Texas Robertson-Freestone-Brazos FEMA R6 Lidar - 2016

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 Robertson-Freestone-Brazos portion of the USGS TX Red River FEMA R6 Lidar 2016 D17 task order.

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 1500 m by 1500 m. A total of 6,563 tiles were produced for the project encompassing an area of approximately 5,445 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 QAQC, Digital Elevation Model (DEM) production, and quality assurance.

Dewberry's Gary D. Simpson completed ground surveying for the project and delivered surveyed checkpoints and ground control points (GCPs). His tasks were to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the lidar-derived surface model and to acquire surveyed GCPs for use during the calibration processing. He also verified the GPS base station coordinates used during lidar data acquisition to ensure that the base station coordinates were accurate. Please see the separate Survey Reports for both the GCPs and checkpoints which are delivered as part of the survey deliverables for this project.

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

Kinetics completed a portion of the lidar editing and all hydrographic breakline collection.

SURVEY AREA

The project area addressed by this report falls within the Texas counties of Brazos, McLennan, Washington, Falls, Grimes, Navarro, Milam, Freestone, Limestone, Hill, Robertson and Burleson.

DATE OF SURVEY

The lidar aerial acquisition was conducted from January 7, 2017 thru March 1, 2017.

COORDINATE REFERENCE SYSTEM

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

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: 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 Texas Robertson-Freestone-Brazos Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **7.5 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 **14.6 cm**, compared with the 19.6 cm specification.

For the Texas Robertson-Freestone-Brazos Lidar Project, the tested VVA of the classified lidar data computed using the 95th percentile was equal to **24.5 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. Project Extents including boundary and tile grid (Shapefiles)
2. Breakline Data (File GDB and Shapefiles)
3. Final classified lidar tiles (LAS)
4. Tiled bare earth DEMs (Raster DEM – IMG Format)
5. Intensity Images (tiled, GeoTIFF)
6. Survey data
7. Metadata (XML)
8. Final Project report

PROJECT TILING FOOTPRINT

Six thousand five hundred sixty-three (6,563) tiles were delivered for the project. Each tile's extent is 1,500 meters by 1,500 meters (see Appendix A for a complete listing of delivered tiles).

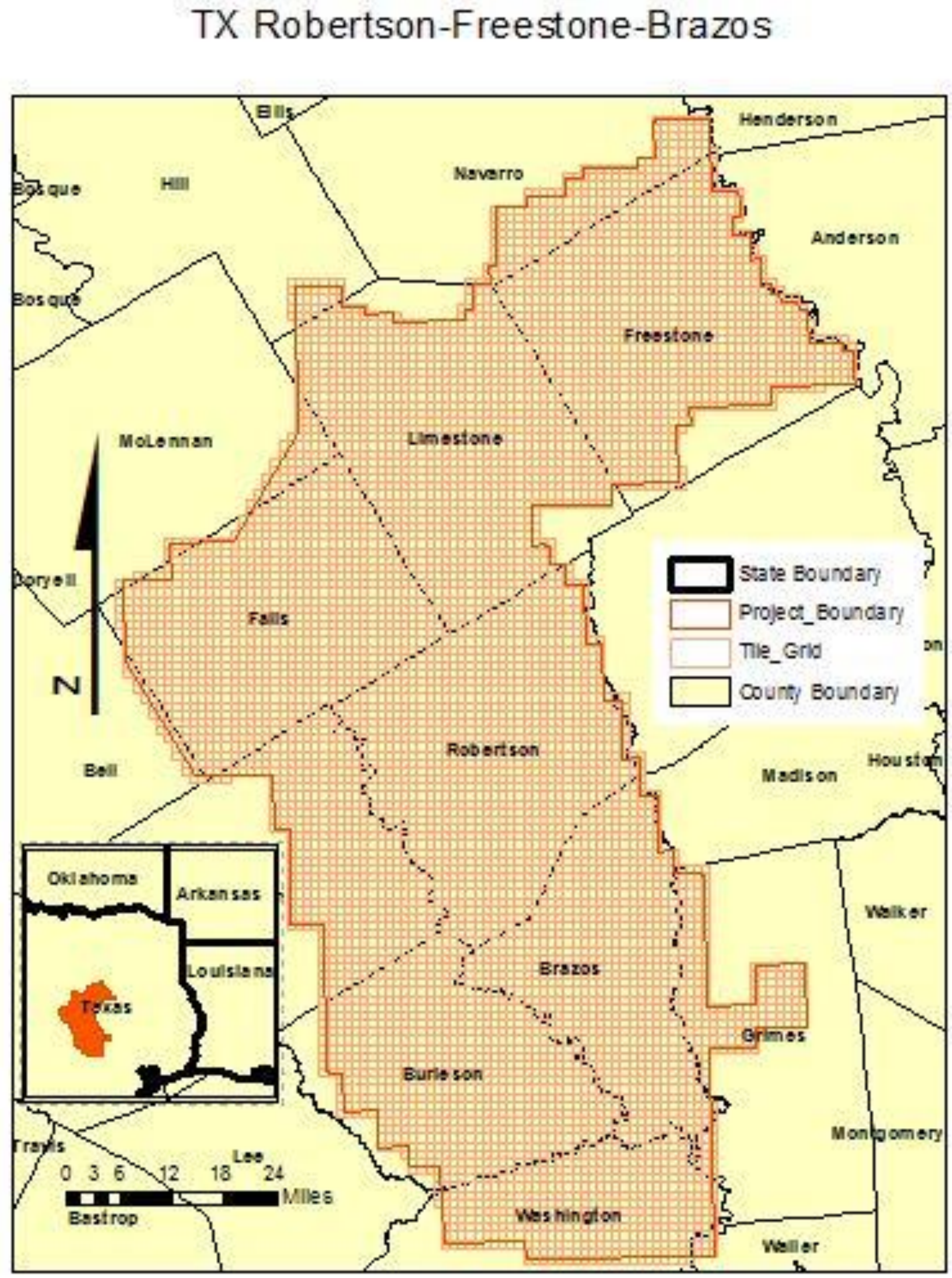


Figure 1 - Project Map

Lidar Acquisition Report

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

Dewberry received calibrated swath data from Digital Aerial Solutions LLC on May 21, 2013 and June 5, 2013.

LIDAR ACQUISITION DETAILS

Digital Aerial Solutions LLC planned 422 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, Digital Aerial Solutions LLC followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

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

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

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

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

LIDAR SYSTEM PARAMETERS

Digital Aerial Solutions LLC operated a Cessna 421 (Tail # N112MJ) outfitted with a LEICA ALS80-HP lidar system during the collection of the study area. Table 1 illustrates Digital Aerial Solutions LLC system parameters for lidar acquisition on this project.

Item	Parameter
System	Leica ALS-80 HP
Altitude (AGL meters)	1770
Approx. Flight Speed (knots)	155
Scanner Pulse Rate (kHz)	297
Scan Frequency (hz)	43.3
Pulse Duration of the Scanner (nanoseconds)	2.93
Pulse Width of the Scanner (m)	0.88
Swath width (m)	1467.79
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes MPIA 2
Beam Divergence (milliradians)	0.15-0.25
Nominal Swath Width on the Ground (m)	1467.79
Swath Overlap (%)	30
Total Sensor Scan Angle (degree)	45
Computed Down Track spacing (m) per beam	0.92
Computed Cross Track Spacing (m) per beam	0.92
Nominal Pulse Spacing (single swath), (m)	0.63
Nominal Pulse Density (single swath) (ppsm), (m)	2.54
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.63
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2.54
Maximum Number of Returns per Pulse	8

Table 1: Digital Aerial Solutions LLC lidar system parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The Acquisition Manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 2 shows the combined trajectory of the flightlines.

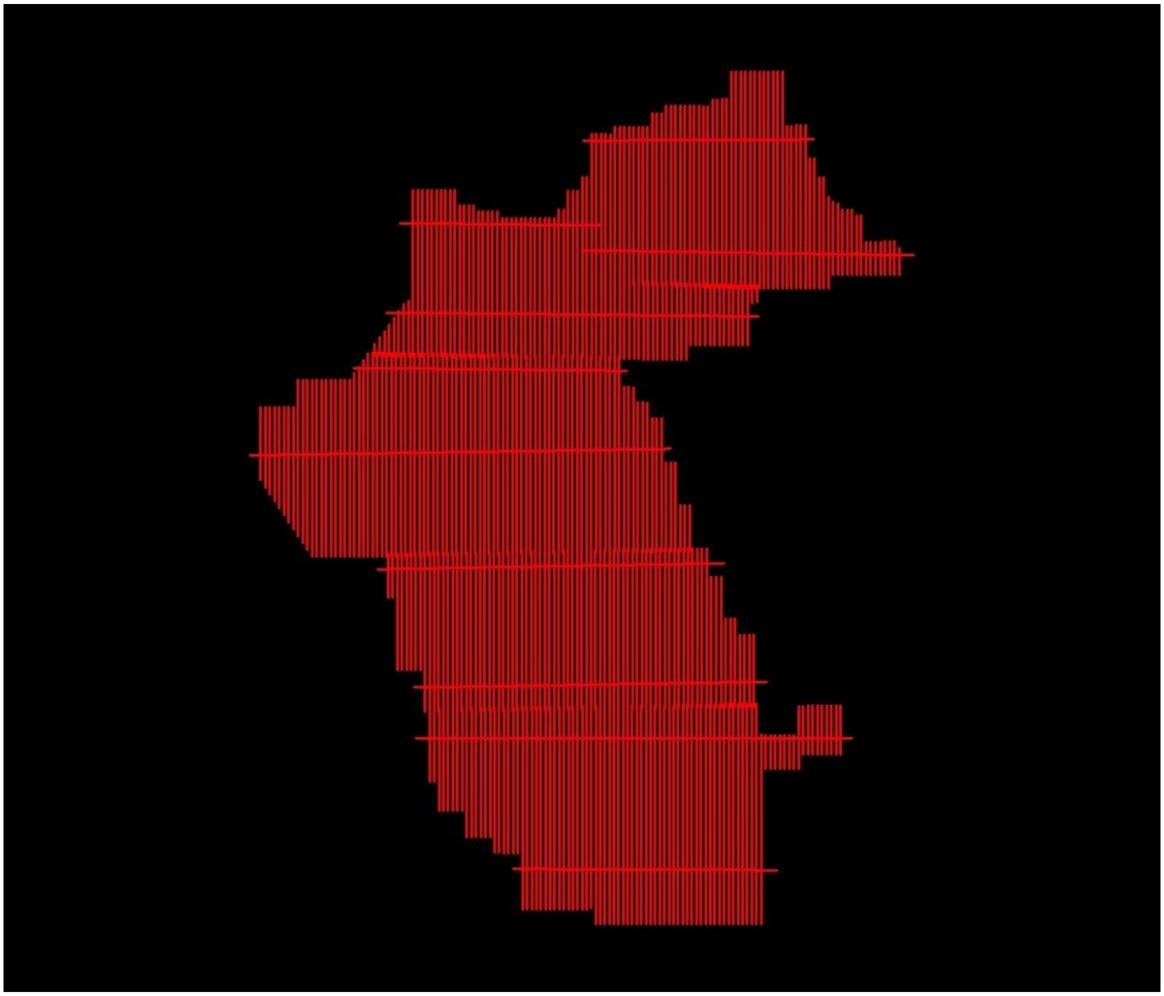


Figure 2: Trajectories as flown by Digital Aerial Solutions LLC

LIDAR CONTROL

Nine existing CORS Stations and five newly established base stations were used to control the lidar acquisition for the TX Robertson-Freestone-Brazos lidar project area. The coordinates of all used base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

Name	North American Datum 1983 (2011) UTM Zone 14		Ellipsoid Height (m)	Orthometric Height (NAVD88 Geoid 12B, m)
	Northing (m)	Easting (m)		
cfd01	3401376.925	755152.505	82.726	109.260
lxy01	3503113.425	735729.857	137.158	162.472
lxy02	3503108.428	735732.472	137.291	162.605
psn01	3519205.169	244145.827	96.151	122.372
tpl01	3447338.955	651274.699	180.903	208.093

TXBT	3434213.166	645162.431	178.345	205.383
TXBX	3401225.927	749305.138	84.931	111.411
TXC2	3417675.626	693841.741	98.270	124.295
TXCK	3467920.448	268208.433	88.710	115.549
TXHE	3333396.627	783000.517	48.696	76.217
TXHI	3540767.280	676686.064	154.997	182.103
TXMX	3498218.476	734891.740	120.905	146.25
TXNA	3547715.714	732405.644	106.656	132.206
TXPI	3512826.976	254128.372	125.856	152.262

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 6 satellites in view (10° above the horizon) and with PDOP of better than 4. Distances form base stations to aircraft were kept to a maximum of 55 km.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3 cm average or better but not larger than 10 cm being recorded.

