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Virginia West Chesapeake Bay Watershed Lidar Project

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 Virginia West Chesapeake Bay Watershed Project Area.

The lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 1500 m by 1500 m. A total of 6517 tiles were produced for the project encompassing an area of approximately 5282 sq. mi.

THE PROJECT TEAM

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

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

Axis Geospatial, LLC and Leading Edge Geomatics completed lidar data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report falls within the state of Virginia. Counties include Alleghany, Amherst, Augusta, Bath, Bedford, Botetourt, Campbell, Craig, Fredrick, Highland, Rockbridge, Rockingham, and Shenandoah. Coverage includes the cities of Bedford, Buena Vista, Clifton Forge, Covington, Lexington, and Lynchburg.

DATE OF SURVEY

The lidar aerial acquisition was conducted between April 4, 2017 and May 25, 2018.

COORDINATE REFERENCE SYSTEM

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

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 17
Units: Horizontal units are in meters, Vertical units are in meters.
Geiod Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the Virginia West Chesapeake Bay Watershed Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **7.1 cm** compared with the 10 cm specification; and the non-vegetated vertical accuracy (NVA) of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to **13.9 cm**, compared with the 19.6 cm specification.

The tested vegetated vertical accuracy (VVA) of the classified lidar data computed using the 95th percentile was **18.6 cm,** compared with the 29.4 cm specification.

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

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Classified Point Cloud Data (Tiled LAS)
2. Bare Earth Surface (Tiled Raster, IMG Format)
3. Intensity Imagery (Tiled Raster, TIF Format)
4. Breakline Data (File GDB Format)
5. Independent Survey Checkpoint Data (Report, Photos, Coordinates, and Shapefile)
6. Calibration Point Data (Coordinates and Shapefiles)
7. Metadata
8. Project Report
9. Project Extents (ESRI Shapefile Format)
10. Contours (File GDB Format)

PROJECT TILING FOOTPRINT

A total of 6517 tiles were delivered for the project, covering the areas shown in Figure 1. Each tile's extent is 1500 m by 1500 m. A list of delivered tiles is attached as Appendix B.

Figure 1 – Project Map

Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities to Axis Geospatial, LLC (Axis) and Leading Edge Geomatics (LEG). Axis and LEG were responsible for providing lidar acquisition, calibration, and delivery of lidar data files to Dewberry.

Dewberry received final calibrated swath data from Axis on April 17, 2018 and LEG on July 28, 2018.

LIDAR ACQUISITION DETAILS

Axis planned 20 passes and LEG planned 596 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent inertial measurement unit (IMU) drift associated with all IMU systems. In order to reduce potential errors in the data attributable to flight planning, Axis and LEG followed FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Survey*. The guidance includes the following minimum criteria:

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

Axis and LEG monitored weather and atmospheric conditions and conducted lidar missions only when no conditions existed below the sensor that would affect the collection of data. Good lidar collection conditions include leaf-off for hardwoods and no snow, rain, fog, smoke, mist, or low clouds. Lidar systems are active sensors that do not require ambient light, thus allowing missions to be conducted during night hours when weather restrictions do not prevent collection. Axis and LEG accessed reliable weather sites and indicators (webcams) to establish the highest probability for successful data acquisition.

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

Axis lidar sensors are calibrated at a designated site located at the Easton Airport in Easton, MD. LEG calibrates their sensors at a designated site in downtown Fredericton, New Brunswick Canada. Sensors are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Axis operated a Cessna 206H single engine aircraft (N223TC) and operated two dual-channel LiDAR sensors on separate missions during data collections: a Riegl LMS-Q1560 and a Riegl VQ-1560i. LEG operated two Cessna 172 aircraft (C-FUNB, C-FCAU) and a Cessna 206 (C-FRBV) for the project. Each of the 172s carried a Riegl VQ-780i scanner and the 206 carried a Riegl VQ-

1560i during the collection of the study area. Table 1 illustrates Axis and LEG system parameters for lidar acquisition on this project.

Item	Parameter (Axis)	Parameter (Axis)	Parameter (LEG)	Parameter (LEG)
System	Riegl LMS-Q1560	Riegl VQ-1560i	Riegl VQ-780i	Riegl VQ-1560i
Altitude (AGL meters)	2087	2087	1600	1600
Approx. Flight Speed (knots)	150	150	100	100
Scanner Pulse Rate (kHz)	687 (343.5 per channel)	687 (343.5 per channel)	300	350x2
Scan Frequency (hz)	153	153	74	82
Pulse Duration of the Scanner (nanoseconds)	3	3	3	3
Pulse Width of the Scanner (m)	0.90	0.90	0.90	0.90
Central Wavelength of the Sensor Laser (nanometers)	1064	1064	1064	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes	Yes	Yes	Yes
Beam Divergence (milliradians)	0.25	0.25	0.25	0.25
Nominal Swath Width on the Ground (m)	2338	2338	1848	1737
Swath Overlap (%)	15	15	55	30
Total Sensor Scan Angle (degree)	58.52	58.52	60	57
Computed Down Track spacing (m) per beam	0.73	0.73	0.70	0.63
Computed Cross Track Spacing (m) per beam	0.73	0.73	0.70	0.63
Nominal Pulse Spacing (single swath), (m)	0.70	0.70	1.0	0.70
Nominal Pulse Density (single swath) (ppsm), (m)	2.0	2.0	1.0	2.0
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.70	0.70	0.70	0.70
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2.0	2.0	2.0	2.0
Maximum Number of Returns per Pulse	15	15	15	15

Table 1 – Axis and LEG lidar system parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

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

Figure 2 shows the combined trajectory of the flightlines.

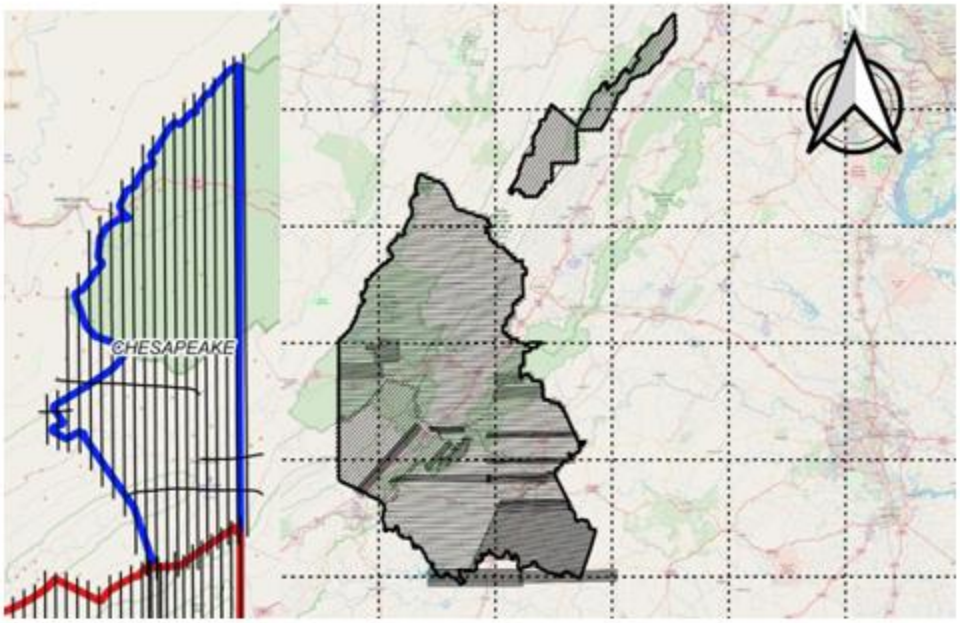


Figure 2 - Trajectories flown by Axis (right) and LEG (left)

LIDAR CONTROL

The coordinates of all CORS stations used by both Axis and LEG are provided in tables 2 and 3, below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

Axis CORS			
Name	NAD83(2011) UTM 17		Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)	
ASUB	4007914.580	438712.270	987.790
BLA1	4118475.610	551418.000	637.600
DOBS	4031172.760	525106.120	372.570
HIPT	3980593.570	588941.720	297.840

KYTL	4149605.690	364244.630	217.360
LOYH	4129770.510	648492.010	236.350
LS04	4135663.390	592316.120	356.540
NCNW	4002421.110	488077.010	302.210
NCRE	4024913.130	619707.640	265.360
NCRX	4029193.080	679510.310	224.300
NCSR	4039165.630	489726.780	870.640
NCWC	4025534.280	573116.840	308.200
NCWJ	4027650.990	457096.430	964.700
UVFM	4194869.310	702834.700	545.090
UVFM	4194869.310	702834.700	545.090
WVAT	4142413.570	493993.490	735.700
WVGB	4254202.740	603253.440	841.890
WVLE	4186255.040	550884.400	686.640
WVOH	4205630.650	488395.550	627.600

Table 2 – Base stations used by Axis to control lidar acquisition

LEG CORS			
Name	**NAD83(2011) UTM 17**		**Orthometric Ht (NAVD88 Geoid12B, m)**
	Easting X (m)	**Northing Y (m)**	
LOYA	684238.900	4255201.140	397.590
LOYC	742003.500	4333841.730	236.760
LOYH	648492.600	4129769.660	237.680
LOYI	718377.300	4212418.270	188.830
LOYJ	760844.300	4262475.140	137.480
LOYP	673914.800	4209942.970	425.510
LOYQ	781996.000	4392303.060	162.620
LOYS	694774.800	4390954.820	202.130
LOYU	550334.100	4112970.370	633.230
LOYV	644975.300	4049294.110	130.500
LOYY	716907.200	4307374.750	255.300
LS02	818278.900	4130122.420	27.270
LS04	592316.700	4135662.540	357.860
LS06	742124.200	4055378.340	104.040

NCRE	619708.200	4024912.300	266.710
NCRX	679510.900	4029192.250	225.650
NCWC	573117.400	4025533.450	309.540
NCWR	753770.600	4031471.240	109.500
UVFM	702835.300	4194868.440	546.410
VABR	684525.500	4100321.550	133.580
VABU	717257.800	4160771.520	142.750
VABV	747667.000	4120169.020	161.540
VADO	786245.300	4079323.150	109.650
VALO	766305.400	4211905.940	162.330
VALY	665874.300	4138184.000	286.820
VAPW	770203.900	4172806.260	100.740
VARY	598815.000	4094983.210	372.160
VAWY	492476.800	4089339.370	705.520
WVAT	493994.100	4142412.730	737.010
WVBF	478808.100	4124381.700	811.480
WVBR	562299.800	4351208.060	302.780
WVBU	679819.100	4356362.560	232.540
WVCV	633590.300	4319606.920	999.970
WVGB	603254.100	4254201.870	843.180
WVHV	745526.300	4365743.540	172.220
WVLE	550885.000	4186254.180	687.950
WVMF	678845.800	4327206.220	345.860
WVMZ	490559.800	4298905.120	330.070
WVNR	598998.800	4305821.280	613.760
WVOH	488396.200	4205629.800	628.890

Table 3 – Base stations used by LEG to control lidar acquisition

AIRBORN GPS KINEMATIC

Axis and LEG used NGS CORS Base Stations to control the LiDAR acquisition for the Virginia West Chesapeake Lidar project area.

Airborne GPS data was processed by Axis using the POSPac Mobile Mapping System (MMS) version 7.2 software suite. 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.

LEG's Airborne GPS data was processed using the POSPac kinematic On-The-Fly (OTF) software suite using Applanix Smartbase processing. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4.

The GPS average residuals for all flights were 3 cm or better, with no residuals greater than 10 cm recorded.

