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TX-Red River Atascosa Lidar

Report Produced for U.S. Geological Survey

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Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (lidar) technology for the USGS FEMA VI Red River, Texas 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 6731 tiles were produced for the project encompassing an area of approximately 5329 sq. miles.

THE PROJECT TEAM

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

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

Airborne Imaging, Inc completed lidar data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report falls within the Texas counties of Atascosa, Frio, Live Oak, Gillespie, Kimble, and Kerr.

DATE OF SURVEY

The lidar aerial acquisition was conducted from January 4, 2018 thru January 22, 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 14

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 FEMA VI – TX Red River Atascosa Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **5.9 cm** compared with the 10 cm specification; and the NVA of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to **11.6 cm**, compared with the 19.6 cm specification.

For the FEMA VI – TX Red River Atascosa Lidar Project, the tested VVA of the classified lidar data computed using the 95^{th} percentile was equal to **12.3 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

Six thousand seven hundred thirty one (6731) tiles were delivered for the project. Each tile's extent is 1,500 meters by 1,500 meters (see Appendix B for a complete listing of delivered tiles).

USGS FEMA VI - TX Red River Atascosa Lidar Project

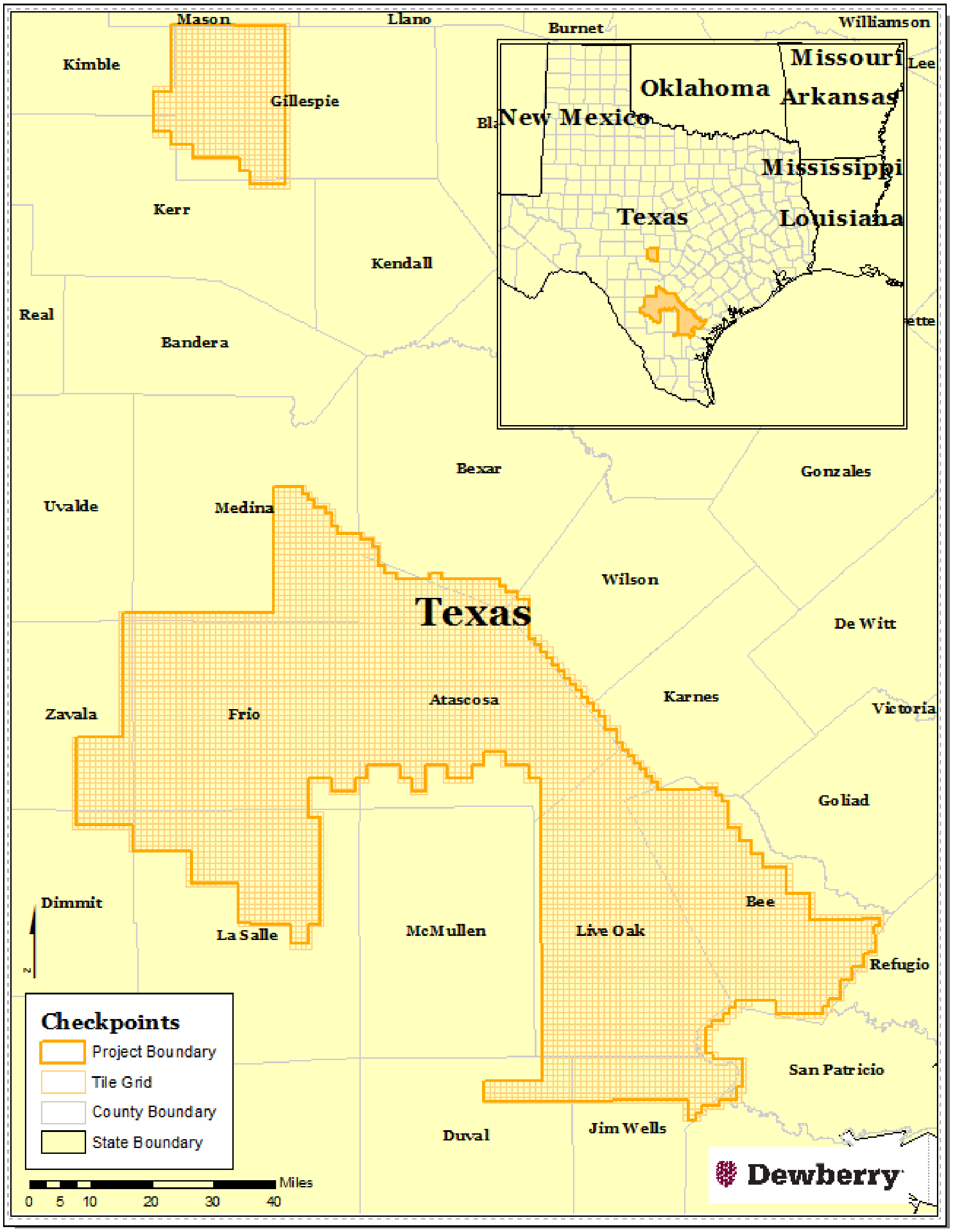

Figure 1 - Project Map

Lidar Acquisition Report

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

Dewberry received calibrated swath data from Airborne Imaging Inc. on March 13, 2018.

LIDAR ACQUISITION DETAILS

Airborne Imaging Inc. planned 178 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, Airborne Imaging Inc. 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, Airborne Imaging Inc. will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Airborne Imaging Inc. 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. Airborne Imaging Inc. 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, Airborne Imaging Inc. 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.

Airborne Imaging Inc. lidar sensors are calibrated at a designated site located at Red Deer, Alberta, Canada or St. Hubert, Quebec, Canada and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Airborne Imaging Inc. operated a Piper PA-31 Navajo (Tail # C-FFRY, and #N-44RL) outfitted with a Riegl Q-1560 lidar system during the collection of the study area. Table 1 illustrates Airborne Imaging Inc. system parameters for lidar acquisition on this project.

Item	Parameter
System	Riegl LMS-Q1560
Altitude (AGL meters)	2100
Approx. Flight Speed (knots)	160
Scanner Pulse Rate (kHz)	800
Scan Frequency (hz)	187
Pulse Duration of the Scanner (nanoseconds)	3
Pulse Width of the Scanner (m)	0.9
Swath width (m)	2425
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	0.25
Nominal Swath Width on the Ground (m)	2353
Swath Overlap (%)	30
Total Sensor Scan Angle (degree)	60
Computed Down Track spacing (m) per beam	0.85
Computed Cross Track Spacing (m) per beam	0.85
Nominal Pulse Spacing (single swath), (m)	0.63
Nominal Pulse Density (single swath) (ppsm), (m)	2.5
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.7
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2
Maximum Number of Returns per Pulse	4

Table 1: Airborne Imaging Inc. 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.

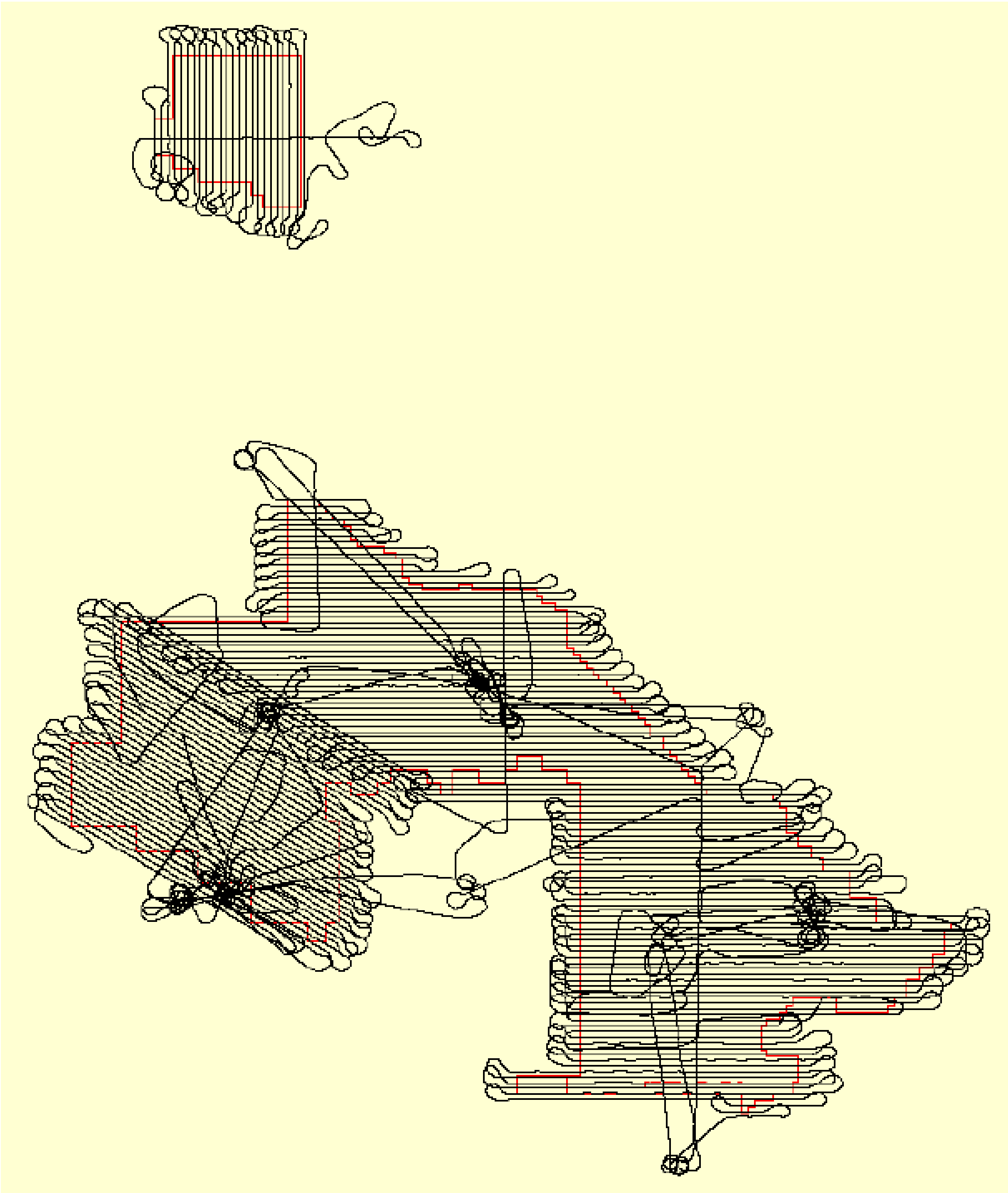

Figure 2: Trajectories as flown by Airborne Imaging Inc.

LIDAR CONTROL

Nineteen existing NGS monuments, seven Continuous Operating Reference Stations (CORS), and seven newly established base stations (B122, and B153-B158) were used to control the LiDAR acquisition for the Atascosa 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 14		Ellipsoid Ht (NAD83(2011), m)	Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)		
8T6A	586247.055	3138133.872	12.298	38.644
AO0192	487035.450	3182338.222	133.032	157.543
AO0257	478627.208	3147449.378	114.584	139.430
AO0849	587757.659	3134418.615	19.335	45.711
AY2106	505637.460	3223306.628	185.846	209.979
B122	527171.686	3192221.368	131.688	156.701
B153	481687.807	3173196.165	138.626	163.184
B154	478663.938	3147516.781	115.159	140.004
B155	492137.580	3222744.909	199.530	223.341
B156	546896.633	3203094.142	100.266	125.511
B157	579873.053	3153689.195	20.252	46.462
B158	618060.155	3138539.313	54.979	81.819
TXAI	588957.035	3073046.951	44.012	70.322
TXBE	623849.538	3144786.745	49.433	76.370
TXCT	476046.481	3146200.169	112.660	137.492
TXKC	606852.961	3194506.237	111.252	137.737
TXPL	550723.919	3206105.524	95.775	121.060
TXPS	492005.048	3195663.213	176.672	201.016
TXTI	542653.669	3149127.155	59.257	84.960

Table 2 – Base stations used to control lidar acquisition

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the Applanix POSPac MMS software suite and Novatel's GrafNav software. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 45 km.

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

Please see Appendix C for the separate GPS processing reports for each mission.