GPS processing reports for each mission are included as the separate Appendix B document.

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 Cloud Pro or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

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

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

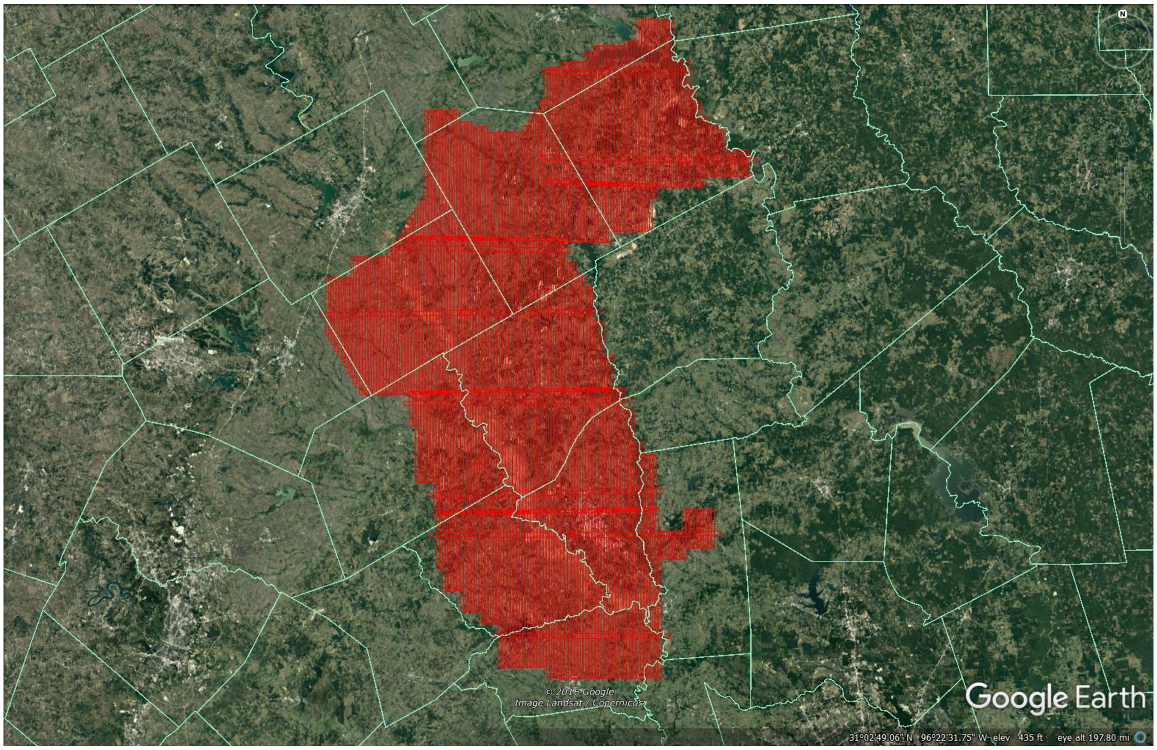


Figure 3 – Lidar swath output showing complete coverage.

BORESIGHT AND RELATIVE ACCURACY

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

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

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

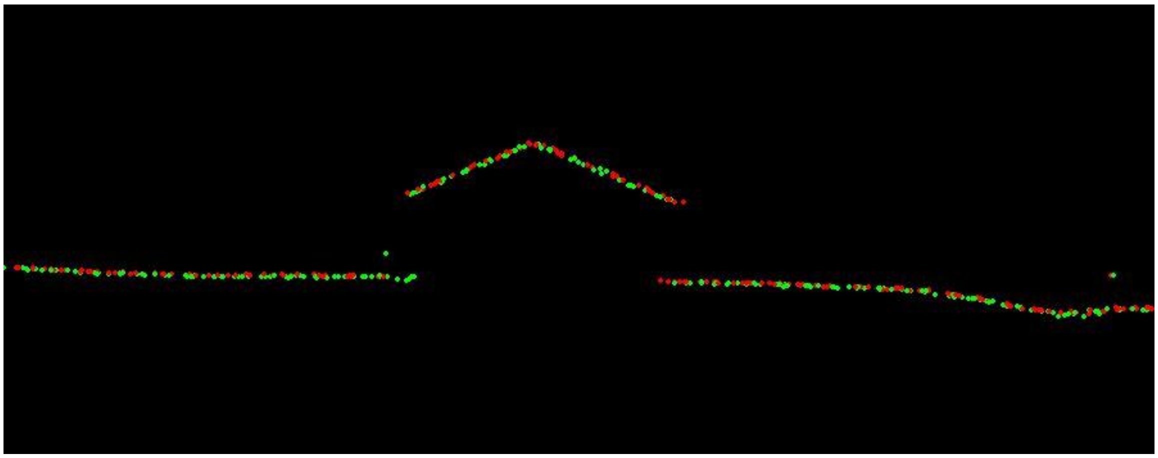


Figure 4 – Profile views showing correct roll and pitch adjustments.

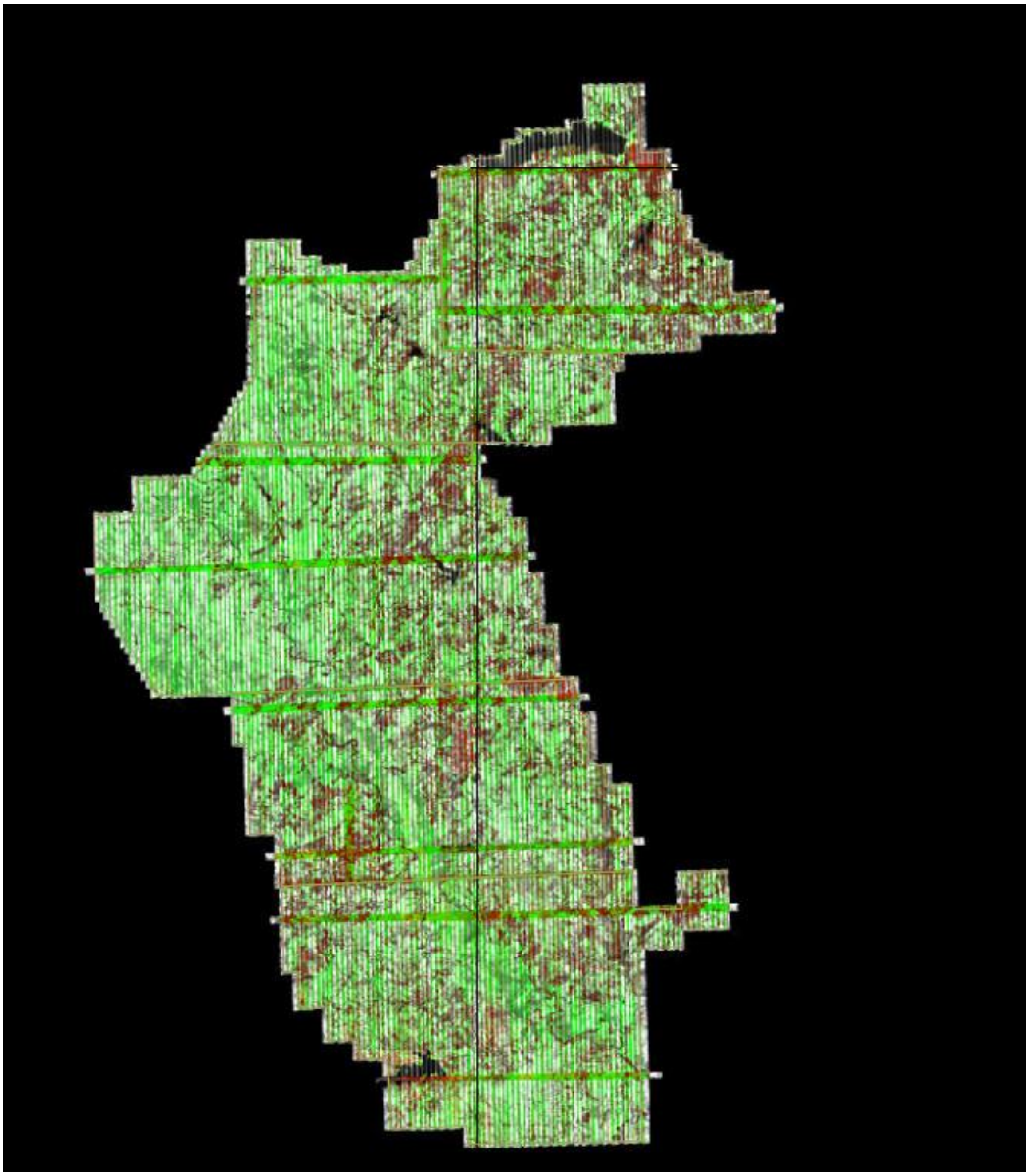


Figure 5 – QC block colored by distance to ensure accuracy at swath edges.

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

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

Lidar Processing & Qualitative Assessment

INITIAL PROCESSING

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

Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Digital Aerial Solutions LLC, Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the ninety-four 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 TX Robertson-Freestone-Brazos 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 $RMSE_z$ = 7.6 cm, equating to +/- 14.8 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	94	0.076	0.148	0.042	0.037	0.501	0.063	-0.065	0.232	-0.143

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

Inter-Swath (Between Swath) Relative Accuracy

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

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

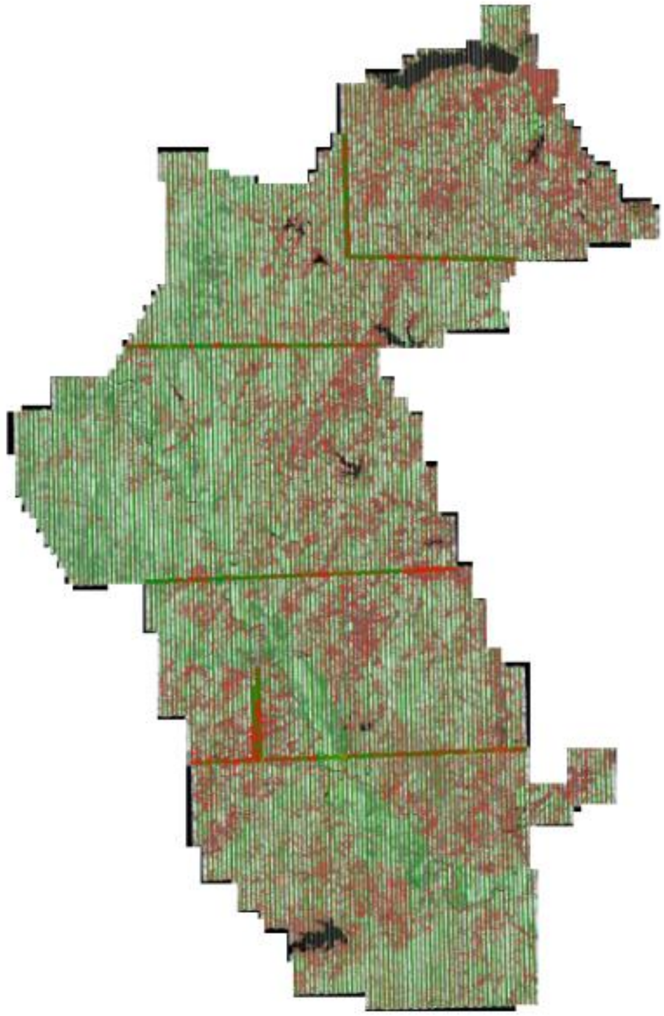


Figure 6– Single return DZ Orthos for TX Robertson-Freestone-Brazos. Inter-swath relative accuracy passes specifications.

