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USGS–Central Virginia Seismic LiDAR

Report Produced for U.S. Geological Survey

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Table of Contents

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 Central Virginia Seismic LiDAR 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 1,500 meters by 1,500 meters and each State Plane tile covering an area of 5,000 feet by 5,000 feet. A total of 320 UTM tiles and 313 State Plane tiles were produced for the project encompassing an area of approximately 230 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 Matthew Rudolph completed ground surveying for the project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. He also verified the GPS base station coordinates used during LiDAR data acquisition to ensure that the base station coordinates were accurate. Please see Appendix A to view the separate Survey Report that was created for this portion of the project.

Laser Mapping Specialist, Inc in conjunction with Precision Aerial Reconnaissance 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, Louisa, Orange and Spotsylvania.

DATE OF SURVEY

The LiDAR aerial acquisition was conducted from May 6, 2014 to May 7, 2014.

DATUM REFERENCES

Data produced for the project were delivered in the following reference systems.
Horizontal Datum: North American Datum of 1983 2011 (NAD 83)
Vertical Datum: North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 17
Units: Horizontal units are in meters, Vertical units are in meters.
Geoid Model: Geoid12A (Geoid12A was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the Central Virginia Seismic LiDAR Project, the tested $RMSE_z$ of the classified LiDAR data for checkpoints in open terrain equaled **0.06 m** compared with the 0.0925 m specification; and the FVA of the classified LiDAR data computed using $RMSE_z$ x 1.9600 was equal to **0.12 m**, compared with the 0.181 m specification.

For the Central Virginia Seismic LiDAR Project, the tested CVA of the classified LiDAR data computed using the 95th percentile was equal to **0.18 m,** compared with the 0.269 m 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. 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

PROJECT TILING FOOTPRINT UTM AND STATEPLANE

Three hundred twenty (320) tiles were delivered in UTM Zone 17 for the project. Each tile's extent is 1,500 meters by 1,500 meters (see Appendix B for a complete listing of delivered UTM tiles).

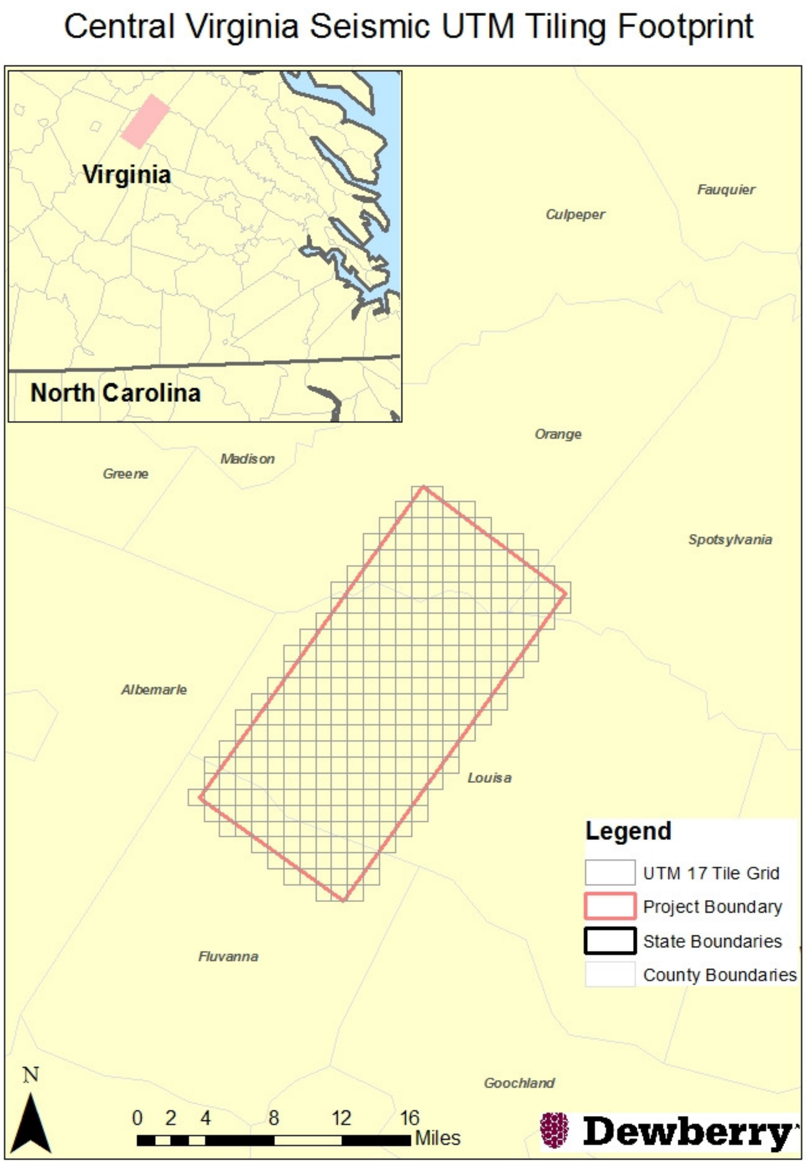


Figure 1 - UTM Project Map

Three hundred and thirteen (313) State Plane tiles were delivered in Virginia South State Plane for the project. Each tile's extent is 5,000 feet by 5,000 feet (see Appendix C for a complete listing of delivered State Plane tiles).

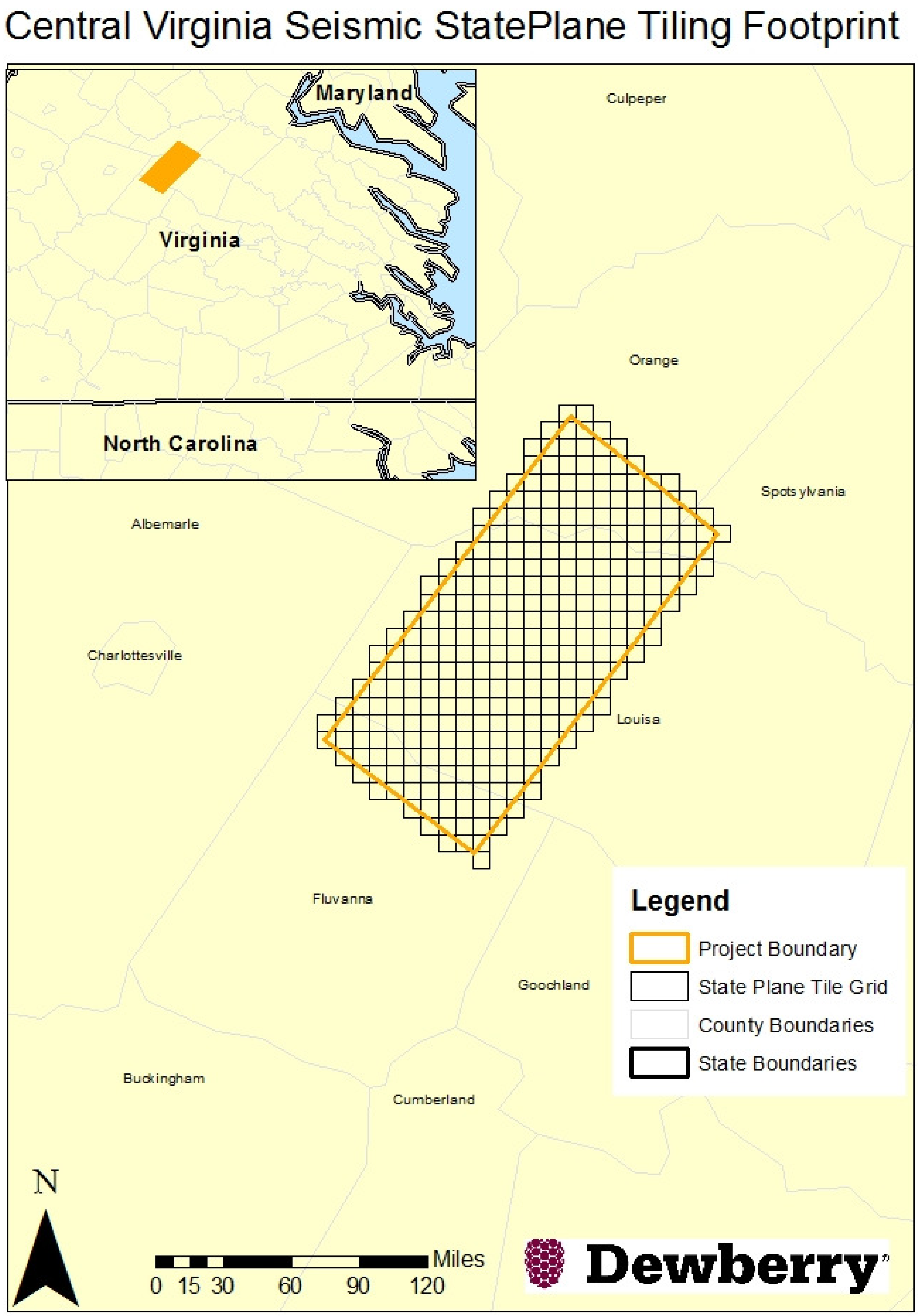


Figure 2 – State Plane Project Map

LiDAR Acquisition Report

Precision Aerial Reconnaissance (PAR) provided high accuracy, calibrated multiple return LiDAR for roughly 230 square miles around the Central Virginia Seismic LiDAR project area. Data was collected and delivered in compliance with the “U.S. Geological Survey National Geospatial Program Base LiDAR Specifications, Version 1.”

LIDAR ACQUISITION DETAILS

LIDAR acquisition began on May 6, 2014 (Julian day 126) and was completed on May 7, 2014 (Julian day 127). A total of 2 survey missions were flown to complete the project. PAR utilized a Lecia ALS70-CM 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 186 flight lines required to complete the project.

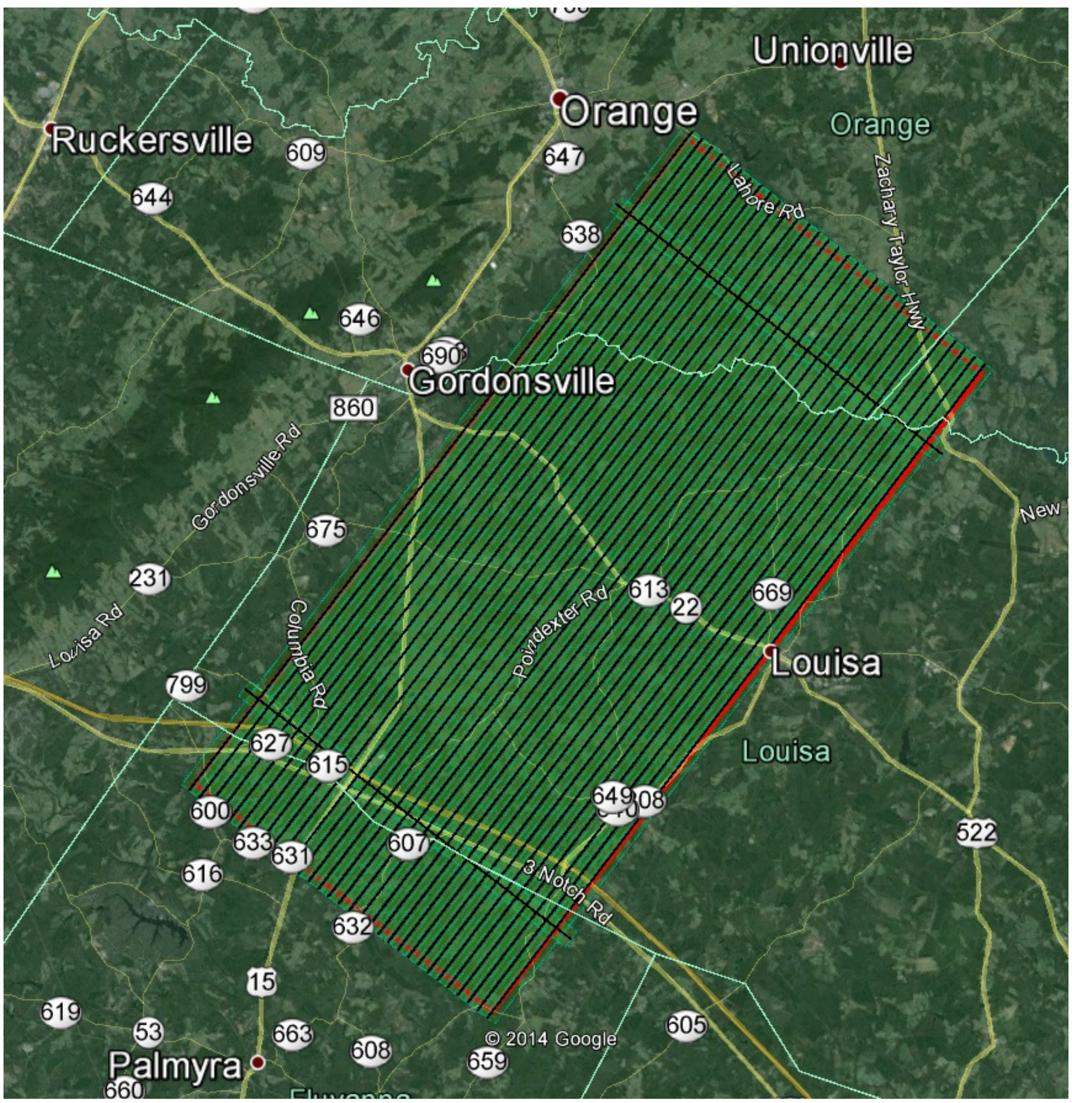


Figure 3 - Flight Layout

Description	Computed	Target	Unit
Sensor ID	ALS70_SN7169		
Terrain and Aircraft			
Reference Height	39 - 143		m
Flying Height AGL	1196 - 1300	1300	m
Altitude AMSL	1339 / 4393		m/ft
Recommended Ground Speed (GS)	115	115	kts
Scanner			
Field of View (FOV)	37.0	37.0	degrees
Maximum Scan Rate	55.3		Hz
Scan Rate Setting used (SR)	40.3		Hz
Laser			
Maximum Laser Pulse Rate	210000		Hz
Laser Pulse Rate used	210000		Hz
Multi Pulse in Air Mode	Disabled	Disabled	
Aircraft Speed Sensitivity	0.42		kts
Fixed Gain	255		
Range Intensity mode	7		
Nominal Maximum Slant Range	1397.20		m
Minimum Range Gate	192.00		m
Maximum Range Gate	1406.60		m
Range Gate size	1214.60		m
Range margin above hills	1004.00		m
Range margin below valleys	33.91		m
Recommended Laser Power	90		%
Coverage			
Full Swath Width	869.95		m
Coverage Rate (No line optimization)	146.62		km^2/h
Recommended Line Spacing (No DTM)	688.43		m
Minimum Sidelap (No DTM, lower)	20.87		%
Minimum Sidelap (upper)	13.98		%
Point Spacing and Density			
Maximum Point Spacing Across Track	0.73		m
Maximum Point Spacing Along Track	0.73		m
Across Track/Along Track Ratio	1.00	1.00	
Average Point Density	4.08	1.00	pts / m^2
Average Point Spacing	0.50		m
Nadir Point Density	3.72		pts / m^2
Reflectivity and SNR			
Illuminated Footprint Diameter	0.30		m, 1/e^2
Terrain Reflectivity	0.10		
Estimated SNR for diffuse targets	25.78 - 24.22		
Line/Rail Cross Section	10.00		mm
Line/Rail Reflectivity	0.30		

Table 1 – Technical Specifications for Mission

LIDAR CONTROL

One existing NGS monument was used to control the LiDAR acquisition for the Central Virginia Seismic LiDAR project area. The coordinates of the base station are provided in the table below.

Name	Latitude	Longitude	Ellipsoid Ht (m)	Orthometric Ht (m)
VA 11	38 00 35.25509(N)	077 58 24.21268(W)	112.461	144.79

Table 2 – Base Stations used to control LiDAR acquisition

AIRBORN GPS KINEMATIC

IPAS-TC software was used to compute the Exterior Orientation of each image at the moment of exposure. The method is by integrating Inertial Navigation Solution by processing IMU data and the simultaneously collected GPS data from SPAN System *(Position and Orientation System/Airborne Vehicle)* along with observables of locally positioned GPS base station on the ground. It computes a carrier phase GPS solution and then blends it with inertial data.

