Dewberry

PROJECT REPORT

For the

Louisa, Virginia LiDAR Project

USGS Contract:
G10PC00013

Task Order Number:
G12PD00264

Prepared for:
USGS

Prepared by:
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1 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 Louisa, Virginia Project Area.

The LiDAR data were processed to a bare-earth digital terrain model (DTM). Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Deliverables were produced in both UTM and State Plane coordinates. The data was formatted according to tiles with each UTM tile covering an area of 1,000 meters by 1,000 meters and each State Plane tile covering an area of 2,500 feet by 2,500 feet. A total of 797 UTM tiles and 1,338 State Plane tiles were produced for the project encompassing an area of approximately 277 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 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. Note that a separate Survey Report was created for this portion of the project.

Laser Mapping Specialist, Inc (LMSI) completed LiDAR data acquisition and data calibration for the project area.

Survey Area

The project area addressed by this report falls within the Virginia counties of Fluvanna, Goochland, Louisa, and Spotsylvania.

Date of Survey

The LiDAR aerial acquisition was conducted from March 9, 2012 thru March 13, 2012.

Datum Reference

Data produced for the project were delivered in both of the following reference systems.

Horizontal Datum: North American Datum of 1983 (NAD 83)
Vertical Datum: North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 18
Units: Horizontal units are in meters, Vertical units are in meters.
Geoid Model: Geoid09 (Geoid 09 was used to convert ellipsoid heights to orthometric heights).

Horizontal Datum: North American Datum of 1983 HARN (NAD83 HARN)
Vertical Datum: North American Vertical Datum of 1988 (NAVD88)
Coordinate System: Virginia State Plane South
Units: Horizontal units are in U.S. Survey feet, Vertical units are in feet.
Geoid Model: Geoid09 (Geoid 09 was used to convert ellipsoid heights to orthometric heights).

LiDAR Vertical Accuracy

For the Louisa, Virginia LiDAR Project, all checkpoints were located in Open Terrain land cover type. The tested $RMSE_z$ for checkpoints in open terrain equaled **0.07 m** compared with the 0.125 m specification; and the FVA computed using $RMSE_z$ x 1.9600 was equal to **0.13 m**, compared with the 0.245 m specification.

For the Louisa, Virginia LiDAR Project, the tested CVA computed using the 95^{th} percentile was equal to **0.12 m,** compared with the 0.363 m specification.

Project Deliverables

The deliverables for the project are listed below.

1. Raw Point Cloud Data (Swaths) in UTM coordinates
2. Classified Point Cloud Data (Tiled) in both UTM and State Plane coordinates
3. Bare Earth Surface (Raster DEM – IMG Format) in both UTM and State Plane coordinates
4. Intensity Images (8-bit gray scale, tiled, GeoTIFF format) in both UTM and State Plane coordinates
5. Breakline Data (File GDB) in both UTM and State Plane coordinates
6. Control & Accuracy Checkpoint Report & Points
7. Metadata
8. Project Report (Acquisition, Processing, QC)
9. Project Extents in both UTM and State Plane coordinates, Including a shapefile derived from the LiDAR Deliverable

2 Project Tiling Footprints

2.1 UTM Tiling Footprints

Seven hundred ninety seven (797) UTM tiles were delivered for the project. Each tile's extent is 1,000 meters by 1,000 meters.

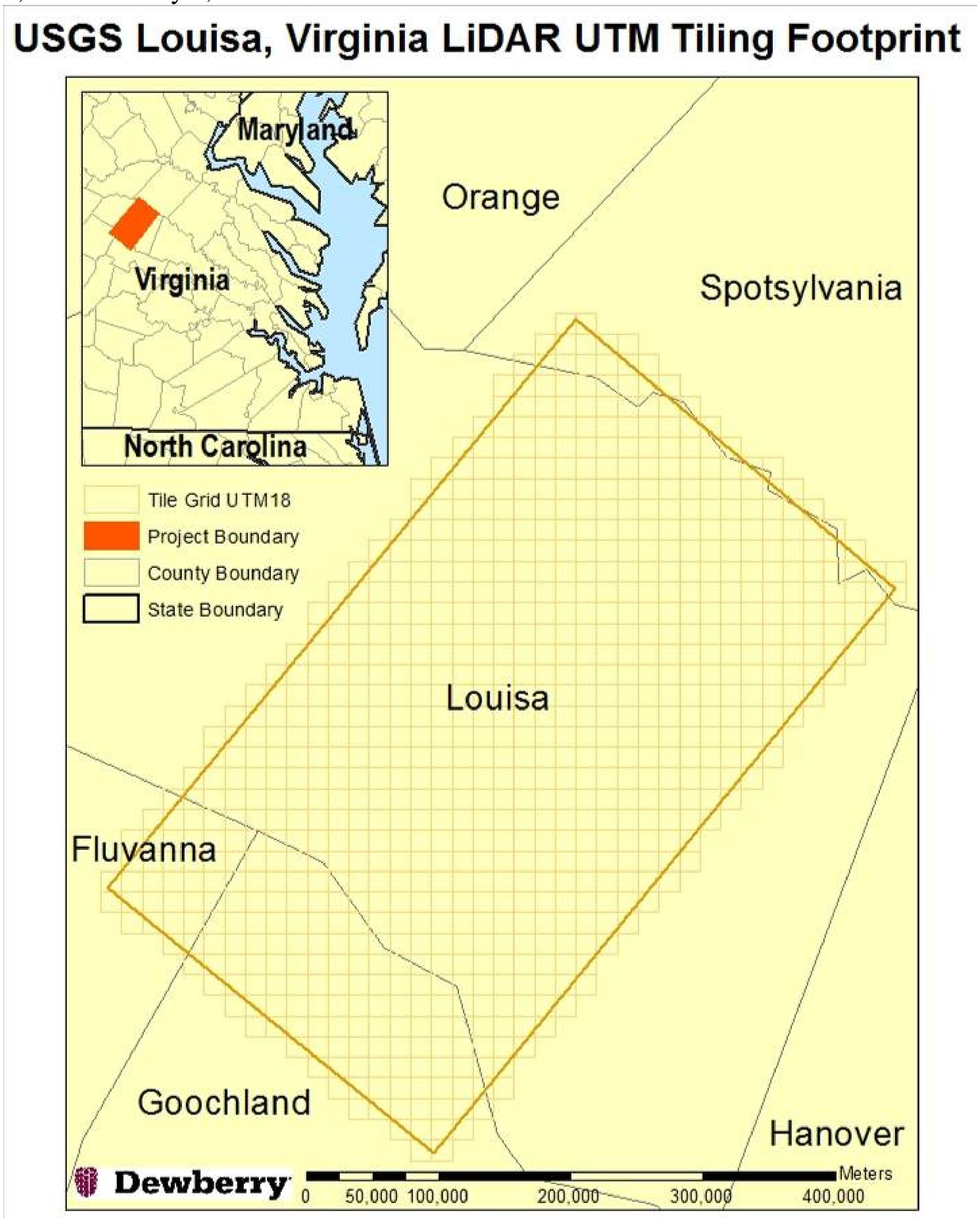

Figure 1: UTM Project Map

2.2 List of delivered UTM tiles (797):

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2.3 State Plane Tiling Footprints

One thousand three hundred and thirty eight (1,338) State Plane tiles were delivered for the project. Each tile's extent is 2,500 feet by 2,500 feet.

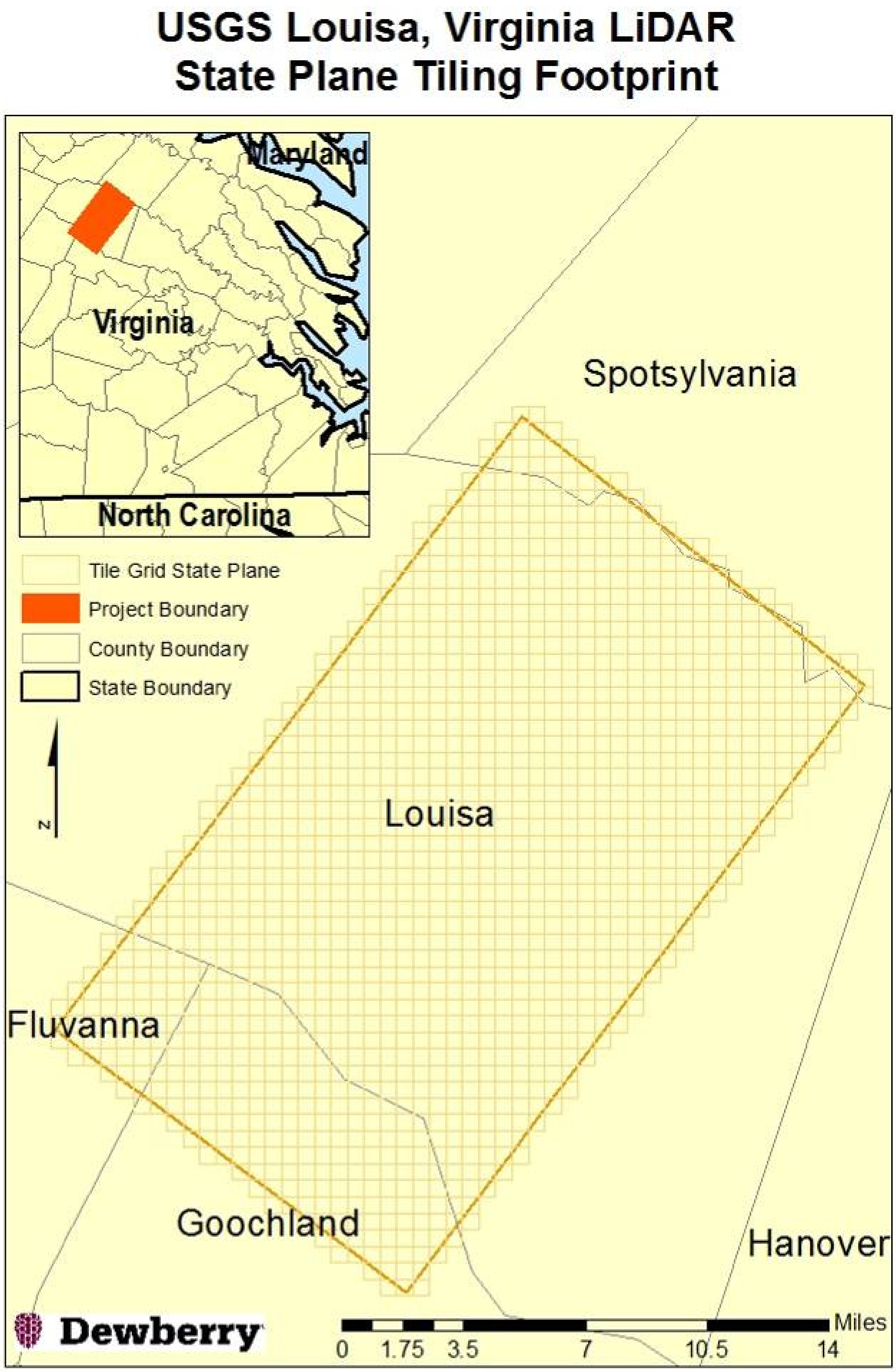

Figure 2: State Plane Project Map

2.4 *List of delivered State Plane tiles (1, 338):*

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18STH600143
18STH625143
18STH650143
18STH675143
18STH700143
18STH725143
18STH750143
18STH775143
18STH800143
18STH825143
18STH850143
18STH400168
18STH425168

18STH450168
18STH475168
18STH500168
18STH525168
18STH550168
18STH575168
18STH600168
18STH625168
18STH650168
18STH675168
18STH700168
18STH725168
18STH750168
18STH775168
18STH800168
18STH825168
18STH400193
18STH425193
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18STH425218
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18STH475218
18STH500218
18STH525218
18STH550218
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18STH500318
18STH525318
18STH550318
18STH575318
18STH600318
18STH625318
18STH525343
18STH550343
18STH575343
18STH600343
18STH550368
18STH575368

3 LiDAR Acquisition

Louisa, VA LiDAR ALTM NAV Flight Plan – Optech ALTM3100EA LiDAR system. Piper Navajo Aircraft.

