference stations. All of the reference stations have been linked together using Trimble GPSNet software, creating a Virtual Reference Station System.

2.4 Field Survey Procedures and Analysis

All locations were occupied once with approximately 50% of the locations being re-observed. All re-observations matched the initially derived station positions within the allowable tolerance of ± 5cm or within the 95% confidence level. Each occupation which utilized the VRS network was occupied for approximately 1.5 minutes in duration and measured to 90 epochs.

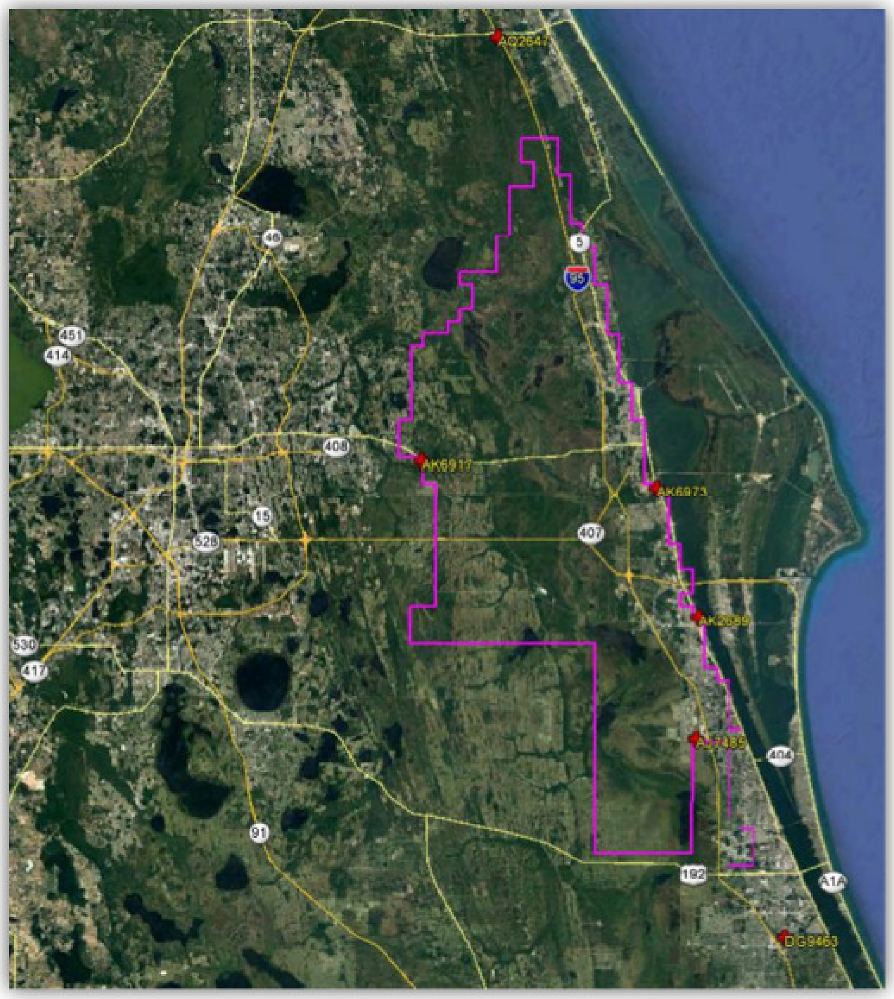
Field GPS observations are detailed on the "Ground Control Point Documentation Reports" submitted as part of this report.

Six (6) existing NGS monuments listed in the NSRS database were located as an additional QA/QC method to check the accuracy of the VRS network. An NGS monument was located at the beginning and end of observations each day to ensure measurement quality. The checks all individually conformed to the required accuracy and the average coordinates for the surveyed NGS monuments are shown below and compared to the published coordinates.

NGS PT. ID	Designation	As Surveyed (ft)			Published (ft)			Differences (ft)		
		Northing	Easting	Elevation	Northing	Easting	Elevation	Δ N	Δ E	Δ Elevation
AJ7485	L 460	1416372.760	741593.888	25.796	1416372.74	741593.91	25.93	0.020	-0.022	-0.134
AK2689	DRIVE	1465653.370	742536.254	20.482	1465653.37	742536.13	20.50	0.000	0.124	-0.018
AK6917	FLGPS 36	1528717.666	629520.575	70.353	1528717.65	629520.54	70.35	0.016	0.035	0.003
AK6973	H 229 RESET	1518319.864	725358.383	21.853	1518319.87	725358.34	21.85	-0.006	0.043	0.003
AQ2647	FLGPS 38	1699958.507	660568.369	28.862	1699958.59	660568.33	28.93	-0.083	0.039	-0.068
DG9463	BREVARD GPS 5024	1335870.774	778164.792	23.382	1335870.75	778164.75	23.36	0.024	0.042	0.022

The above results indicate that the VRS network is providing positional values within the ±5cm parameters for this survey.