The raw airborne kinematic GPS data was processed along with ground GPS data observables. The NAD83 (2011) Epoch 2009.55 & 2010 coordinates were used to compute the final Inertial Positions.

The resulting trajectory was post processed using IPAS-TC and trajectory data was exported to an SOL for further processing and to be blended with IMU data.

There was no significant problem encountered in the processing. The accuracy of the processed Airborne GPS data is well within 10cm or better as shown in the combined forward/reverse separation plot.

GPS processing reports for each mission are included in Appendix D.

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 initially with default values from the sensor software. 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.

FINAL SWATH VERTICAL ACCURACY ASSESSMENT

Once Dewberry received the calibrated swath data from LMSI/PAR, Dewberry tested the vertical accuracy of the open terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the twenty one (21) open terrain independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in open terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in open 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. Project specifications require a FVA of 0.181 m based on the $RMSE_z$ (0.0925 m) x 1.96. The dataset for the Central Virginia Seismic LiDAR Project satisfies this criteria. The raw LiDAR swath data tested 0.12 m vertical accuracy at 95% confidence level in open terrain, based on $RMSE_z$ (0.061m) x 1.9600. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	$RMSE_z$ (m) Open Terrain Spec=0.0925	FVA – Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.181	Mean (m)	Median (m)	Skew	Std Dev m)	# of Points	Min (m)	Max (m)
Open Terrain	0.061	0.120	0.023	0.027	-0.828	0.058	21	-0.138	0.125

Table 3 – Raw Swath Vertical Accuracy Statistics

LiDAR Processing & Qualitative Assessment

DATA CLASSIFICATION AND EDITING

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

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, or 10 including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- 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 10 cm of each other, the pixel is colored green. If the elevations of points within each pixel are between 10 cm and 15 cm of each other, the pixel is colored yellow, and if the elevations of points within each pixel are greater than 15 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 Central Virginia Seismic 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.

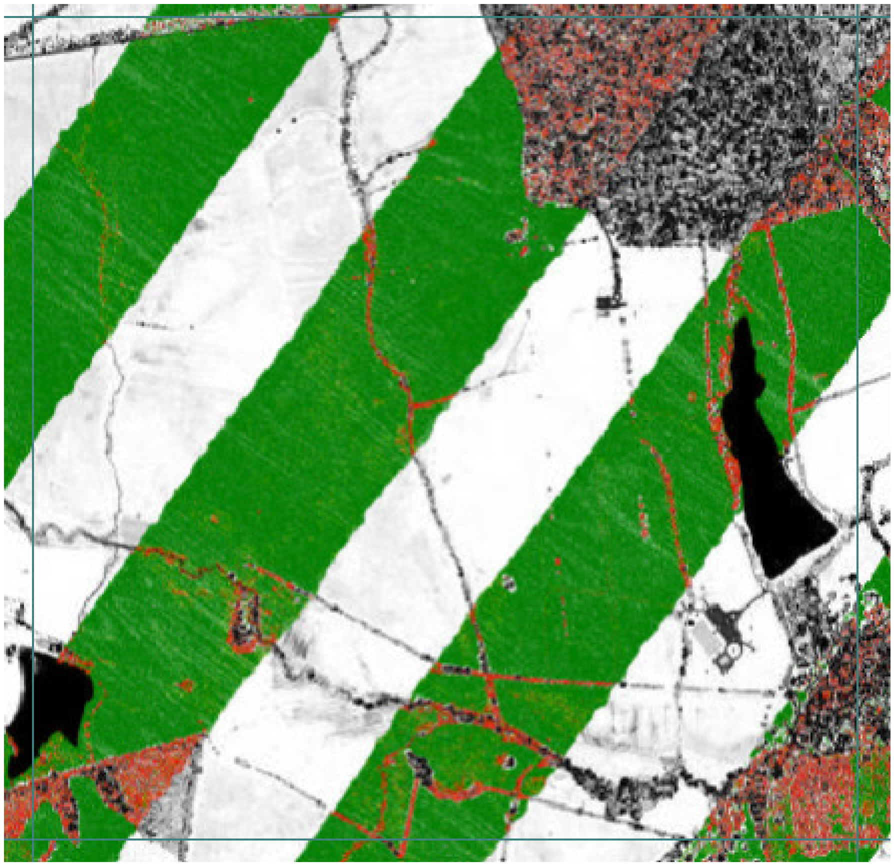


Figure 4 - DZ orthos created from the full point cloud. Some red pixels are visible along embankments, sloped terrain, and in vegetated land cover, as expected. Open, flat areas are green indicating the calibration and relative accuracy of the data is acceptable.

Once the calibration and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The LAS dataset was 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.

QUALITATIVE ASSESSMENT

Dewberry's 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 0.7 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.

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 Central Virginia Seismic LiDAR project incorporated the following reviews:

1. *Format:* The LAS files are verified to meet project specifications. The LAS files for the Central Virginia Seismic 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
- Projection
    - Datum – North American Datum 1983 (2011)
    - Projected Coordinate System – UTM Zone 17
    - Linear Units – Meters
    - Vertical Datum – North American Vertical Datum 1988, Geoid 12A
    - Vertical Units - Meters
- LAS header information:
    - Class (Integer)
    - Adjusted GPS 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 Central Virginia Seismic LiDAR project it is stipulated that the minimum post spacing in un-obscured areas should be 1 point per 0.7 square meters.

   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. No unacceptable voids are present in the Central Virginia Seismic LiDAR project.

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. *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.

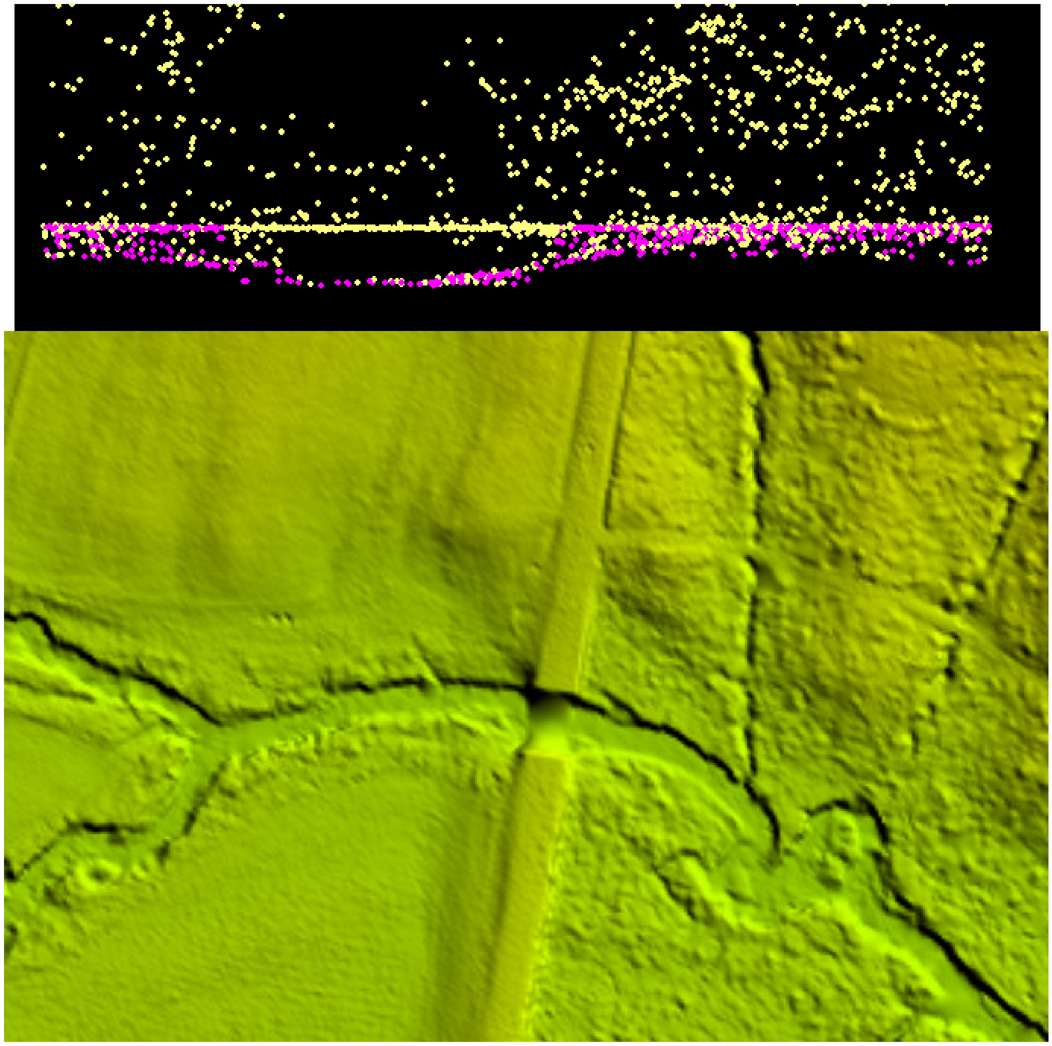


Figure 5 – Tile number 17SQC470175. The DEM in the bottom view shows a visual artifact because the surface model is interpolated from the ground points on the slope leading to the bridge to the lower ground points on either side of the bridge. The surface model must make a continuous model and in order 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.

b. *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.

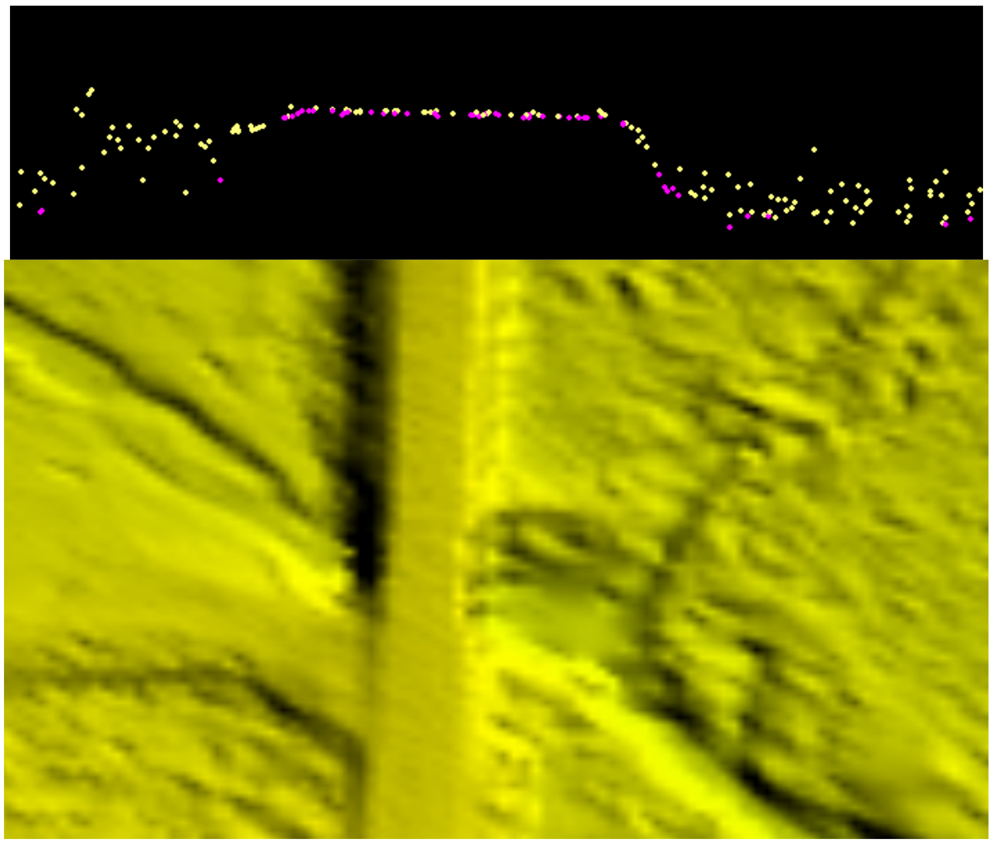


Figure 6– Tile number 17SQC455160. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 1.

c. *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.

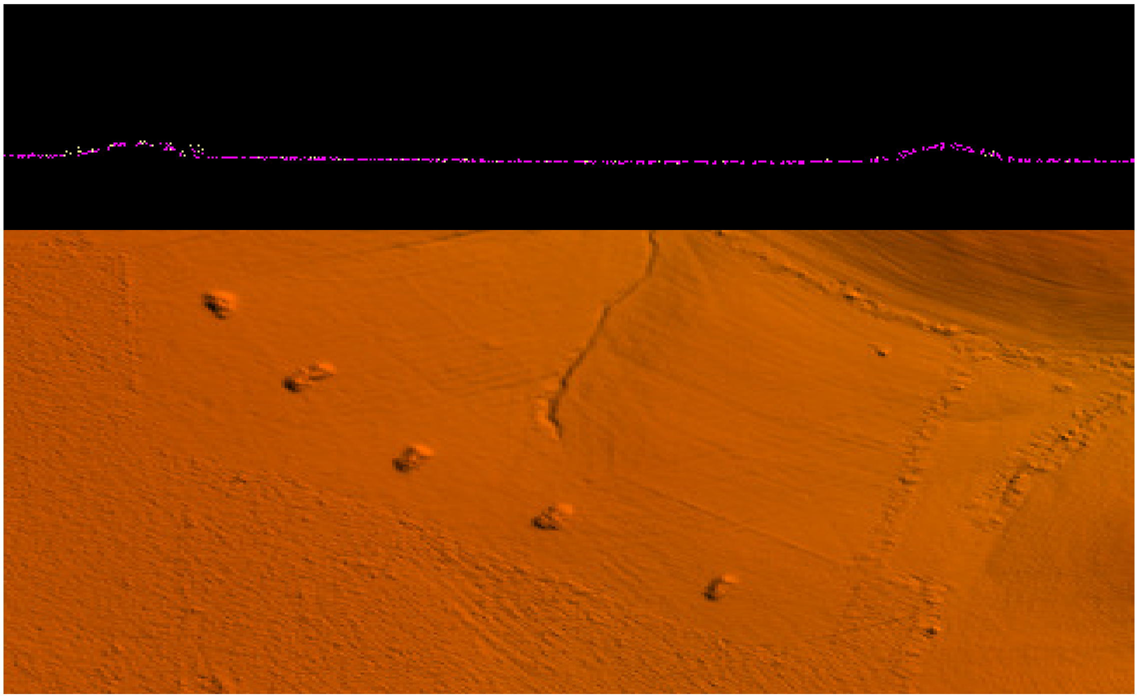


Figure 7 - Tile 17SQC485145. Profile with the points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

Survey Vertical Accuracy Checkpoints

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table. A total of sixty three (63) checkpoints were surveyed for the Central Virginia Seismic LiDAR Project.