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 an example of the intra-swath relative accuracy of TX Robertson-Freestone-Brazos; this project meets intra-swath relative accuracy specifications.

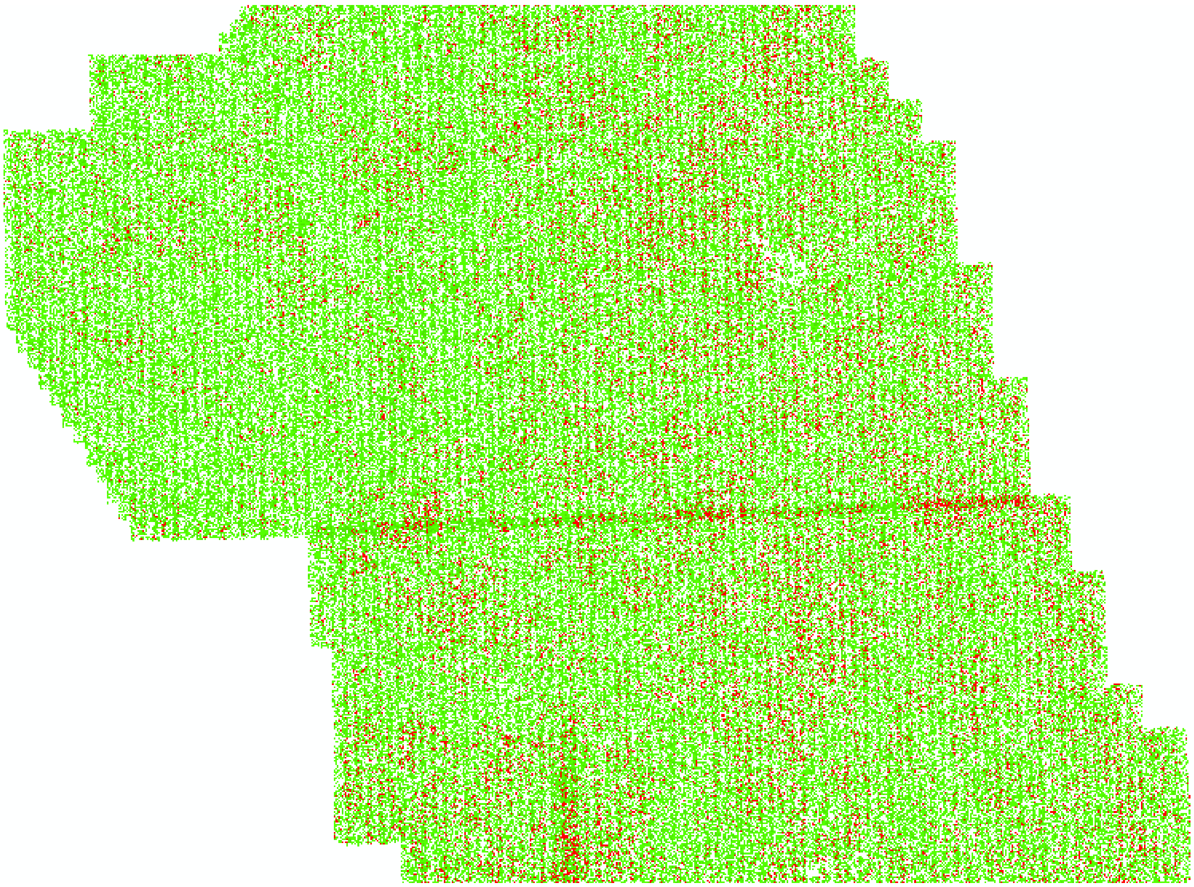


Figure 7–Intra-swath relative accuracy. The image shows a portion of the project area; areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. Intra-swath relative accuracy passes specifications.

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 Robertson-Freestone-Brazos; no horizontal alignment issues were identified.

Figure 8– Horizontal Alignment. Two separate flight lines differentiated by color (Red/Green) 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 0.59 meters or an ANPD of 2.84 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.

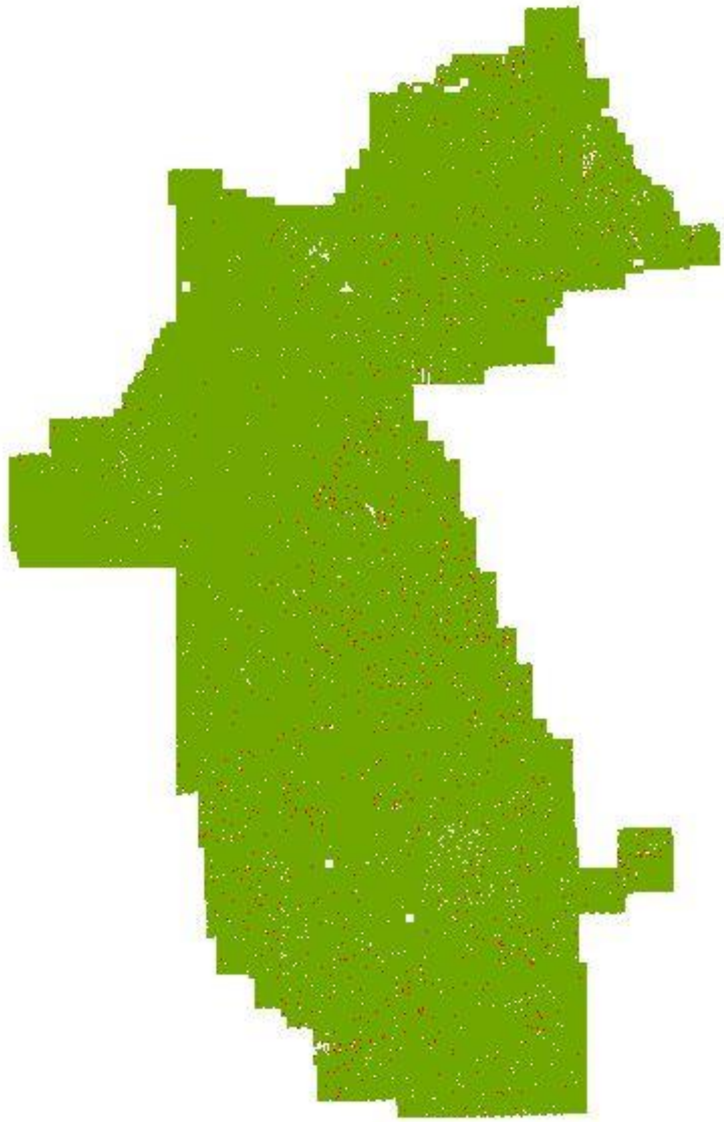


Figure 9– 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) showing there are no systematic density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

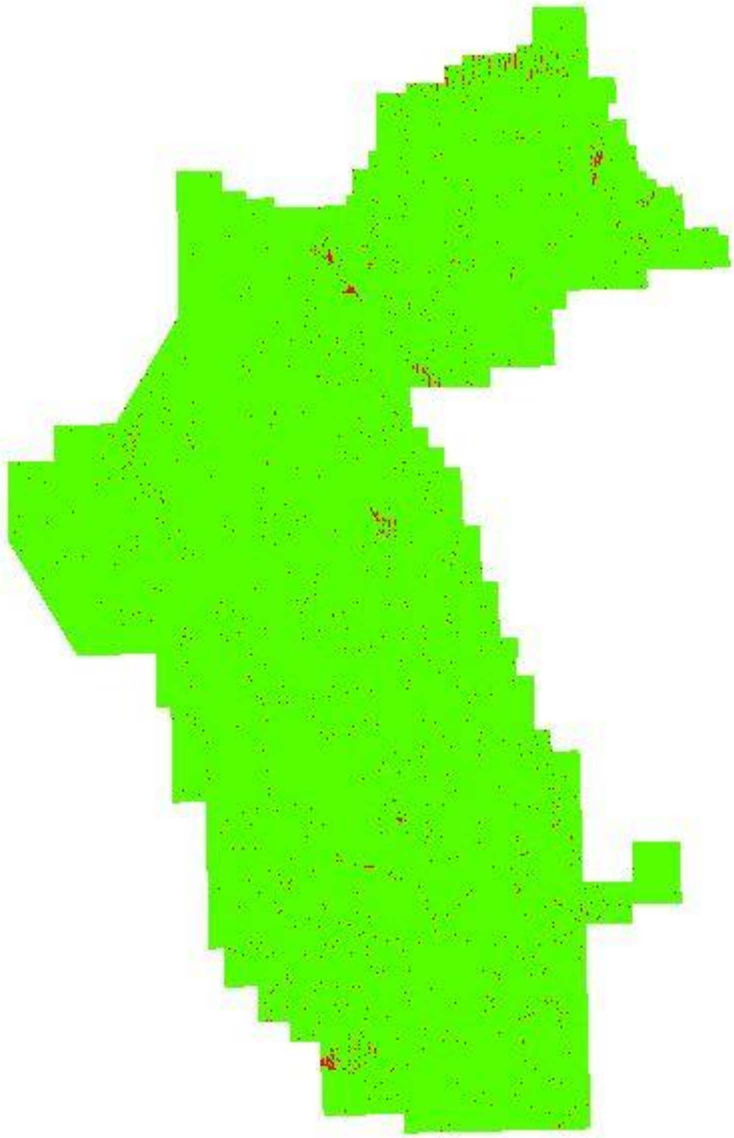


Figure 10– Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies which are acceptable NoData area, are colored red. Without removing acceptable NoData areas due to water, 97.6% of cells contain 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 Robertson-Freestone-Brazos.

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 Robertson-Freestone-Brazos 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.

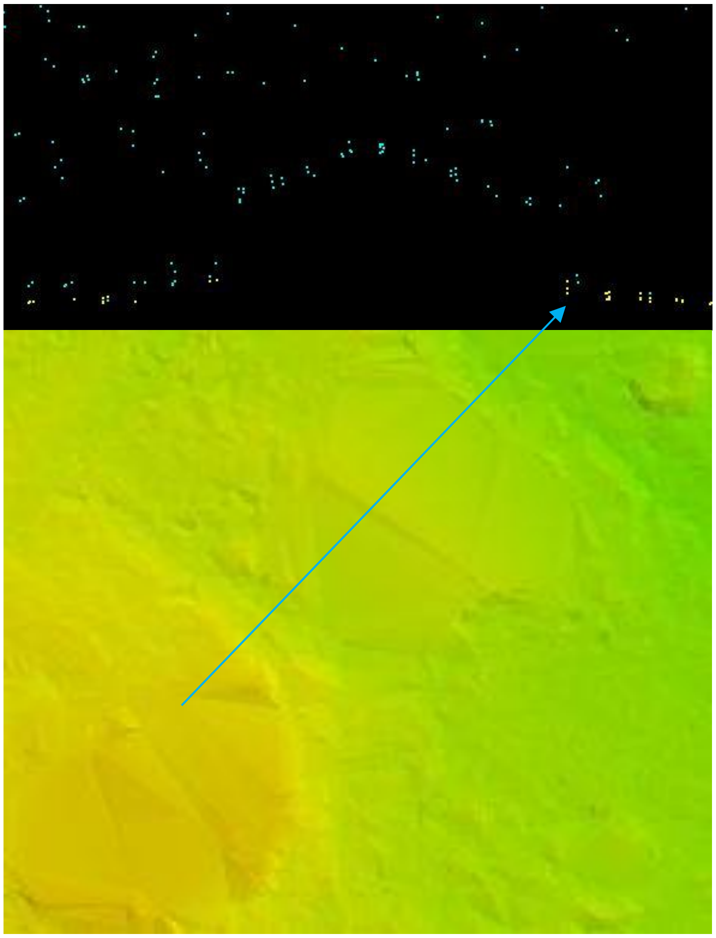


Figure 11 – Tile number 14RQU575870. Profile with points colored by class (class 1=cyan, class 2=yellow) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but 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.