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

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

Subsequently the mission points are output using Riegl's RiProcess, initially with default values from the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the lidar unit is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

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

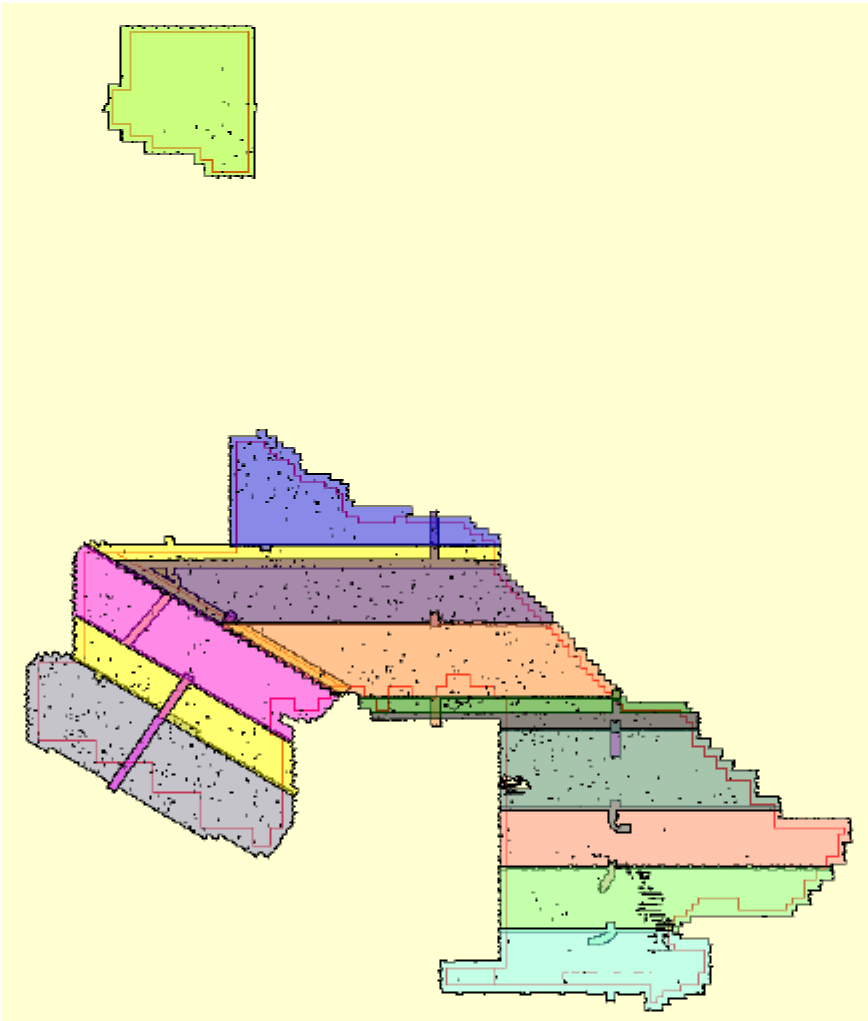

Figure 3 – Lidar swath output showing complete coverage.

BORESIGHT AND RELATIVE ACCURACY

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

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

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

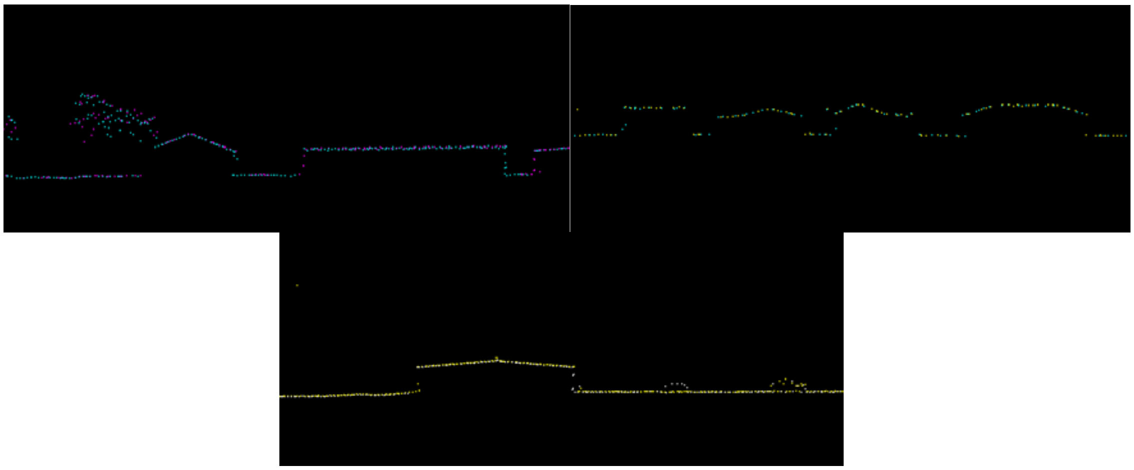

Figure 4 – Profile views showing correct roll and pitch adjustments.

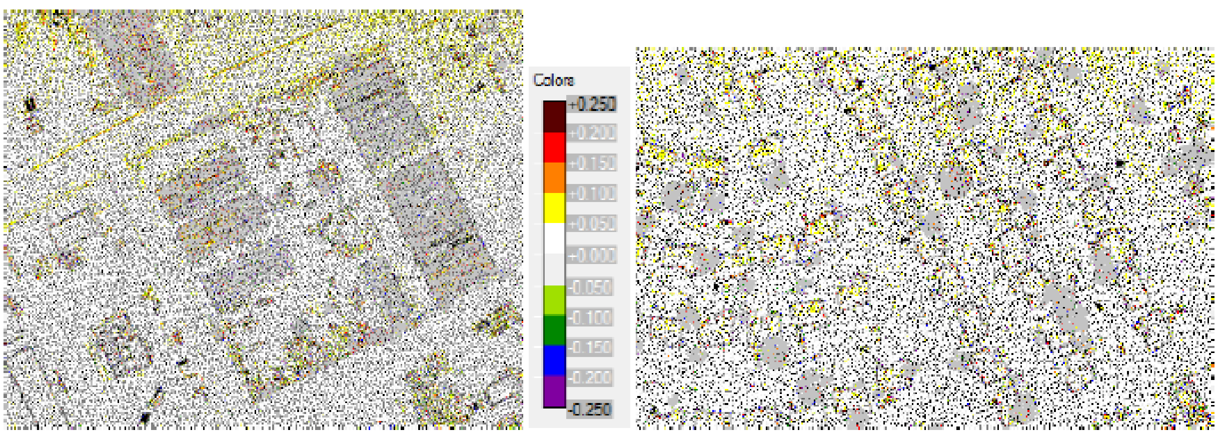

Figure 5 – QC block colored by distance to ensure accuracy at swath edges.

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

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check is performed by Airborne Imaging Inc. 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 Atascosa lidar dataset was tested to 0.096 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.0718 m x 1.9600) when compared to over 16,000 GNSS kinematic check points.

The following are the final statistics for the GNSS kinematic checkpoints used by Airborne Imaging Inc. to internally verify vertical accuracy.

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	16442	0.073	0.143	-0.024	0.049	-0.125	0.085

Table 3 - Static GPS Vertical Accuracy Results

Overall the calibrated lidar data products collected by Airborne Imaging Inc. meet or exceed the requirements set out in the Statement of Work. The quality control requirements of Airborne Imaging Inc. 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 Airborne Imaging Inc., 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 one hundred twenty nine 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 FEMA VI-TX Red River Atascosa 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 $RMSE_z$ = 5.6 cm, equating to +/- 10.9 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	128	0.056	0.109	-0.035	-0.035	0.591	0.043	-0.134	0.151	1.813

Table 4: NVA at 95% Confidence Level for Raw Swaths

Inter-Swath (Between Swath) Relative Accuracy

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

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

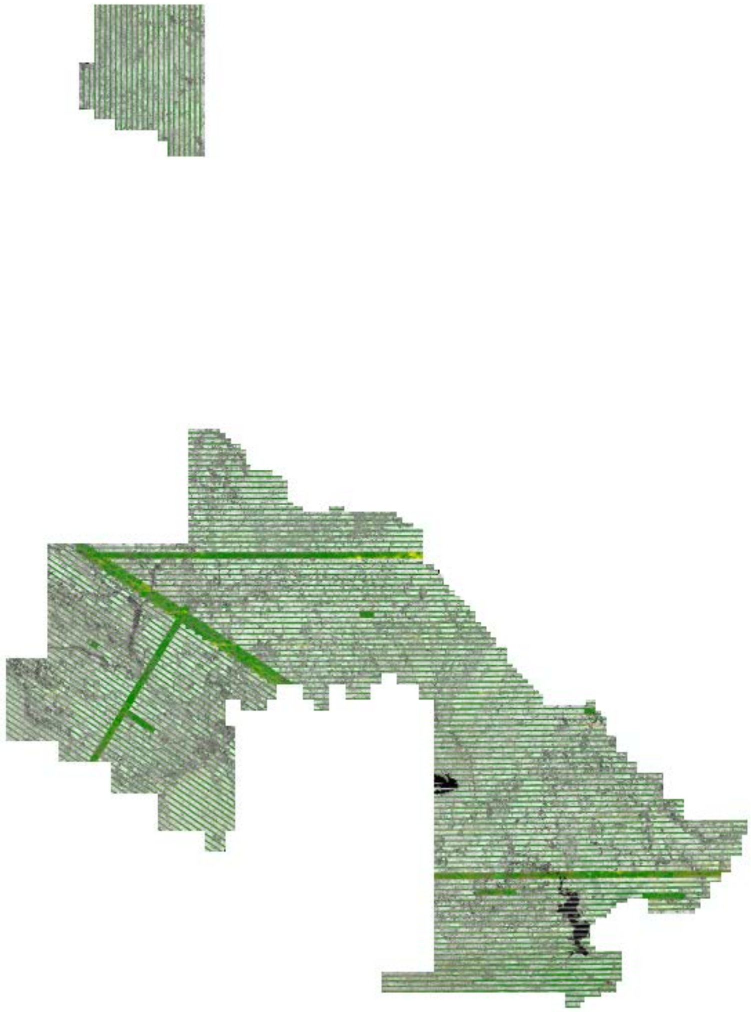

Figure 6– Single return DZ Orthos for the TX Red River Atascosa Lidar project. Inter-swath relative accuracy passes specifications.