GPS processing reports for each mission are included in Appendix C (Axis) and Appendix D (LEG).

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

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

Subsequently the mission points were output using Riegl's RiProcess. The initial point generation for each mission calibration was verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification was observed within the mission, the necessary roll, pitch, and scanner scale corrections were calculated. The missions with the new calibration values were regenerated and validated internally once again to ensure quality.

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

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

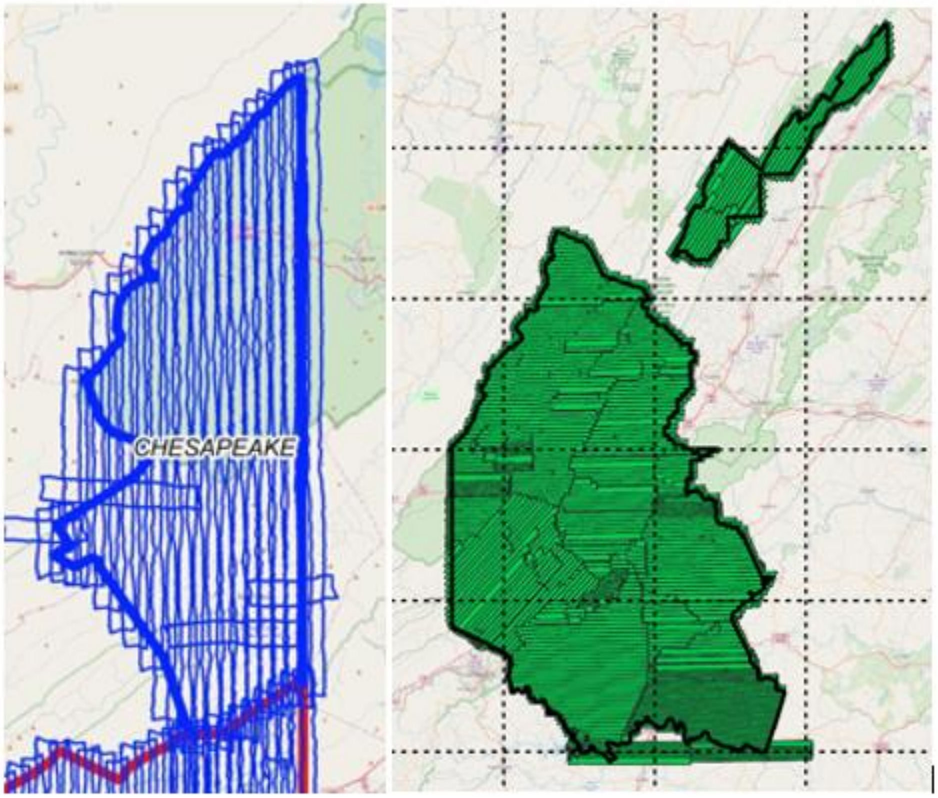


Figure 3 – Lidar swath output showing complete coverage of the project area by Axis (left) and LEG (right)

BORESIGHT AND RELATIVE ACCURACY

The initial points for each mission calibration were 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 were optimized during the calibration process until the relative accuracy was met.

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

For this project the relative accuracy specifications used are as follows:

- ≤ 6 cm maximum difference within individual swaths; and
- ≤ 8 cm RMSDz between adjacent and overlapping swaths.

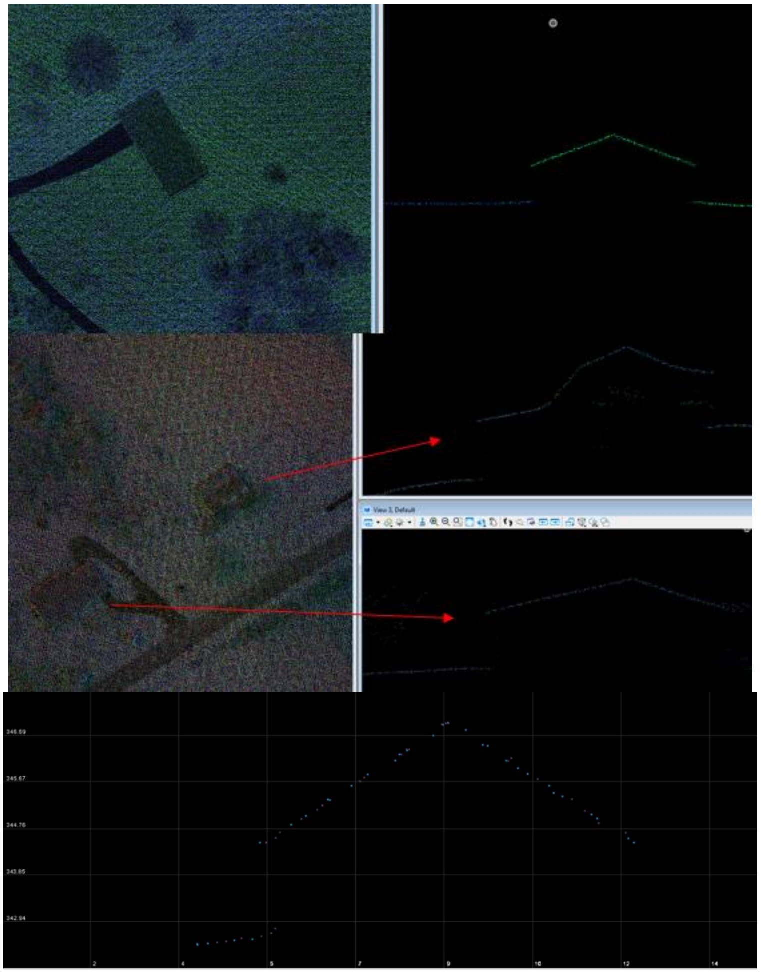


Figure 4 – Profile views showing correct roll and pitch adjustments from Axis (top, middle) LEG (bottom)

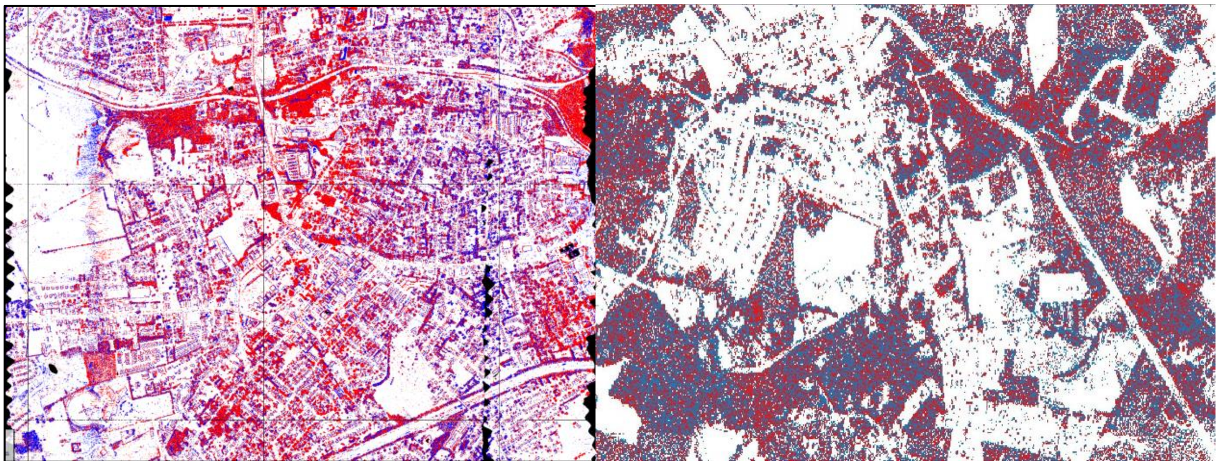


Figure 5 – QC block colored by distance to ensure accuracy at swath edges. Axis (Left) LEG (Right)

A different set of QC blocks were generated for final review after all transformations were applied.

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check was performed by Axis and LEG at this stage of the project life cycle in the raw lidar dataset against GPS static and kinematic data. The results were compared to $RMSE_z$ project specifications. The lidar data was examined in non-vegetated, flat areas away from breaks. Lidar ground points for each flight line generated by an automatic classification routine were used.

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met NVA requirements ($RMSE_z \leq 10$ cm and $Accuracy_z$ at the 95% confidence level ≤ 19.6 cm) when compared to static and kinematic GPS checkpoints. Below are summaries for the tests, as provided by LEG and Axis:

LEG: The calibrated LEG dataset was tested to 0.166 m vertical accuracy at the 95% confidence level based on consolidated $RMSE_z$ (0.085 m x 1.9600) when compared to 1147 independently collected RTK check points.

The following are the final statistics for the GPS static checkpoints used by LEG to internally verify vertical accuracy:

Average dz	0.070 m
Root mean square	0.085 m
Standard deviation	0.060 m

Axis: The calibrated Axis LiDAR dataset was tested to 0.127 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.065 m x 1.9600) when compared to 10 GPS static check points.

The final statistics for the GPS static checkpoints used by Axis to internally verify vertical accuracy are shown in Table 4 and summarized in Table 5, below.

Point ID	NAD83(2011) UTM Zone 17N		NAVD88 (Geoid 12B)		DeltaZ
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)	
GCLC_10	581173.660	4185534.473	429.96	429.96	-0.002
GCLC_11	567615.697	4181887.002	707.8	707.75	-0.045
GCLC_12	572539.004	4177289.247	483.08	483.09	0.014
GCLC_13	582629.410	4175721.219	404.23	404.24	0.011
GCLC_14	575817.834	4167634.806	464.93	464.92	-0.007
GCLC_15	566424.337	4164624.076	617.54	617.34	-0.201
GCLC_16	564390.168	4154791.960	822.51	822.41	-0.096
GCLC_17	578600.383	4151068.262	399.1	399.1	0.005
GCLC_18	583616.025	4156924.216	403.54	403.36	-0.176
GCLC_9	581241.683	4196424.794	680.64	680.58	-0.055
GCP_1	511180.930	4100224.145	661.69	661.72	0.035
GCP_10	535034.922	4087711.202	841.86	841.84	-0.019
GCP_11	501040.616	4071954.598	710.23	710.2	-0.025
GCP_12	522477.535	4067641.875	748.34	748.35	0.011
GCP_13	518657.853	4046365.553	475.93	476	0.071
GCP_14	548254.701	4045955.892	444.13	444.09	-0.039
GCP_16	560556.405	4085510.351	758.86	758.79	-0.07
GCP_17	581675.563	4084708.818	406.36	406.31	-0.05
GCP_18	571625.258	4067956.590	461.15	461.09	-0.059
GCP_19	582319.691	4050816.621	322.61	322.65	0.041
GCP_2	534120.527	4117775.422	545.28	545.21	-0.069
GCP_3	547078.523	4126423.277	670.99	671.02	0.026
GCP_4	576672.903	4137163.453	585.16	585.07	-0.091
GCP_5	582448.579	4136359.106	386.98	386.96	-0.024
GCP_6	581470.113	4117092.101	414.75	414.71	-0.039
GCP_7	568607.843	4121671.271	369.81	369.8	-0.012
GCP_8	569470.825	4106632.781	467.76	467.74	-0.024
GCP_9	551096.525	4108549.058	668.18	668.2	0.023

Table 4 – Axis static GPS points

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	NVA at 95% Spec=0.196 m	Mean (m)	Std Dev (m)	Min (m)	Max (m)
Non-Vegetated Terrain	28	0.067	0.131	-0.031	0.059	-0.201	0.071

Table 5 – Axis static GPS vertical accuracy results

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

Lidar Processing & Qualitative Assessment

INITIAL PROCESSING

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

Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Axis and LEG, Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using one hundred twenty five non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96. The dataset for Virginia West Chesapeake Bay Watershed Lidar Project satisfies this criteria. The raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was calculated to be $RMSE_z$ = 6.6 cm, equating to +/- 12.9cm at 95% confidence level. The table below shows calculated statistics for the raw swath data.