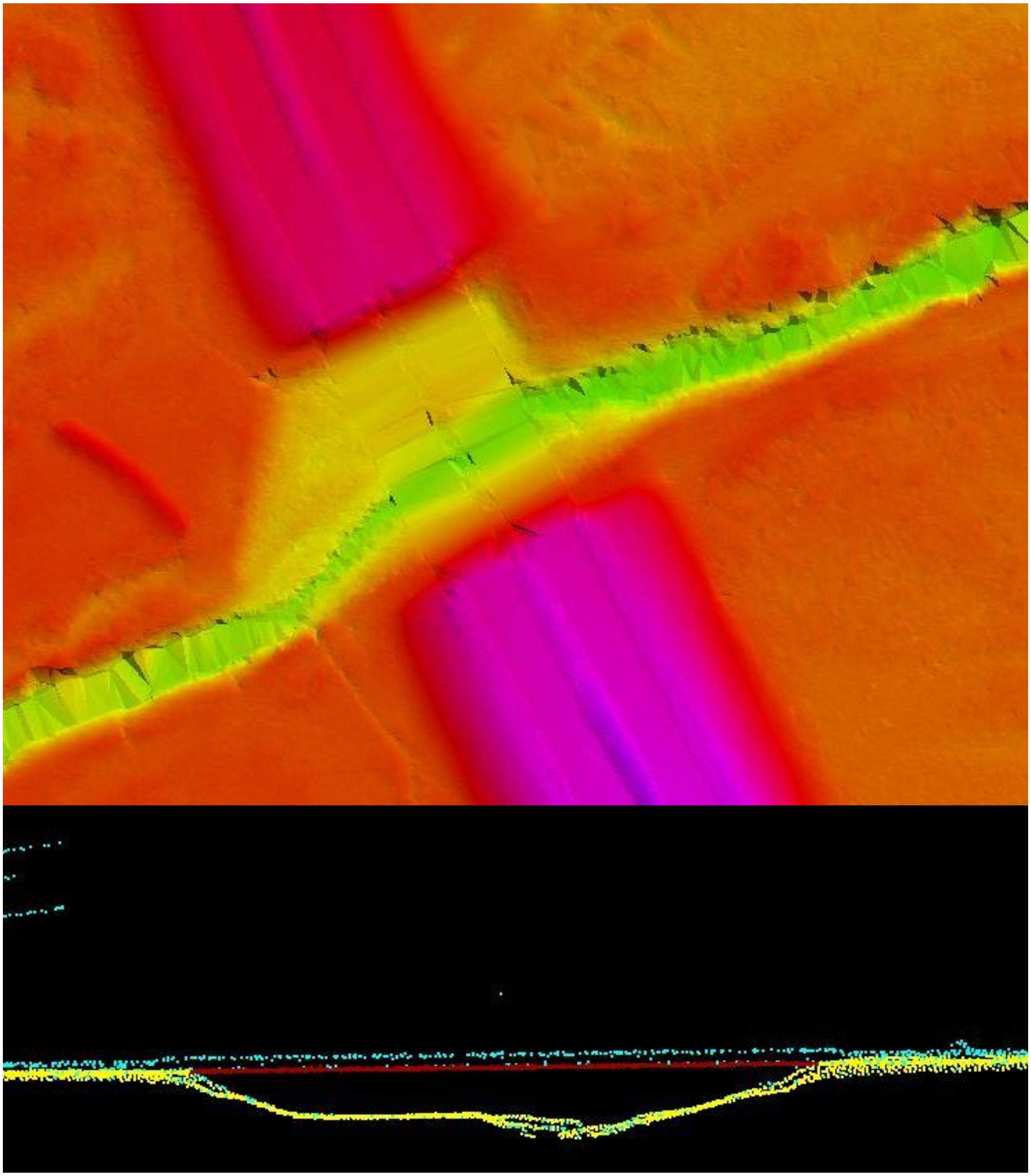


Figure 12 – Tile number 14RQU590885. The DEM in the top view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the bottom view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (yellow) and are classified to bridge deck (red). Unclassified points are cyan.

Culverts and Bridges

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

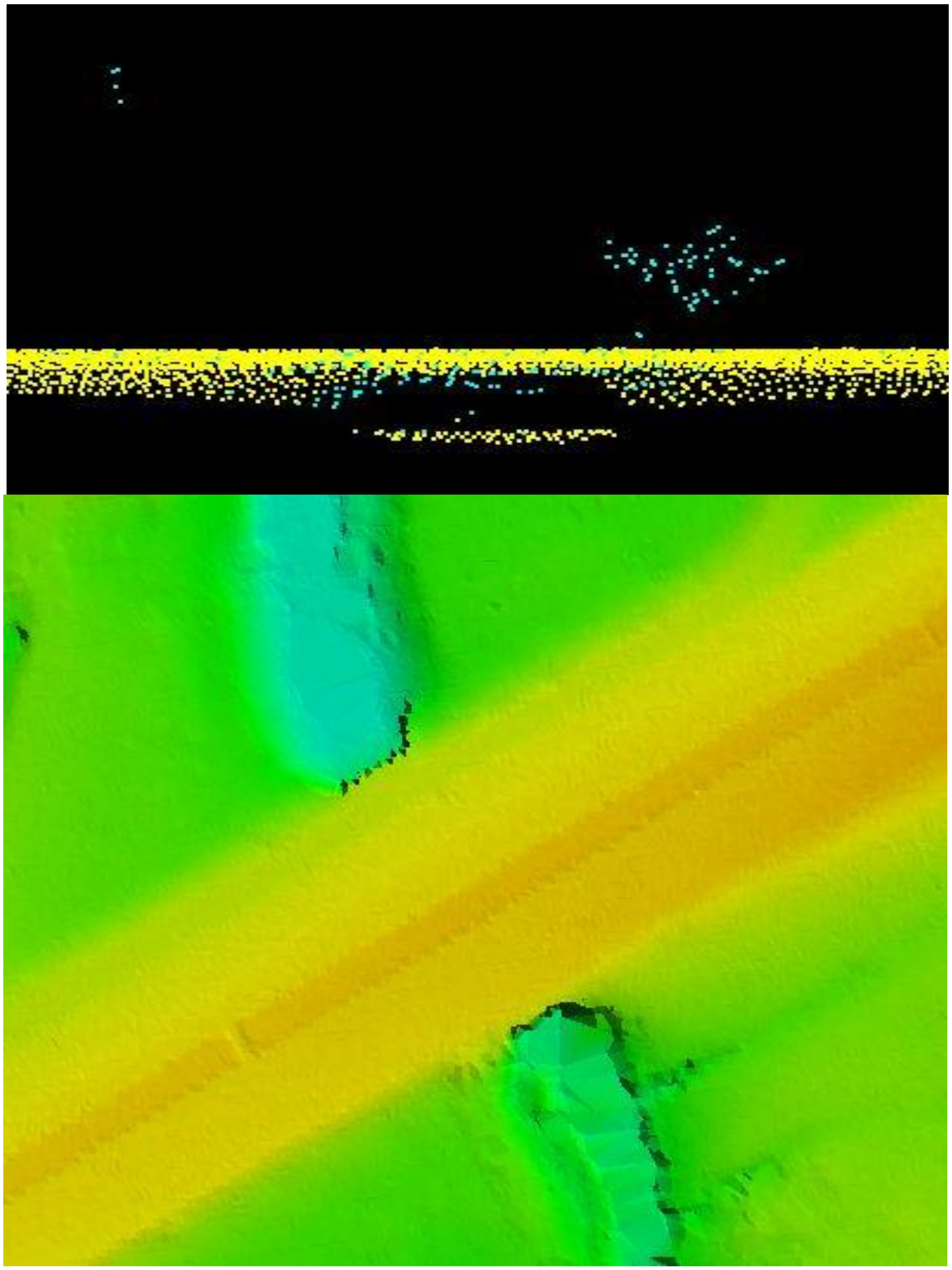


Figure 13– Tile number 14RQU575870. Profile with points colored by class (class 1=cyan, class 2=yellow) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in

the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

Dirt Mounds

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

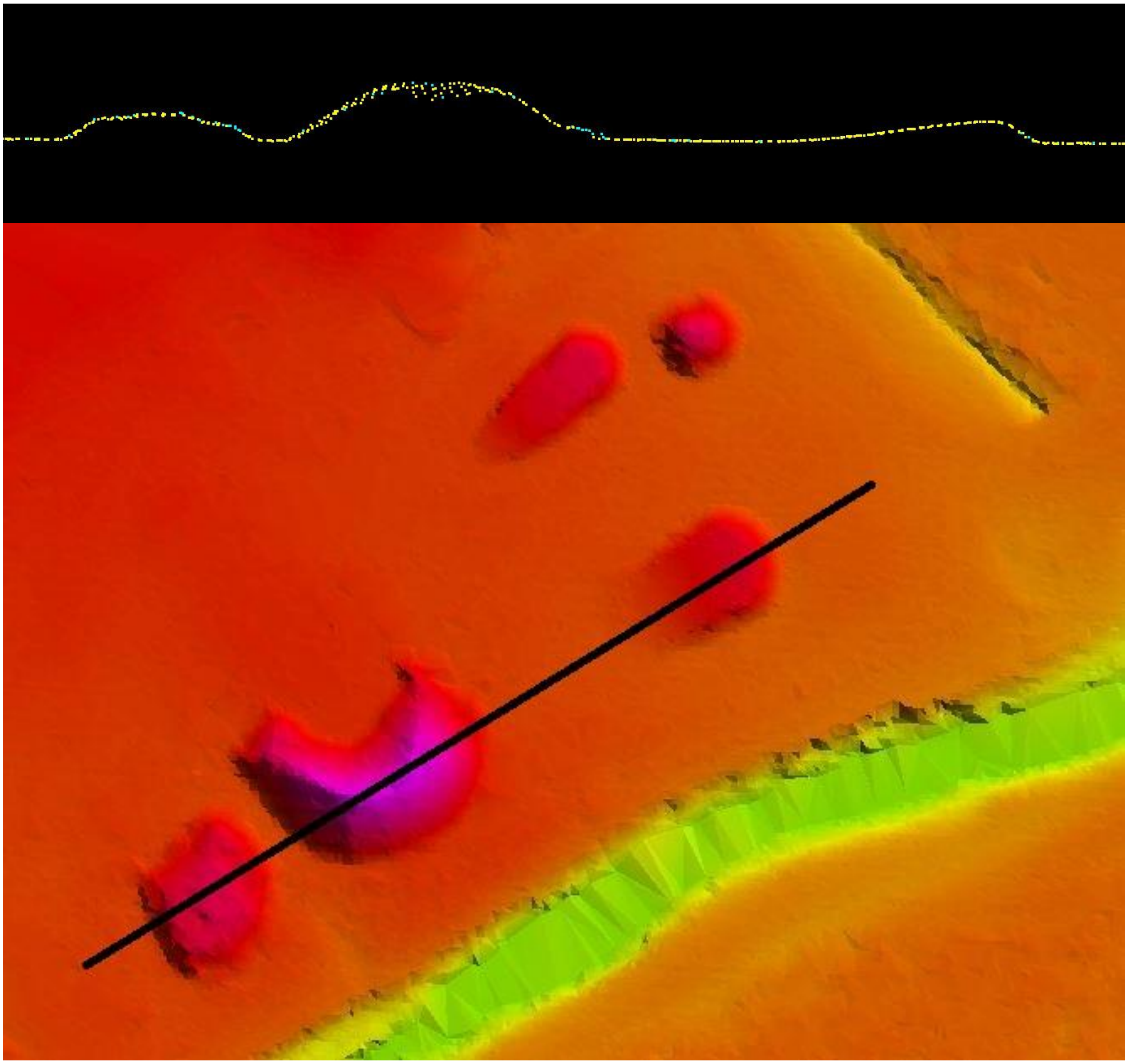


Figure 14 - Tile 14RQU575885. Profile with the points colored by class (class 1=cyan, class 2=yellow) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

Temporal Changes

There are some temporal differences along some hydrographic rivers and streams where adjoining flight lines were from different missions and water levels varied between the missions. To show continuous downhill flow, there were some portions of rivers with higher water levels, which were arbitrarily lowered in the breaklines and final DEMs to maintain flow with lower water levels from adjacent flight lines.