Intra-Swath (Within a Single Swath) Relative Accuracy

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

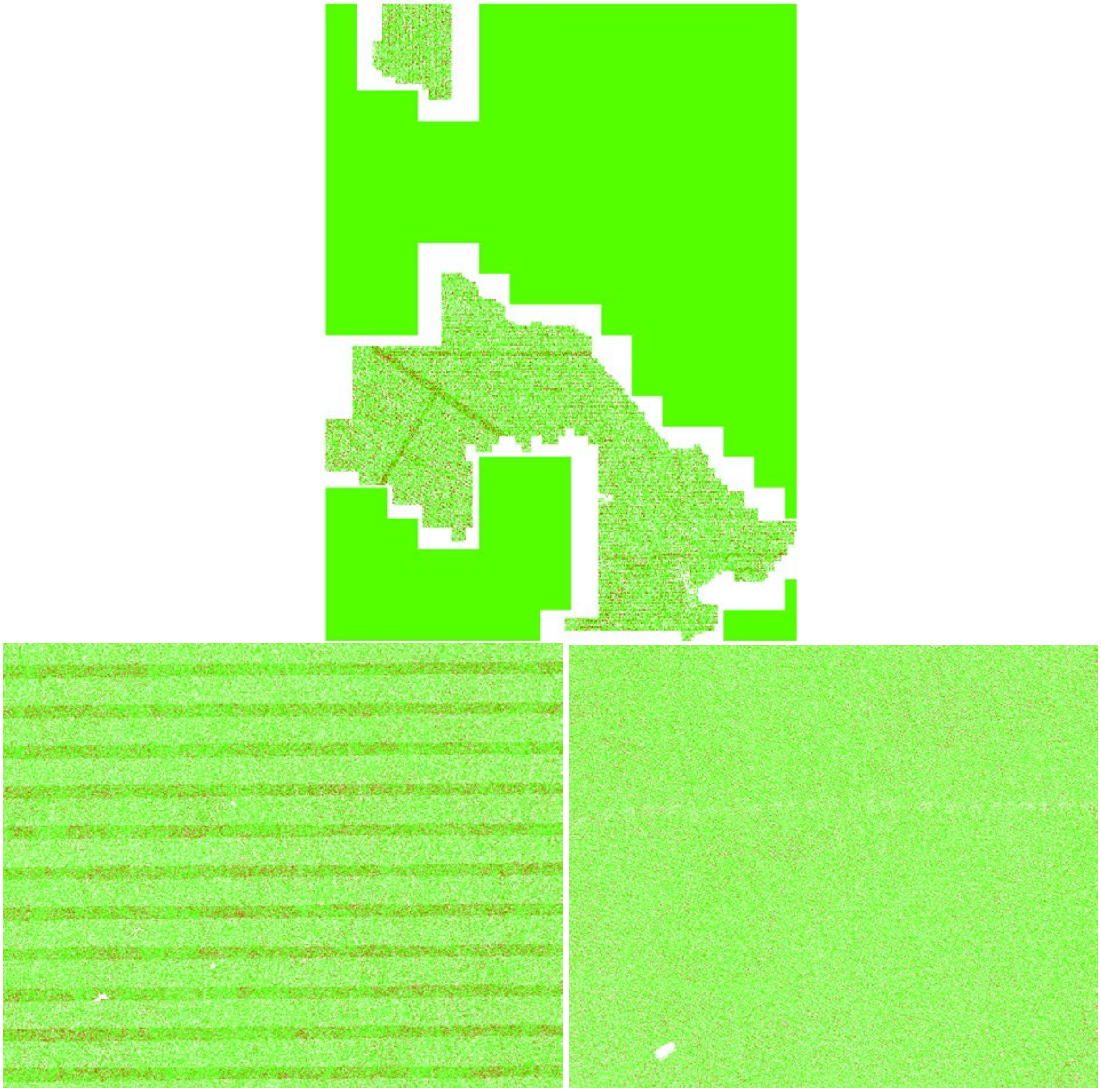

Figure 7–Intra-swath relative accuracy. The top image shows the full project area; areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The left image shows a large portion of the dataset; flat, open areas are colored green as they are within 6 cm whereas sloped terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change. The right image is a close-up of a flat area. With the exception of few trees (shown in red as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.

Horizontal Alignment

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

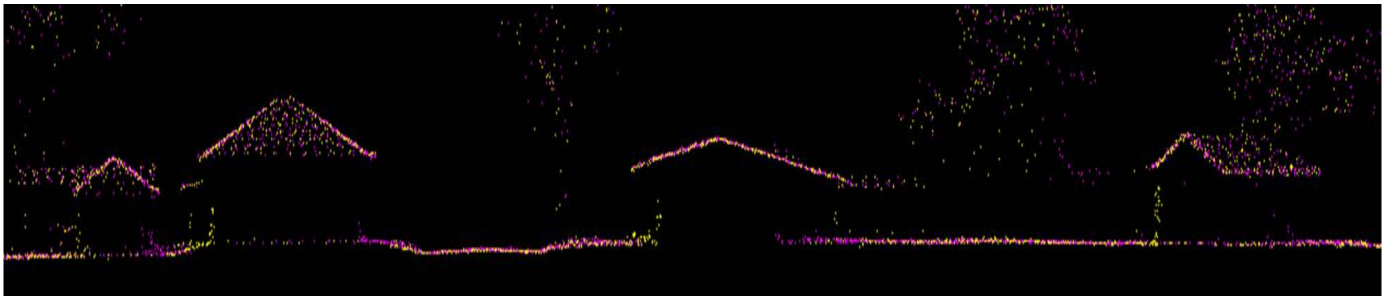

Figure 8– Horizontal Alignment. Two separate flight lines differentiated by color (Yellow/Purple) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.71 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 2 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.4 meters or an ANPD of 3.64 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.

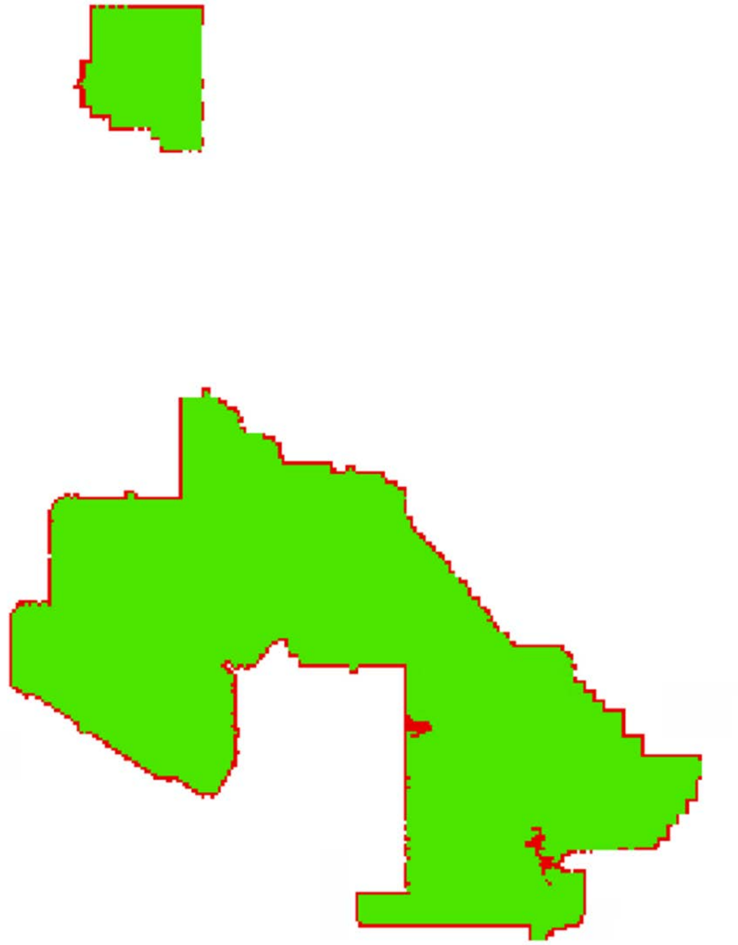

Figure 9 – 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) showing there are no systematic density issues. When density is viewed/analyzed by representative 1-square kilometer areas, density passes with no issues.

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.

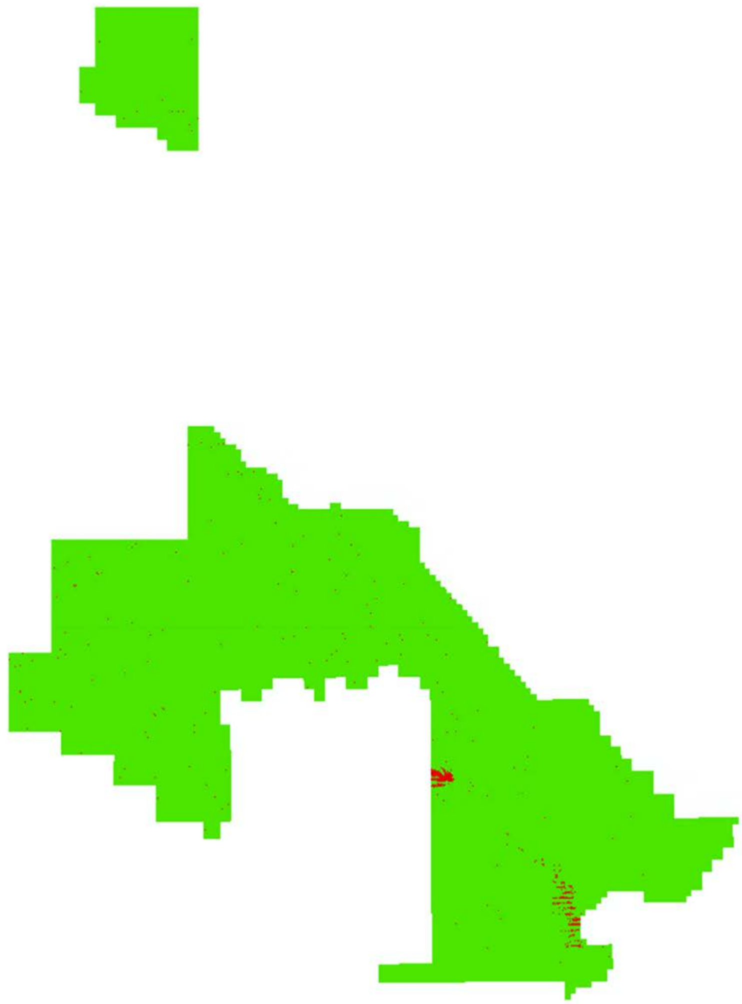

Figure 10 – Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies which are acceptable NoData area, are colored red. Without removing acceptable NoData areas due to water, 99.5% of cells contain at least one lidar point.

DATA CLASSIFICATION AND EDITING

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

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

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

The lidar tiles were classified to the following classification schema:

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

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

Lidar Qualitative Assessment

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

VISUAL REVIEW

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

Data Voids

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

Artifacts

Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

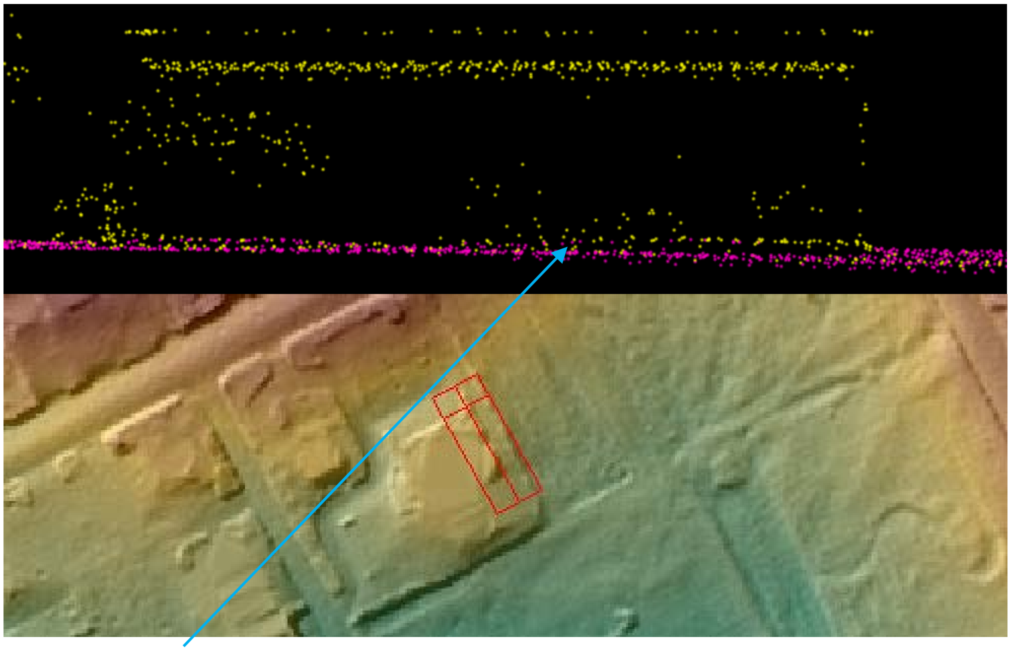

Figure 11 – Tile number 14RPS225425. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

