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LA DOTD Amite Watershed Lidar Project

Report Produced for U.S. Geological Survey

LA DOTD Contract: 4400008293

Task Order: 6

Report Date: 01/25/2019

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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 LA DOTD Amite Watershed Lidar Project.

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 1500m by 1500m. A total of 2410 tiles were produced for the project encompassing an area of approximately 1884 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.

Forte and Tablada 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. He also verified the GPS base station coordinates used during lidar data acquisition to ensure that the base station coordinates were accurate. Please see Appendix A and Appendix B to view the separate Survey Report that was created for this portion of the project.

Precision Aerial Reconnaissance (PAR) completed lidar data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report falls within the Lousiana parishes of East Feliciana, St. Helena, East Baton Rouge, Livingston, Iberville, and Ascension, and the Mississippi counties of Amite, Wilkinson, Franklin, and Lincoln.

DATE OF SURVEY

The lidar aerial acquisition was conducted from March 01, 2018 thru April 12, 2018.

COORDINATE REFERENCE SYSTEM

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

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 15
Units: Horizontal units are in meters, Vertical units are in meters.
Geiod Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the LA DOTD Amite Watershed Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **3.6 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 **7 cm**, compared with the 19.6 cm specification.

For the LA DOTD Amite Watershed Lidar Project, the tested VVA of the classified lidar data computed using the 95^{th} percentile was equal to **11.6 cm,** compared with the 29.4 cm specification.

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

PROJECT DELIVERABLES

The deliverables for the project are listed below.

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

PROJECT TILING FOOTPRINT

Two thousand four hundred and ten (2,410) tiles were delivered for the project. Each tile's extent is 1,500 meters by 1,500 meters (see Appendix C for a complete listing of delivered tiles).

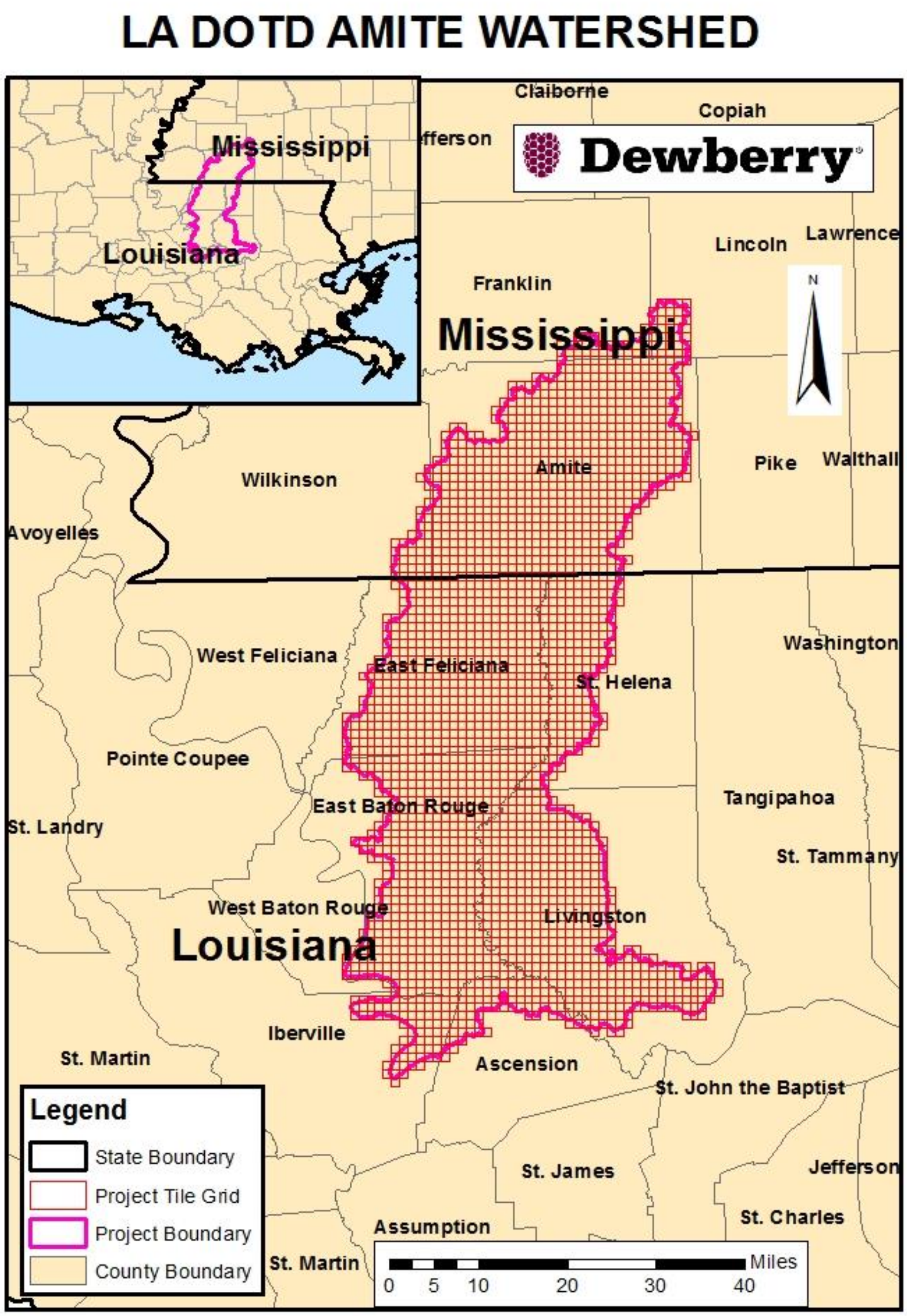


Figure 1 - Project Map

Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities to Precision Aerial Reconnaissance (PAR). Precision Aerial Reconnaissance (PAR) was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry.

Dewberry received calibrated swath data from Precision Aerial Reconnaissance (PAR) on March 13, 2018 and final project deliverables on May 14, 2018.

LIDAR ACQUISITION DETAILS

Precision Aerial Reconnaissance (PAR) planned 310 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Precision Aerial Reconnaissance (PAR) followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using LEICA MISSION PRO flight design software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Precision Aerial Reconnaissance (PAR) will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Precision Aerial Reconnaissance (PAR) 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. Precision Aerial Reconnaissance (PAR) 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, Precision Aerial Reconnaissance (PAR) 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.

Precision Aerial Reconnaissance (PAR) lidar sensors are calibrated at a designated site located at the Shreveport Downtown Airport in Shreveport, Louisiana and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Precision Aerial Reconnaissance (PAR) operated a Cessna U206G (Tail # N799AC) and a Cessna 206 (Tail # 6461Z) outfitted with a LEICA ALS70-HP LiDAR system during the Amite Watershed aerial survey. Table 1 illustrates Precision Aerial Reconnaissance (PAR) system parameters for lidar acquisition on this project.

Item	Parameter
System	Leica ALS-70 HP
Altitude (AGL meters)	1152
Approx. Flight Speed (knots)	115
Scanner Pulse Rate (kHz)	450
Scan Frequency (hz)	42.3
Pulse Duration of the Scanner (nanoseconds)	9
Pulse Width of the Scanner (m)	0.2
Swath width (m)	838.59
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	yes
Beam Divergence (milliradians)	0.22
Nominal Swath Width on the Ground (m)	1252.54
Swath Overlap (%)	30
Total Sensor Scan Angle (degree)	40
Computed Down Track spacing (m) per beam	1.22
Computed Cross Track Spacing (m) per beam	0.44
Nominal Pulse Spacing (single swath), (m)	0.33
Nominal Pulse Density (single swath) (ppsm), (m)	9.18
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.33
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	9.18
Maximum Number of Returns per Pulse	7

Table 1: Precision Aerial Reconnaissance (PAR) 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.

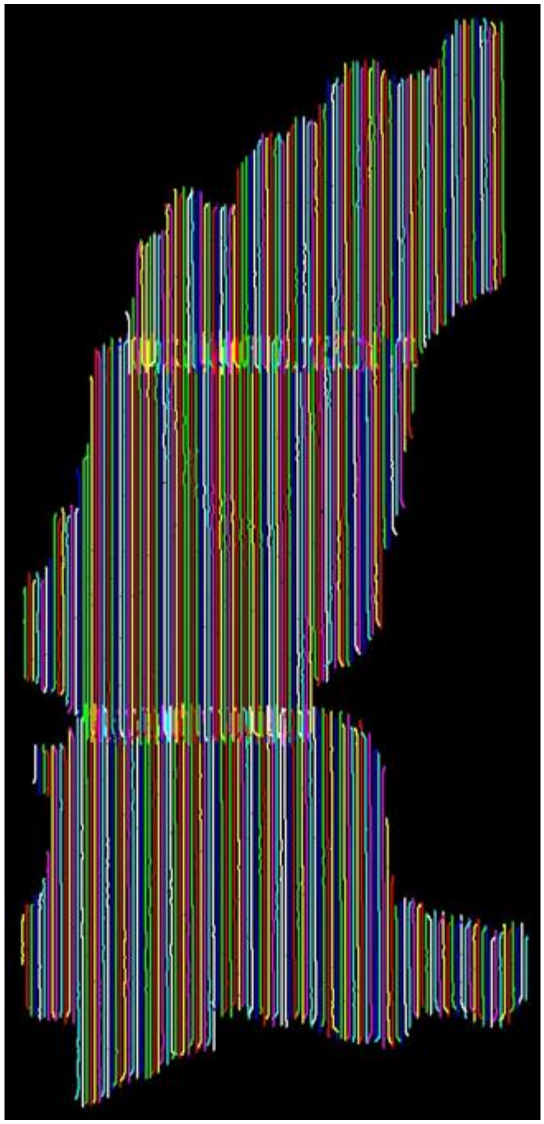


Figure 2: Trajectories as flown by Precision Aerial Reconnaissance (PAR)

LIDAR CONTROL

Two existing NGS monuments were used to control the lidar acquisition for the LA DOTD Amite Watershed Lidar Project area. The coordinates of all used base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

Name	NAD83(2011) UTM 15		Ellipsoid Ht (NAD83(2011), m)	Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)		
McComb	740860.6217	3452620.068	97.008	123.6
Baton Rouge	677199.3355	3378390.39	-8.507	18.606

Table 2 – Base stations used to control lidar acquisition

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the Inertial Explorer software suite. Flights were flown with a minimum of 13 satellites in view (12° above the horizon) and with a PDOP of better than 3. Distances from base station to aircraft were kept to a maximum of 70 km.

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

GPS processing reports and GPS figures for each mission are included in Appendix A, while flightlogs are available in Appendix B.

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

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

Subsequently the mission points are output using Leica Cloud Pro, initially with default values from Leica or the last mission calibrated for the system. Bayes StripAlign software (version 2.04B) was utilized for LiDAR calibration, assessment of calibration validity, and assessment of point cloud alignment to control. 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.

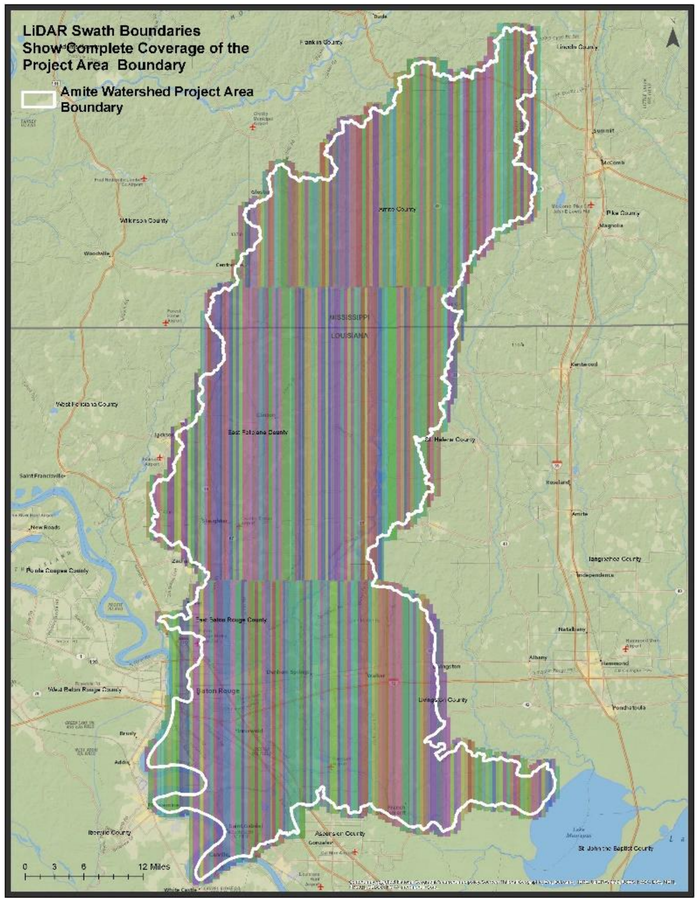


Figure 3 – Lidar swath output showing complete coverage.

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.

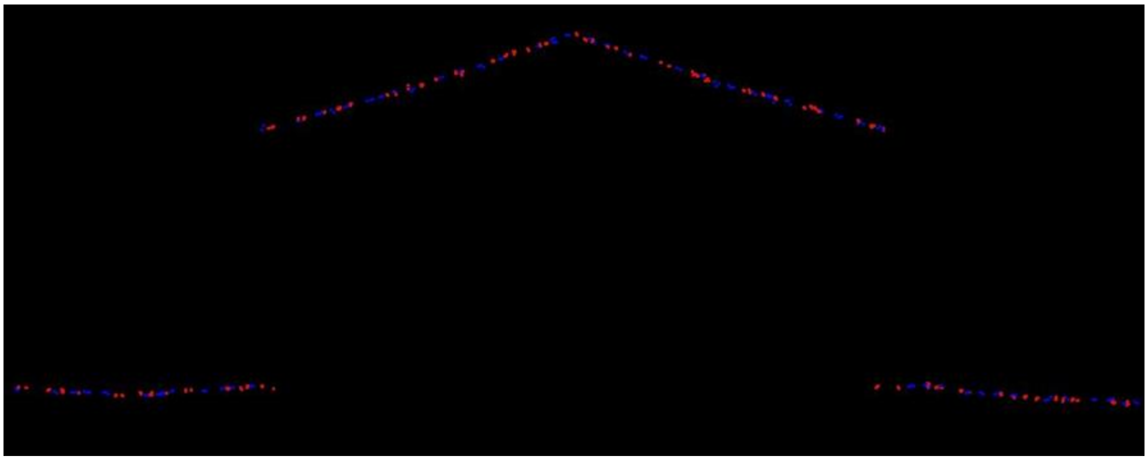


Figure 4 – Profile views showing correct roll and pitch adjustments.

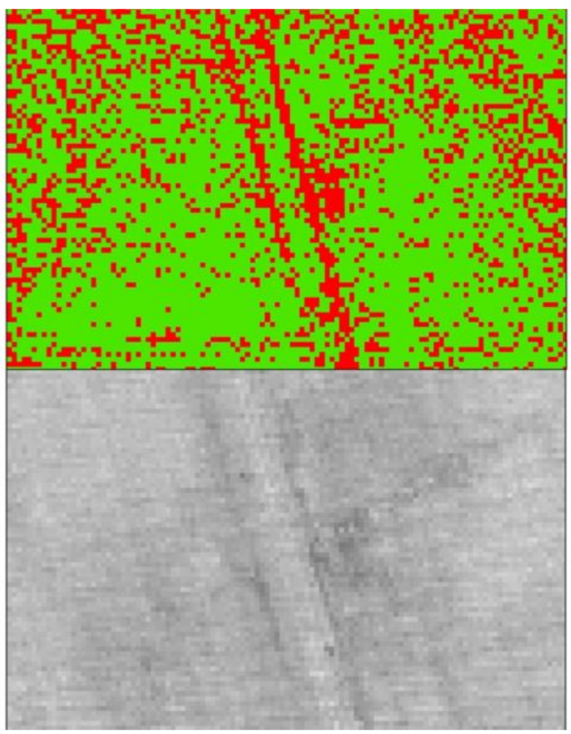


Figure 5. Relative accuracy of swath data over road and pasture. Top view illustrates green points representing elevation offsets between adjacent points that are within 6 cm. Red points represent elevation offsets greater than 6 cm. Bottom view shows lidar intensity image of the road.

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 Precision Aerial Reconnaissance (PAR) 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 LA DOTD Amite Watershed Lidar Project dataset was tested to 0.072 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.0367 m x 1.9600) when compared to 70 GPS static check points.

The following are the final statistics for the GPS static checkpoints used by Precision Aerial Reconnaissance (PAR) to internally verify vertical accuracy.