3.1 Flight Layout

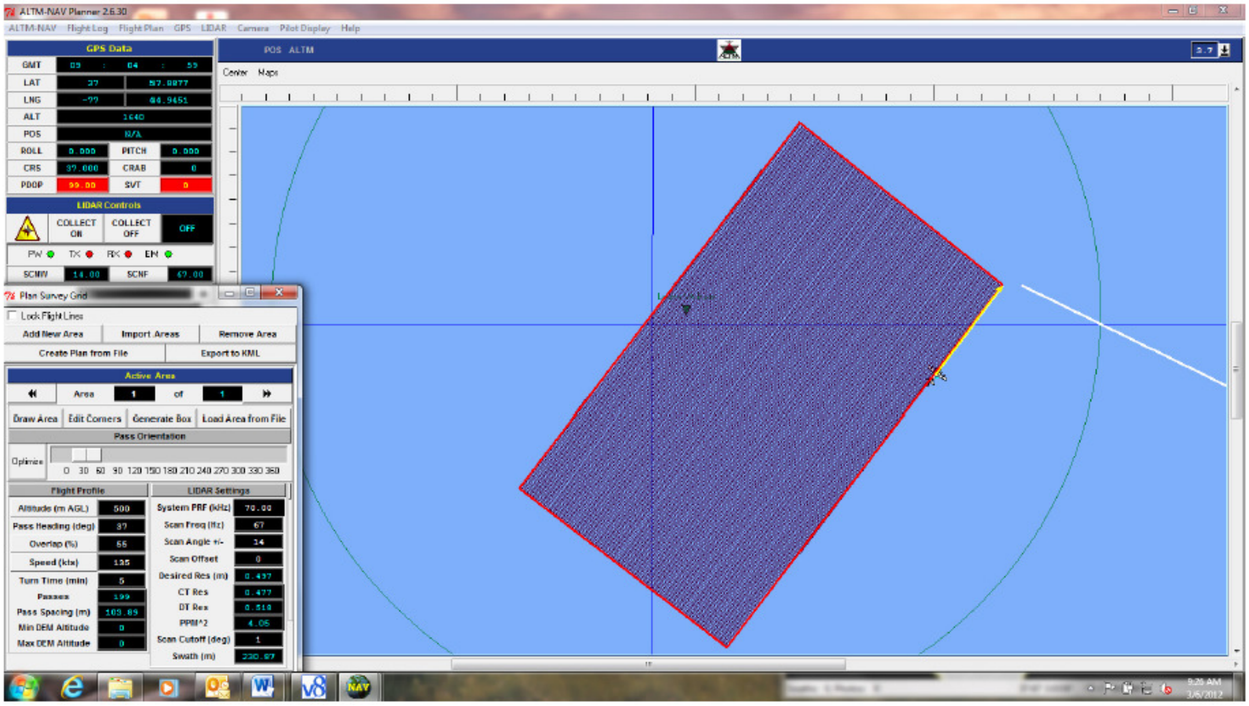

Figure 3: Flight Layout

3.2 LiDAR Flight Parameters

Laser Firing Rate:	70000
Altitude (mtr. AGL):	500
Swath Overlap (%):	55
Approx. Ground Speed (kts):	135
Scan Rate (Hz):	67
Scan Angle (°±):	14
Computed Along Track Spacing (mtr):	0.5
Computed Cross track Spacing (mtr.):	0.5
Computed Swath Width (mtr.):	230
Number of Lines Req'd:	199
Line Spacing (mtr.)	104

Table 1: Flight Parameters

3.3 *LiDAR Surveys*

LIDAR acquisition began on March 10, 2012 (julian day 069) and was completed on March 14, 2012 (julian day 073). A total of 11 survey missions were flown to complete the project. LMSI utilized an Optech ALTM3100EA for the acquisition. The flight plan was flown as planned with no modifications. There were no unusual occurrences during the acquisition and the sensor performed within specifications. There were 198 flight lines required to complete the project.

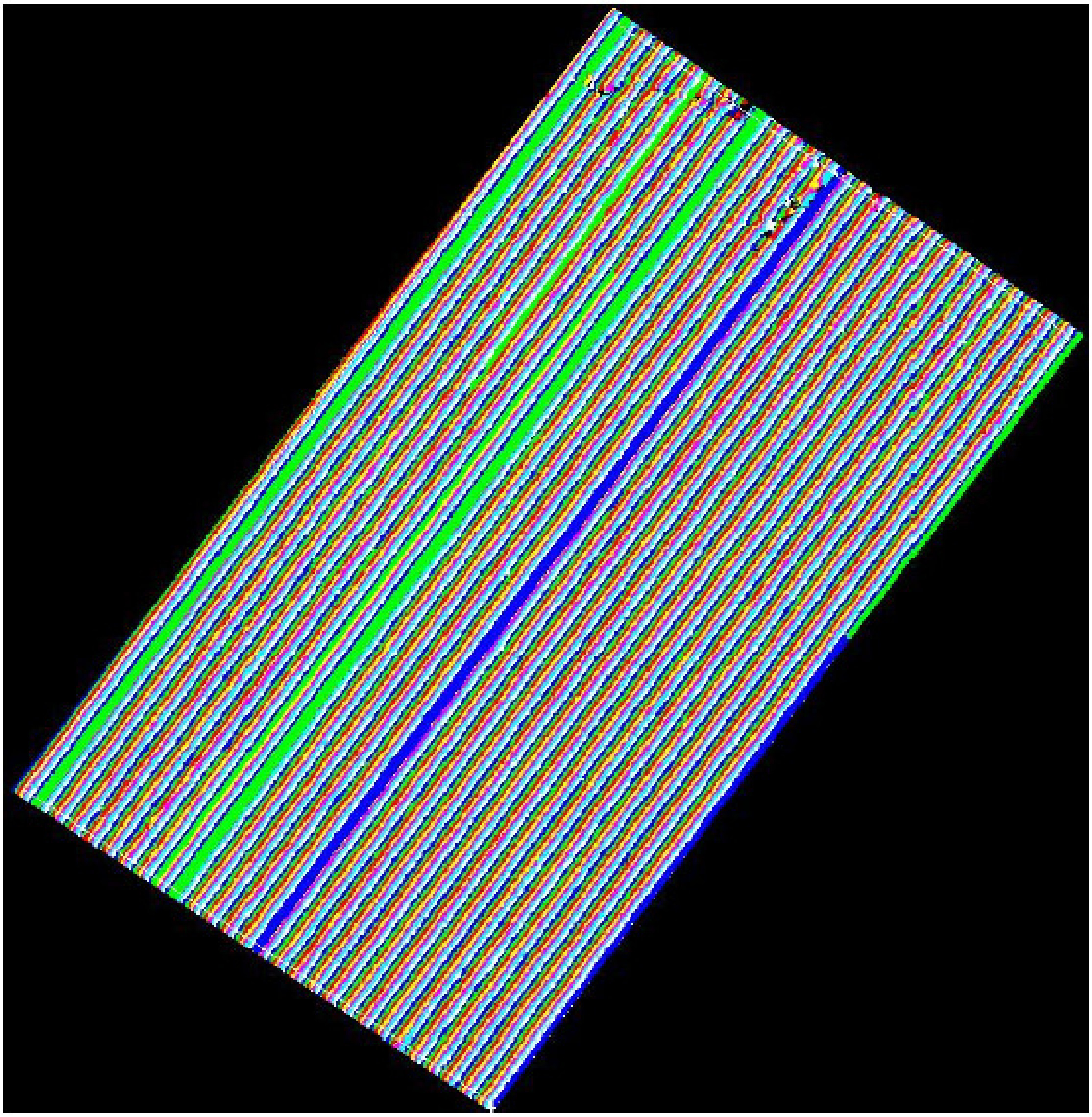

Figure 4: LiDAR coverage map

3.4 LiDAR Survey Coverage Check

Project coverage was checked on site with no data gaps except for water features.

3.5 GPS Surveys

Base Stations

Three base stations were utilized, LKU_A, LKU_B, and VA_21. The base station coordinates are set forth below:

LKU_A Latitude: 28 00 28.8599
Longitude: -77 57 52.49022
Ellipsoid Height: 116.4462
Orthometric Height: 148.7701

LKU_B Latitude: 28 00 24.09984
Longitude: -77 58 28.25092
Ellipsoid Height: 110.0956
Orthometric Height: 142.4221

VA_21 Latitude: 28 00 25.25513
Longitude: -77 58 24.21356
Ellipsoid Height: 112.472
Orthometric Height: 144.7978

Ground Control/QC Check Points

4 kinematic cross sections and 11 static points were surveyed at various locations throughout the project to be utilized for quality control and adjustment of the LIDAR data.

Airborne GPS Trajectories

All airborne GPS trajectories were processed and checked on site. All trajectories were very high quality with forward/reverse separation rms between 1cm-3cm.

3.6 Acquisition Summary

All equipment performed within specifications with no unusual occurrences or anomalies. All data was of a very high quality and the project was executed as planned.

4 Raw LiDAR Calibration at the Time of Acquisition

This LiDAR project was to provide high accuracy, calibrated multiple return LiDAR for the Louisa, VA area. Raw calibrated LiDAR data was collected and delivered to Dewberry by LMSI in compliance with the “U.S.

Geological Survey National Geospatial Program Base LiDAR Specifications, Version 13 – ILMF 2010”.

The elevation data was verified internally by LMSI prior to delivery to Dewberry to ensure it met fundamental accuracy requirements (vertical accuracy NSSDA RMSEZ = 12.5cm (NSSDA AccuracyZ 95% = 24.5 cm) or better; in open, non-vegetated terrain) when compared to kinematic and static GPS checkpoints. The following results apply to the raw LiDAR swath data at the time of acquisition as tested by LMSI. Dewberry’s accuracy results for the final deliverable products can be found in section 7 of this report:

The LiDAR dataset was tested to 0.035m vertical accuracy at 95% confidence level based on consolidated $RMSE_z$ (0.018m x 1.960) when compared to 11 GPS static check points.

All data delivered meets or exceeds LMSI’s deliverable product requirements.

LiDAR data is remotely sensed high-resolution elevation data collected by an airborne collection platform. By positioning laser range finding with the use of 1 second GPS with 200 Hz inertial measurement unit corrections; LMSI’s LiDAR instruments are able to make highly detailed geospatial elevation products of the ground, man-made structures and vegetation.

The purpose of this LiDAR data was to produce high accuracy 3D terrain geospatial products for flood mapping and other applications.

This report covers the LiDAR processing methods and deliverable products. A GPS Validation Report has been included as an appendix.

Please note that this report focuses solely on the LMSI activities pertaining to the LiDAR data processing component of this project.

4.1 LiDAR Data Processing

4.1.1 Airborn GPS Kinematic

Airborne GPS kinematic data was processed on-site using GrafNav kinematic On-The-Fly (OTF) 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 40km.

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

4.1.2 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 Optech's Dashmap, initially with default values from Optech or the last mission calibrated for 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.

All missions are validated against the adjoining missions for relative vertical biases and collected GPS kinematic validation points for absolute vertical accuracy purposes.

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

4.1.3 Vertical Bias Resolution
When the LiDAR data was compared to the GPS kinematic and static points, no bias was detected.

4.1.4 Deliverable Product Generation
The raw, unclassified LiDAR data were delivered in LAS format 1.2 adjusted GPS time, both as raw strips, with files bigger than 2 GB split in 2 both. Header is populated with the projection information. Angles +/- 20 are usually moved to class 11 and not included in the ground classification process. No angles greater than +/-14 are present in the Louisa, VA data so no points were withheld based on scan angle.

All products were delivered in UTM17 north meters, NAD83(NSRS 07), NAVD88(Geoid09).

4.2 Quality Control for Data Processing LiDAR Calibration

Quality assurance and quality control procedures for the raw LiDAR data are performed in an iterative fashion through the entire data processing cycle.

The following list provides a step-by-step explanation of the process used by LMSI to review the data prior to customer delivery.

4.2.1 Calibration Setup and Data Inventory
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.

4.2.2 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, flightline to flightline and mission to mission agreement. For this project the specifications used are as follows:

Relative accuracy <= 5cm RMSEZ within individual swaths and <=7 cm RMSEZ or within swath overlap (between adjacent swaths).
A different set of QC blocks are generated for final review after all transformations have been applied.

4.2.3 Absolute accuracy

A preliminary $RMSE_z$ error check is performed 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 open, flat areas away from breaks. Lidar ground points for each flightline generated by an automatic classification routine are used.

Results:
Prior to delivery the elevation data was verified internally to ensure it met fundamental accuracy requirements of 12.5cm vertical accuracy at the 95% confidence level (2 sigma = RMSE * 1.96) in when compared to LMSI kinematic and static GPS checkpoints.

Data is compiled to meet 1m horizontal accuracy at the 95% confidence level (2 sigma = RMSE * 1.96)

The LiDAR dataset was tested to 0.035m vertical accuracy at 95% confidence level based on consolidated $RMSE_z$ (0.018m x 1.960) when compared to 11 GPS static check points.