Point ID	NAD83 UTM Zone 17		NAVD88
	Easting X (m)	Northing Y (m)	Elevation (m)
BE-1	738266.635	4205923.338	146.451
BE-2	746479.682	4203414.456	158.513
BE-3	749487.308	4199325.52	129.006
BE-4	743030.99	4210077.428	157.501
BE-5	746395.346	4209005.05	146.01
BE-6	748983.928	4208516.72	135.017
BE-7	752160.721	4207806.456	134.485
BE-8	755424.937	4210970.96	140.858
BE-9	759304.868	4208558.963	122.677
BE-10	746668.328	4215044.178	134.657
BE-11	754393.073	4218264.261	157.888
BE-12	759466.55	4213962.033	158.478
BE-13	762871.92	4215236.355	121.242
BE-14	749914.866	4221973.621	167.102
BE-15	755460.975	4222735.756	143.945
BE-16	762982.793	4216962.612	110.563
BE-17	756571.987	4226411.574	125.615
BE-18	758880.416	4227206.591	127.374
BE-19	762912.569	4223380.954	99.706
BE-20	764628.486	4226838.83	118.702
BE-21	767929.509	4223813.94	85.474
FO1	739869.008	4205279.158	127.666
FO2	742592.427	4205856.625	151.814
FO3	743085.954	4203783.284	135.297
FO4	751134.38	4202063.09	158.205
FO5	741009.128	4209632.286	144.742
FO6	744579.765	4207516.693	143.527
FO7	749050.253	4205666.017	146.319
FO8	753441.359	4205307.683	153.343

FO9	747488.756	4212441.304	127.174
FO10	752191.847	4213075.587	131.462
FO11	756009.393	4211918.396	138.772
FO12	757339.677	4210549.947	118.66
FO13	750930.136	4219311.284	133.971
FO14	758167.518	4220068.104	125.919
FO15	765598.1	4217373.261	113.242
FO16	756885.075	4231583.672	145.71
FO17	761699.282	4232604.009	135.698
FO18	762829.338	4229966.527	134.038
FO19	765893.662	4225912.924	109.987
FO20	768009.365	4225078.951	110.329
FO21	770932.635	4224687.011	108.591
UA1	739772.433	4207667.568	136.051
UA2	742111.944	4203010.436	144.485
UA3	745680.342	4201189.534	159.344
UA4	752762.015	4198972.223	131.723
UA5	742529.849	4208537.854	161.868
UA6	745645.187	4205664.871	157.548
UA7	750599.464	4203724.201	163.472
UA8	755796.043	4204877.624	155.288
UA9	746822.286	4217428.815	150.254
UA10	756756.6	4215497.947	155.058
UA11	762298.902	4213245.725	147.012
UA12	752617.203	4221046.307	159.143
UA13	759892.776	4220581.326	128.516
UA14	767412.33	4220551.312	111.851
UA15	754035.965	4229134.716	137.12
UA16	758713.151	4223359.43	126.209
UA17	761739.17	4228753.827	142.225
UA18	762947.77	4227248.984	122.523
UA19	762047.898	4222693.563	88.564
UA20	770343.993	4223917.942	92.066
UA21	750727.808	4209800.163	121.076

Table 4: Central Virginia Seismic LiDAR surveyed accuracy checkpoints

One checkpoint (UA15) was removed from the vertical accuracy testing for the classified LiDAR due to the point being outside of the project boundary. The coordinates of this checkpoint are provided in the table below and an illustration showing the checkpoint located outside the boundary are provided in the figures below.

Point ID	NAD83 UTM Zone 17		NAVD88	LiDAR Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
UA15	4229134.716	754035.965	137.120	137.077	-0.043	0.043

Table 5: Checkpoint removed from vertical accuracy testing due its being outside of the project boundary.

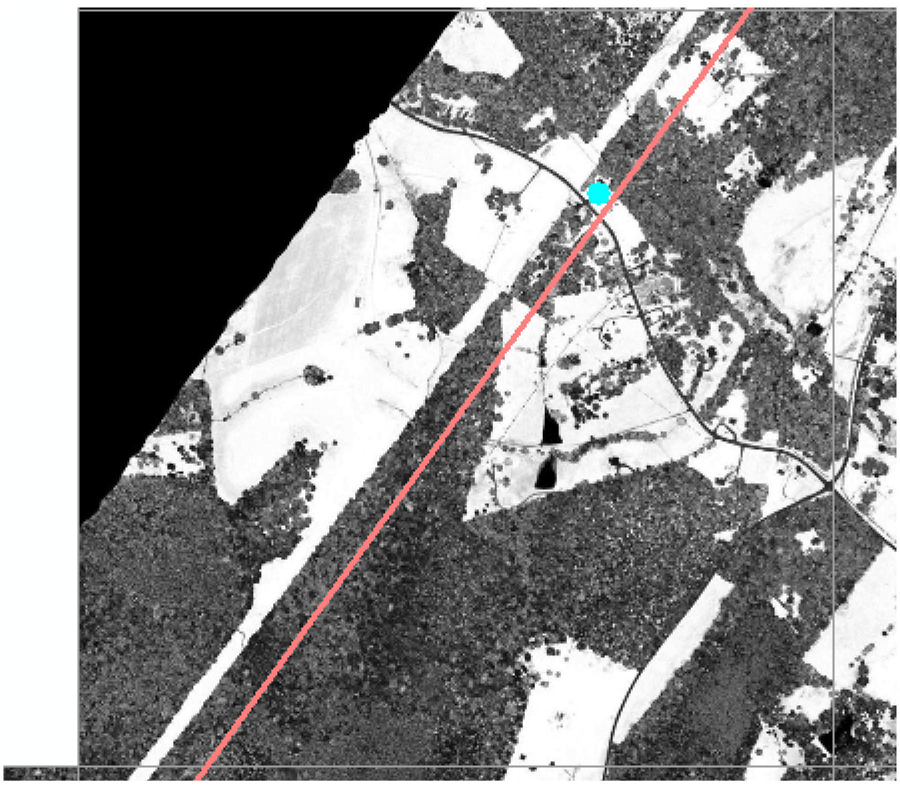


Figure 8 – Urban Checkpoint 15, shown as the teal circle on the intensity ortho, is located outside the project boundary, shown in salmon.

LiDAR Vertical Accuracy Statistics & Analysis

BACKGROUND

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

For quantitative assessment (i.e. vertical accuracy assessment), Sixty two (62) check points were surveyed for the project and are located within bare earth/open terrain, urban, tall weeds/crops, brush lands/tress, and forested/fully grown land cover categories. The checkpoints were surveyed for the project using RTK survey methods. Please see appendix A to view the survey report which details and validates how the survey was completed for this project.

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

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 ($RMSE_z$) of the checkpoints x 1.9600. For the Central Virginia Seismic LiDAR project, vertical accuracy must be 0.181 meters or less based on an $RMSE_z$ of 0.0925 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 95^{th} percentile error for all checkpoints in all land cover categories combined. The Central Virginia Seismic LiDAR Project CVA standard is 0.269 meters based on the 95^{th} percentile. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} 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 95^{th} percentile error for all checkpoints in each land cover category. Central Virginia Seismic LiDAR Project SVA target is 0.269 meters based on the 95^{th} percentile. 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.

The relevant testing criteria are summarized in Table 6.

Quantitative Criteria	Measure of Acceptability
Fundamental Vertical Accuracy (FVA) in open terrain only using $RMSE_z$ *1.9600	0.181 meters (based on $RMSE_z$ (0.0925 meters) * 1.9600)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined at the 95% confidence level	0.269 meters (based on combined 95^{th} percentile)
Supplemental Vertical Accuracy (SVA) in each land cover category separately	0.269 meters (based on 95^{th}

at the 95% confidence level	percentile for each land cover category)

Table 6 — Acceptance Criteria

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 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 FVA, CVA, and SVA values.
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.

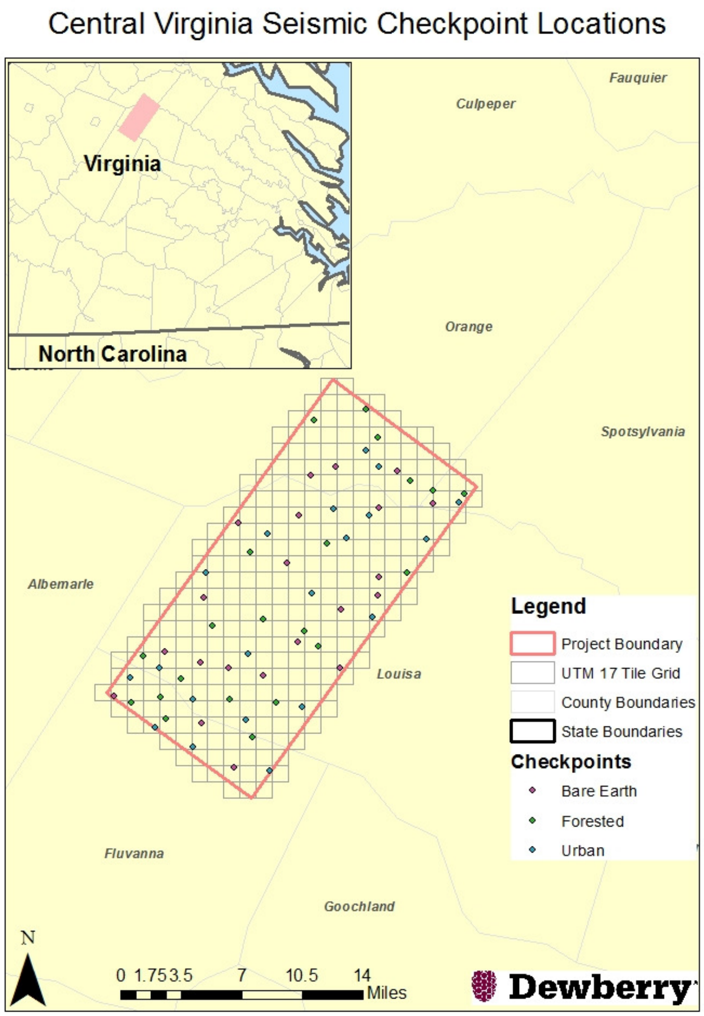


Figure 9 – Location of QA/QC Checkpoints

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	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.181 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.269 m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.269 m
Consolidated	62		0.188	
Bare Earth-Open Terrain	21	0.120		
Urban	20			0.290
Forested and Fully Grown	21			0.190

Table 7 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.06 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.12 meters at the 95% confidence level based on $RMSE_z$ x 1.9600. `

Compared with the 0.269 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.188 meters based on the 95^{th} percentile.

Compared with the target 0.269 meters specification, SVA for checkpoints in the urban land cover category tested 0.29 meters based on the 95^{th} percentile, and checkpoints in the Forrested and Fully Grown land cover category tested 0.19 meters 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 +/- 0.10 meters of the checkpoints elevations, but there were some outliers where LiDAR and checkpoint elevations differed by up to +0.36 meters.

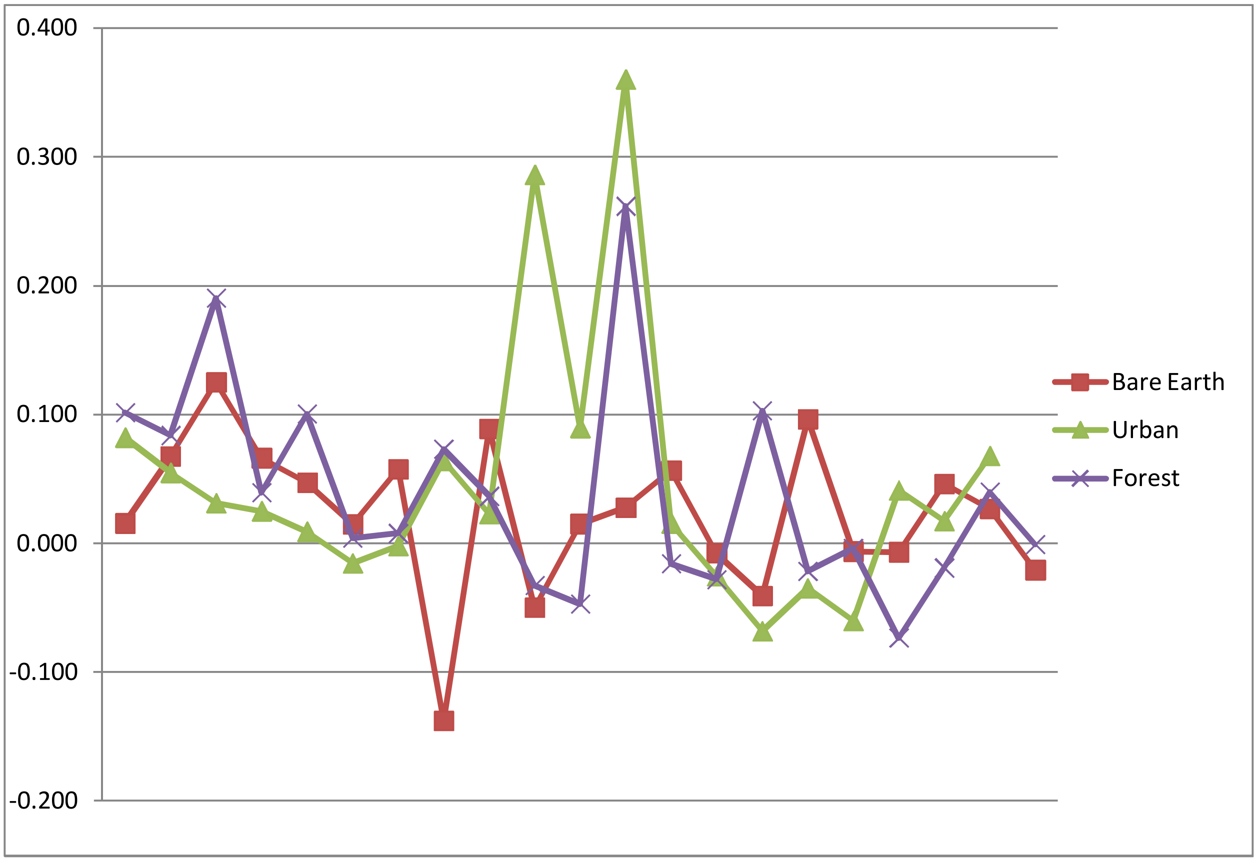


Figure 10 – Magnitude of elevation discrepancies per land cover category

Table 8 lists the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83 UTM Zone 18N		NAVD88		Delta Z	AbsDelta Z
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
UA12	4221046.307	752617.203	159.143	159.503	0.360	0.360
FO3	4203783.284	743085.954	135.297	135.487	0.190	0.190
FO12	4210549.947	757339.677	118.660	118.922	0.262	0.262
UA10	4215497.947	756756.600	155.058	155.344	0.286	0.286

Table 8 – 5% Outliers

Table 9 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) Open Terrain Spec=0.0925 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
Consolidated	62		0.036	0.024	1.651	0.082	4.633	-0.138	0.360
Open Terrain	21	0.061	0.023	0.027	-0.828	0.058	1.743	-0.138	0.125
Urban	20		0.048	0.024	2.045	0.104	4.473	-0.068	0.360
Forested and Fully Grown	21		0.038	0.008	1.249	0.081	1.676	-0.073	0.262

Table 9 — Overall Descriptive Statistics

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.14 meters and a high of +0.36 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 meters to +0.125 meters.

