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Palm Beach County Lidar

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 Palm Beach County, Florida Project Area.

The lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 2,500 ft by 2,500 ft. A total of 9,222 tiles were produced for the project encompassing an area of approximately 1994 sq. miles.

THE PROJECT TEAM

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

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

Axis Geospatial, LLC completed lidar data acquisition and data calibration for the project area.

Digital Aerial Solutions completed breakline production for Palm Beach County, Florida Project. Dewberry was responsible for all QA/QC of the final deliverables.

SURVEY AREA

The project area addressed by this report falls within the Palm Beach County, Florida.

DATE OF SURVEY

The lidar aerial acquisition was conducted from December 28, 2016 thru March 10, 2017.

COORDINATE REFERENCE SYSTEM

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

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

LIDAR VERTICAL ACCURACY

For the Palm Beach County Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled 0.16 ft (4.9 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 0.31 ft (9.4 cm), compared with the 19.6 cm specification.

For the Palm Beach County Lidar Project, the tested VVA of the classified lidar data computed using the 95^{th} percentile was equal to 0.59 ft (18 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 – Grid Format)
3. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
4. Contours
5. Breakline Data (File GDB)
6. 2D Building Footprints
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 thousand two hundred twenty two (9,222) tiles were delivered for the project. Each tile's extent is 2,500 ft by 2,500 ft (see Appendix B for a complete listing of delivered tiles).

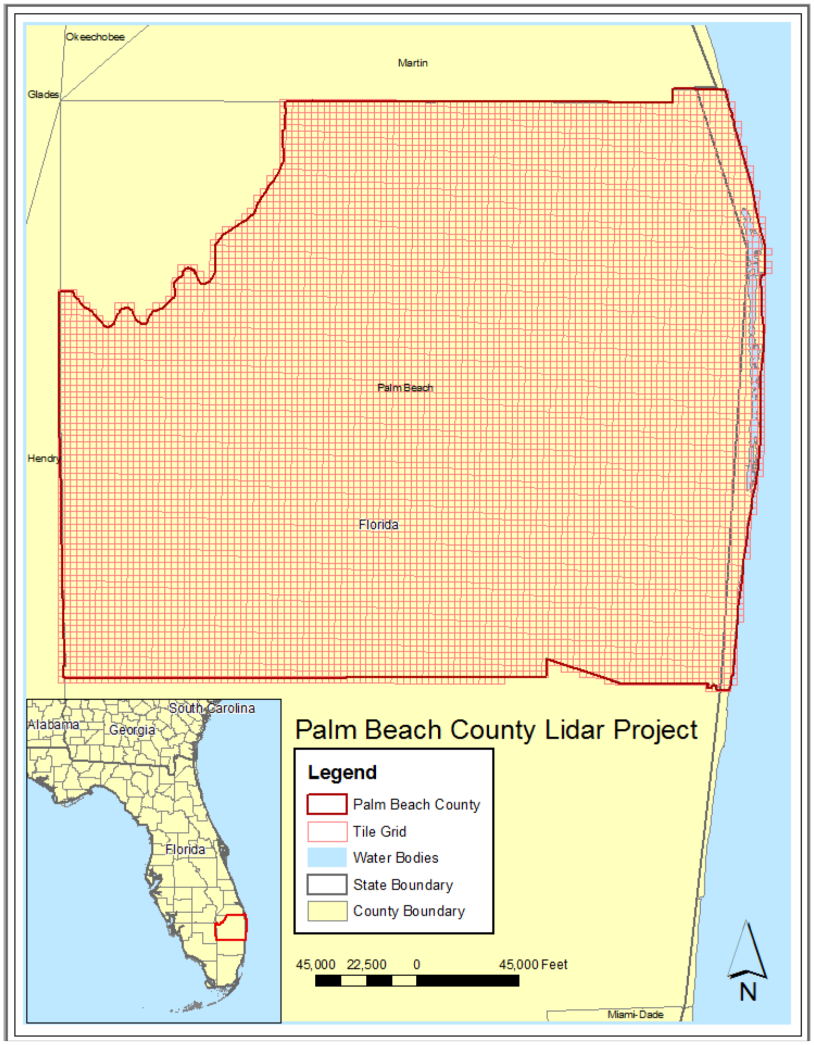


Figure 1 - Project Map

Lidar Acquisition Report

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

Dewberry received calibrated swath data from Axis Geospatial, LLC on March 31, 2017.

LIDAR ACQUISITION DETAILS

Axis Geospatial, LLC planned 228 passes for the project area as a series of north-south parallel flight lines with cross flightlines for the purposes of quality control. Two (2) geographical areas were planned to follow this configuration. The flight plan configuration was based upon total line length to minimize IMU drift. In order to reduce any margin for error in the flight plan, Axis GeoSpatial, LLC followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using TrackAir 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, Axis Geospatial, LLC will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Axis Geospatial, LLC 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. Axis Geospatial, LLC 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, Axis Geospatial, LLC 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.

Axis Geospatial, LLC lidar sensors are calibrated at a designated site located at the Easton Airport in Easton, Maryland and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Axis Geospatial, LLC operated a Cessna 206H single engine aircraft (N223TC) outfitted with a Riegl LMS-Q1560 dual channel laser scanner LiDAR system during the collection of the study area. Table 1 illustrates Axis Geospatial, LLC system parameters for lidar acquisition on this project.

Item	Parameter
System	Riegl LMS-Q1560
Altitude (AGL meters)	907
Approx. Flight Speed (knots)	140
Scanner Pulse Rate (kHz)	800
Scan Frequency (hz)	267
Pulse Duration of the Scanner (nanoseconds)	3
Pulse Width of the Scanner (m)	.51
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	.25
Nominal Swath Width on the Ground (m)	1016
Swath Overlap (%)	30
Total Sensor Scan Angle (degree)	58.52
Computed Down Track spacing (m) per beam	0.52
Computed Cross Track Spacing (m) per beam	0.52
Nominal Pulse Spacing (single swath), (m)	0.52
Nominal Pulse Density (single swath) (ppsm), (m)	7.3
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.52
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	7.3
Maximum Number of Returns per Pulse	unlimited

Table 1: Axis Geospatial, LLC 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.

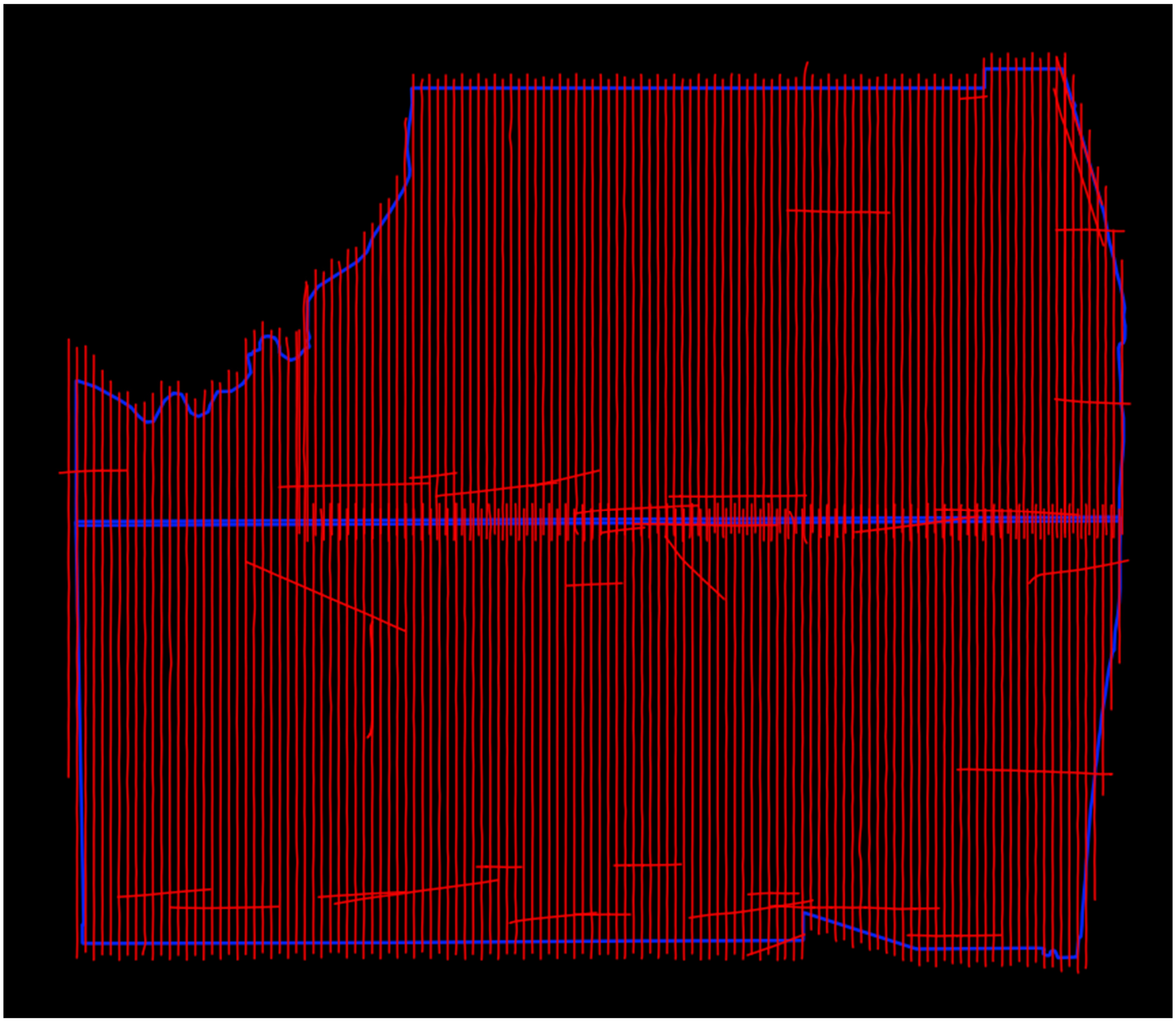


Figure 2 - Trajectories as flown by Axis Geospatial, LLC

LIDAR CONTROL

NGS CORS Base Stations were used to control the lidar acquisition for the Palm Beach County 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)
AD0692	750065.45	846966.62	19.88
AD8025	957185.87	900458.65	16.71

Number	NAD83 (2011) State Plane Florida East FIPS 0901 US Feet		NAVD88 (Geoid 12B)
AD8038	963705.25	798923.64	11.31
AD8198	879.898.37	854938.08	15.39
AE7219	858571.72	747311.64	21.40
AJ2050	776091.71	919959.32	33.35

Table 2 – Base stations used to control lidar acquisition

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the PosPac Mobile Mapping System (MMS) version 7.2 software suite. 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, initially with default values from Riegl or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. 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.

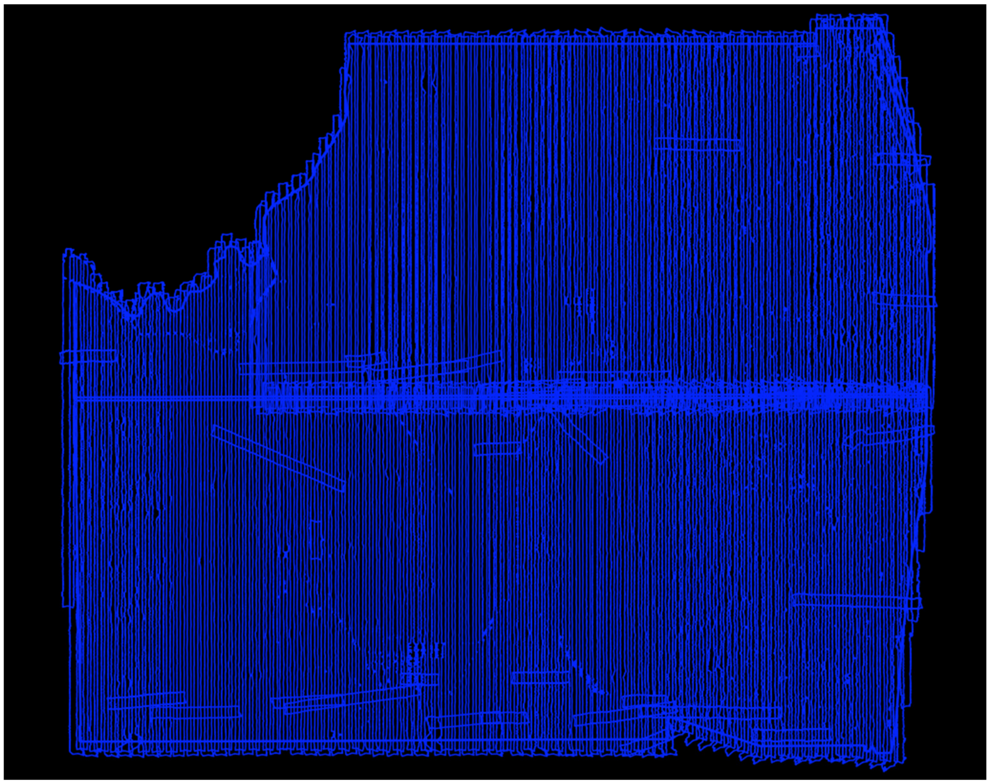


Figure 3 - Lidar swath output showing complete coverage.

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:
Relative accuracy <= 6 cm maximum difference within individual swaths and <=8 cm RMSDz between adjacent and overlapping swaths.

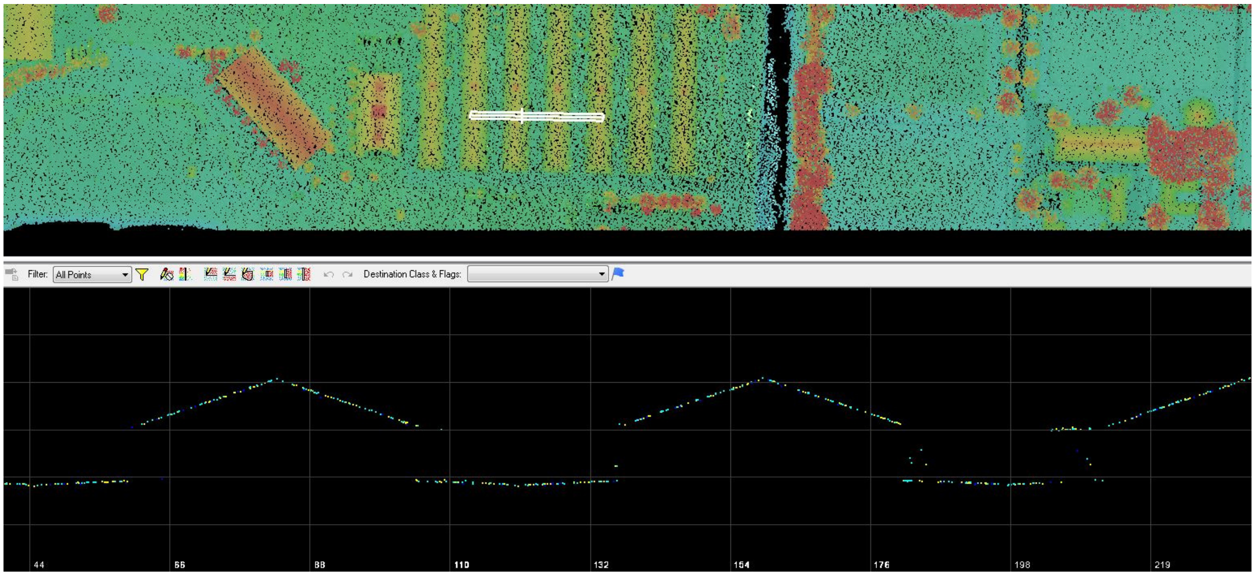


Figure 4 - Profile views showing correct roll and pitch adjustments.

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 Axis Geospatial, LLC at this stage of the project life cycle in the raw lidar dataset against GPS static and kinematic data and compared to $RMSE_z$ project specifications. The lidar data is examined in non-vegetated, flat areas away from breaks. Lidar ground points for each flight line generated by an automatic classification routine are used.