Static GPS Validation
X:\projects\Louisa\control\static-new.txt

Number	Easting	Northing	Known Z	Laser Z	Dz
10	779082.100	4208915.140	106.870	106.870	+0.000
5	771486.430	4211451.540	143.380	143.420	+0.040
6	767707.320	4203490.850	116.930	116.920	-0.010
8	783074.730	4213618.480	83.800	83.770	-0.030
9	776313.090	4219276.100	111.700	111.700	+0.000
1	765400.570	4192747.620	122.800	122.780	-0.020
2	775267.650	4203147.160	113.130	113.140	+0.010
3	766826.880	4209601.820	142.670	142.670	+0.000
111	766468.650	4211361.270	148.760	slope	*
21	765722.840	4211225.710	144.810	144.810	+0.000
222	765379.130	4211178.860	142.420	142.420	+0.000

Average dz	-0.001
Minimum dz	-0.030
Maximum dz	+0.040
Average magnitude	0.011
Root mean square	0.018
Std deviation	0.019

Table 2: GPS Validation

4.3 Calibration Summary

Overall the LiDAR data products collected for Dewberry and Davis meet or exceed the requirements set out in the Statement of Work for this project. The quality control requirements of LMSI's Quality management program were adhered to throughout the acquisition stage of this project to ensure product quality.

5 LiDAR Processing & Qualitative Assessment

5.1 Data Classification and Editing

LiDAR mass points were produced to LAS 1.2 specifications, including the following LAS classification codes:

- Class 1 = Unclassified, and used for all other features that do not fit into the Classes 2, 7, 9, or 10, including vegetation, buildings, etc.
- Class 2 = Ground, includes accurate LiDAR points in overlapping flight lines
- Class 7 = Noise, low and high points
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity.

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 outliers in the dataset to class 7. 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.

The following fields within the LAS files are populated to the following precision: GPS Time (0.000001 second precision), Easting (0.003 meter precision), Northing (0.003 meter precision), Elevation (0.003 meter precision), Intensity (integer value - 12 bit dynamic range), Number of Returns (integer - range of 1-4), Return number (integer range of 1-4), Scan Direction Flag (integer - range 0-1), Classification (integer), Scan Angle Rank (integer), Edge of flight line (integer, range 0-1), User bit field (integer - flight line information encoded). The LAS file also contains a Variable length record in the file header that defines the projection, datums, and units.

Once the initial ground routine has been performed on the data, Dewberry creates Delta Z (DZ) orthos to check the relative accuracy of the LiDAR data. These orthos compare the elevations of LiDAR points from overlapping flight lines on a 1 meter pixel cell size basis. If the elevations of points within each pixel are within 5 cm of each other, the pixel is colored green. If the elevations of points within each pixel are between 5 cm and 10 cm of each other, the pixel is colored yellow, and if the elevations of points within each pixel are greater than 10 cm in difference, the pixel is colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. DZ orthos can be created using the full point cloud or ground only points and are used to review and verify the calibration of the data is acceptable. Some areas are expected to show sections or portions of red, including terrain variations, slope changes, and vegetated areas or buildings if the full point cloud is used. However, 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. The DZ orthos for Louisa, Virginia showed that the data was calibrated correctly with no issues that would affect its usability. The figure below shows an example of the DZ orthos.

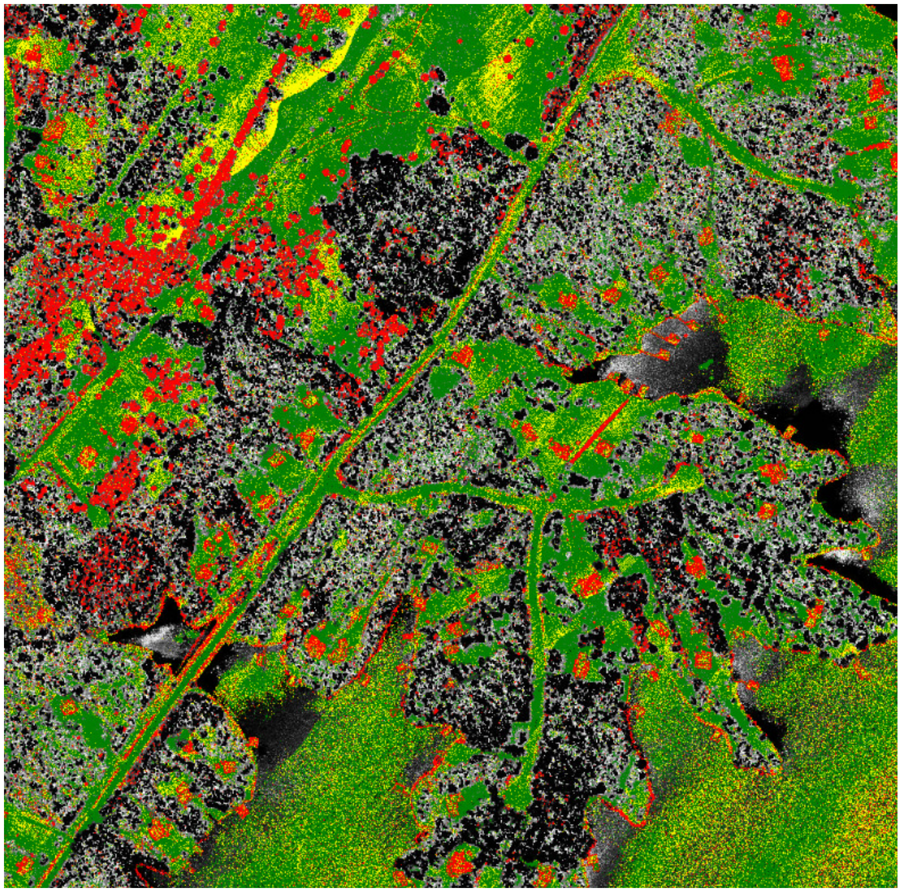

Figure 5: DZ orthos created from the full point cloud. Some red pixels are visible along embankments, sloped terrain, and in vegetated land cover, as expected. Open, flat areas are green indicating the calibration and relative accuracy of the data is acceptable.

Dewberry utilized a variety of software suites for data processing. The LAS dataset was received and imported into GeoCue task management software for processing in Terrascan. Each tile was 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. 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. The final classification routine applied to the dataset selects ground points within a specified distance of the water breaklines and classifies them as class 10, ignored ground due to breakline proximity.

5.2 *Qualitative Assessment*

Dewberry qualitative assessment utilizes a combination of statistical analysis and interpretative methodology to assess the quality of the data for a bare-earth digital terrain model (DTM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model.

Within this review of the LiDAR data, two fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Did the vegetation removal process yield desirable results for the intended bare-earth terrain product?

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data set is typically accepted. Now with the proliferation of LiDAR, new issues arise due to the vast amount of data. Unlike photogrammetrically-derived DEMs where point spacing can be eight meters or more, LiDAR nominal point spacing for this project is 1 point per 0.5 square meters. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for traditional elevation mapping technologies and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the dataset is statistically bound to have some errors both in the measurement process and in the artifact removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and 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 with DZ orthos. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DTM.

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the artifact removal process was performed correctly. To reiterate the quantitative approach, if the LiDAR sensor operated correctly over open terrain areas, then it most likely operated correctly over the vegetated areas. This does not mean that the entire bare-earth was measured; only that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the LiDAR pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness (or removal of above-ground artifacts) is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, Dewberry employs a combination of statistical and visualization processes. 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. By creating multiple images and using overlay techniques, not only can potential errors be found, but Dewberry can also find where the data meets and exceeds expectations. This report will present representative examples where the LiDAR and post processing had issues as well as examples of where the LiDAR performed well.

5.3 Analysis

Dewberry utilizes GeoCue software as the primary geospatial process management system. GeoCue is a three tier, multi-user architecture that uses .NET technology from Microsoft. .NET technology provides the real-time notification system that updates users with real-time project status, regardless of who makes changes to project entities. GeoCue uses database technology for sorting project metadata. Dewberry uses Microsoft SQL Server as the database of choice. Specific analysis is conducted in Terrascan and QT Modeler environments.

Following the completion of LiDAR point classification, the Dewberry qualitative assessment process flow for the Louisa, Virginia LiDAR Project incorporated the following reviews:

1. *Format:* The LAS files are verified to meet project specifications. The LAS files for the Louisa, Virginia LiDAR Project conform to the specifications outlined below.

   -Format, Echos, Intensity
   - LAS format 1.2
   - Point data record format 1
   - Multiple returns (echos) per pulse
   - Intensity values populated for each point

   -ASPRS classification scheme
   - Class 1 – unclassified
   - Class 2 – Bare-earth ground
   - Class 7 – Noise
   - Class 9 – Water
   - Class 10 – Ignored Ground due to breakline proximity

   -Projections
   - Datum – North American Datum 1983
   - Projected Coordinate System – UTM Zone 18
   - Units – Meters
   - Vertical Datum – North American Vertical Datum 1988, Geoid 09
   - Vertical Units – Meters

- Datum – North American Datum 1983 HARN
- Projected Coordinate System – Virginia State Plane, South Zone
- Units – US Survey Feet
- Vertical Datum – North American Vertical Datum 1988, Geoid 09
- Vertical Units – US Survey Feet

- LAS header information:
  - Class (Integer)
  - GPS Week Time (0.0001 seconds)
  - Easting (0.003 meters)
  - Northing (0.003 meters)
  - Elevation (0.003 meters)
  - Echo Number (Integer 1 to 4)
  - Echo (Integer 1 to 4)
  - Intensity (8 bit integer)
  - Flight Line (Integer)
  - Scan Angle (Integer degree)

2. *Data density, data voids:* The LAS files are used to produce Digital Elevation Models using the commercial software package "QT Modeler" 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. For the Louisa, Virginia LiDAR project it is stipulated that the minimum post spacing in un-obscured areas should be 1 point per 0.5 square meter.

   a. 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. These are considered to be acceptable voids.

3. *Bare earth quality:* Dewberry reviewed the cleanliness of the bare earth to ensure the ground has correct definition, meets the project requirements, there is correct classification of points, and there are less than 5% residual artifacts.

   a. *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.

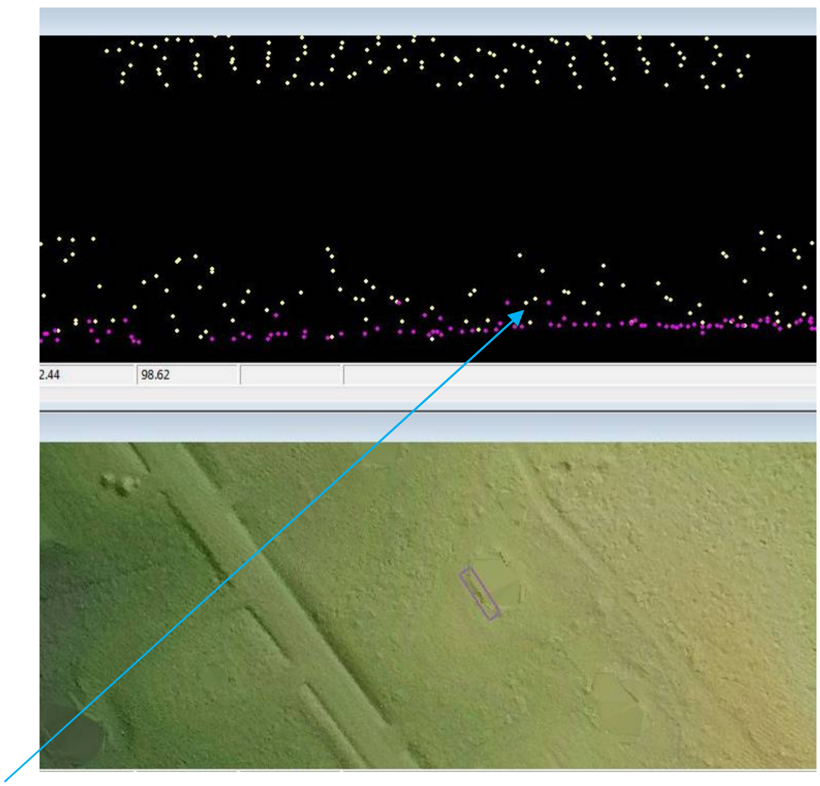

Figure 6 – Tile number 18STH551091. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground.

b. *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 triangulate across a bridge opening from legitimate ground points on either side of the actual bridge. This can cause visual artifacts or "saddles." These "artifacts" are only visual and do not exist in the LiDAR points or breaklines.