Number	NAD83(2011) UTM 15		NAVD88 (Geoid 12B)	Laser Z (m)	Delta Z
	Easting X (m)	Northing Y (m)	Known Z (m)		
8CCP1	3355852.011	623628.131	20.302	20.276	-0.03
8CCP3	3351193.969	652003.476	11.929	11.934	0.005
8CCP4	3372158.637	660119.613	12.093	12.136	0.043
8CCP5	3452376.568	650242.041	9.941	9.798	-0.14
8CCP8	3353160.934	678851.847	34.97	34.822	-0.15
8CCP8	3353160.934	678851.847	34.97	34.852	-0.12
8CCP10	3404810.104	672855.934	21.499	21.601	0.101
8CCP11	3430687.199	678190.943	12.241	12.233	-0.01
8CCP12	3454810.406	678418.344	18.284	18.218	-0.07
8CCP14	3350717.306	705322.146	50.121	49.997	-0.12
8CCP15	3378150.653	704636.835	63.205	63.181	-0.02
8CCP16	3404266.999	705675.266	36.709	36.601	-0.11
8CCP17	3430144.761	704424.594	24.514	24.597	0.083
8CCP18	3454813.329	703805.646	26.119	26.008	-0.11
8CCP19	3351406.397	732359.547	58.409	58.369	-0.04
8CCP20	3378741.373	731243.607	49.029	49.169	0.14
8CCP21	3404655.213	731723.041	51.946	52.157	0.211
8CCP22	3429642.481	730999.177	51.585	51.555	-0.03
8CCP23	3456753.876	729910.709	37.854	37.619	-0.23
8CCP24	3348397.508	756232.308	66.844	67.096	0.252
8CCP25	3377273.101	757516.382	70.22	70.1845	-0.04
8CCP26	3404075.714	757489.861	69.518	69.514	0
8CCP28	3459410.994	757460.726	65.446	65.456	0.01
8CCP29	3350700.759	783676.714	93.245	93.385	0.14

8CCP30	3377323.44	784015.792	103.31	103.296	-0.01
8CCP31	3405693.957	785029.168	89.918	89.702	-0.22
8CCP32	3428478.167	778480.961	98.353	98.338	-0.02
8CCP33	3329638.308	809943.774	126.637	126.467	-0.17
8CCP34	3347501.04	810289.92	133.511	133.418	-0.09
8CCP35	3374763.088	810937.515	140.105	140.174	0.069
8CCP35	3374763.088	810937.515	140.105	140.198	0.093
8CCP37	3430690.762	811133.381	120.328	120.317	-0.01
8CCP38	3348047.678	835657.813	160.03	159.8745	-0.16
8CCP39	3383150.094	836054.955	211.07	211.205	0.135
8CCP40	3413414.364	837405.916	202.241	202.085	-0.16
8CCP41	3429005.713	834415.198	155.669	155.684	0.015
8CCP42	3460123.556	835191.89	251.434	251.566	0.132
8CCP43	3350147.047	861306.788	248.944	248.8085	-0.14
8CCP44	3378285.158	860426.694	186.07	185.9685	-0.1
8CCP45	3403379.622	864545.447	252.89	252.831	-0.06
8CCP46	3427527.133	868940.251	180.873	180.8675	-0.01
8CCP47	3457773.423	863683.774	295.971	296.111	0.14
8CCP48	3352325.205	890819.56	315.594	315.605	0.011
8CCP49	3378976.131	885471.865	302.123	301.986	-0.14
8CCP50	3401262.598	888629.294	306.549	306.469	-0.08
8CCP51	3429760.026	889765.174	191.191	191.065	-0.13
8CCP52	3459046.511	888261.394	254.206	254.307	0.101
8CCP53	3352999.639	916889.01	336.03	335.962	-0.07
8CCP53	3352999.639	916889.01	336.03	335.978	-0.05
8CCP54	3375452.158	905428.502	325.039	325.108	0.069
8CCP56	3433783.034	918498.308	217.917	218.019	0.102
8CCP57	3456391.985	914921.747	342.53	342.698	0.168
8CCP58	3379881.368	944615.71	377.933	378.104	0.171
8CCP59	3403144.762	941059.761	331.368	331.454	0.086
8CCP59	3403144.762	941059.761	331.368	331.465	0.096
8CCP60	3428659.224	941956.699	263.018	263.2345	0.217
8CCP61	3449320.308	943565.358	359.557	359.595	0.038
8CCP62	3377113.763	969712.852	391.388	391.543	0.155
8CCP63	3406683.689	968201.299	385.053	385.261	0.208
8CCP64	3431378.255	969746.961	310.689	310.871	0.182
8CCP65	3456403.629	969607.207	385.082	385.233	0.151
8CCP66	3483965.366	970993.456	354.813	354.854	0.041
8CCP67	3513042.45	967784.739	431.188	431.2005	0.012
8CCP69	3455608.496	996652.348	426.02	426.167	0.147
8CCP70	3483025.61	994141.605	377.484	377.491	0.007
8CCP71	3510731.197	994140.593	438.005	437.886	-0.12
8CCP72	3457061.622	1021903.137	433.074	433.2925	0.219
8CCP73	3480796.511	1021332.079	462.326	462.2865	-0.04
8CCP74	3508219.946	1021126.329	417.7	417.646	-0.05
8CCP76	3509233.785	1047188.283	423.967	424.084	0.117

Table 3 - Static GPS Points

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	NVA at 95% Spec=0.196 m	Mean (m)	Std Dev (m)	Min (m)	Max (m)
Non-Vegetated Terrain	70	0.367	0.072	0.004	0.036	-0.072	0.077

Table 4 - Static GPS Vertical Accuracy Results

Overall the calibrated lidar data products collected by Precision Aerial Reconnaissance (PAR) meet or exceed the requirements set out in the Statement of Work. The quality control requirements of Precision Aerial Reconnaissance (PAR) 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 Precision Aerial Reconnaissance (PAR), Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the fifty-five 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 LA DOTD Amite Watershed 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 $RMSE_z$ = 3.6 cm, equating to +/- 7 cm at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.10 m	NVA –Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Non-Vegetated Terrain	71	0.036	0.070	-0.003	-0.005	-0.189	0.036	-0.100	0.074	-0.331

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

Three checkpoints (NVA56, ENVA9, and ENVA14) were removed from the raw swath vertical accuracy testing due to their location outside the project boundary. Only non-vegetated terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation, structures, and other above ground features from the ground classification. Table 4, below, provides the coordinates for these. Figure 4, below, shows a project map and the location of the checkpoints outside the project boundary.

Point ID	NAD83(2011) UTM 15		NAVD88 (Geoid 12B)	Lidar Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
NVA56	3400946.520	624330.980	14.150	outside		
ENVA9	707943.048	3393466.063	33.670	outside		
ENVA14	696593.871	3352074.451	6.429	outside		

Table 6: Checkpoints removed from raw swath vertical accuracy testing.

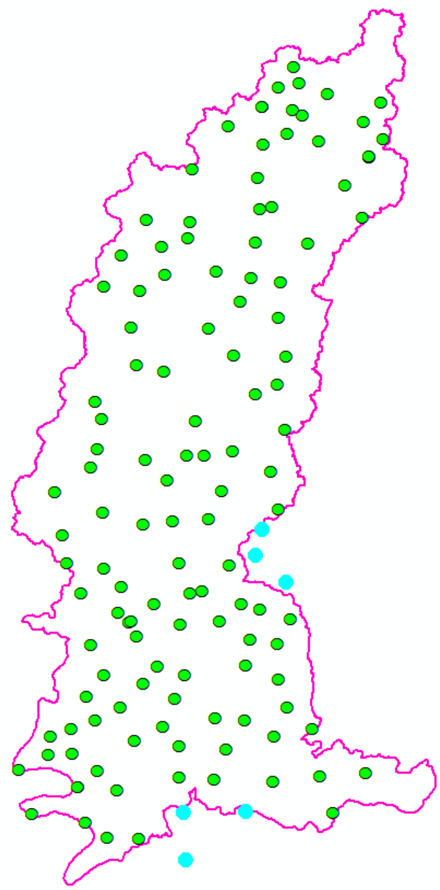


Figure 6 – Checkpoints NVA56, ENVA9, and ENVA14 (along with 3 VVA excluded points), shown here highlighted in blue, are located outside the project boundary. These points were removed from raw swath vertical accuracy testing.

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 LA DOTD Amite Watershed Lidar Project are shown in the figure below; this project meets inter-swath relative accuracy specifications.

Figure 7– Single return DZ Orthos for the LA DOTD Amite Watershed Lidar Project. Inter-swath relative accuracy passes specifications. Due to the very dense vegetation in this project, many areas of the DZ Orthos show failing in red, however this data passes inter-swath accuracy in the flat open areas.

Intra-Swath (Within a Single Swath) Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using ArcMap and visual reviews. ArcMap 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 an example of the intra-swath relative accuracy of LA DOTD Amite Watershed Lidar Project; this project meets intra-swath relative accuracy specifications.

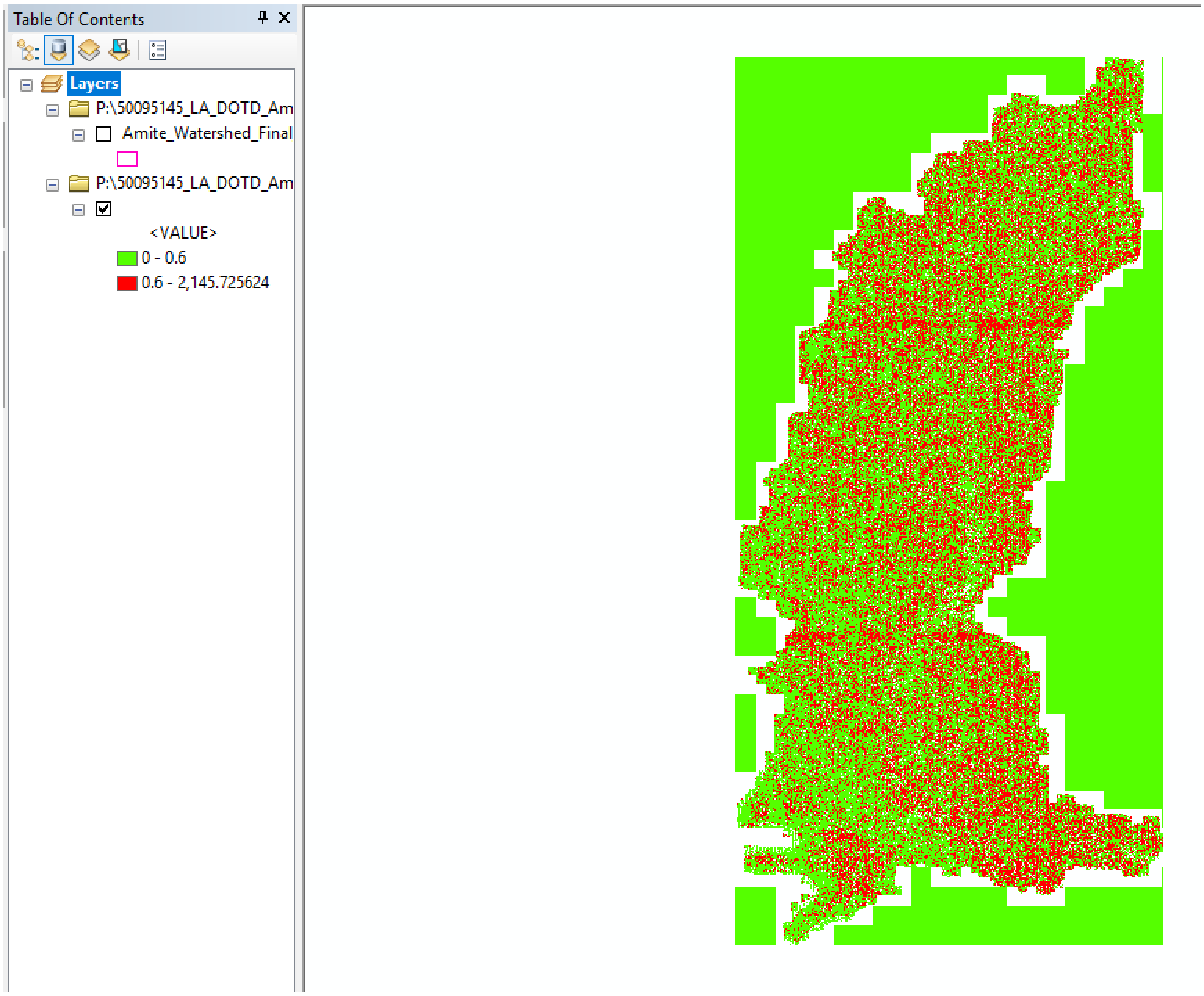


Figure 8–Intra-swath relative accuracy. The image shows the full project area; areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. Again, areas shown in red are heavily vegetated and the open flat areas are acceptable. Intra-swath 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 LA DOTD Amite Watershed Lidar Project; no horizontal alignment issues were identified.

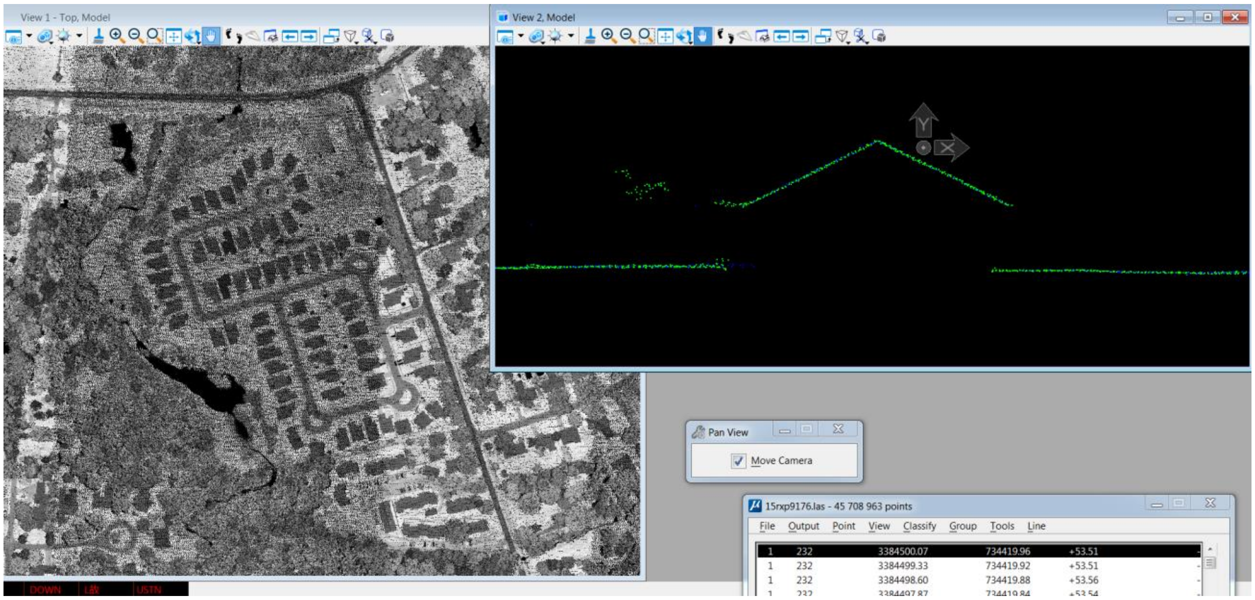


Figure 9– Horizontal Alignment. Two separate flight lines differentiated by color (Green/Blue) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.35 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 9 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 0.4 meters or an ANPD of 10.41 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 9 points per square meter (red areas) due to large areas of water. Most 1-sqaure meter cells contain at least 9 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.

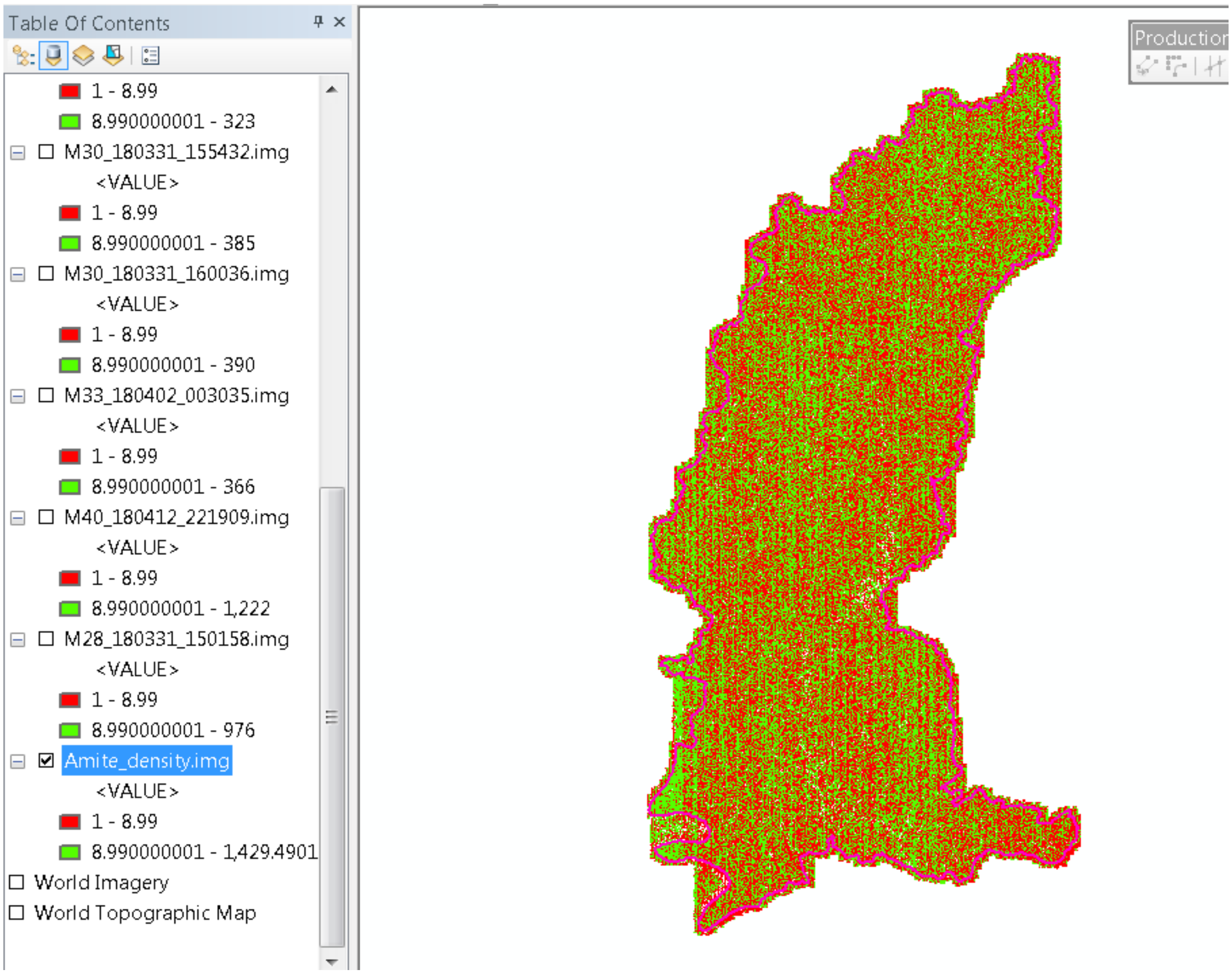


Figure 10–Most 1-sqaure meter cells contain at least 9 points per square meter (green areas) showing there are no systematic density issues. However there were a few swaths that did not contain at least 9 points per square meter. At closer inspection it was determined that these areas were due to large areas of open water. When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues.

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

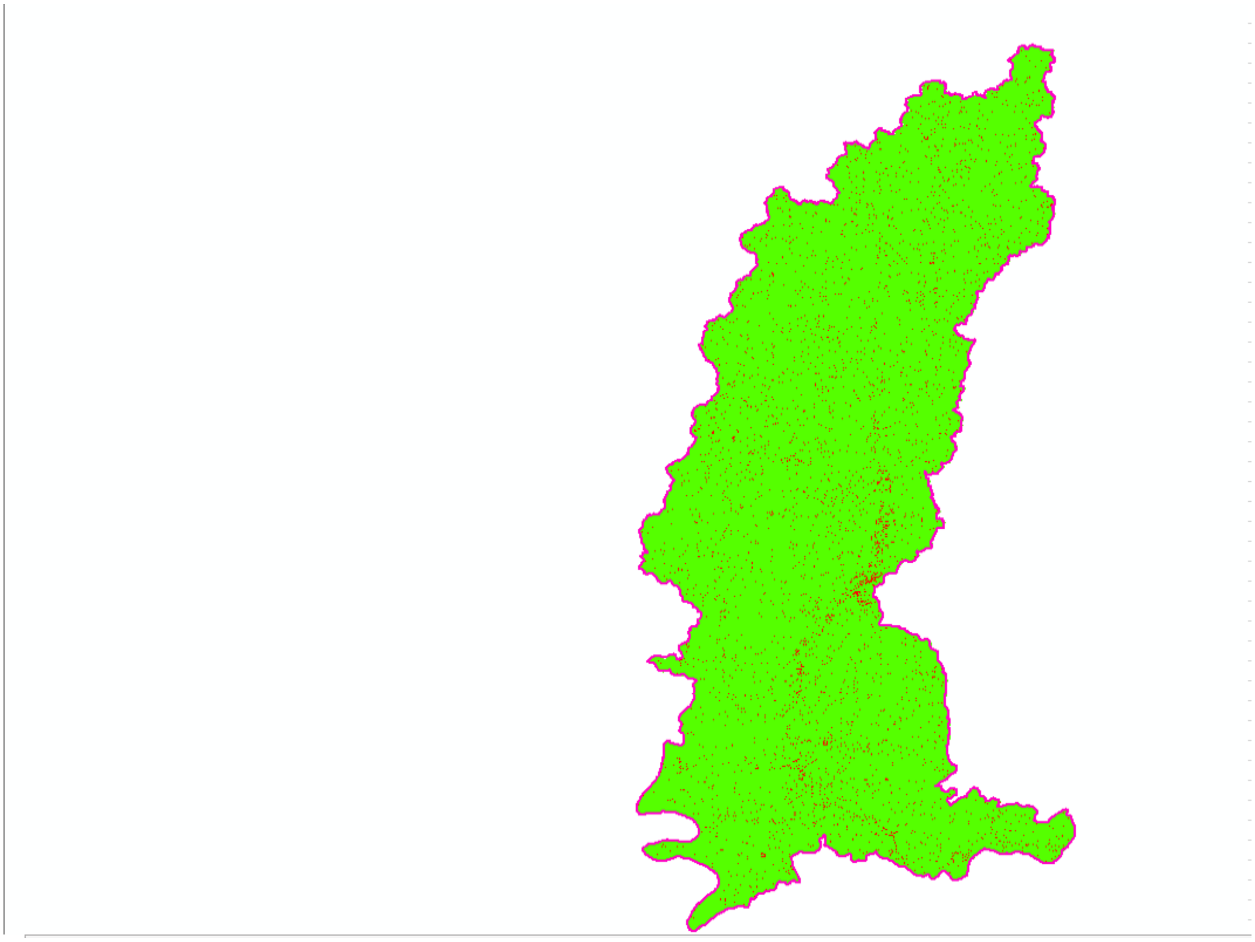


Figure 11– Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies which are acceptable NoData area, are colored red. Without removing acceptable NoData areas due to water, 97.48% of cells contain at least one lidar point.