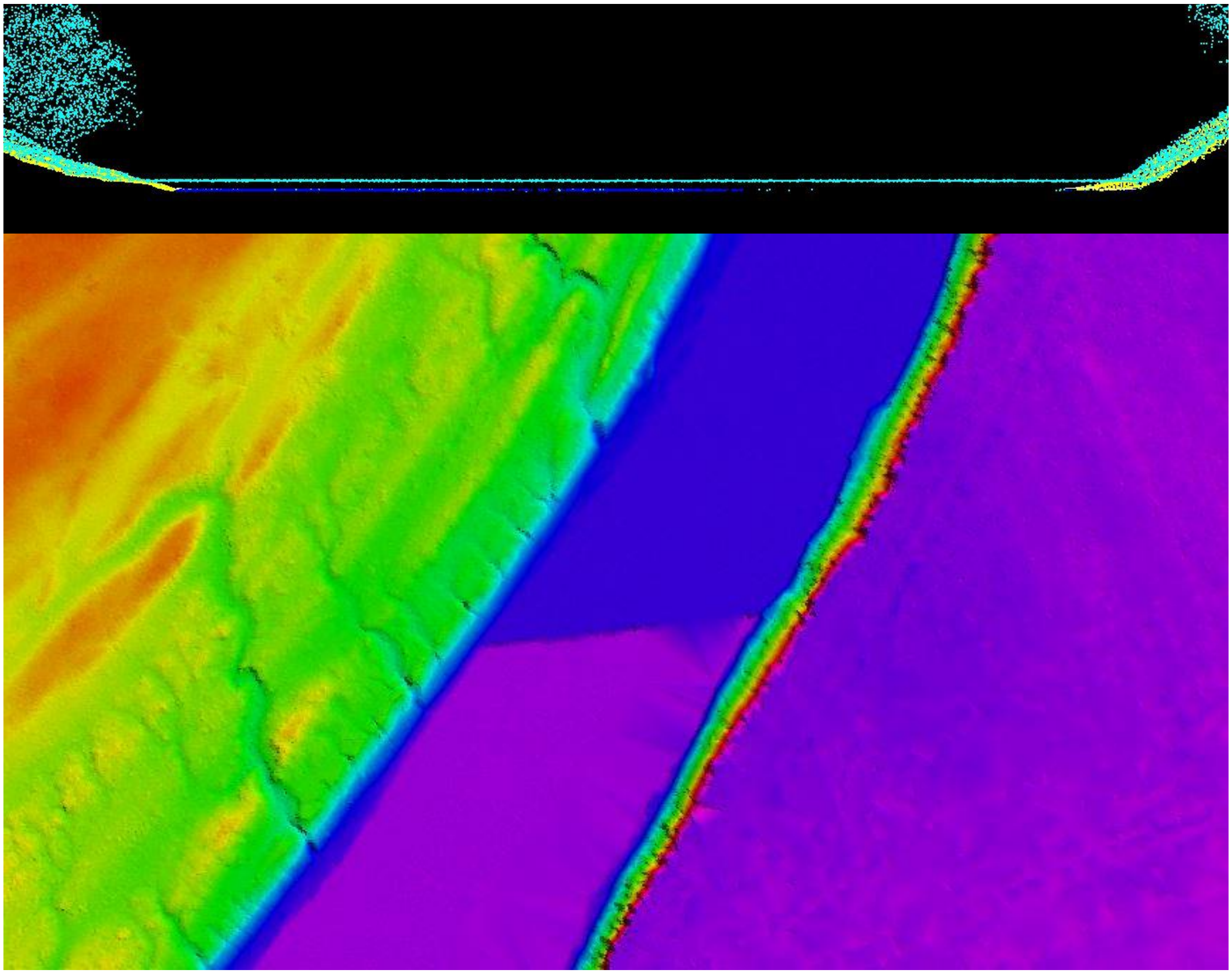


Figure 15-Tile number 14RQU305930. The DEM in the bottom view is colored by elevation and shows stair steps that lower the elevation from one flight line to a lower, adjacent flight line to the south. The flight line to the north was collected during a higher rainfall stage. The cross section above shows the higher unclassified points as class 1 (cyan); these are the higher points from the north flightline. The lower points classified as water (class 9) shown in blue are the points from the south flightline. The grounding routine grounds the lower points and breaklines are used to classify the ground points within breaklines to water (class 9), leaving a layer of unclassified points where there are temporal water level differences.

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	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, one hundred fifty nine (159) 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 the separate survey report delivered with the survey deliverables which details and validates how the survey was completed for this project.

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

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

Point ID	NAD83 (2011) UTM Zone 14		NAVD88 (Geoid 12B)
	Easting X (m)	Northing Y (m)	Elevation (m)
NVA-51	796600.412	3506235.797	93.187
NVA-52	782413.097	3506103.291	137.107
NVA-53	779267.338	3525261.468	100.346
NVA-54	772215.597	3530473.982	102.807
NVA-55	769399.207	3544717.996	100.299
NVA-56	758019.172	3535635.205	122.300
NVA-57	762555.865	3523472.634	117.650
NVA-58	767826.734	3512652.675	145.411
NVA-59	769862.086	3499351.618	153.544
NVA-60	758812.403	3502645.248	152.492
NVA-61	752682.584	3514794.109	140.806
NVA-62	747016.240	3525333.973	119.987
NVA-63	739866.123	3518927.376	140.125
NVA-64	739095.373	3508258.558	158.756
NVA-65	748552.803	3498129.521	140.205

NVA-66	758036.163	3489979.716	142.883
NVA-67	743528.372	3489200.989	127.036
NVA-68	734823.089	3497376.764	129.170
NVA-69	715647.820	3509265.482	153.300
NVA-70	709162.997	3504082.627	182.473
NVA-71	707050.877	3491788.545	163.479
NVA-72	722854.851	3491221.152	164.651
NVA-73	735109.341	3488418.466	133.165
NVA-74	739324.176	3476102.553	145.959
NVA-75	729813.280	3477589.490	143.198
NVA-76	717308.842	3485933.074	139.701
NVA-77	696945.575	3484535.498	146.563
NVA-78	694146.626	3473388.038	107.354
NVA-79	712758.286	3474331.966	125.423
NVA-80	725423.444	3466323.056	152.632
NVA-81	737159.023	3463704.764	136.414
NVA-82	749986.292	3461584.251	100.563
NVA-83	746273.585	3452038.727	112.519
NVA-84	724614.963	3455809.057	157.613
NVA-85	702742.314	3465508.458	120.102
NVA-86	684676.547	3463183.363	137.828
NVA-87	671206.947	3463815.604	183.066
NVA-88	687123.242	3453669.117	160.644
NVA-89	706713.990	3450637.578	98.202
NVA-90	730052.068	3450343.339	117.219
NVA-91	749508.111	3444164.354	116.414
NVA-92	736548.804	3440755.761	144.329
NVA-93	717989.258	3443424.420	128.069
NVA-94	699839.217	3445946.719	133.618
NVA-95	692586.421	3440486.196	124.822
NVA-96	675334.605	3448271.487	169.265
NVA-97	683129.040	3435067.629	144.403
NVA-98	702322.648	3431758.381	113.310
NVA-99	721974.691	3429745.621	99.424
NVA-100	740105.062	3434926.211	135.599
NVA-101	746055.678	3424861.429	126.527
NVA-102	761116.346	3428598.142	102.784
NVA-103	766918.839	3416595.718	89.563
NVA-104	749287.707	3415906.777	112.233
NVA-105	728885.345	3421165.762	103.365
NVA-106	717327.379	3424037.786	86.524
NVA-107	706217.201	3422296.224	111.582
NVA-108	701083.911	3411861.812	136.636

NVA-109	709289.978	3407928.031	128.920
NVA-110	720066.939	3409744.870	104.526
NVA-111	734941.448	3408653.513	81.529
NVA-112	754246.813	3408495.611	102.864
NVA-113	769403.159	3402413.139	81.434
NVA-114	764890.849	3391990.265	85.747
NVA-115	751768.144	3398109.187	106.323
NVA-116	737832.375	3398011.833	74.264
NVA-117	726207.626	3398935.878	107.732
NVA-118	714970.664	3399986.752	118.886
NVA-119	708991.270	3393539.523	162.136
NVA-120	722036.113	3391106.445	92.273
NVA-121	736412.354	3392155.065	75.105
NVA-122	754233.444	3386944.629	94.681
NVA-123	767926.107	3385041.729	64.584
NVA-124	793179.787	3387582.380	109.906
NVA-125	772156.969	3374827.500	75.384
NVA-126	743880.015	3382168.099	69.109
NVA-127	720737.761	3380777.366	102.210
NVA-128	708642.195	3383586.569	147.598
NVA-129	712874.889	3371521.817	131.448
NVA-130	726690.694	3369188.805	84.660
NVA-131	737980.208	3371544.970	100.903
NVA-132	752106.043	3371498.467	64.069
NVA-133	765045.271	3366315.965	61.547
NVA-134	774269.884	3362590.650	56.710
NVA-135	755338.332	3362849.550	60.405
NVA-136	743771.029	3365010.747	92.105
NVA-137	734323.016	3363877.304	102.938
NVA-138	719251.617	3365077.567	107.615
NVA-139	731273.476	3347977.618	106.977
NVA-140	741946.160	3351794.752	107.231
NVA-141	754230.665	3352793.717	92.412
NVA-142	764646.336	3351795.394	95.271
NVA-143	770420.654	3345540.442	58.453
NVA-144	749587.368	3342987.311	99.431
VVA-36	771043.339	3350195.349	68.273
VVA-37	752382.507	3348318.694	102.565
VVA-38	733887.728	3350956.942	92.970
VVA-39	726380.913	3361516.519	97.663
VVA-40	747141.243	3355670.433	96.331
VVA-41	758876.118	3360702.423	81.819
VVA-42	771025.477	3366707.956	58.246

VVA-43	766361.920	3374466.225	99.770
VVA-44	747645.821	3370050.773	70.385
VVA-45	731117.417	3371463.262	101.381
VVA-46	718207.684	3371904.867	99.528
VVA-47	711504.642	3382216.758	155.705
VVA-48	734026.404	3382066.123	98.896
VVA-49	754077.639	3381090.841	84.336
VVA-50	776363.216	3386633.508	84.688
VVA-51	789402.336	3392040.744	84.567
VVA-52	768629.340	3394583.187	77.252
VVA-53	746093.521	3397036.150	105.619
VVA-54	728608.834	3389498.970	106.329
VVA-55	716406.552	3394799.825	108.927
VVA-56	701571.447	3406091.433	113.180
VVA-57	724216.881	3405358.865	106.016
VVA-58	744967.222	3407005.652	112.795
VVA-59	765256.974	3405467.204	85.572
VVA-60	761191.574	3416688.438	83.329
VVA-61	741032.172	3420559.039	132.721
VVA-62	731208.557	3416107.605	85.806
VVA-63	713278.178	3416694.451	86.545
VVA-64	703118.311	3425973.842	127.744
VVA-65	726576.770	3435032.916	123.380
VVA-66	738667.620	3429822.859	142.729
VVA-67	756660.317	3436053.431	111.507
VVA-68	748476.993	3448398.096	118.259
VVA-69	732616.988	3441244.060	120.894
VVA-70	713884.298	3442446.318	103.991
VVA-71	697107.680	3440132.865	118.978
VVA-72	683904.743	3446143.478	137.468
VVA-73	673742.837	3457632.181	152.764
VVA-74	695894.184	3454007.139	105.137
VVA-75	716378.934	3456456.907	114.312
VVA-76	734569.161	3452786.908	147.810
VVA-77	744912.630	3458969.824	135.931
VVA-78	735495.554	3470992.181	124.339
VVA-79	722865.449	3471689.259	154.032
VVA-80	707831.458	3472292.790	127.170
VVA-81	682249.256	3469085.354	129.249
VVA-82	696203.028	3477587.477	140.697
VVA-83	714212.789	3482351.906	134.986
VVA-84	734435.865	3480200.223	152.078
VVA-85	749869.905	3484722.628	128.458