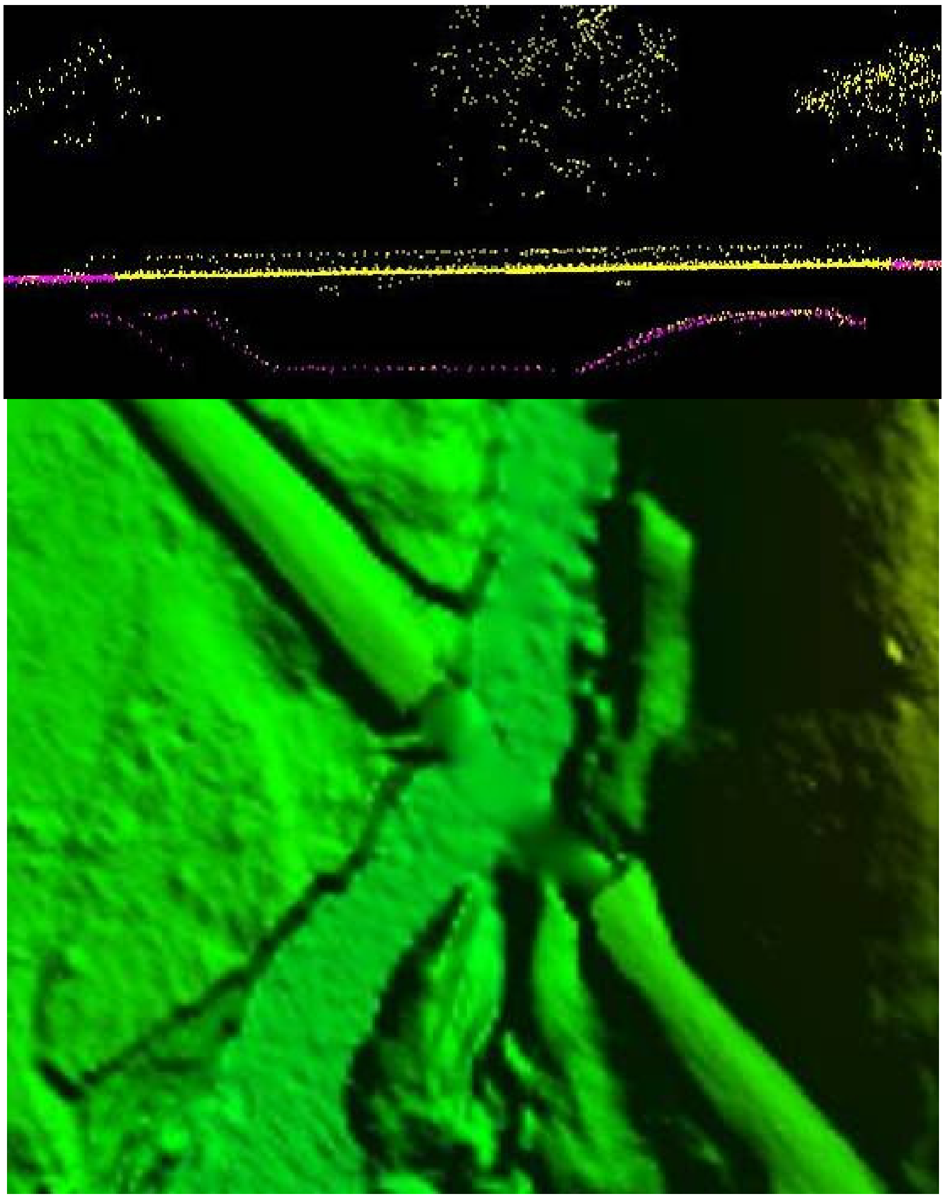

Figure 7 – Tile number 18STH371031. The DEM in the bottom view shows a visual artifact because the surface model is interpolating from the slope leading to the bridge to the lower ground points on either side of the bridge points that were removed. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This can cause visual artifacts when there are features with large elevation differences. 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 are unclassified (yellow). There are no ground points that can be modified to correct this visual artifact.

c. *Building Removal Artifacts:* Large buildings, unique construction, and buildings built on sloped terrain or built into the ground can make a noticeable impact on the bare earth DEM once they have been removed, often in the form of large void areas with obvious triangulation or interpolation across the area and general lack of detail in the ground where the structure stood. In a few areas, this interpolation has resulted in visual artifacts within building footprints. These "artifacts" are only visual and do not exist in the LiDAR points. Two examples are shown below.

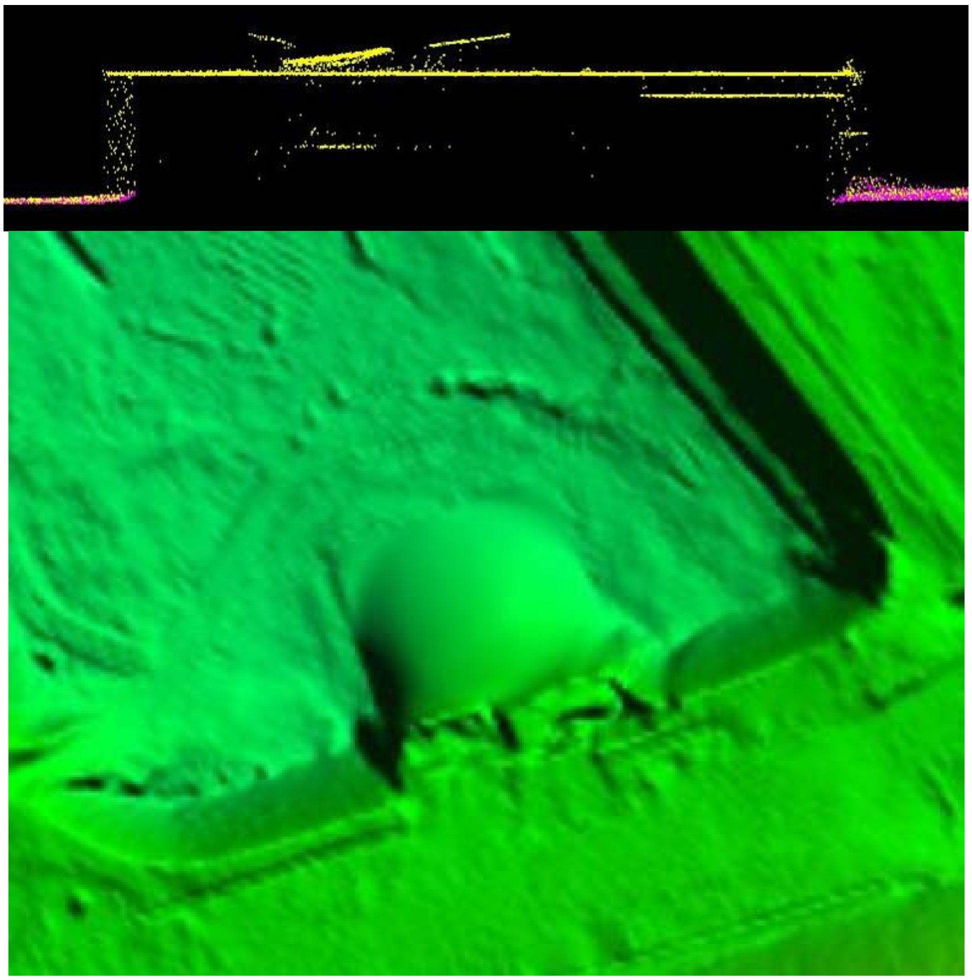

Figure 8 – Tile number 18STH541151. The DEM in the bottom view shows a visual artifact because the surface model is interpolating between the available ground points on either side of the building points that were removed. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This can cause visual artifacts in areas where the ground elevation is slightly lower on one side of building than the other. The profile in the top view shows the LiDAR points of this particular feature colored by class. All building points have been removed from ground (pink) and are unclassified (yellow). There are no ground points that can be modified to correct this visual artifact.

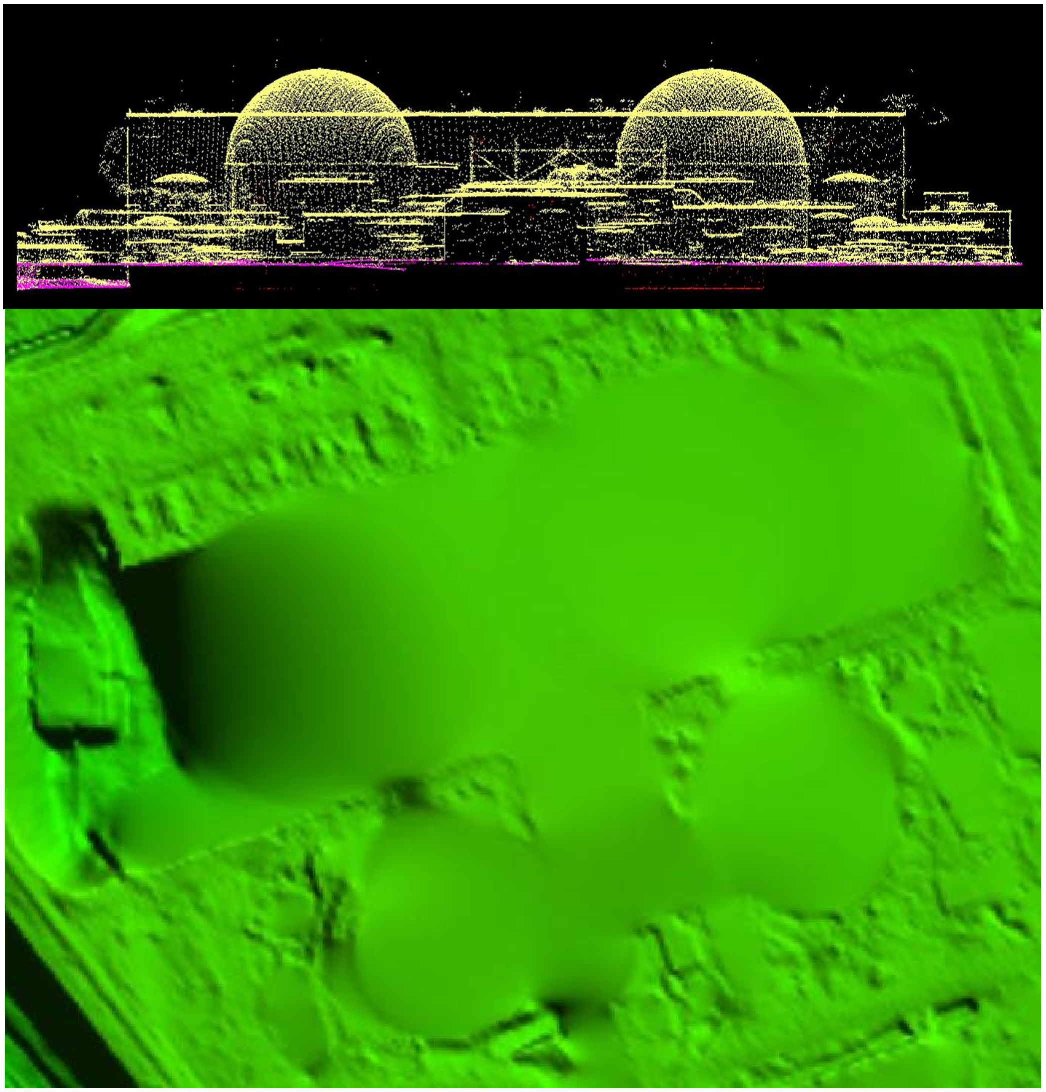

Figure 9 – Tile number 18STH551161. The DEM in the bottom view shows a visual artifact because the surface model is interpolating between the available ground points on either side of the North Anna Nuclear Generating Station points that were removed. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This can cause visual artifacts in areas where the ground elevation is slightly lower on one side of building than the other. The profile in the top view shows the LiDAR points of this particular feature colored by class. All building points have been removed from ground (pink) and are unclassified (yellow) or noise (red). There are no ground points that can be modified to correct this visual artifact.

d. *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 included the feature in the bare earth surface as culverts, especially if they are on secondary or tertiary roads. There were also several large structures throughout the project area that Dewberry determined to be box culverts. Below is an example of a culvert that has been left in the ground surface.