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

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

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

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 10, 17, or 18, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 8 = Model Key Points
- 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 LA DOTD Amite Watershed Lidar Project.

Data Voids

The Amite dataset has a void 274,427.58 square meters (0.1 sq miles) in size, located in tiles 15RXP7252 and 15RXP7254. This void is occurring at the edge of two flight lines, shown in the image below. Based on the geometry of the artifact, this can only be explained as range based artifact. Since the system flown was a Leica ALS, this system is susceptible to a limited range gate in the multiple pulses in air operation.

When multiple pulses are in the air, the unambiguous ranges are limited to a range window, depending on the flight parameters this window may be as narrow as a few hundred meters from min to max range. In the case that the aircraft flies too high or changes in topography increase there can be the chance that the collection of points is cut out due to the range being outside the min/max range of the range gate. Additional consideration must be made for the fact that the range changes across track from nadir to the swath edge, depending on flying height and field of view, this variation can also be considerable.

In this example, the data was just at the edge of the range gate threshold, which is why the very edge of the flight line is cut out. At the edge points that are closer to the aircraft (higher) are recorded while points farther in range (lower and at a higher scan angle) are missing.

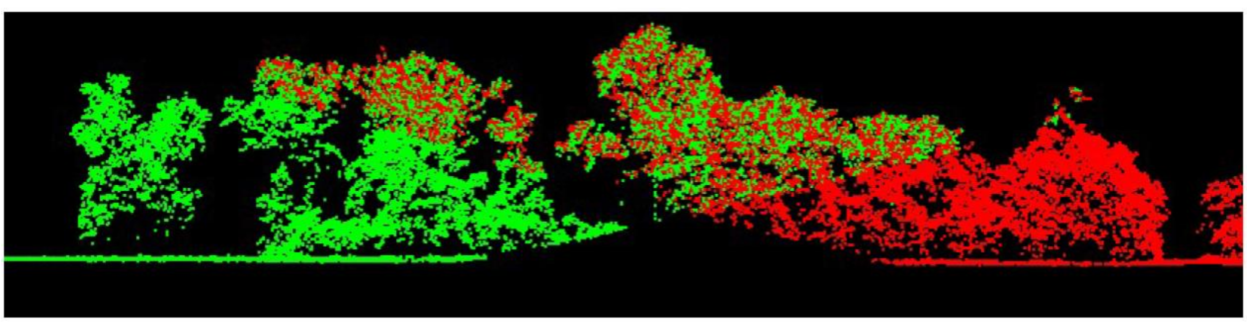


Figure 12-Profile of point cloud colored by flight line where red and green each represent different flight lines. Data are missing in the center where they are out of the min/max range of the range gate.

In plan view a void is visible along this edge which opens up wider towards the flight line ends.

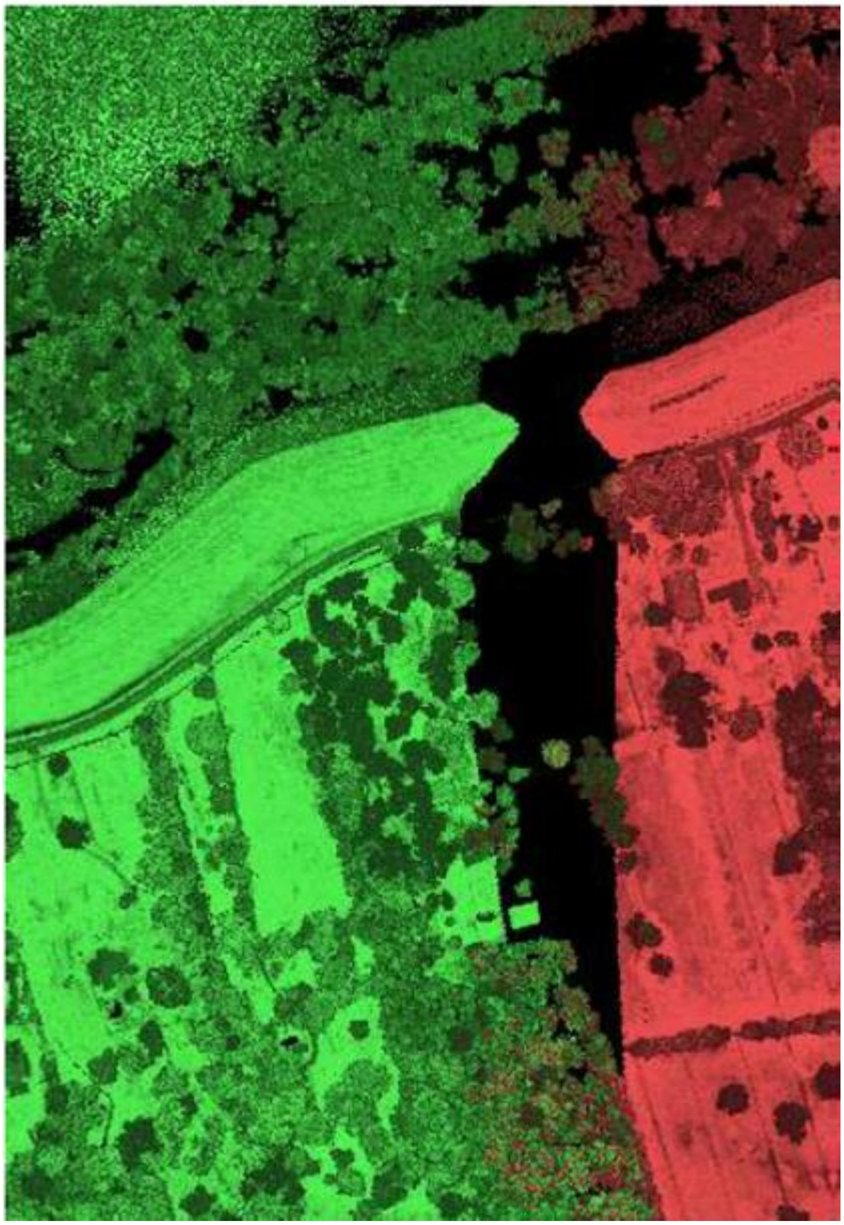


Figure 13-Plan view of lidar point cloud colored by flight line (green, red). A void (black area) is visible between these two flight lines.

It is also noticeable that the levee running east-west has slightly more data recorded than the surrounding area. This correlates with the range theory as this data is slightly lower in range than the surrounding area.

This artifact can also be observed in other flight lines as a dropout of ground points at the edge of flight lines, shown in the image below. The very edge extent of the magenta flight line is not fully reaching the ground level. Based on the geometry of this edge, this again is very likely the same range gate based artifact. In these cases however there is enough overlap between flight lines without range issues that the artifact is not of concern and does not cause data voids or gaps in coverage.

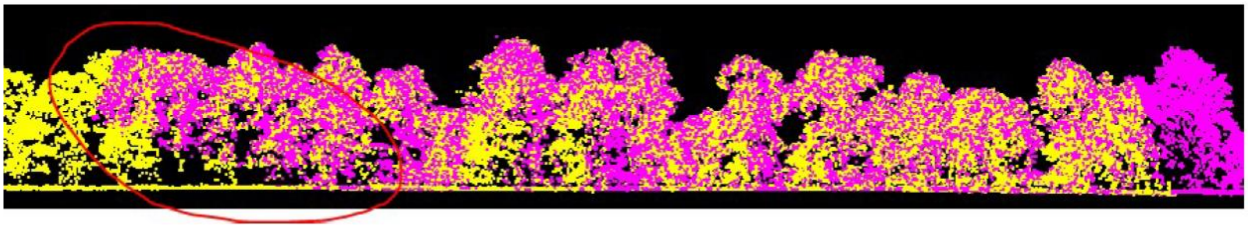


Figure 14-Profile of point cloud colored by flight line where yellow and magenta each represent different flight lines. Data are missing at ground level along the western edge of the magenta flight line where they are out of the min/max range of the range gate. However, overlap from adjacent flight lines fill this area and prevents a void from occurring.

The full dataset was reviewed for the existence of additional voids and no other voids were identified. As the only solution to fill this data would be a re-flight, the data was processed as-is with this small void. This void is identified by a shapefile in the final deliverables and a statement identifying this void is also provided in the metadata.

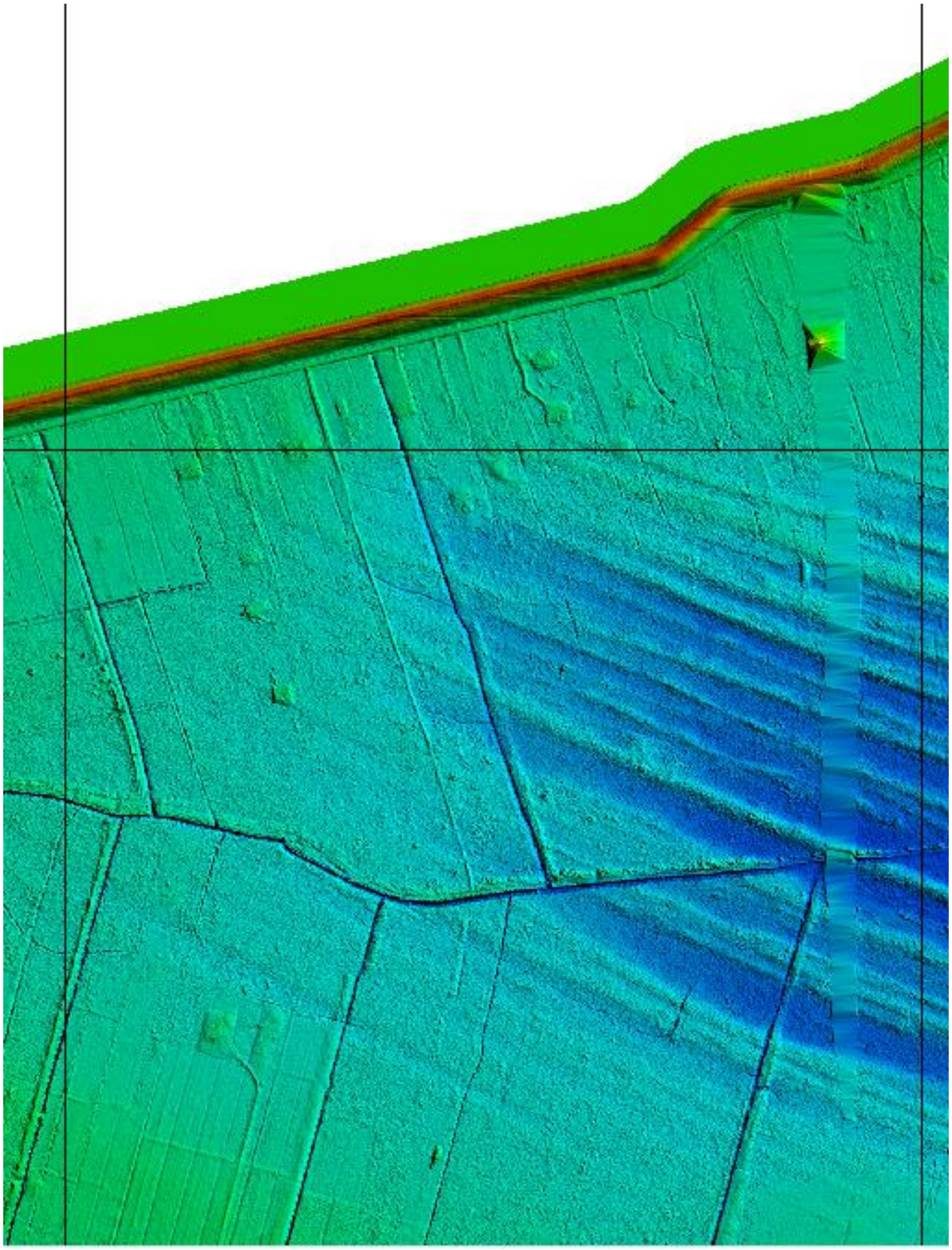


Figure 15– Tiles 15RXP7252 and 15RXP7254 show where the above void area appears in the DEM.

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.

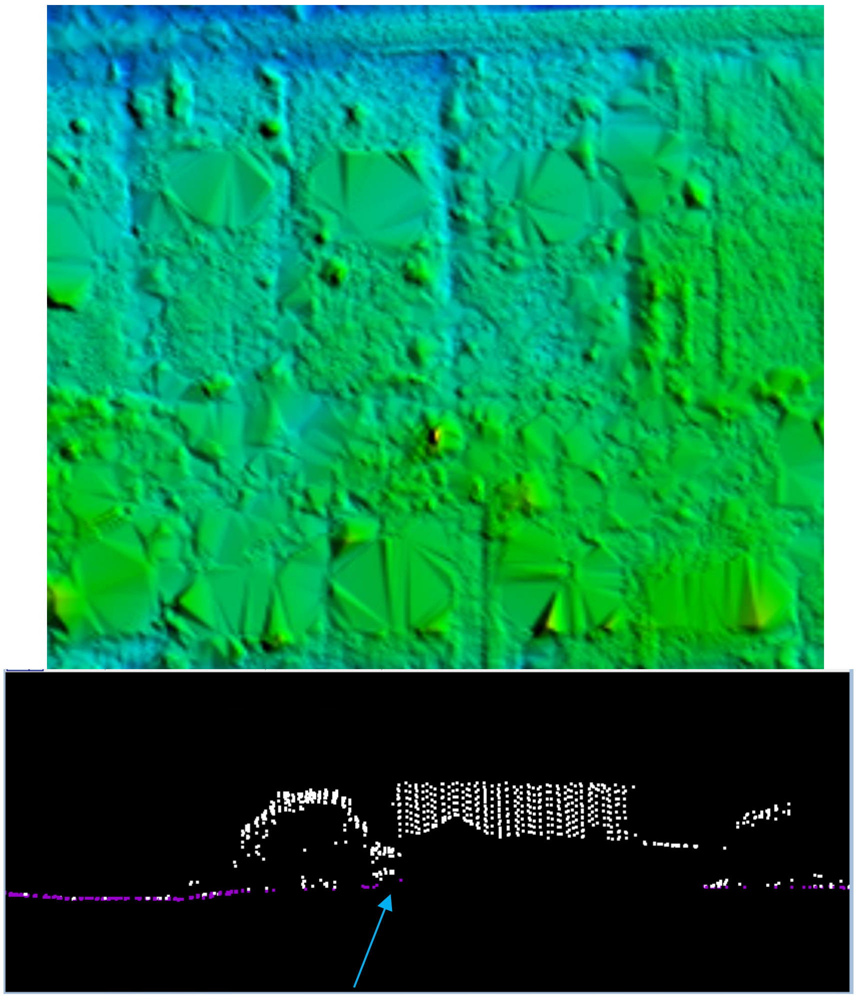


Figure 16 – Tile number 15RXP8469. Profile with points colored by class (class 1=white, class 2=purple) is shown in the bottom view and a TIN of the surface is shown in the top view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but 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.

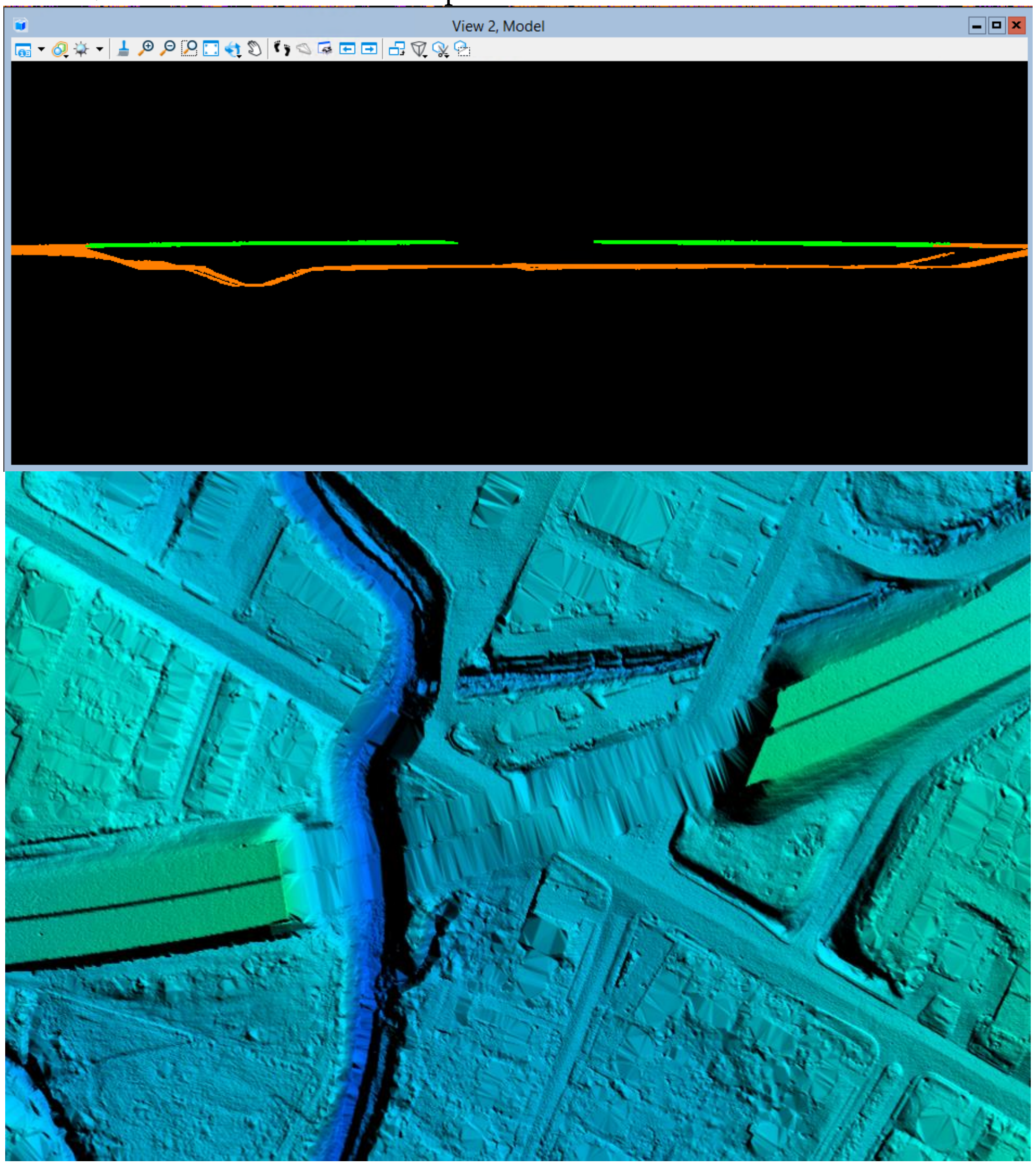


Figure 17 – Tile number 15RXP8266. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. 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 (brown) and have been moved to class 17 bridge deck (green).