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.10 m	NVA –Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Non-Vegetated Terrain	125	0.066	0.129	-0.016	-0.013	-0.511	0.064	-0.227	0.115	0.749

Table 6 - NVA at 95% confidence level for raw swaths

Three checkpoints (NVA-53, 58, and 99) were removed from the raw swath vertical accuracy testing due to proximity to vegetation and/or vehicles. Only non-vegetated terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation, structures, and other above ground features from the ground classification. While these three points were located in open terrain, overhead branches or transient objects (vehicles) were also collected and modeled by the lidar point cloud. These high points caused erroneous high values during the swath vertical accuracy testing; therefore, these points were removed from the final calculations. Once the data underwent the classification process, the vegetation were removed from the final ground classification and these checkpoints were added back into the final vertical accuracy testing for the fully classified lidar data. Table 7, below, provides the coordinates for these checkpoints and the vertical accuracy results from the raw swath data. Table 8 provides the usable vertical accuracy results of this checkpoint from the fully classified lidar. Figure 6 shows a 3D model of the lidar point cloud and the location of the checkpoints beneath vegetation.

Point ID	NAD83(2011) UTM Zone 17N		NAVD88 (Geoid 12B)		Delta Z	AbsDelta Z
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
NVA-53	640506.501	4195324.572	345.602	346.318	0.716	0.716
NVA-58	591097.184	4205561.611	488.159	490.530	2.371	2.371
NVA-99	626727.428	4151764.049	697.927	707.144	9.217	9.217

Table 7 - Checkpoints removed from raw swath vertical accuracy testing

Point ID	NAD83(2011) UTM Zone 17N		NAVD88 (Geoid 12B)		Delta Z	AbsDelta Z
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
NVA-53	640506.501	4195324.572	345.602	346.318	0.008	0.008
NVA-58	591097.184	4205561.611	488.159	490.530	0.051	0.051
NVA-99	626727.428	4151764.049	697.927	707.144	-0.037	0.037

Table 8 - Final tested vertical accuracy post ground classification

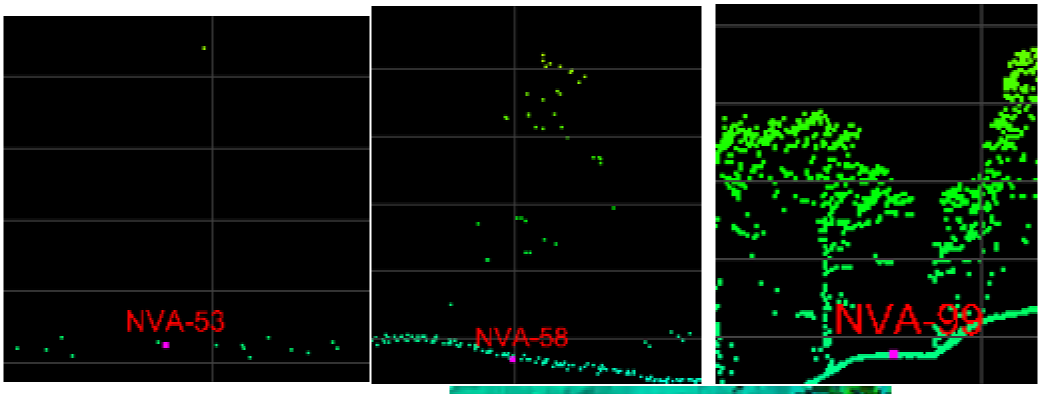


Figure 6 – Open terrain checkpoints NVA-53, 58, and 99, shown in pink, are located underneath transient objects or vegetation. These points were removed from raw swath vertical accuracy testing because above ground features had not been separated from the ground classification yet.

Inter-Swath (Between Swath) Relative Accuracy

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

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

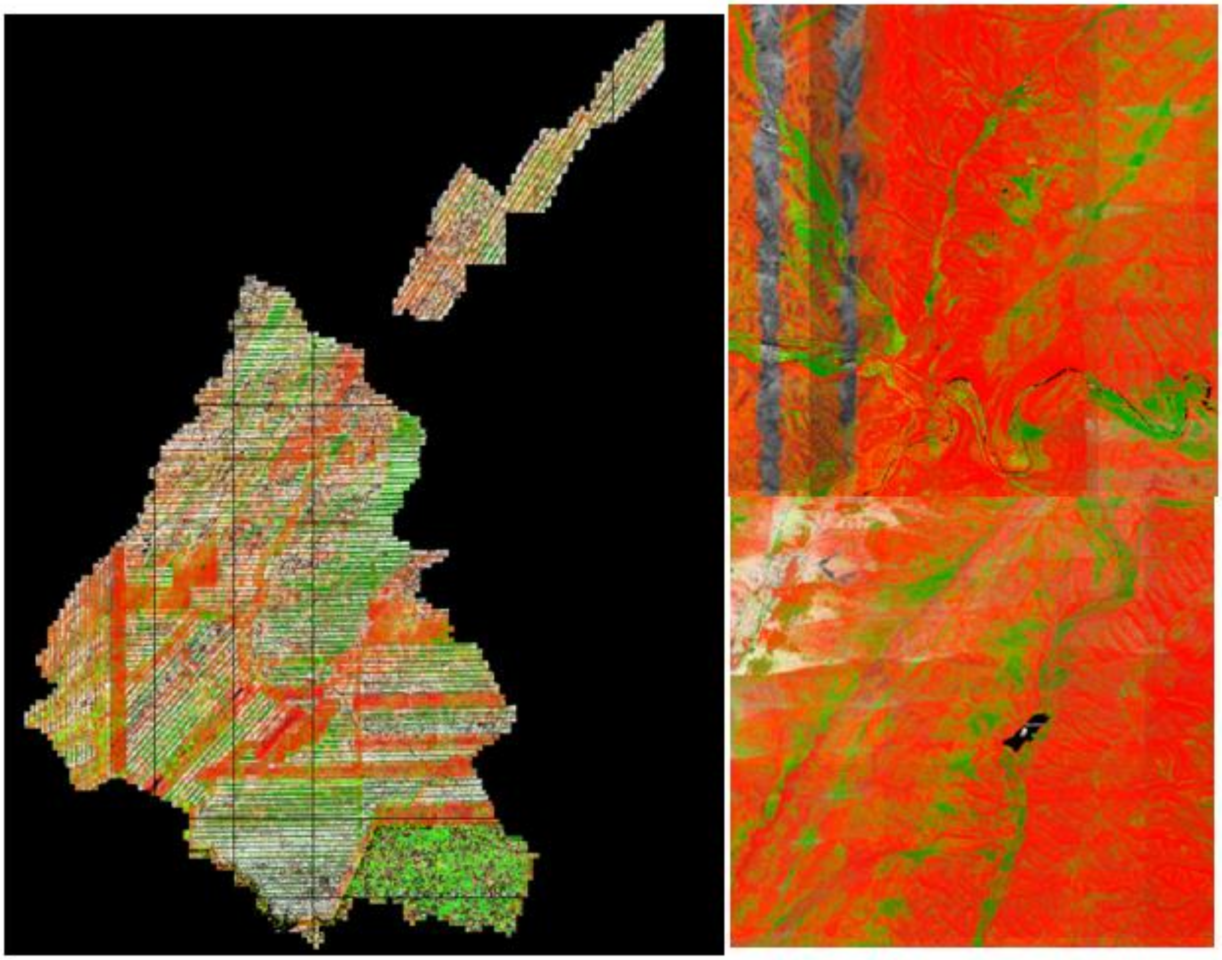


Figure 7– Single return DZ Orthos for the Virginia West Chesapeake Bay Watershed lidar project. Inter-swath relative accuracy passes specifications. The screenshot on the right shows a close-up of areas that may appear to exceed the threshold from a distance. These are mountainous forested regions but have threads of green where there are clearings spread throughout.

Intra-Swath (Within a Single Swath) Relative Accuracy

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

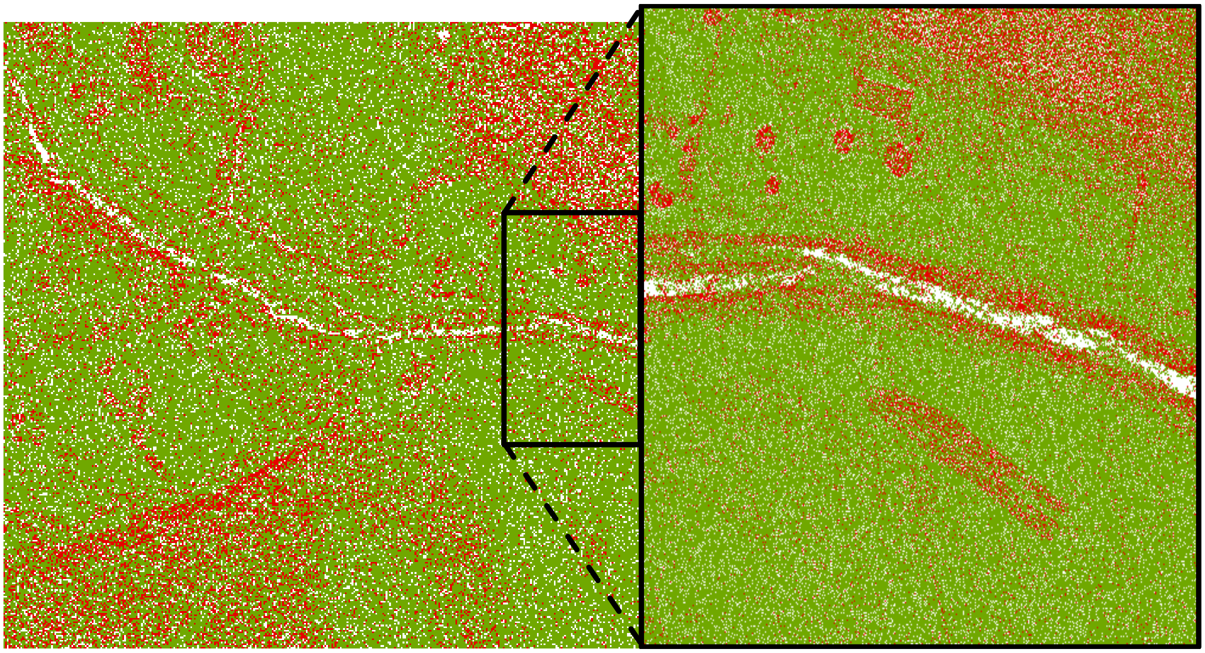


Figure 8–Intra-swath relative accuracy. Areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The left image shows a large portion of the dataset; flat, open areas are colored green, whereas sloped terrain is colored red because the terrain itself exceeds the 6 cm threshold. This is expected. The right image is an inset showing a flat area. With the exception of a few trees (shown in red as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.