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met Non-vegetated Vertical Accuracy (NVA) requirements ($RMSE_z \leq 10$ cm and $Accuracy_z$ at the 95%

confidence level ≤ 19.6 cm) when compared to static and kinematic GPS checkpoints. Below is a summary for the test:

The calibrated Palm Beach County dataset was tested to 0.357 ft vertical accuracy at 95% confidence level based on $RMSE_z$ (0.182 ft x 1.9600) when compared to 61 GPS static check points.

The following are the final statistics for the GPS static checkpoints used by Axis Geospatial, LLC to internally verify vertical accuracy.

Number	NAD83 (2011) State Plane Florida East FIPS 0901 US Feet		NAVD88 (Geoid 12B)	Laser Z (USft)	Delta Z
	Easting X (USft)	Northing Y (USft)	Known Z (USft)		
GC_01	783299.648	953197.913	18.948	19.050	0.102
GC_02	858986.987	955179.734	26.272	26.340	0.068
GC_03	954935.876	956109.807	12.951	13.000	0.049
GC_04	960156.902	902576.061	4.649	4.810	0.161
GC_05	965261.047	797608.132	1.960	2.190	0.230
GC_06	954881.241	729257.754	12.785	12.880	0.095
GC_07	886648.624	725829.548	10.849	10.790	-0.059
GC_08	807508.264	727814.650	18.288	18.170	-0.118
GC_09	729890.265	726178.467	21.538	21.560	0.022
GC_10	694327.151	772899.889	17.229	17.460	0.231
GC_11	694869.245	874086.162	12.838	13.080	0.242
GC_12	763236.627	858986.935	12.630	12.910	0.280
GC_13	780197.991	913070.360	15.142	15.320	0.178
GC_14	829792.328	911871.765	15.634	16.060	0.426
GC_15	895328.672	901001.455	22.495	22.570	0.075
GC_16	858281.483	851899.248	21.065	21.300	0.235
GC_17	969906.763	838396.609	4.443	4.620	0.177
GC_18	958548.722	764623.870	17.371	17.170	-0.201
GC_19	925854.986	837457.691	21.058	21.260	0.202
GC_20	939518.581	806034.620	18.098	18.390	0.292
GC_21	907043.515	871274.770	17.141	17.050	-0.091
GC_22	810951.277	890926.573	17.156	17.280	0.124
GC_23	816559.621	852432.417	15.725	15.860	0.135
GC_24	885249.506	839344.322	14.493	14.700	0.207
GC_25	837185.071	777736.110	16.350	16.260	-0.090
GC_26	769364.804	782188.493	15.557	15.800	0.243
GC_27	751383.412	807580.466	17.345	17.420	0.075
GC_28	836969.366	823322.213	17.975	17.840	-0.135
GC_29	865427.748	876318.145	18.332	17.940	-0.392
GC_30	701355.325	842927.663	16.396	16.610	0.214
GC_31	758604.127	750111.169	20.429	20.450	0.021
GC_32	794868.150	810245.887	11.064	11.350	0.286
GC_33	757079.865	893099.751	10.661	10.940	0.279

Number	NAD83 (2011) State Plane Florida East FIPS 0901 US Feet		NAVD88 (Geoid 12B)	Laser Z (USft)	Delta Z
GC_34	941455.059	927613.700	19.900	**Slope	
GC_35	942425.211	884819.219	16.282	16.340	0.058
GC_36	905651.952	814961.838	17.224	17.310	0.086
GC_37	935374.902	751796.816	19.590	19.640	0.050
GC_38	815998.190	769902.799	11.197	11.330	0.133
GC_39	694668.772	726585.120	23.193	23.270	0.077
GC_40	718390.217	859401.049	15.031	15.160	0.129
GC_41	791867.921	840299.564	18.763	18.900	0.137
GC_42	892026.412	931369.091	21.377	21.250	-0.127
GC_43	911888.362	772640.959	16.762	16.730	-0.032
GC_44	898264.407	948568.897	22.238	22.310	0.072
GC_45	707829.405	811209.825	16.241	16.480	0.239
GC_46	813352.730	954246.667	25.289	25.410	0.121
GC_47	933851.310	951501.722	12.300	12.430	0.130
GC_49	916828.479	726871.348	18.526	18.600	0.074
GC_50	749721.016	847011.137	13.595	13.790	0.195
GC_51	719307.289	764164.380	14.494	14.730	0.236
HC_01	783263.505	951214.588	15.992	16.150	0.158
HC_02	954979.525	955976.065	12.006	12.240	0.234
HC_03	954909.190	729258.353	12.817	12.900	0.083
HC_04	729790.697	726347.390	16.310	16.170	-0.140
HC_05	763231.528	859026.171	12.812	13.180	0.368
HC_06	895236.867	901179.170	22.220	22.300	0.080
HC_07	837491.200	777740.561	13.632	13.560	-0.072
HC_08	751360.909	807603.741	17.500	17.570	0.070
HC_09	925811.698	837381.777	21.625	21.790	0.165
HC_10	858246.165	851825.661	19.289	19.310	0.021
HC_11	791876.038	840290.967	18.625	18.960	0.335
HC_12	694874.962	874598.917	12.346	12.480	0.134

Table 3 - Static GPS Points

100 % of Totals	# of Points	RMSEz (USft) NVA Spec=0.328 ft	NVA at 95% Spec=0.643 ft	Mean (ft)	Std Dev (ft)	Min (ft)	Max (ft)
Non-Vegetated Terrain	61	0.182	0.357	0.108	0.148	-0.392	0.426

Table 4 - Static GPS Vertical Accuracy Results

Overall the calibrated lidar data products collected by Axis Geospatial, LLC meet or exceed the requirements set out in the Statement of Work. The quality control requirements of Axis Geospatial, LLC quality management program were adhered to throughout the acquisition stage 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 Axis Geospatial, LLC, 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 seventy nine (79) 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 Palm Beach County 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 $RMSE_z$ = 0.17 ft (5.2 cm), equating to +/- 0.34 ft (10.4 cm) at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

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	79	0.17	0.34	0.08	0.07	0.42	0.15	-0.25	0.63	1.04

Table 5: NVA at 95% Confidence Level for Raw Swaths

Inter-Swath (Between Swath) Relative Accuracy

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

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

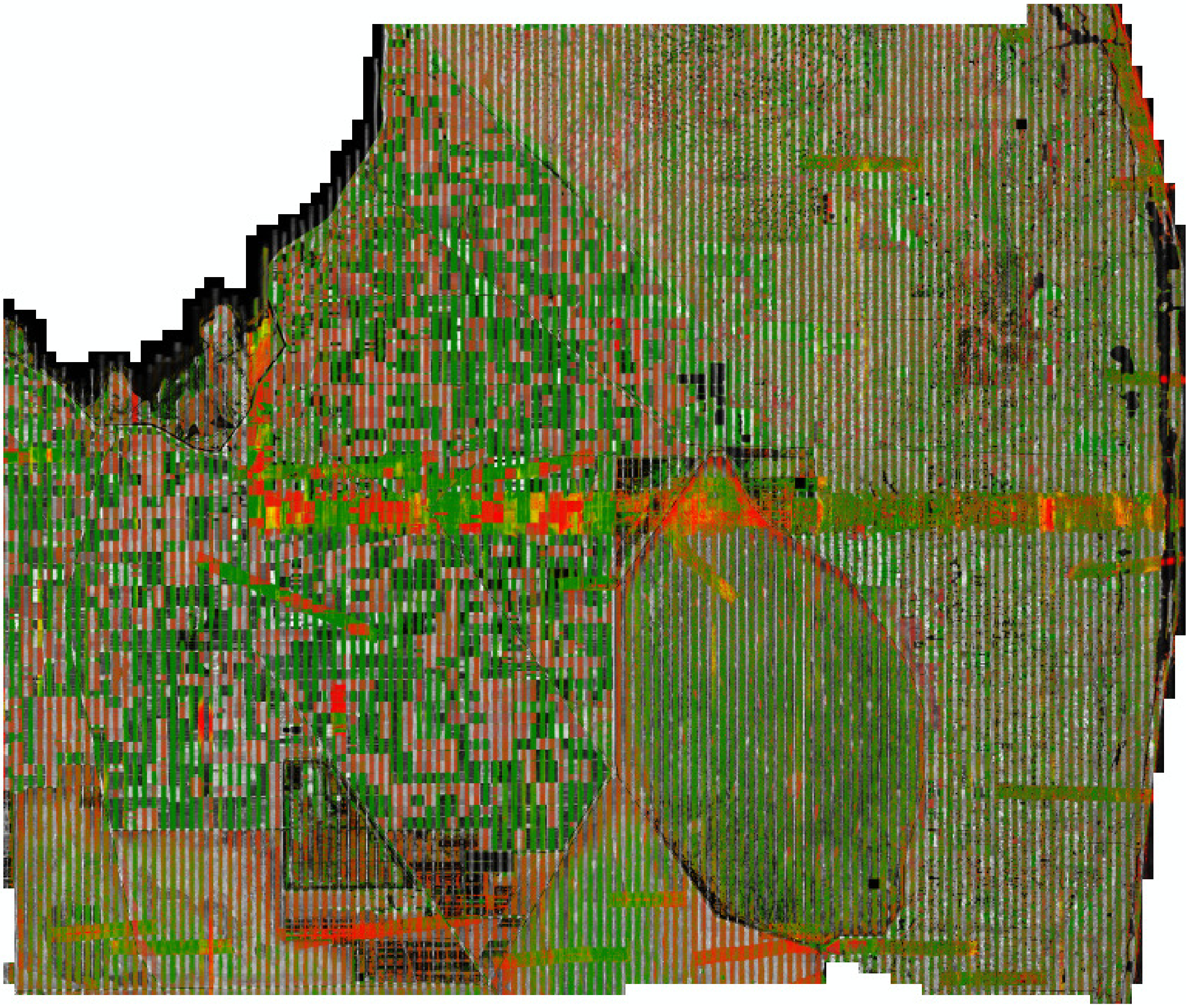


Figure 6 - Single return DZ Orthos for the Palm Beach County Lidar Project. Inter-swath relative accuracy passes specifications.

Intra-Swath (Within a Single Swath) Relative Accuracy

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

Figure 7 - Intra-swath relative accuracy. The image is a close-up of a flat area. With the exception of few trees and an airplane (shown in red as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.

Horizontal Alignment

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

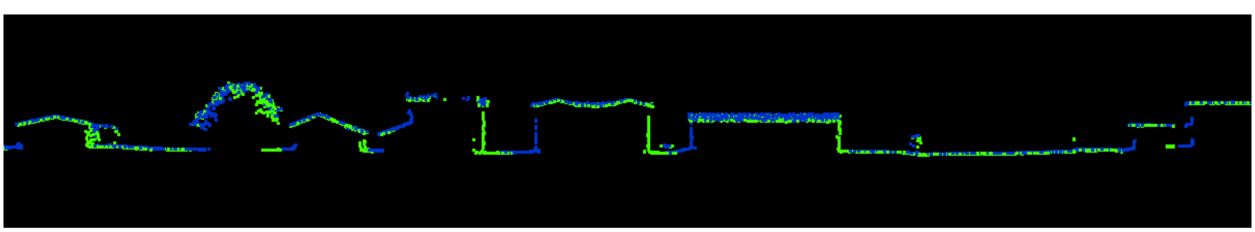


Figure 8 - Horizontal Alignment. Two separate flight lines differentiated by color (Green/Blue) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.71 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 2 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.27 meters or an ANPD of 14.2 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.

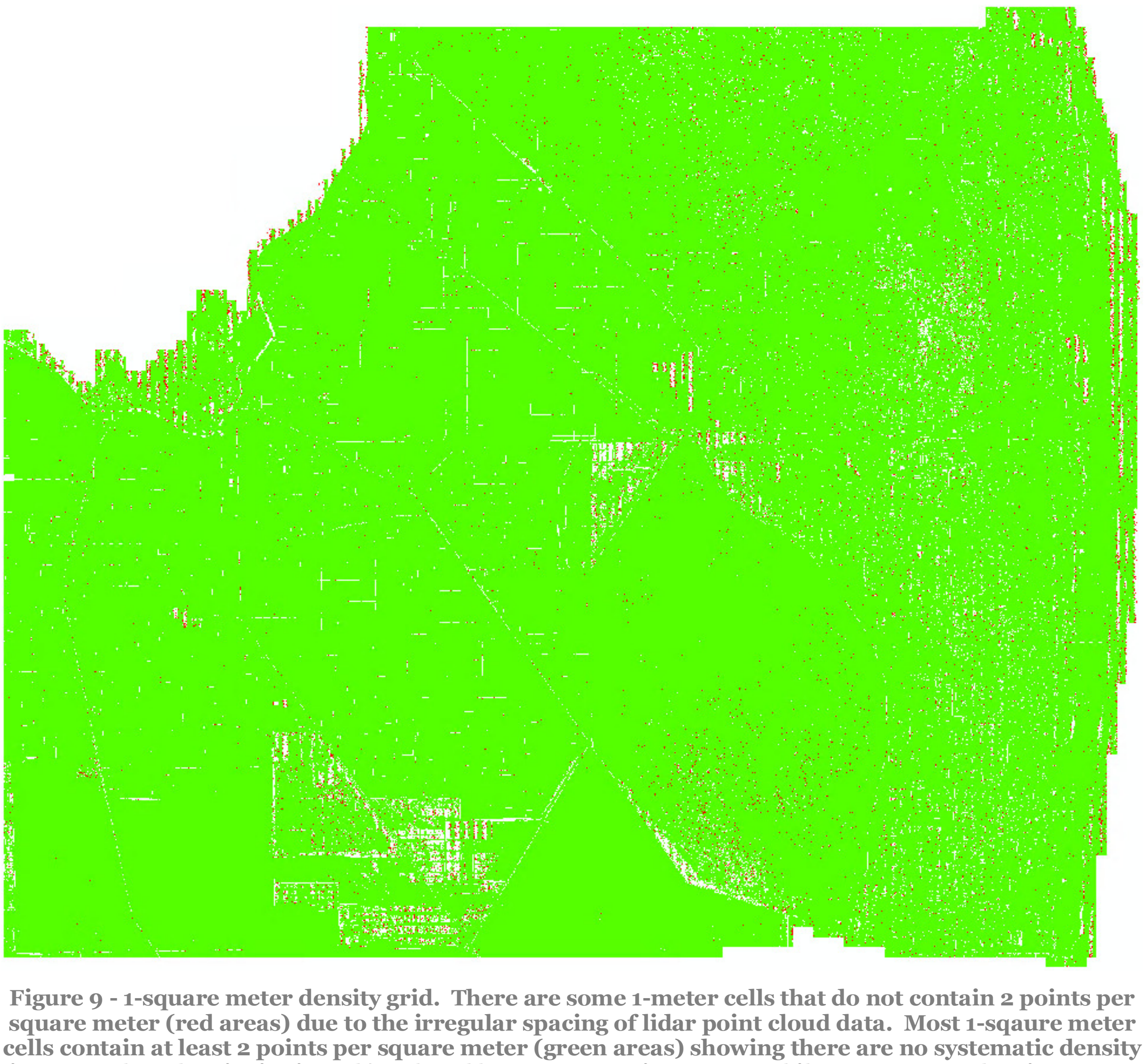


Figure 9 - 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) showing there are no systematic density 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 8 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.