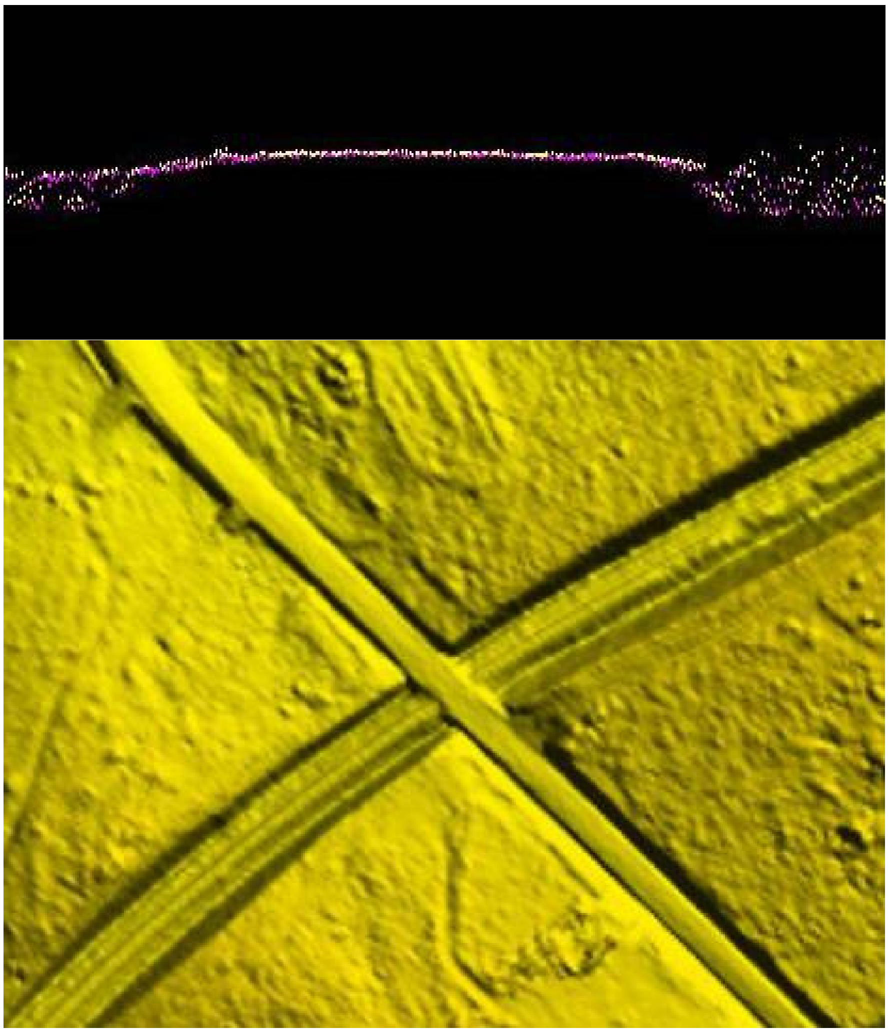

Figure 10– Tile number 18STH521141. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 1.

e. Flattened Areas within Collected Breaklines: Water bodies are flattened in the final DEMs. In order to ensure that no floating vertices are present, Dewberry has enforced the lowest elevation of each hydrographic feature. In the large lakes that are present within the project area, enforcing the lowest elevation of each feature can cause some sections to appear significantly lower than the surrounding terrain. This is expected and has been correctly shown in the final DEMs. Dewberry has gone through the DEMs making sure that the elevation of each feature is consistent from bank to bank. An example showing the elevation of a flattened water body from bank to bank is shown below.

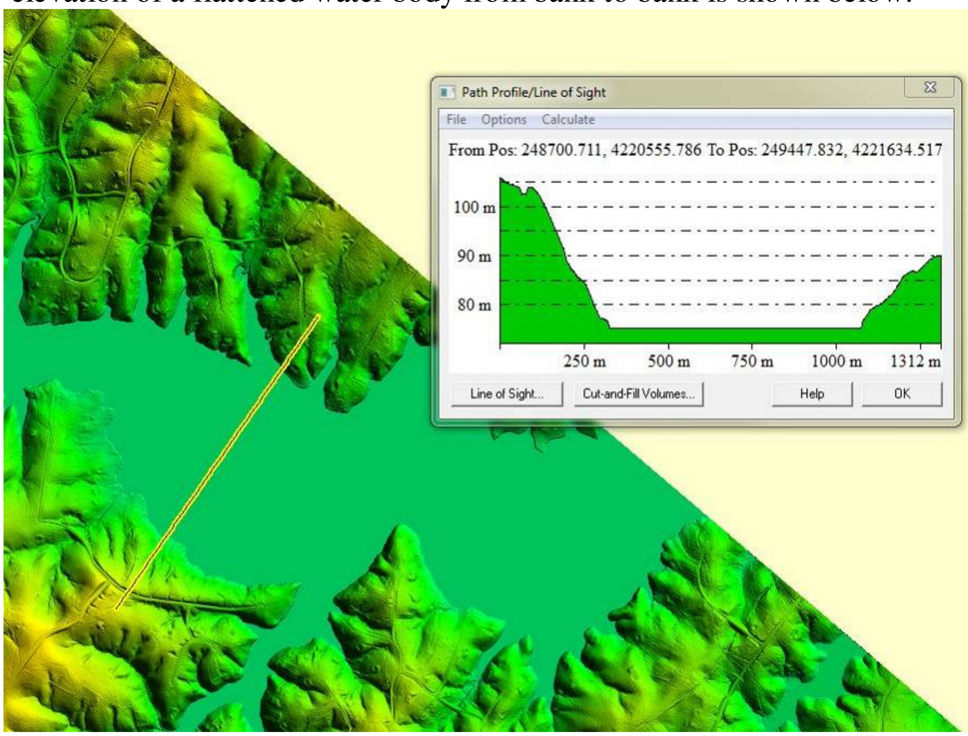

***Figure 11– Tile numbers 18STH4812*01, 18STH491201, 18STH491211, and 18STH481211. Elevation of a flattened water body shown from bank to bank**

f. Flightline Ridges: Ridges occur when there is a difference between the elevations of adjoining flightlines or swaths. Some flightline 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.

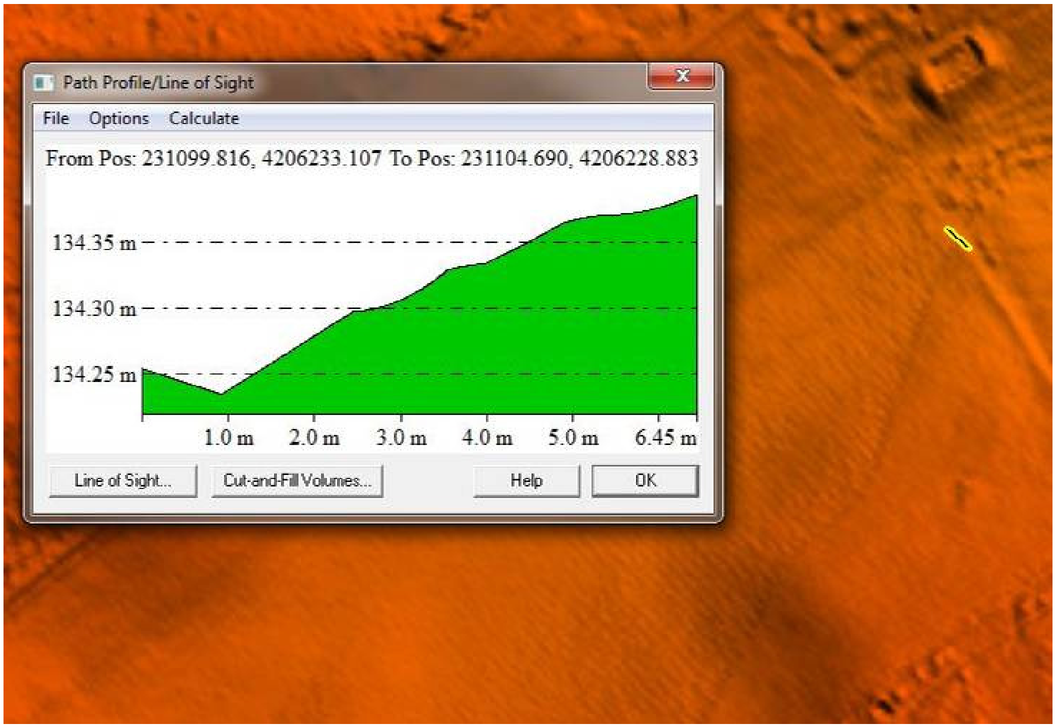

Figure 12 – Tile number 17SQC301061. The flight line ridge is less than 10 cm. Overall, the Louisa, Virginia LiDAR data meets the project specifications for 10 cm RMSE relative accuracy.

g. *Multi tile ridge:* A large square shaped ridge was identified within the Louisa project area. While ridges are known to occur when there is a difference between the elevations of adjoining flightlines or swaths, this particular ridge did not follow the project flightline paths. It is an odd feature that is present in all flightlines in the area. If it had been present in only a single flightline, Dewberry would have considered removing the points causing the ridge and using only points from adjacent flightlines. In this instance, removing the ridge would result in a square shaped void since the points would have to be removed from all flighlines. Because the ridge appears to be a gradual drop of a fairly consistent elevation all along its perimeter, Dewberry decided that it was more accurate to leave the feature in the ground then attempt to remove it. Examples are shown below.

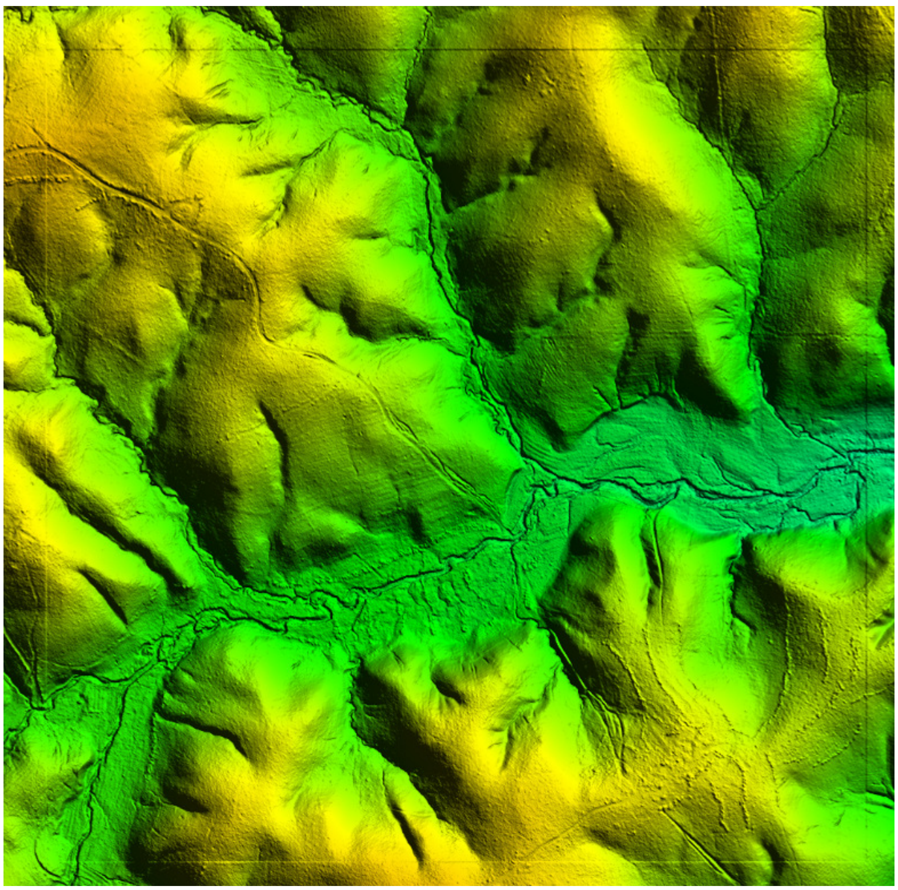

Figure 13: Tile numbers 17SQC341031, 17SQC341021, 17SQC351021, and 17SQC351031. Overview of the entire area where the ridge is present.

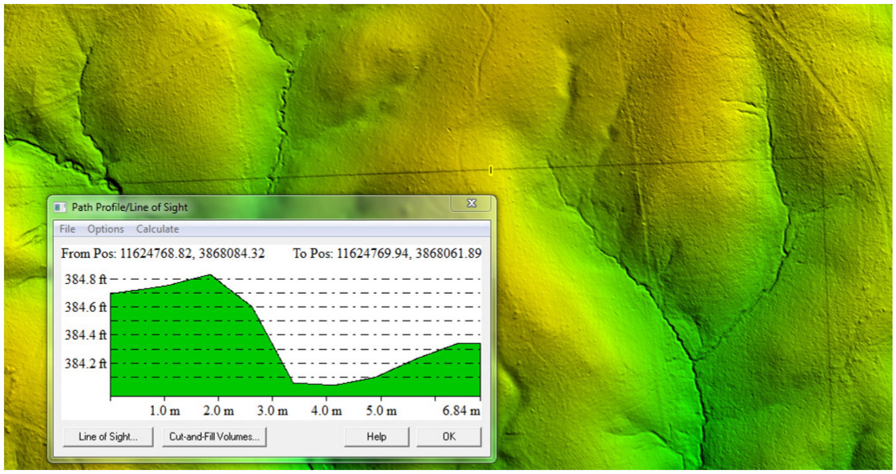

Figure 14: Tile numbers 17SQC341031, 17SQC341021, 17SQC351021, and 17SQC351031. Profile showing the area of the ridge with the greatest change in elevation.