Bridge Removal Artifacts

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

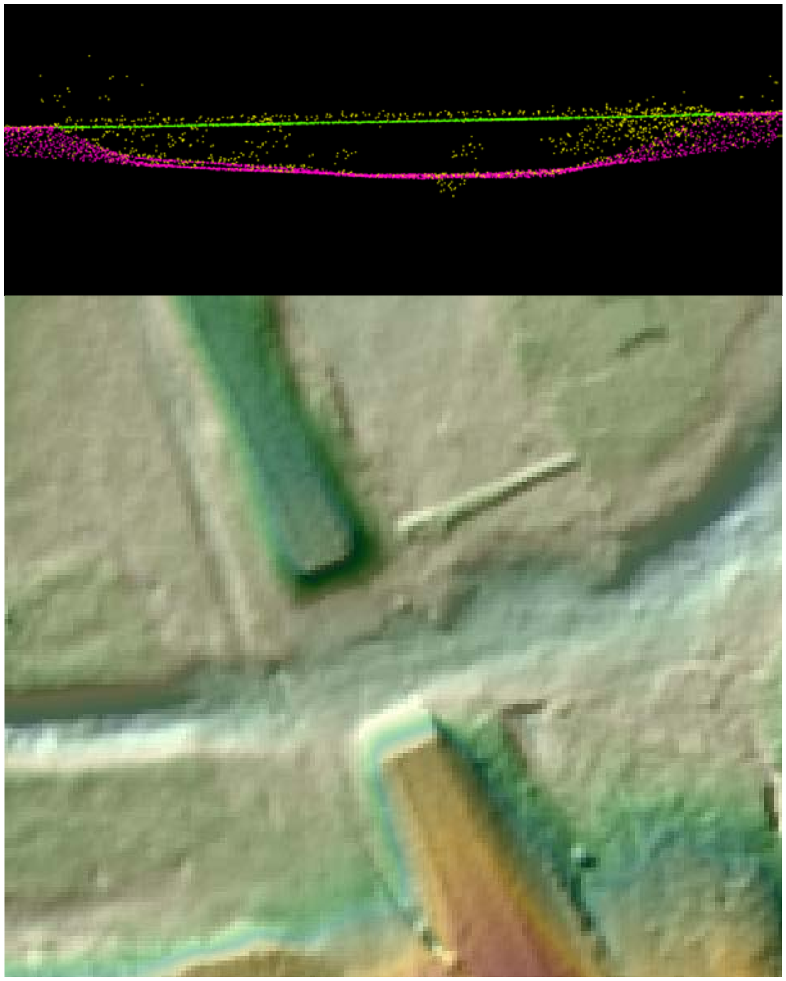

Figure 12 – Tile number 14RPS030020. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (pink) and unclassified (yellow) and are 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.

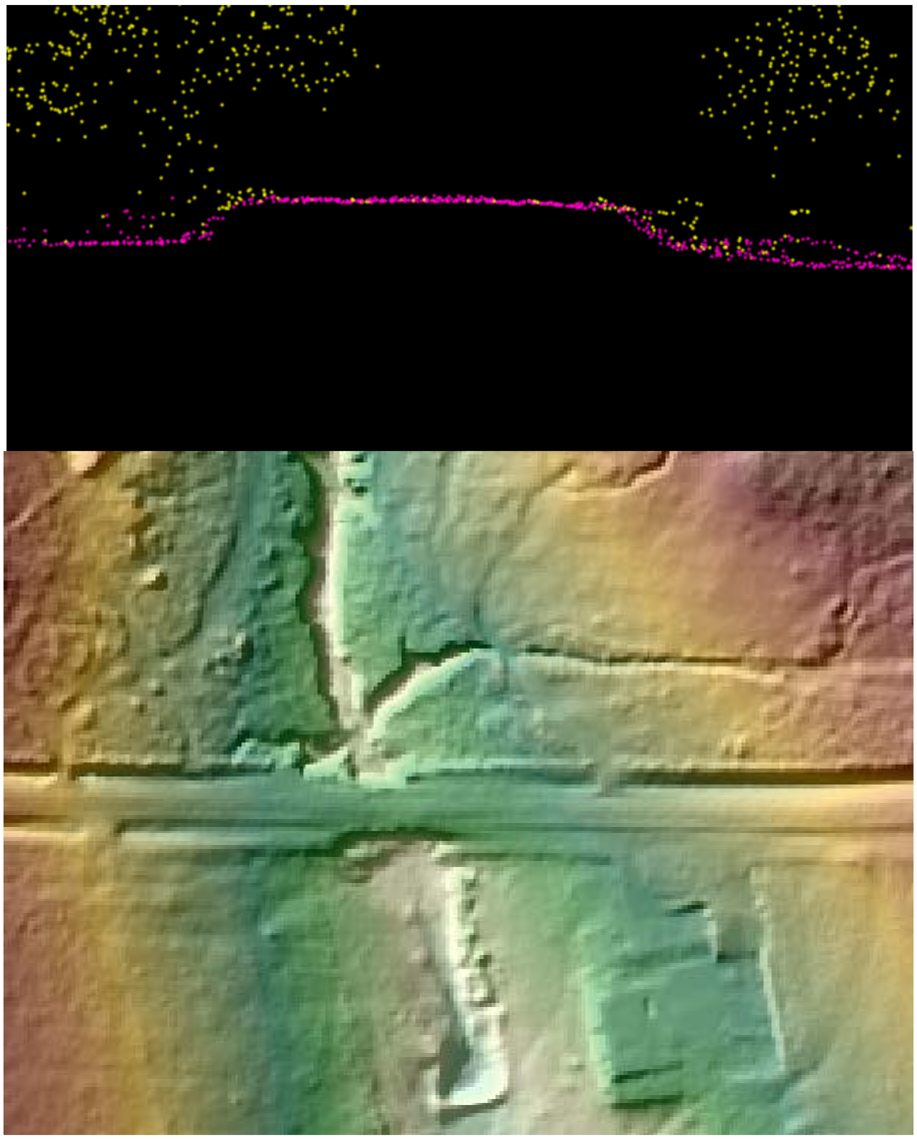

Figure 13– Tile number 14RPS030020. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

In Ground Structures

In ground structures exist within the project area. These types of structures occur mainly on military bases and in facilities designed for munitions testing and storage. These features are correctly included in the ground classification.

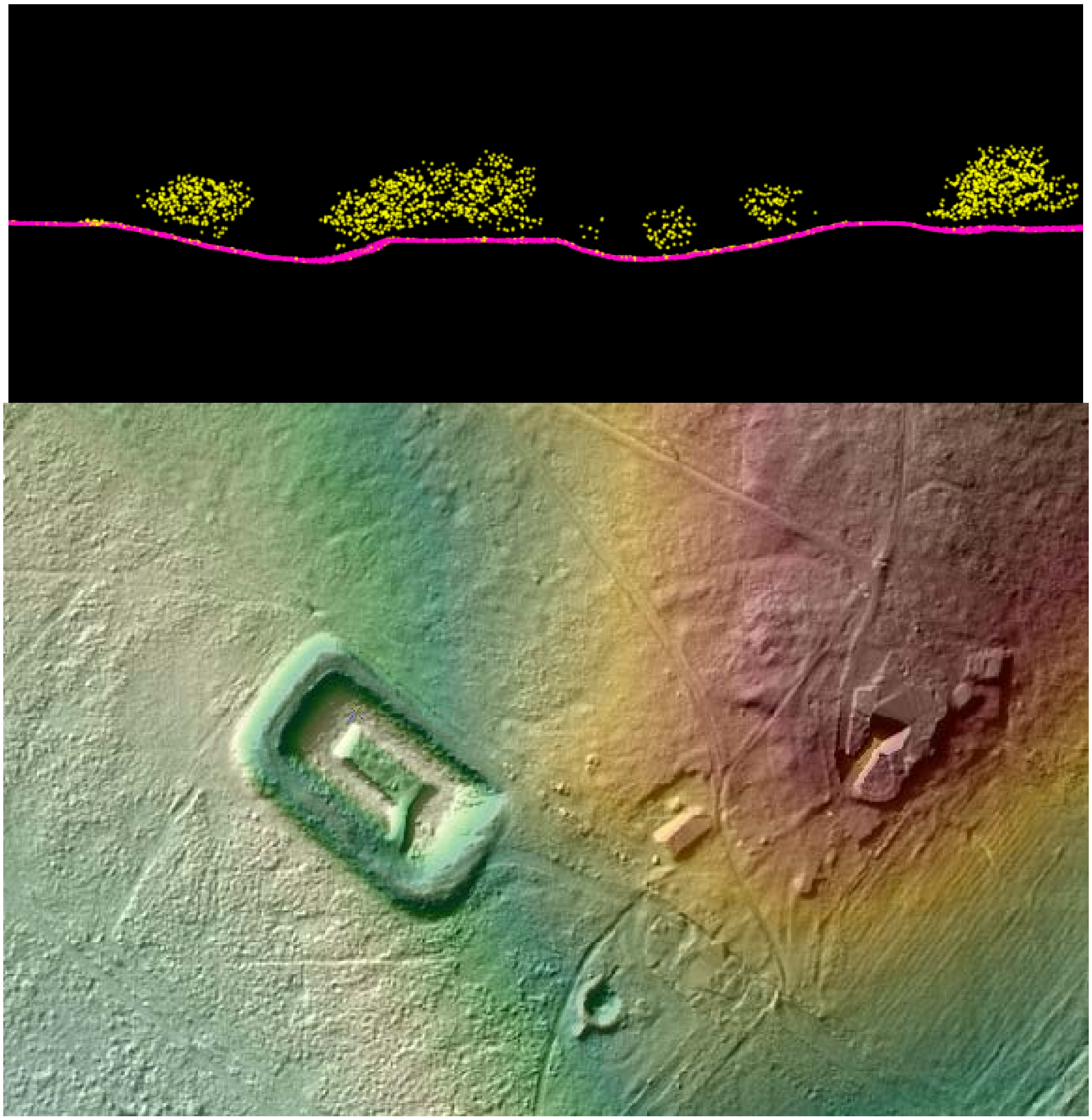

Figure 14 – Tile 14RNS970335. Profile with the points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

Dirt Mounds

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

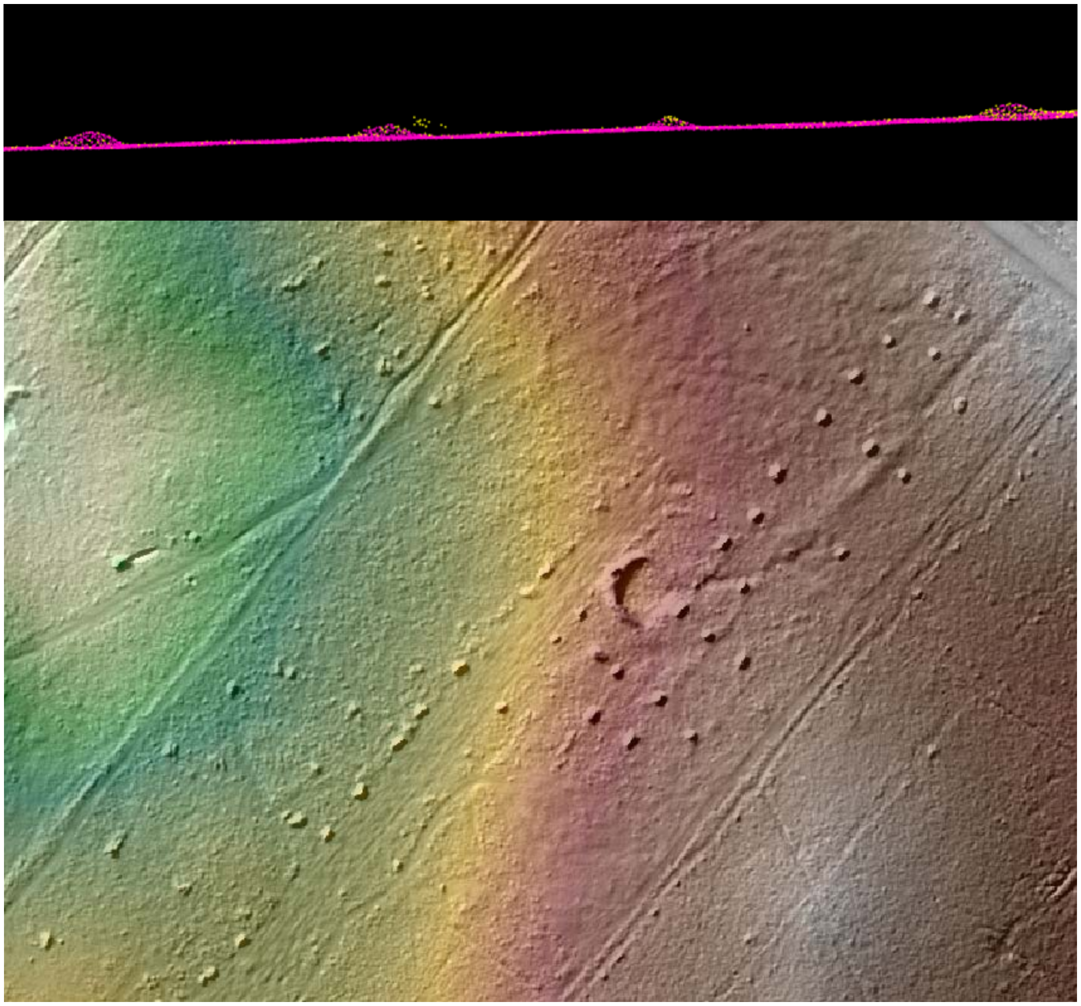

Figure 15 - Tile 14RNS985380. Profile with the points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