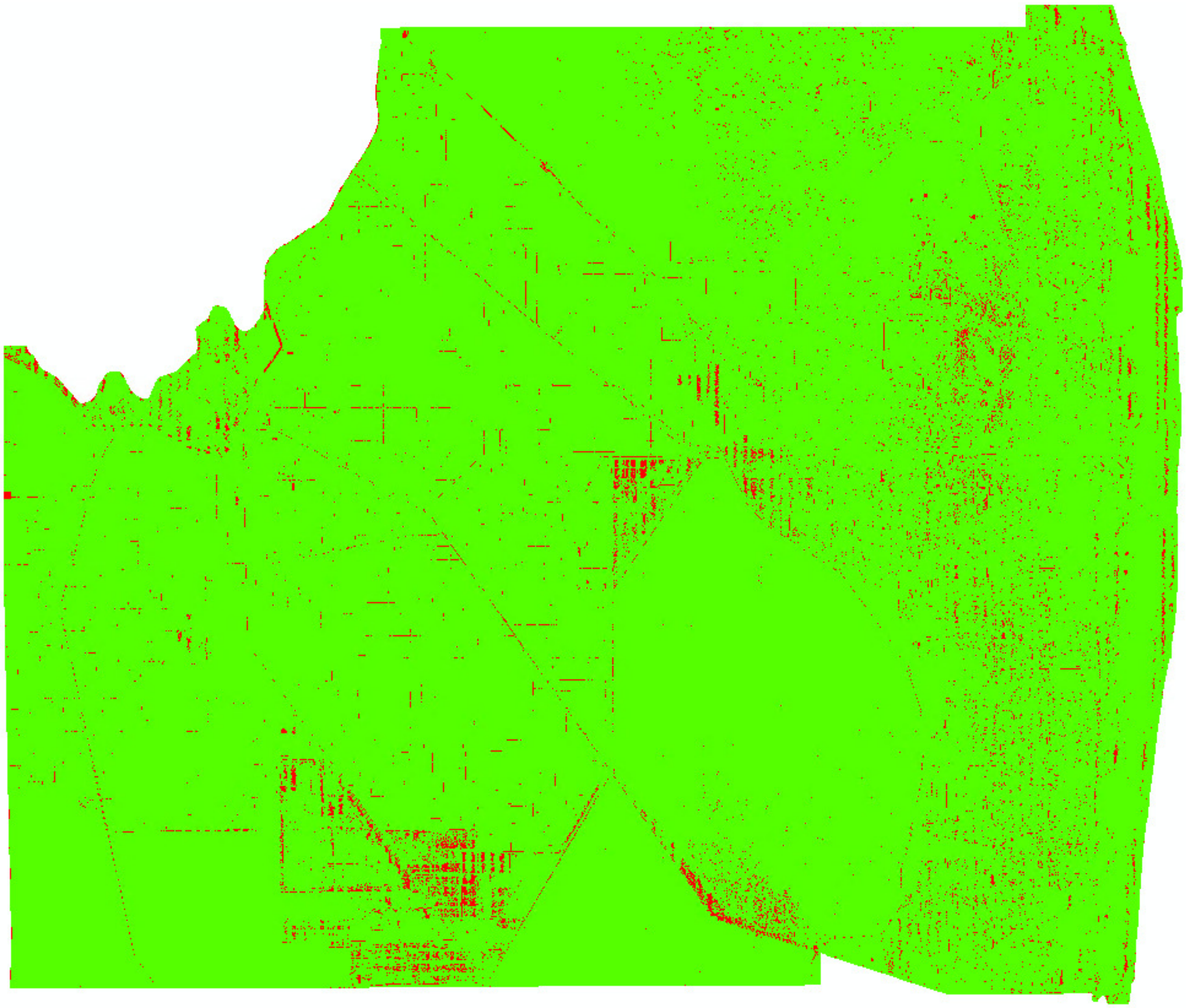


Figure 11 - Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies which are acceptable NoData area, are colored red. Without removing acceptable NoData areas due to water, 97.1% of cells 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 = Processed, but unclassified
- 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 Palm Beach County Lidar Project.

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 Palm Beach County 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.

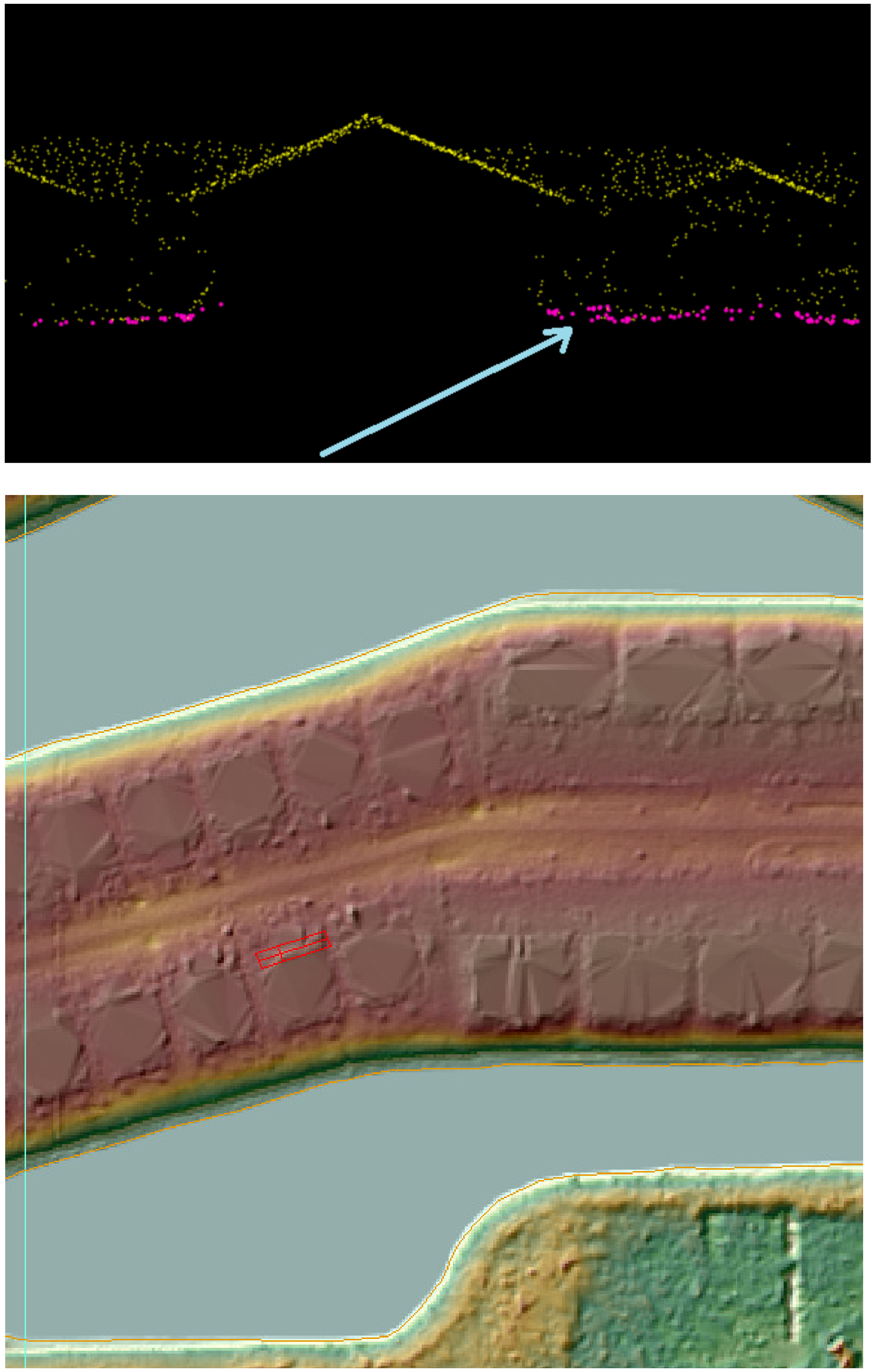


Figure 12 - Tile number 927500_800000. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground 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.

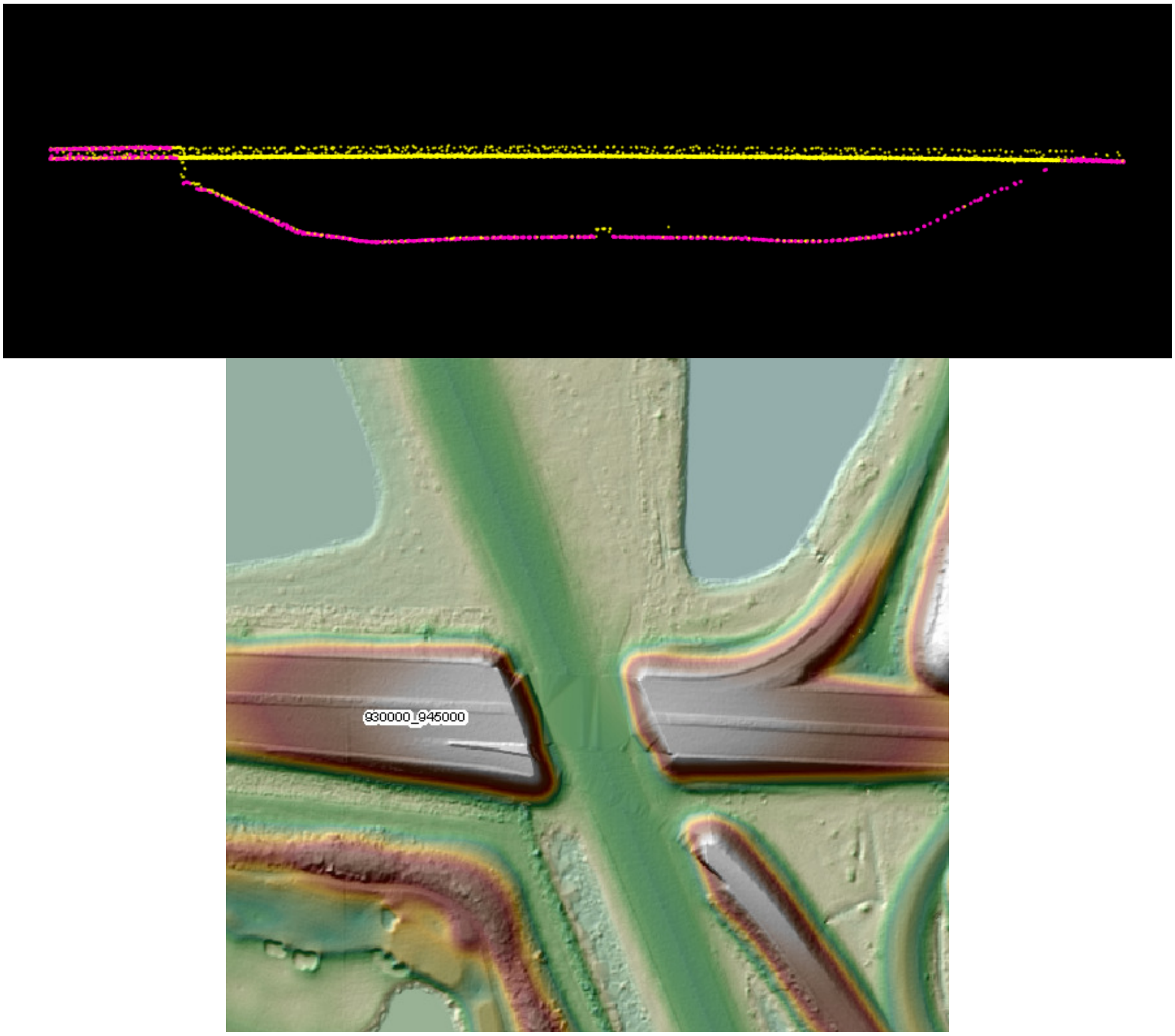


Figure 13 -Tile number 930000_945000. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. 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.

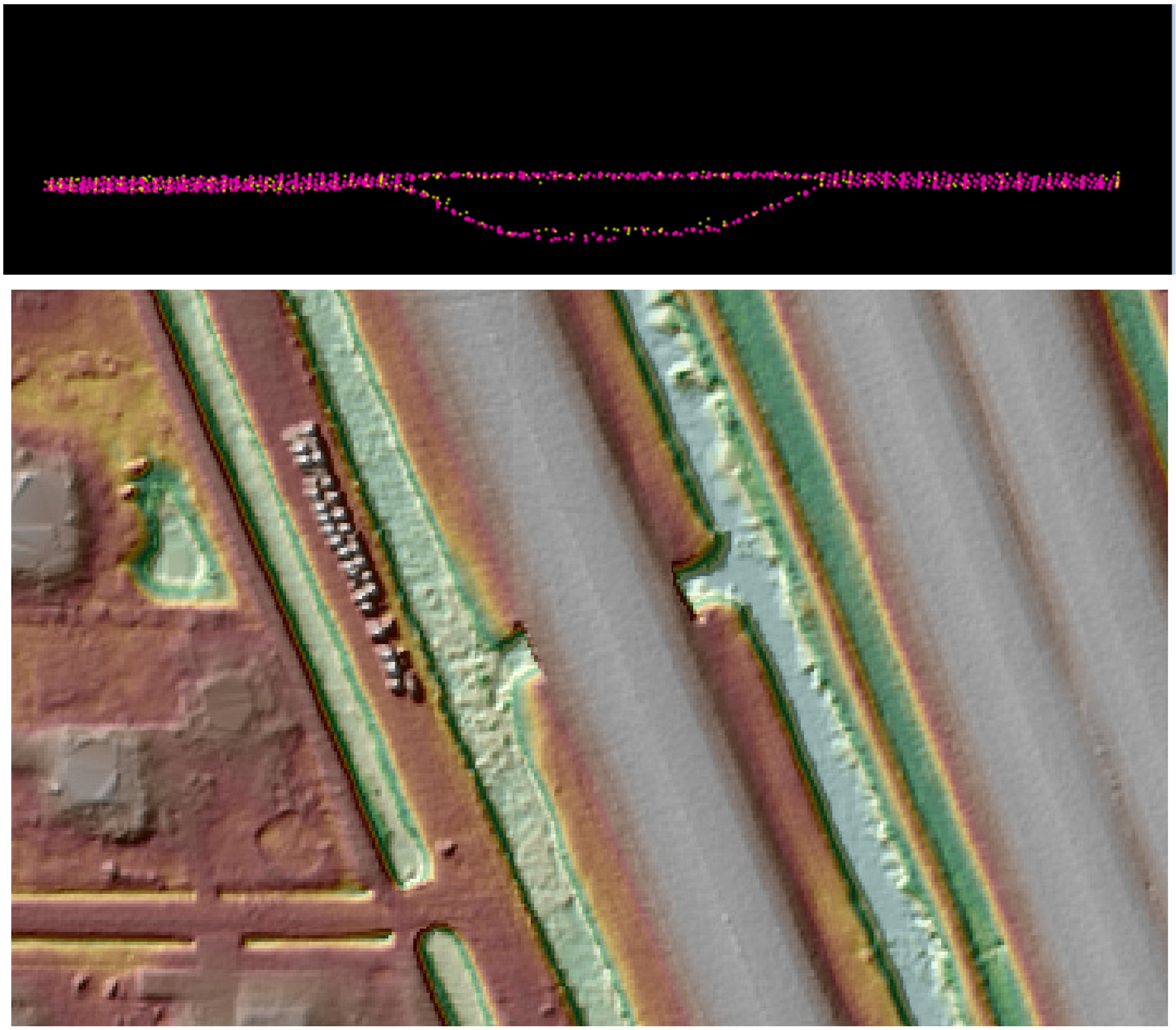


Figure 14 - Tile number 932500_940000. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

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.