VVA-86	739340.266	3491694.518	120.745
VVA-87	722615.761	3495894.000	171.205
VVA-88	706356.324	3499752.330	179.600
VVA-89	707202.488	3515164.376	171.727
VVA-90	721598.051	3508270.727	154.645
VVA-91	745698.366	3502978.337	158.416
VVA-92	757513.309	3497123.471	139.414
VVA-93	777482.532	3503616.793	129.982
VVA-94	759963.503	3515502.146	113.088
VVA-95	746375.214	3515032.445	133.541
VVA-96	742869.797	3531959.360	108.805
VVA-97	764603.428	3537860.491	122.171
VVA-98	770177.274	3525543.480	111.596
VVA-99	782132.171	3517278.945	134.640
VVA-100	794012.637	3506839.031	93.486

Table 4-Survey checkpoints for the TX Robertson-Freestone-Brazos AOI

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

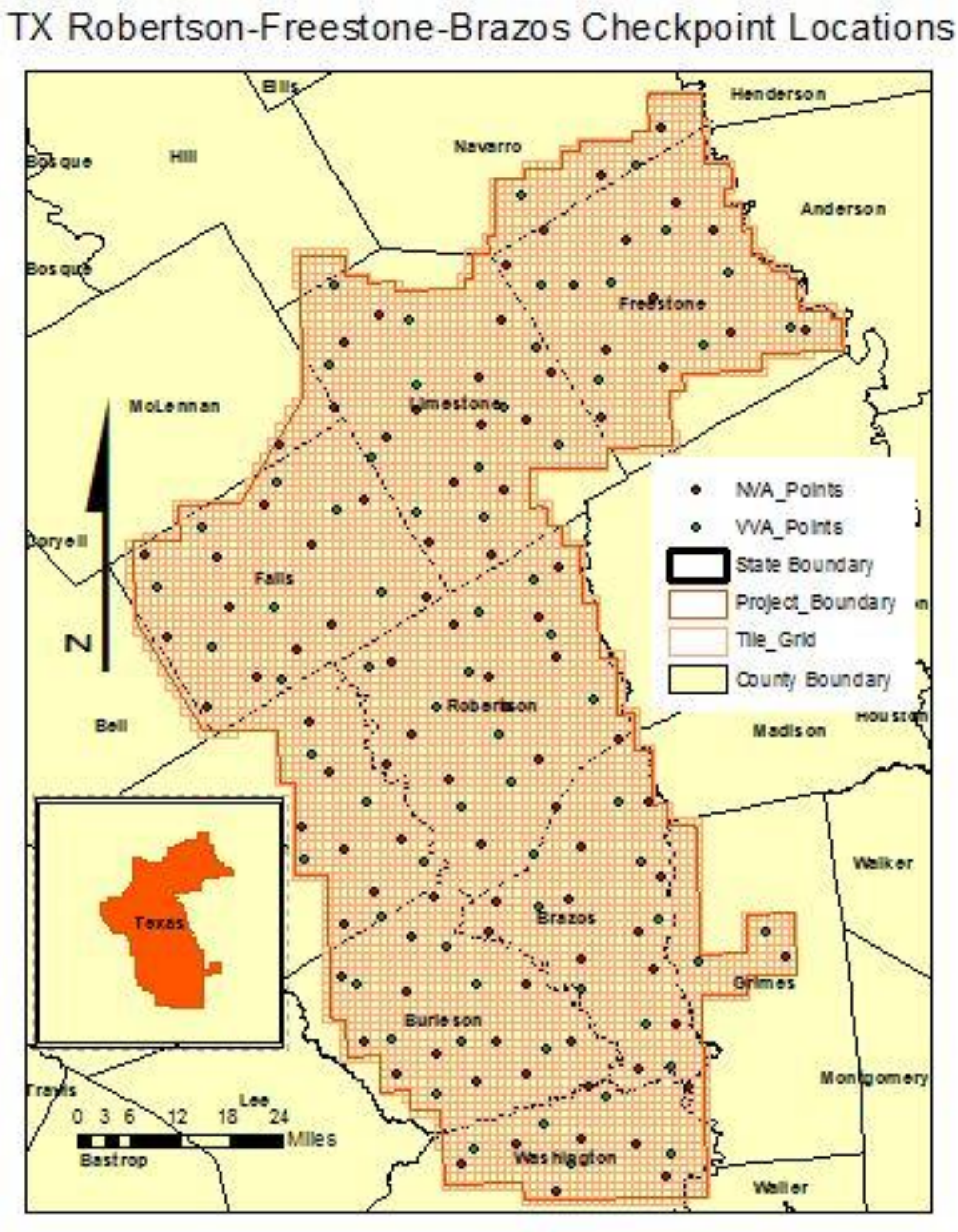


Figure 16 – Location of QA/QC Checkpoints

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 Robertson-Freestone-Brazos 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 95^{th} percentile error for all checkpoints in all vegetated land cover categories combined. The TX Robertson-Freestone-Brazos Lidar Project VVA standard is 29.4 cm based on the 95^{th} percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 5.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	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 95^{th} percentile)

Table 5 – Acceptance Criteria

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

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

VERTICAL ACCURACY RESULTS

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

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm

		(RMSE$_z$ x 1.9600) Spec=19.6 cm	
NVA	94	14.6	
VVA	65		24.5

Table 6 — 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$_z$ =7.5 cm, equating to +/- 14.6 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 24.5 cm at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within +/- 8 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to -2.126 m.

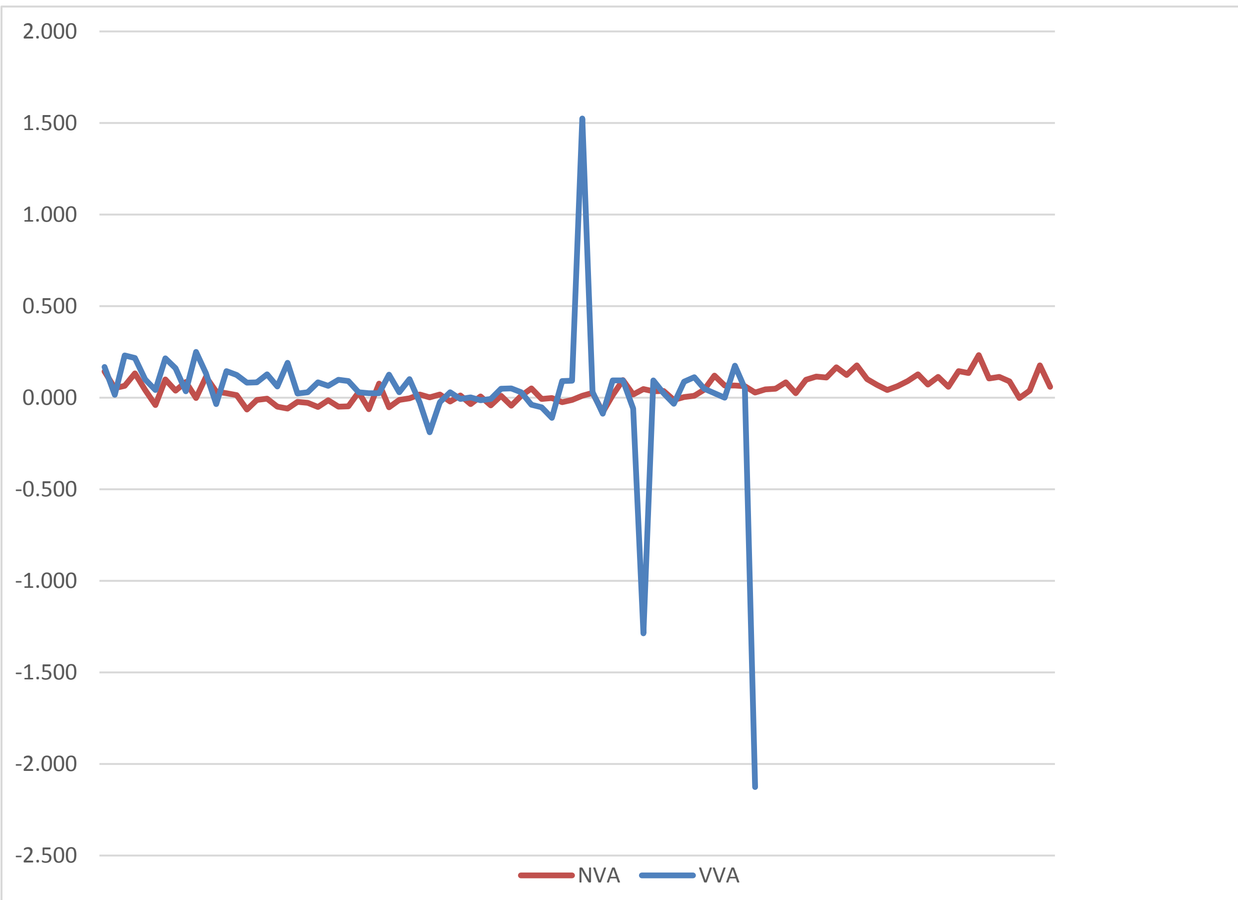


Figure 17 – Magnitude of elevation discrepancies per land cover category

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

Point ID	NAD83(2011) UTM Zone 14		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA-100	794012.637	3506839.031	93.486	91.360	-2.126	2.126
VVA-83	714212.789	3482351.906	134.986	136.510	1.524	1.524
VVA-89	707202.488	3515164.376	171.727	170.440	-1.287	1.287
VVA-45	731117.417	3371463.262	101.381	101.630	0.249	0.249

Table 7 — 5% Outliers

Table 8 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	94	0.075	0.039	0.034	0.453	0.064	-0.134	-0.079	0.232
VVA	65	N/A	0.026	0.049	-2.661	0.377	21.942	-2.126	1.524

Table 8 — Overall Descriptive Statistics

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -2.126 meters and a high of +1.524 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 -0.075 m to +0.075 m.

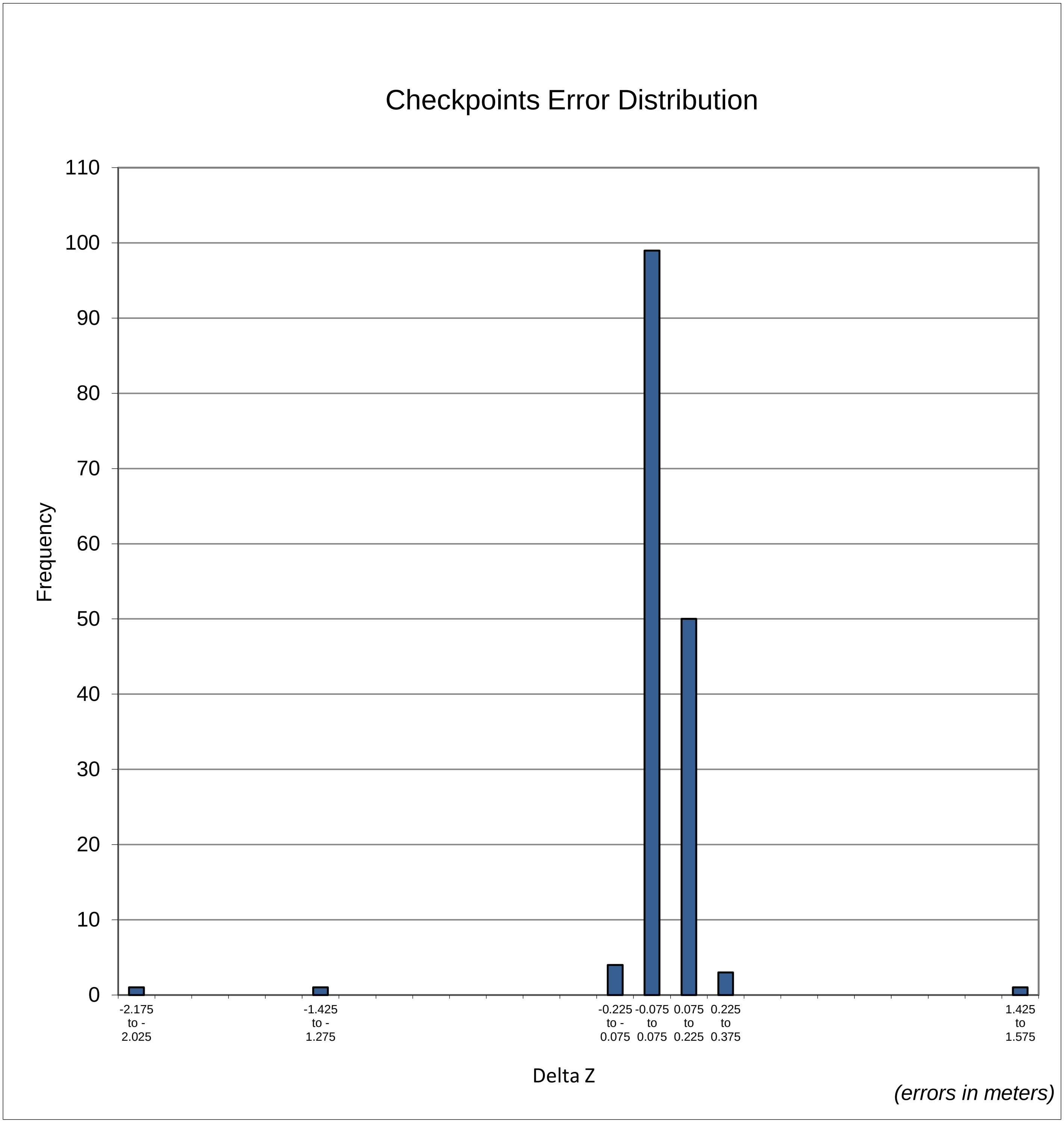


Figure 18 – Histogram of elevation discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the TX Robertson-Freestone-Brazos Project satisfies the project's pre-defined vertical accuracy criteria.