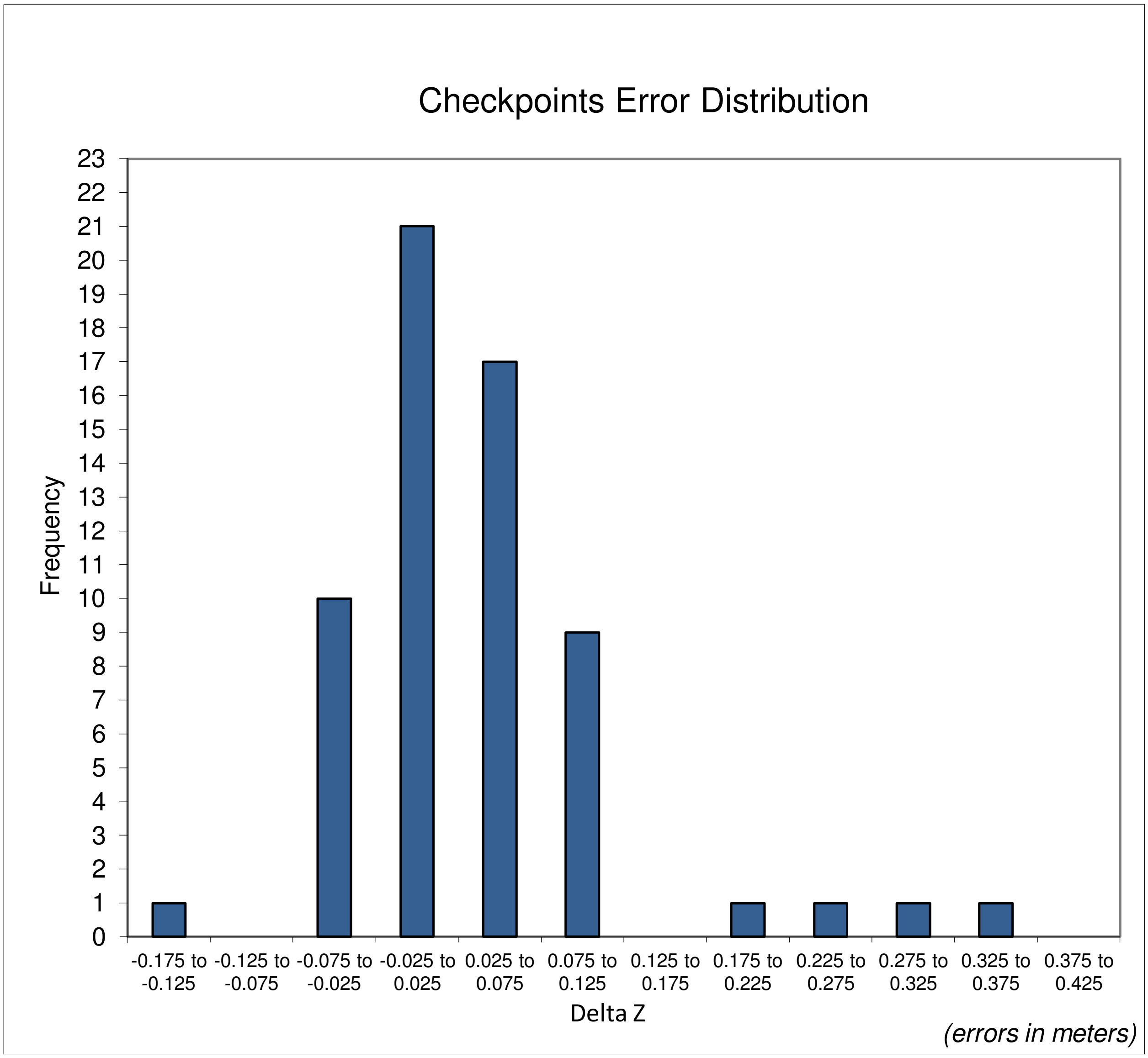


Figure 11 – Histogram of Elevation Discrepancies

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

Breakline Production & Qualitative Assessment Report

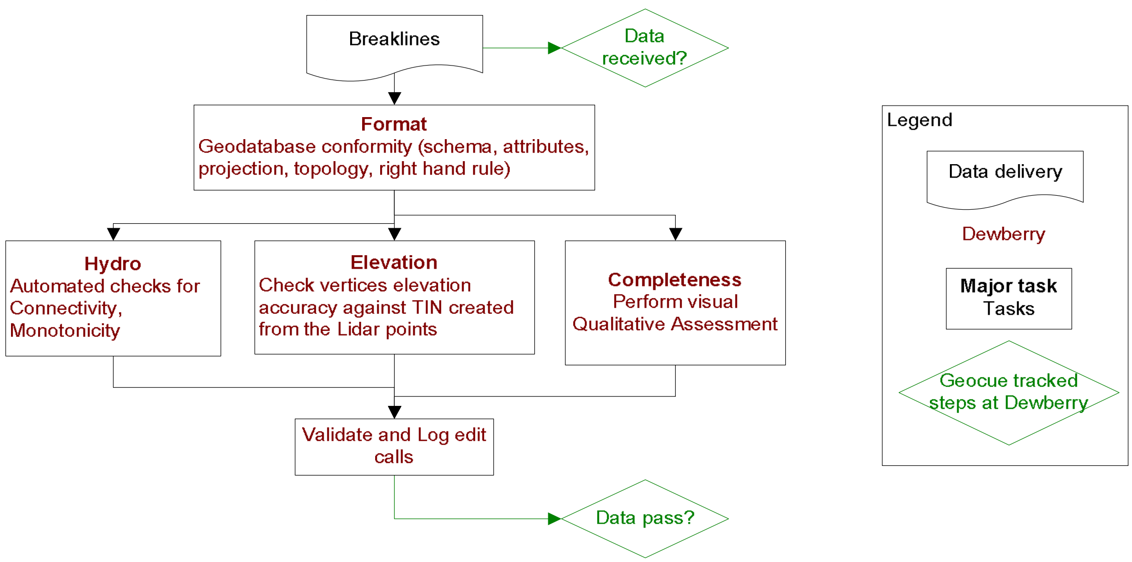
BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop LiDAR stereo models of the Central Virginia Seismic 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.

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.



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.

BREAKLINE QA/QC CHECKLIST

Project Number/Description: G13PD00814-Central Virginia Seismic LiDAR

Date: 07/2014

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). 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, 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 ESRI's Data Reviewer

The following data checks are performed utilizing ESRI's Data Reviewer 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. Data Reviewer 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 Lakes, Tidal Waters, and Islands (if delivered as a separate feature class) feature classes. This tool is found under "Topology Checks."

☒ Perform "different Z-Value at intersection check" (Inland Streams and Rivers to Inland Streams and Rivers), (Ponds and Lakes to Ponds and Lakes), (Tidal Waters to Tidal Waters), (Streams and Rivers to Ponds and Lakes), (Streams and Rivers to Tidal Waters), (Ponds and Lakes to Tidal Waters), (Island to Inland Ponds and Lakes), (Island to Tidal Waters), (Island to Island),and (Islands to Inland Streams and Rivers) (Elevation Difference Tolerance= .01 feet Minimum, 600 feet Maximum, Touches). This tool is found under "Z Value Checks." Please note that polygon feature classes will need to be converted to lines for this check.

☒ Perform "duplicate geometry check" on (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal Waters to Tidal Waters), (Islands to Islands-if delivered as a separate shapefile), (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes). Attributes do not need to be checked during this tool. This tool is found under "Duplicate Geometry Checks."

☒ Perform "geometry on geometry check" (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal waters to Tidal waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes), (Islands to Islands). Spatial relationship is crosses, attributes do not need to be checked. This tool is found under "Feature on Feature Checks." Please note that "crosses" only works with line feature classes and not polygons. If the inputs are polygons, they will need to be converted to a line prior to running this tool.

☒ Perform "geometry on geometry check (Tidal Waters to Islands), and (Inland Ponds and Lakes to Islands), (Inland Streams and Rivers to Islands). Spatial relationship is contains, attributes do not need to be checked. This tool is found under "Feature on Feature Checks."

☒ Perform "geometry on geometry check" (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal waters to Tidal waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes), (Islands to Islands). Spatial relationship is intersect, attributes do not need to be checked. This tool is found under "Feature on Feature Checks." Please note that false positives may be returned with this tool but that this tool may identify issues not found with "crosses."

☒ Perform "polygon overlap/gap is sliver check" on (Tidal Waters to Tidal Waters), (Island to Island), (Island to Inland Ponds and Lakes) and (Inland Ponds and Lakes to Inland Ponds and Lakes), (Inland Ponds and Lakes to Tidal Waters). 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 and Rivers) and (Tidal Waters to Tidal Waters if they are not a constant elevation) 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 features are ok and 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 and must be a line. If features are a polygon they will need to be converted to a line feature. Z tolerance is 0.01 meters.

☒ Perform connectivity check between (Inland Streams and Rivers to Inland Streams and Rivers), (Ponds and Lakes to Ponds and Lakes), (Tidal Waters to Tidal Waters), (Streams and Rivers to Ponds and Lakes), (Streams and Rivers to Tidal Waters), (Ponds and Lakes to Tidal Waters), (Island to Inland Ponds and Lakes), (Island to Tidal Waters), (Island to Island),and (Islands to Inland Streams and Rivers) 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.

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

Data Dictionary

HORIZONTAL AND VERTICAL DATUM

The horizontal datum shall be North American Datum of 1983(2011), 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. Geoid12A shall be used to convert ellipsoidal heights to orthometric heights.

COORDINATE SYSTEM AND PROJECTION

All data shall be projected to both UTM Zone 17, 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 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	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

	qualify for this project.	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 1/2 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 1/2 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

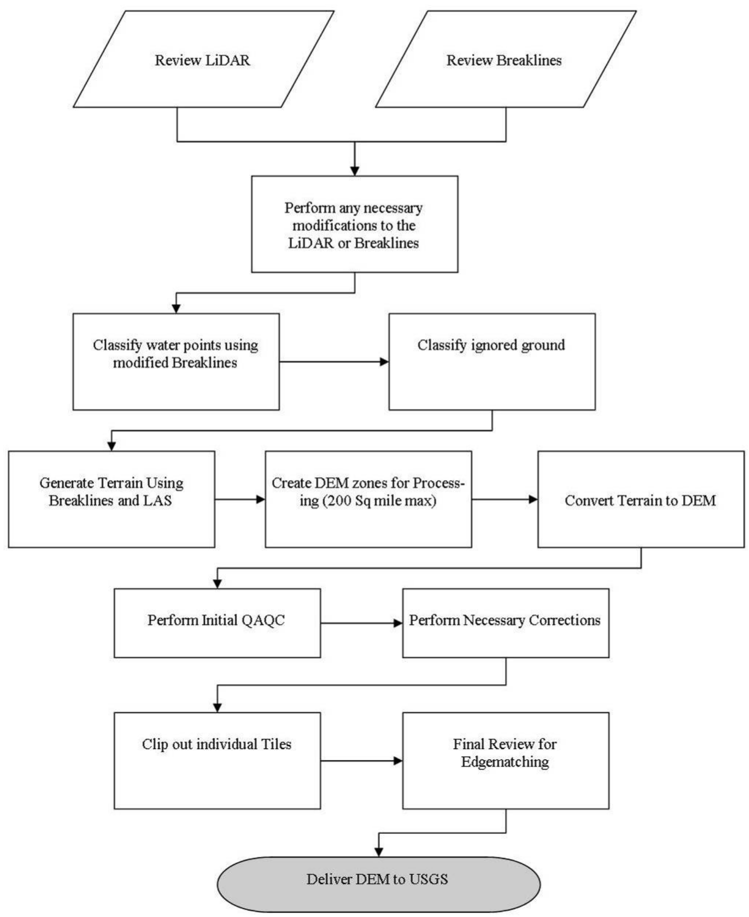
		probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

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.

Dewberry Hydro-Flattening Workflow



1. Classify Water Points: 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. Classify Ignored Ground Points: 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.
3. Terrain Processing: A Terrain will be generated using the Breaklines and LAS data that has been imported into Arc as a Multipoint File.
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 4. 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 a Dewberry proprietary tool.
9. Final QA: Final QA will be performed on the dataset to ensure that tile boundaries are seamless.

DEM QUALITATIVE ASSESSMENT

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

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

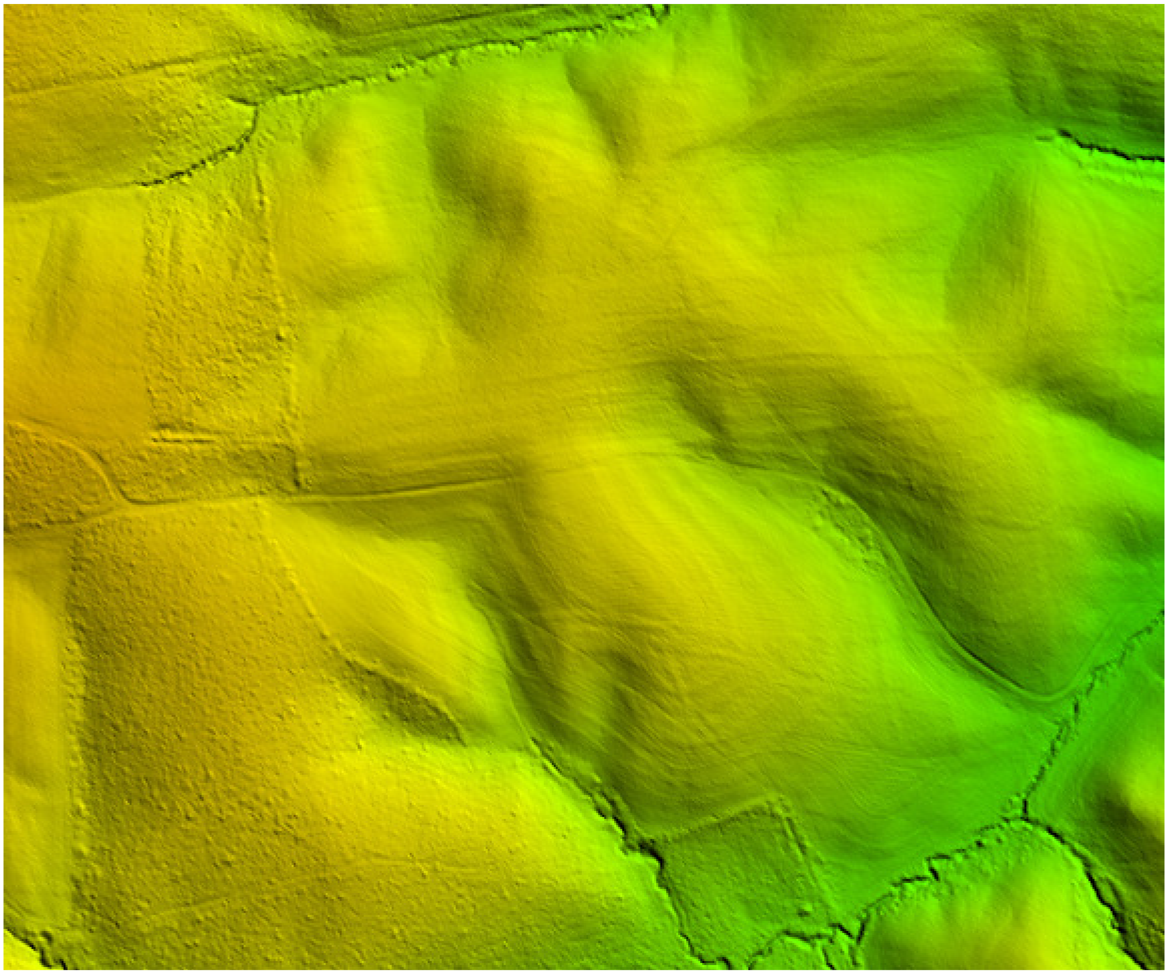


Figure 12-Tile 17SQC575235. The bare earth DEM

Edge-Matching

Central Virginia Seismic LiDAR project was compared to the previously collected and accepted Louisa dataset to verify the bare-earth models created a seamless dataset across county boundaries and between adjacent datasets. Hydrographic features did not show significant temporal changes between datasets even though they were collected at different time periods. All ground or bare-earth from the Central Virginia Seismic LiDAR area should correctly edge-match with previously collected data. Dewberry verified edge-matching and consistency between this Central Virginia LiDAR project and adjacent Louisa, Virginia LiDAR. Over 99% of the overlapping data matches within the RMSEz value of 9.25cm.

Below is an example of the difference raster between the Louisa and Central Virginia datasets.

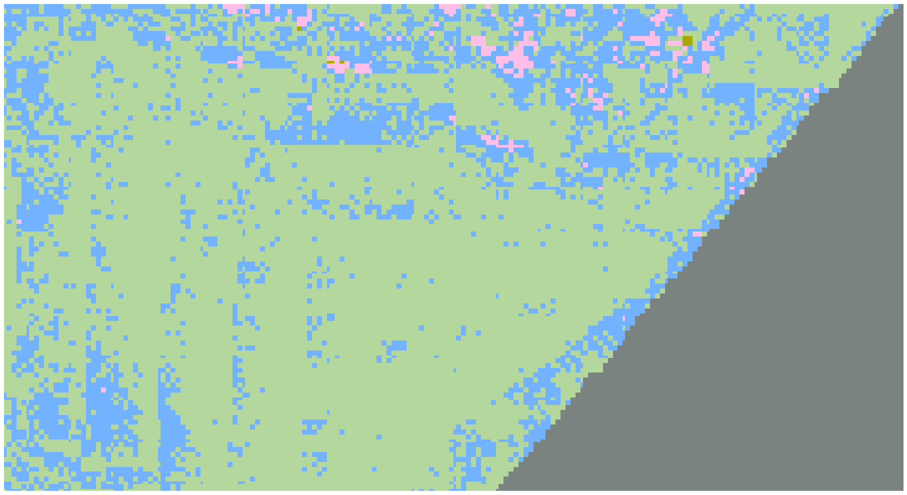


Figure 13 - Tile 17SQB530995- (Green - < 0.0925m; Blue – 0.0925m to 0.18m; Pink – 0.18m to 0.36m, Grey- No Overlap) - Central Virginia Seismic data edge-matches with previously collected and accepted Louisa to create a seamless dataset. Some minor elevation differences exist in the bare-earth models between the two datasets, but 99% of measured differences are within the project specified RMSEz value of 0.0925 meters.