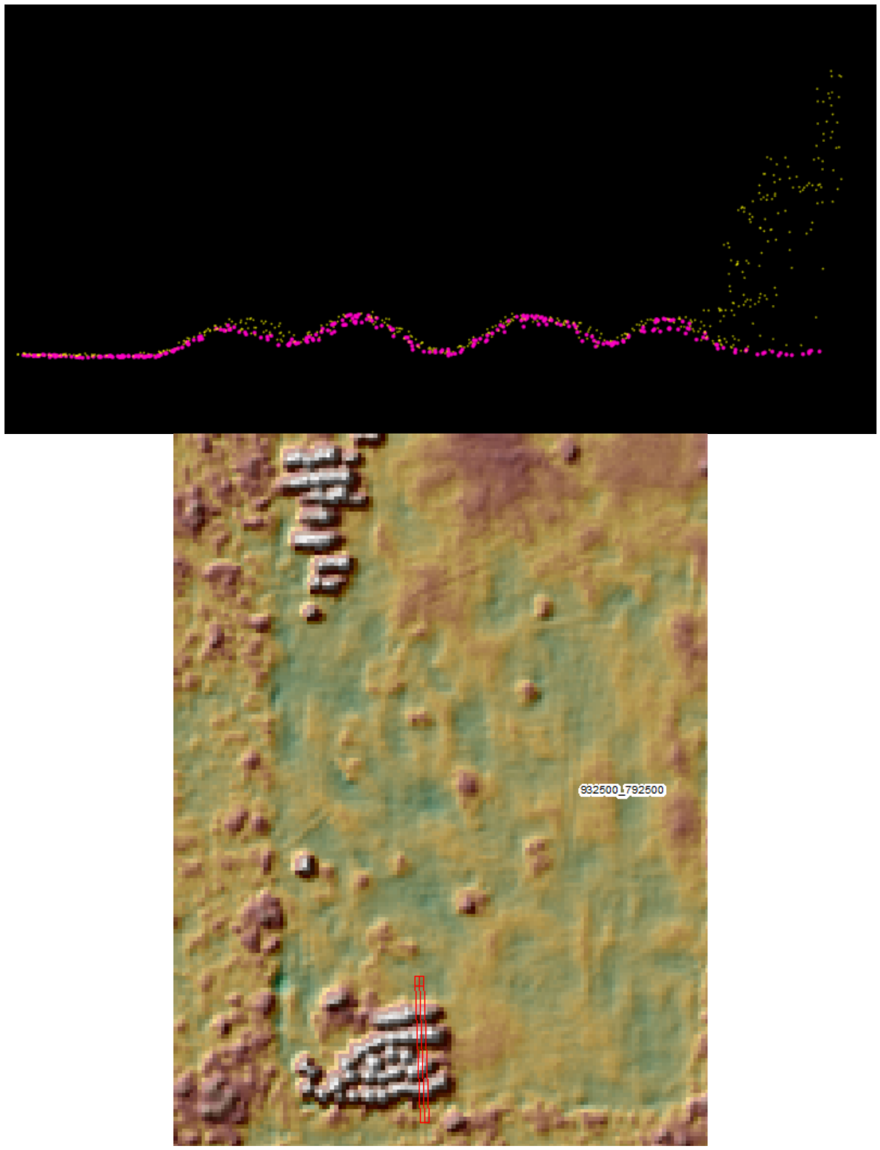


Figure 15 - Tile 932500_792500. Profile with the points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

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.

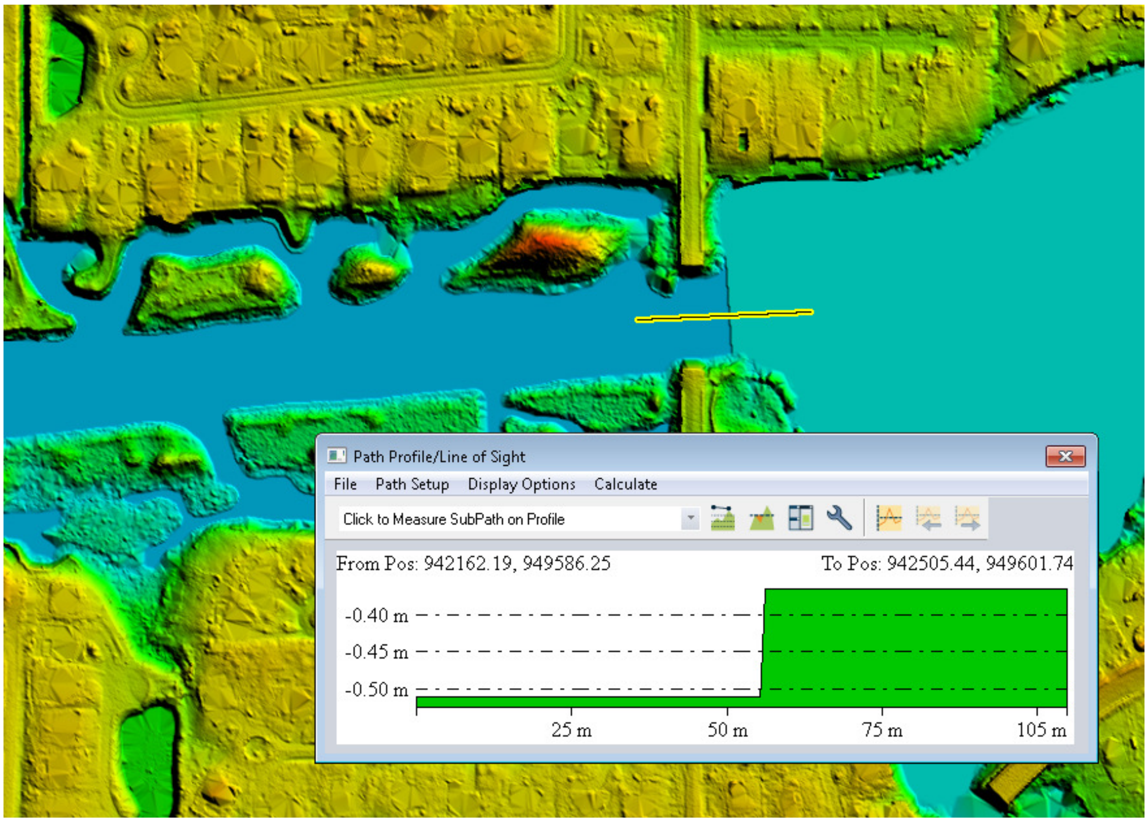


Figure 16 - Tile number 940000_947500. Elevation change shown from bank to bank. The step is flat from bank to bank and flow consistently downhill.

Irrigated Agricultural Areas

The Palm Beach County is a highly productive agricultural area. This is apparent throughout the project. Dewberry collected all areas of standing water greater than or equal to 2 acres. Areas of standing water that did not meet the 2 acre size criteria were not collected. Examples are shown below.

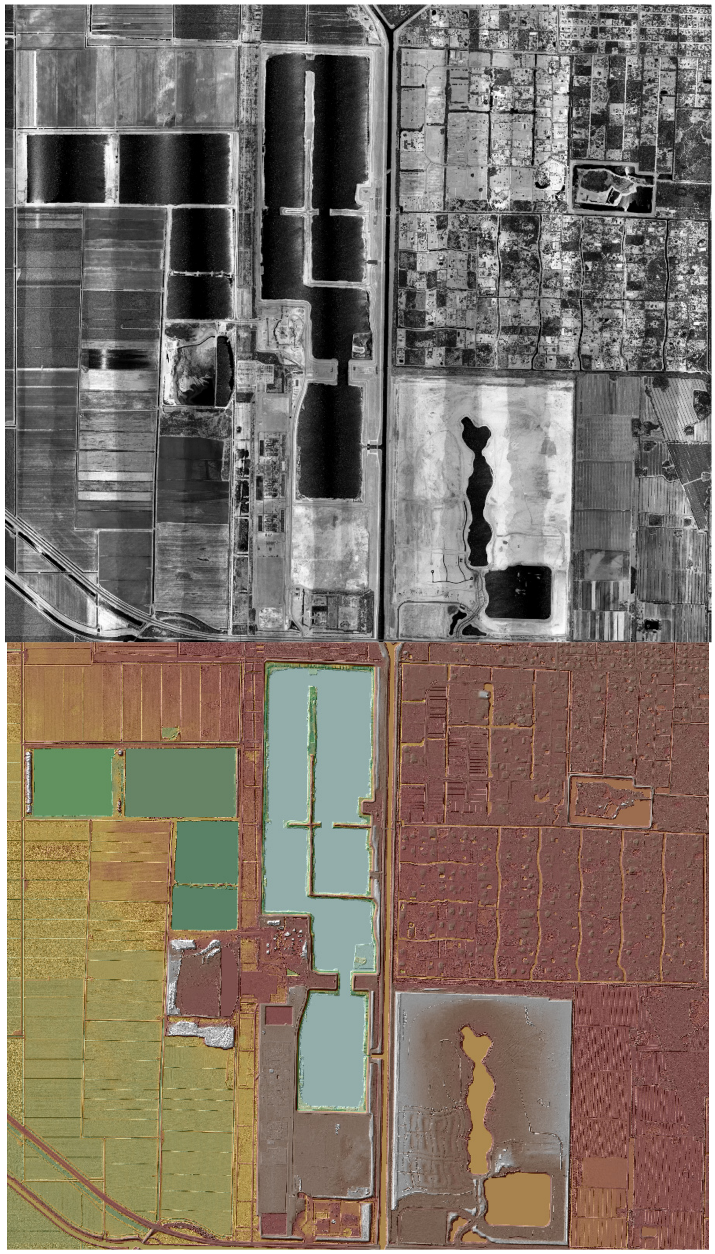


Figure 17 - Area bounded by tiles 850000_855000, 850000_872500, 872500_872500, 872500_855000. All lakes, ponds, irrigated agricultural fields, aquaculture areas and other areas of standing water greater than or equal to 2 acres are included in the delivered breaklines.

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.

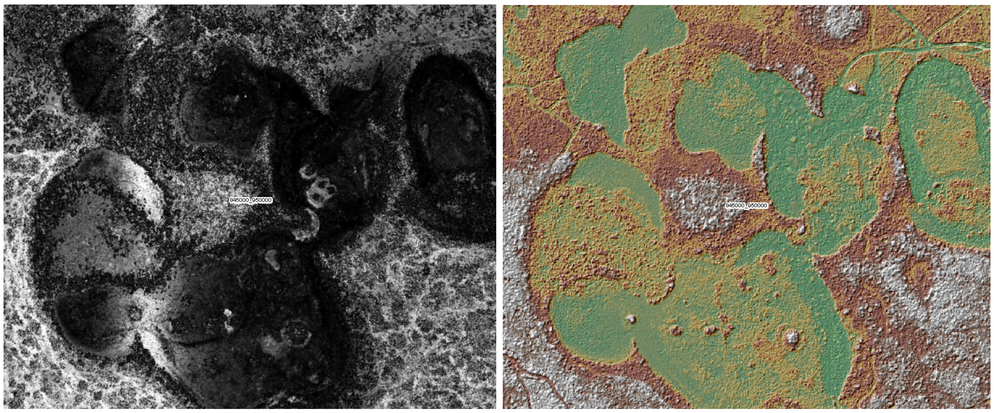


Figure 18 - Tile 845000_950000. The intensity on the left shows a marsh area that was not included in the collected breaklines. The same area is shown in the DEM on the right. Due to wet soils and broken terrain, the point density in marsh areas is sparser than surrounding areas and there is more variation in the low points representing ground.

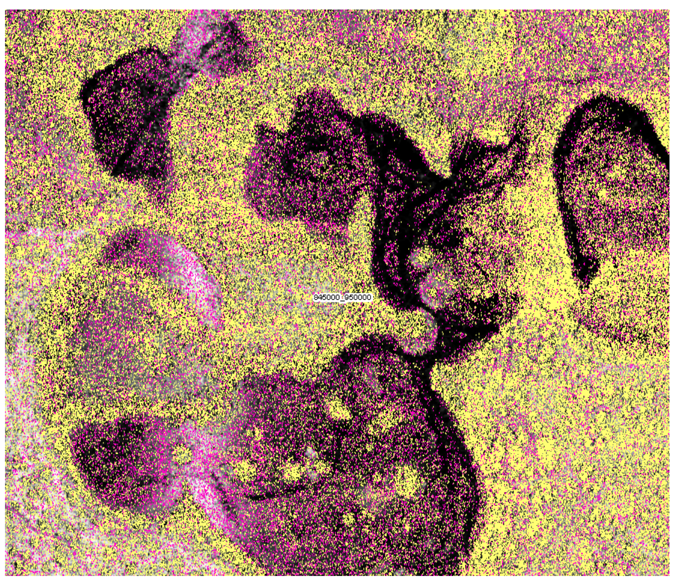


Figure 19 - Tile 84500_950000. The same marsh area shown in the figure above is shown in this image with the points colored by class (class 1=yellow, class 2=pink). Though ground points are sparse they are present, indicating that the area is wet but should not be classified as water (class 9). Doing 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 and the overall relative accuracy requirements for the project area have been met. An example of a visible ridge that is within tolerance is shown below.

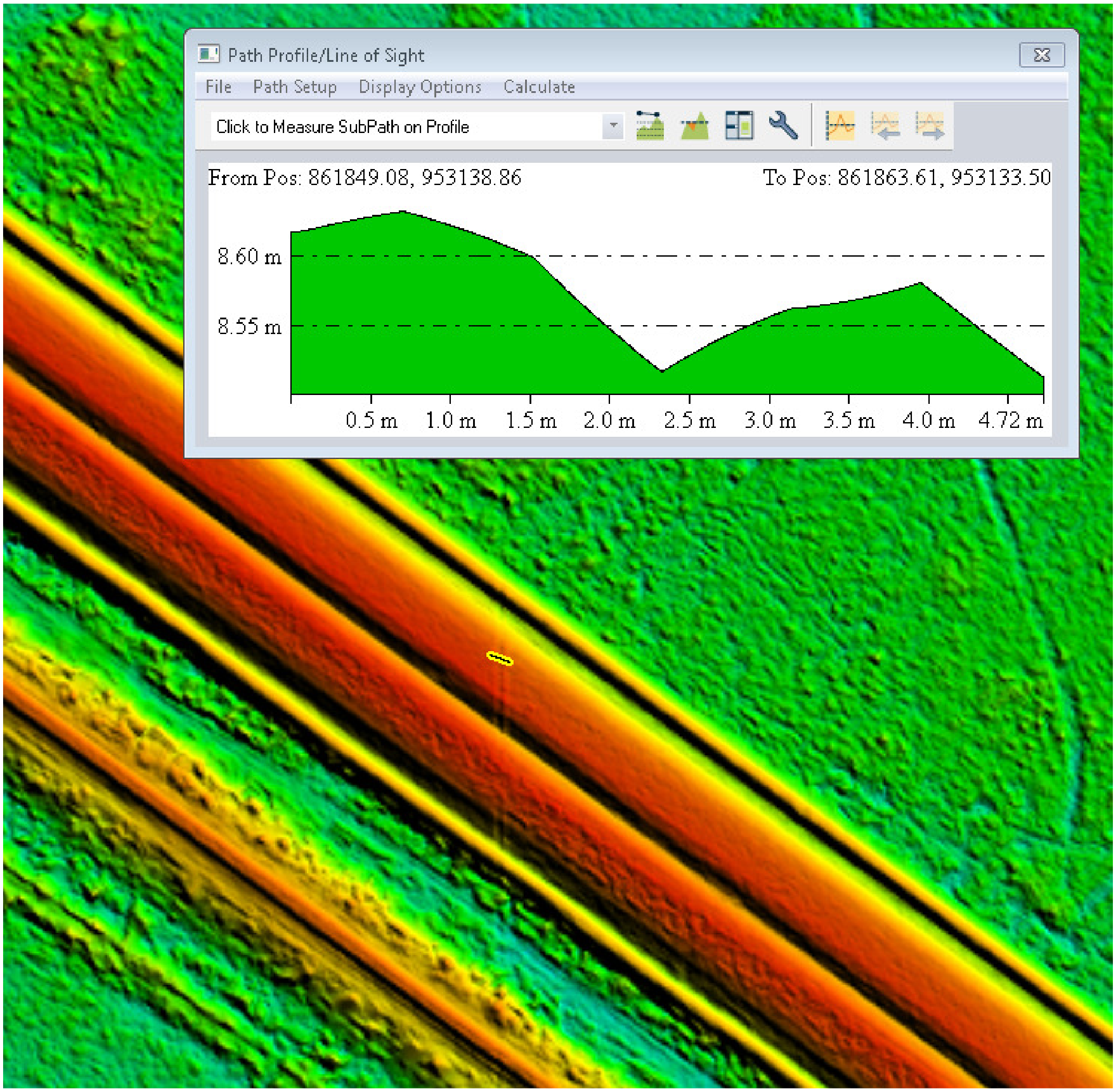


Figure 20 - Tile number 860000_952500. The flight line ridge is less than 10 cm. Overall, the Palm Beach County Lidar Project data meets the project specifications for 10 cm RMSE relative accuracy.

Low NIR Reflectivity

Some areas of asphalt on roads and parking lots and some rooftops due to the roofing material composition have resulted in low NIR reflectivity. In these areas, the NIR lidar pulses are absorbed by the asphalt or roofing material, resulting in diminished to absent lidar returns for these areas. An example is shown below.