Marsh Areas

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

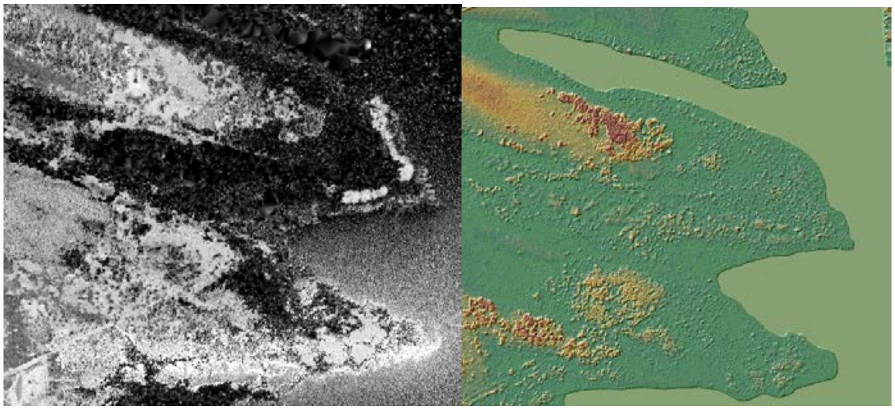

Figure 17 - Tile 14RPS045200. The intensity on the left shows a marsh area that was not included in the collected breaklines. The same area is shown in the DEM on the right. Due to wet soils and broken terrain, the point density in marsh areas is sparser than surrounding areas and there is more variation in the low points representing ground.

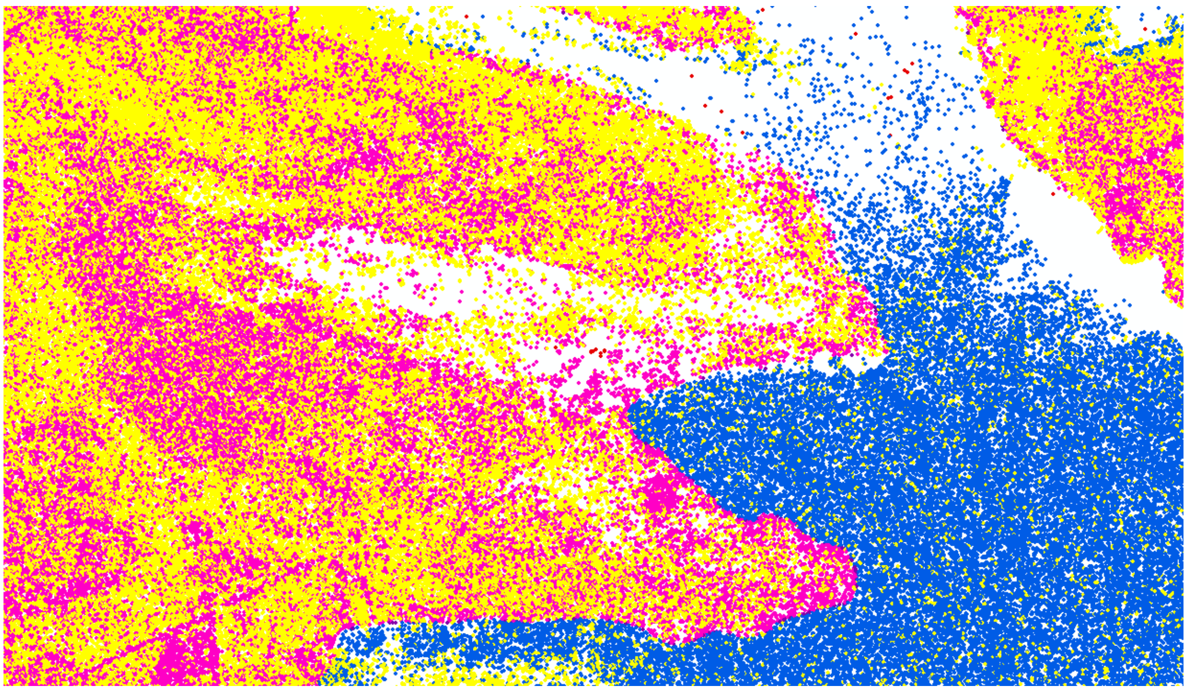

Figure 18 - Tile 14RPS045200. The same marsh area shown in the figure above is shown in this image with the points colored by class (class 1=yellow, class 2=pink). Though ground points are sparse they are present, indicating that the area is wet but should not be classified as water (class 9). Doing so would strip the detail from this area and result in incorrectly flattening ground as part of the hydro mask.

Flight line Ridges

Ridges occur when there is a difference between the elevations of adjoining flight lines or swaths. Some flight line ridges are visible in the final DEMs but they do not exceed the project specifications and the overall relative accuracy requirements for the project area have been met. An example of a visible ridge that is within tolerance is shown below.

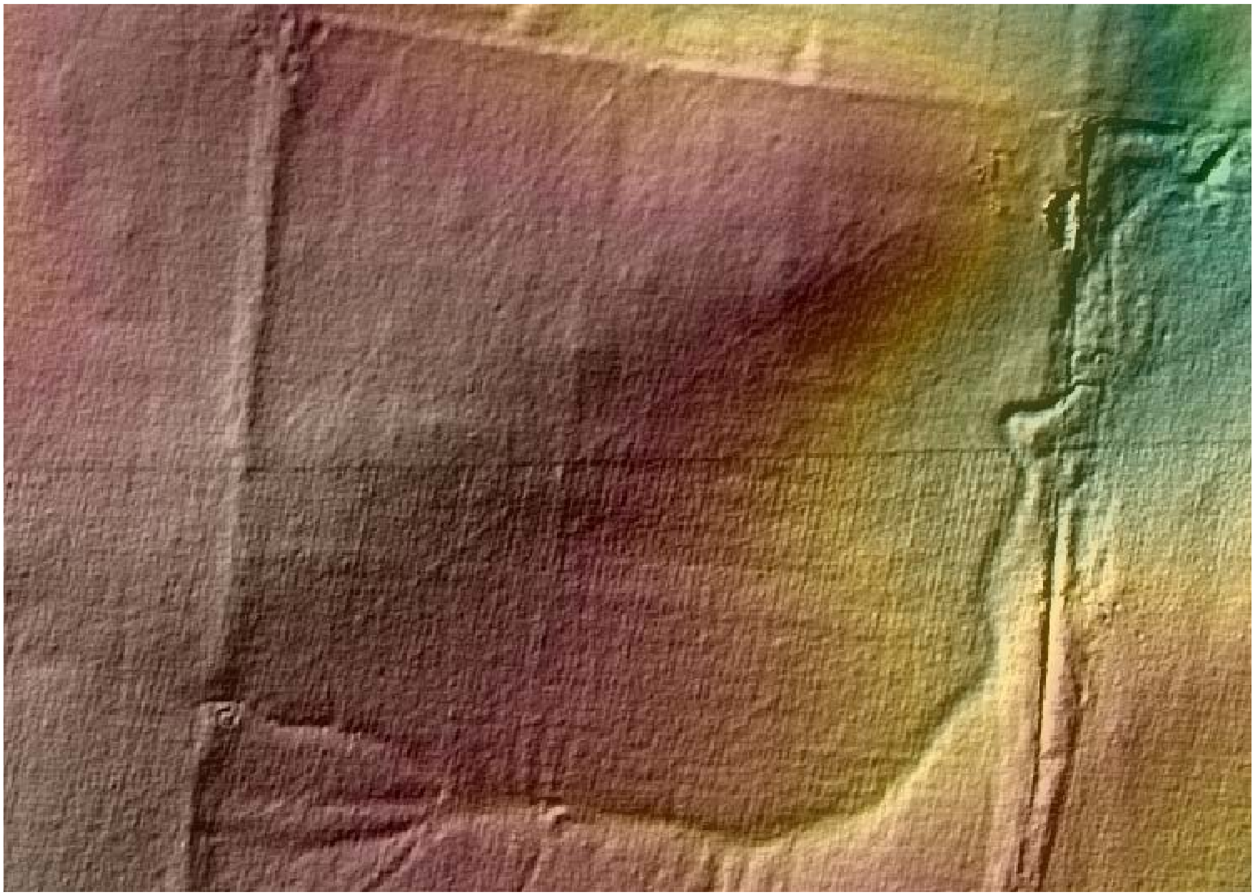

Figure 19 – Tile number 14RNT145130. The flight line ridge is less than 8 cm. Overall, the FEMA VI – TX Red River Atascosa Lidar data meets the project specifications for 8 cm relative accuracy.

Low NIR Reflectivity

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

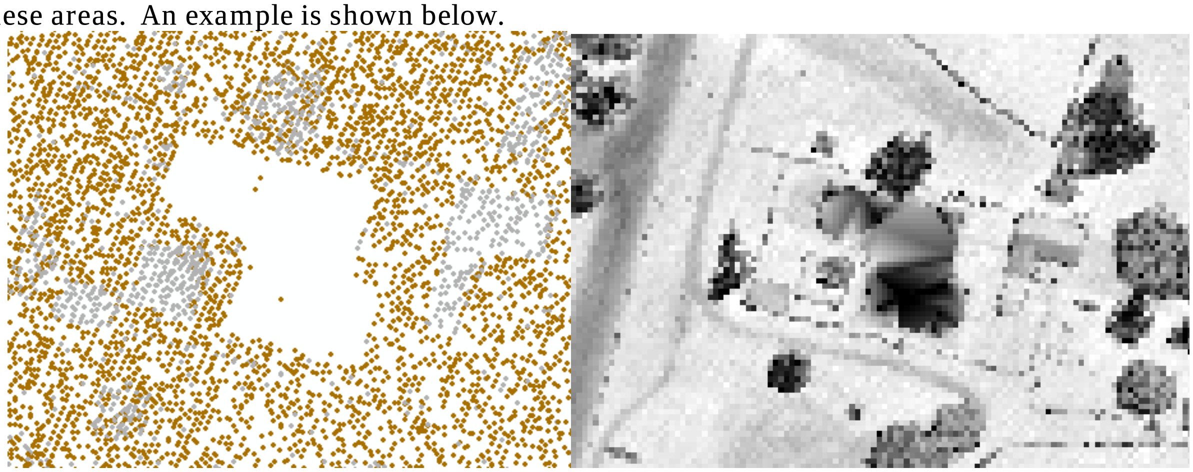

Figure 20-Tile number 14RMS830710. Full lidar point cloud (gray=unclassified, brown=ground) is shown in the left image and intensity imagery of the same location is shown in the right image. This rooftop is an area of low NIR reflectivity because the composition of the roofing materials result in

the absorption of the NIR laser, reducing the number of lidar returns defining the building. Areas of low NIR reflectivity exist within this dataset.