HORIZONTAL ACCURACY TEST PROCEDURES

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

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

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

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

HORIZONTAL ACCURACY RESULTS

Eight checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset. As only eight (8) checkpoints were photo-identifiable, the results are not statistically significant enough to report as a final tested value, but the results of the testing are still shown in the Table below.

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

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

# of Points	$RMSE_x$ (Target=41 cm)	$RMSE_y$ (Target=41 cm)	$RMSE_r$ (Target=58 cm)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=100 cm
8	24.6	32.5	40.8	70.6

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

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1 meter at a 95% confidence level. Eight (8) checkpoints were photo-identifiable but do not produce a statistically significant tested horizontal accuracy value. Using this small sample set of photo-identifiable checkpoints, positional accuracy of this dataset was found to be RMSEx = 24.6 cm and RMSEy = 32.5 cm which equates to +/- 70.6 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

Kinetics used LP360 and intensity imagery to collect the Lakes and Ponds and Rivers and Streams 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.

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	Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains
Pass	Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement.
Pass	Using a terrain created from lidar ground (all ground including 2, 8, and 10) and water points (class 9), compare breakline Z values to interpolated lidar elevations.
Pass	Perform all Topology and Data Integrity Checks
Pass	Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic.

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

DATA DICTIONARY

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983(2011), Units in 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 19-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 examples of bare earth DEMs.

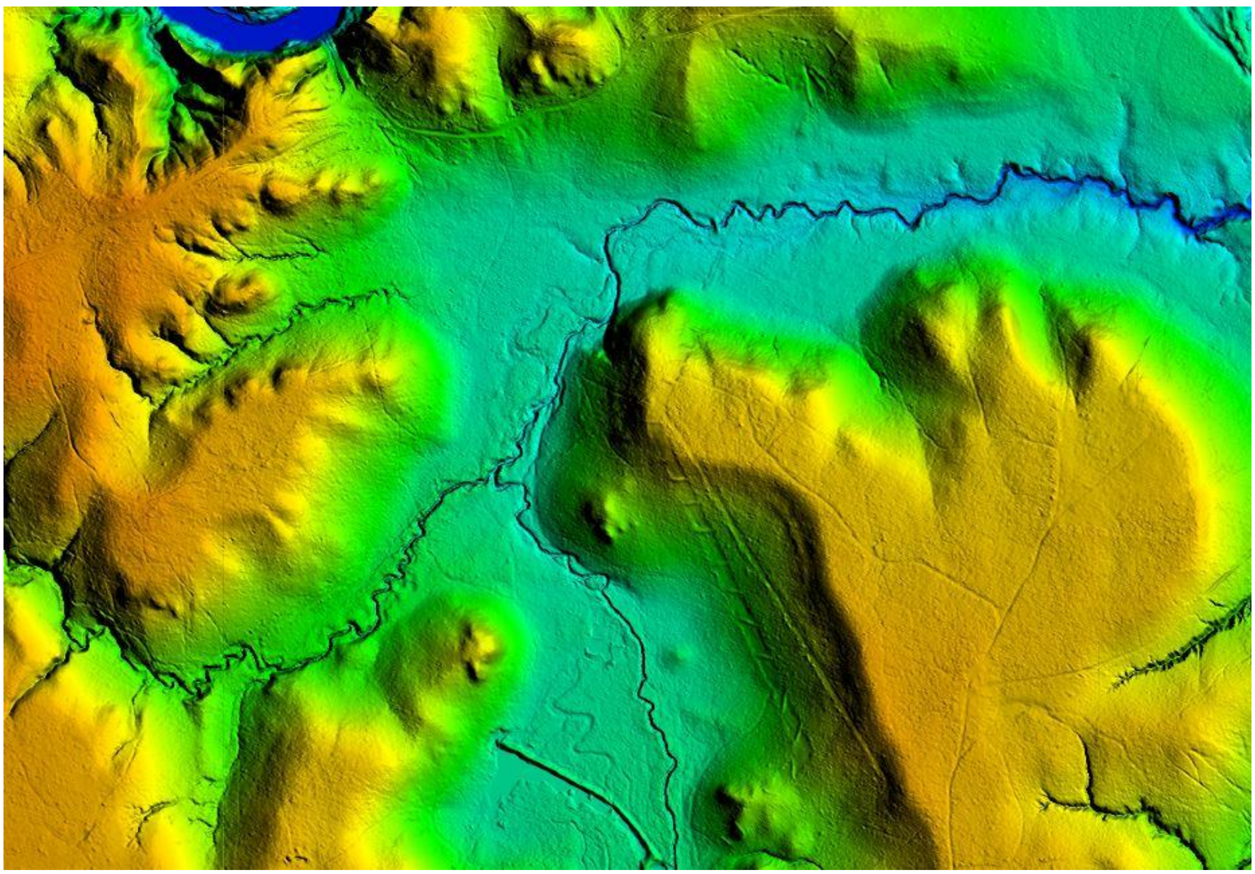


Figure 20. Bare earth DEM

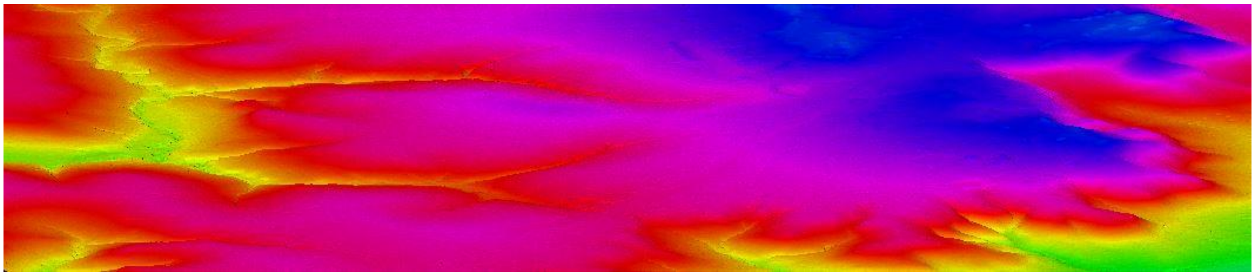
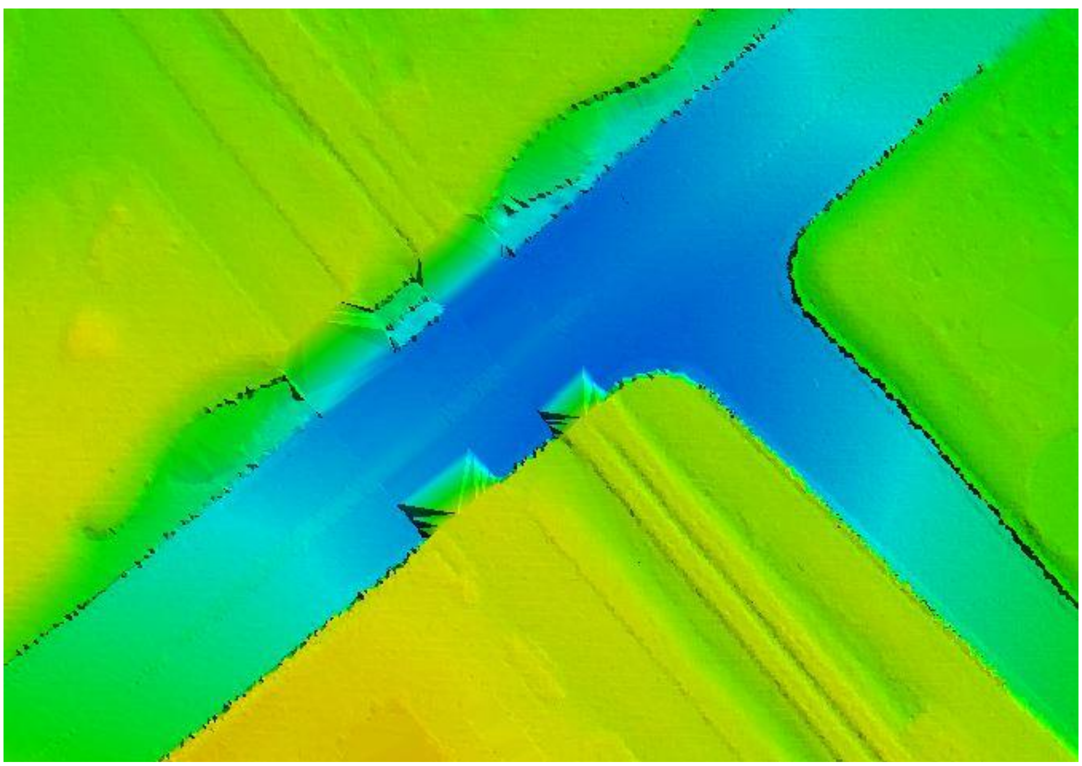


Figure 21. 3D Profile view of the bare earth DEM

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



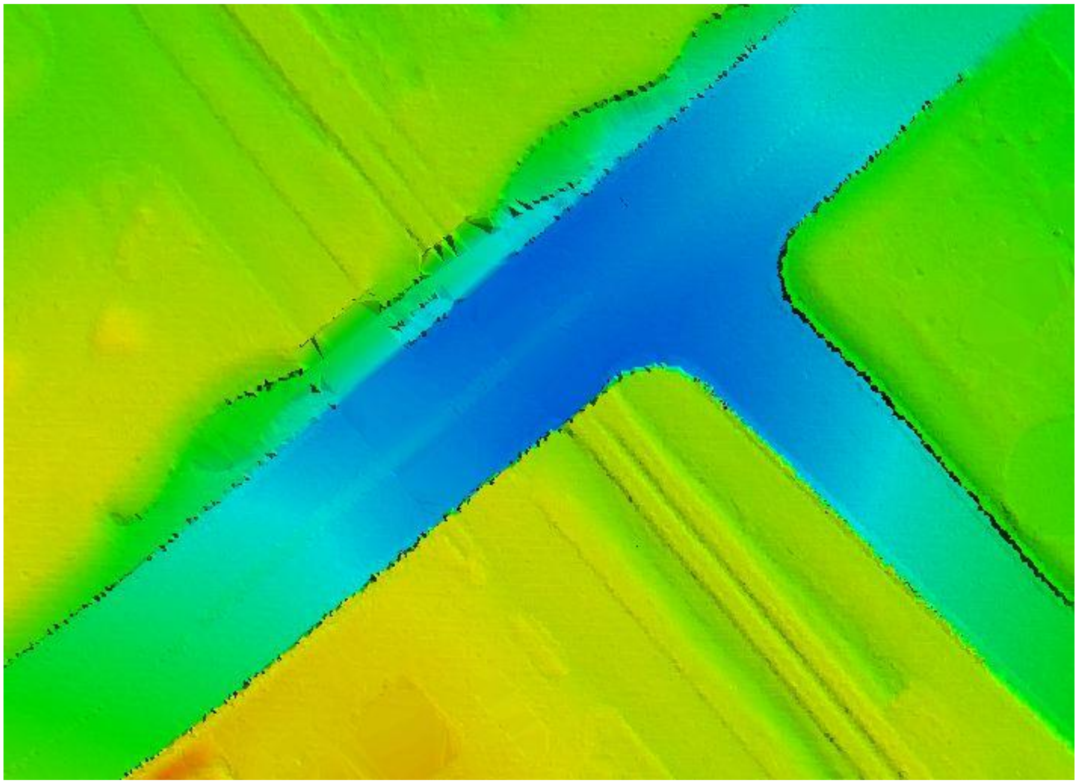


Figure 22. The DEM on the top shows a bridge saddle artifact while the DEM on the bottom shows the same location after bridge saddle breaklines have been enforced.