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.

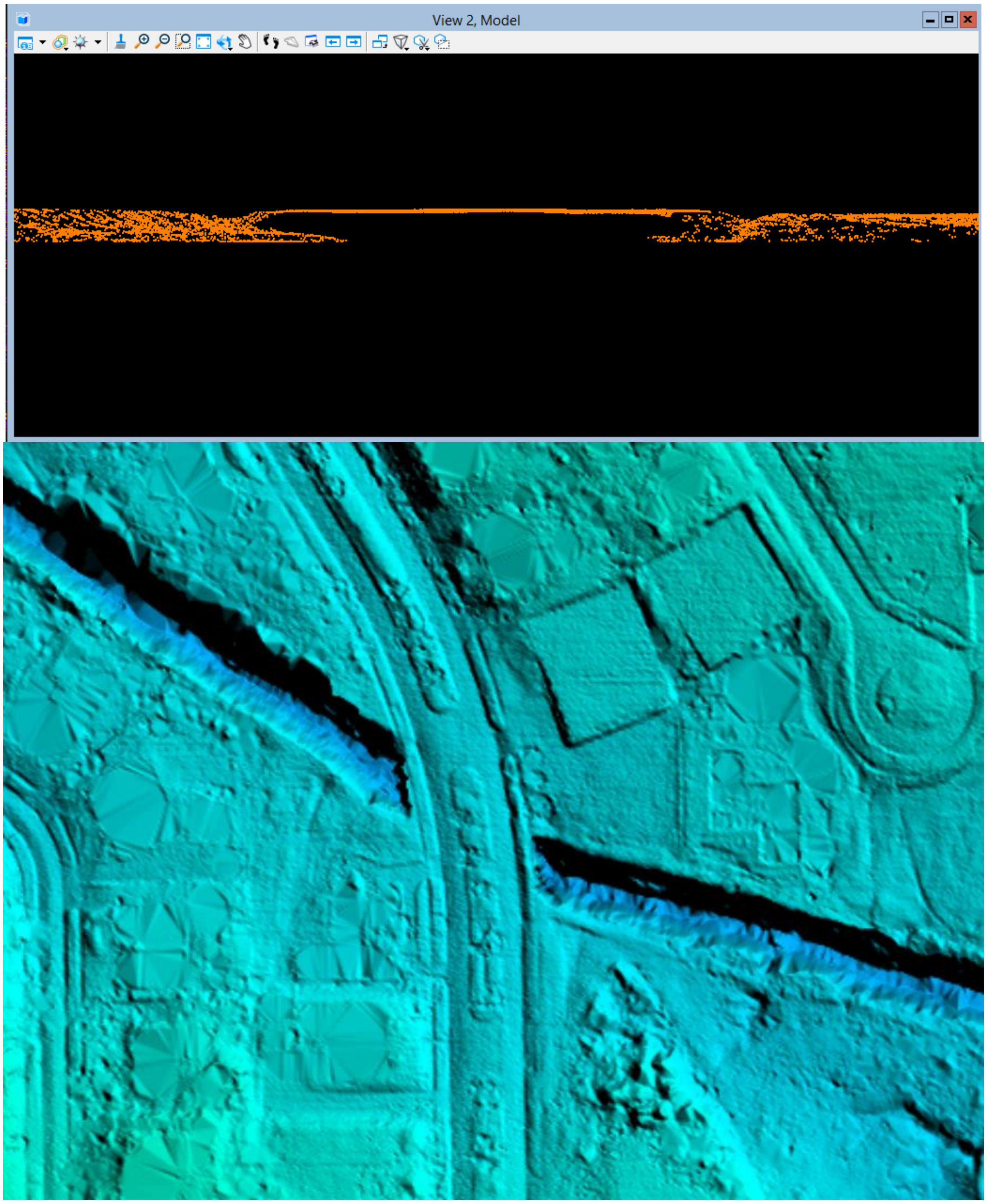
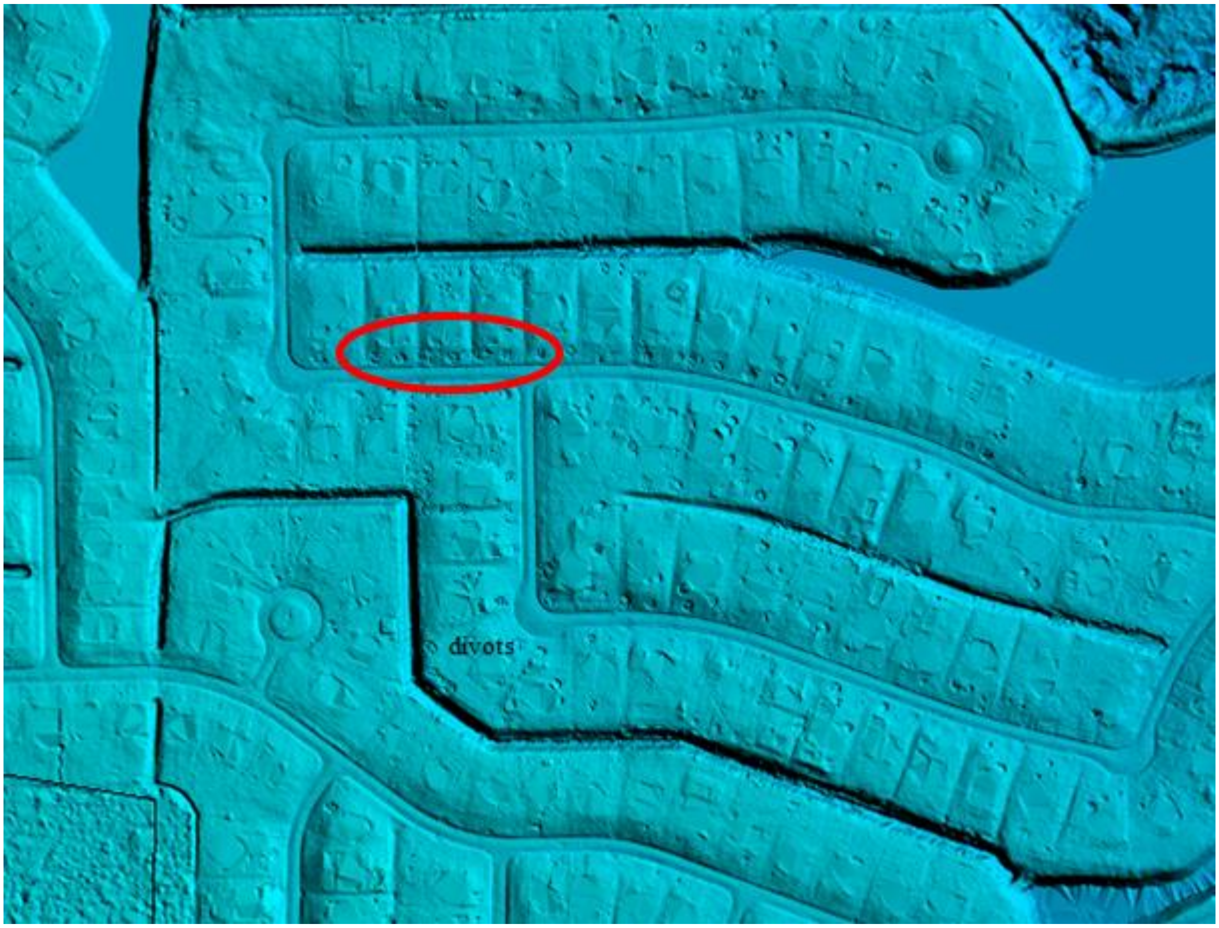


Figure 18– Tile number 15RXP8267. The DEM in the bottom view shows an area where a culvert has been left in the bare earth surface. The top view shows a profile with culvert area left as ground points colored in brown. Bridges have been removed from the bare earth surface and classified to class 17.

Divots

Divots caused by sensor issues beneath single standing trees were found throughout this data. A series of macros were run to help remove these divots along with manual fixes, however some of these divots still remain in areas where no lidar points were available to accurately model the ground beneath the tree.




15RYP0564

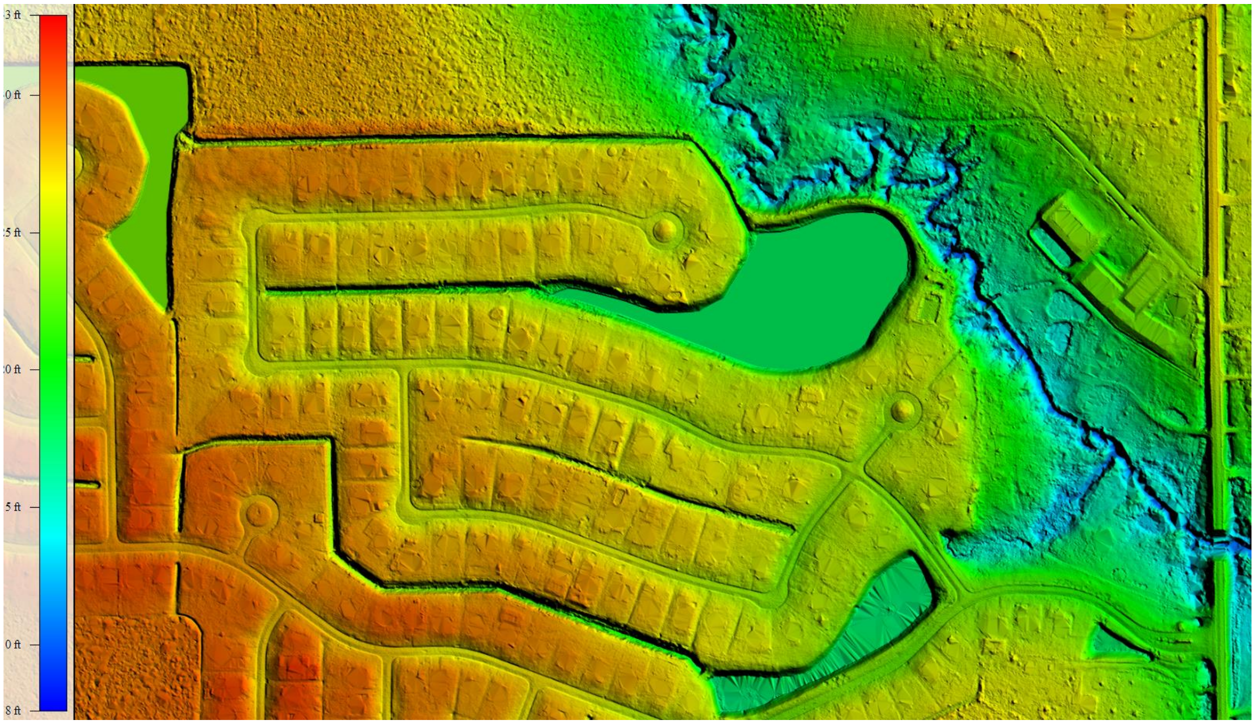


Figure 19– Tile number 15RYP0564. The DEM in the top view shows an area with divots left in the bare earth surface. In the intensity and color imagery, single trees can easily be seen in the area above where the divots appear. The DEM in the bottom view shows the same subdivision where the majority of these divots were able to be removed with during the editing process.

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.

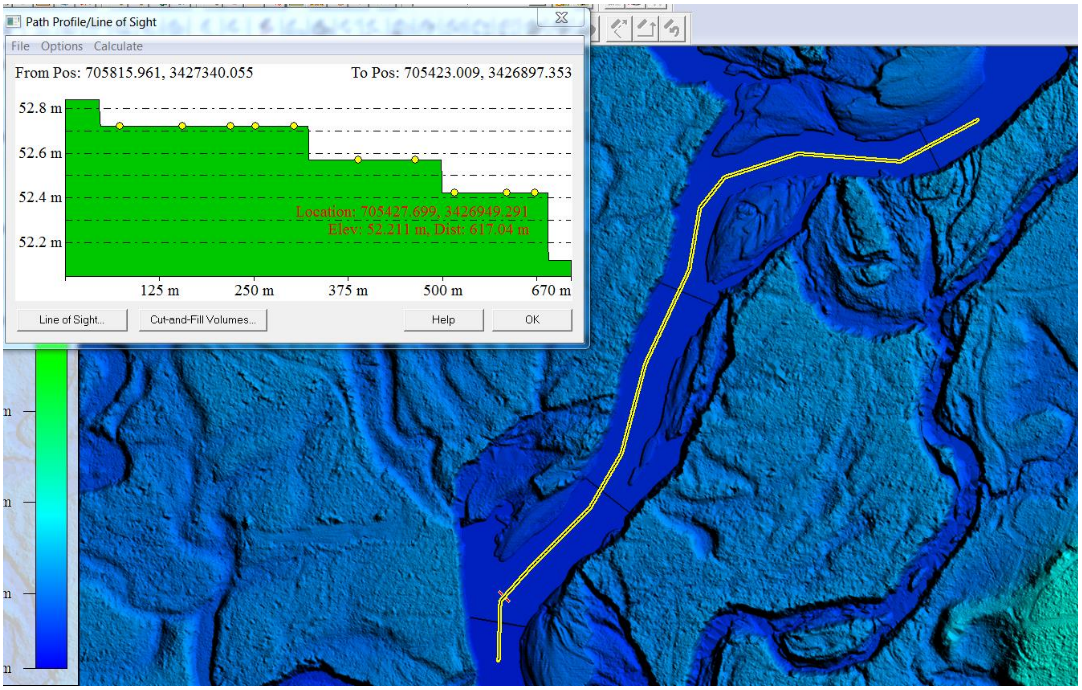


Figure 20 – Tile number 15RYQ0526. Elevation change has been stair stepped. The steps are flat from bank to bank and flow consistently downhill.

Marsh Areas

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

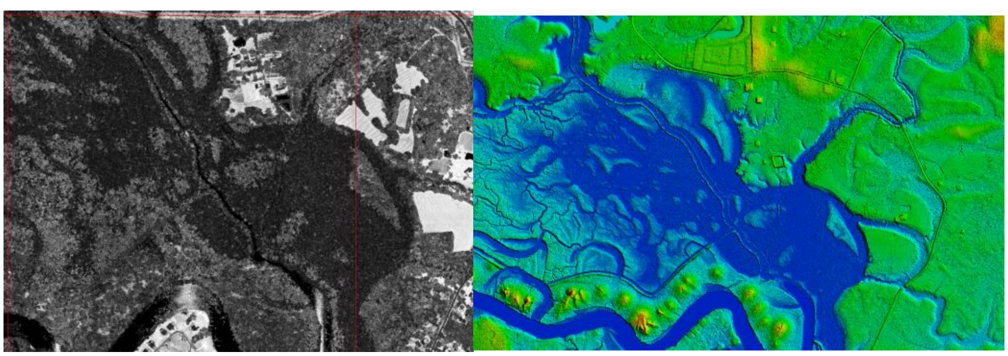


Figure 21 - Tiles 15RYP0558 and 15RYP0658. The intensity on the left shows a marsh area that was not included in the collected breaklines. The same area is shown in the DEM on the right. Due to wet soils and broken terrain, the point density in marsh areas is sparser than surrounding areas and there is more variation in the low points representing ground.

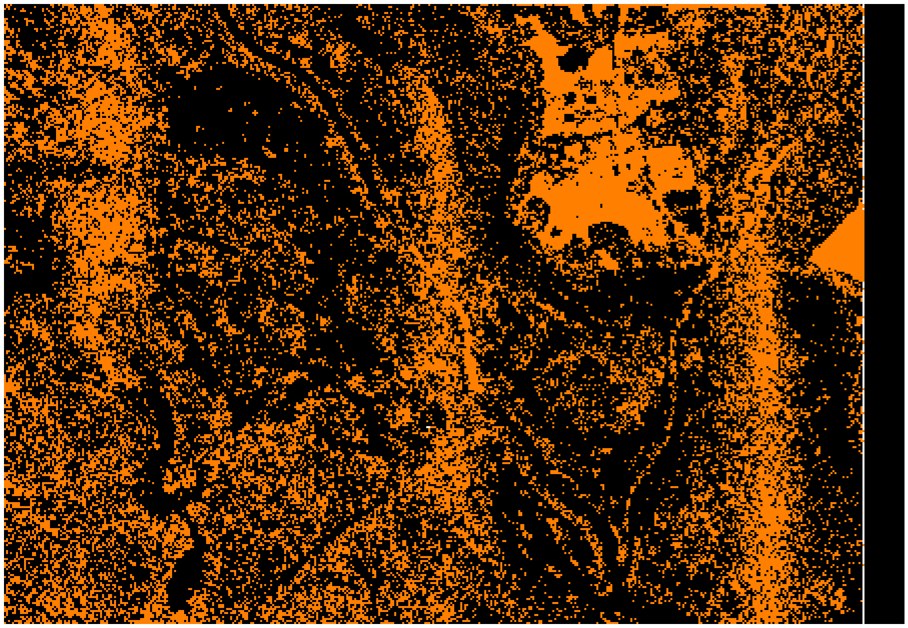


Figure 22 - Tile 15RYP0558. The same marsh area shown in the figure above is shown in this image with the points colored by class 2= brown. Though ground points are sparse they are present, indicating that the area is wet but should not be classified as water (class 9). Doing so would strip the detail from this area and result in incorrectly flattening ground as part of the hydro mask.

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.