2.4 Field Survey Procedures and Analysis (continued)



NGS Monuments

Legend:

Horizontal + Vertical NGS Benchmark

Vertical NGS Benchmark

2.5 Adjustment

The survey data was collected using Virtual Reference Stations within both the Florida Permanent Reference Network and the Trimble VRS Now Virtual Reference System. These systems are designed to provide a true Network RTK performance, enabling high-accuracy positioning in real time across a geographic region. Trimble VRS Now uses real-time data streams from the system user and generates correction models for high-accuracy RTK GPS corrections throughout the network. These corrections are applied to the points as they are being collected, negating the need for a post process adjustment.

2.6 Data Processing Procedures

After field data is collected the information is downloaded from the data collectors Spectra Precision – Survey Office. Downloaded data is run through the Survey Office program to obtain the following reports: points list, point derivations and a vector spreadsheet. The reports are reviewed for point accuracy and precision.

After review of the point data an "ASCII" or "txt" file, which is the industry standard is created. Point files are loaded into AutoCAD Civil 3D 2016 to make a visual check of the point data (Pt. #, Coordinates, Elev. and Description). The data is now imported into the final product.

2.7 Accuracy Reporting

The accuracy of the Trimble VRS Now Virtual Reference System meets the 5-centimeter local accuracy standard for the horizontal and vertical coordinate values (heights) at the 95-percent confidence level.

3. FINAL COORDINATES

Point ID	Northing (SPC FL E)	Easting (SPC FL E)	Elevation (Feet)
GCP 1	1659605.28	680210.04	27.27
GCP 2	1645850.35	684107.12	27.07
GCP 3	1616695.00	693942.11	27.12
GCP 4	1583036.35	700601.38	27.88
GCP 5	1592888.44	651055.22	10.83
GCP 6	1530338.94	627753.02	65.86
GCP 7	1522558.83	653431.65	50.85
GCP 8	1538165.09	649338.13	53.26
GCP 9	1559233.48	704848.63	23.57
GCP 10	1536083.17	718302.35	24.20
GCP 11	1532952.24	691952.28	13.85
GCP 12	1520134.53	712962.90	22.88
GCP 13	1505631.82	711178.47	20.73
GCP 14	1498413.80	661967.69	35.59
GCP 15	1574665.56	681351.67	12.78
GCP 16	1511880.83	642348.16	66.41
GCP 17	1492543.92	713058.00	21.64
GCP 18	1551932.10	630860.05	59.23
GCP 19	1461290.40	625688.86	72.54
GCP 20	1474830.50	675555.38	35.29
GCP 21	1478739.66	728186.57	35.45
GCP 22	1467376.68	697632.50	17.17
GCP 23	1471877.10	720164.32	24.50
GCP 24	1462152.98	734364.66	19.17
GCP 25	1443073.91	741650.05	23.01
GCP 26	1416925.68	755935.72	32.92
GCP 27	1425777.15	736871.02	23.35
GCP 28	1403001.55	755311.38	35.16
GCP 29	1386689.27	742205.33	18.14
GCP 30	1379515.34	758263.57	27.21