DEM VERTICAL ACCURACY RESULTS

The same 159 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

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

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	94	14.9	

VVA	65		25.5

Table 11 — DEM tested NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =7.6 cm, equating to +/- 14.9 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 25.5 cm at the 95th percentile.

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

Point ID	NAD83 (2011)UTM Zone 14N		NAVD88 (Geoid 12B)		Delta Z	AbsDelta Z
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
VVA-100	794012.637	3506839.031	93.486	91.355	-2.131	2.131
VVA-83	714212.789	3482351.906	134.986	136.505	1.519	1.519
VVA-89	707202.488	3515164.376	171.727	170.444	-1.283	1.283
VVA-45	731117.417	3371463.262	101.381	101.639	0.258	0.258

Table 12 — 5% Outliers

Table 13 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz NVA Spec=0.100 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	94	0.076	0.038	0.033	0.520	0.066	0.483	-0.103	0.261
VVA	65	N/A	0.029	0.050	-2.683	0.378	21.847	-2.131	1.519

Table 13 — Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the TX Robertson-Freestone-Brazos 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: Complete List of Delivered Tiles

14RQV440800	14RQU695405	14RQV725035	14RPV825455	14RQA095130
14RQV455800	14RQU680540	14RQV725020	14RPV825470	14RQA095145
14RQV440785	14RQU680555	14RQV725005	14RPV825485	14RQA095160
14RQV440770	14RQU680570	14RQU725990	14RPV825500	14RQA095040
14RQV440755	14RQU680585	14RQU725975	14RPV825515	14RQA095025
14RQV425755	14RQU680600	14RQV710080	14RPV825530	14RQA095010
14RQV425770	14RQU680615	14RQV710095	14RPV825545	14RQV095995
14RQV425785	14RQU680630	14RQV710110	14RPV825560	14RQV095980
14RQV425800	14RQU680645	14RQV710125	14RPV825575	14RQV095965
14RQV410800	14RQU680660	14RQV710065	14RPV825590	14RQV095950
14RQV410785	14RQU680675	14RQV710050	14RPV825605	14RQV095935
14RQV410770	14RQU680690	14RQV710035	14RPV825620	14RQV095920
14RQV410755	14RQU680705	14RQV710020	14RPV825635	14RQV095905
14RQV395800	14RQU680720	14RQV710005	14RPV825650	14RQV095890
14RQV395785	14RQU680735	14RQU710990	14RPV825665	14RQV095875
14RQV395770	14RQU680750	14RQU710975	14RPV825680	14RQV095860
14RQV395755	14RQU680765	14RQU695975	14RPV825695	14RQV095845
14RQV380755	14RQU680780	14RQU695990	14RPV825710	14RQV095830
14RQV380770	14RQU680795	14RQV695005	14RPV825725	14RQV095815
14RQV380785	14RQU680810	14RQV695020	14RPV840710	14RQV080815
14RQV380800	14RQU680825	14RQV695035	14RPV840695	14RQV080830
14RQV365755	14RQU680840	14RQV695050	14RPV840680	14RQV080845
14RQV365770	14RQU680855	14RQV695065	14RPV840665	14RQV080860
14RQV365785	14RQU680870	14RQV695080	14RPV840650	14RQV080875
14RQV365800	14RQU680885	14RQV695095	14RPV840635	14RQV080890
14RQV350800	14RQU680900	14RQV695110	14RPV840620	14RQV080905
14RQV350785	14RQU680915	14RQV695125	14RPV840605	14RQV080920
14RQV350770	14RQU665930	14RQV695140	14RPV840590	14RQV080935
14RQV350755	14RQU665915	14RQV695155	14RPV840575	14RQV080950
14RQV335800	14RQU665900	14RQV680155	14RPV840560	14RQV080965
14RQV335785	14RQU665885	14RQV680140	14RPV840545	14RQV080980
14RQV335770	14RQU665870	14RQV680125	14RPV840530	14RQV080995
14RQV335755	14RQU665855	14RQV680110	14RPV840515	14RQA080010
14RQV320755	14RQU665840	14RQV680095	14RPV840500	14RQA080025
14RQV320770	14RQU665825	14RQV680080	14RPV840485	14RQA080040
14RQV320785	14RQU665810	14RQV680065	14RPV840470	14RQA080055
14RQV320800	14RQU665795	14RQU560960	14RPV840455	14RQA080070
14RQV305755	14RQU665780	14RQU560975	14RPV840440	14RQA080085
14RQV305770	14RQU665765	14RQU560990	14RPV840425	14RQA080100
14RQV305785	14RQU680525	14RQV560005	14RPV840410	14RQA080115
14RQV305800	14RQU680510	14RQV560020	14RPV840395	14RQA080130

14RQV290800	14RQU680495	14RQV560035	14RPV840380	14RQA080145
14RQV290785	14RQU680480	14RQV560050	14RPV840365	14RQA080160
14RQV290770	14RQU680465	14RQV560065	14RPV840350	14RQA080175
14RQV290755	14RQU680450	14RQV560080	14RPV840335	14RQA080190
14RQV275800	14RQU680435	14RQV545305	14RPV840320	14RQA080205
14RQV275785	14RQU680420	14RQV545320	14RPV840305	14RQA065205
14RQV275770	14RQU680405	14RQV545335	14RPV840290	14RQA065190
14RQV275755	14RQU665405	14RQV545290	14RPV855290	14RQA065175
14RQV260785	14RQU665420	14RQV545275	14RPV855305	14RQA065160
14RQV260800	14RQU665435	14RQV545260	14RPV855320	14RQA065145
14RQV260770	14RQU665450	14RQV545245	14RPV855335	14RQA065130
14RQV260755	14RQU665465	14RQV545230	14RPV855350	14RQA065115
14RQV200755	14RQU665480	14RQV545215	14RPV855365	14RQA065100
14RQV200770	14RQU665495	14RQV545200	14RPV855380	14RQA065085
14RQV200785	14RQU665510	14RQV545185	14RPV855395	14RQV065815
14RQV200800	14RQU665525	14RQV545170	14RPV855410	14RQV065830
14RQV245755	14RQU665540	14RQV545155	14RPV840725	14RQV065845
14RQV245770	14RQU665555	14RQV545140	14RPV855725	14RQV065860
14RQV245785	14RQU665570	14RQV545125	14RPV855710	14RQV065875
14RQV245800	14RQU665585	14RQV545110	14RPV855695	14RQV065890
14RQV230755	14RQU665600	14RQV545095	14RPV855680	14RQV065905
14RQV230770	14RQU665615	14RQV545080	14RPV855665	14RQV065920
14RQV230785	14RQU665630	14RQV545065	14RPV855650	14RQV065935
14RQV230800	14RQU665645	14RQV545050	14RPV855635	14RQV065950
14RQV215800	14RQU665660	14RQV545035	14RPV855620	14RQV065965
14RQV215785	14RQU665675	14RQV545020	14RPV855605	14RQV065980
14RQV215770	14RQU665690	14RQV545005	14RPV855590	14RQV065995
14RQV215755	14RQU665705	14RQU545990	14RPV855575	14RQA065010
14RQA245130	14RQU665720	14RQU545975	14RPV855560	14RQA065025
14RQA230130	14RQU665735	14RQU545960	14RPV855545	14RQA065040
14RQA245115	14RQU665750	14RQV530125	14RPV855530	14RQA065055
14RQA230115	14RQU650930	14RQV530140	14RPV855515	14RQA065070
14RQA245100	14RQU650915	14RQV530155	14RPV855500	14RQA050205
14RQA230100	14RQU650900	14RQV530170	14RPV855485	14RQA050190
14RQA245085	14RQU650885	14RQV530185	14RPV855470	14RQA050175
14RQA230085	14RQU650870	14RQV530200	14RPV855455	14RQA050160
14RQA245070	14RQU650855	14RQV530215	14RPV855440	14RQA050145
14RQA230070	14RQU650840	14RQV530230	14RPV855425	14RQA050130
14RQA245055	14RQU650825	14RQV530245	14RPV870290	14RQA050115
14RQA230055	14RQU650810	14RQV530260	14RPV870305	14RQA050100
14RQA245040	14RQU650795	14RQV530275	14RPV870320	14RQA050085
14RQA230040	14RQU650780	14RQV530290	14RPV870335	14RQA050070

14RQA245025	14RQU650765	14RQV530305	14RPV870350	14RQA050055
14RQA230025	14RQU650750	14RQV530320	14RPV870365	14RQA050040
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14RQU695885	14RQU755990	14RPV810515	14RQA110115	14RQV575875
14RQU695900	14RQU740990	14RPV810530	14RQA110100	14RQV575890
14RQU695915	14RQV755005	14RPV810545	14RQA110085	14RQV575905
14RQU695930	14RQV740005	14RPV810560	14RQA110070	14RQV575920
14RQU695945	14RQV755020	14RPV810575	14RQA110055	14RQV560965
14RQU695960	14RQV740020	14RPV810590	14RQA110040	14RQV560950
14RQU680930	14RQV755035	14RPV810605	14RQA110025	14RQV560935
14RQU695705	14RQV740035	14RPV810620	14RQA110010	14RQV560920
14RQU695690	14RQV755050	14RPV810635	14RQV110995	14RQV560905
14RQU695675	14RQV740050	14RPV810650	14RQV110980	14RQV560890
14RQU695660	14RQV755065	14RPV810665	14RQV110965	14RQV560875
14RQU695645	14RQV740065	14RPV810680	14RQV110950	14RQV560860
14RQU695630	14RQV755080	14RPV810695	14RQV110935	14RQV560845
14RQU695615	14RQV740080	14RPV810725	14RQV110920	14RQV560830
14RQU695600	14RQV755095	14RPV810710	14RQV110905	14RQV560815

14RQU695585	14RQV740095	14RPV825440	14RQV110890	14RQV560800
14RQU695570	14RQV755110	14RPV825425	14RQV110875	14RQV545905
14RQU695555	14RQV740110	14RPV825410	14RQV110860	14RQV545920
14RQU695540	14RQV755125	14RPV825395	14RQV110845	14RQV545935
14RQU695525	14RQV740125	14RPV825380	14RQV110830	14RQV545950
14RQU695510	14RQV725125	14RPV825365	14RQV110815	14RQV545965
14RQU695495	14RQV725110	14RPV825350	14RQA095055	14RQV545890
14RQU695480	14RQV725095	14RPV825335	14RQA095070	14RQV545875
14RQU695465	14RQV725080	14RPV825320	14RQA095085	14RQV545860
14RQU695450	14RQV725065	14RPV825305	14RQA095100	14RQV545845
14RQU695435	14RQV725050	14RPV825290	14RQA095115	14RQV545830
14RQU695420	14RQV545815	14RQV545800		

Appendix B: GPS and IMU Processing

Please see the separate document “Appendix_B_GPS_and_IMU_Processing.pdf” delivered with this report.