Horizontal Alignment

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

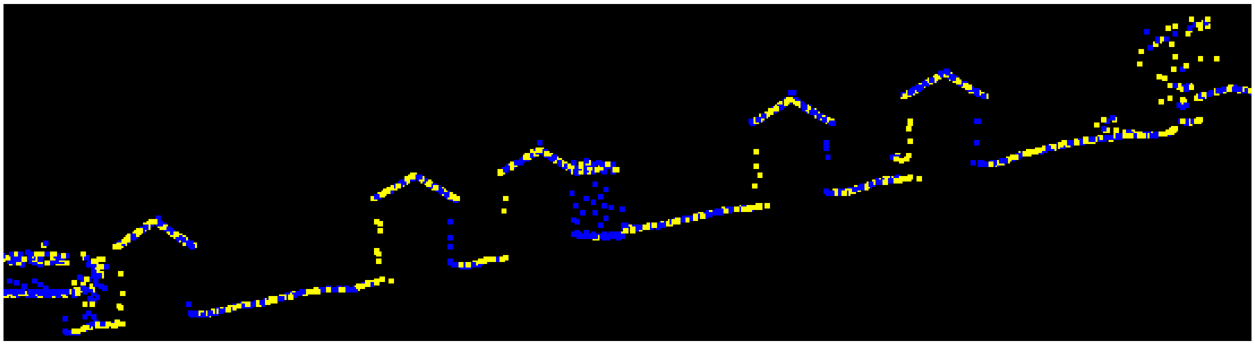


Figure 9 – Two separate flight lines differentiated by color (Blue/Yellow) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.71 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 2 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.4 meters and an ANPD of 5.3 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-square meter cells contain at least 2 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.

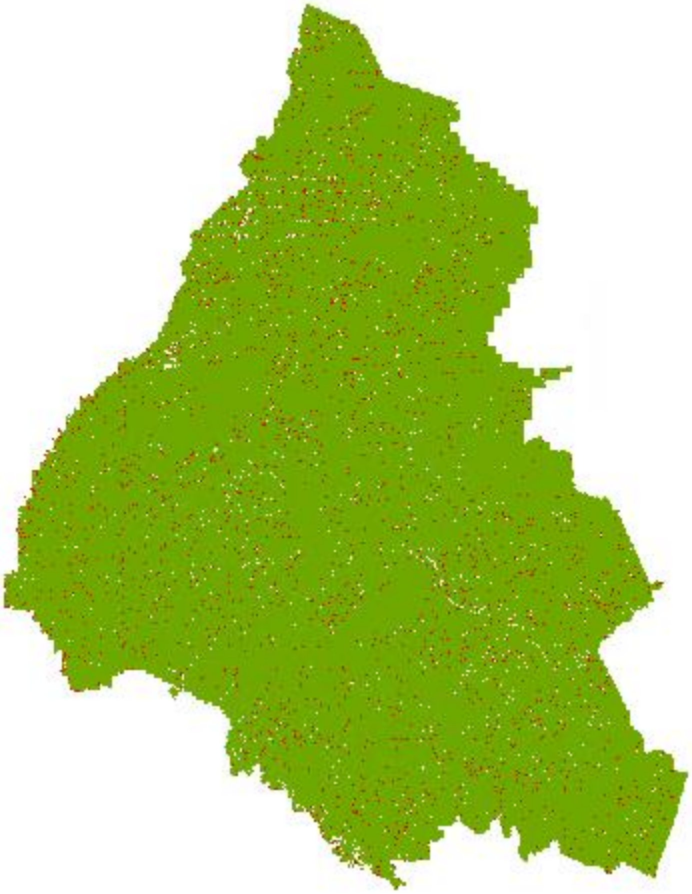


Figure 10 – 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) showing there are no systematic density issues.

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

Figure 11 – All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies and other acceptable NoData areas, are colored red. Including acceptable NoData areas, 99.3% of cells contain at least one lidar point.

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, Dewberry utilized a variety of software suites for data processing. The data were processed using GeoCue and TerraScan software. The acquired 3D laser point clouds, in LAS binary format, were imported into a GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan.

This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After these points are classified (i.e., removed from class 1), the ground layer is extracted from this remaining point cloud by an iterative surface model.

This surface model is generated using four main parameters: building size, iteration angle, iteration distance, and maximum terrain angle. 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. Points that do not relate to classified ground within the maximum terrain angle are not captured by the initial model.

After the initial automated ground routine, 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 employed 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. Bridge decks were classified to class 17 using bridge breaklines compiled by Dewberry. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that are within 1 NPS distance of the hydrographic feature boundaries are moved to class 10, ignored ground, to avoid hydroflattening artifacts along the edges of hydro features.

Overage points were then identified in Terrascan and GeoCue was used to set the overlap bit for the overage points. The withheld bit was set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into classes 2, 7, 9, 10, 17, or 18, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 9 = Water
- Class 10 = Ignored Ground

- Class 17 = Bridge Decks
- Class 18 = High Noise

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

Lidar Qualitative Assessment

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

VISUAL REVIEW

The following sections describe common types of issues identified in lidar data and summarize the results of the visual qualitative assessment for Virginia West Chesapeake Bay Watershed.

Data Voids

The LAS files are used to produce density grids with the commercial software package QT Modeler (QTM), which creates a 3-dimensional data model derived from Class 2 (ground) points. Grid spacing is based on the project density deliverable requirement for un-obscured areas. Acceptable voids (areas with no lidar returns in the LAS files) that are present in the majority of lidar projects include voids caused by bodies of water. One atypical void was found in the Virginia West Chesapeake Bay Watershed lidar project AOI. The issue is illustrated in Figure 12, below.

Figure 12 – LAS_17SNB880835. One atypical void exists in the dataset. The Ingevity Activated Carbon Plant and the smoke from the smokestacks inhibited the lidar from penetrating the ground. This issue affected only one tile.

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.

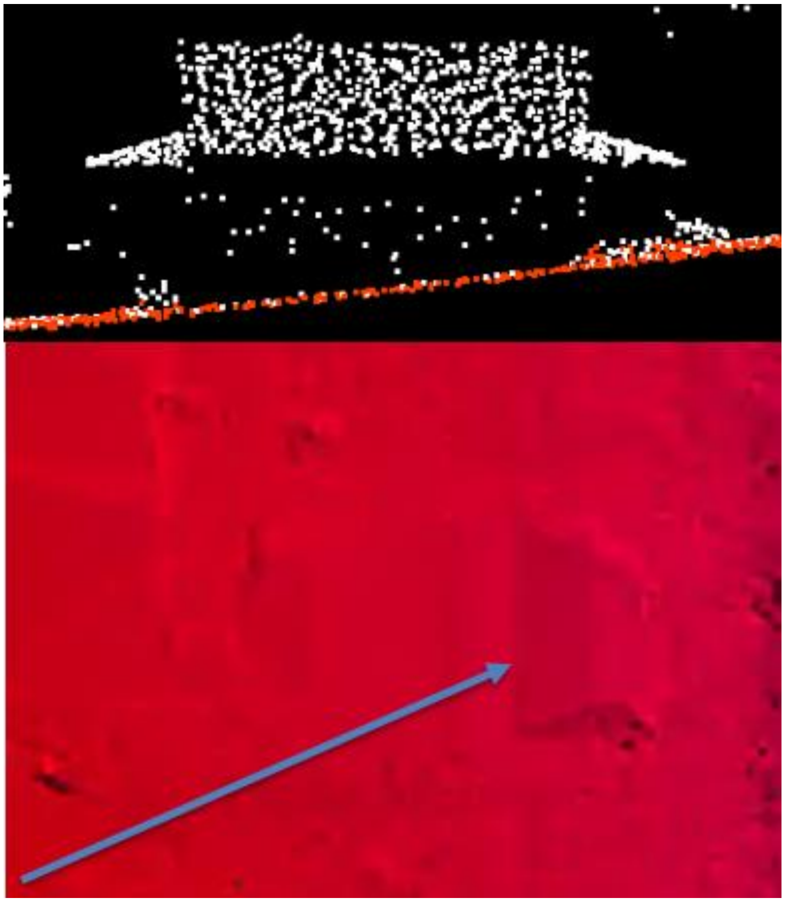


Figure 13 – LAS_17SNB880835. A profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

Bridge Removal Artifacts

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

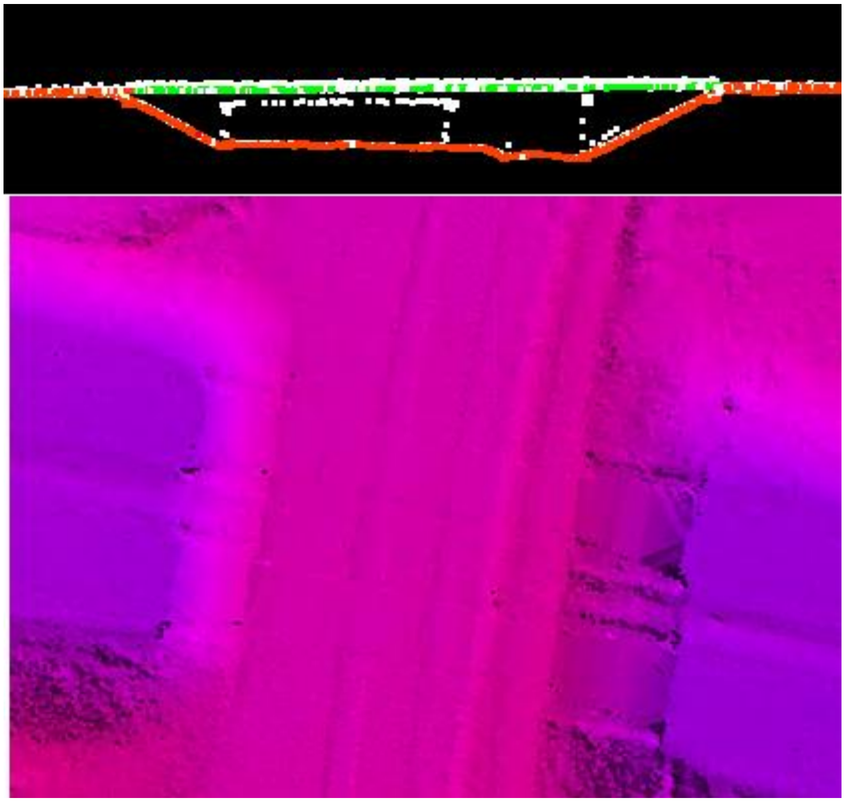


Figure 14 – LAS_17SNB880805. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (orange) and are unclassified (white)/bridge deck (green).