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 14, 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 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

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, two hundred twenty four (224) 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	NAD1983(2011) UTM 14N		NAVD88 (Geoid 12B)
	Easting X (m)	Northing Y (m)	Elevation (m)
NVA-001	474766.238	3373666.046	558.514
NVA-002	495119.792	3368138.466	535.905
NVA-003	495211.987	3361218.863	641.788
NVA-004	487460.015	3367895.366	529.793
NVA-005	475687.505	3361912.917	668.951
NVA-006	468831.703	3352045.961	665.001

NVA-007	479947.621	3352080.657	646.390
NVA-008	494286.037	3352324.894	581.950
NVA-009	495675.938	3335849.509	569.582
NVA-010	494832.839	3345896.357	548.821
NVA-011	484300.661	3342501.406	629.333
NVA-012	476625.056	3347689.337	643.645
NVA-013	457582.068	3213206.993	215.911
NVA-014	469238.744	3210152.350	203.830
NVA-015	479246.396	3208607.054	181.296
NVA-016	495181.533	3210962.276	231.256
NVA-017	487282.967	3209199.539	178.348
NVA-018	472326.273	3207435.554	192.720
NVA-019	462179.174	3211002.881	205.818
NVA-020	461562.015	3202077.904	221.906
NVA-021	471000.656	3201887.087	200.111
NVA-022	481848.746	3201799.693	167.834
NVA-023	492958.978	3204970.766	204.960
NVA-024	491085.372	3197467.734	194.126
NVA-025	498454.767	3199027.259	193.696
NVA-026	499051.306	3191429.985	186.479
NVA-027	482919.913	3190444.549	159.996
NVA-028	460268.929	3191091.587	178.657
NVA-029	464520.512	3186268.094	185.511
NVA-030	477545.520	3185867.793	156.948
NVA-031	488798.912	3188933.985	179.073
NVA-032	501463.442	3182699.894	176.736
NVA-033	495372.716	3176709.759	152.243
NVA-034	487023.890	3182322.678	157.708
NVA-035	475098.085	3181579.113	157.702
NVA-036	461765.561	3176870.060	185.468
NVA-037	453841.351	3181066.258	214.488
NVA-038	446077.494	3181034.932	212.657
NVA-039	454684.768	3164119.826	166.659
NVA-040	460038.818	3168096.386	186.147
NVA-041	483114.341	3171210.164	171.218
NVA-042	486804.757	3168400.571	156.393
NVA-043	509164.976	3153141.888	104.586
NVA-044	486048.073	3158364.486	145.113
NVA-045	466731.588	3165341.276	164.153
NVA-046	479034.288	3155296.907	175.167
NVA-047	495016.138	3155825.807	132.703
NVA-048	506636.479	3146367.944	102.849
NVA-049	489502.252	3148691.977	156.799
NVA-050	498379.283	3143975.742	118.461
NVA-051	500014.700	3138971.732	129.466
NVA-052	510207.697	3246652.327	283.368
NVA-053	502006.767	3245902.312	296.692

NVA-054	512641.634	3237881.067	245.000
NVA-055	499047.106	3232714.637	248.848
NVA-056	507502.526	3232527.830	237.113
NVA-057	520408.527	3233578.091	219.901
NVA-058	530878.753	3226181.271	216.656
NVA-059	540219.692	3227249.115	215.990
NVA-060	555330.090	3219858.398	163.976
NVA-061	542025.374	3212559.864	137.029
NVA-062	519466.042	3219614.797	189.310
NVA-063	510351.425	3224845.313	207.646
NVA-064	500183.835	3223563.388	223.453
NVA-065	500574.069	3209902.227	181.270
NVA-066	512176.881	3213247.447	204.544
NVA-067	531063.718	3218154.641	170.747
NVA-068	550921.419	3209376.918	129.675
NVA-069	562298.597	3210590.831	144.201
NVA-070	568301.088	3203620.363	113.460
NVA-071	554984.688	3198849.848	125.914
NVA-072	544009.316	3199022.329	138.462
NVA-073	528227.260	3207067.672	164.709
NVA-074	513799.912	3204183.570	179.314
NVA-075	508330.479	3197437.441	148.004
NVA-076	518239.876	3193996.976	170.703
NVA-077	528638.507	3192941.688	164.167
NVA-078	539642.509	3193549.908	145.923
NVA-079	552210.747	3194474.610	131.992
NVA-080	566688.737	3195017.319	102.529
NVA-081	575489.984	3189346.694	102.857
NVA-082	588794.175	3180661.119	115.827
NVA-083	573568.141	3178677.196	118.156
NVA-084	566844.171	3183886.815	79.503
NVA-085	553272.378	3184758.121	97.354
NVA-086	544866.756	3181541.474	113.734
NVA-087	533289.209	3179253.874	129.992
NVA-088	522863.644	3184021.603	143.123
NVA-089	511861.256	3186982.484	153.193
NVA-090	574492.764	3166934.166	73.550
NVA-091	585693.765	3171655.536	76.573
NVA-092	597235.769	3169893.928	115.481
NVA-093	609123.555	3166085.784	128.992
NVA-094	617418.062	3160937.775	94.468
NVA-095	607189.941	3158487.184	102.197
NVA-096	591278.886	3157902.986	64.668
NVA-097	580150.369	3155263.971	50.547
NVA-098	569267.770	3147087.062	74.262
NVA-099	570970.182	3136605.334	98.458
NVA-100	582300.628	3140392.472	64.498

NVA-101	592707.531	3148961.659	84.208
NVA-102	602557.829	3145287.965	102.138
NVA-103	614689.559	3150457.865	107.715
NVA-104	623215.316	3145538.075	79.410
NVA-105	634754.834	3139599.360	55.129
NVA-106	611899.402	3135854.723	84.024
NVA-107	595325.457	3134955.794	52.992
NVA-108	588037.345	3134572.122	46.074
NVA-109	576097.352	3128701.652	88.857
NVA-110	572909.242	3117773.517	121.704
NVA-111	587637.826	3122374.122	106.591
NVA-112	606312.702	3124943.538	57.794
NVA-113	617033.513	3130626.426	66.629
NVA-114	627075.949	3133511.377	46.851
NVA-115	634728.647	3129800.594	36.486
NVA-116	645240.046	3135262.801	31.942
NVA-117	647891.977	3130954.112	35.855
NVA-118	637286.048	3117149.539	27.056
NVA-119	628959.164	3124991.837	49.632
NVA-120	616031.068	3121674.050	65.416
NVA-121	610611.423	3117651.326	66.610
NVA-122	601281.976	3111776.144	51.114
NVA-123	584204.034	3111117.624	72.228
NVA-124	580399.155	3104006.909	96.787
NVA-125	573260.161	3097368.975	128.218
NVA-126	594350.500	3099231.530	86.462
NVA-127	609853.241	3099859.378	40.284
NVA-128	463852.936	3169611.153	169.361
NVA-129	491256.855	3172599.297	144.558
VVA-001	480021.057	3372413.415	610.485
VVA-002	496298.305	3370872.177	547.799
VVA-003	481005.958	3363316.197	566.518
VVA-004	491873.858	3354032.961	647.931
VVA-005	472203.023	3357160.607	674.285
VVA-006	471854.308	3348763.281	651.727
VVA-007	488343.906	3347011.614	567.434
VVA-008	498863.899	3338710.391	535.131
VVA-009	482577.143	3345371.625	596.225
VVA-010	459888.495	3211585.323	211.633
VVA-011	490150.478	3219614.740	202.668
VVA-012	498181.737	3215259.553	212.476
VVA-013	499658.352	3204965.970	184.320
VVA-014	482358.769	3208810.837	181.444
VVA-015	476967.841	3205996.551	181.808
VVA-016	464185.343	3202170.014	229.809
VVA-017	463943.589	3196388.252	203.311
VVA-018	485263.100	3199740.709	179.231

VVA-019	492912.391	3195336.159	194.503
VVA-020	503510.139	3197808.414	162.554
VVA-021	486700.008	3190312.126	167.476
VVA-022	472707.153	3187401.495	164.472
VVA-023	460400.893	3187377.395	188.381
VVA-024	452221.061	3181082.562	208.406
VVA-025	471099.819	3179351.867	175.805
VVA-026	483637.552	3183913.596	146.632
VVA-027	495032.810	3184405.813	177.710
VVA-028	504334.206	3179909.878	166.690
VVA-029	487100.319	3174563.203	152.090
VVA-030	462729.382	3173080.710	177.280
VVA-031	473007.980	3163457.508	162.469
VVA-032	488570.265	3168705.230	149.940
VVA-033	505558.101	3154043.887	111.374
VVA-034	491835.418	3156655.706	140.653
VVA-035	493553.914	3146332.717	126.748
VVA-036	499955.130	3149879.928	121.863
VVA-037	502830.978	3147876.909	110.966
VVA-038	500749.859	3249783.343	294.315
VVA-039	507008.910	3239993.030	273.459
VVA-040	500305.204	3228326.875	229.569
VVA-041	519989.610	3231067.389	213.643
VVA-042	535224.647	3223985.696	201.712
VVA-043	553065.034	3219547.837	154.140
VVA-044	546634.797	3216027.444	143.466
VVA-045	526806.647	3216430.670	181.091
VVA-046	510560.536	3215010.667	204.273
VVA-047	503925.862	3213123.136	191.115
VVA-048	510357.466	3202169.975	159.209
VVA-049	522056.053	3206729.643	181.431
VVA-050	536987.500	3207395.980	149.459
VVA-051	543855.981	3203689.472	144.320
VVA-052	563144.295	3206514.678	118.636
VVA-053	570124.303	3197971.264	107.108
VVA-054	554638.425	3195525.500	106.853
VVA-055	531677.246	3198873.720	179.633
VVA-056	523790.216	3194845.975	141.320
VVA-057	507661.310	3188514.609	157.359
VVA-058	520959.830	3178079.166	120.763
VVA-059	528257.458	3188286.544	146.190
VVA-060	538858.469	3185310.421	130.875
VVA-061	554841.171	3188796.118	100.055
VVA-062	569743.756	3189084.078	83.523
VVA-063	581756.994	3185229.078	141.505
VVA-064	569311.186	3172854.926	95.120
VVA-065	581223.315	3178145.853	109.817

VVA-066	609264.821	3169863.241	123.713
VVA-067	595506.081	3166645.303	106.834
VVA-068	579863.646	3169137.106	80.295
VVA-069	573368.060	3157332.051	89.631
VVA-070	572148.214	3142457.038	61.478
VVA-071	590178.099	3153049.379	54.031
VVA-072	600693.227	3156016.237	125.167
VVA-073	614887.170	3157611.288	104.241
VVA-074	626604.176	3147079.462	67.496
VVA-075	612004.776	3149347.175	89.118
VVA-076	597594.139	3144472.299	76.048
VVA-077	588952.687	3142833.802	45.684
VVA-078	577283.613	3133317.647	104.825
VVA-079	571574.483	3124033.327	97.974
VVA-080	592986.756	3128638.903	50.367
VVA-081	606143.817	3135546.253	76.089
VVA-082	620374.360	3136181.927	65.344
VVA-083	632014.225	3139299.053	55.455
VVA-084	644720.081	3138350.330	37.266
VVA-085	634314.046	3128087.669	37.489
VVA-086	634041.642	3120723.304	32.876
VVA-087	622890.009	3125926.589	55.039
VVA-088	612664.298	3127194.309	72.623
VVA-089	601184.935	3123368.637	35.631
VVA-090	582427.326	3121689.318	100.872
VVA-091	572874.266	3108996.246	109.070
VVA-092	598072.462	3110021.216	45.815
VVA-093	610404.337	3095460.985	40.726
VVA-094	586251.808	3102237.204	79.532
VVA-095	588074.272	3113830.511	73.773
VVA-096	486288.966	3170889.662	149.412

Table 5 USGS FEMA VI – TX Red River Atascosa Lidar surveyed accuracy checkpoints

One checkpoint (NVA-039) was removed from the vertical accuracy testing for the classified lidar due to being located outside of the project boundary. The coordinates of this checkpoint is provided in the table below and the location of the checkpoint outside of the project boundary is shown in the figure below.

Point ID	NAD83(2011) State Plane VA		NAVD88 (Geoid 12B)	Lidar Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
NVA-039	454684.768	3164119.826	166.659	166.630	-0.029	0.029

Table 6: Checkpoint removed from vertical accuracy testing due to the location being outside of the project boundary.