Figure 21 - Tile number 947500_910000. Full lidar point cloud (red=unclassified, orange=ground) is shown in the left image and orthoimagery of the same location is shown in the right image. This road and the parking lot are an area of low NIR reflectivity because the composition of the road materials result in the absorption of the NIR laser, reducing the number of lidar returns defining the road and the parking lot. Areas of low NIR reflectivity exist within this dataset.

NIR Depressions

Marsh areas within the project contain north-south strips of minimally "depressed" NIR data at nadir. The cause of these artifacts is due to high reflectivity in extremely shallow waters, or high absorption of the NIR wavelength in saturated soils. These depressions are a characteristic of the NIR wavelength and do not negatively impact the overall usability of the data. An example is shown below.

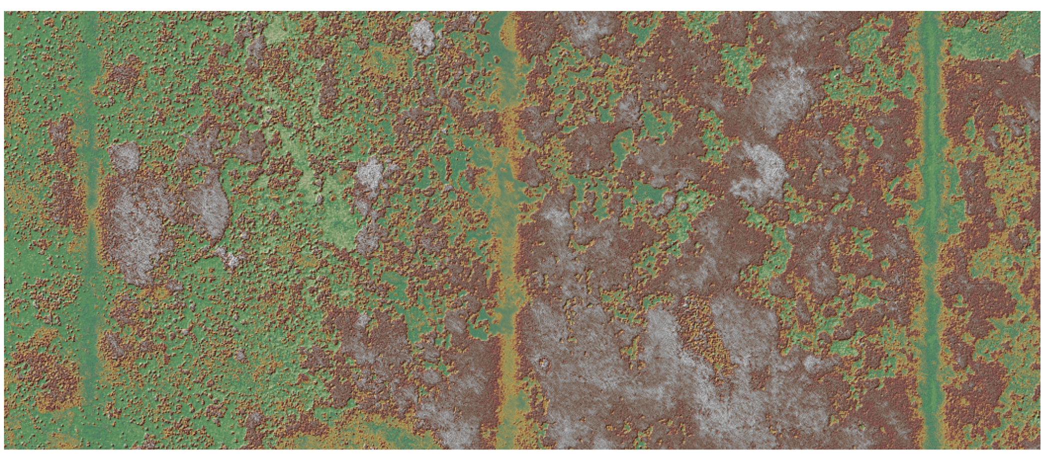


Figure 22 - Tile numbers 840000_800000, 842500_800000, and 845000_800000. The DEM shows strips of minimally depressed NIR data, following a north-south direction. These strips are a characteristic of the NIR wavelength in saturated soils in marshy areas, and do not negatively impact the overall usability of the data.

Laser Shadowing

Vegetation and building shadow is caused when these features obstruct the lidar pulse, preventing collection of data on one or more sides of the feature. First return data is collected on at least one side or portion of these features, usually the side facing toward the incident angle of transmission (or towards the sensor), while the opposite side or side facing away from the incident angle of transmission (or away from the sensor) is not collected because the feature itself blocks the incoming laser pulses. Vegetation and building shadow typically occurs in areas of single swath coverage because data in single coverages are only collected once from one direction. Laser shadowing can be more pronounced at the outer edges of the single coverage where higher scanning angles correspond to more area obstructed by features, resulting in larger shadows. And building shadow can be more pronounced around very tall buildings and structures. Building shadow is present within this dataset. An example is shown below.

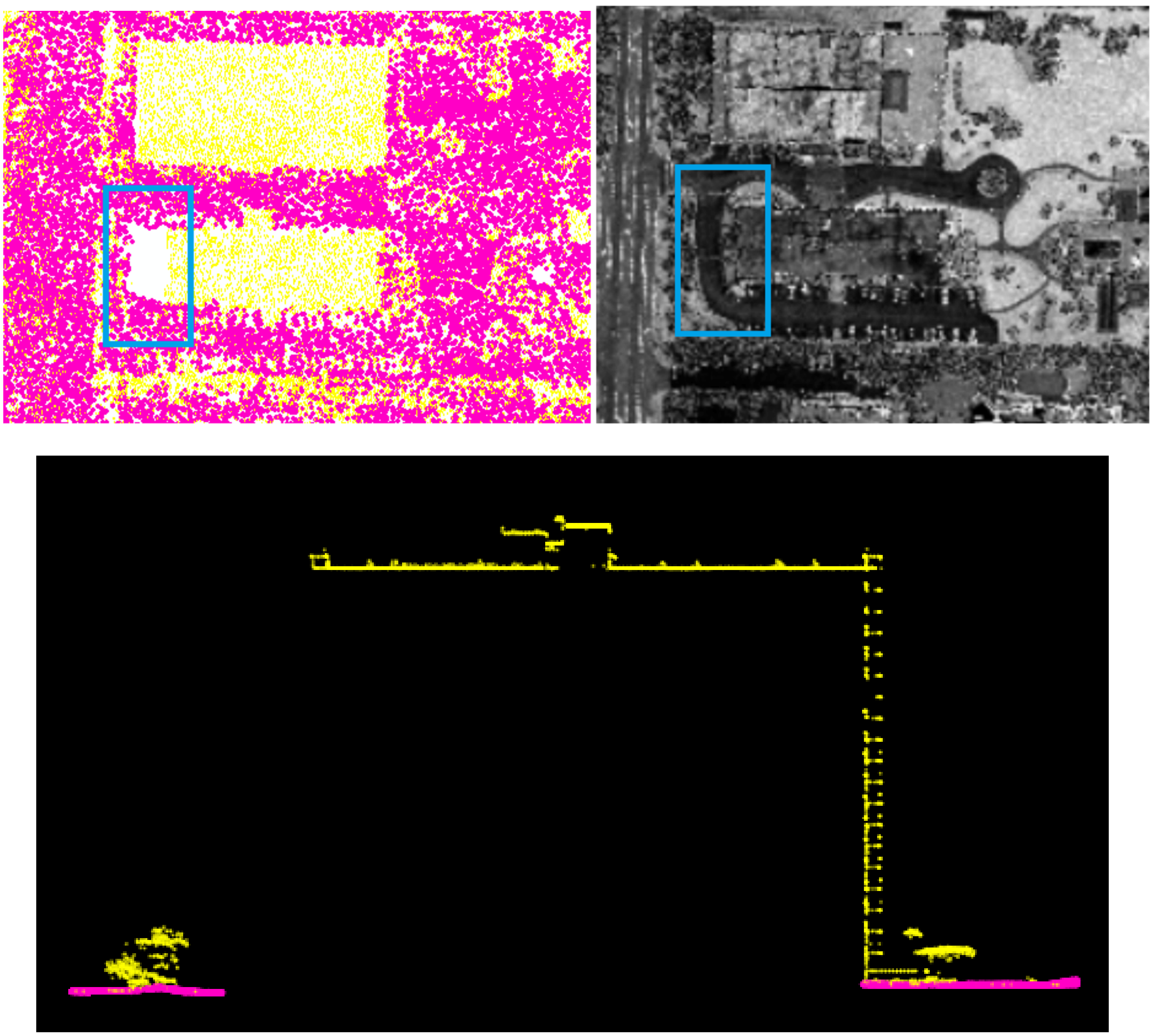


Figure 23 - Tile number 970000_892500. The top left image shows the full lidar point cloud (yellow=unclassified, pink=ground), the top right image shows the lidar intensity image, and bottom image shows a profile of this building. This feature is a tall building over 50 feet in height (bottom image) and there is building shadow or an absence of lidar returns along the north/northwest side of the building (blue square in top left and top right images).

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 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 Class 10: Ignored Ground Class 17: Bridge Decks Class 18: High Noise	Pass
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

Derivative Lidar Products

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

CONTOURS

One-foot contours have been created for the full project area. The contour attributes include labeling as either Index or Intermediate and an elevation value. The contours are also 3D, storing the elevation value within its internal geometry. Some smoothing has been applied to the contours to enhance their aesthetic quality. All contours have been reviewed and edited for correct topology and correct behavior, including correct hydrographic crossings.

Lidar Positional Accuracy

BACKGROUND

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

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

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, one hundred forty (140) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see appendix A to view the survey report which details and validates how the survey was completed for this project.

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

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

Point ID	NAD83(2011) State Plane Florida East FIPS 0901 US Feet		NAVD88 (Geoid 12B)
	Easting X (ft)	Northing Y (ft)	Elevation (ft)
NVA-100	783325.89	953773.62	19.73
NVA-101	866780.04	949511.75	28.02
NVA-102	901560.55	949033.53	21.47
NVA-103	936680.67	958726.70	6.88
NVA-104	953597.87	959007.27	14.60
NVA-105	958280.96	946305.10	2.88
NVA-106	936646.02	945566.21	11.70
NVA-107	966345.14	910696.78	4.07
NVA-108	937785.24	910696.27	16.71
NVA-109	917554.04	912199.80	20.19
NVA-110	830010.84	910432.07	15.65
NVA-111	772093.63	910602.44	13.85
NVA-112	693537.37	875871.09	18.24
NVA-113	759260.11	875435.03	13.77
NVA-114	798597.43	901295.14	16.61
NVA-115	870257.12	902885.87	23.85
NVA-116	901689.94	901436.85	20.73
NVA-117	960168.45	890294.99	14.96
NVA-118	970605.00	875833.97	4.97
NVA-119	938081.94	874356.26	40.63
NVA-120	901650.30	875762.66	18.48
NVA-121	866688.97	874952.13	19.91
NVA-122	829431.95	875577.82	15.51
NVA-123	726659.47	859531.16	16.42
NVA-124	796233.14	869846.07	14.55
NVA-125	830739.49	852589.32	16.45
NVA-126	866300.99	855171.14	20.41
NVA-127	901056.40	854703.57	20.06
NVA-128	953603.75	861403.85	12.15
NVA-129	970054.12	840609.87	5.24
NVA-130	936637.15	841120.33	17.58
NVA-131	901719.78	841118.50	16.72
NVA-132	884889.18	840359.70	15.07
NVA-133	885932.76	892400.98	19.70
NVA-134	791850.64	840403.43	19.23
NVA-135	750159.48	840614.82	17.47
NVA-136	726679.83	840532.92	8.92
NVA-137	693778.10	805644.48	11.74
NVA-138	725528.96	806358.81	10.54
NVA-139	750409.21	827283.90	18.56
NVA-140	753025.18	805125.71	14.26
NVA-141	797504.71	805079.83	10.04
NVA-142	831416.68	805199.92	8.67

NVA-143	901341.65	827007.39	15.43
NVA-144	921021.96	825608.64	19.60
NVA-145	910505.63	805280.76	15.80
NVA-146	936578.52	804769.03	18.82
NVA-147	968944.28	805265.59	21.38
NVA-148	954206.91	791283.10	12.12
NVA-149	928818.81	793050.68	17.65
NVA-150	916203.51	787724.92	19.47
NVA-151	912113.66	771358.72	16.42
NVA-152	936627.07	771204.42	19.21
NVA-153	963048.21	770474.18	2.11
NVA-154	950269.48	756125.02	11.27
NVA-155	922470.34	749946.54	17.36
NVA-156	908916.75	749155.92	19.59
NVA-157	936025.46	744437.74	15.16
NVA-158	959923.70	736004.84	5.31
NVA-159	957767.38	723379.20	7.58
NVA-160	936628.83	726351.06	13.68
NVA-161	922047.70	727696.91	14.04
NVA-162	906452.95	728921.44	17.45
NVA-163	762705.35	791423.11	14.62
NVA-164	769536.92	781926.06	16.23
NVA-165	776539.28	771827.14	15.25
NVA-166	797408.43	769848.23	10.85
NVA-167	783813.21	761370.98	14.81
NVA-168	790027.28	752706.56	15.33
NVA-169	796907.41	742636.09	14.25
NVA-170	807516.26	727734.64	16.97
NVA-171	831643.63	771032.99	11.30
NVA-172	797040.57	727238.64	13.66
NVA-173	782623.97	727127.00	14.68
NVA-174	761631.80	726977.62	15.53
NVA-175	694773.23	726948.62	18.49
NVA-176	719991.46	753442.34	22.44
NVA-177	726600.20	771834.28	13.05
NVA-178	694361.27	770566.83	16.71
VVA-200	761833.05	841778.49	8.18
VVA-201	815268.49	954211.28	23.21
VVA-202	708232.05	865955.37	13.85
VVA-203	829449.23	839881.86	12.81
VVA-204	693545.89	840632.07	11.11
VVA-205	798269.32	943034.13	15.53
VVA-206	782514.44	930101.83	10.72
VVA-207	761752.00	902877.21	11.95
VVA-208	741062.62	843531.94	8.05
VVA-209	856389.95	856402.67	7.36
VVA-210	836587.67	870032.87	7.72
VVA-211	809021.12	911804.29	9.09
VVA-212	841613.16	954426.65	23.65
VVA-213	918251.05	901580.14	18.05
VVA-214	849258.22	893173.27	17.04

VVA-215	813849.06	927474.83	15.54
VVA-216	814022.16	888168.51	10.38
VVA-217	791694.26	840536.40	10.68
VVA-218	777710.64	869978.10	8.62
VVA-219	817357.81	869951.78	7.30
VVA-220	932950.19	900960.08	15.18
VVA-221	901943.42	923398.78	20.95
VVA-222	887098.04	934523.91	21.79
VVA-223	846350.93	863945.50	7.33
VVA-224	885557.71	854801.44	16.75
VVA-225	882221.63	875787.81	19.86
VVA-226	886814.94	906302.79	22.07
VVA-227	866845.66	741726.00	21.25
VVA-228	837443.07	778431.14	16.03
VVA-229	821290.01	759501.27	7.81
VVA-230	829000.37	823664.23	6.46
VVA-231	916176.06	773412.77	15.08
VVA-232	915294.69	805610.36	15.74
VVA-233	896042.68	732171.21	12.13
VVA-234	921967.27	760430.43	18.78
VVA-235	934482.20	783761.93	19.60
VVA-236	955522.81	805182.51	10.90
VVA-237	921898.61	836700.49	17.55
VVA-238	917389.99	726370.39	17.53
VVA-239	953138.14	826643.84	10.82
VVA-240	936803.81	733925.32	11.93
VVA-241	906557.02	740587.41	12.75
VVA-242	849446.02	760208.80	20.42
VVA-243	831803.20	793345.57	10.65
VVA-244	879340.61	737705.77	20.82
VVA-245	694784.69	752660.07	13.85
VVA-246	694393.95	770601.92	12.34
VVA-247	693620.43	821829.52	12.98
VVA-248	726806.37	840579.38	7.70
VVA-249	725372.83	822089.19	8.42
VVA-250	726066.01	788147.16	8.28
VVA-251	729065.72	727505.84	13.05
VVA-252	758624.52	750190.42	13.10
VVA-253	802129.04	735168.36	13.93
VVA-254	812077.94	735542.09	15.21
VVA-255	813490.09	785847.20	11.15
VVA-256	797433.52	820784.11	7.54
VVA-257	750544.25	817133.97	11.06
VVA-258	779213.21	820902.52	8.12
VVA-259	781472.77	786417.73	8.24
VVA-260	809308.23	743184.34	16.41