Culverts and Bridges

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

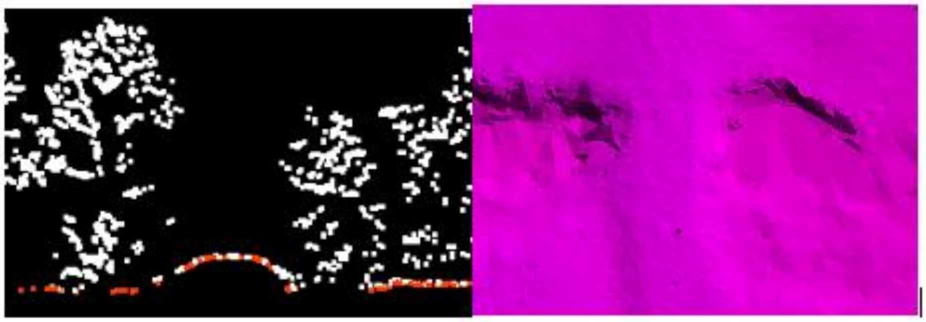
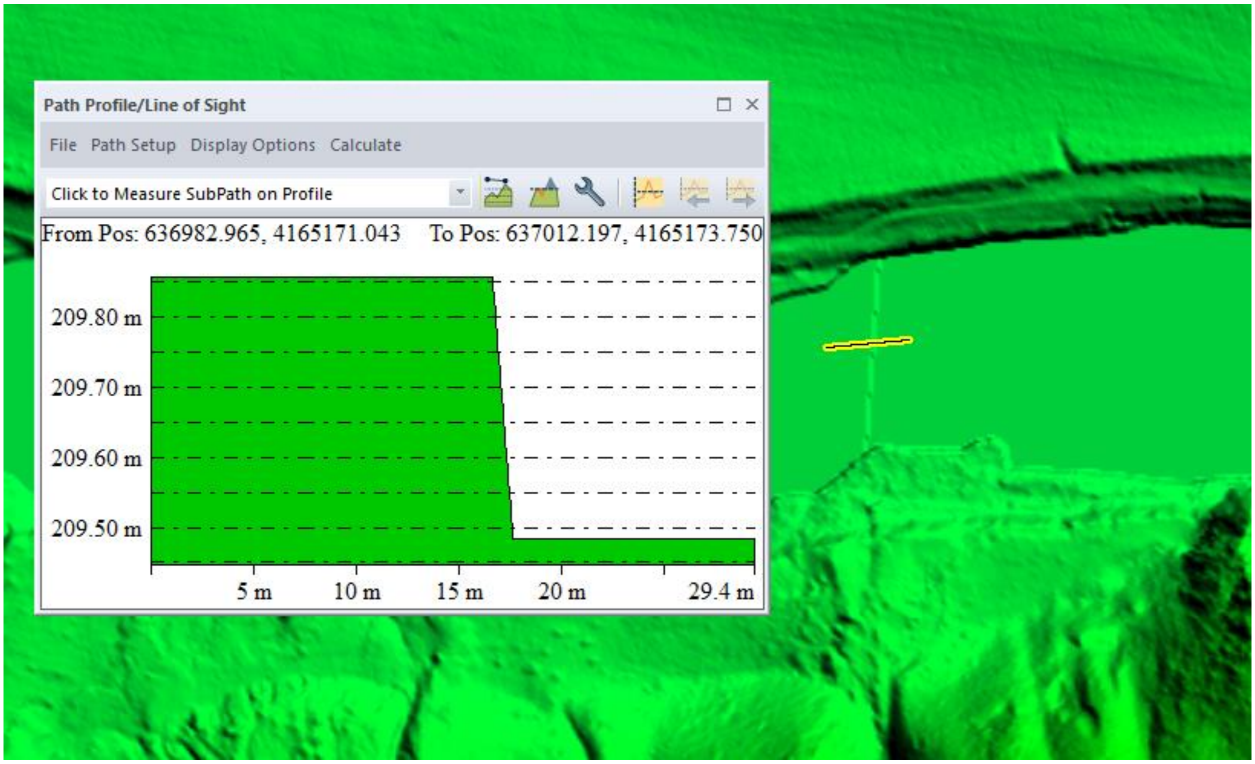


Figure 15 – LAS_17SPB090550. A profile with points colored by class (class 1=white, class 2=orange) is shown in the left view and the DEM is shown in the right view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

Elevation Change within Breaklines

While water bodies are flattened in the final DEMs, other features, such as linear hydrographic features, can have significant changes in elevation within a small distance. In linear hydrographic features, this is often due to the presence of a structure that affects flow such as a dam or spillway. Dewberry has reviewed the DEMs to ensure that changes in elevation are shown from bank to bank. These changes are often shown as steps to reduce the presence of artifacts while ensuring consistent downhill flow. An example is shown below.



From Pos: 636982.965, 4165171.043 To Pos: 637012.197, 4165173.750

Figure 16 – LAS_17SPB360640. The elevation change of approximately 0.35 m has been stair stepped. The steps are flat from bank to bank and are consistently monotonic.

FORMATTING

After the final QA/QC is performed and all corrections have been applied to the dataset, all lidar files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using Dewberry proprietary tools. The table below lists some of the main lidar header fields that are updated and verified.

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	6	Pass
Coordinate Reference System	NAD83 (2011) UTM Zone 17, meters and NAVD88 (Geoid 12B), meters in WKT format	Pass
Global Encoder Bit	17 (adjusted GPS time)	Pass
Time Stamp	Adjusted GPS time (unique timestamps)	Pass

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
System ID	Set to the processing system/software (NIIRS10 for GeoCue software)	Pass
Multiple Returns	Yes, and the return numbers are recorded	Pass
Intensity	16 bit intensity values for each pulse	Pass
Classification	Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 9: Water Class 10: Ignored Ground Class 17: Bridge Decks Class 18: High Noise	Pass
Overlap and Withheld Points	Set to the Overlap and Withheld bits	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Synthetic Points

Time of flight laser measurements have their maximum unambiguous range restricted by the maximum distance the laser can travel round-trip before the next laser pulse is emitted. One solution to this problem is to limit “valid” returns to a certain window between specified elevations, or a “range gate”; however, this technique can prevent some returns from being captured if there is terrain outside of the range gate. It can also cause some late returns to be georeferenced as part subsequent pulses.

The multiple time around (MTA) capabilities of Riegl sensors enable the recording of lidar returns any distance from the laser (within detection capabilities) without forcing range gate restrictions. However, there is still a possibility that a late return will occur simultaneously with a pulse emission. The backscatter energy from the laser optics and the atmosphere directly below the aircraft during this event can effectively blind the sensor, making it unable to discern information about the laser return. Because this occurs more consistently with later returns, this blind zone is typically found in a narrow band along the edges of the sensor’s range. The result is a predictable geometry of voids (typically within project specifications) in the point cloud.

During post-processing of the lidar data, Riegl software interpolates coordinates within the blind zones between last returns on each side of the gap. These are flagged as “synthetic” points and are assigned a valid time stamp, though they do not have any waveform data or pulse width information. Amplitude and reflectance are averaged from surrounding points. The assignment of synthetic points does not change the original raw point cloud data.

This dataset contains flagged synthetic points. The images below show an example from a different dataset of synthetic points applied to the ground class of the lidar point cloud.

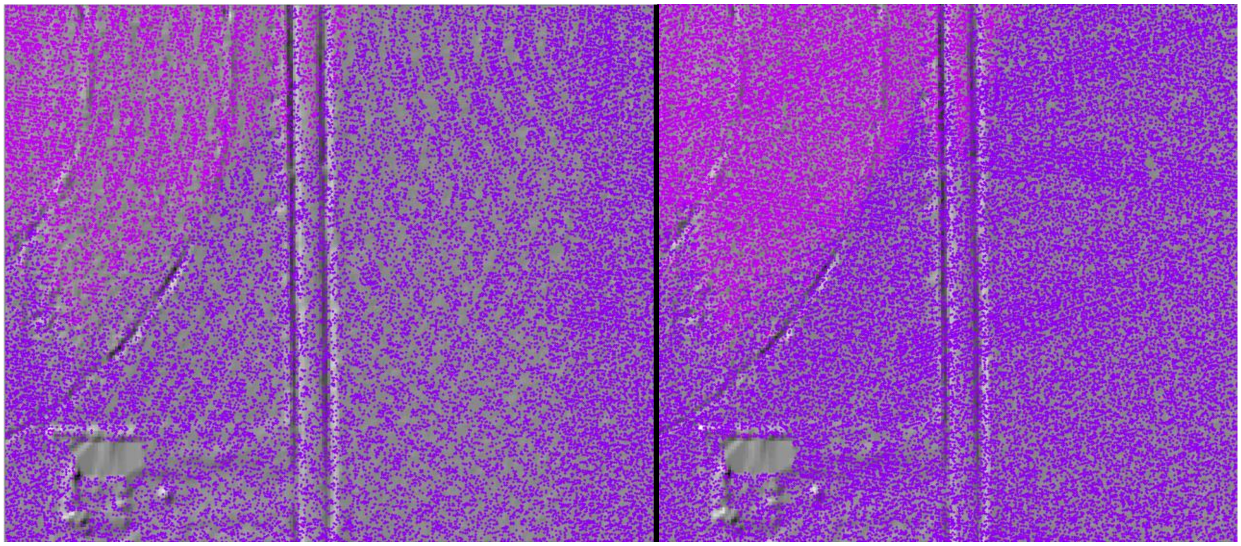


Figure 17 – The left image shows ground classified without synthetic points. The right image shows ground classified with synthetic points. Both images are overlaid on a hillshade of the example area

Derivative Lidar Products

CONTOURS

One-foot contours have been created for the full project area. The contour attributes include labeling as either Index or Intermediate and an elevation value. The contours are also 3D, storing the elevation value within their internal geometry. Some smoothing has been applied to the contours to enhance their aesthetic quality. All contours have been reviewed and edited for correct topology and correct behavior, including correct hydrographic crossings. Due to the large number of contours present and their file size, the contours have been tiled to the project tiles. The contour tiles are all located within one file GDB and are named according to the final project tile grid.

Lidar Positional Accuracy

BACKGROUND

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discrete positional measurement of each survey checkpoint to the position of the interpolated value triangulated between the three closest lidar points to that checkpoint. The relative accuracy of the dataset, which is verified as part of initial processing, is then used to extrapolate the validity of the absolute vertical accuracy. If the relative accuracy of the dataset is within specifications and the dataset passes vertical accuracy requirements at the survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Dewberry also tested the horizontal accuracy of the lidar dataset with a subset of checkpoints that were photo-identifiable in the intensity imagery. Photo-identifiable checkpoints in intensity imagery typically include checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90 degree corners of different reflectivity, e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints, as defined in the intensity imagery, are compared to surveyed XY coordinates for each photo-identifiable checkpoint. These differences are used to compute the tested horizontal accuracy of the lidar.

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, 224 check points—located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories—were surveyed. Survey details and validation are included in the survey report, attached as Appendix A.

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

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

Point ID	NAD83(2011) UTM Zone 17N		NAVD88 (Geoid 12B)	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
NVA-1	725111.933	4333032.766	256.029	256.070
NVA-2	716953.307	4324490.533	399.712	399.780
NVA-3	712631.651	4317571.506	404.339	404.330
NVA-4	702444.391	4307764.821	308.729	308.690
NVA-5	692059.128	4297793.585	396.207	396.260
NVA-6	680432.484	4278914.289	375.500	375.530
NVA-7	673621.143	4290920.407	484.053	483.990
NVA-8	672549.918	4281069.861	475.803	475.810
NVA-9	669817.932	4264820.008	517.895	518.010
NVA-10	619327.507	4263936.795	1045.222	1045.120
NVA-11	616136.937	4257475.422	1140.726	1140.630
NVA-12	630032.789	4260400.289	709.653	709.570
NVA-13	635818.448	4254977.640	773.543	773.450
NVA-14	641461.194	4245702.907	663.070	662.990
NVA-15	654865.718	4238750.558	516.709	516.650
NVA-16	643176.318	4241124.756	683.462	683.400
NVA-17	633072.849	4247086.191	663.864	663.750
NVA-18	623737.139	4252055.083	880.195	880.120
NVA-19	616809.995	4249318.067	864.568	864.460
NVA-20	613345.986	4242268.206	782.194	782.060
NVA-21	620584.217	4240491.171	768.522	768.350
NVA-22	634733.294	4239019.216	577.802	577.700