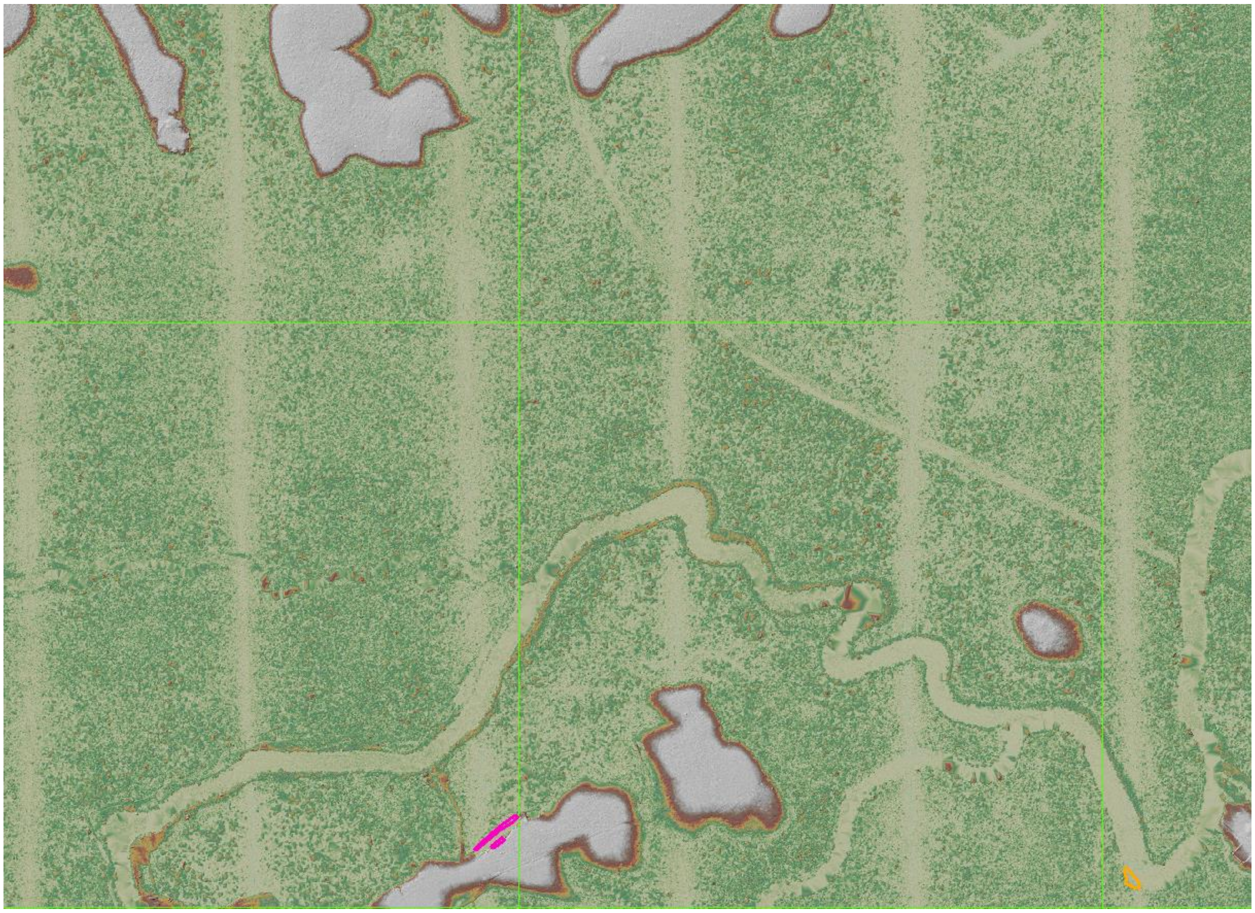
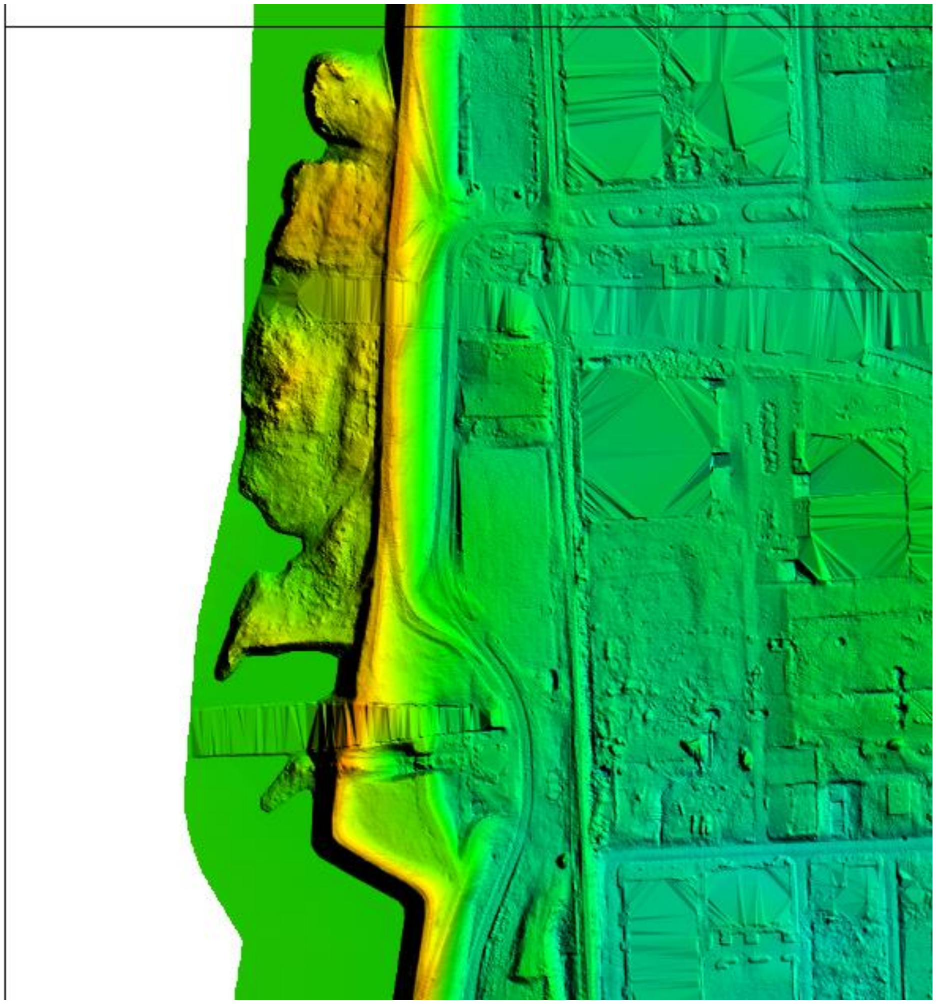


Figure 23 - Tile numbers 15RYP2052, 15RYP1852, 15RYP1854, and 15RYP1854. The DEM shows strips of minimally depressed NIR data, following a north-south direction. These strips are a characteristic of the NIR wavelength in saturated soils in marshy areas, and do not negatively impact the overall usability of the data.

High Water

At the time of lidar acquisition, the water level of the Mississippi River was extremely high and exceeded normal water levels. As a result, there are many buildings, structures, and roads along the shoreline which were flooded. Because these features would not normally be hydro-flattened, Dewberry collected the river around these features, where they could be discerned, so they would not be hydro-flattened in these bare earth DEMs either. The exclusion of the flooded features from the breaklines does cause several of these areas to look like artifacts in the water. However, comparing these locations to the intensity imagery will show they are a result of not having ground points on these flooded features but that these areas should not be hydro-flattened as they are not normally part of the riverine system.



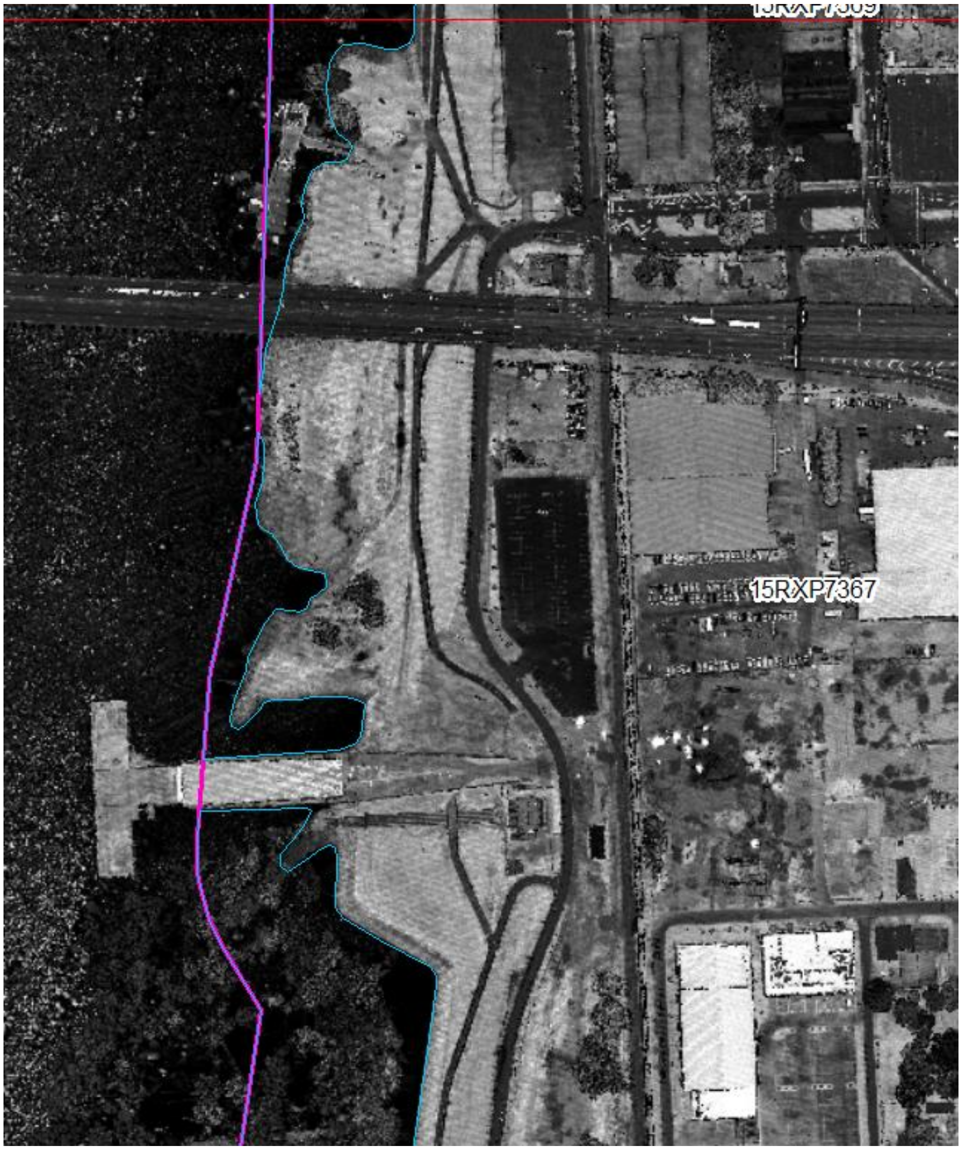
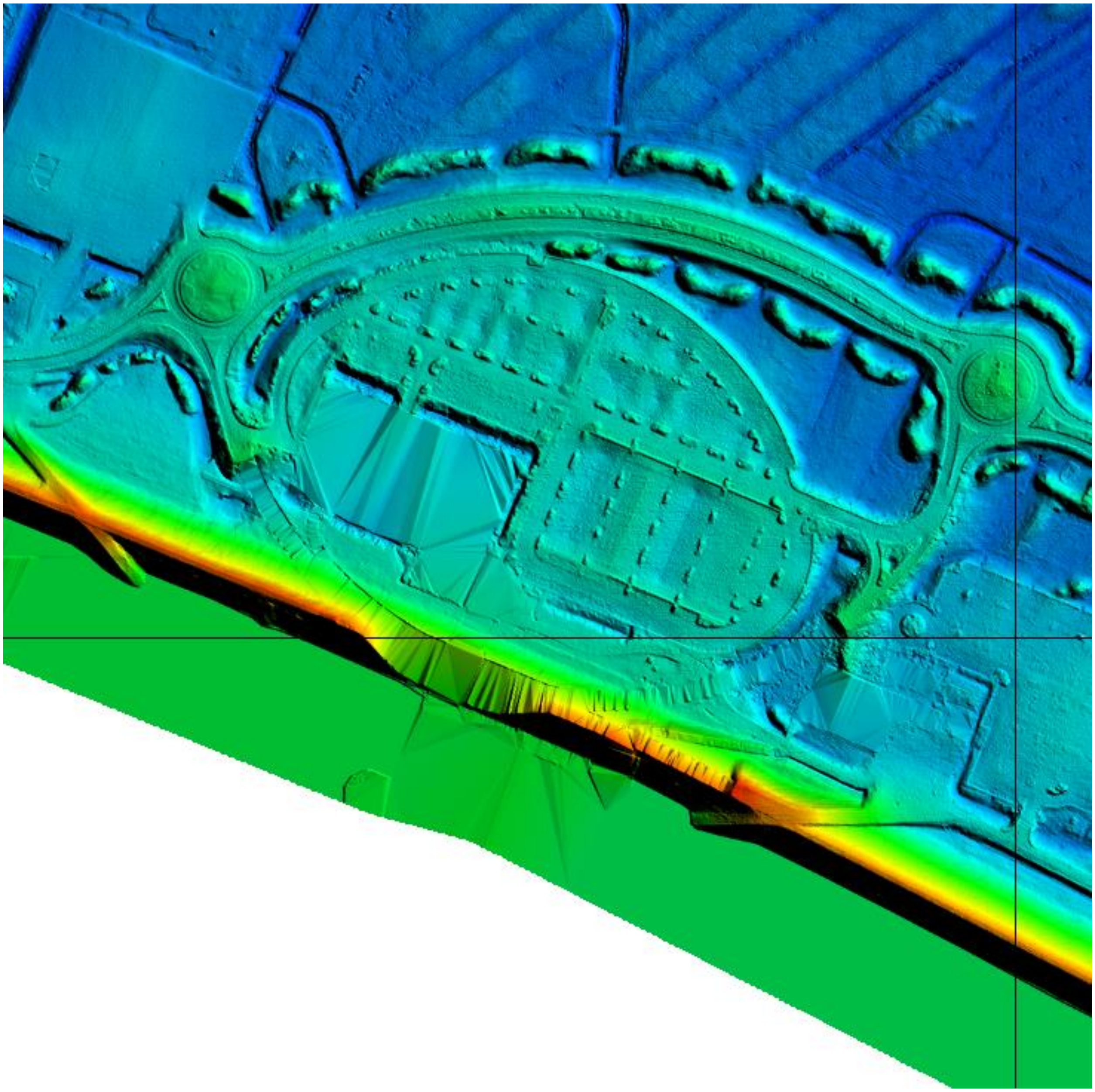

15RXP7367

Figure 24 - Tile number 15RXP7367. The DEM image on top shows what looks to be artifacts in the water, however in the intensity image and basemap imagery on the bottom, a pier can easily be seen above the water (shown in blue, with the project buffered boundary shown in pink). Given that the water elevation was so high at the time of acquisition, the water is nearly covering the pier. Since the water is abnormally high here, the decision was made to leave the remaining ground points in the data, making it appear as if there are artifacts in the water.




15RXP7658
15RXP7657

Figure 25 - Tile numbers 15RXP7657 and 15RXP7658. The DEM image on top shows what looks to be artifacts in the water and also missing ground, however in the intensity image and basemap imagery on the bottom, a structure, along with both a beach area and grassy vegetated area, can easily be seen here. Given that the water elevation was so high at the time of acquisition, the water would be covering the structure and also the surrounding area. Since the water is abnormally high here, the river (shown in blue, with the pink being the project boundary) was drawn around the structure, and the decision was made to leave the remaining ground points in the data, making it appear as artifacts in the water.

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) UTM Zone 15, meters and NAVD88 (Geoid 12B), meters 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 8: Model Key Points 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

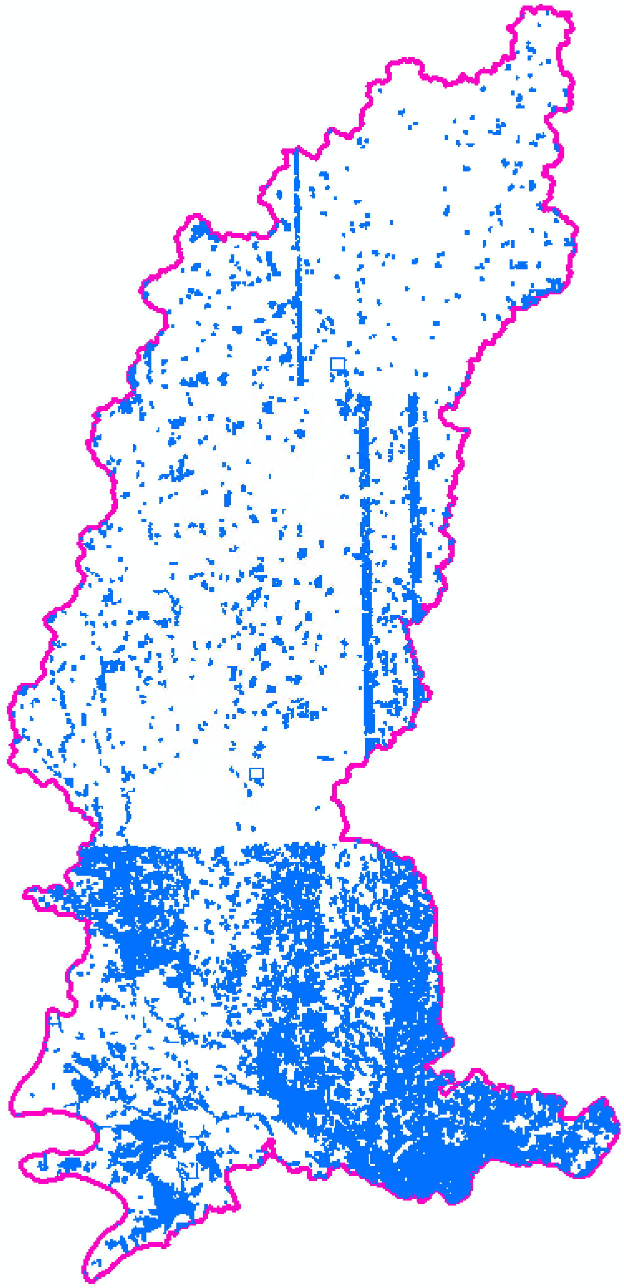
Derivative Lidar Products

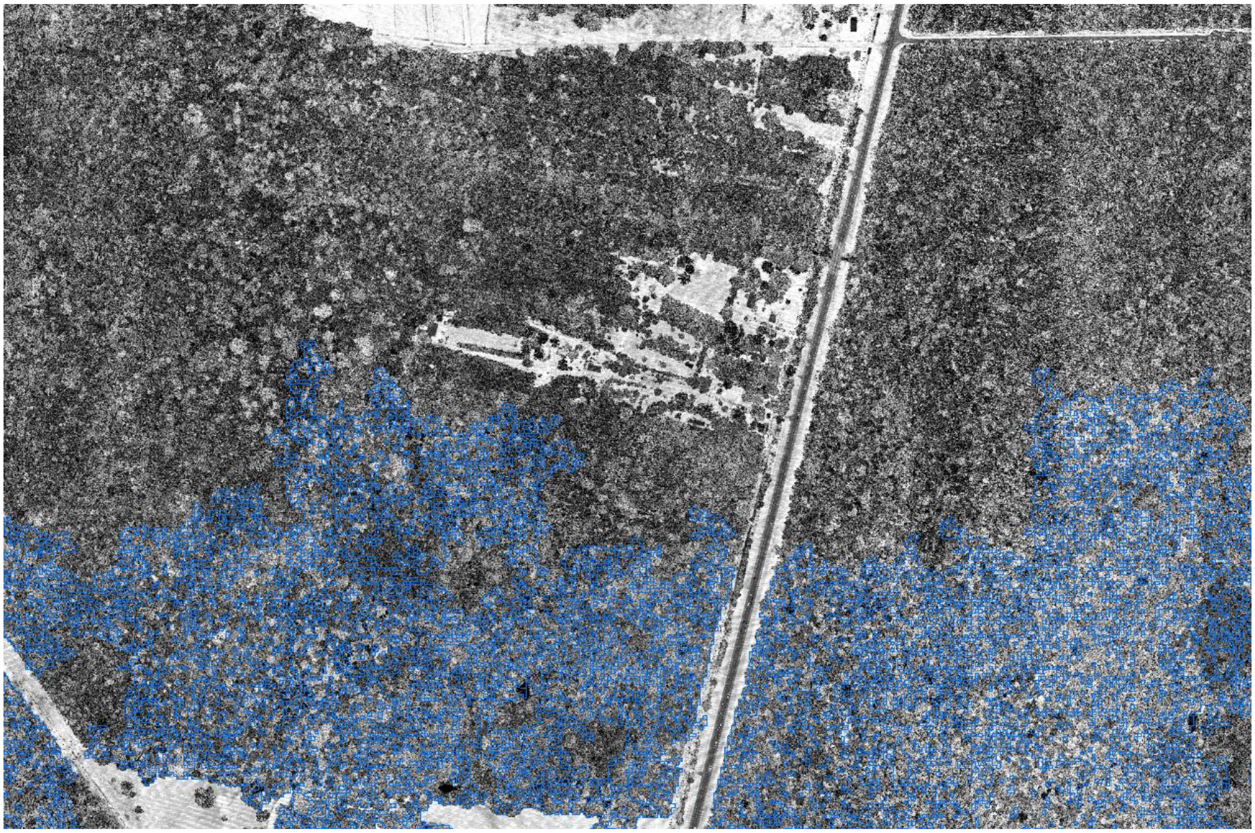
USGS required several derivative lidar products to be created. Each type of derived product is described below.