DEM VERTICAL ACCURACY RESULTS

The same 62 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.

Table 10 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 ($RMSE_z$ x 1.9600) Spec=0.181 m	CVA – Consolidated Vertical Accuracy (95th Percentile) Spec=0.269 m	SVA – Supplemental Vertical Accuracy (95th Percentile) Target=0.269 m
Consolidated	62		0.165	
Bare Earth-Open Terrain	21	0.125		
Urban	20			0.309
Forested and Fully Grown	21			0.166

Table 10 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.064 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.125 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.269 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.165 meters based on the 95th percentile.

Compared with the target 0.269 meters specification, SVA for checkpoints in the forested and fully grown land cover category tested 0.166 meters based on the 95th percentile, and checkpoints in the urban land cover category tested 0.309 meters based on the 95th percentile.

Table 11 lists the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83 UTM Zone 18N		NAVD88		Delta Z	AbsDelta Z
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
FO3	743085.954	4203783.284	135.297	135.463	0.166	0.166
UA12	752617.203	4221046.307	159.143	159.499	0.356	0.356
FO12	757339.677	4210549.947	118.660	118.883	0.223	0.223
UA10	756756.600	4215497.947	155.058	155.364	0.306	0.306

Table 11 — 5% Outliers

Table 12 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) Open Terrain Spec=0.0925 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
Consolidated	62		0.039	0.032	1.535	0.080	4.959	-0.150	0.356
Open Terrain	21	0.064	0.026	0.030	-1.136	0.060	2.701	-0.150	0.124
Urban	20		0.052	0.034	2.048	0.105	4.382	-0.071	0.356
Forested and Fully Grown	21		0.040	0.023	0.801	0.073	0.546	-0.059	0.223

Table 12— Overall Descriptive Statistics

DEM QA/QC CHECKLIST

Project Number/Description: G13PD00814-Central Virginia Seismic LiDAR

Date: 07/2014

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 in Arc with a hillshade to check for issues with the hydro-flattening 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.
☒ DEM cell size is 1 Meter for UTM and 2.5 feet in StatePlane

☒ Perform all necessary corrections in Arc using Dewberry's proprietary correction workflow.
☒ Review all corrections in Global Mapper
☒ Perform final overview on tiled data 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

Appendix A: Survey Report

INTRODUCTION

Project Summary

Dewberry Engineers Inc., under contract to United States Geodetic Survey to provide 60 Quality Assurance check points for 230 square miles in Fluvanna, Louisa, Orange, and Spotsylvania Counties in Virginia. Under the above USGS Task Order, Dewberry is tasked to complete the quality assurance of high resolution LiDAR-derived elevation products. As a part of this contract Dewberry staff has completed checkpoint surveys that will be used to evaluate vertical accuracy on the bare-earth terrain derived from the LiDAR.

Existing NGC Control Points were located and surveyed to check the accuracy of the RTK/GPS survey equipment with the results shown in section 2.4 of this report.

As an internal QA/QC procedure and to verify that the Check Points meet the 95% confidence level approximately 50% of the points were re-observed and are shown in section 5.0 in this report.

Final horizontal coordinates are referenced to UTM Zone 17 North (Universal Transverse Mercator), NAD83, in meters (North American Datum). Final Vertical elevations are referenced to NAVD88, in meters (North American Vertical Datum).

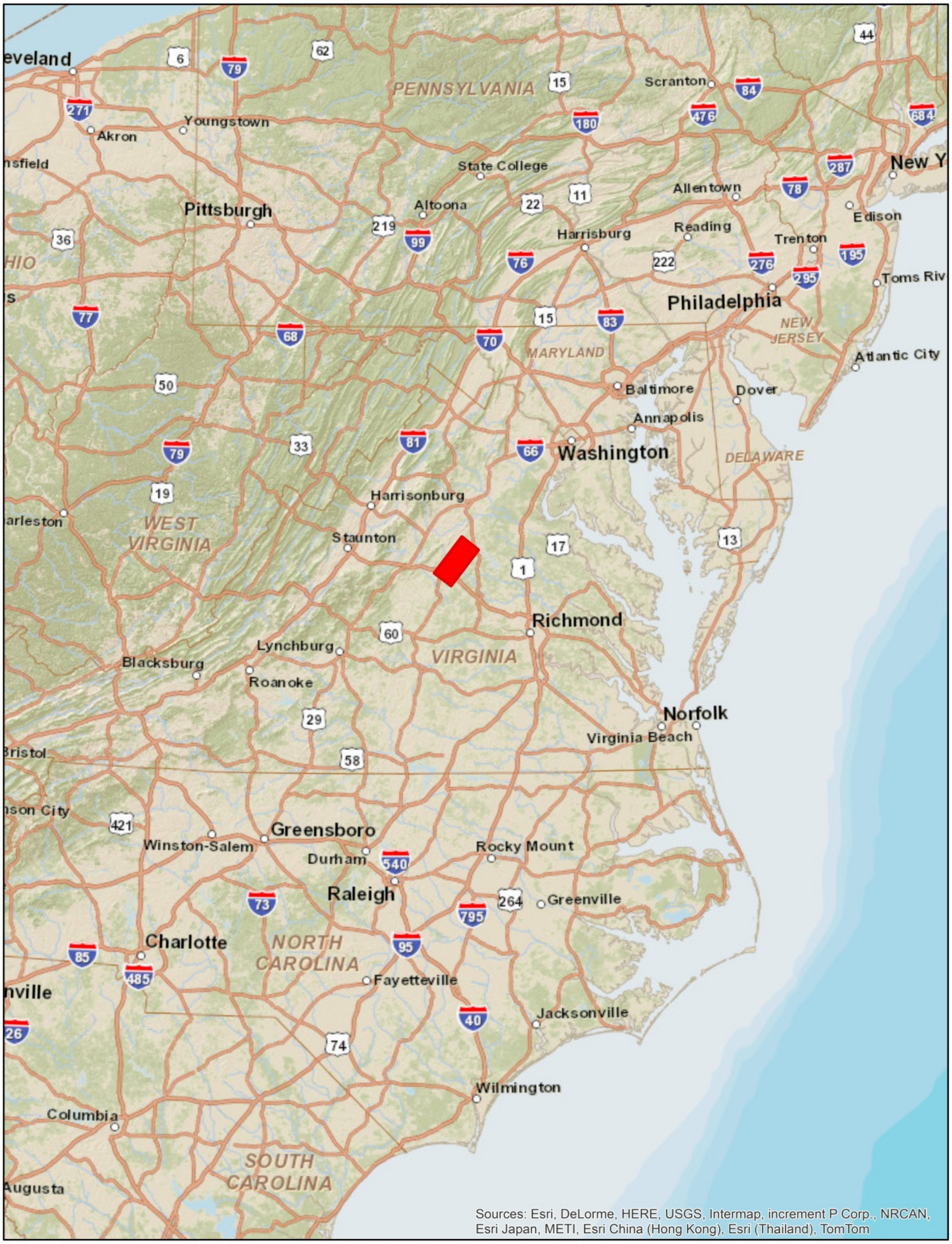
Points of Contact

Questions regarding the technical aspects of this report should be addressed to:

Dewberry Engineers Inc.

Matthew Rudolph
6135 Lakeview Road
Suite 150
Charlotte, NC 20269
(704)264-1257direct
(704)509-9937

Project Area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Scranton
Youngstown
Akron
State College
New Y
Allentown
Edison
Pittsburgh
Altoona
Harrisburg
Reading
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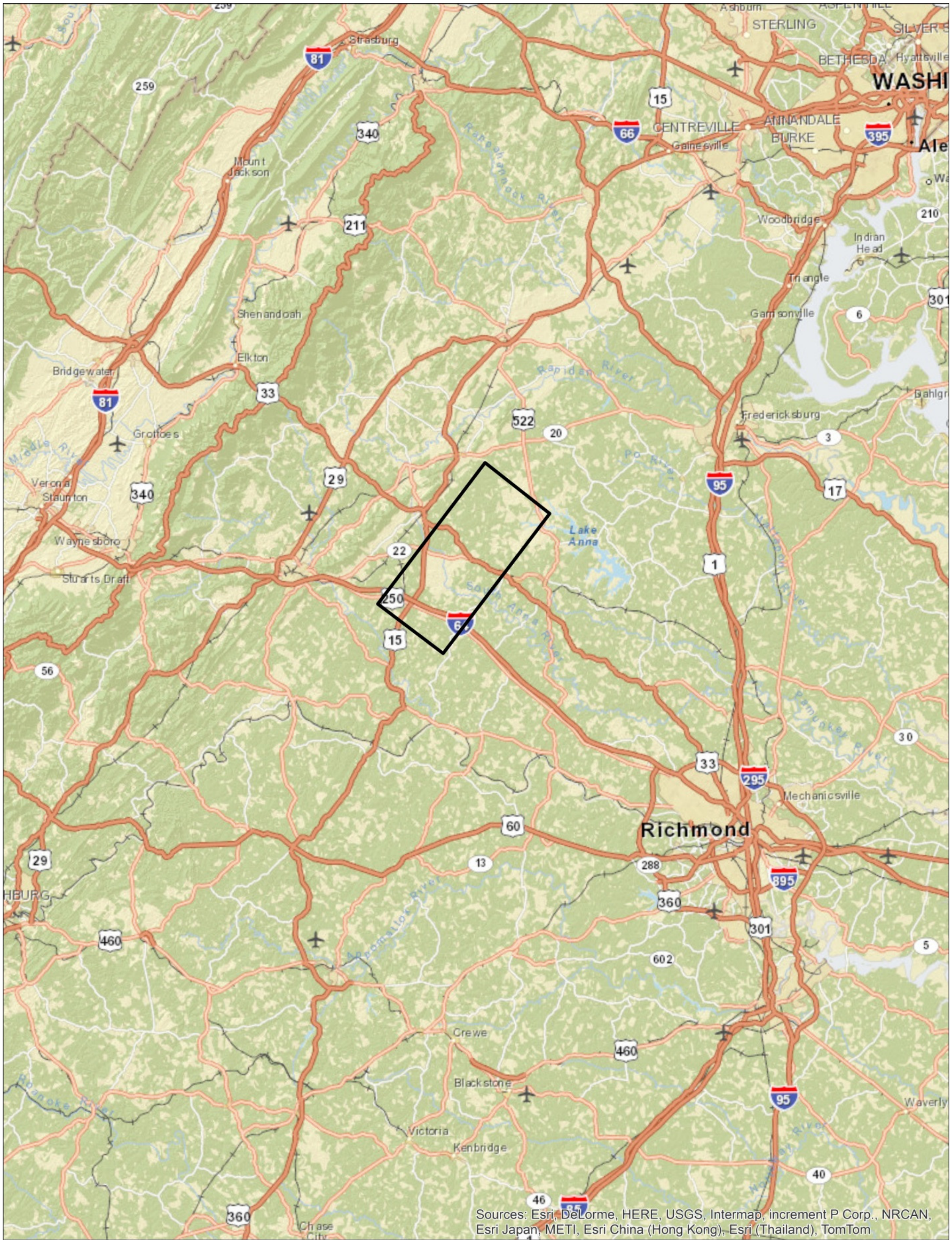
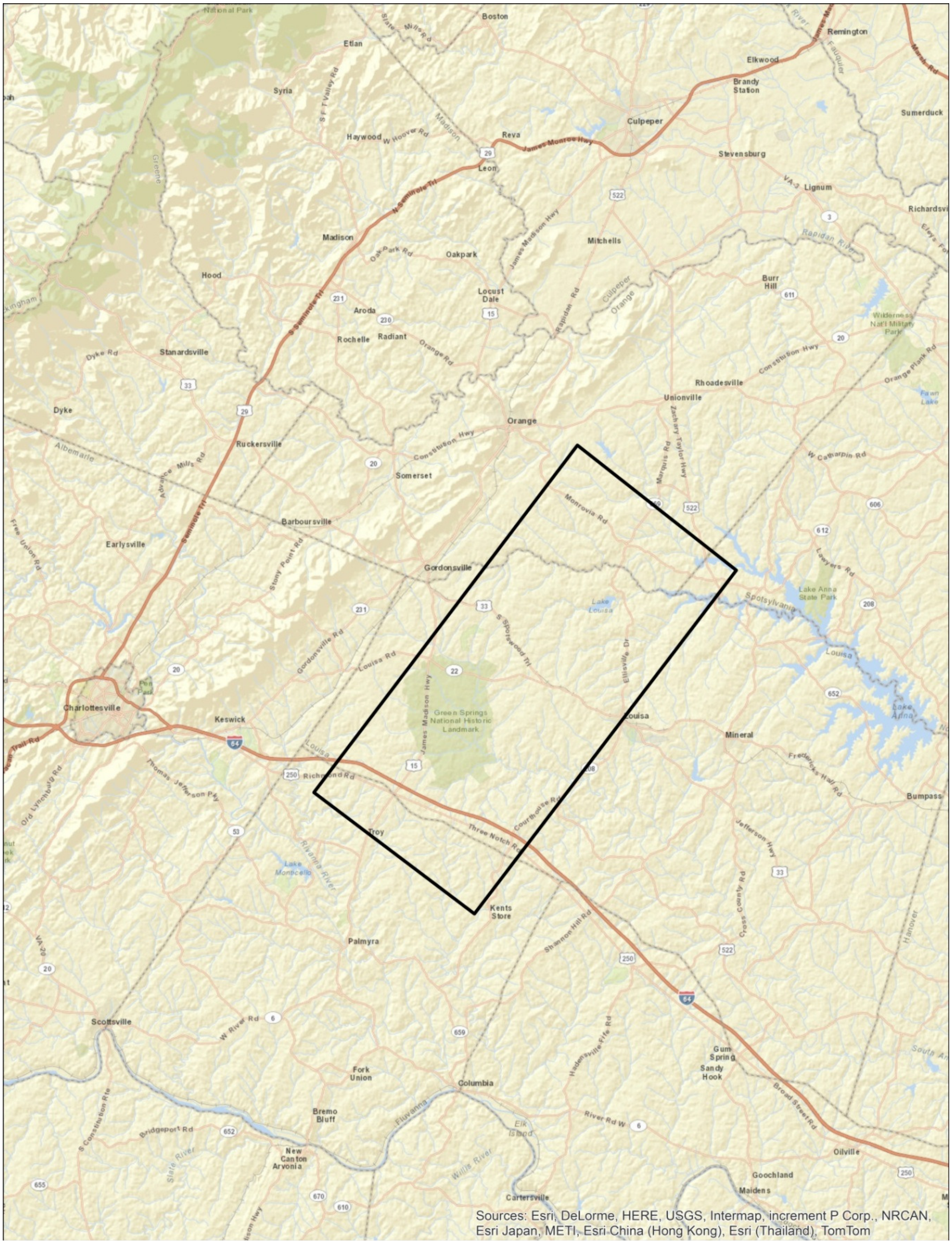
Toms Riv
Philadelphia
NEW JERSEY
MARYLAND
Atlantic City
Baltimore
Dover
Annapolis
Washington
DELAWARE
Harrisonburg
WEST VIRGINIA
Staunton
Richmond
Lynchburg
VIRGINIA
Blacksburg
Roanoke
Norfolk
Virginia Beach
Greensboro
Winston-Salem
Durham
Rocky Mount
Raleigh
Greenville
Charlotte
NORTH CAROLINA
Fayetteville
Jacksonville
Wilmington
Columbia
SOUTH CAROLINA
Augusta
Sources: Esri, DeLorme, HERE, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom

Dewberry


Strasburg
STERLING
BETHESDA
WASHI
CENTREVILLE
ANNANDALE
BURKE
Gainesville
Mount Jackson
Woodbridge
Indian Head
Triangle
Garrisonville
Shenandoah
Elkton
Bridgewater
Rapidan River
Fredericksburg
Grottoes
Po River
Verona
Staunton
Lake Anna
Waynesboro
Stuarts Draft
Mechanicsville
Richmond
Crewe
Blackstone
Victoria
Kenbridge
Waverly
Sources: Esri, DeLorme, HERE, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom

Dewberry



PROJECT DETAILS

Survey Equipment

For the purpose of GPS observations the following equipment was utilized for data collection.