Point ID	NAD83(2011) UTM Zone 17N		NAVD88 (Geoid 12B)	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
NVA-23	648036.932	4237172.518	576.995	576.940
NVA-24	656776.496	4232718.062	514.426	514.400
NVA-25	660719.138	4232332.754	436.221	436.170
NVA-26	653766.380	4228073.540	546.967	546.930
NVA-27	640168.913	4229060.849	527.101	527.050
NVA-28	630655.031	4234935.014	537.474	537.320
NVA-29	626009.050	4236154.278	565.867	565.800
NVA-30	618271.559	4234332.101	818.550	818.400
NVA-31	605582.939	4239008.189	889.815	889.700
NVA-32	603903.155	4231071.128	1012.717	1012.490
NVA-33	613723.473	4231889.184	642.110	642.070
NVA-34	625135.348	4228456.112	493.876	493.660
NVA-35	637984.194	4221980.638	495.594	495.460
NVA-36	647088.803	4218128.024	492.959	492.910
NVA-37	661699.340	4223254.619	478.012	477.960
NVA-38	656775.221	4212944.842	566.057	565.970
NVA-39	641728.382	4215638.971	467.310	467.240
NVA-40	633835.983	4215111.186	460.083	460.010
NVA-41	625751.926	4216931.122	521.907	521.880
NVA-42	610459.621	4225600.176	615.895	615.850
NVA-43	602757.190	4227050.256	617.329	617.260
NVA-44	597584.456	4217745.917	545.323	545.320
NVA-45	606925.980	4212345.739	706.643	706.610
NVA-46	614485.428	4212309.563	493.903	493.870
NVA-47	632180.861	4205226.184	425.264	425.240
NVA-48	642460.086	4204765.872	403.734	403.720
NVA-49	649183.883	4201873.215	434.202	434.170
NVA-50	657851.300	4198950.758	512.829	512.820
NVA-51	659955.955	4190597.064	630.491	630.470
NVA-52	651823.855	4194687.279	510.717	510.740
NVA-53	640506.501	4195324.572	345.602	345.610
NVA-54	631833.176	4198987.477	535.852	535.760
NVA-55	622665.322	4204145.185	531.387	531.400
NVA-56	610993.841	4203979.933	453.535	453.470
NVA-57	602535.942	4205718.617	715.298	715.270
NVA-58	591097.184	4205561.611	488.159	488.210
NVA-59	589091.232	4203604.689	489.606	489.580

Point ID	NAD83(2011) UTM Zone 17N		NAVD88 (Geoid 12B)	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
NVA-60	597714.370	4198341.599	748.981	748.940
NVA-61	611665.184	4196521.456	368.860	368.890
NVA-62	623964.108	4194894.583	591.866	591.950
NVA-63	633268.818	4190154.567	343.430	343.47
NVA-64	639915.110	4184972.004	318.348	318.390
NVA-65	651576.831	4182062.516	840.589	840.590
NVA-66	659568.289	4180603.285	1047.476	1047.410
NVA-67	670348.971	4176384.738	225.085	225.100
NVA-68	676691.202	4166730.947	225.456	225.510
NVA-69	659917.622	4170272.103	241.875	241.970
NVA-70	646878.648	4170946.729	656.118	656.150
NVA-71	644760.016	4176919.793	249.867	249.910
NVA-72	635185.387	4177081.470	310.431	310.500
NVA-73	624344.447	4182885.901	376.998	377.060
NVA-74	611337.746	4184371.208	337.399	337.400
NVA-75	604771.825	4186051.150	365.225	365.270
NVA-76	589981.438	4193917.281	442.286	442.290
NVA-77	581312.443	4197229.950	641.831	641.810
NVA-78	577453.885	4191169.907	507.252	507.140
NVA-79	570737.089	4184381.394	677.783	677.770
NVA-80	589017.774	4180151.306	389.072	389.150
NVA-81	604106.987	4178915.338	300.998	300.990
NVA-82	616148.074	4173843.060	650.686	650.700
NVA-83	628581.681	4165864.619	332.254	332.310
NVA-84	647819.023	4159784.245	303.541	303.550
NVA-85	661867.465	4160897.672	319.705	319.730
NVA-86	673407.757	4160257.492	224.125	224.170
NVA-87	675624.021	4152087.421	224.009	223.950
NVA-88	651688.811	4150180.764	293.512	293.460
NVA-89	634621.849	4158881.955	397.504	397.480
NVA-90	620577.346	4161125.166	382.731	382.760
NVA-91	605943.928	4166495.093	287.704	287.700
NVA-92	597884.319	4172223.796	292.235	292.240
NVA-93	580278.598	4176108.201	548.551	548.430
NVA-94	570304.860	4174959.048	500.537	500.510
NVA-95	578398.723	4170233.177	457.969	457.870
NVA-96	589512.795	4163704.974	340.532	340.440

Point ID	NAD83(2011) UTM Zone 17N		NAVD88 (Geoid 12B)	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
NVA-97	612174.119	4159386.307	290.980	291.030
NVA-98	613740.844	4152201.602	261.600	261.610
NVA-99	626727.428	4151764.049	697.927	697.890
NVA-100	638046.257	4150224.676	314.375	314.390
NVA-101	657190.479	4139757.959	236.821	236.780
NVA-102	676430.075	4137277.438	238.160	238.150
NVA-103	678020.092	4129443.163	251.789	251.710
NVA-104	687788.854	4118347.295	197.018	197.030
NVA-105	682487.603	4102640.816	167.433	167.460
NVA-106	668691.461	4127282.726	271.777	271.770
NVA-107	656136.427	4130812.720	283.750	283.740
NVA-108	644534.475	4129488.214	266.473	266.430
NVA-109	628538.169	4133371.669	296.834	296.750
NVA-110	620687.601	4143133.321	435.625	435.540
NVA-111	606446.225	4147850.369	360.344	360.340
NVA-112	592279.381	4150329.765	379.610	379.600
NVA-113	576741.316	4156053.021	483.994	483.940
NVA-114	570983.823	4151726.462	486.561	486.420
NVA-115	576033.909	4142576.953	423.266	423.080
NVA-116	597265.616	4138248.824	379.745	379.770
NVA-117	605575.964	4130571.274	606.498	606.460
NVA-118	622229.639	4128308.268	292.307	292.290
NVA-119	635975.523	4122317.442	288.345	288.290
NVA-120	651337.480	4122631.987	252.477	252.460
NVA-121	659406.292	4116682.683	259.119	259.120
NVA-122	676063.982	4114845.282	196.508	196.620
NVA-123	669050.001	4104925.901	138.690	138.690
NVA-124	650709.703	4112913.906	227.835	227.900
NVA-125	635873.570	4114226.373	249.462	249.570
NVA-126	627418.676	4105243.071	254.921	254.880
NVA-127	625504.404	4118188.526	252.396	252.360
NVA-128	613418.282	4119453.901	287.645	287.710
VVA-1	724272.398	4337044.727	478.388	478.490
VVA-2	716086.757	4320530.956	336.290	336.360
VVA-3	697008.882	4303632.740	354.575	354.640
VVA-4	678177.047	4297331.535	473.043	473.040
VVA-5	670894.159	4287149.921	593.201	592.790
VVA-6	668198.164	4276788.069	1080.848	1080.910
VVA-7	666661.414	4270368.915	596.958	597.010
VVA-08	624806.015	4268911.388	816.554	816.470

Point ID	NAD83(2011) UTM Zone 17N		NAVD88 (Geoid 12B)	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
VVA-09	628322.122	4256274.235	799.229	799.210
VVA-10	639857.265	4249654.808	690.562	690.390
VVA-11	649344.049	4239186.112	597.712	597.580
VVA-12	660217.504	4229383.230	459.537	459.530
VVA-13	645891.248	4231688.908	565.806	565.750
VVA-14	632754.699	4237683.919	582.804	582.820
VVA-15	627681.033	4245556.371	737.601	737.540
VVA-16	617972.557	4256724.828	974.458	974.450
VVA-17	613490.995	4247205.606	791.746	791.590
VVA-18	613606.420	4131115.675	336.229	336.200
VVA-19	627975.886	4231498.626	510.975	510.920
VVA-20	639693.247	4226914.006	510.883	510.890
VVA-21	649970.977	4220577.565	545.396	545.490
VVA-22	652303.024	4215007.885	538.102	538.020
VVA-23	640376.522	4213578.955	547.188	547.210
VVA-24	631118.443	4220712.126	621.033	621.010
VVA-25	621445.869	4221867.835	466.847	466.910
VVA-26	612291.887	4230175.652	639.218	639.150
VVA-27	608184.625	4234483.864	668.695	668.610
VVA-28	596825.796	4224567.177	633.067	633.080
VVA-29	610854.232	4220596.720	772.962	772.820
VVA-30	624758.954	4212894.763	549.599	549.640
VVA-31	636926.699	4205776.436	417.457	417.610
VVA-32	653495.549	4202591.274	556.799	556.760
VVA-33	661215.216	4199017.423	485.191	485.010
VVA-34	656946.789	4187201.942	500.384	500.330
VVA-35	644541.244	4200287.242	383.678	383.660
VVA-36	635271.027	4201219.443	409.228	409.150
VVA-37	624627.841	4207025.124	498.058	498.020
VVA-38	613010.093	4207201.762	429.684	429.760
VVA-39	597606.326	4214083.483	515.842	515.790
VVA-40	592819.111	4209713.840	545.863	545.900
VVA-41	602261.065	4201343.508	1147.777	1147.850
VVA-42	614666.205	4200360.432	433.600	433.630
VVA-43	628279.735	4191941.163	398.732	399.000
VVA-44	640178.752	4188590.153	391.87	391.870
VVA-45	649196.695	4185672.236	321.753	321.840
VVA-46	655166.651	4179973.061	741.694	741.660
VVA-47	666347.880	4179400.012	375.797	375.880
VVA-48	674265.755	4171679.288	257.539	257.710

Point ID	NAD83(2011) UTM Zone 17N		NAVD88 (Geoid 12B)	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
VVA-49	682732.629	4160576.875	273.861	273.830
VVA-50	666566.022	4165499.512	247.930	248.000
VVA-51	657454.093	4170739.039	266.510	266.630
VVA-52	648724.553	4175862.630	645.361	645.250
VVA-53	639128.945	4176858.887	343.958	344.160
VVA-54	630973.002	4184162.136	431.557	431.700
VVA-55	611289.534	4192145.844	343.076	343.230
VVA-56	604467.298	4192019.681	383.589	383.640
VVA-57	596540.816	4203813.030	507.474	507.540
VVA-58	592177.701	4205611.521	497.424	497.390
VVA-59	586151.601	4192452.433	493.236	493.270
VVA-60	592758.435	4191846.790	659.288	659.420
VVA-61	606864.235	4179326.270	334.954	335.060
VVA-62	621936.414	4177671.209	412.054	412.170
VVA-63	640173.674	4170457.435	295.357	295.450
VVA-64	655059.267	4164361.105	272.681	272.690
VVA-65	675601.149	4159048.045	232.444	232.610
VVA-66	672187.321	4146033.728	242.329	242.410
VVA-67	655897.808	4150995.744	248.703	248.740
VVA-68	641359.970	4155458.865	308.338	308.370
VVA-69	628512.853	4158743.455	415.206	414.830
VVA-70	611726.513	4165778.667	357.446	357.580
VVA-71	599319.081	4170760.329	293.050	293.130
VVA-72	581789.143	4180949.580	512.637	512.560
VVA-73	571398.321	4176968.811	488.297	488.310
VVA-74	586029.689	4167990.163	835.242	835.330
VVA-75	603392.620	4157201.542	327.488	327.560
VVA-76	622612.819	4152271.007	342.773	342.620
VVA-77	633630.090	4143118.667	276.100	276.140
VVA-78	650847.783	4138489.917	263.034	263.000
VVA-79	674624.532	4132805.536	251.716	251.660
VVA-80	679942.940	4118774.913	163.350	163.480
VVA-81	665489.105	4111470.208	204.529	204.620
VVA-82	645609.482	4122253.244	244.619	244.730
VVA-83	635145.258	4128846.439	253.570	253.650
VVA-84	615820.833	4136345.620	319.233	319.230
VVA-85	606823.407	4145143.101	357.959	358.020
VVA-86	588945.042	4157418.984	391.581	391.500
VVA-87	571742.219	4163714.994	527.822	527.460
VVA-88	561704.736	4156301.919	594.324	594.240