4. GPS OBSERVATION & RE-OBSERVATION SCHEDULE

Point ID	Observation Date	Julian Date	Time of Day	Re-observation Date	Re-observation Julian Date	Re-observation Time of Day
GCP 1	4/27/2018	117	12:08	5/1/2018	121	9:02
GCP 2	4/27/2018	117	11:37	N/A	N/A	N/A
GCP 3	4/27/2018	117	11:15	5/1/2018	121	8:35
GCP 4	4/27/2018	117	10:54	N/A	N/A	N/A
GCP 5	4/27/2018	117	10:19	N/A	N/A	N/A
GCP 6	4/25/2018	115	14:22	4/30/2018	120	12:13
GCP 7	4/25/2018	115	14:58	N/A	N/A	N/A
GCP 8	4/25/2018	115	15:14	N/A	N/A	N/A
GCP 9	4/27/2018	117	9:08	4/30/2018	120	14:40
GCP 10	4/27/2018	117	8:05	N/A	N/A	N/A
GCP 11	4/27/2018	117	7:47	4/30/2018	120	13:58
GCP 12	4/27/2018	117	8:25	4/30/2018	120	14:16
GCP 13	4/27/2018	117	8:44	N/A	N/A	N/A
GCP 14	4/25/2018	115	11:36	4/30/2018	120	11:55
GCP 15	4/27/2018	117	9:46	5/1/2018	121	8:12
GCP 16	4/25/2018	115	14:37	N/A	N/A	N/A
GCP 17	4/25/2018	115	9:36	4/30/2018	120	10:47
GCP 18	4/25/2018	115	15:34	4/30/2018	120	13:35
GCP 19	4/25/2018	115	12:24	N/A	N/A	N/A
GCP 20	4/25/2018	115	11:14	N/A	N/A	N/A
GCP 21	4/25/2018	115	10:07	N/A	N/A	N/A
GCP 22	4/25/2018	115	10:55	4/30/2018	120	11:25
GCP 23	4/25/2018	115	10:29	4/30/2018	120	11:13
GCP 24	4/24/2018	114	14:22	N/A	N/A	N/A
GCP 25	4/24/2018	114	14:00	4/30/2018	120	10:12
GCP 26	4/24/2018	114	11:53	4/30/2018	120	9:40
GCP 27	4/24/2018	114	13:40	N/A	N/A	N/A
GCP 28	4/24/2018	114	11:31	4/30/2018	120	9:18
GCP 29	4/24/2018	114	11:05	4/30/2018	120	8:46
GCP 30	4/24/2018	114	10:42	4/30/2018	120	8:22

5. POINT COMPARISON REPORT

Point ID	Check Point ID	Δ North	Δ East	Δ Vertical
GCP 1	CHK_GCP1	-0.015	0.059	-0.009
GCP 3	CHK_GCP3	-0.003	-0.027	-0.039
GCP 6	CHK_GCP6	-0.042	-0.030	-0.092
GCP 9	CHK_GCP9	0.025	0.004	0.032
GCP 11	CHK_GCP11	-0.012	0.046	0.008
GCP 12	CHK_GCP12	0.005	0.018	-0.049
GCP 14	CHK_GCP14	-0.076	-0.029	0.007
GCP 15	CHK_GCP15	-0.071	0.009	-0.071
GCP 17	CHK_GCP17	-0.009	0.041	-0.042
GCP 18	CHK_GCP18	0.012	-0.016	-0.119
GCP 22	CHK_GCP22	-0.046	0.009	0.030
GCP 23	CHK_GCP23	0.063	0.002	0.023
GCP 25	CHK_GCP25	0.039	-0.003	-0.006
GCP 26	CHK_GCP26	-0.038	0.092	-0.158
GCP 28	CHK_GCP28	-0.009	0.065	-0.012
GCP 29	CHK_GCP29	-0.013	-0.051	-0.016
GCP 30	CHK_GCP30	-0.089	-0.045	0.003

6. SURVEY NOTES

1) Coordinates shown hereon are based on the Florida State Plane Coordinate System, East Zone, North American Datum of 1983 with 2011 adjustment.
2) Elevations shown hereon are based on the North American Vertical Datum of 1988.
3) The purpose of this survey was to survey points across the Upper St. John's River Basin North (Puzzle Lakes), Florida, for the verification of LiDAR data.

7. GLOSSARY/LEGEND

CHK	Check
ELEV	Elevation
FPRN	Florida Permanent Reference Network
ft	feet
GCP	Gound Control Point
GPS	Global Positioning System
ID	Identification
LiDAR	Light Detection and Ranging
LS	Land Surveyor
NAD	North American Datum
NAVD	North American Verrtical Datum
NGS	National Geodetic Survey
QA/QC	Quality Assurance/Quality Control
RTK	Real Time Kinematic
RTN	Real-Time Network
SPC	State Plane Coordinate
SJRWMD	St. John's River Water Management District
VRS	Virtual Reference System

8. SURVEYOR'S CERTIFICATION

I hereby certify this survey report meets the applicable "Standards of Practice" as set forth by the Florida Board of Professional Surveyors and Mappers in rule 5J17.050-.052, Florida Administrative Code.

William D. Donley

William D. Donley
Florida Licensed Surveyor & Mapper No. LS 5381

WILLIAM D. DONLEY CERTIFICATE NO. 5381 STATE OF FLORIDA REGISTERED LAND SURVEYOR

05-04-2018
Date

This Survey is not valid without the signature and original raised seal of a Florida Licensed Surveyor and Mapper.