Table 6: Palm Beach County lidar surveyed accuracy checkpoints

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

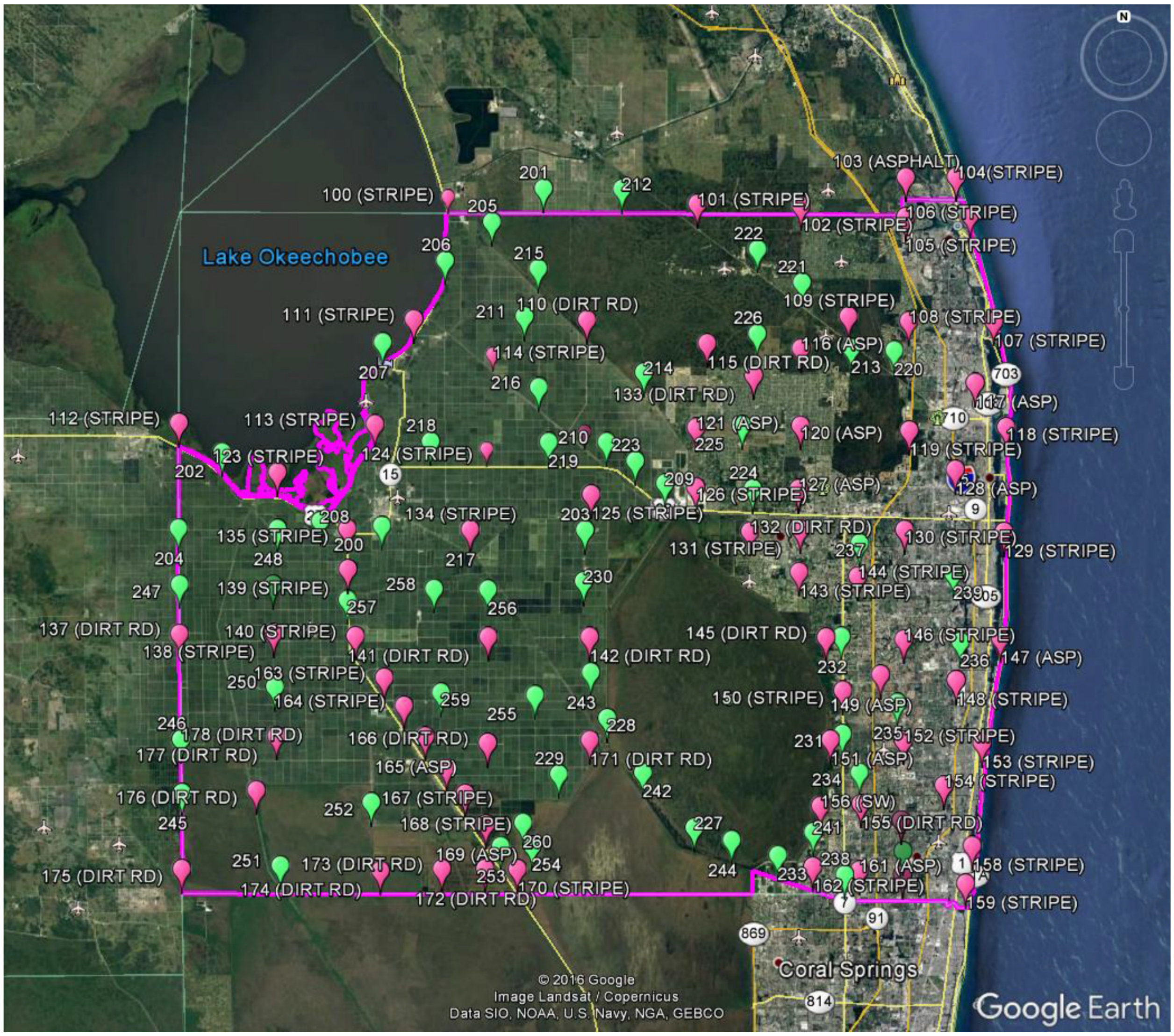


Figure 22 - Location of QA/QC Checkpoints

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 Palm Beach County lidar project, vertical accuracy must be 19.6 cm or less based on an $RMSE_z$ of 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 Palm Beach County 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 7.

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

Table 7 — 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=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	79	0.31	
VVA	61		0.59

Table 8 — 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 $RMSE_z$ = 0.16 ft (4.9 cm), equating to +/- 0.31 ft (9.4 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.59 ft (18 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 +/- 20 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +30 cm.

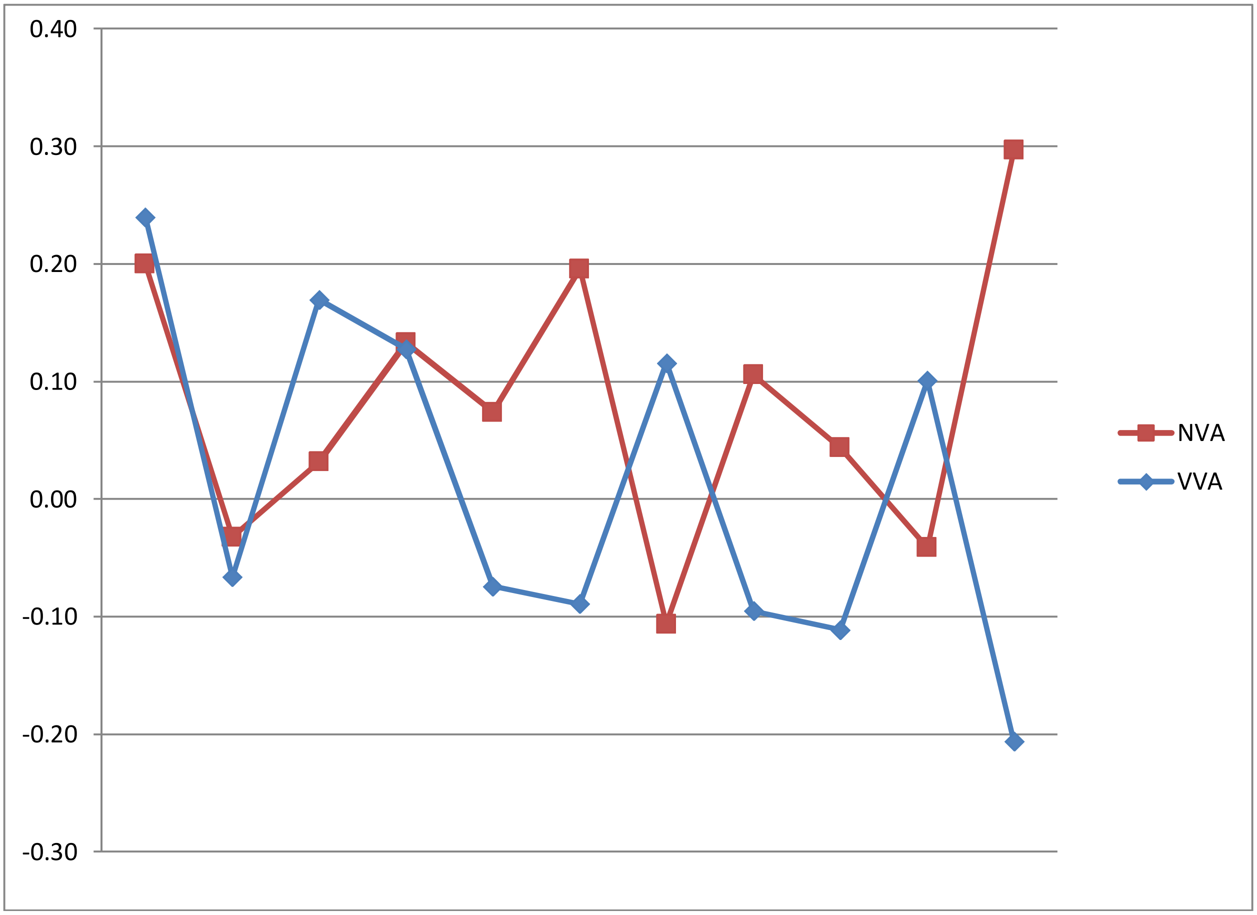


Figure 25 - Magnitude of elevation discrepancies per land cover category

Table 9 lists the 5% outliers that are larger than the VVA 95^{th} percentile.

Point ID	NAD83 (2011) State Plane Florida East FIPS 0901 US Feet		NAVD88 (Geoid 12B)	Lidar Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
VVA-200	761833.05	841778.49	8.18	8.91	0.73	0.73
VVA-206	782514.44	930101.83	10.72	12.81	2.09	2.09

VVA-256	797433.52	820784.11	7.54	9.19	1.65	1.65

Table 9 — 5% Outliers

Table 10 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	79	0.16	0.07	0.08	0.51	0.15	1.47	-0.25	0.63
VVA	61	N/A	0.20	0.14	3.02	0.38	12.54	-0.33	2.09

Table 10 — 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 -0.175 ft and a high of +0.225 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 -0.075 ft (-2.3 cm) to +0.025 ft (0.8 cm).

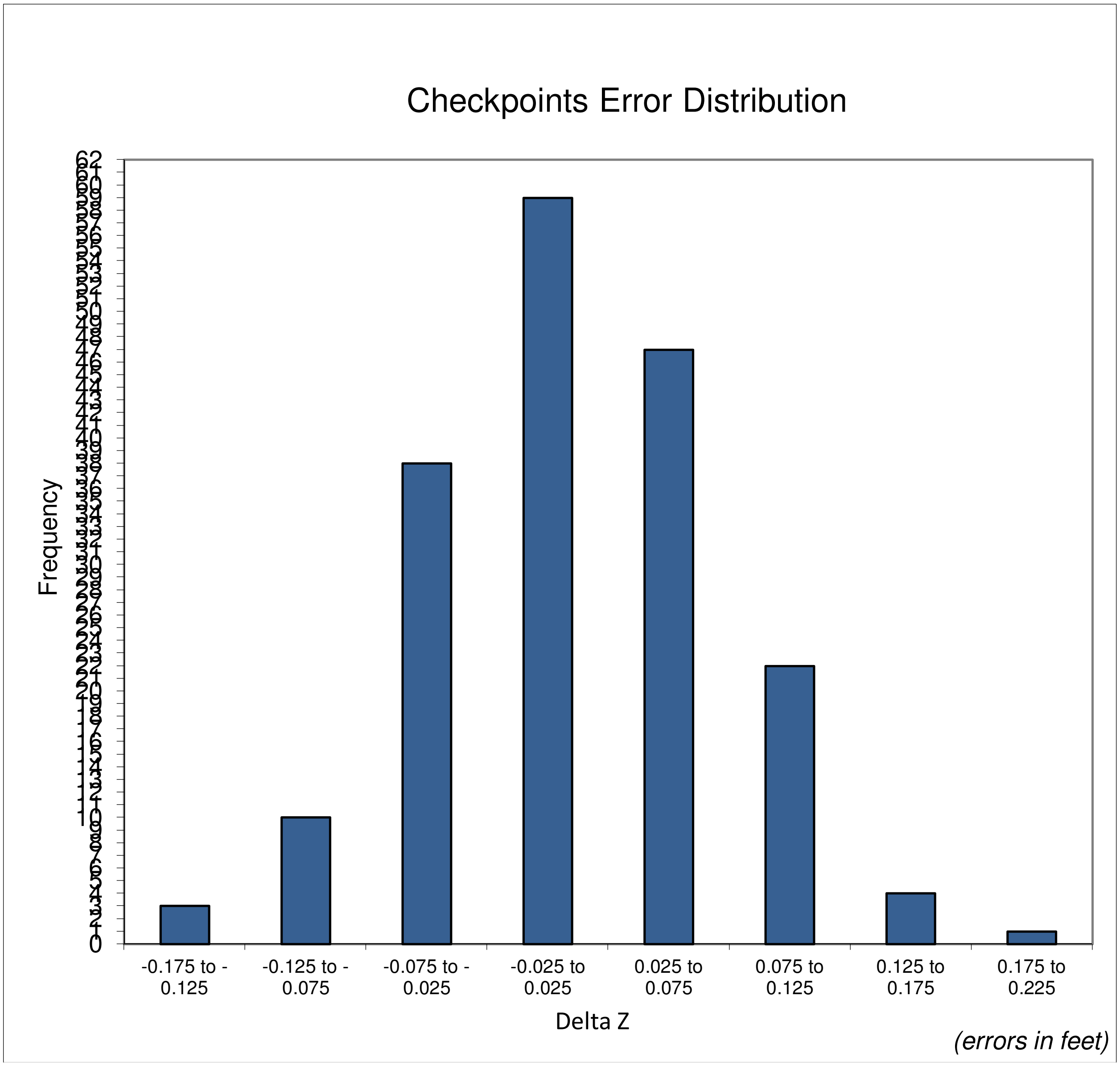


Figure 23 - Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the Palm Beach County 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

Eight 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 eight (8) 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.

# 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
8	0.79	0.47	0.92	1.59

Table 11-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 1.35 ft (41 cm) RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 3.28 ft (1 meter) at a 95% confidence level. Eight (8) 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 = 0.79 ft (24.1 cm) and RMSEy = 0.47 ft (14.3 cm) which equates to +/- 1.59 ft (48.5 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

Digital Aerial Solutions used LP360 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.

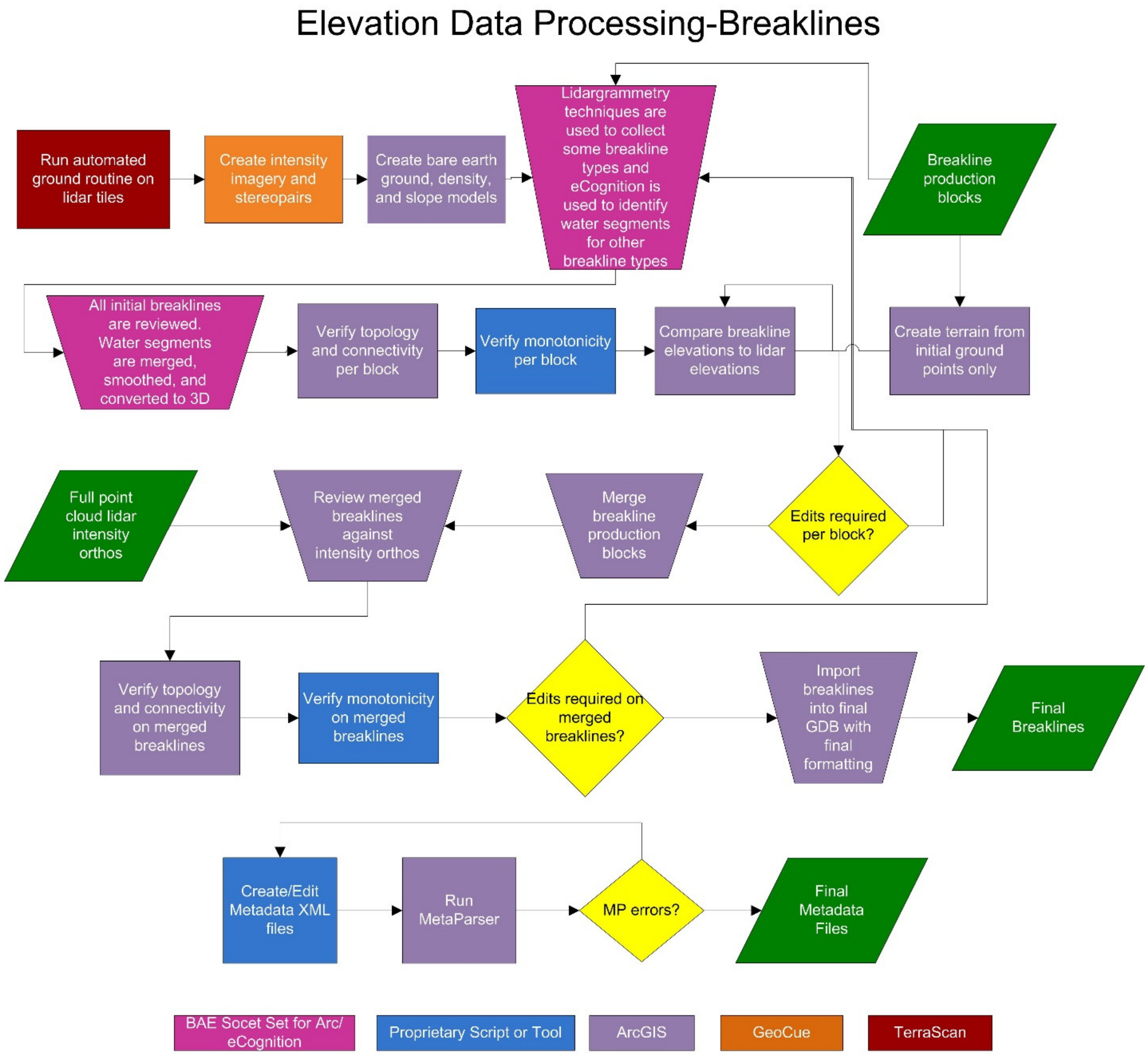


Figure 24 - Breakline QA/QC workflow

BREAKLINE CHECKLIST

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

Pass/Fail	Validation Step
Pass	Use lidar-derived data, which may include intensity imagery, stereo pairs, bare earth ground models, density models, slope models, and terrains, to collect breaklines according to project specifications.
Pass	In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS).