Point ID	NAD83(2011) UTM Zone 17N		NAVD88 (Geoid 12B)	
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)
VVA-89	579672.490	4144263.512	414.374	414.330
VVA-90	586588.171	4142931.324	456.009	456.090
VVA-91	608191.173	4124817.234	320.210	320.190
VVA-92	622020.055	4122372.900	303.132	303.200
VVA-93	622853.880	4110921.510	314.930	314.960
VVA-94	634134.473	4101324.808	189.980	190.020
VVA-95	651638.152	4116450.315	213.480	213.470
VVA-96	683690.988	4106186.900	136.630	136.760

Table 9 – Virginia West Chesapeake lidar surveyed accuracy checkpoints

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

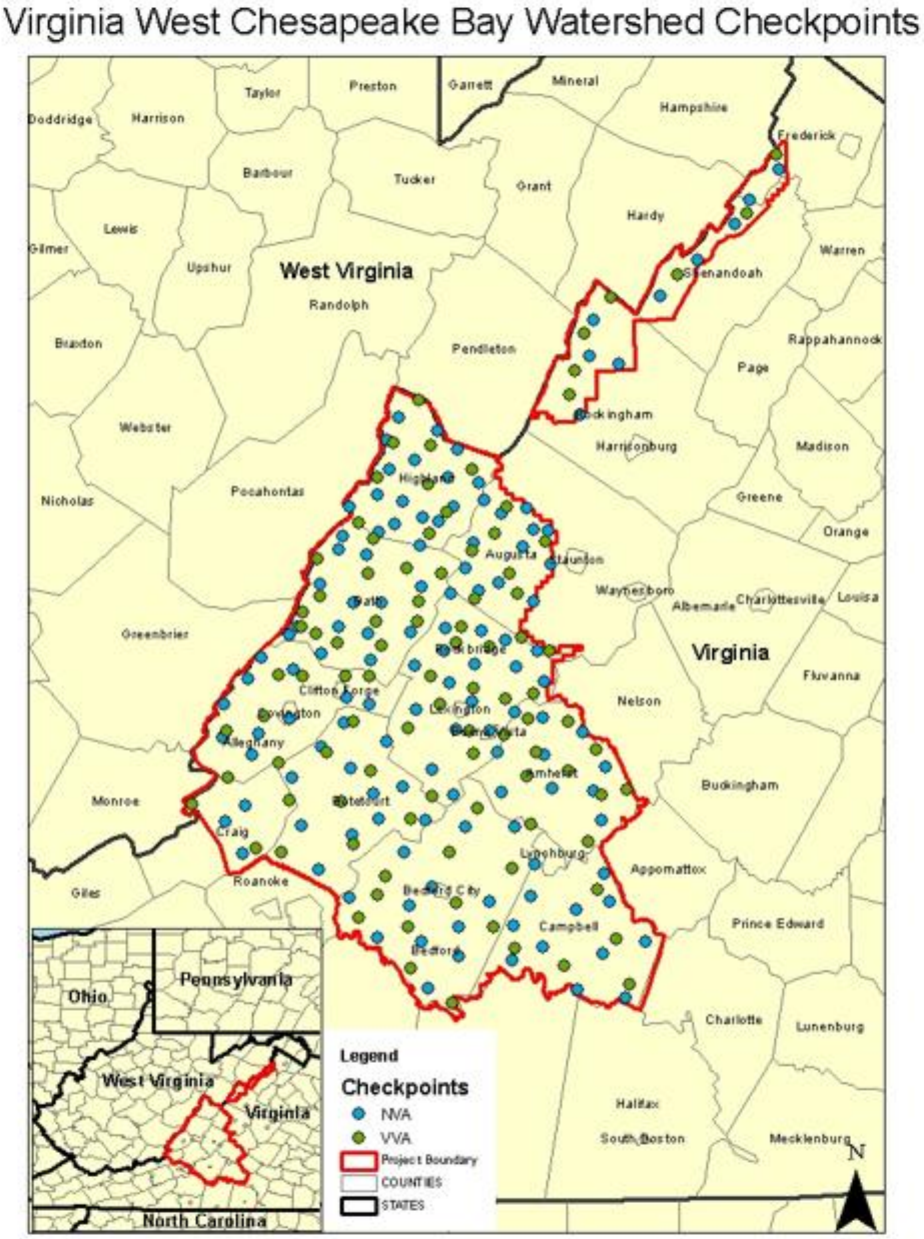


Figure 18 – Location of QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

Non-Vegetated Vertical Accuracy

NVA is determined with checkpoints located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, where there is a very high probability that the lidar sensor has detected the bare-earth ground surface and where random errors in the point cloud are expected to follow a normal error distribution. The NVA determines how well the calibrated lidar sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the Virginia West Chesapeake lidar project, vertical accuracy must be 19.6 cm or less based on an $RMSE_z$ of 10 cm x 1.9600.

Vegetated Vertical Accuracy

VVA is determined with checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The Virginia West Chesapeake Lidar Project VVA standard is 29.4 cm based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA. These are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 10.

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

Table 10 — Acceptance criteria

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

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

VERTICAL ACCURACY RESULTS

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

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	128	0.139	
VVA	96		0.186

Table 11 – Tested lidar NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 7.1cm, equating to ± 13.9 cm at 95% confidence level. Actual VVA accuracy was found to be ± 18.6 cm at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within ± 20 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +41 cm.

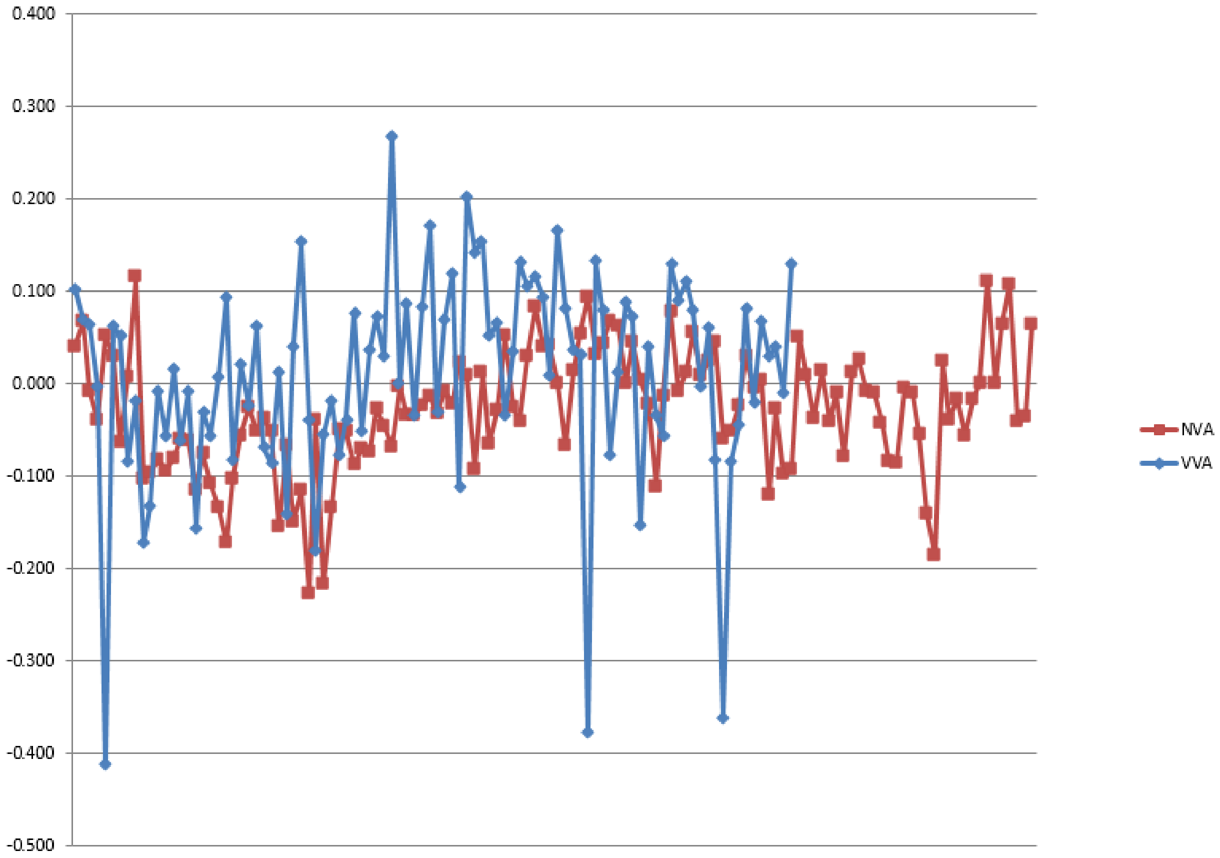


Figure 19 – Magnitude of elevation discrepancies per land cover category

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

Point ID	NAD83(2011) UTM Zone 18N		NAVD88 (Geoid 12B)		Delta Z	AbsDelta Z
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
VVA-5	670894.159	4287149.921	593.201	592.790	-0.411	0.411
VVA-69	628512.853	4158743.455	415.206	414.830	-0.376	0.376
VVA-87	571742.219	4163714.994	527.822	527.460	-0.362	0.362
VVA-53	639128.945	4176858.887	343.958	344.160	0.202	0.202
VVA-43	628279.735	4191941.163	398.732	399.000	0.268	0.268

Table 12— Lidar VVA 5% outliers

Table 13 provides overall descriptive statistics for NVA and VVA assessments.

100 % of Totals	# of Points	RMSEz (m) Spec=0.100 m NVA/ 0.180 m Submerged Topography	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	128	0.071	-0.028	-0.026	-0.375	0.066	0.355	-0.227	0.115
VVA	96	N/A	0.009	0.026	-1.229	0.112	3.240	-0.411	0.268

Table 13 — Lidar NVA and VVA 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 vast majority of points are within the ranges of -0.05 meters to +0.05 meters.