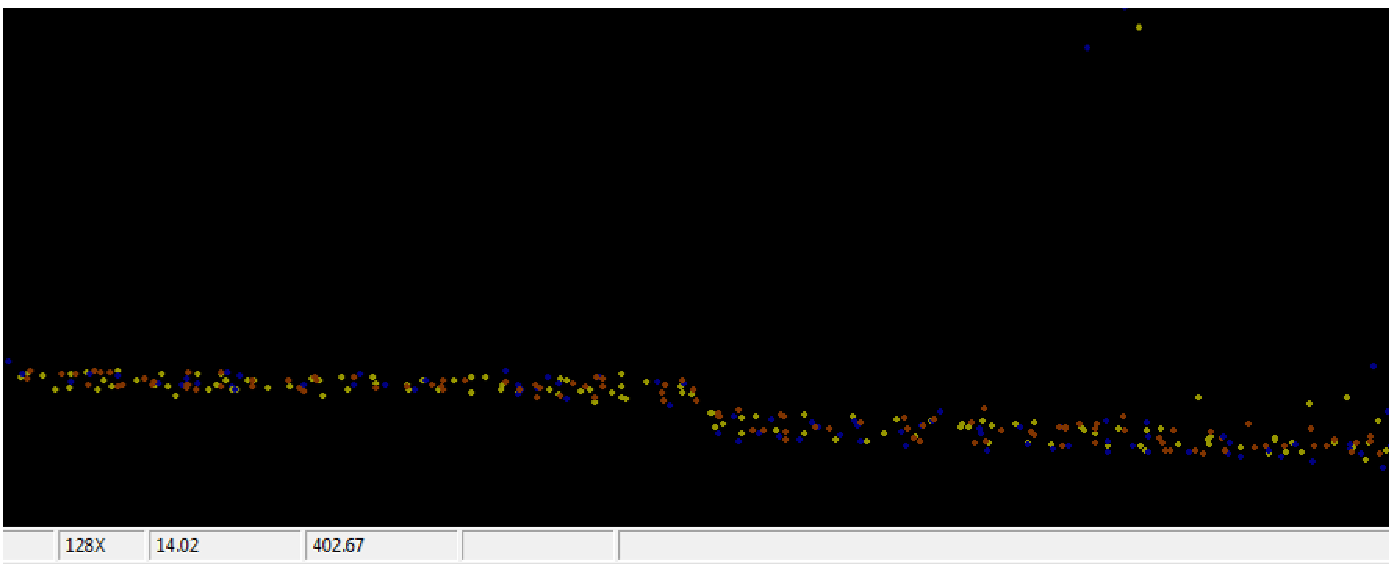

Figure 15: Tile numbers 17SQC341031, 17SQC341021, 17SQC351021, and 17SQC351031. . Profile with points colored by flightline showing the change in elevation is consistent in all flightlines.

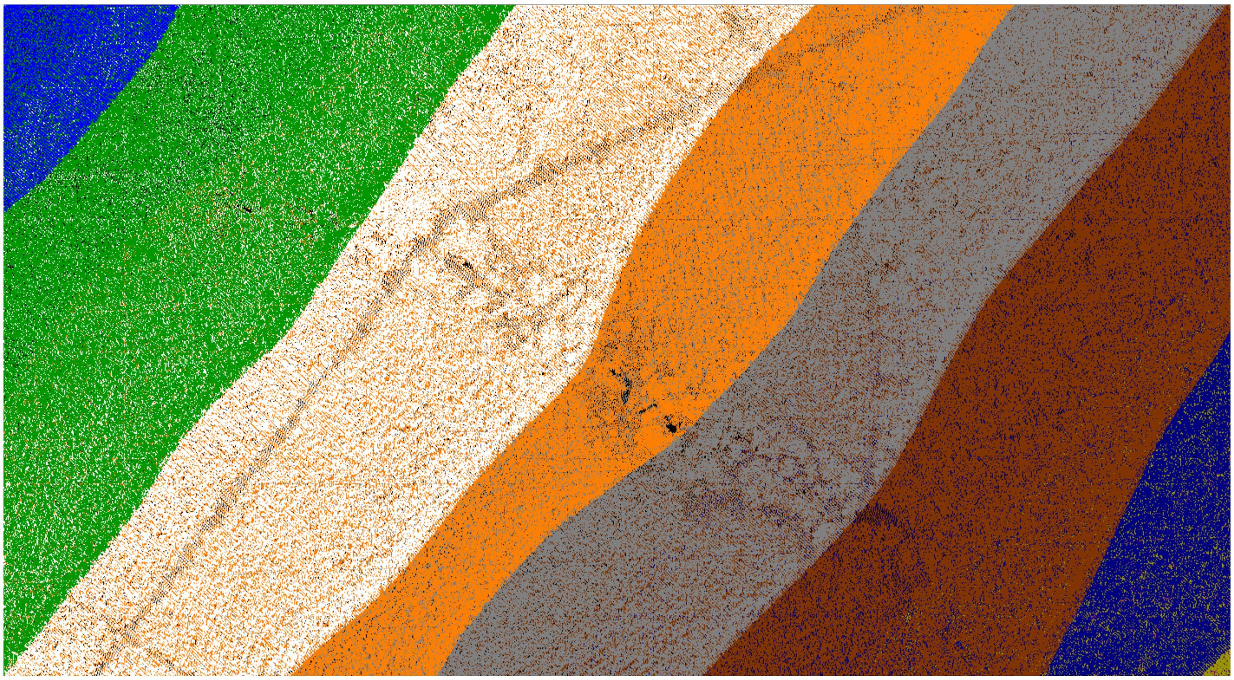

Figure 16: Tile numbers 17SQC341031, 17SQC341021, 17SQC351021, and 17SQC351031. The image shows a tile view of the LAS points colored by flightline. The ridge does not follow the flightline paths. It is not isolated to a single flightline but occurs in all flightlines in the area.

5.4 Conclusion

The dataset conforms to project specifications for format and header values. The spatial projection information and classification of points is correct. Minor artifacts and small areas of misclassification are isolated and have minimal impact on the usability of the dataset.

6 Survey Vertical Accuracy Checkpoints

LOUISA, VIRGINIA LiDAR QA			
UTM ZONE 18 COORDINATE SYSTEM			
	NAD83 (m)		NAVD88 (m)
POINT ID	NORTHING (m)	EASTING (m)	ORTHO HEIGHT (m)
OPEN TERRAIN POINTS			
OT-1	4223780.061	246334.167	99.726
OT-2	4220660.185	248679.867	103.899
OT-3	4217770.888	250747.009	98.399
OT-4	4215531.335	254256.194	103.109
OT-5	4214065.721	256802.691	84.791
OT-6	4210445.772	257932.492	79.821
OT-7	4207546.480	257188.888	83.926
OT-8	4210303.473	254347.241	84.391
OT-9	4210177.053	248284.651	131.940
OT-10	4218621.780	247456.675	127.745
OT-11	4219653.849	245162.049	90.414
OT-12	4218107.005	242413.234	121.080
OT-13	4212655.926	241274.385	144.029
OT-14	4214015.328	246634.629	132.701
OT-15	4209404.457	250008.772	111.231
OT-16	4206234.512	253216.736	99.772
OT-17	4201831.875	250721.408	108.985
OT-18	4205075.536	248499.542	99.862
OT-19	4208978.633	246381.997	145.011
OT-20	4211008.178	244747.636	142.979
OT-21	4212237.938	237351.251	127.684
OT-22	4207306.609	236782.495	132.358
OT-23	4204335.982	237540.178	116.591
OT-24	4203370.179	241983.361	121.661
OT-25	4199574.800	247816.766	121.627
OT-26	4197143.475	249010.598	96.515
OT-27	4194712.869	245353.418	78.948
OT-28	4197907.516	245272.386	102.598
OT-29	4201140.683	237622.671	133.236
OT-30	4206228.697	231945.961	130.331
OT-31	4202745.399	231777.230	135.291

OT-32	4192731.704	237743.951	119.420
OT-33	4198474.968	242076.753	90.501
OT-34	4195581.033	238768.986	122.261
OT-35	4191032.375	242823.317	113.339
OT-36	4186669.411	238662.740	91.882
OT-37	4197323.415	233251.810	155.836
OT-38	4191024.595	233863.911	84.293
OT-39	4194841.392	230399.740	150.240
OT-40	4199415.218	229870.041	150.996
OT-41	4197319.757	224775.655	114.062
OT-42	4207631.392	252559.615	101.619
OT-43	4204510.643	245197.517	130.127
OT-44	4196976.214	232730.660	159.520

Table 3: USGS Louisa, Virginia LiDAR surveyed accuracy checkpoints

7 LiDAR Vertical Accuracy Statistics & Analysis

7.1 Background

Dewberry tests and reviews project data both quantitatively (for accuracy) and qualitatively (for usability).

For qualitative assessment (i.e. vertical accuracy assessment), forty four (44) points were surveyed for the project and all are located within open terrain land cover category The checkpoints were surveyed for the project using RTK survey methods. A survey report was produced 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.

Out of the forty four checkpoints received from the surveyor, one was not used in the final accuracy testing due to the presence of medium vegetation at the survey site. The resulting difference in elevation was significant enough to justify the omission of this point. Forty three surveyed checkpoints were used for the final qualitative assessment. The checkpoint that was not included in the accuracy testing is listed below accompanied by photos of the site.

Open terrain point number OT-26 shown below was not used.

7.2 *Vertical Accuracy Test Procedures*

FVA (Fundamental Vertical Accuracy) is determined with check points located only in the open terrain (grass, dirt, sand, and/or rocks) land cover category, 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 FVA 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 (RMSEz) of the checkpoints x 1.9600. For the Louisa, Virginia LiDAR project, vertical accuracy must be 0.245 meters or less based on an RMSEz of 0.125 meters x 1.9600.

CVA (Consolidated Vertical Accuracy) is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all land cover categories combined. The Louisa, Virginia LiDAR Project CVA standard is 0.363 meters at the 95% confidence level. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA (Supplemental Vertical Accuracy) is determined for each land cover category other than open terrain. SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each land cover category. The Louisa, Virginia LiDAR Project SVA target is 0.363 meters at the 95% confidence level. Target specifications are given for SVA's as one individual land cover category may exceed this target value as long as the overall CVA is within specified tolerances. Again, $Accuracy_z$ differs from SVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas SVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid. Because there were no checkpoints in land cover categories other than open terrain, it was not necessary to determine the SVA for the Louisa, Virginia Project.

The relevant testing criteria are summarized in the table below.

Quantitative Criteria	Measure of Acceptability
Fundamental Vertical Accuracy (FVA) in open terrain only using RMSEz *1.9600	0.245 meters (based on RMSEz (0.125 meters) * 1.9600)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined at the 95% confidence level	0.363 meters (based on combined 95th percentile)
Supplemental Vertical Accuracy (SVA) in each land cover category separately at the 95% confidence level	0.363 meters (based on 95th percentile for each land cover category)

Table 4 — Acceptance Criteria

7.3 *Vertical Accuracy Testing Steps*

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 each of the 43 checkpoints.
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 FVA andCVA values. There were no checkpoints in land cover categories other than open terrain so computing the SVA value was not necessary .
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.

The figure below shows the location of the QA/QC checkpoints within the project area.

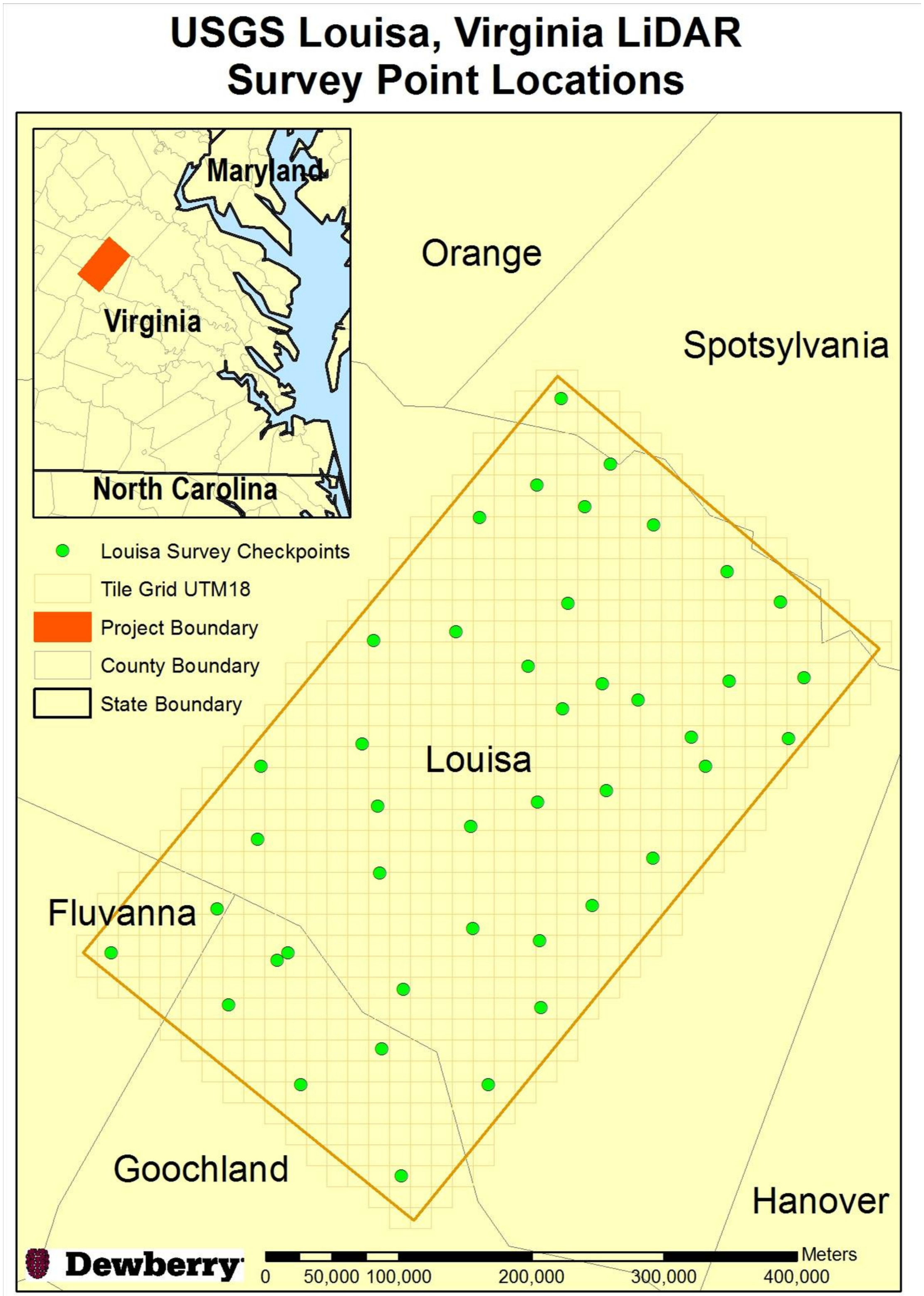

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Figure 17 – Location of QA/QC Checkpoints

7.4 *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 LiDAR LAS files.