LOW CONFIDENCE POLYGONS

Low confidence polygons have been delivered with this dataset. These polygons represent areas where heavy vegetation greatly diminishes penetration of the lidar pulse, resulting in a bare earth surface that is potentially less accurate due to the lack of lidar returns from the ground beneath the vegetation. Low confidence polygons delineate areas where conformance to VVA standards may not be met. The low confidence polygons created for this dataset were delineated according to the criteria and assumptions outlined in the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014). Low confidence areas are identified using a ground density raster. All areas with a Nominal Ground Point Density less than a specified threshold are identified as low confidence cells in the ground density raster. The low confidence cells are exported to polygons and aggregated into larger shapes. Areas of expected low density in the ground, such as water or where buildings/structures have been removed, are deleted from the aggregated low confidence polygons. The size of all polygons are then calculated and polygons below the minimum size threshold are removed from the final low confidence polygon dataset.

When reviewing the low confidence polygons for the Amite dataset, there is a noticeable increase in the number and size of low confidence polygons in the southern portion of the dataset and several individual flight lines in the northern portion of the dataset, as shown in the image below. The Amite dataset was acquired March 1, 2018 thru April 12, 2018. The northern portion of the AOI was acquired first (March) whereas the southern portion and the re-flights were acquired later (April). The later flights acquired in April encountered much more vegetation and leaf-on conditions. This increase in foliage resulted in poorer lidar penetration to the ground in the southern areas and re-flights, which is reflected in the low confidence polygons.





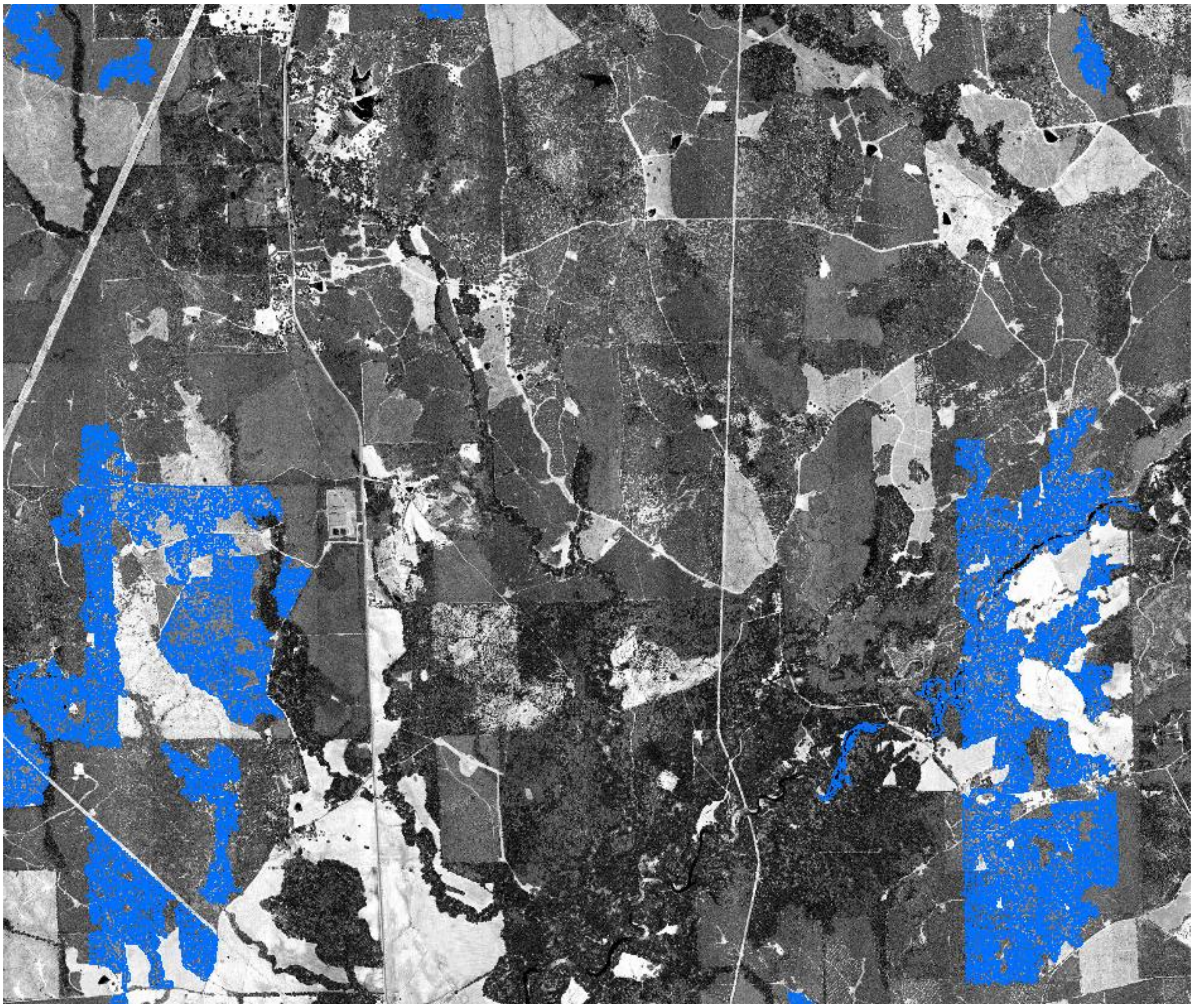


Figure 26 - The image on top shows the full AOI boundary (magenta outline) overlaid with the low confidence polygons (blue outline). More low confidence polygons are present in the southern portion of the dataset and in individual flight lines in the north (re-flights) where acquisition dates were late spring and increased foliage was present. The images on the bottom show a close-up view of the low confidence polygons overlaid on intensity imagery. The major difference in low confidence polygon generation is not due to land cover change or terrain or processing but is due to time of acquisition and increased foliage or leaf-on conditions in portions of the AOI.

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 thirty one (131) 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	Horizontal Datum/Projection		NAVD88 (Geoid 12B)	LAND COVER
	Easting X (m)	Northing Y (m)	Elevation (m)	
ENVA1	715544.136	3464237.920	126.307	
ENVA2	697923.344	3455564.010	126.333	
ENVA3	709052.106	3465512.308	131.724	
ENVA4	708053.963	3443672.199	112.413	
ENVA5	693163.427	3442996.823	86.652	
ENVA6	711533.678	3420887.866	76.451	
ENVA7	694007.079	3405482.054	45.128	
ENVA8	681950.984	3407524.262	59.824	
ENVA9	707943.048	3393466.063	33.670	
ENVA10	711489.496	3379208.277	14.608	
ENVA11	692369.415	3375628.399	16.699	
ENVA12	678762.281	3365571.378	10.623	
ENVA13	675169.990	3361487.389	6.830	
ENVA14	696593.871	3352074.451	6.429	
ENVA15	684566.656	3348050.423	4.390	

ENVA16	693239.832	3365881.151	11.877	
ENVA17	720237.587	3352135.787	2.767	
ENVA18	694799.855	3398952.104	37.440	
EVVA1	713965.880	3465047.156	129.530	
EVVA2	725941.495	3457495.235	130.593	
EVVA3	725966.384	3457587.097	133.752	
EVVA4	707398.315	3438053.712	111.758	
EVVA6	712917.450	3425359.598	64.832	
EVVA7	710415.932	3406974.133	51.523	
EVVA8	683828.411	3400413.202	38.002	
EVVA9	705775.276	3385635.187	21.673	
EVVA10	710936.359	3364396.359	3.854	
EVVA11	682676.986	3366877.989	14.832	
EVVA12	679798.248	3356293.594	6.452	
EVVA40	679798.247	3356293.594	6.445	
NVA1	714023.701	3471988.435	143.566	
NVA2	690250.345	3372881.366	13.335	
NVA3	709052.106	3465512.308	131.724	
NVA4	718095.760	3459970.772	127.240	
NVA5	728319.513	3460358.197	130.851	
NVA6	724979.137	3447797.358	125.029	
NVA7	710622.504	3449534.393	122.850	
NVA8	708712.326	3449107.772	107.098	
NVA9	712016.968	3437369.291	78.225	
NVA10	690734.116	3447382.937	93.507	
NVA11	701737.622	3439001.861	83.749	
NVA12	684049.231	3436668.714	110.616	
NVA13	698433.511	3415044.198	80.964	
NVA14	693447.660	3422944.324	79.865	
NVA15	704594.863	3425553.805	58.228	
NVA16	712610.681	3413594.539	85.658	
NVA17	687917.870	3382663.398	19.902	
NVA18	683577.674	3415456.133	76.049	
NVA19	676174.501	3403686.519	45.069	
NVA20	690241.220	3398371.464	39.071	
NVA21	702692.167	3403874.935	50.588	
NVA22	703887.245	3391913.226	28.847	
NVA23	697695.463	3387364.565	23.976	
NVA24	677485.456	3396655.883	34.668	
NVA25	688223.599	3382846.493	20.137	
NVA26	696113.124	3382307.174	17.294	
NVA27	708795.425	3384739.479	21.248	
NVA28	711649.602	3373614.512	11.018	
NVA29	696761.306	3374281.550	14.615	
NVA30	675585.860	3364361.356	6.349	
NVA31	683982.172	3374193.407	13.723	
NVA32	672638.045	3351920.231	8.172	

NVA33	688872.820	3363637.529	7.841	
NVA34	701561.726	3367273.839	10.528	
NVA35	717027.405	3365510.351	6.766	
NVA36	725411.668	3358506.262	4.265	
NVA37	701391.475	3357535.541	6.515	
NVA38	703360.230	3362318.357	5.500	
NVA39	682942.466	3358890.747	3.699	
NVA40	680958.336	3350557.269	7.132	
NVA41	700622.930	3399339.393	37.610	
NVA42	690613.858	3408896.398	64.589	
NVA43	688349.425	3430140.007	90.752	
NVA44	693624.768	3438529.970	91.755	
NVA45	716369.339	3443626.616	92.434	
NVA46	722212.148	3452945.023	124.380	
NVA47	709313.258	3459498.158	115.824	
NVA48	714886.023	3469353.870	138.589	
NVA49	725117.229	3463097.199	124.063	
NVA50	686833.421	3388449.333	25.789	
NVA51	710769.534	3357074.757	2.763	
NVA52	697599.693	3447106.437	114.913	
NVA53	689157.831	3380460.342	18.692	
NVA54	678159.127	3392299.790	30.058	
NVA55	670535.571	3358975.984	9.601	
NVA56	697015.789	3344518.408	4.312	
VVA1	711683.926	3468685.848	125.396	
VVA2	719493.540	3467603.189	135.991	
VVA3	727969.946	3466290.790	133.487	
VVA4	713115.977	3461230.174	135.544	
VVA5	708409.614	3454056.538	126.768	
VVA6	703670.002	3462383.874	133.656	
VVA7	697324.551	3444494.016	110.618	
VVA8	686786.752	3441696.393	111.627	
VVA9	700583.446	3429962.335	68.346	
VVA10	689141.360	3423989.943	92.152	
VVA11	682531.874	3418126.678	87.348	
VVA12	699852.950	3409520.561	61.643	
VVA13	707978.466	3419451.326	59.838	
VVA14	704353.818	3410249.315	59.440	
VVA15	697048.607	3409480.947	70.277	
VVA16	682903.642	3410624.122	68.162	
VVA17	711730.151	3431624.454	104.439	
VVA18	711635.138	3400817.401	51.455	
VVA19	708994.393	3397649.597	45.100	
VVA20	712832.226	3389054.927	21.243	
VVA21	695879.767	3392270.570	23.857	
VVA22	683906.916	3391434.352	27.236	
VVA23	680388.986	3387364.725	22.770	

VVA24	686224.986	3384248.044	20.404	
VVA25	691882.320	3385634.430	20.486	
VVA26	699490.483	3387672.620	24.237	
VVA27	707123.445	3379853.557	16.183	
VVA28	706490.871	3352335.793	3.888	
VVA29	681269.887	3370813.289	15.834	
VVA30	689598.100	3347863.700	2.808	
VVA31	678958.407	3361634.077	5.402	
VVA32	695837.303	3357761.475	6.991	
VVA33	686638.169	3369092.096	12.801	
VVA34	695930.390	3362749.836	6.340	
VVA35	695230.389	3370473.620	11.596	
VVA36	706508.847	3375855.537	14.731	
VVA37	706241.019	3367045.849	6.459	
VVA38	686033.975	3355663.574	4.328	
VVA39	718142.009	3357990.483	4.257	
VVA40	713065.017	3368978.865	7.971	
VVA41	702288.164	3382886.937	19.323	
VVA42	681987.201	3379136.125	16.779	
VVA43	713528.575	3383204.314	18.422	
VVA44	689748.362	3435924.057	103.796	
VVA45	705665.537	3434297.628	65.518	

Table 7: LA DOTD Amite Watershed Lidar Project surveyed accuracy checkpoints

There were six checkpoints that were removed from vertical accuracy testing because they fell outside the project boundary, and one checkpoint that was removed because no data was sent with it. Even with the removal of these seven points, there are enough total checkpoints and enough checkpoints per land cover category to satisfy project requirements. The image below shows a graphic of the checkpoints located outside the project boundary.

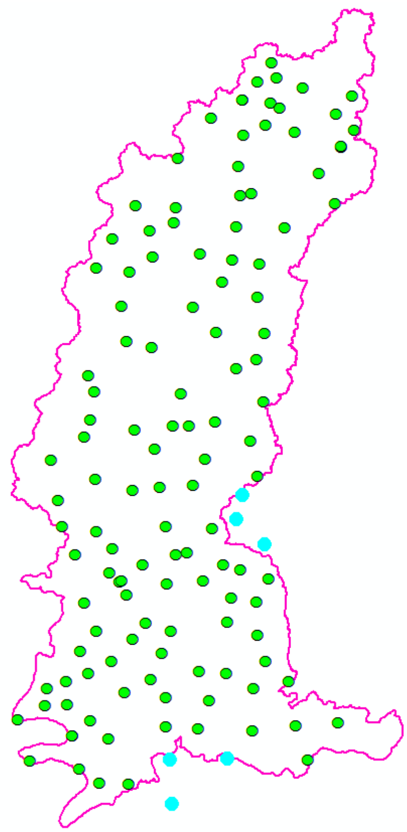


Figure 27-Image of the project area showing checkpoints. Checkpoints in green are within the project boundary, the seven checkpoints highlighted in blue are outside the Amite project boundary.

The coordinates of these seven checkpoints outside the project boundary are provided in the table below.

Point ID	NAD83(2011) UTM 15		NAVD88 (Geoid 12B)	Lidar Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
NVA56	697015.789	3344518.408	4.312	outside		
VVA20	712832.226	3389054.927	21.243	outside		
VVA28	706490.871	3352335.793	3.888	outside		
ENVA9	707943.048	3393466.063	33.670	outside		
ENVA14	696593.871	3352074.451	6.429	outside		
VVA19	708994.393	3397649.597	45.100	45.120	0.020	

Table 8: Checkpoints removed from vertical accuracy testing due to their location outside the project boundary.