- Trimble R-8 GNSS (Global Navigation Satellite System) receiver / antenna
- 2 meter fixed height pole
- Trimble TSC2 Data Collector

Survey Point Detail

The 60 check points were well distributed throughout the project area so as to cover as many flight lines as possible using “dispersed method” of placement.

A “Ground Control Point Documentation Report” sheet was used to show the placement of the nail and a sketch for each of the points surveyed.

Network Design

The GPS survey performed by Dewberry Engineers Inc. was tied to a Real Time Network (RTN) managed by KeyNetGPS inc. KeyNetGPS is a series of continuously operating, high precision GNSS reference stations. These reference stations have all been linked together using Trimble VRS3Net App software, creating a Virtual Reference Station System (VRS).

Field Survey Procedures and Analysis

Dewberry Engineers Inc. used Trimble R-8 GNSS receivers, which is a geodetic quality dual frequency GPS receiver, to collect data at each surveyed location.

All locations were occupied once with approximately 50% of the locations being re-observed. All re-observations matched the initially derived station positions within the allowable tolerances of 5cm or within the 95% confidence level. Each occupation which utilized the VRS network was occupied for approximately three (3) minutes in duration and measured to at least 180 epochs.

Field GPS observations are detailed on the “Ground Control Point Documentation Reports” submitted as part of this report.

10 existing NGS (National Geodetic Survey) monuments listed in the NSRS (National Spatial Reference System) database were located as an additional QA/QC method to check the accuracy of the VRS network. Some of these monuments were used as Horizontal and Vertical control checks. Some monuments were used as Horizontal or Vertical checks only as shown in the table below.

	AS SURVEYED(m)			AS PUBLISHED(m)						
NGS PT. ID	NORTHING	EASTING	ELEV	NORTHING	EASTING	ELEV	Δ N	Δ E	Δ ELEV	CHK TYPE
LKU A	4075440.488	380599.04	3.73	4,075,440.59	380,599.12	3.75	-0.103	-0.084	-0.020	VERT.
VA 21	4100627.566	384554.955	2.124	4,100,627.56	384,554.95	2.3	0.010	0.007	X	HORIZ.
K 502	4098672.971	376462.99	3.503	4,098,672.96	376,463.00	4	0.008	-0.006	X	HORIZ.
P 94	4097985.036	375769.747	2.108	4,097,985.03	375,769.74	2	0.004	0.007	X	HORIZ.
F-455	4096857.383	376079.277	3.927	X	X	3.957	X	X	-0.030	VERT.
MON 007	4135651.82	349236.942	23.259	4,135,651.79	349,236.96	23.5	0.031	-0.022	X	HORIZ.
124	4107886.234	372228.771	8.579	4,107,886.28	372,228.77	8.7	-0.048	0.003	X	HORIZ.
PASCALE	4071366.848	371222.946	5.515	4,071,366.85	371,222.94	5.6	-0.003	0.009	X	HORIZ.
PEAKE	4094521.001	376414.781	2.479	4,094,520.99	376,414.77	2.5	0.008	0.013	-0.021	VERT.
D 470	4076051.123	3999352.192	3.401	X	X	3.447	X	X	-0.046	VERT.

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

Data Processing Procedures

After field data was collected the information was downloaded from the data collectors into the office software. The software programs used included Trimble Business Center and ArcGIS 10.1.

Downloaded field data is processed through the Trimble Business Center program to obtain the following reports; points report, point comparison, and a point detail report. The reports are reviewed for point accuracy and precision.

After review of the point data an "ASCII" or "txt" file is created. Point files are loaded into ArcGIS software for a visual check of the point data to confirm that it also checks with the "Ground Control Point Documentation Report" sketch and description as well as the point ID, Coordinates, and Elevation.

FINAL COORDINATES

The final coordinate system for checkpoints is as follows:

- Coordinate System = UTM
- UTM Zone = Zone 17 N
- Horizontal Datum = NAD83 (2011)
- Vertical Datum = NAVD88
- Units = both in Meters
- Geoid Model = GEOID12A

BARE EARTH			
PT ID	NORTHING	EASTING	ELEVATION
BE-1	4205923.338	738266.635	146.451
BE-2	4203414.456	746479.682	158.513
BE-3	4199325.52	749487.308	129.006
BE-4	4210077.428	743030.99	157.501
BE-5	4209005.05	746395.346	146.01
BE-6	4208516.72	748983.928	135.017
BE-7	4207806.456	752160.721	134.485
BE-8	4210970.96	755424.937	140.858
BE-9	4208558.963	759304.868	122.677
BE-10	4215044.178	746668.328	134.657
BE-11	4218264.261	754393.073	157.888
BE-12	4213962.033	759466.55	158.478
BE-13	4215236.355	762871.92	121.242
BE-14	4221973.621	749914.866	167.102
BE-15	4222735.756	755460.975	143.945
BE-16	4216962.612	762982.793	110.563
BE-17	4226411.574	756571.987	125.615
BE-18	4227206.591	758880.416	127.374
BE-19	4223380.954	762912.569	99.706
BE-20	4226838.83	764628.486	118.702
BE-21	4223813.94	767929.509	85.474

URBAN AREA			
PT ID	NORTHING	EASTING	ELEVATION
UA1	4207667.568	739772.433	136.051
UA2	4203010.436	742111.944	144.485
UA3	4201189.534	745680.342	159.344
UA4	4198972.223	752762.015	131.723
UA5CHKA	4208537.881	742529.854	161.803
UA6	4205664.871	745645.187	157.548
UA7	4203724.201	750599.464	163.472
UA8	4204877.624	755796.043	155.288
UA9	4217428.815	746822.286	150.254
UA10	4215497.947	756756.6	155.058
UA11	4213245.725	762298.902	147.012
UA12CHKA	4221046.288	752617.21	159.425
UA13	4220581.326	759892.776	128.516
UA14	4220551.312	767412.33	111.851
UA15	4229134.716	754035.965	137.12
UA16CHKA	4223359.401	758713.273	126.115
UA17	4228753.827	761739.17	142.225
UA18	4227248.984	762947.77	122.523
UA19	4222693.563	762047.898	88.564
UA20	4223917.942	770343.993	92.066
UA21	4209800.163	750727.808	121.076

FORESTED OBSERVATION			
PT ID	NORTHING	EASTING	ELEVATION
FO1	4205279.158	739869.008	127.666
FO2	4205856.625	742592.427	151.814
FO3	4203783.284	743085.954	135.297
FO4	4202063.09	751134.38	158.205
FO5	4209632.286	741009.128	144.742
FO6	4207516.693	744579.765	143.527
FO7	4205666.017	749050.253	146.319
FO8	4205307.683	753441.359	153.343
FO9	4212441.304	747488.756	127.174
FO10	4213075.587	752191.847	131.462
FO11	4211918.396	756009.393	138.772
FO12	4210549.947	757339.677	118.66
FO13	4219311.284	750930.136	133.971
FO14	4220068.104	758167.518	125.919
FO15	4217373.261	765598.1	113.242
FO16	4231583.672	756885.075	145.71
FO17	4232604.009	761699.282	135.698
FO18	4229966.527	762829.338	134.038
FO19	4225912.924	765893.662	109.987
FO20	4225078.951	768009.365	110.329
FO21	4224687.011	770932.635	108.591

GPS OBSERVATIONS

PT ID	OBSERVATION DATE	JULIAN DATE	TIME OF DAY	RE-OBSERVATION DATE	RE-OBSERVATION TIME
BE-1	4/17/2014	107	9:42	X	X
BE-2	4/17/2014	107	13:31	4/18/2014	13:02
BE-3	4/17/2014	107	14:40	X	X
BE-4	4/17/2014	107	18:05	4/18/2014	14:32
BE-5	4/17/2014	107	17:45	4/18/2014	14:52
BE-6	4/17/2014	107	16:43	4/18/2014	14:12
BE-7	4/17/2014	107	16:22	4/18/2014	14:02
BE-8	4/18/2014	108	10:19	X	X
BE-9	4/18/2014	108	9:59	5/1/2014	12:56
BE-10	4/18/2014	108	8:22	X	X
BE-11	4/18/2014	108	8:52	4/18/2014	15:38
BE-12	4/18/2014	108	9:34	4/18/2014	15:59
BE-13	4/17/2014	107	12:57	X	X
BE-14	4/17/2014	107	18:33	4/19/2014	9:22
BE-15	4/17/2014	107	11:40	4/19/2014	11:11
BE-16	4/17/2014	107	12:30	4/19/2014	12:20

BE-17	4/17/2014	107	10:26	4/19/2014	8:59
BE-18	4/17/2014	107	9:52	X	X
BE-19	4/16/2014	106	17:43	4/19/2014	12:01
BE-20	4/16/2014	106	17:04	X	X
BE-21	4/17/2014	107	16:21	4/18/2014	174/28/201406
FO-1	4/17/2014	107	10:09	X	X
FO-2	4/17/2014	107	11:37	X	X
FO-3	4/17/2014	107	12:24	X	X
FO-4	4/17/2014	107	14:59	X	X
FO-5	4/17/2014	107	18:24	X	X
FO-6	4/17/2014	107	17:16	X	X
FO-7	4/17/2014	107	16:43	X	X
FO-8	4/17/2014	107	15:51	X	X
FO-9	4/17/2014	107	18:59	X	X
FO-10	4/17/2014	107	19:30	X	X
FO-11	4/18/2014	108	10:29	X	X
FO-12	4/18/2014	108	11:19	X	X
FO-13	4/19/2014	109	10:02	X	X
FO-14	4/18/2014	108	18:36	X	X
FO-15	4/17/2014	107	14:01	X	X
FO-16	4/16/2014	106	14:43	X	X
FO-17	4/18/2014	108	10:43	X	X
FO-18	4/18/2014	108	11:55	X	X
FO-19	4/18/2014	108	13:40	X	X
FO-20	4/18/2014	108	14:55	X	X
FO-21	4/18/2014	108	16:20	X	X
UA-1	4/17/2014	107	9:55	4/18/2014	12:28
UA-2	4/17/2014	107	12:58	4/18/2014	12:45
UA-3	4/17/2014	107	13:17	4/18/2014	13:12
UA-4	4/17/2014	107	14:10	4/18/2014	13:39
UA-5CHKA	5/1/2014	121	14:21	4/18/2014	14:25
UA-6	4/17/2014	107	13:40	5/1/2014	13:38
UA-7	4/17/2014	107	13:52	4/18/2014	13:23
UA-8	4/17/2014	107	15:38	4/18/2014	13:51
UA-9	4/18/2014	108	8:09	4/18/2014	15:06
UA-10	4/18/2014	108	9:17	X	X
UA-11	4/18/2014	108	9:44	4/18/2014	16:09
UA-12CHKA	5/1/2014	121	15:23	4/18/2014	15:23
UA-13	4/16/2014	106	20:18	4/18/2014	18:02

UA-14	4/17/2014	107	15:33	4/18/2014	17:34
UA-15	4/17/2014	107	19:19	4/19/2014	8:37
UA-16CHKA	5/1/2014	121	11:26	4/19/2014	11:26
UA-17	4/16/2014	106	16:12	4/18/2014	12:48
UA-18	4/16/2014	106	16:40	4/18/2014	13:06
UA-19	4/17/2014	107	17:48	4/19/2014	12:46
UA-20	4/17/2014	107	16:57	4/18/2014	15:57
UA-21	4/18/2014	108	12:04	X	X

POINT COMPARISON

POINT ID	N	E	EL	CHECK POINT ID	N	E	EL	Δ NORTHING	Δ EASTING	Δ ELEVATION
BE2	4203414.456	746479.682	158.513	BE2CHK	4203414.44	746479.67	158.537	-0.019	-0.012	0.024
BE4	4210077.428	743030.99	157.501	BE4CHK	4210077.43	743030.975	157.523	0.000	-0.015	0.022
BE5	4209005.05	746395.346	146.01	BE5CHK	4209005.06	746395.351	145.996	0.010	0.005	-0.014
BE6	4208516.72	748983.928	135.017	BE6CHK	4208516.72	748983.923	135.001	0.004	-0.005	-0.016
BE7	4207806.456	752160.721	134.485	BE7CHK	4207806.46	752160.704	134.463	-0.001	-0.017	-0.022
BE9	4208558.963	759304.868	122.677	BE9CHKA	4208558.98	759304.881	122.641	0.014	0.013	-0.036
BE11	4218264.261	754393.073	157.888	BE11CHK	4218264.26	754393.081	157.873	0.000	0.008	-0.015
BE12	4213962.033	759466.55	158.478	BE12CHK	4213962.07	759466.556	158.475	0.041	0.006	-0.003
BE14	4221973.621	749914.866	167.102	BE14CHK	4221973.63	749914.855	167.074	0.007	-0.011	-0.028
BE15	4222735.756	755460.975	143.945	BE15CHK	4222735.75	755460.98	143.946	-0.005	0.005	0.001
BE16	4216962.612	762982.793	110.563	BE16CHK	4216962.6	762982.784	110.575	-0.013	-0.009	0.012
BE17	4226411.574	756571.987	125.615	BE17CHK	4226411.58	756571.963	125.59	0.003	-0.024	-0.025
BE19	4223380.954	762912.569	99.706	BE19CHK	4223380.94	762912.575	99.705	-0.013	0.006	-0.001
BE21	4223813.94	767929.509	85.474	BE21CHK	4223813.93	767929.519	85.438	-0.008	0.01	-0.036
UA1	4207667.568	739772.433	136.051	UA1CHK	4207667.52	739772.441	136.094	-0.048	0.008	0.043
UA2	4203010.436	742111.944	144.485	UA2CHK	4203010.44	742111.95	144.467	0.002	0.006	-0.018
UA3	4201189.534	745680.342	159.344	UA3CHK	4201189.54	745680.335	159.351	0.001	-0.007	0.007
UA4	4198972.223	752762.015	131.723	UA4CHK	4198972.22	752762.024	131.745	-0.003	0.009	0.022
UA5CHKA	4208537.881	742529.854	161.803	UA5CHK	4208537.87	742529.83	161.816	-0.011	-0.024	0.013
UA6	4205664.871	745645.187	157.548	UA6CHKA	4205664.87	745645.205	157.498	-0.006	0.018	-0.05
UA7	4203724.201	750599.464	163.472	UA7CHK	4203724.21	750599.466	163.471	0.004	0.002	-0.001
UA8	4204877.624	755796.043	155.288	UA8CHK	4204877.66	755796.051	155.307	0.034	0.008	0.019
UA9	4217428.815	746822.286	150.254	UA9CHK	4217428.83	746822.298	150.265	0.013	0.012	0.011
UA11	4213245.725	762298.902	147.012	UA11CHK	4213245.74	762298.909	146.978	0.013	0.007	-0.034
UA12CHKA	4221046.288	752617.21	159.425	UA12CHK	4221046.27	752617.23	159.464	-0.023	0.02	0.039
UA13	4220581.326	759892.776	128.516	UA13CHK	4220581.31	759892.792	128.493	-0.014	0.016	-0.023
UA14	4220551.312	767412.33	111.851	UA14CHK	4220551.32	767412.329	111.832	0.012	-0.001	-0.019
UA15	4229134.716	754035.965	137.12	UA15CHK	4229134.71	754035.952	137.106	-0.003	-0.013	-0.014
UA16CHKA	4223359.401	758713.273	126.115	UA16CHK3	4223359.42	758713.248	126.11	0.023	-0.025	-0.005
UA17	4228753.827	761739.17	142.225	UA17CHK	4228753.82	761739.162	142.238	-0.008	-0.008	0.013
UA18	4227248.984	762947.77	122.523	UA18CHK	4227248.98	762947.789	122.531	-0.005	0.019	0.008
UA19	4222693.563	762047.898	88.564	UA19CHK	4222693.56	762047.888	88.598	-0.006	-0.01	0.034
UA20	4223917.942	770343.993	92.066	UA20CHK	4223917.92	770343.993	92.068	-0.018	0	0.002