Pass	After each producer finishes breakline collection for a block, each producer must perform a completeness check, breakline variance check, and all automated checks on their block before calling that block complete and ready for the final merge and QC
Pass	After breaklines are completed for production blocks, all production blocks should be merged together and completeness and automated checks should be performed on the final, merged GDB. Ensure correct snapping-horizontal (x,y) and vertical (z)-between all production blocks.
Pass	Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains
Pass	Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement.
Pass	Using a terrain created from lidar ground (all ground including 2, 8, and 10) and water points (class 9), compare breakline Z values to interpolated lidar elevations.
Pass	Perform all Topology and Data Integrity Checks
Pass	Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic.

Table 12 A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.

DATA DICTIONARY

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983 (2011), Units in 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 (2011) 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 100 feet.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software

SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the island is greater than 1 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

Inland Ponds and Lakes

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

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

Description

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

Table Definition

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

Feature Definition

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

		If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Tidal Waters

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

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

Description

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

Table Definition

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

Feature Definition

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

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.

Building Footprints

Feature Dataset: Building_Footprints
Feature Type: Polygon
Contains Z Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: Building_Footprints
Contains M Values: No
Annotation Subclass: None

Description

This 2D polygon feature class will depict all structures greater than 1000 square 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
Building Footprints	All structures that are 1000 square feet or greater in area should be captured.	The roofs of some buildings or structures may be offset from the true footprint in the imagery. Care should be taken to collect the actual or true footprint of each structure by collecting the base of the structure. All building footprints should be captured in 2D, but should still show correct topology. All building corners must be square and all edges must be straight.

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.

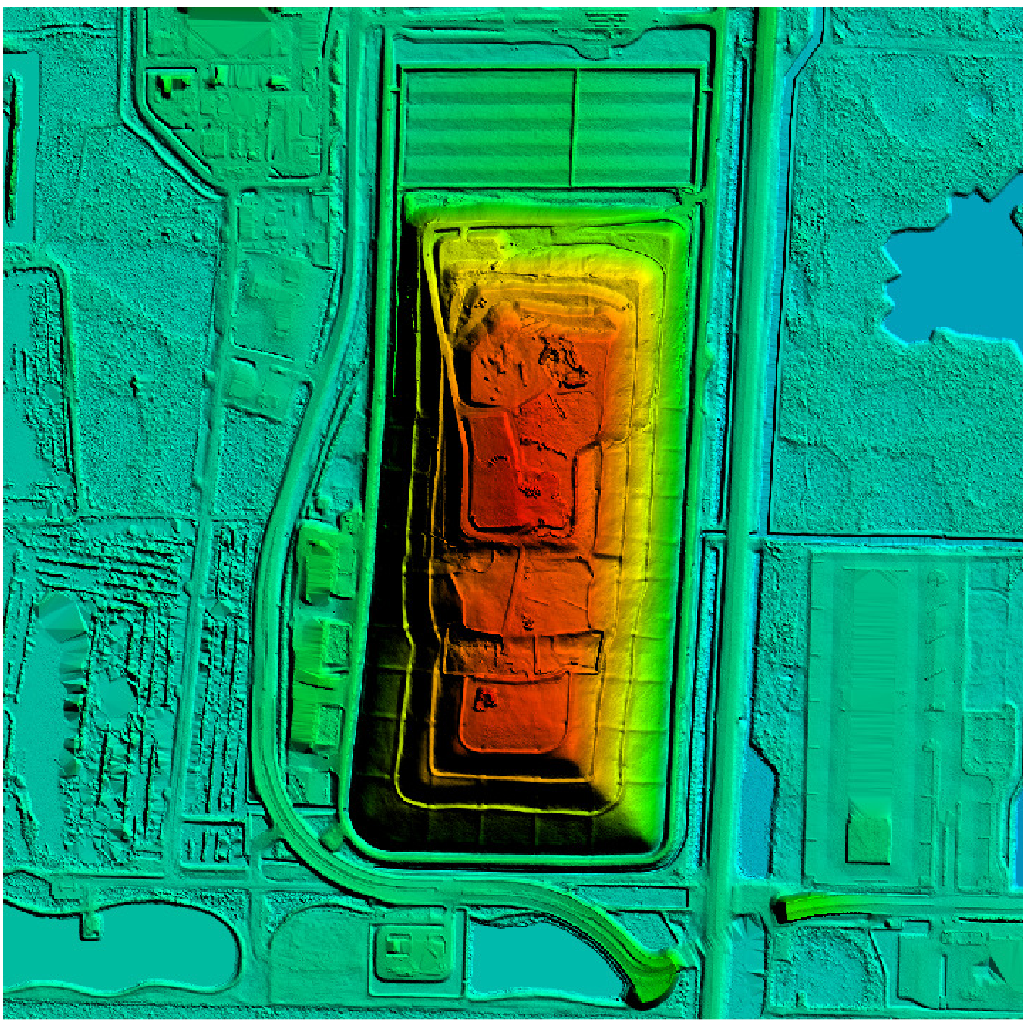


Figure 26 - Tiles 935000_882500, 935000_885000, 937500_885000 and 937500_882500. The bare earth DEM.

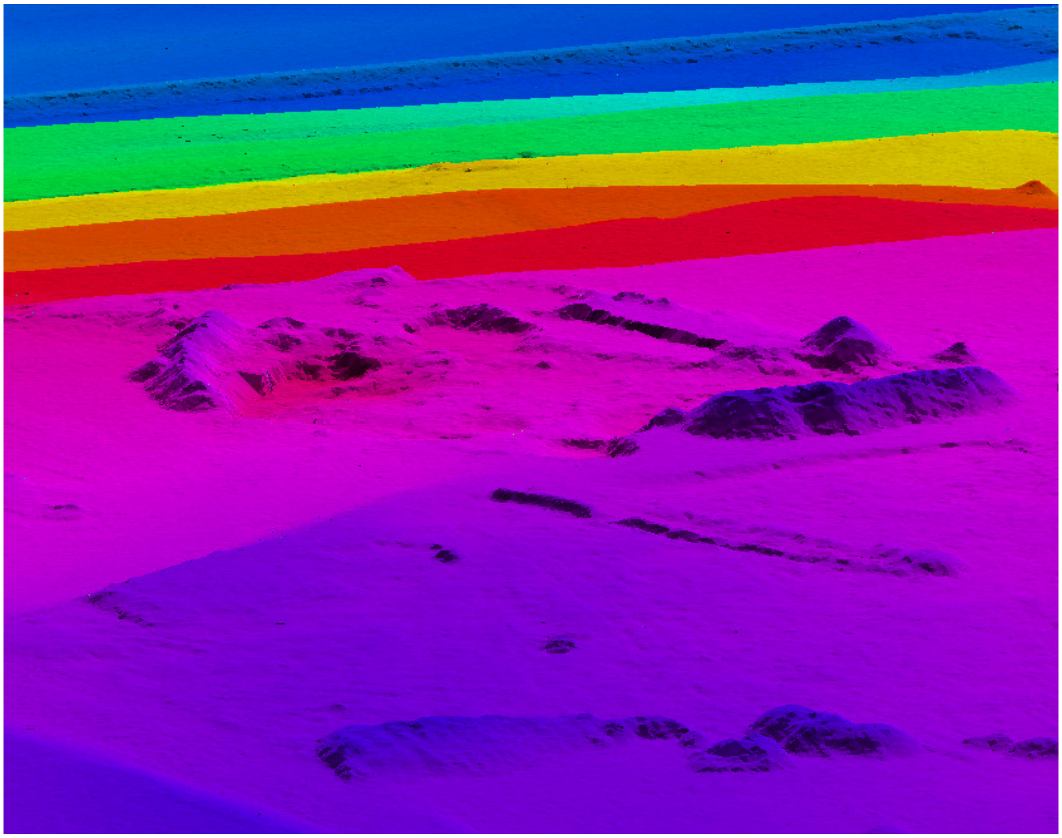


Figure 30 - Tile 937500_885000. 3D Profile view of the bare earth DEM

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.

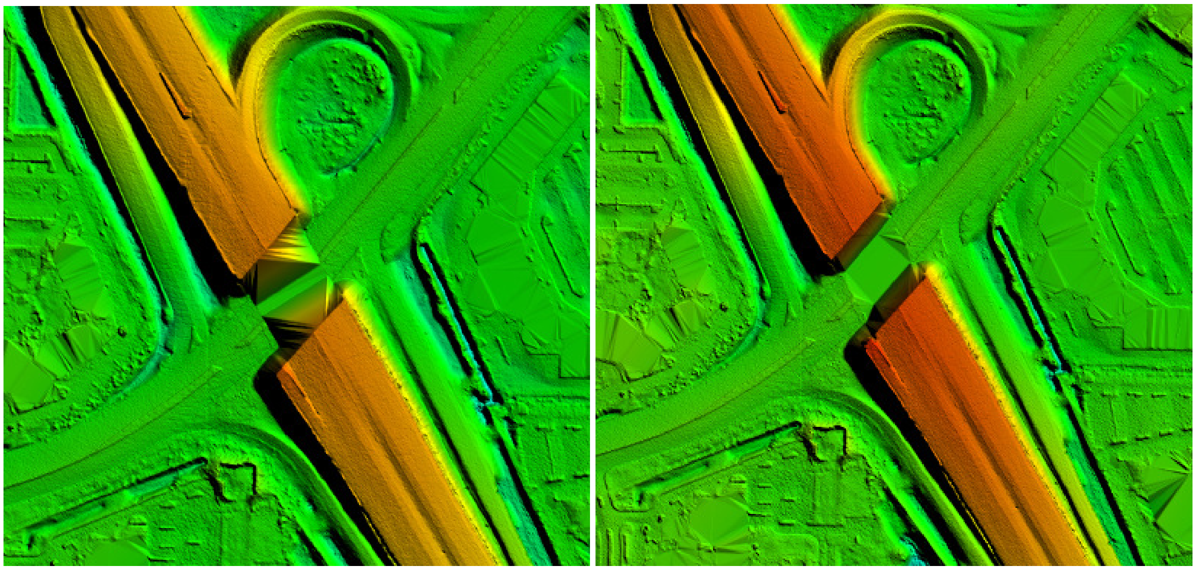


Figure 27 - Tile 947500_910000. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 140 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 13 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	79	0.30	
VVA	61		0.72

Table 13 – DEM tested NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 0.15 ft (4.6 cm), equating to +/- 0.30 ft (9.1 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.72 ft (22 cm) at the 95th percentile.

Table 14 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83(2011) State Plane Florida East FIPS 0901 US Feet		NAVD88 (Geoid 12B)	DEM Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
VA-200	841778.49	761833.05	8.18	8.96	0.78	0.78
VVA-206	930101.83	782514.44	10.72	13.01	2.29	2.29
VVA-208	843531.94	741062.62	8.05	8.59	0.55	0.55
VVA-212	954426.65	841613.16	23.65	24.36	0.72	0.72
VVA-247	821829.52	693620.43	12.98	60.108	0.64	0.64
VVA-255	785847.20	813490.09	11.15	11.68	0.53	0.53
VVA-256	820784.11	797433.52	7.54	9.23	1.69	1.69

Table 14 — 5% Outliers

Table 15 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	79.00	0.15	0.06	0.07	0.33	0.14	0.84	-0.29	0.56
VVA	61.00	N/A	0.23	0.15	3.16	0.40	13.70	-0.33	2.29

Table 15 — Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the Palm Beach County 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 16-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

"PALM BEACH COUNTY LiDAR"

USGS Contract: G16PC00020
Task Order Number:
G16PD00456

Prepared for:
United States Geological Survey (USGS)

Prepared By:
Dewberry Engineers, Inc.
131 W. Kaley Street
Orlando, Florida, 32806
Phone (407) 843-5120

TABLE OF CONTENTS

1. INTRODUCTION

1.1 *Project Summary*

Dewberry Consultants LLC is under contract to the United States Geological Survey to provide 65 Ground Control Points in the County of Palm Beach, in the State of Florida. Under the above referenced USGS Task Order, 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 (GCPs) that will be used to evaluate vertical and horizontal accuracy. The ground survey was conducted from December 20, 2016 – February 14, 2017.

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.

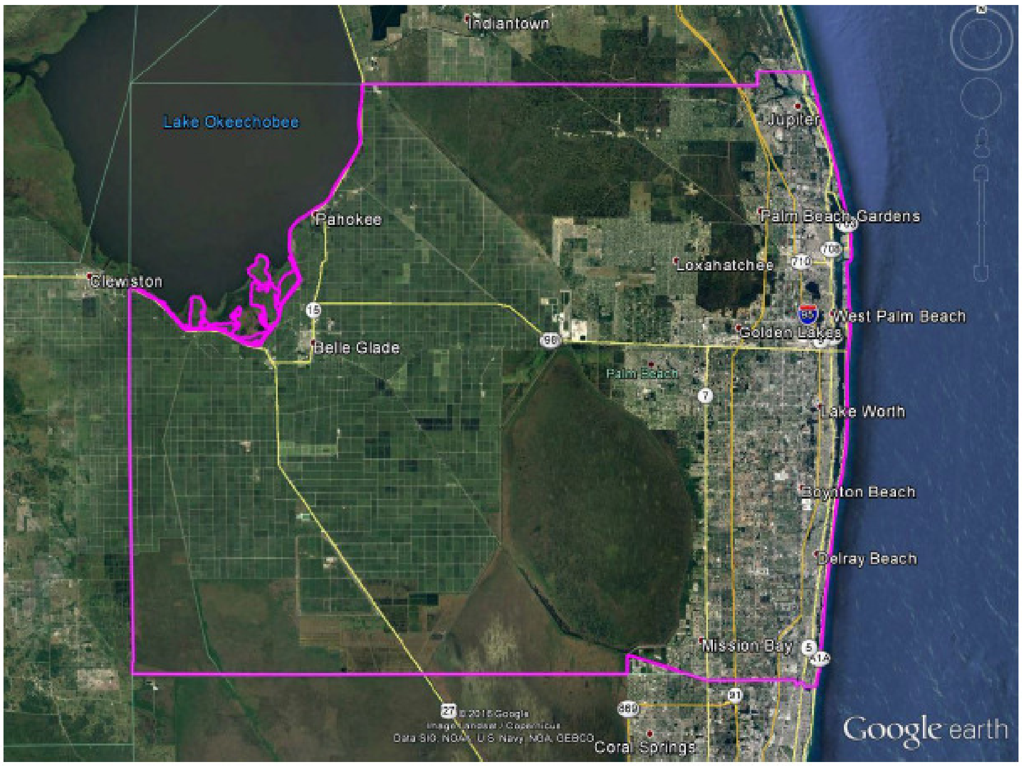
Final horizontal coordinates are referenced to Florida State Plane Coordinate System, East Zone, NAD83 (2011 Adjustment) in U.S. Survey feet. Final vertical elevations are referenced to NAVD88 in U.S. Survey feet using Geoid model 2012B (Geoid12B).

1.2 *Points 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*



Dewberry

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 to perform the field surveys.

2.2 *Survey Point Details*

The 65 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 Report" 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 a Real Time Network (RTN) managed by Trimble. The network is 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 (VRS).

2.4 *Field Survey Procedures and Analysis*

Dewberry field surveyors used a Spectra Precision SP80 receiver, which is a geodetic quality dual frequency GPS receiver, to collect data at each surveyed location.