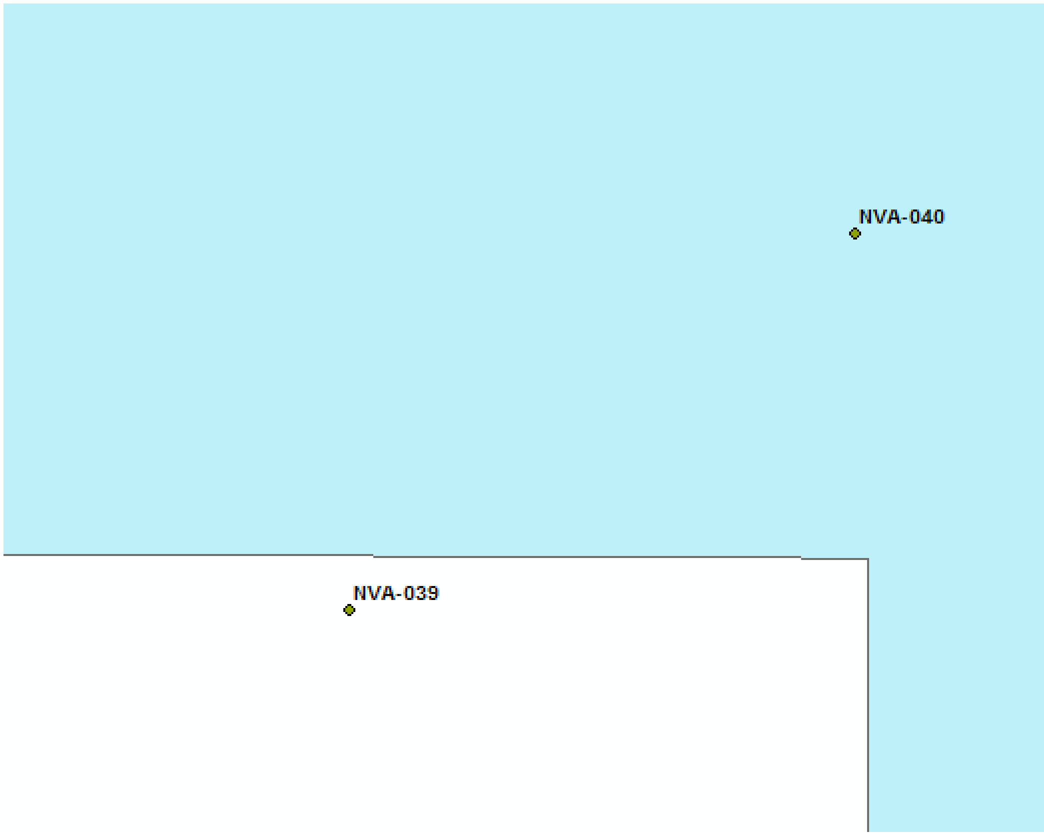

Figure 21 – Checkpoint NVA-039 was removed from all vertical accuracy calculations due to its location outside of the project boundary.

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

USGS FEMA VI - TX Red River Atascosa Checkpoint Locations

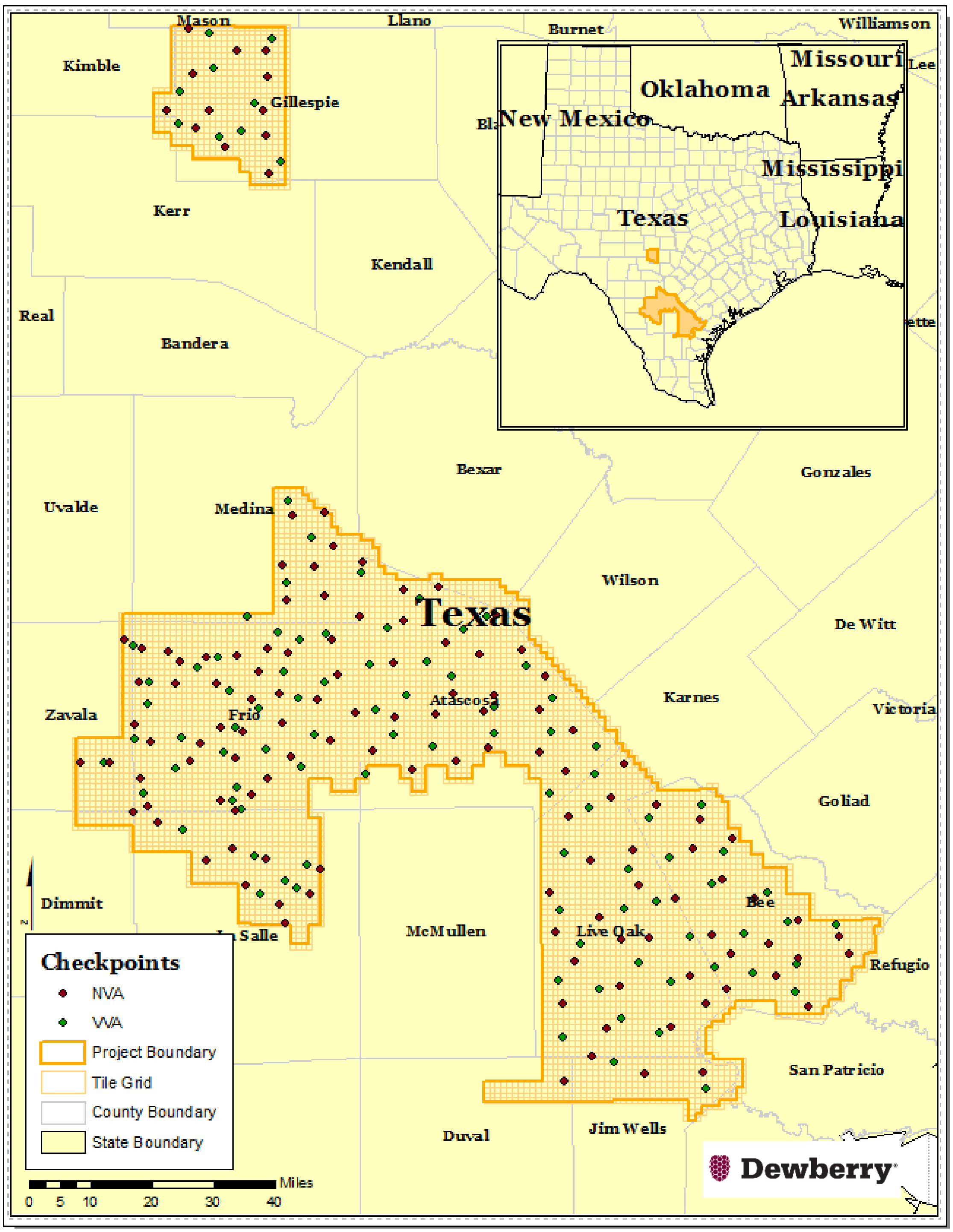

Figure 22 – Location of QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, where there is a very high probability that the lidar sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The NVA determines how well the calibrated lidar sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the TX Red River Atascosa 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 TX Red River Atascosa 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 7.

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

Table 7 — Acceptance Criteria

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

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

VERTICAL ACCURACY RESULTS

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

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	128	11.6	
VVA	96		12.3

Table 8 — 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 $RMSE_z$ =5.9 cm, equating to +/- 11.6 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 12.3 cm at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within +/- 20 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +23 cm.

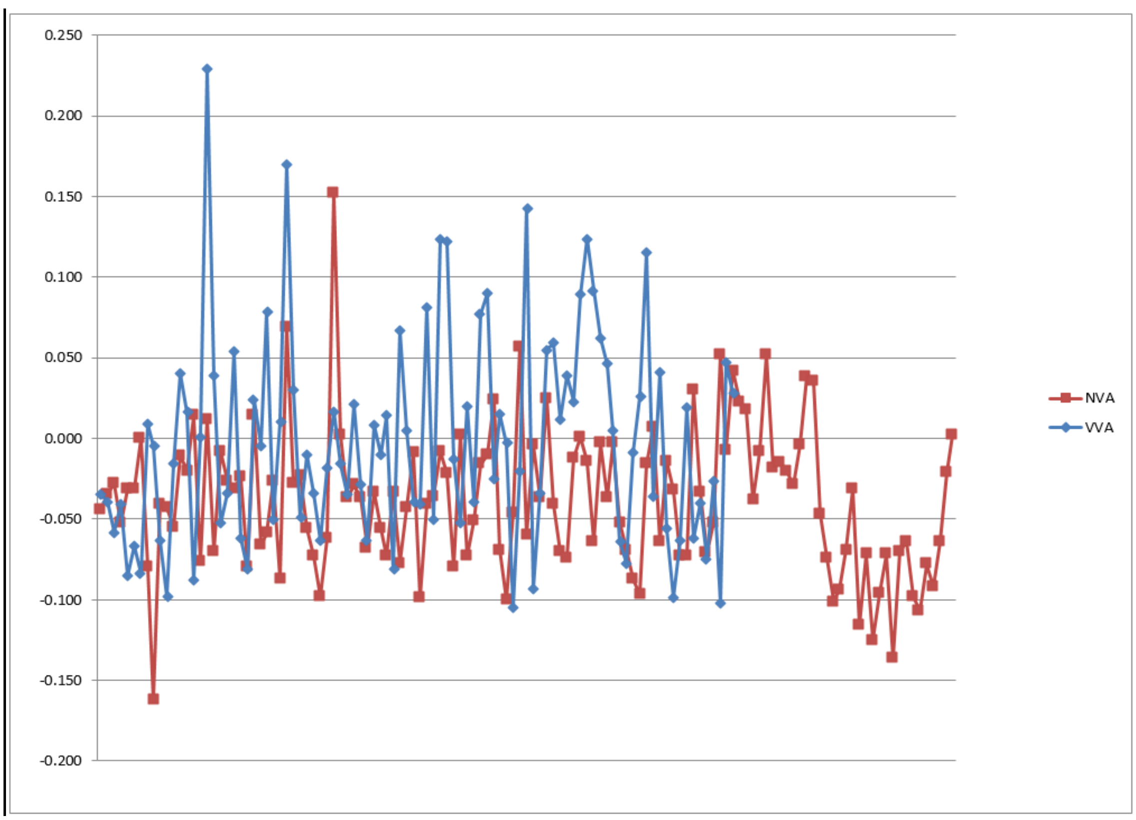

Figure 23 – Magnitude of elevation discrepancies per land cover category

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

Point ID	NAD83(2011) UTM Zone 14		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA-017	463943.589	3196388.252	203.311	203.540	0.229	0.229
VVA-029	487100.319	3174563.203	152.090	152.260	0.170	0.170
VVA-052	563144.295	3206514.678	118.636	118.760	0.124	0.124
VVA-065	581223.315	3178145.853	109.817	109.960	0.143	0.143
VVA-074	626604.176	3147079.462	67.496	67.620	0.124	0.124

Table 9 — 5% Outliers

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 -0.162 meters and a high of +2.29 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 -0.025 meters to +0.025 meters.