Appendix B: Complete List of Delivered Tiles UTM

17SQB485965
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17SQB470980
17SQB485980
17SQB500980
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17SQB470995
17SQB485995
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Appendix C: Complete List of Delivered Tiles State Plane

18STH300000	18STH300550	17SQC550700	17SQC100800
18STH300050	17SQB850400	17SQC600700	17SQC150800
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17SQB600550
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Appendix D: GPS Processing Reports for Each Mission

TRAJECTORY PLOT FOR M1_20140506 FLIGHT

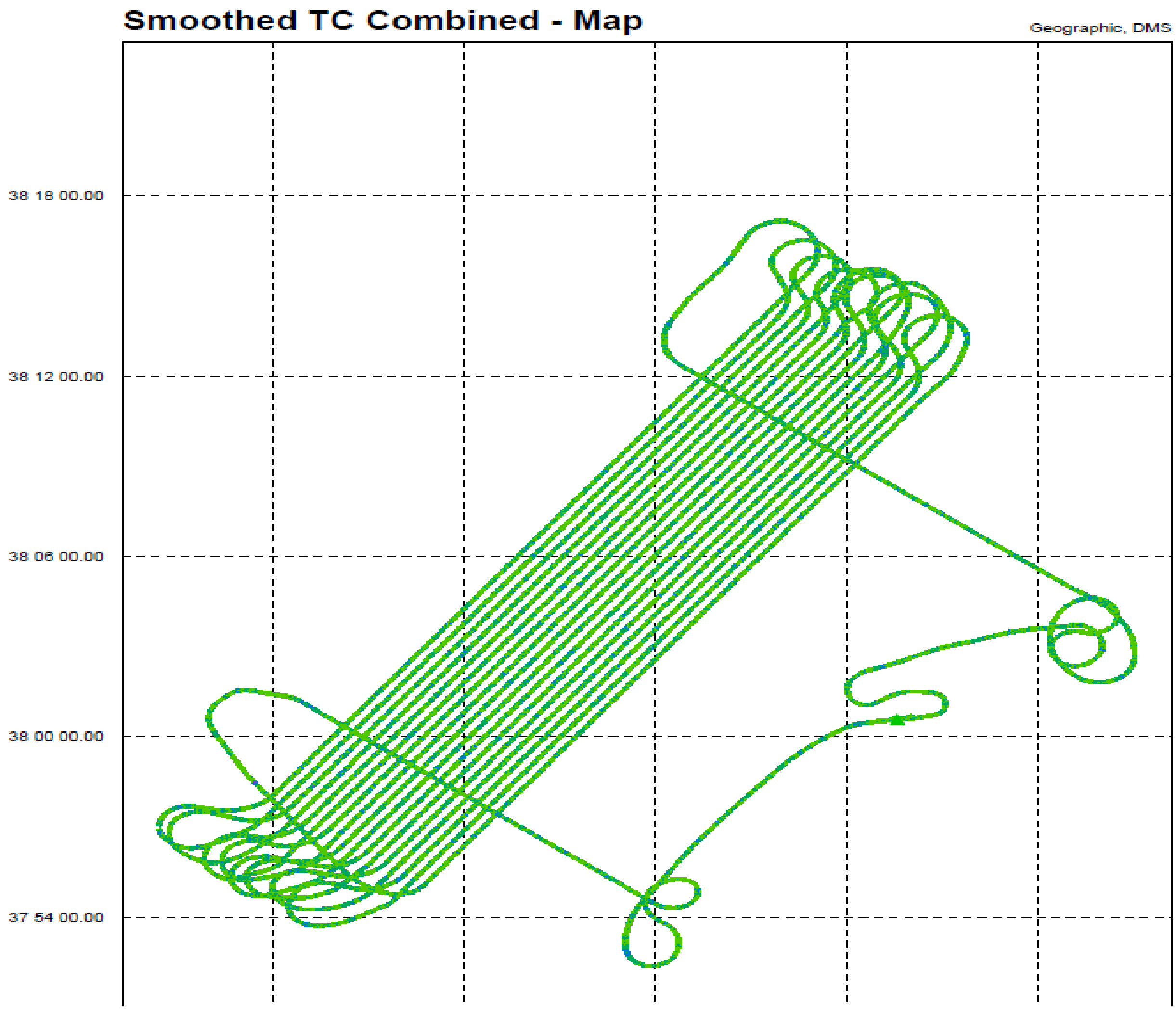


Figure 1 Trajectory 05/06/2014

COMBINED SEPARATION PLOT 5/6/2014 FLIGHT

The combined position separation plot is a measure of the difference between the forward run and the backward run solution of the trajectory. The Kalman filter is run in both directions to remove directional specific anomalies. The close these two solutions match, the better is the overall reliability of the solution. PAR's goal is to maintain a combines Separation Difference of <10cm, often achieving results well below this cap.