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

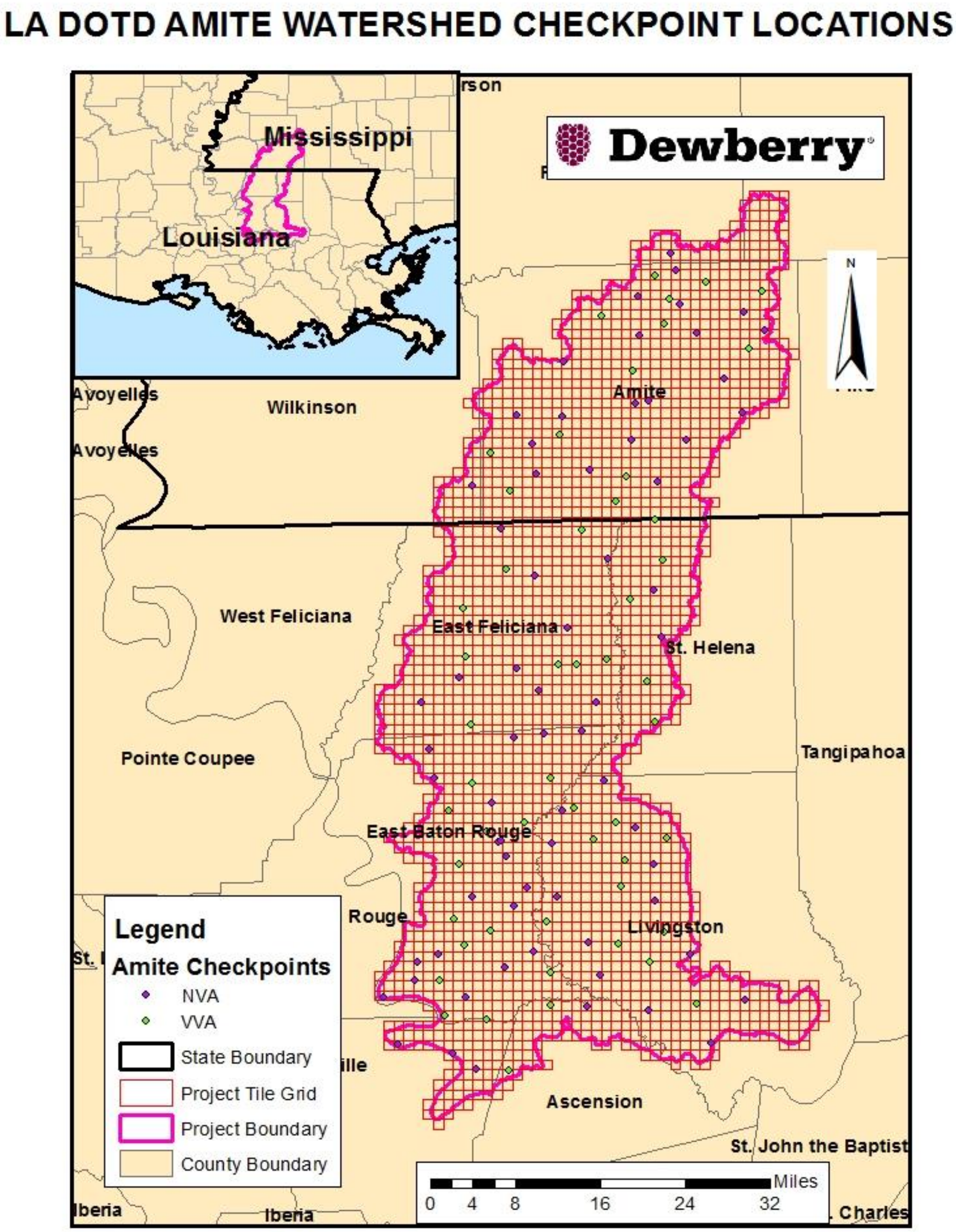


Figure 28 – Location of QA/QC Checkpoints

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 LA_DOTD Amite Watershed 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 LA_DOTD Amite Watershed Lidar Project VVA standard is 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 4.

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 9 — 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	71	0.070	
VVA	54		0.116

Table 10 – Tested NVA and VVA

This lidar 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 $RMSE_z$ =7 cm, equating to +/- 10 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 11.6 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 +/- 5 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +10 cm.

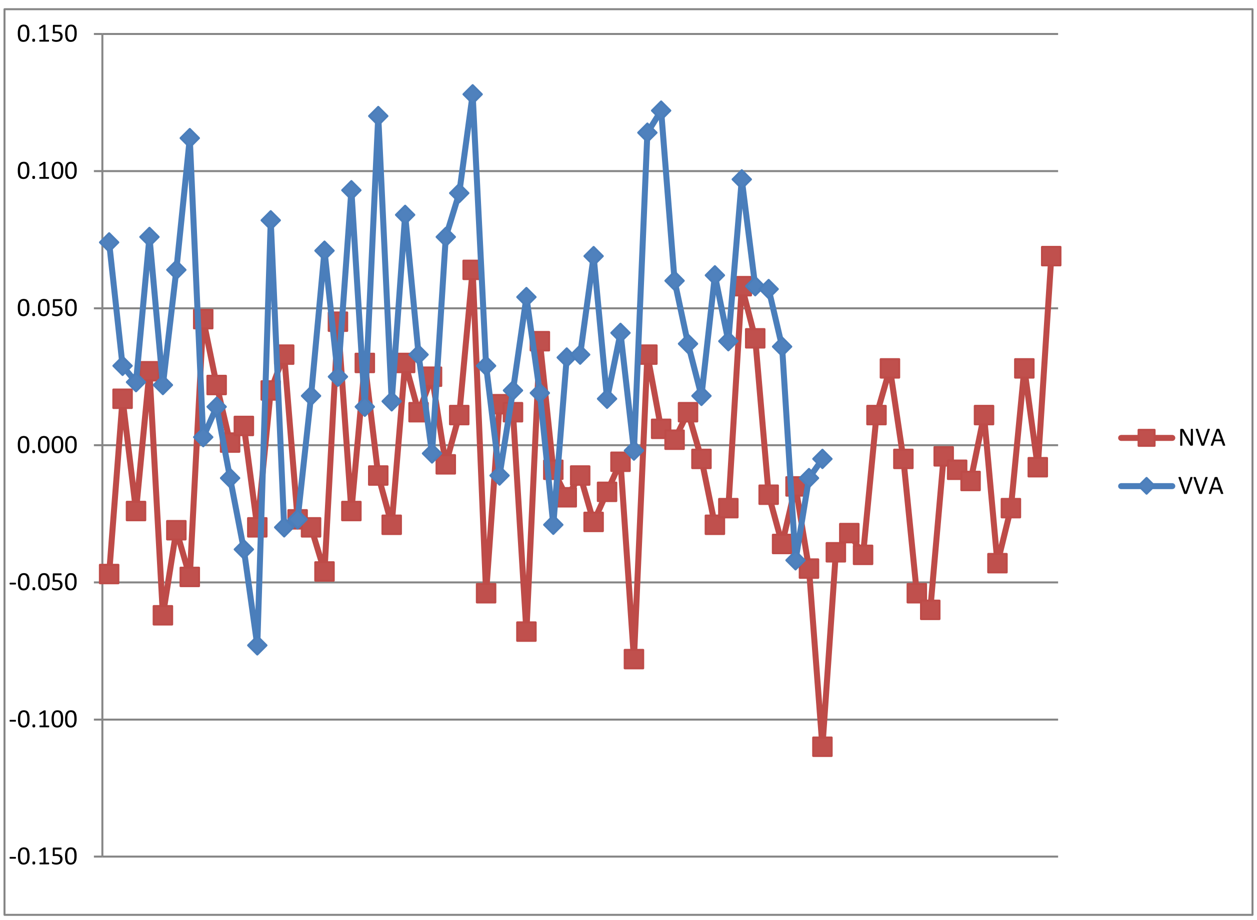


Figure 29 – Magnitude of elevation discrepancies per land cover categor

Table 6 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83(2011) UTM Zone 15		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA23	680388.986	3387364.725	22.770	22.890	0.120	0.12
VVA31	678958.407	3361634.077	5.402	5.530	0.128	0.128
VVA45	705665.537	3434297.628	65.518	65.640	0.122	0.122

Table 11 — 5% Outliers

Table 7 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	71	0.036	-0.008	-0.009	-0.138	0.035	0.056	-0.110	0.069
VVA	54	N/A	0.037	0.033	0.026	0.046	-0.380	-0.073	0.128

Table 12 — 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 -0.11 meters and a high of +0.128 meters, 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 -0.05 meters to +0.05 meters.

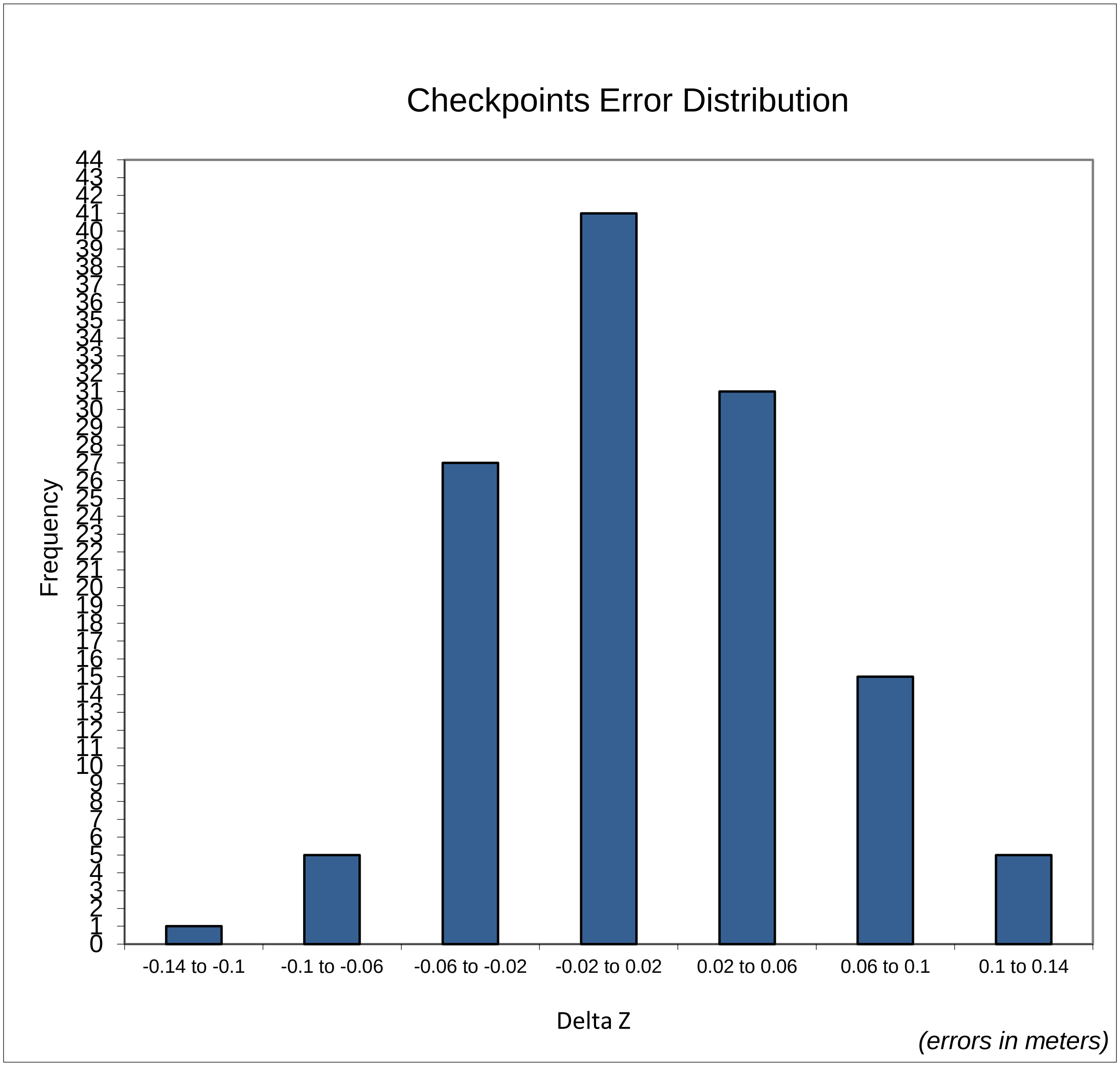


Figure 30 – Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the LA DOTD Amite Watershed 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

No checkpoints were photo-identifiable in the intensity imagery; horizontal accuracy could not be tested on this dataset.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop lidar stereo models of the project area so the lidar derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using lidargrammetry procedures with lidar intensity imagery, Dewberry used the stereo models to stereo-compile the two types of hydrographic breaklines 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.

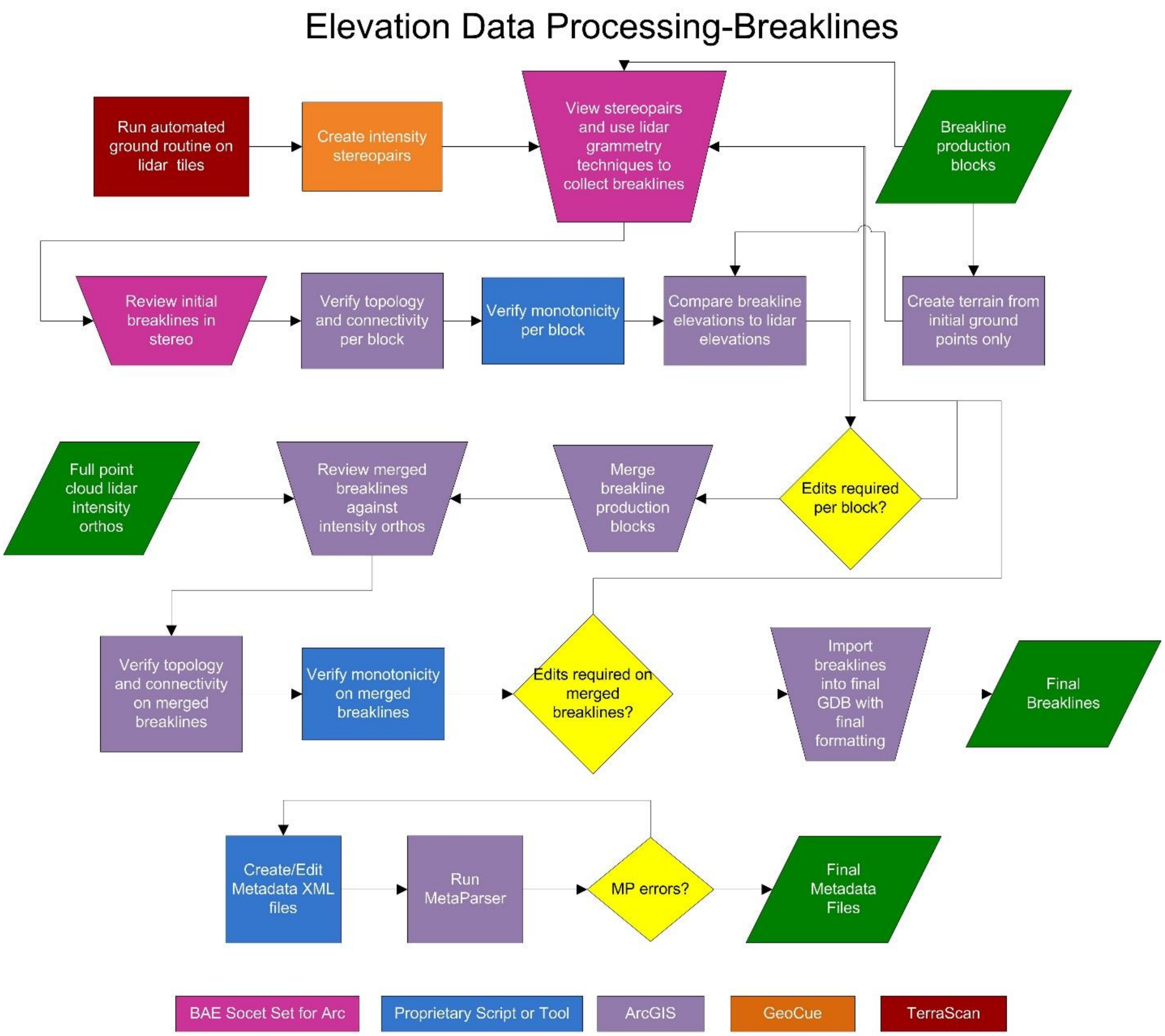


Figure 31-Breakline QA/QC workflow

Figure x-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 13-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 Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Meters. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to UTM Zone 15, Horizontal Units in Meters and Vertical Units in Meters.

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.

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

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

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

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

Figure 32-DEM Production Workflow

DEM QUALITATIVE ASSESSMENT

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

The images below show an example of a bare earth DEM.

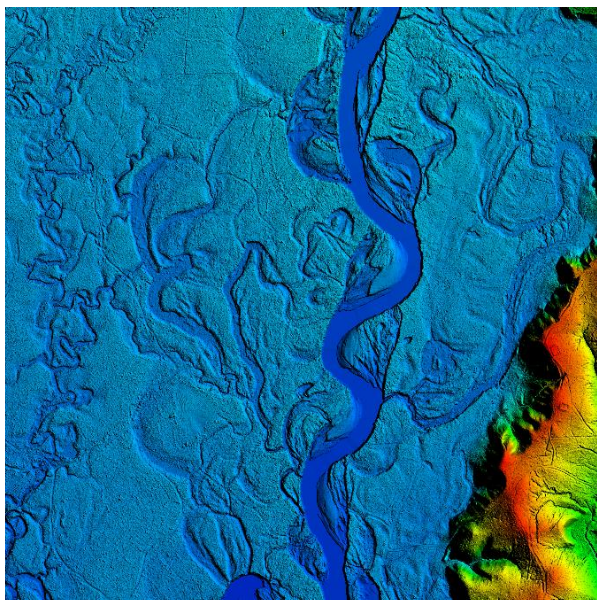


Figure 33-Tile 15RYQ0527. The bare earth DEM.

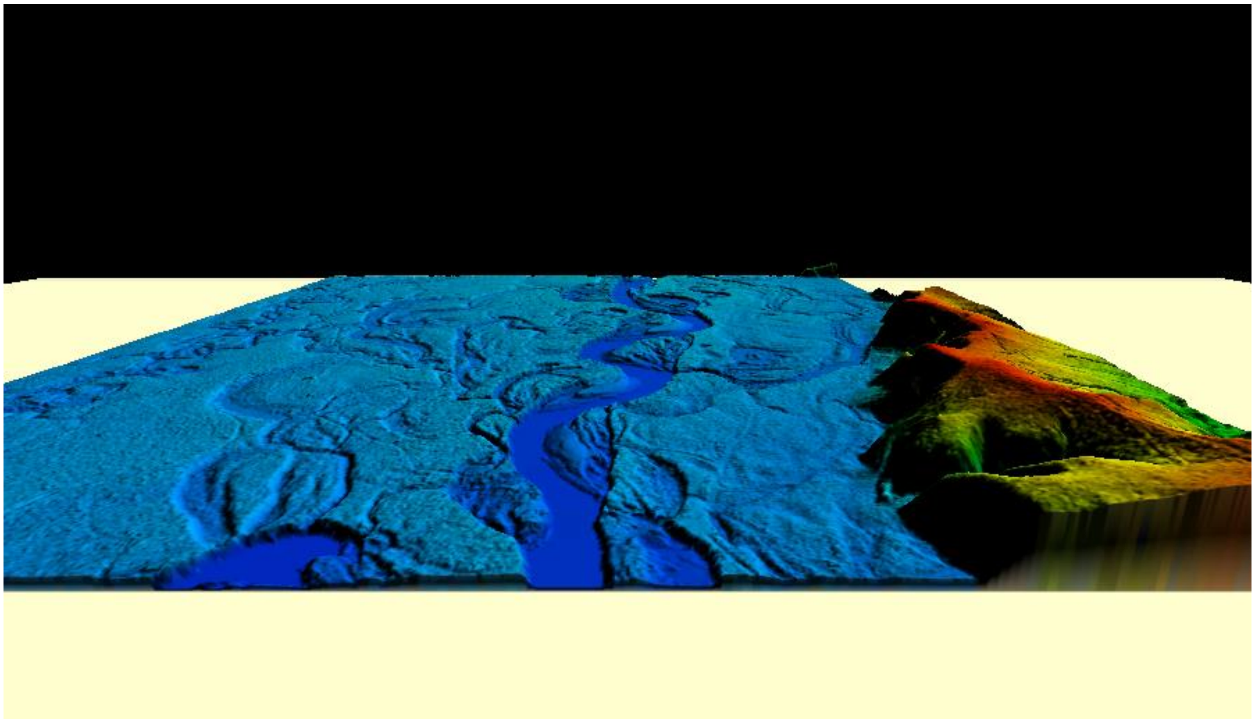


Figure 34-Tile 15RYQ0527. 3D Profile view of the bare earth DEM

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 saddle 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.