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.245 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.363 m
Consolidated	43		0.12
Open Terrain	43	0.13	

Table 5 — FVA and CVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.07 meters, within the target criteria of 0.125 meters. Compared with the 0.245 meters specification, the FVA tested 0.13 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.363 meters specification, CVA tested 0.12 meters at the 95% confidence level based on the 95^{th} percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data. This shows that the majority of LiDAR elevations were within +/- 0.13 meters of the checkpoints elevations.

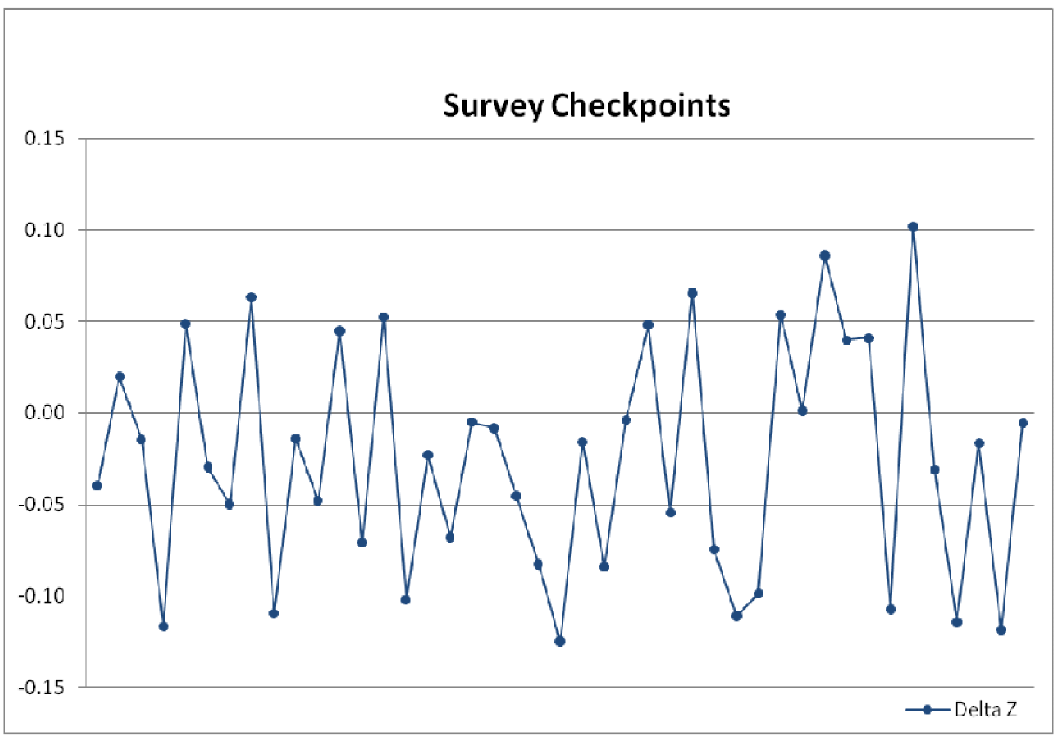


Figure 18– Magnitude of Elevation Discrepancies

The following table shows the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83 UTM Zone 18		NAVD 88	LiDAR – Z (m)	Delta Z	AbsDelta Z
	Easting – X (m)	Northing – Y (m)	Survey – Z (m)			
OT-22	236782.495	4207306.609	132.358	132.23300	-0.13	0.13

Table 6 — 5% Outliers

The following table provides overall descriptive statistics.

100 % of Totals	RMSE (m) Open Terrain Spec=0.125m	Mean (m)	Mean Absolute (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated		-0.03	0.06	-0.02	0.14	0.06	43	-0.13	0.10
Open Terrain	0.07	-0.03	0.06	-0.02	0.14	0.06	43	-0.13	0.10

Table 7 — 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. The discrepancies vary between a low of -0.13 meters and a high of +0.10 meters. The histogram shows that the majority of the discrepancies are skewed on the negative side.

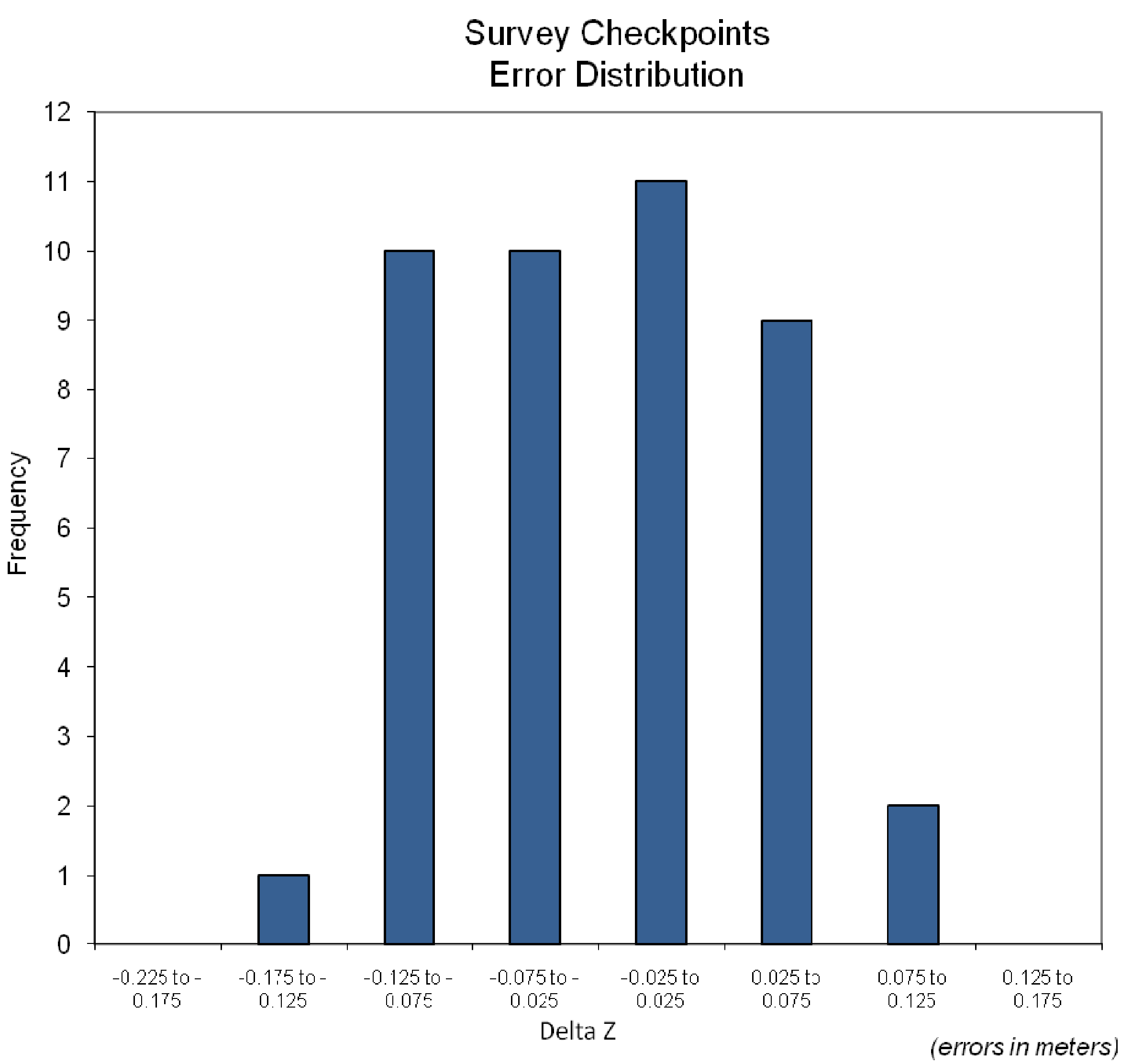


Figure 19 — Histogram of Elevation Discrepancies within errors in meters

7.5 Conclusion

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the Louisa, Virginia LiDAR Project satisfies the project's pre-defined vertical accuracy criteria.

8 Breakline Production & Qualitative Assessment Report

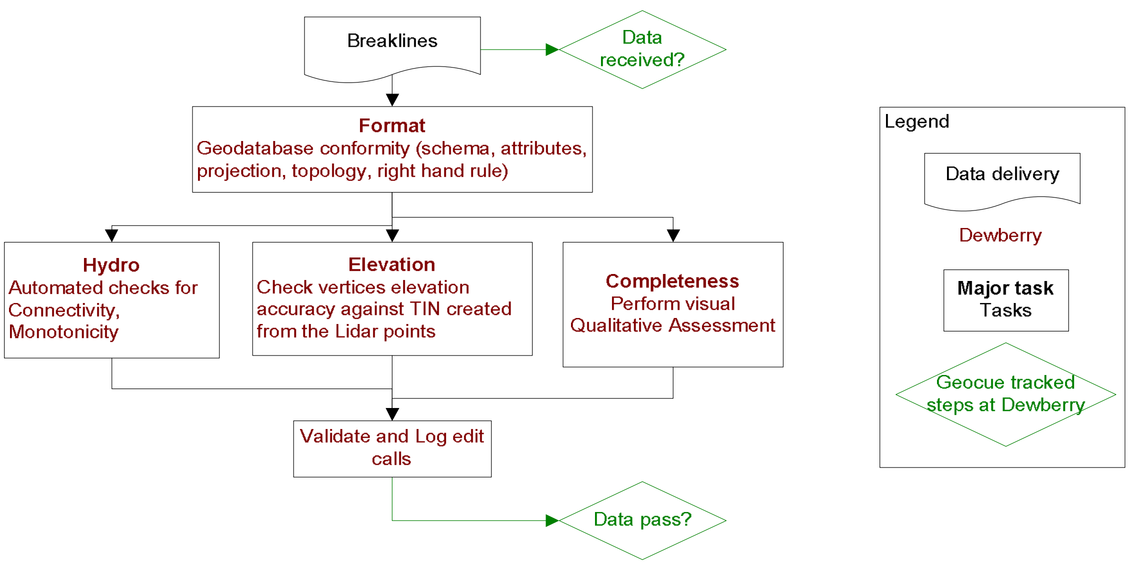
8.1 Breakline Production Methodology

Dewberry used GeoCue software to develop LiDAR stereo models of the Louisa, Virginia LiDAR 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 developed by Dewberry to stereo-compile the three types of hard breaklines in accordance with the project's Data Dictionary.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are reviewed in stereo and the lowest elevation is applied to the entire waterbody.

8.2 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.



8.3 Breakline Topology Rules

Automated checks are applied on hydro features to validate the 3D connectivity of the feature and the monotonicity of the hydrographic breaklines. Dewberry's major concern was that the hydrographic breaklines have a continuous flow downhill and that breaklines do not undulate. Error points are generated at each vertex not complying with the tested rules and these potential edit calls are then visually validated during the visual evaluation of the data. This step also helped validate that breakline vertices did not have excessive minimum or maximum elevations and that elevations are consistent with adjacent vertex elevations.

The next step is to compare the elevation of the breakline vertices against the 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.

Dewberry's final check for the breaklines was to perform a full qualitative analysis. Dewberry compared the breaklines against LiDAR intensity images to ensure breaklines were captured in the required locations. The quality control steps taken by Dewberry are outlined in the QA Checklist below.

8.4 Breakline QA/QC Checklist

Project Number/Description: TO G10PC00013 USGS Louisa, Virginia LiDAR

Date:______08/02/2012____

Overview

☒ All Feature Classes are present in GDB

☒ All features have been loaded into the geodatabase correctly. Ensure feature classes with subtypes are domained correctly.