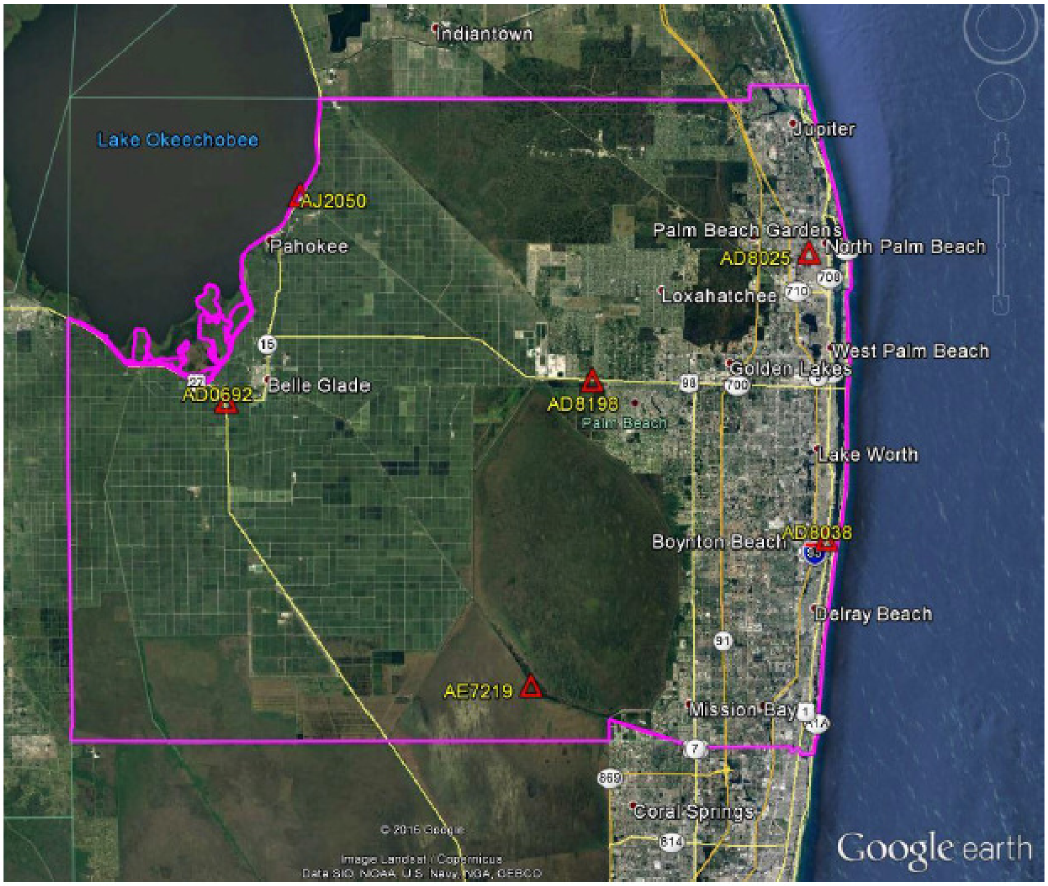
All locations were occupied once with approximately 50% of the locations being re-observed. All re-observations matched the initially derived station positions within the allowable tolerance of ± 5cm or within the 95% confidence level. Each occupation which utilized the VRS network was occupied for approximately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

Field GPS observations are detailed on the "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. The results are as follows:

NGS PT. ID	Designation	As Surveyed (ft)			Published (ft)			Differences (ft)		
		Northing	Easting	Elev.	Northing	Easting	Elev.	Δ N	Δ E	Δ Elev.
AD8198	J 413	854938.05	879898.39	15.29	854938.08	879898.37	15.39	0.03	0.02	0.10
AD0692	872 2625 TIDAL 1	846966.62	750065.45	19.83	846966.62	750065.45	19.88	0.00	0.00	0.05
AD8025	V 402	900458.58	957185.90	16.60	900458.65	957185.87	16.71	0.07	0.03	0.11
AD8038	G 402	798923.76	963705.28	11.23	798923.64	963705.25	11.31	0.12	0.03	0.09
AE7219	FCE 1987	747311.68	858571.74	21.34	747311.64	858571.72	21.40	0.04	0.02	0.06
AJ2050	CAN RM 1	919959.27	776091.69	33.26	919959.32	776091.71	33.35	0.05	0.02	0.10

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



NGS Monuments

2.5 *Adjustment*

The survey data was collected using Virtual Reference Stations (VRS) methodology within a Virtual Reference System (VRS).

The system is designed to provide a true Network RTK performance, the Trimble VRS Now software enables high-accuracy positioning in real time across a geographic region. The Trimble VRS Now software package uses real-time data streams from the system user and generates correction models for high-accuracy RTK GPS corrections throughout the network. Therefore, corrections were applied to the points as they were being collected, thus 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 into the office software. The Software program used is called 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 our AutoCAD Civil 3D 2016 to make a visual check of the point data (Pt. #, Coordinates, Elev. and Description). The data can now be imported into the final product.

3. *FINAL COORDINATES*

PALM BEACH COUNTY LiDAR POINTS			
POINT ID	NORTHING (FT)	EASTING (FT)	ELEV. (FT)
GCP			
GC_01	953197.913	783299.648	18.948
GC_02	955179.734	858986.987	26.272
GC_03	956109.807	954935.876	12.951
GC_04	902576.061	960156.902	4.649
GC_05	797608.132	965261.047	1.960
GC_06	729257.754	954881.241	12.785
GC_07	725829.548	886648.624	10.849
GC_08	727814.650	807508.264	18.288
GC_09	726178.467	729890.265	21.538
GC_10	772899.889	694327.151	17.229
GC_11	874086.162	694869.245	12.838
GC_12	858986.935	763236.627	12.630
GC_13	913070.360	780197.991	15.142
GC_14	911871.765	829792.328	15.634
GC_15	901001.455	895328.672	22.495
GC_16	851899.248	858281.483	21.065
GC_17	838396.609	969906.763	4.443
GC_18	764623.870	958548.722	17.371
GC_19	837457.691	925854.986	21.058
GC_20	806034.620	939518.581	18.098
GC_21	871274.770	907043.515	17.141
GC_22	890926.573	810951.277	17.156
GC_23	852432.417	816559.621	15.725
GC_24	839344.322	885249.506	14.493
GC_25	777736.110	837185.071	16.350
GC_26	782188.493	769364.804	15.557
GC_27	807580.466	751383.412	17.345
GC_28	823322.213	836969.366	17.975
GC_29	876318.145	865427.748	18.332
GC_30	842927.663	701355.325	16.396
GC_31	750111.169	758604.127	20.429
GC_32	810245.887	794868.150	11.064
GC_33	893099.751	757079.865	10.661

PALM BEACH COUNTY LiDAR POINTS			
POINT ID	NORTHING (FT)	EASTING (FTE)	ELEV. (FT)
GCP			
GC_34	927613.700	941455.059	19.900
GC_35	884819.219	942425.211	16.282
GC_36	814961.838	905651.952	17.224
GC_37	751796.816	935374.902	19.590
GC_38	769902.799	815998.190	11.197
GC_39	726585.120	694668.772	23.193
GC_40	859401.049	718390.217	15.031
GC_41	840299.564	791867.921	18.763
GC_42	931369.091	892026.412	21.377
GC_43	772640.959	911888.362	16.762
GC_44	948568.897	898264.407	22.238
GC_45	811209.825	707829.405	16.241
GC_46	954246.667	813352.730	25.289
GC_47	951501.722	933851.310	12.300
GC 48	747339.445	858534.924	21.379
GC_49	726871.348	916828.479	18.526
GC_50	847011.137	749721.016	13.595
GC_51	764164.380	719307.289	14.494
HC_01	951214.588	783263.505	15.992
HC_02	955976.065	954979.525	12.006
HC_03	729258.353	954909.190	12.817
HC_04	726347.390	729790.697	16.310
HC_05	859026.171	763231.528	12.812
HC_06	901179.170	895236.867	22.220
HC_07	777740.561	837491.200	13.632
HC_08	807603.741	751360.909	17.500
HC_09	837381.777	925811.698	21.625
HC_10	851825.661	858246.165	19.289
HC 11	839441.514	885401.657	14.493
HC_11	840290.967	791876.038	18.625
HC 12	823296.993	836959.274	18.688
HC_12	874598.917	694874.962	12.346

4. *GPS OBSERVATIONS*

POINT #	OBSERV. DATE	JULIAN DATE	TIME OF DAY	RE-OBVERV. DATE	RE-OBSERV. JULIAN DATE	RE-OBSERV. TIME
GCP						
GC_01	1/26/2017	026	16:21	2/14/2017	045	12:05
GC_02	1/26/2017	026	14:39	N/A	N/A	N/A
GC_03	12/22/2016	357	9:50	12/22/2016	357	14:59
GC_04	1/3/2017	003	14:18	1/4/2017	004	13:59
GC_05	1/10/2017	010	12:12	1/11/2017	011	8:17
GC_06	1/21/2017	021	7:35	N/A	N/A	N/A
GC_07	1/19/2017	019	14:58	1/20/2017	020	10:38
GC_08	2/8/2017	039	9:55	2/14/2017	045	10:10
GC_09	2/9/2017	040	8:52	N/A	N/A	N/A
GC_10	2/9/2017	040	10:35	N/A	N/A	N/A
GC_11	2/7/2017	038	13:38	2/8/2017	039	13:46
GC_12	2/7/2017	038	12:22	2/14/2017	045	10:56
GC_13	2/7/2017	038	10:45	2/14/2017	045	11:36
GC_14	2/7/2017	038	11:35	N/A	N/A	N/A
GC_15	1/26/2017	026	12:18	N/A	N/A	N/A
GC_16	1/27/2017	027	8:03	N/A	N/A	N/A
GC_17	1/10/2017	010	11:05	1/11/2017	011	7:30
GC_18	1/11/2017	011	14:20	1/18/2017	018	14:57
GC_19	1/9/2017	009	15:59	1/10/2017	010	7:36
GC_20	1/10/2017	010	15:19	1/11/2017	011	9:34
GC_21	1/5/2017	005	13:01	1/9/2017	009	11:24
GC_22	1/26/2017	026	17:25	N/A	N/A	N/A
GC_23	1/27/2017	027	12:18	N/A	N/A	N/A
GC_24	1/5/2017	005	14:26	1/6/2017	006	14:15
GC_25	1/27/2017	027	9:35	N/A	N/A	N/A
GC_26	2/8/2017	039	8:12	2/14/2017	045	10:31
GC_27	2/8/2017	039	11:26	2/8/2017	039	17:17
GC_28	1/27/2017	027	8:51	N/A	N/A	N/A
GC_29	1/20/2017	020	14:26	N/A	N/A	N/A
GC_30	2/7/2017	038	14:15	N/A	N/A	N/A
GC_31	2/8/2017	039	15:27	N/A	N/A	N/A
GC_32	2/8/2017	039	8:48	N/A	N/A	N/A
GC_33	1/27/2017	027	13:09	2/14/2017	045	11:18

POINT #	OBSERV. DATE	JULIAN DATE	TIME OF DAY	RE-OBVERV. DATE	RE-OBSERV. JULIAN DATE	RE-OBSERV. TIME
GCP						
GC_34	1/3/2017	003	15:14	1/4/2017	004	10:54
GC_35	1/3/2017	003	16:19	1/4/2017	004	15:04
GC_36	1/10/2017	010	8:16	1/10/2017	010	16:41
GC_37	1/19/2017	019	10:37	N/A	N/A	N/A
GC_38	2/9/2017	040	16:06	N/A	N/A	N/A
GC_39	2/9/2017	040	9:57	N/A	N/A	N/A
GC_40	2/7/2017	038	13:09	2/8/2017	039	13:24
GC_41	1/27/2017	027	12:43	N/A	N/A	N/A
GC_42	12/21/2016	356	14:51	1/3/2017	003	11:00
GC_43	1/11/2017	011	11:33	2/14/2017	045	8:42
GC_44	12/21/2016	356	13:38	12/22/2016	357	14:00
GC_45	2/7/2017	038	14:54	N/A	N/A	N/A
GC_46	1/26/2017	026	15:45	N/A	N/A	N/A
GC_47	12/22/2016	357	13:16	1/3/2017	003	9:53
GC 48	1/27/2017	027	10:11	N/A	N/A	N/A
GC_49	1/20/2017	020	12:00	N/A	N/A	N/A
GC_50	2/8/2017	039	12:09	2/8/2017	039	17:36
GC_51	2/8/2017	039	16:09	N/A	N/A	N/A
HC_01	1/26/2017	026	16:33	2/14/2017	045	12:00
HC_02	12/22/2016	357	10:15	12/22/2016	357	14:55
HC_03	1/21/2017	021	7:32	N/A	N/A	N/A
HC_04	2/9/2017	040	9:04	N/A	N/A	N/A
HC_05	2/7/2017	038	12:25	2/14/2017	045	11:03
HC_06	1/26/2017	026	12:03	N/A	N/A	N/A
HC_07	1/27/2017	027	9:28	N/A	N/A	N/A
HC_08	2/8/2017	039	11:28	2/8/2017	039	17:19
HC_09	1/9/2017	009	16:02	1/10/2017	010	7:34
HC_10	1/27/2017	027	8:15	N/A	N/A	N/A
HC 11*	1/5/2017	005	14:31	1/6/2017	006	14:19
HC_11*	1/27/2017	027	12:41	N/A	N/A	N/A
HC 12*	1/27/2017	027	8:48	N/A	N/A	N/A
HC_12*	2/7/2017	038	13:29	2/8/2017	039	13:40

* Dewberry Engineers, Inc. was provided the GCPs for this project. Within the GCPs provided were two HC 11 and two HC 12 points, with one label being separated by a space and the other separated by "_" as shown above.

5. POINT COMPARISON

LiDAR QA/QC				
POINT ID	CHECK POINT ID	Δ NORTH	Δ EAST	VERTICAL Δ
GCP				
GC_01	GC_01B	0.04	0.01	0.01
GC_03	GC_03B	0.03	0.06	0.03
GC_04	GC_04B	0.06	0.01	0.12
GC_05	GC_05B	0.05	0.03	0.04
GC_07	GC_07B	0.00	0.02	0.04
GC_08	GC_08B	0.03	0.05	0.13
GC_11	GC_11B	0.02	0.02	0.11
GC_12	GC_12B	0.01	0.05	0.13
GC_13	GC_13B	0.05	0.02	0.03
GC_17	GC_17B	0.08	0.00	0.03
GC_18	GC_18B	0.04	0.01	0.05
GC_19	GC_19B	0.07	0.00	0.03
GC_20	GC_20B	0.01	0.01	0.06
GC_21	GC_21C	0.01	0.02	0.11
GC_24	GC_24	0.01	0.03	0.12
GC_26	GC_26	0.01	0.01	0.14
GC_27B	GC_27C	0.04	0.00	0.08
GC_33	GC_33B	0.04	0.01	0.07
GC_34	GC_34B	0.13	0.09	0.16
GC_35	GC_35C	0.11	0.13	0.00
GC_36B	GC_36C	0.08	0.01	0.03
GC_40	GC_40B	0.00	0.10	0.04
GC_42	GC_42B	0.00	0.02	0.13
GC_43	GC_43C	0.05	0.00	0.09
GC_44	GC_44B	0.02	0.08	0.02
GC_47	GC_47B	0.02	0.00	0.07
GC_50B	GC_50C	0.05	0.02	0.06
HC_01	HC_01B	0.03	0.01	0.03
HC_02	HC_02B	0.02	0.05	0.00
HC_05	HC_05B	0.06	0.02	0.04
HC_08B	HC_08C	0.00	0.03	0.09
HC_09	HC_09B	0.00	0.03	0.07
HC 11	HC 11B	0.07	0.04	0.15
HC_12	HC_12B	0.03	0.05	0.06

Appendix B: Complete List of Delivered Tiles

692500_732500	785000_725000	957500_725000	792500_727500	910000_727500
950000_722500	787500_725000	692500_727500	795000_727500	912500_727500
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947500_942500	870000_945000	795000_947500	900000_947500	825000_950000
950000_942500	872500_945000	797500_947500	902500_947500	827500_950000
952500_942500	875000_945000	800000_947500	905000_947500	830000_950000
955000_942500	877500_945000	802500_947500	907500_947500	832500_950000
957500_942500	880000_945000	805000_947500	910000_947500	835000_950000
960000_942500	882500_945000	807500_947500	912500_947500	837500_950000
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Appendix C: GPS Processing

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