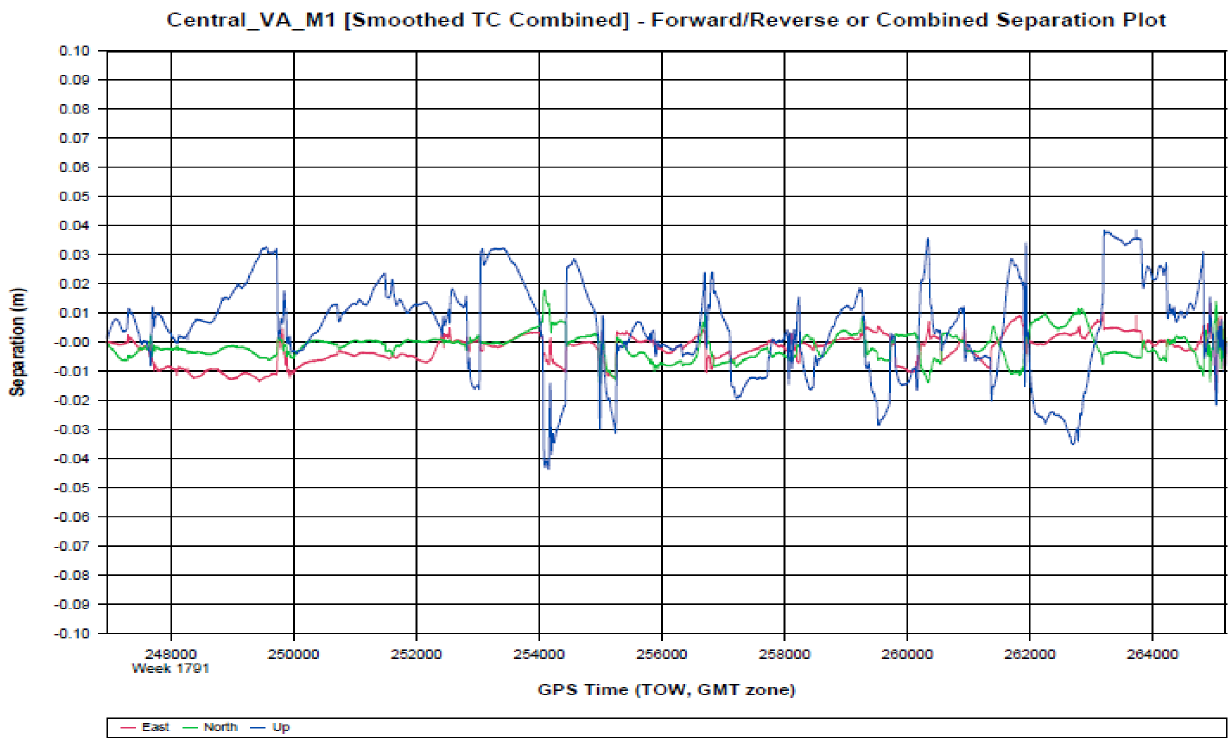


Figure 2 Combined Separation Plot of 5/6/2014 Flight

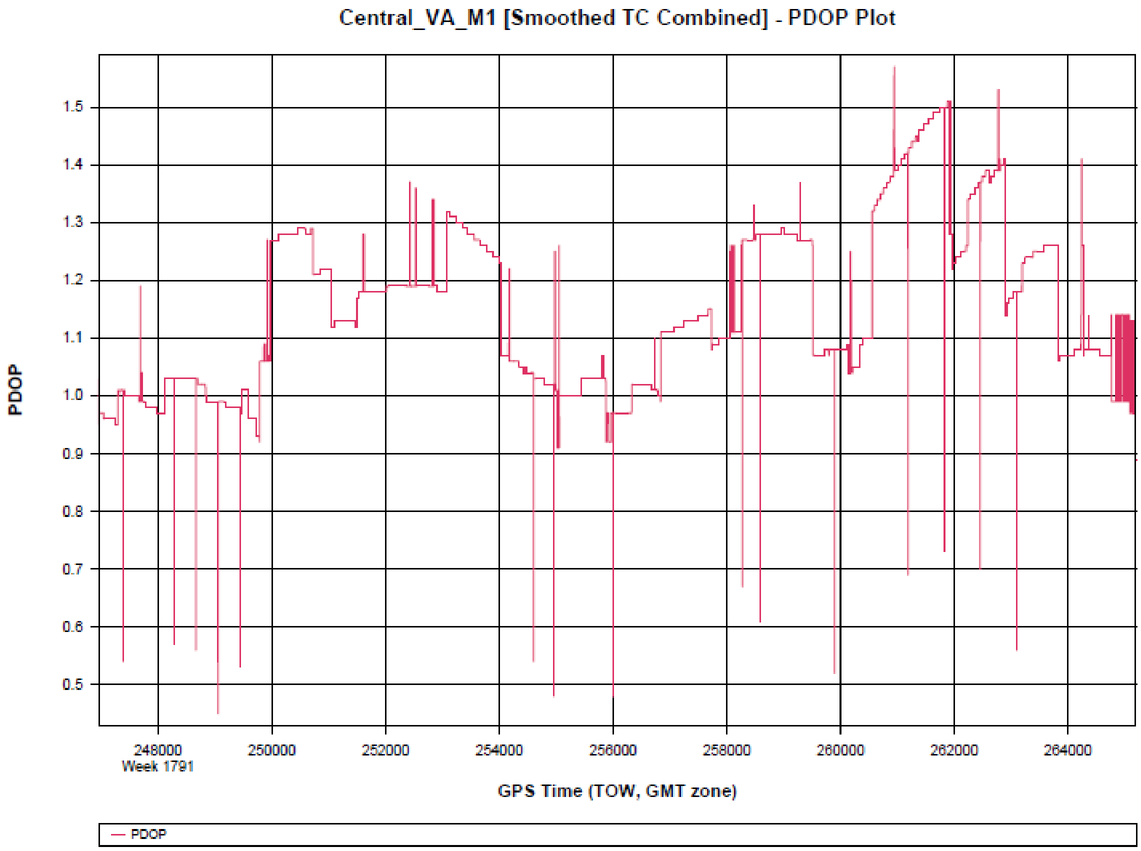


Figure 3 PDOP of 5/6/2014 Flight

TRAJECTORY PLOT FOR M2_20140507 FLIGHT

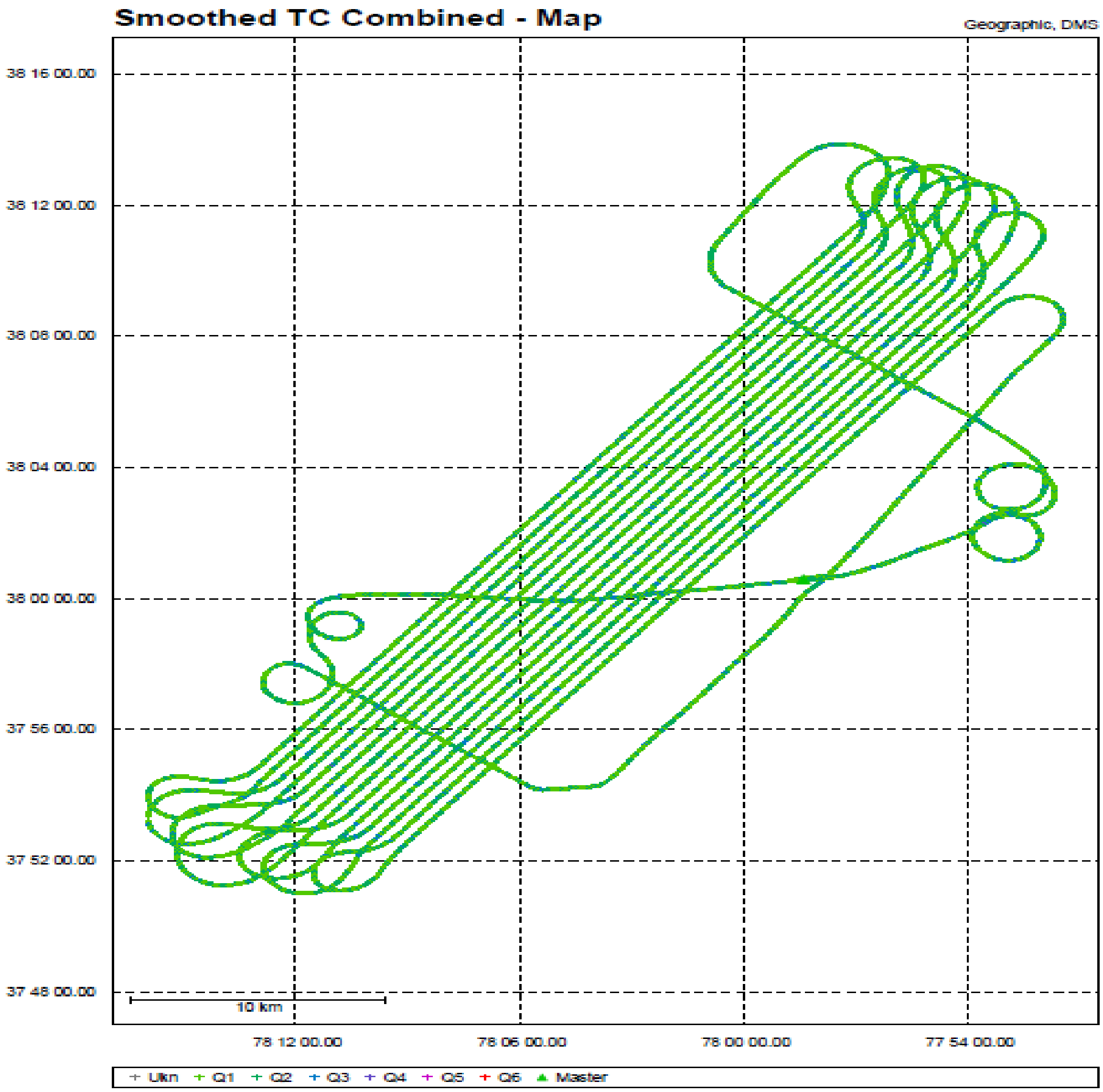


Figure 4Trajectory 05/07/2014

COMBINED POSITION SEPARATION PLOT 05/07/2014 FLIGHT

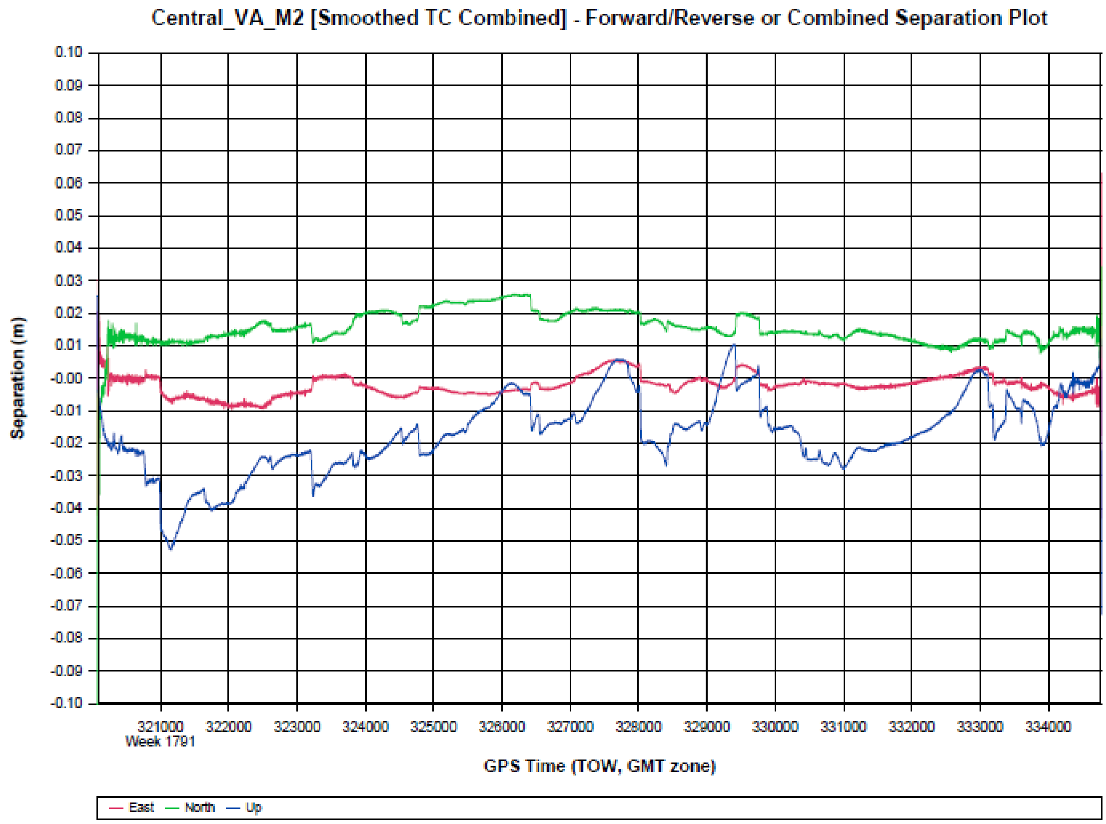
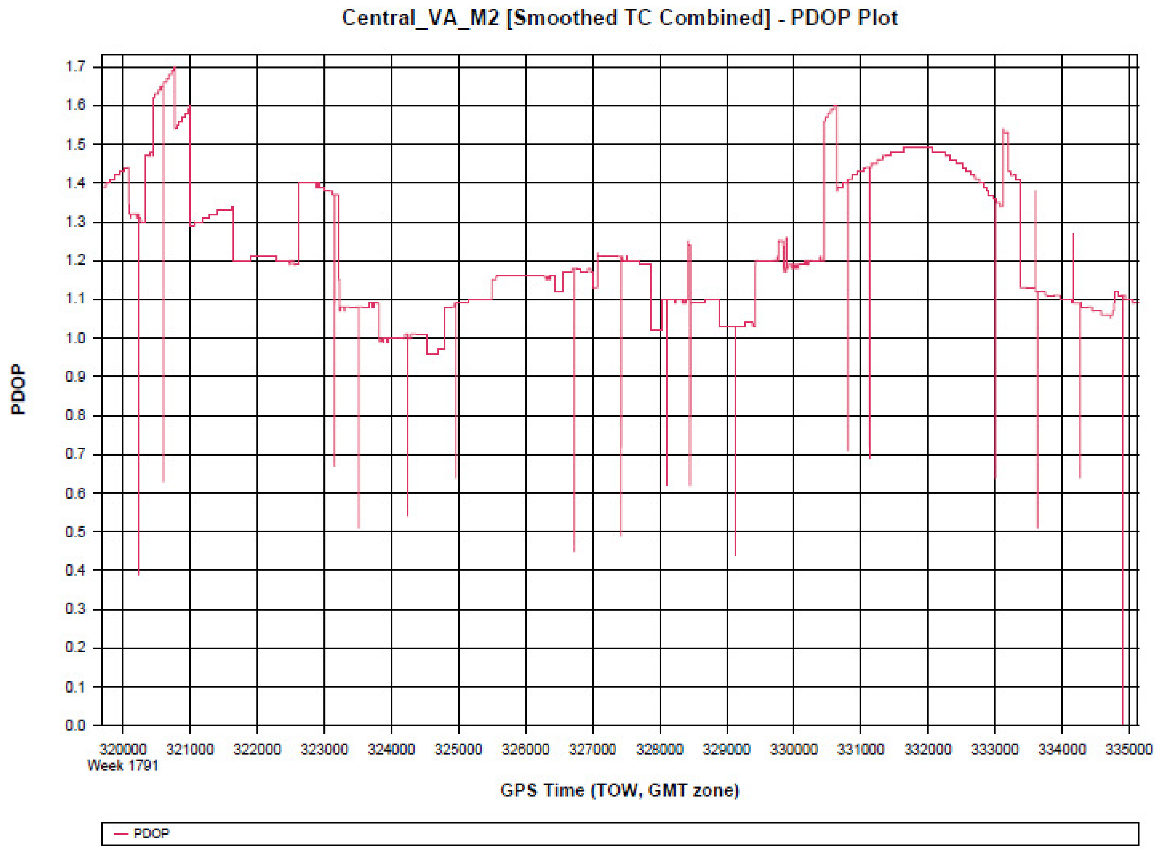


Figure 5 Position Separation Plot of 05/07/2014 Flight



I.

Figure 6 PDOP of 5/7/2014 Flight

FLIGHT LOG M1-05 06 2014

PAR LLC
PRECISION AERIAL RECONNAISSANCE
P.O. Box 72357
Bossier City, LA 72357

LIDAR Daily Log

Field Crew		
	Project #	
	Project Description	Dewberry_VA
FTP		
SN7169	Location	Louisa,VA
MISSION 1		

Flight Date (UTC)	Pilot	Operator	Sensor	Aircraft	SENSOR NAVIGATION FILE NAME
5/6/2014	Farrar	Tomlinson	ALS70	N799AC	20140506_203252

Lever Arm	x	y	z
GPS (m)	-0.110	0.210	-1.220

GPS Information	
Base 1	19821260.T02
Base 2	
Base3	
Aero 1	

AGC
Auto

IMU Information	
Start Time	20:34:32
Stop Time	1:40:15

Meteorological Conditions	Elevation	Temp		Pressure	
Airport	493	16.0'c	289.15'k	29.94 inHg	101388 Pa
@ Altitude	4500AGL	16.0'c	289.15'k	29.92 inHg	101321 Pa
@ Altitude					

GPS Base Station Information	File Name	RNX File	Ant Hgt	Ant Type
Base 1	19821260.T02		2.05m	Trimble R10
Base 2				
Base 3				

Reflight	Line	Dir	Start	Stop	Total Time	FOV	Scan Rate	Pulse Rate Hz	Roll Comp	Muti Pulse (Y,N)	Altitude ellipsoid (m)	Altitude ellipsoid (ft)	Speed	Nautical Miles Flown	Void "Y"	PDOP	Operator	Conditions/Comments
	33	140506_210129	21:01:47	21:06:59	0:05:12	37.7	40.3	105000	YES	N	1273	4177					Tomlinson	TieLine
	1	140506_211206	21:12:24	21:22:39	0:10:15	37.1	40.3	105000	YES	N	1238	4062					Tomlinson	
	2	140506_212631	21:26:49	21:37:13	0:10:24	38.1	40.3	105000	YES	N	1267	4157					Tomlinson	
	3	140506_214101	21:41:18	21:51:52	0:10:34	37.2	40.3	105000	YES	N	1254	4114					Tomlinson	
	4	140506_215603	21:56:21	22:06:36	0:10:15	38	40.3	105000	YES	N	1283	4209					Tomlinson	
	5	140506_220956	22:10:13	22:20:28	0:10:15	37.1	40.3	105000	YES	N	1269	4163					Tomlinson	
	6	140506_222421	22:24:38	22:34:44	0:10:06	38.6	40.3	105000	YES	N	1293	4242					Tomlinson	
	7	140506_223810	22:38:27	22:48:42	0:10:15	37.3	40.3	105000	YES	N	1271	4170					Tomlinson	
	8	140506_225233	22:52:50	23:02:56	0:10:06	37.5	40.3	105000	YES	N	1281	4203					Tomlinson	
	9	140506_230644	23:07:01	23:17:16	0:10:15	37.1	40.3	105000	YES	N	1286	4219					Tomlinson	
	10	140506_232116	23:21:33	23:31:39	0:10:06	37.2	40.3	105000	YES	N	1242	4075					Tomlinson	
	11	140506_233534	23:35:52	23:45:58	0:10:06	37.4	40.3	105000	YES	N	1261	4137					Tomlinson	
	12	140506_235003	23:50:21	0:00:26	0:10:05	37.8	40.3	105000	YES	N	1242	4075					Tomlinson	
	13	140507_000409	0:04:26	0:14:32	0:10:06	36.9	40.3	105000	YES	N	1277	4190					Tomlinson	
	14	140507_001818	0:18:35	0:28:32	0:09:57	37	40.3	105000	YES	N	1225	4019					Tomlinson	
	15	140507_003250	0:33:07	0:43:04	0:09:57	37	40.3	105000	YES	N	1294	4245					Tomlinson	
	16	140507_004713	0:47:30	0:57:26	0:09:56	37.6	40.3	105000	YES	N	1233	4045					Tomlinson	
	17	140507_010101	1:01:18	1:11:14	0:09:56	36.9	40.3	105000	YES	N	1285	4216					Tomlinson	
	32	140507_011727	1:17:43	1:22:37	0:04:54	38.7	40.3	105000	YES	N	1269	4163					Tomlinson	TieLine

LIDAR FLIGHT SUMMARY			
		Hobbs Start	1636.9
Aircraft IMU Time	5:05:43	Hobbs Stop	1642.2
Sensor Collection Time	3:02:40	Hobbs Total	5.3
Line Miles Flown	0.0	Mission Hobbs	#DIV/0!
Average Flight Lines Speed	0 kts	Reflight Hobbs	#DIV/0!
Average Nautical Line miles Per Mission Hour			#DIV/0!

DATA COLLECTION			
Total Lines	0	Project % Complete	#DIV/0!
# Reflight Lines	0	Total Flight Lines	0
Reflight Percent	#DIV/0!	Line Complete	0
Sensor Re-Flight Miles	0.0	Mission Lines	0
Average Nautical Line Miles Per Re-Flight Hour	#DIV/0!		

Comments

Cloud Cover	
Clear	X
Fair	
Partly Cloudy	
Cloudy	

FLIGHT LOG M2-05 07 2014

PAR LLC
PRECISION AERIAL RECONNAISSANCE
P.O. Box 72357
Bossier City, LA 72357

LIDAR Daily Log

Field Crew	
FTP	
SN7169	
MISSION 2	
Project #	
Project Description	Dewberry_VA
Location	Louisa,VA
Lever Arm GPS (m) x	-0.110
Lever Arm GPS (m) y	0.210
Lever Arm GPS (m) z	-1.220
Flight Date (UTC)	5/7/2014
Pilot	Farrar
Operator	Tomlinson
Sensor	ALS70
Aircraft	N799AC
SENSOR NAVIGATION FILE NAME	20140506_203252

GPS Information	
Base 1	19821270.T02
Base 2	
Base3	
Aero 1	

IMU Information	
Start Time	16:47:42
Stop Time	21:06:25

AGC
Auto

Meteorological Conditions	Elevation	Temp		Pressure	
Airport	493	16.0'c	289.15'k	29.94 inHg	101388 Pa
@ Altitude	4500AGL	16.0'c	289.15'k	29.92 inHg	101321 Pa
@ Altitude					

GPS Base Station Information	File Name	RNX File	Ant Hgt	Ant Type
Base 1	19821270.T02		2.05m	Trimble R10
Base 2				
Base 3				

Reflight	Line	Dir	Start	Stop	Total Time	FOV	Scan Rate	Pulse Rate Hz	Roll Comp	Muti Pulse (Y,N)	Altitude ellipsoid (m)	Altitude ellipsoid (ft)	Speed	Nautical Miles Flown	Void "Y"	PDOP	Operator	Conditions/Comments
	33	140507_170905	17:09:20	17:12:05	0:02:45	36.8	40.3	105000	YES	N	1271	4170					Tomlinson	Partial Tie Line, Only over lines collected
	18	140507_171642	17:16:57	17:27:12	0:10:15	36.8	40.3	105000	YES	N	1272	4173					Tomlinson	
	19	140507_173041	17:30:57	17:41:02	0:10:05	36.9	40.3	105000	YES	N	1227	4026					Tomlinson	
	20	140507_174448	17:45:03	17:55:09	0:10:06	36.8	40.3	105000	YES	N	1291	4236					Tomlinson	
	21	140507_175911	17:59:26	18:09:32	0:10:06	36.8	40.3	105000	YES	N	1226	4022					Tomlinson	
	22	140507_181317	18:13:33	18:23:47	0:10:14	36.8	40.3	105000	YES	N	1244	4081					Tomlinson	
	23	140507_182749	18:28:04	18:38:01	0:09:57	36.8	40.3	105000	YES	N	1215	3986					Tomlinson	
	24	140507_184215	18:42:30	18:52:45	0:10:15	36.9	40.3	105000	YES	N	1279	4196					Tomlinson	
	25	140507_185731	18:57:46	19:07:42	0:09:56	36.8	40.3	105000	YES	N	1274	4180					Tomlinson	
	26	140507_191201	19:12:15	19:22:58	0:10:43	36.8	40.3	105000	YES	N	1308	4291					Tomlinson	
	27	140507_192626	19:26:42	19:36:38	0:09:56	36.8	40.3	105000	YES	N	1252	4108					Tomlinson	
	28	140507_194106	19:41:21	19:51:46	0:10:25	36.9	40.3	105000	YES	N	1264	4147					Tomlinson	
	29	140507_195517	19:55:33	20:05:38	0:10:05	36.9	40.3	105000	YES	N	1249	4098					Tomlinson	
	30	140507_200937	20:09:52	20:20:07	0:10:15	36.8	40.3	105000	YES	N	1310	4298					Tomlinson	
	31	140507_202254	20:23:09	20:33:15	0:10:06	36.9	40.3	105000	YES	N	1229	4032					Tomlinson	
	32	140507_204455	20:45:10	20:47:46	0:02:36	36.8	40.3	105000	YES	N	1272	4173					Tomlinson	Partial Tie Line, Only over lines collected

LIDAR FLIGHT SUMMARY

		Hobbs Start	1642.8
Aircraft IMU Time	4:18:43	Hobbs Stop	1647.4
Sensor Collection Time	2:27:45	Hobbs Total	4.6
Line Miles Flown	0.0	Mission Hobbs	#DIV/0!
Average Flight Lines Speed	0 kts	Reflight Hobbs	#DIV/0!
Average Nautical Line miles Per Mission Hour			#DIV/0!

DATA COLLECTION

Total Lines	0	Project % Complete	#DIV/0!
# Reflight Lines	0	Total Flight Lines	0
Reflight Percent	#DIV/0!	Line Complete	0
Sensor Re-Flight Miles	0.0	Mission Lines	0
Average Nautical Line Miles Per Re-Flight Hour	#DIV/0!		

Comments

Cloud Cover

Clear	X
Fair	
Partly Cloudy	
Cloudy	