Certificate of Authorization No. LB8011

Appendix B: Complete List of Delivered Tiles

250601	253301	254502	255403	256293
250602	253302	254503	255404	256294
250603	253303	254504	255405	256295
250901	253304	254505	255406	256296
250902	253305	254506	255407	256297
250903	253306	254507	255408	256298
251202	253599	254796	255692	256299
251203	253600	254797	255693	256300
251502	253601	254798	255694	256301
251503	253602	254799	255695	256302
251504	253603	254800	255696	256303
251800	253604	254801	255697	256304
251801	253605	254802	255698	256305
251802	253606	254803	255699	256306
251803	253896	254804	255700	256307
251804	253897	254805	255701	256308
252100	253898	254806	255702	256592
252101	253899	254807	255703	256593
252102	253900	255095	255704	256594
252103	253901	255096	255705	256595
252104	253902	255097	255706	256596
252400	253903	255098	255707	256597
252401	253904	255099	255708	256598
252402	253905	255100	255992	256599
252403	253906	255101	255993	256600
252404	254197	255102	255994	256601
252700	254198	255103	255995	256602
252701	254199	255104	255996	256603
252702	254200	255105	255997	256604
252703	254201	255106	255998	256605
252704	254202	255107	255999	256606
252705	254203	255393	256000	256607
252999	254204	255394	256001	256608
253000	254205	255395	256002	256609
253001	254206	255396	256003	256892
253002	254207	255397	256004	256893
253003	254497	255398	256005	256894
253004	254498	255399	256006	256895
253005	254499	255400	256007	256896
253299	254500	255401	256008	256897
253300	254501	255402	256292	256898

256899	257504	258106	258995	259600
256900	257505	258107	258996	259601
256901	257506	258108	258997	259602
256902	257507	258109	258998	259603
256903	257508	258110	258999	259604
256904	257509	258393	259000	259605
256905	257510	258394	259001	259606
256906	257791	258395	259002	259607
256907	257792	258396	259003	259608
256908	257793	258397	259004	259609
256909	257794	258398	259005	259610
257192	257795	258399	259006	259611
257193	257796	258400	259007	259612
257194	257797	258401	259008	259894
257195	257798	258402	259009	259895
257196	257799	258403	259010	259896
257197	257800	258404	259011	259897
257198	257801	258405	259294	259898
257199	257802	258406	259295	259899
257200	257803	258407	259296	259900
257201	257804	258408	259297	259901
257202	257805	258409	259298	259902
257203	257806	258410	259299	259903
257204	257807	258693	259300	259904
257205	257808	258694	259301	259905
257206	257809	258695	259302	259906
257207	257810	258696	259303	259907
257208	258091	258697	259304	259908
257209	258092	258698	259305	259909
257491	258093	258699	259306	259910
257492	258094	258700	259307	259911
257493	258095	258701	259308	259912
257494	258096	258702	259309	260194
257495	258097	258703	259310	260195
257496	258098	258704	259311	260196
257497	258099	258705	259312	260197
257498	258100	258706	259594	260198
257499	258101	258707	259595	260199
257500	258102	258708	259596	260200
257501	258103	258709	259597	260201
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260206	260809	261410	262009	262604
260207	260810	261411	262010	262605
260208	260811	261412	262011	262606
260209	260812	261413	262012	262607
260210	260813	261414	262013	262608
260211	261094	261694	262014	262609
260212	261095	261695	262292	262610
260494	261096	261696	262293	262611
260495	261097	261697	262294	262612
260496	261098	261698	262295	262613
260497	261099	261699	262296	262614
260498	261100	261700	262297	262615
260499	261101	261701	262298	262907
260500	261102	261702	262299	262908
260501	261103	261703	262300	262909
260502	261104	261704	262301	262910
260503	261105	261705	262302	262911
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260508	261110	261710	262307	263207
260509	261111	261711	262308	263208
260510	261112	261712	262309	263209
260511	261113	261713	262310	263210
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260794	261395	261994	262313	263213
260795	261396	261995	262314	263214
260796	261397	261996	262315	263215
260797	261398	261997	262592	263507
260798	261399	261998	262593	263508
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260800	261401	262000	262595	263510
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260806	261407	262006	262601	263516

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Appendix C: GPS Processing

Appendix C is a separate document located in the reports folder of the deliverables.