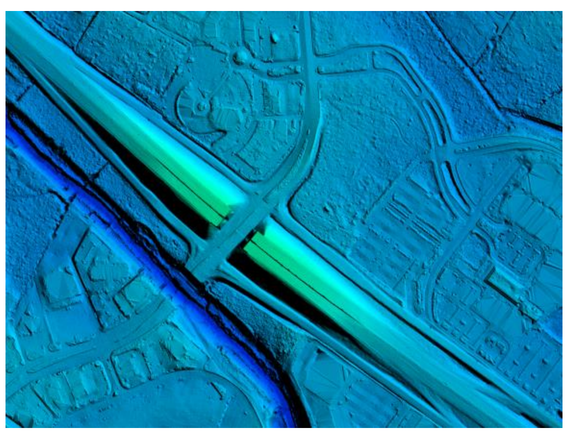


Figure 35-Tile 15RXP8263. The DEM shows the bridge after breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 131 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.

Out of the 131 checkpoints received from the surveyor, there were six checkpoints that were removed from vertical accuracy testing because they fell outside the project boundary, and one checkpoint that was removed because no data was sent with it. The coordinates for the removed checkpoints are provided below.

Point ID	NAD83(2011) UTM Zone 15		NAVD88 (Geoid 12B)	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
NVA56	697015.789	3344518.408	4.312	outside		
VVA20	712832.226	3389054.927	21.243	outside		
VVA28	706490.871	3352335.793	3.888	outside		
ENVA9	707943.048	3393466.063	33.670	outside		
ENVA14	696593.871	3352074.451	6.429	outside		
VVA19	708994.393	3397649.597	45.100	45.120	0.020	

Table 14 – Checkpoint omitted from the DEM accuracy testing.

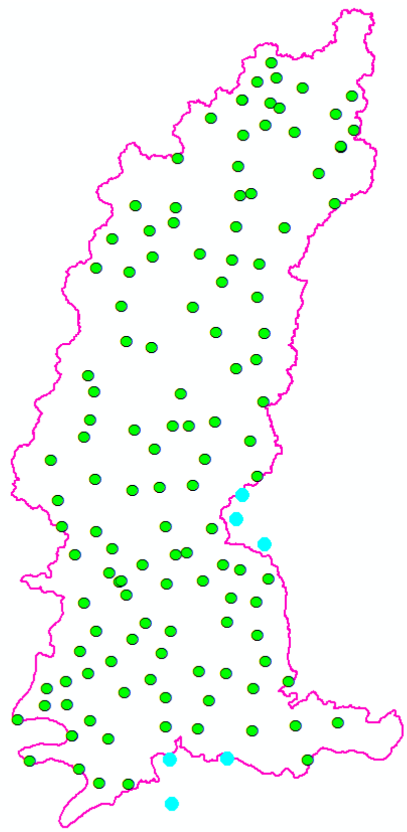


Figure 36-Image of the project area showing checkpoints. Checkpoints in green are within the project boundary, the seven checkpoints highlighted in blue are outside the Amite project boundary.

Table 9 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=19.6 cm	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	71	0.068	
VVA	54		0.108

Table 15 – 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 $RMSE_z$ =6.8 cm, equating to +/- 10 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 10.8 cm at the 95th percentile.

Table 10 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83(2011) UTM Zone 15		NAVD88 (Geoid 12B)	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
NVA38	703360.230	3362318.357	5.500	5.380	-0.120	0.12
VVA23	680388.986	3387364.725	22.770	22.902	0.132	0.132
VVA31	678958.407	3361634.077	5.402	5.523	0.121	0.12
VVA44	689748.362	3435924.057	103.796	103.908	0.112	0.112

Table 16 — 5% Outliers

Table 11 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	71	0.035	-0.008	-0.008	-0.109	0.034	0.917	-0.120	0.078
VVA	54	N/A	0.038	0.034	-0.037	0.044	-0.128	-0.076	0.132

Table 17 — Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the LA DOTD Amite Watershed 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 18-A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Appendix A: Checkpoint Survey Report

FORTE & TABLADA

Baton Rouge: Corporate Office
9107 Interline Avenue
Baton Rouge, LA 70809
T. 225.927.9321
F. 225.927.9326

May 18, 2018

Mr. Sam Crampton, P.E., CFM
Associate Vice President
Dewberry
2835 Brandywine Road, Suite 100
Atlanta, GA 30341

RE: Ryan Ligon
Amite River Basin QL1 LiDAR Project
Independent Check Points
Forte and Tablada Project #: 161605.01R

Attn: Mr. Ligon:

Transmitted herewith is the completed survey for the captioned project. This field survey is certified to have been performed within acceptable standards set forth ASPRS guidelines, has been reviewed, checked, and is considered to be correct within those guidelines. Ross A Wilson will be certifying all surveyed points in the State of Mississippi and Steve A LeBlanc will be certifying all points in Louisiana. This transmittal includes the following:

1. Excel spreadsheet of all surveyed points.
2. Field notes of all surveyed points
3. Pictures/images of all surveyed points
4. KML file of all surveyed points (Check Shots.kml)

Project Summary

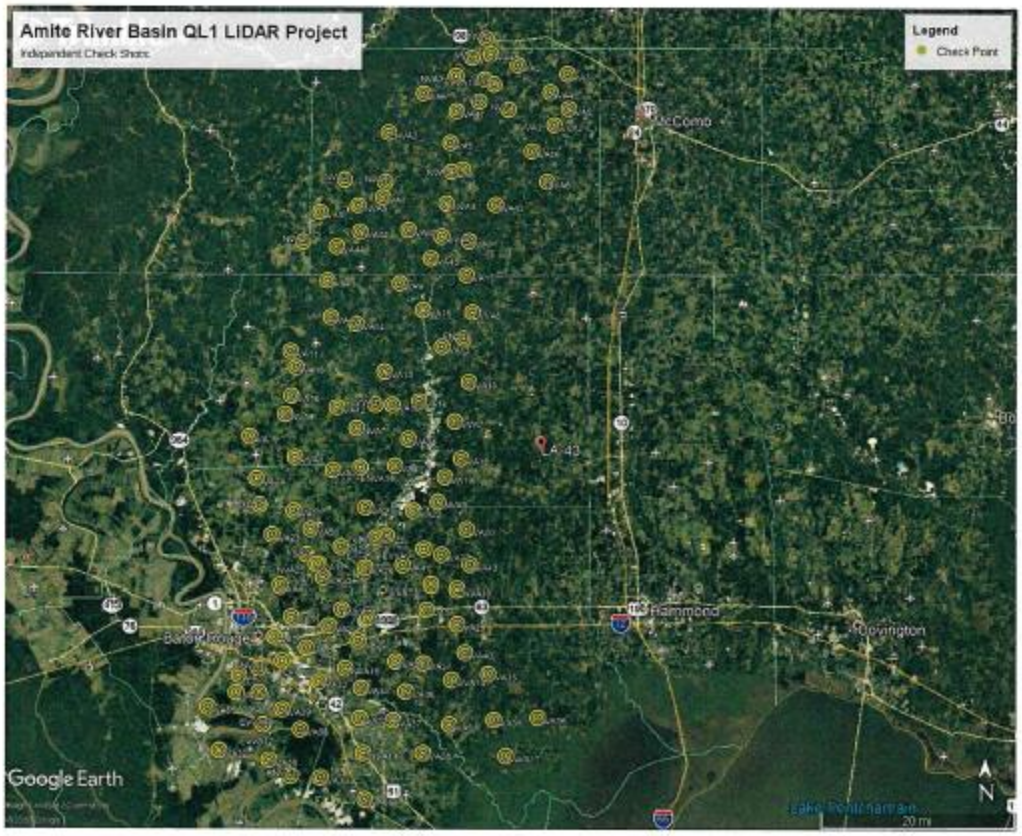
This project scope required the survey of Independent Check Points for the use to test the accuracy of the LiDAR data and derivative products. All points have been selected by Forte and Tablada and approved by Dewberry called ARB Task Order 3 (Check Shots) _revised. The collection of the data was surveyed as close to the LiDAR acquisition timeframe as possible. The timeframe in which the survey took place started on March 19, 2018 and was completed on April 20, 2018.

Point of Contact

The surveyors in charge for this project are Steve A. LeBlanc and Ross A. Wilson. Mr. Leblanc will be certifying all surveyed points in Louisiana. Mr. Wilson will be certifying all surveyed points that continued in Mississippi. Field crew supervisors in charge of gather the survey data was Madison Mills and Steven Sullivan.

Project Area

For the location of the surveyed Independent Check Shots, see (Check Shots.kml).



Survey Equipment & Network Design

The main equipment used for this project was survey grade GPS system. The GPS rover receiver used was a Trimble R-10 receiver along with a Trimble TCS3 data collector. RTN system was utilized to derive the coordinates of each surveyed point. The RTN system used was Leica Smartnet.

Survey Point Detail

Check shots were dispersed based on ASPRS guideline. Where possible, check shots were place at a locate that had relatively flat terrain. Also, points were placed at locations where LiDAR intensity-visible features. Locations the had tall vertical objects nearby were avoided or kept a minimum distance of 5 meters away from the structure.

Field Survey Procedure and Analysis

Before the Independent Check points were surveyed a check was performed on control point number 14. The origin of point 14 was provided from an ongoing LA DOTD project, State Project No. H004100.5 and was transformed to coordinated system UTM 15N. Control sketch for point 14 will be attached to deliverable. To establish an additional control point a minimum of three separate three minute (180 epochs) are taken and averaged together. To establish a check shot, one occupation of 180 epochs was observed. After the first observation initialization between the base and rover was "broken" and then re-initialized. Once regained a second occupation of 180 epochs was observed. The point was considered acceptable if both observations meet a tolerance of 0.05 cm. If the tolerance was not met a third occupation was observed and compared and the outlier was discarded. The two acceptable observations were then averaged and the check shot's coordinates were established. Elevation mask for satellites was set at 12 degrees and PDOPs were set a 6.0.

Data Processing and Quality Control Procedure

For validation of the survey data, 50% of the check shots were re-observed at different date using the same procedure. If the re-observation was not within a tolerance of 0.05 cm the check shot was observed a third time at a later date and time. Once the third observation was collected the outlier was discarded and the last observed coordinates were held and accepted.

Final Coordinates

See excel spreadsheet for coordinates. The format for the excel spreadsheet is as followed:
Easting, Northing, Elevation, Point ID, Type of Survey, Description, Date surveyed, Spatial reference, and Check shot.

FORTE & TABLADA

Baton Rouge: Corporate Office
9107 Interline Avenue
Baton Rouge, LA 70809
T. 225.927.9321
F. 225.927.9326

May 18, 2018

Mr. Sam Crampton, P.E., CFM
Associate Vice President
Dewberry
2835 Brandywine Road, Suite 100
Atlanta, GA 30341

RE: Ryan Ligon
Amite River Basin QL1 LiDAR Project
Independent Check Points
Forte and Tablada Project #: 161605.01R

Attn: Mr. Ligon:

Transmitted herewith is the completed survey for the captioned project. This field survey is certified to have been performed within acceptable standards set forth ASPRS guidelines, has been reviewed, checked, and is considered to be correct within those guidelines. Ross A Wilson will be certifying all surveyed points in the State of Mississippi and Steve A LeBlanc will be certifying all points in Louisiana. This transmittal includes the following:

1. Excel spreadsheet of all surveyed points.
2. Field notes of all surveyed points
3. Pictures/images of all surveyed points
4. KML file of all surveyed points (Check Shots.kml)

Project Summary

This project scope required the survey of Independent Check Points for the use to test the accuracy of the LiDAR data and derivative products. All points have been selected by Forte and Tablada and approved by Dewberry called ARB Task Order 3 (Check Shots) _revised. The collection of the data was surveyed as close to the LiDAR acquisition timeframe as possible. The timeframe in which the survey took place started on March 19, 2018 and was completed on April 20, 2018.

Appendix B: Ground Control Survey Report

FORTE & TABLADA

Baton Rouge: Corporate Office
9107 Interline Avenue
Baton Rouge, LA 70809
T. 225.927.9321
F. 225.927.9326

May 18, 2018

Mr. Sam Crampton, P.E., CFM
Associate Vice President
Dewberry
2835 Brandywine Road, Suite 100
Atlanta, GA 30341

Ryan Ligon
RE: Amite River Basin QL1 LiDAR Project
Acquisition Ground Control
Forte and Tablada Project #: 161605.01R

Attn: Mr. Ligon:

Transmitted herewith is the completed survey for the captioned project. This field survey is certified to have been performed within acceptable standards set forth ASPRS guidelines, has been reviewed, checked, and is considered to be correct within those guidelines. Ross A Wilson will be certifying all surveyed points in the State of Mississippi and Steve A LeBlanc will be certifying all points in Louisiana. This transmittal includes the following:

1. Excel spreadsheet of all surveyed points.
2. Field notes of all surveyed points
3. Pictures/images of all surveyed points
4. KML file of all surveyed points (Calibrated Control Points.kml)

Project Summary

This project scope required the survey of Acquisition Ground Control points for the use of LiDAR calibration. All points have been supplied by Dewberry (Amite_Control_Planned) and where surveyed as close to the LiDAR acquisition timeframe. The timeframe in which the survey took place started on March 19, 2018 and was completed on April 20, 2018.

Point of Contact

The surveyors in charge for this project are Steve A. LeBlanc and Ross A. Wilson. Mr. Leblanc will be certifying all surveyed points in Louisiana. Mr. Wilson will be certifying all surveyed points that continued in

Mississippi. Field crew supervisors in charge of gather the survey data was Madison Mills and Steven Sullivan.

Project Area

For the location of the surveyed Acquisition Ground Control Points (Calibrated Control Points), see (Calibrated Control Points.kml).

Survey Equipment & Network Design

The main equipment used for this project was survey grade GPS system. The GPS rover receiver used was a Trimble R-10 receiver along with a Trimble TCS3 data collector. RTN system was utilized to derive the coordinates of each surveyed point. The RTN system used was Leica Smartnet.

Field Survey Procedure and Analysis
Before the Calibrated Control Points (CCP) were surveyed a check was performed on control point number 14. The origin of point 14 was provided from an ongoing LA DOTD project, State Project No. H004100.5 and was transformed to coordinated system UTM 15N. Control sketch for point 14 will be attached to deliverable. To establish an additional control point a minimum of three separate three minute (180 epochs) are taken and averaged together. To establish a CCP, one occupation of 180 epochs was observed. After the first observation initialization between the base and rover was "broken" and then re-initialized. Once regained a second occupation of 180 epochs was observed. The point was considered acceptable if both observations meet a tolerance of 0.05 cm. If the tolerance was not met a third occupation was observed and compared and the outlier was discarded. The two acceptable observations were then averaged and the CCP coordinates were established. Elevation mask for satellites was set at 12 degrees and PDOPs were set a 6.0.

Data Processing and Quality Control Procedure
For validation of the survey data, 50% of the CCP were re-observed at different date using the same procedure. If the re-observation was not within a tolerance of 0.05 cm the CCP was observed a third at a later date and time. Once the third observation was collected the outlier was discarded and the last observed coordinates were held and accepted.

Final Coordinates
See excel spreadsheet for coordinates. The format for the excel spreadsheet is as followed:
Easting, Northing, Elevation, Point ID, Type of Survey, Description, Date surveyed, Spatial reference, and Check shot.

Should you have any questions or require any further assistance, please do not hesitate to contact me.

Sincerely,

STATE OF LOUISIANA
STEVE A. LeBLANC
License No. 5143
PROFESSIONAL
LAND SURVEYOR

Steve A. LeBlanc, P.L.S.

ROSS A. WILSON
LICENSED PROFESSIONAL
SURVEYOR
PS-27607
STATE OF MISSISSIPPI

Ross A. Wilson, P.S., P.L.S., R.P.L.S.

Appendix C: Complete List of Delivered Tiles

15RXP6958	15RXP7361	15RXP7596	15RXP7840	15RXP7940
15RXP6960	15RXP7363	15RXP7597	15RXP7842	15RXP7942
15RXP6961	15RXP7364	15RXP7599	15RXP7843	15RXP7943
15RXP6996	15RXP7366	15RXP7640	15RXP7845	15RXP7945
15RXP6997	15RXP7367	15RXP7642	15RXP7851	15RXP7946
15RXP6999	15RXP7369	15RXP7651	15RXP7852	15RXP7949
15RXP7051	15RXP7379	15RXP7652	15RXP7854	15RXP7951
15RXP7052	15RXP7381	15RXP7654	15RXP7855	15RXP7952
15RXP7054	15RXP7382	15RXP7657	15RXP7857	15RXP7954
15RXP7058	15RXP7384	15RXP7658	15RXP7858	15RXP7955
15RXP7060	15RXP7394	15RXP7660	15RXP7860	15RXP7957
15RXP7061	15RXP7396	15RXP7661	15RXP7861	15RXP7958
15RXP7063	15RXP7397	15RXP7663	15RXP7863	15RXP7960
15RXP7082	15RXP7399	15RXP7664	15RXP7864	15RXP7961
15RXP7096	15RXP7551	15RXP7666	15RXP7866	15RXP7963
15RXP7097	15RXP7552	15RXP7667	15RXP7867	15RXP7964
15RXP7099	15RXP7554	15RXP7669	15RXP7869	15RXP7966
15RXP7251	15RXP7558	15RXP7670	15RXP7870	15RXP7967
15RXP7252	15RXP7560	15RXP7672	15RXP7872	15RXP7969
15RXP7254	15RXP7561	15RXP7673	15RXP7873	15RXP7970
15RXP7258	15RXP7563	15RXP7675	15RXP7875	15RXP7972
15RXP7260	15RXP7564	15RXP7676	15RXP7876	15RXP7973
15RXP7261	15RXP7566	15RXP7678	15RXP7878	15RXP7975
15RXP7263	15RXP7567	15RXP7679	15RXP7879	15RXP7976
15RXP7264	15RXP7569	15RXP7681	15RXP7881	15RXP7978
15RXP7266	15RXP7570	15RXP7682	15RXP7882	15RXP7979
15RXP7281	15RXP7572	15RXP7684	15RXP7884	15RXP7981
15RXP7282	15RXP7573	15RXP7685	15RXP7885	15RXP7982
15RXP7294	15RXP7575	15RXP7687	15RXP7887	15RXP7984
15RXP7296	15RXP7579	15RXP7688	15RXP7888	15RXP7985
15RXP7297	15RXP7581	15RXP7691	15RXP7890	15RXP7987
15RXP7299	15RXP7582	15RXP7693	15RXP7891	15RXP7988
15RXP7351	15RXP7584	15RXP7694	15RXP7893	15RXP7990
15RXP7352	15RXP7585	15RXP7696	15RXP7894	15RXP7991
15RXP7354	15RXP7591	15RXP7697	15RXP7896	15RXP7993
15RXP7358	15RXP7593	15RXP7699	15RXP7897	15RXP7994
15RXP7360	15RXP7594	15RXP7839	15RXP7899	15RXP7996

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