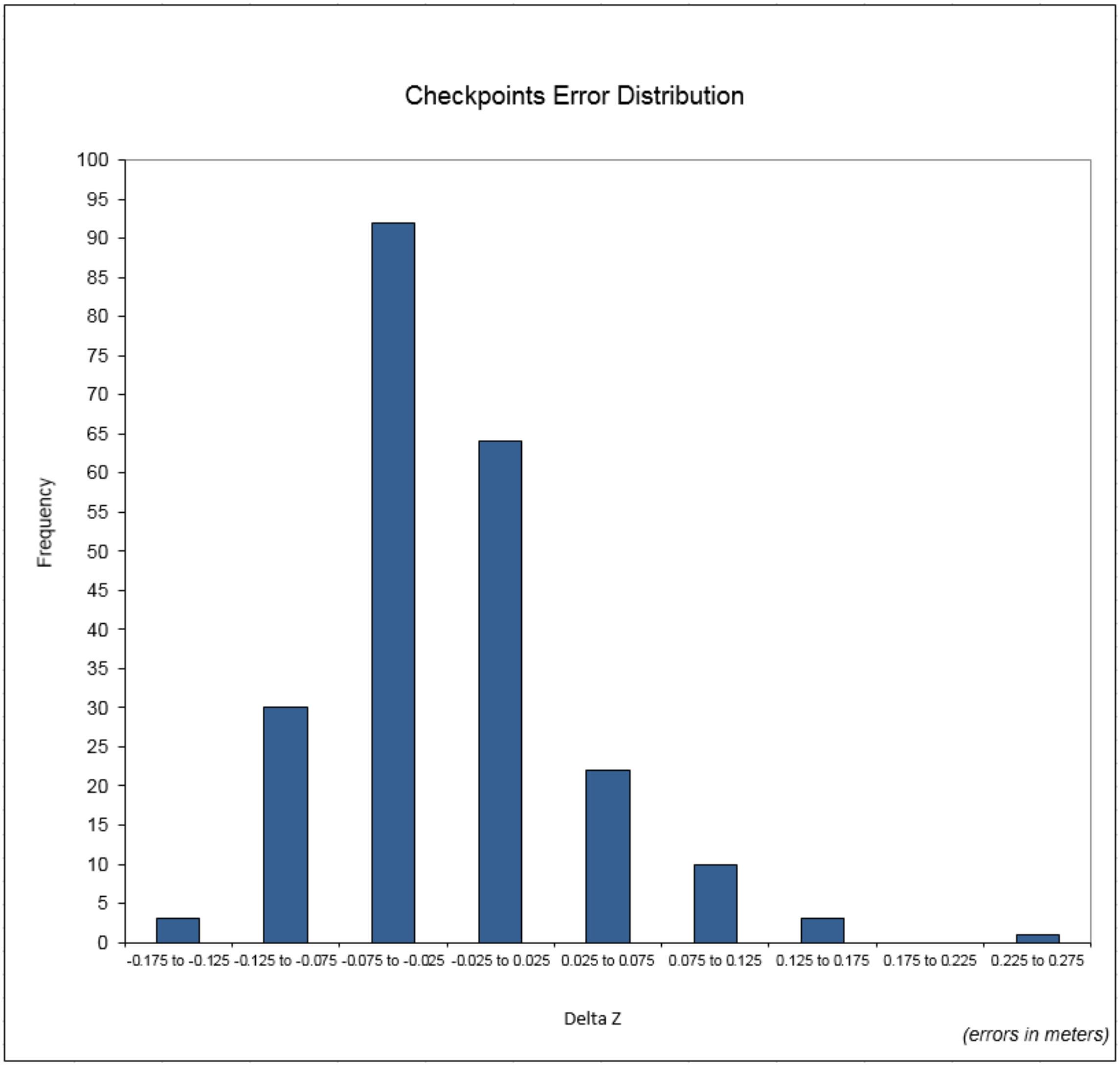

Figure 24 — Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the USGS FEMA VI – TX Red River Atascosa 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

Six checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset. As only six (6) checkpoints were photo-identifiable, the results are not statistically significant enough to report as a final tested value, but the results of the testing are still shown in the Table below.

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

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

# of Points	$RMSE_x$ (Target=41 cm)	$RMSE_y$ (Target=41 cm)	$RMSE_r$ (Target=58 cm)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=100 cm
6	34.2	45.2	56.7	98.1

Table 10-Tested horizontal accuracy at the 95% confidence level

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1 meter at a 95% confidence level. Six (6) checkpoints were photo-identifiable but do not produce a statistically significant tested horizontal accuracy value. Using this small sample set of photo-identifiable checkpoints, positional accuracy of this dataset was found to be RMSEx = 34.2 cm and RMSEy = 45.2 cm which equates to +/- 98.1 cm at 95% confidence level. While not statistically significant, the results of the small sample set of checkpoints are within the produced to meet horizontal accuracy.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

Dewberry 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.

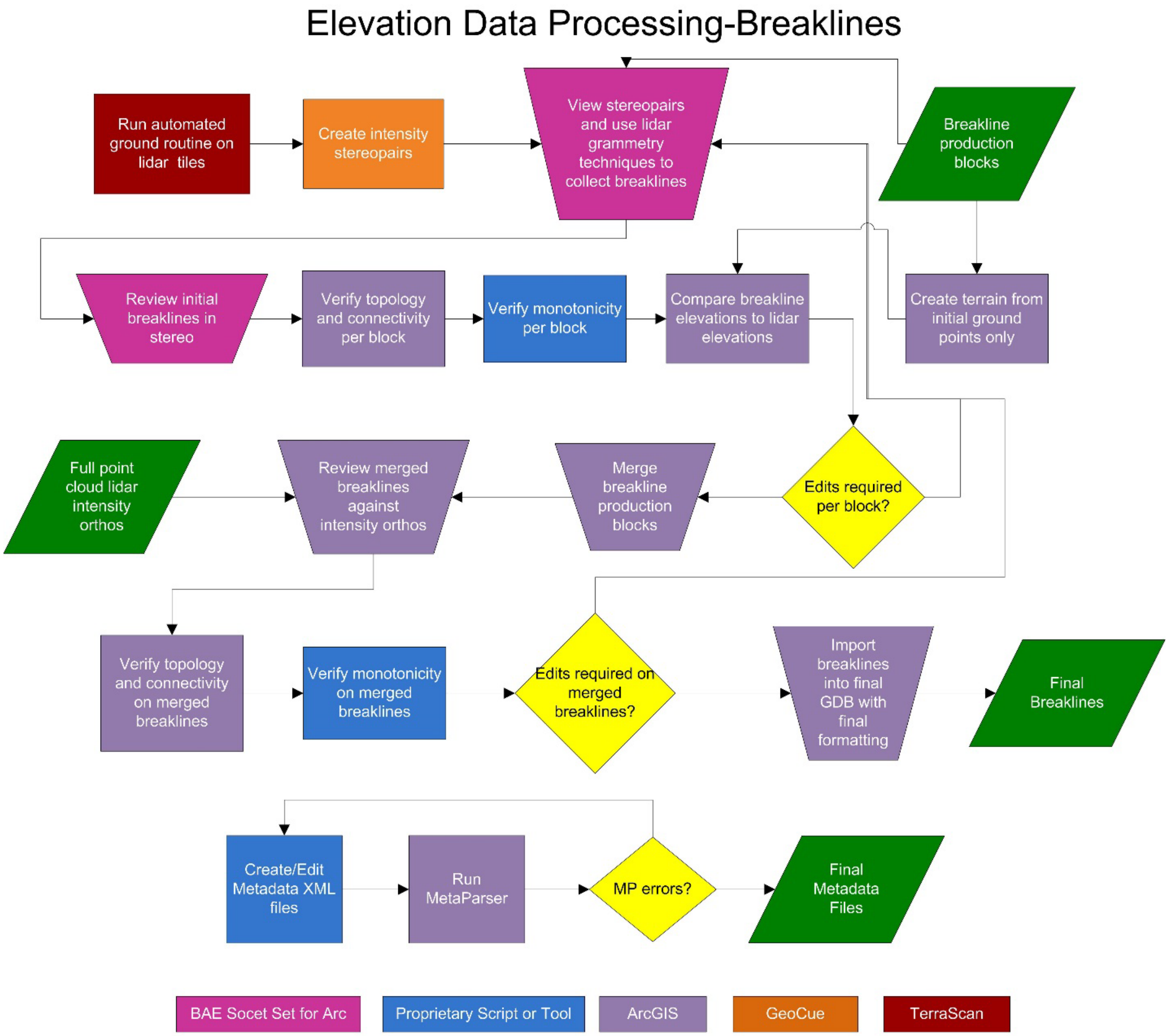

Figure 25-Breakline QA/QC workflow

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 11-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 14, 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.

Beneath Bridge Breaklines

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

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

Description

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

Table Definition

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

Feature Definition

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

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

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

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

Figure 26-DEM Production Workflow

DEM QUALITATIVE ASSESSMENT

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

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

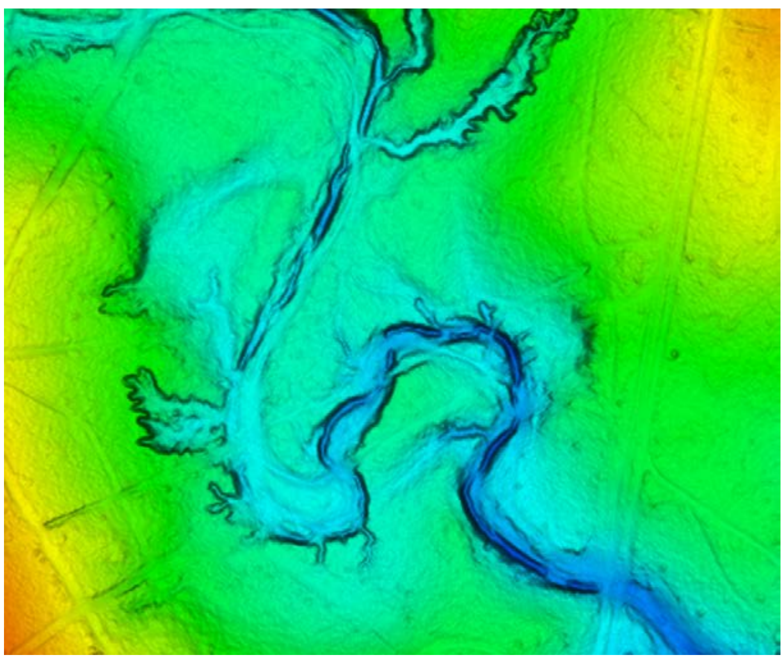

Figure 27-Tile 14RNR000990. The bare earth DEM is shown

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

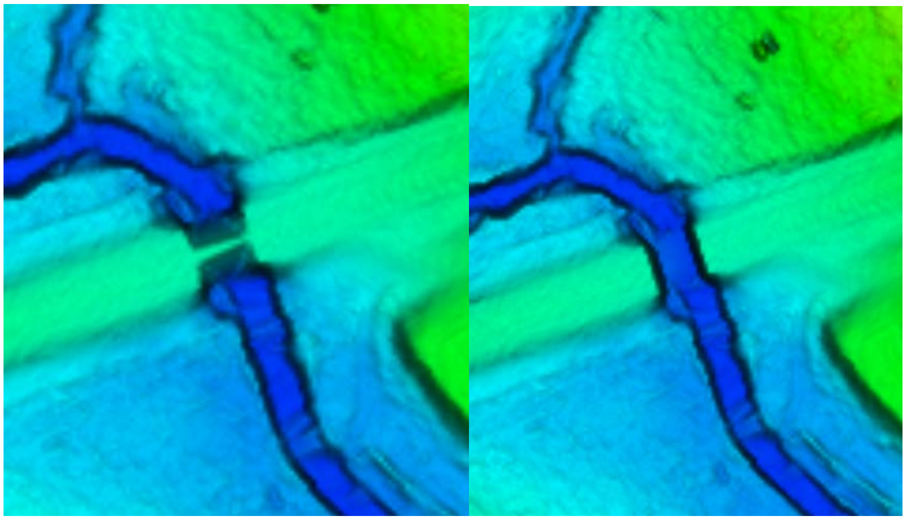

Figure 28-14RNT205340. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 224 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 12 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	128	11.0	
VVA	96		10.8

Table 12 — 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 $RMSE_z$ =5.6 cm, equating to +/- 11.0 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)			
VVA-017	463943.589	3196388.252	203.311	203.572	0.261	0.261
VVA-029	487100.319	3174563.203	152.090	152.250	0.160	0.160
VVA-052	563144.295	3206514.678	118.636	118.749	0.113	0.113
VVA-083	632014.225	3139299.053	55.455	55.565	0.110	0.110
VVA-094	586251.808	3102237.204	79.532	79.423	-0.109	0.109

Table 13 — 5% Outliers

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the USGS FEMA TX Red River Atascosa Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

DEM CHECKLIST

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

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

Pass	Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt.

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

Appendix A: Checkpoint Survey Report

Please see the report included with this deliverable:
Appendix_A_Checkpoint_Survey_Report

Appendix B: Complete List of Delivered Tiles

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Appendix C: GPS Processing

Please see the report included with this deliverable:
Appendix_C_GPS Processing