☒ The breakline topology inside of the geodatabase has been validated. See Data Dictionary for specific rules

☒ Projection/coordinate system of GDB is accurate with project specifications

Perform Completeness check on breaklines using either intensity or ortho imagery

☒ Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency (See Data Dictionary for specific collection rules). NHD data will be used to help evaluate completeness of collected hydrographic features. Features should be collected consistently across tile bounds within a dataset as well as be collected consistently between datasets.

☒ Check to make sure breaklines are compiled to correct tile grid boundary and there is full coverage without overlap

☒ Check to make sure breaklines are correctly edge-matched to adjoining datasets if applicable. Ensure breaklines from one dataset join breaklines from another dataset that are coded the same and all connecting vertices between the two datasets match in X,Y, and Z (elevation). There should be no breaklines abruptly ending at dataset boundaries and no discrepancies of Z-elevation in overlapping vertices between datasets.

Compare Breakline Z elevations to LiDAR elevations

☒ Using a terrain created from LiDAR ground points and water points and GeoFIRM tools, drape breaklines on terrain to compare Z values. Breakline elevations should be at or below the elevations of the immediately surrounding terrain. This should be performed before other breakline checks are completed.

Perform automated data checks using PLTS

The following data checks are performed utilizing ESRI's PLTS extension. These checks allow automated validation of 100% of the data. Error records can either be written to a table for future correction, or browsed for immediate correction. PLTS checks should always be performed on the full dataset.

☒ Perform "adjacent vertex elevation change check" on the Inland Ponds feature class (Elevation Difference Tolerance=.001 meters). This check will return Waterbodies whose vertices are not all identical. This tool is found under "Z Value Checks."
☒ Perform "unnecessary polygon boundaries check" on Inland Ponds and Inland Streams feature classes. This tool is found under "Topology Checks."
☒ Perform "duplicate geometry check" on (inland streams to inland streams), (inland ponds to inland ponds), (inland ponds to inland streams). Attributes do not need to be checked during this tool. This tool is found under "Duplicate Geometry Checks."
☒ Perform "geometry on geometry check" on (inland ponds to inland streams). Spatial relationship is contains, attributes do not need to be checked. This tool is found under "Feature on Feature Checks."
☒ Perform "polygon overlap/gap is sliver check" (inland streams to inland streams), (inland ponds to inland ponds), (inland ponds to inland streams). Maximum Polygon Area is not required. This tool is found under "Feature on Feature Checks."
Perform Dewberry Proprietary Tool Checks
☒ Perform monotonicity check on inland streams features using "A3_checkMonotonicityStreamLines." This tool looks at line direction as well as elevation. Features in the output shapefile attributed with a "d" are correct monotonically, but were compiled from low elevation to high elevation. These errors can be ignored. Features in the output shapefile attributed with an "m" are not correct monotonically and need elevations to be corrected. Input features for this tool need to be in a geodatabase. Z tolerance is .01 meters. Polygons need to be exported as lines for the monotonicity tool.
☒ Perform connectivity check between (inland ponds to inland streams) using the tool "07_CheckConnectivityForHydro." The input for this tool needs to be in a geodatabase. The output is a shapefile showing the location of overlapping vertices from the polygon features and polyline features that are at different Z-elevation. The unnecessary polygon boundary check must be run and all errors fixed prior to performing connectivity check. If there are exceptions to the polygon boundary rule then that feature class must be checked against itself, i.e. inland streams to inland streams.
Metadata
☒ Each XML file (1 per feature class) is error free as determined by the USGS MP tool
☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc. Content should be consistent across all feature classes.

Completion Comments: Complete – Approved

8.5 LiDARgrammetry Data Dictionary & Stereo Compilation Rules

HORIZONTAL AND VERTICAL DATUM

The horizontal datum shall be North American Datum of 1983, Units in Meters as well as North American Datum of 1983 HARN, Units in U.S Survey Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Meters as well as North American Vertical Datum of 1988 (NAVD 88), Units in Feet. Geoid09 shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to both UTM Zone 18, Horizontal Units in Meters and Vertical Units in Meters as well as Virginia State Plane South, Horizontal Units in U.S. Survey Feet and Vertical Units in Feet

Inland Streams and Rivers

Feature Dataset: BREAKLINES **Feature Class:** STREAMS_AND_RIVERS **Feature Type:** Polygon

Contains M Values: No
Contains Z Values: Yes
Annotation Subclass: None

XY Resolution: Accept Default Setting
Z Resolution: Accept Default Setting

XY Tolerance: 0.003
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 length. 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 great than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity and data is required to show “closed polygon”. 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 features on either side of the island meet the criteria for capture. 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 Class: PONDS_AND_LAKES
Feature Type: Polygon
Contains M Values: No
Contains Z Values: Yes
Annotation Subclass: None
XY Resolution: Accept Default Setting
Z Resolution: Accept Default Setting

XY Tolerance: 0.003
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	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 will

	are islands within a closed water body feature greater than ½ acre in size.	also have a "donut polygon" compiled. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Tidal Waters

Feature Dataset: BREAKLINES
Feature Class: TIDAL_WATERS
Feature Type: Polygon
Contains M Values: No
Contains Z Values: Yes
Annotation Subclass: None
XY Resolution: Accept Default Setting
Z Resolution: Accept Default Setting

XY Tolerance: 0.003
Z Tolerance: 0.001

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

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
SHAPE_AREA	Double	Yes			0	0		Calculated by Dewberry

Feature Definition

Description	Definition	Capture Rules
TIDAL_WATERS	The coastal breakline will delineate the land water interface using LiDAR data as reference. In flight line boundary areas with tidal variation the coastal shoreline may require some feathering or edge matching to ensure a smooth transition.	The feature shall be extracted at the apparent land/water interface, as determined by the LiDAR intensity data, to the extent of the tile boundaries. Differences caused by tidal variation are acceptable and breaklines delineated should reflect that change with no feathering. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding LiDAR points. Acceptable variance in the negative direction will be defined for each project individually.

		If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Breaklines shall snap and merge seamlessly with linear hydrographic features.

Contact Information

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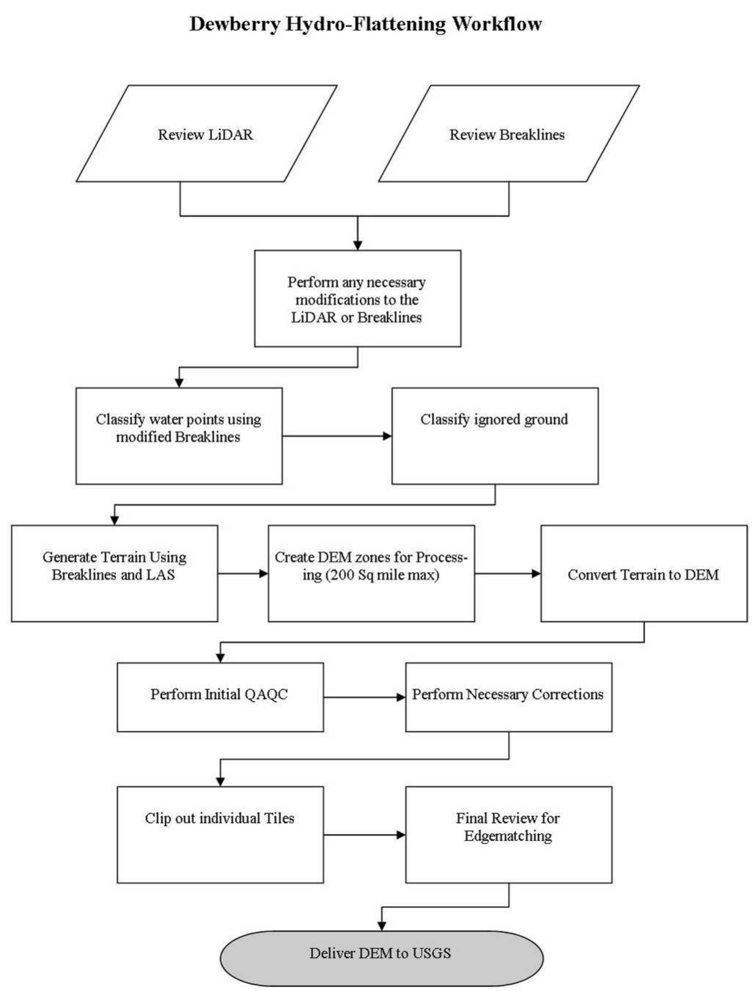
9 DEM Production & Qualitative Assessment

9.1 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.



1. <u>Classify Water Points</u>: LAS point falling within hydrographic breaklines shall be classified to ASPRS class 9 using TerraScan. Breaklines must be prepared correctly prior to performing this task.
2. <u>Classify Ignored Ground Points</u>: Classify points in close proximity to the breaklines from Ground to class 10 (Ignored Ground). Close proximity will be defined as no more than 1x the nominal point spacing on the landward side of the breakline. Breaklines will be buffered using this specification and the subsequent file will need to be prepared in the same manner as the water breaklines for classification. This process will be performed after the water points have been classified and only run on remaining ground points.

3. Terrain Processing: A Terrain will be generated using the Breaklines and LAS data that has been imported into Arc as a Multipoint File. If the final DEMs are to be clipped to a project boundary that boundary will be used during the generation of the Terrain.
4. Create DEM Zones for Processing: Create DEM Zones that are buffered around the edges. Zones should be created in a logical manner to minimize the number of zones without creating zones too large for processing. Dewberry will make zones no larger than 200 square miles (taking into account that a DEM will fill in the entire extent not just where LiDAR is present). Once the first zone is created it must be verified against the tile grid to ensure that the cells line up perfectly with the tile grid edge.
5. Convert Terrain to Raster: Convert Terrain to raster using the DEM Zones created in step 6. In the environmental properties set the extents of the raster to the buffered Zone. For each subsequent zone, the first DEM will be utilized as the snap raster to ensure that zones consistently snap to one another.
6. Perform Initial QAQC on Zones: During the initial QA process anomalies will be identified and corrective polygons will be created.
7. Correct Issues on Zones: Dewberry will perform corrections on zones following Dewberry's correction process.
8. Extract Individual Tiles: Dewberry will extract individual tiles from the zones utilizing the Dewberry created tool.
9. Final QA: Final QA will be performed on the dataset to ensure that tile boundaries are seamless.

9.2 DEM Qualitative Assessment

Dewberry performed a comprehensive qualitative assessment of the 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. Upon completion of this review the DEM data is loaded into Global Mapper to ensure that all files are readable and that no artifacts exist between tiles.

9.3 DEM Vertical Accuracy Results

The same 43 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 following table 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	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.245 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.363 m
Consolidated	43		0.12
Open Terrain	43	0.14	

Table 8 — FVA, CVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.07 meters, within the target criteria of 0.125 meters. Compared with the 0.245 meters specification, the FVA tested 0.14 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.363 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.12 meters at the 95% confidence level based on the 95th percentile.

There were no checkpoints in land cover categories other than open terrain so computing the SVA value was not necessary.

The following table lists the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83 UTM North Zone 18		NAVD88	DEM - Z (m)	Delta Z	AbsDeltaZ
	Easting - X (m)	Northing - Y (m)	Survey -Z (m)			
OT-22	236782.495	4207306.609	132.358	132.23300	-0.13	0.13

Table 9 — 5% Outliers

The following table provides overall descriptive statistics.

100 % of Totals	RMSE (m) Open Terrain Spec=0.125 m	Mean (m)	Mean Absolute (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated		-0.03	0.06	-0.03	0.18	0.06	43	-0.12	0.10
Bare Earth-Open Terrain	0.07	-0.03	0.06	-0.03	0.18	0.06	43	-0.12	0.10

Table 10 — Overall Descriptive Statistics

9.4 DEM QA/QC Checklist

Project Number/Description: TO G11PD00336 USGS Louisa, Virginia LiDAR
Date:______08/02/2012_____
Overview
☒ Correct number of files is delivered and all files are in ERDAS IMG format
☒ Verify Raster Extents
☒ Verify Projection/Coordinate System

Review
☒ Manually review bare-earth DEMs with a hillshade to check for issues with hydro-enforcement process or any general anomalies that may be present. Specifically, water should be flowing downhill, water features should NOT be floating above surrounding terrain and bridges should NOT be present in bare-earth DEM. Hydrologic breaklines should be overlaid during review of DEMs.
☒ Overlap points (in the event they are supplied to fill in gaps between adjacent flightlines) are not to be used to create the bare-earth DEMs
☒ DEM cell size is 1 meter
☒ Perform final overview in Global Mapper to ensure seamless product.

Metadata
☒ Project level DEM metadata XML file is error free as determined by the USGS MP tool
☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc.
Completion Comments: Complete - Approved