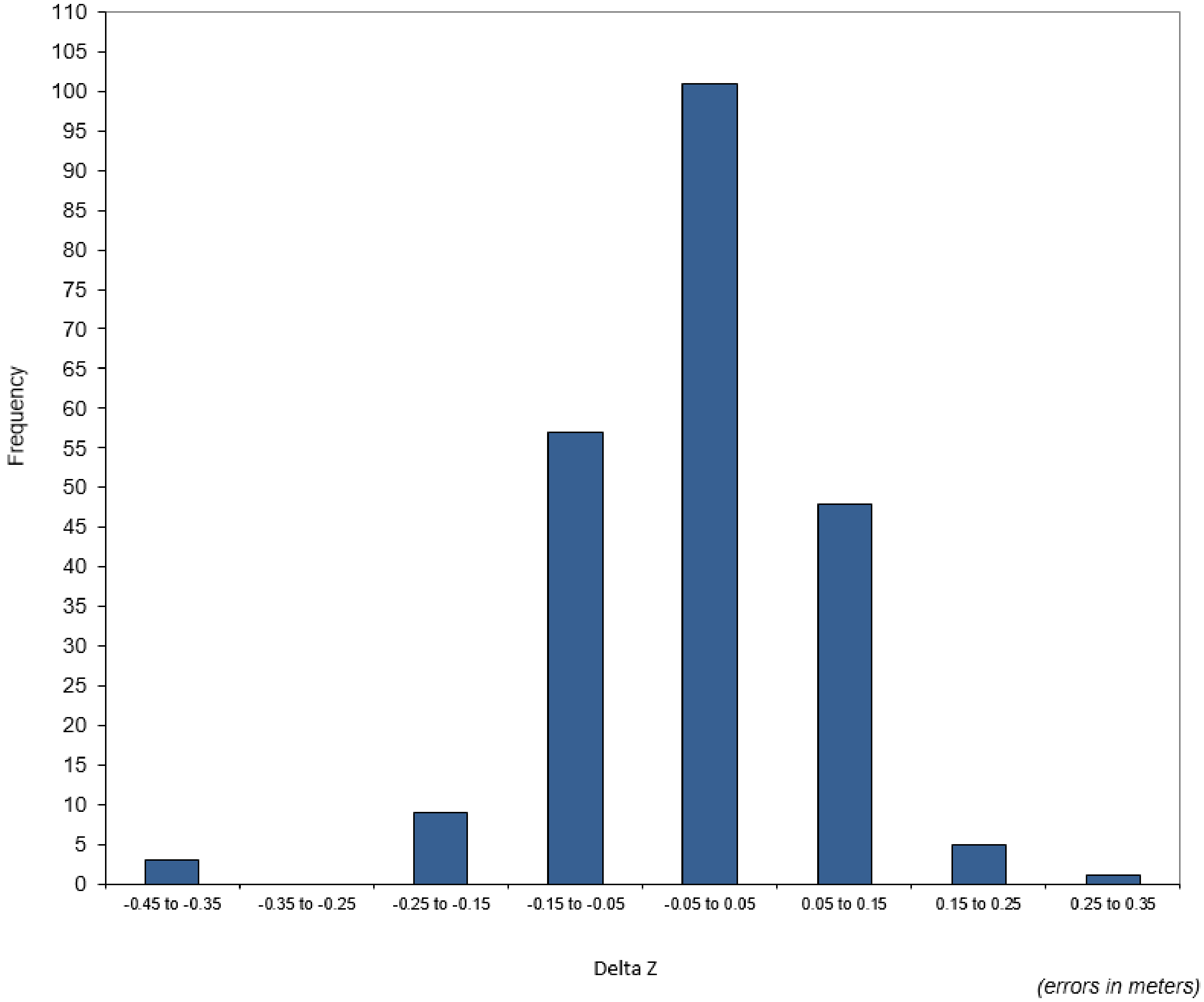


Figure 20 – Histogram of elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the USGS Virginia West Chesapeake Bay Watershed Lidar Project satisfies the project's defined vertical accuracy criteria.

HORIZONTAL ACCURACY TEST PROCEDURES

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

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

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

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

HORIZONTAL ACCURACY RESULTS

Twenty-two checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset. Using NSSDA methodology (endorsed by the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)), horizontal accuracy at the 95% confidence level (called Accuracy_r) is computed by the formula RMSE_r x 1.7308 or RMSE_{xy} x 2.448.

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

# of Points	RMSE_x (Target=41 cm)	RMSE_y (Target=41 cm)	RMSE_r (Target=58 cm)	ACCURACY_r (RMSE_r x 1.7308) Target=100 cm
22	0.234	0.322	0.398	0.689

Table 14 – Tested horizontal accuracy at the 95% confidence level

This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSE_x/RMSE_y Horizontal Accuracy Class which equates to a positional horizontal accuracy of ± 1 meter at a 95% confidence level. 22 checkpoints were used for horizontal accuracy testing. Actual positional accuracy of this dataset was found to be RMSE_x = 23.4 cm and RMSE_y = 32.2 cm, which equates to ± 68.9 cm at 95% confidence level.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

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

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are at a constant elevation where the lowest elevation of the water body has been applied to the entire water body.

BREAKLINE QUALITATIVE ASSESSMENT

Dewberry completed breakline qualitative assessments according to a defined workflow. The workflow diagram below represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.

Completeness and horizontal placement were verified through visual reviews against lidar intensity imagery. Automated checks were applied on all breakline features to validate topology, including the 3D connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies.

The next step compared the elevation of the breakline vertices against the ground elevation extracted from the ESRI Terrain built from the lidar ground points, keeping in mind that a discrepancy was expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance was used to validate if the elevations differed too much from the lidar.

After all corrections and edits to the breakline features, the breaklines were imported into the final GDB and verified for correct formatting.

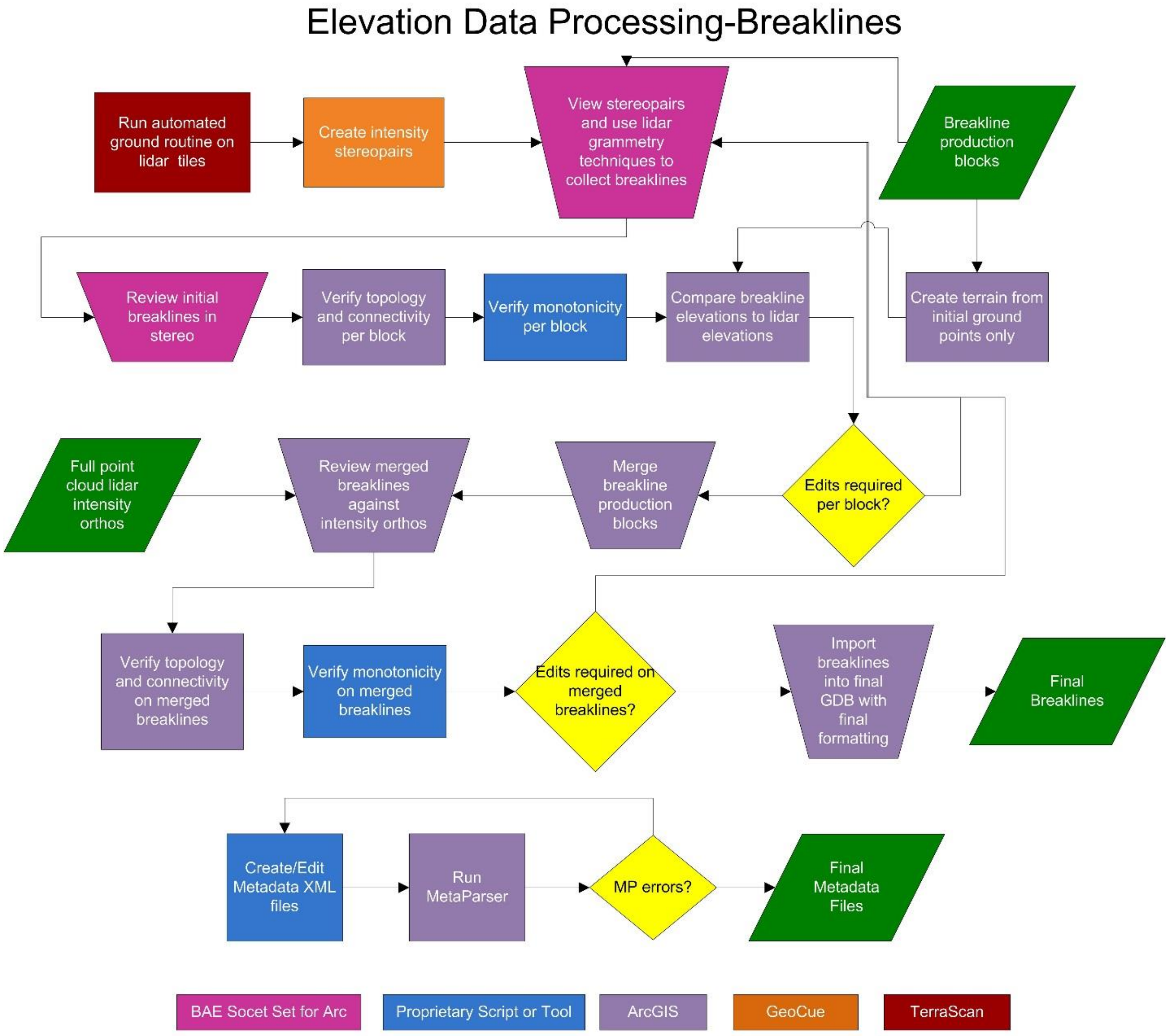


Figure 21 – Breakline QA/QC workflow

BREAKLINE CHECKLIST

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

Pass/Fail	Validation Step
Pass	Use lidar-derived data, which may include intensity imagery, stereo pairs, bare earth ground models, density models, slope models, and terrains, to collect breaklines according to project specifications.
Pass	In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS).

Pass/Fail	Validation Step
Pass	After each producer finishes breakline collection for a block, each producer must perform a completeness check, breakline variance check, and all automated checks on their block before calling that block complete and ready for the final merge and QC
Pass	After breaklines are completed for production blocks, all production blocks should be merged together and completeness and automated checks should be performed on the final, merged GDB. Ensure correct snapping-horizontal (x,y) and vertical (z)-between all production blocks.
Pass	Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains
Pass	Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement.
Pass	Using a terrain created from lidar ground (all ground including 2, 8, and 10) and water points (class 9), compare breakline Z values to interpolated lidar elevations.
Pass	Perform all Topology and Data Integrity Checks
Pass	Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic.

Table 15 – A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.

DATA DICTIONARY

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum is North American Datum of 1983 (2011 adjustment), units in meters. The vertical datum is North American Vertical Datum of 1988, units in meters. Geoid12B is used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data is projected to UTM Zone 17, with horizontal and vertical units in meters.

Inland Streams and Rivers

Feature Dataset: Breaklines
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: 0.0001
XY Tolerance: 0.001

Feature Class: Rivers_Streams
Contains M Values: No
Annotation Subclass: None
Z Resolution: 0.0001
Z Tolerance: 0.001

Description

This polygon feature class depicts linear hydrographic features with a width greater than 100 feet.

Table Definition

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

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the island is greater than 1 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

Inland Ponds and Lakes

Feature Dataset: Breaklines
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: 0.0001
XY Tolerance: 0.001

Feature Class: Ponds_Lakes
Contains M Values: No
Annotation Subclass: None
Z Resolution: 0.0001
Z Tolerance: 0.001

Description

This polygon feature class depicts closed water body features that are at a constant elevation.

Table Definition

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

Feature Definition

Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. “Donuts” will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature that is 1 acre in size or greater will also have a “donut polygon” compiled. These instructions are only for docks or piers that follow the coastline or water’s edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water’s edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Beneath Bridge Breaklines

Feature Dataset: Breaklines
Feature Type: Polyline
Contains Z Values: Yes
XY Resolution: 0.0001
XY Tolerance: 0.001

Feature Class: Bridge_Saddle_Breaklines
Contains M Values: No
Annotation Subclass: None
Z Resolution: 0.0001
Z Tolerance: 0.001

Description

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

Table Definition

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

Feature Definition

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

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

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

The final bare-earth lidar points were used to create a terrain. The final 3D breaklines collected for the project were also enforced in the terrain. The terrain was then converted to raster format using linear interpolation. The DEM was reviewed for any issues requiring corrections, including remaining lidar mis-classifications, erroneous breakline elevations, poor hydro-flattening or hydro-enforcement, and processing artifacts. After corrections were applied, the DEM was then split into individual tiles following the project tiling scheme. The tiles were verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

Figure 22 – DEM production workflow

DEM QUALITATIVE ASSESSMENT

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

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

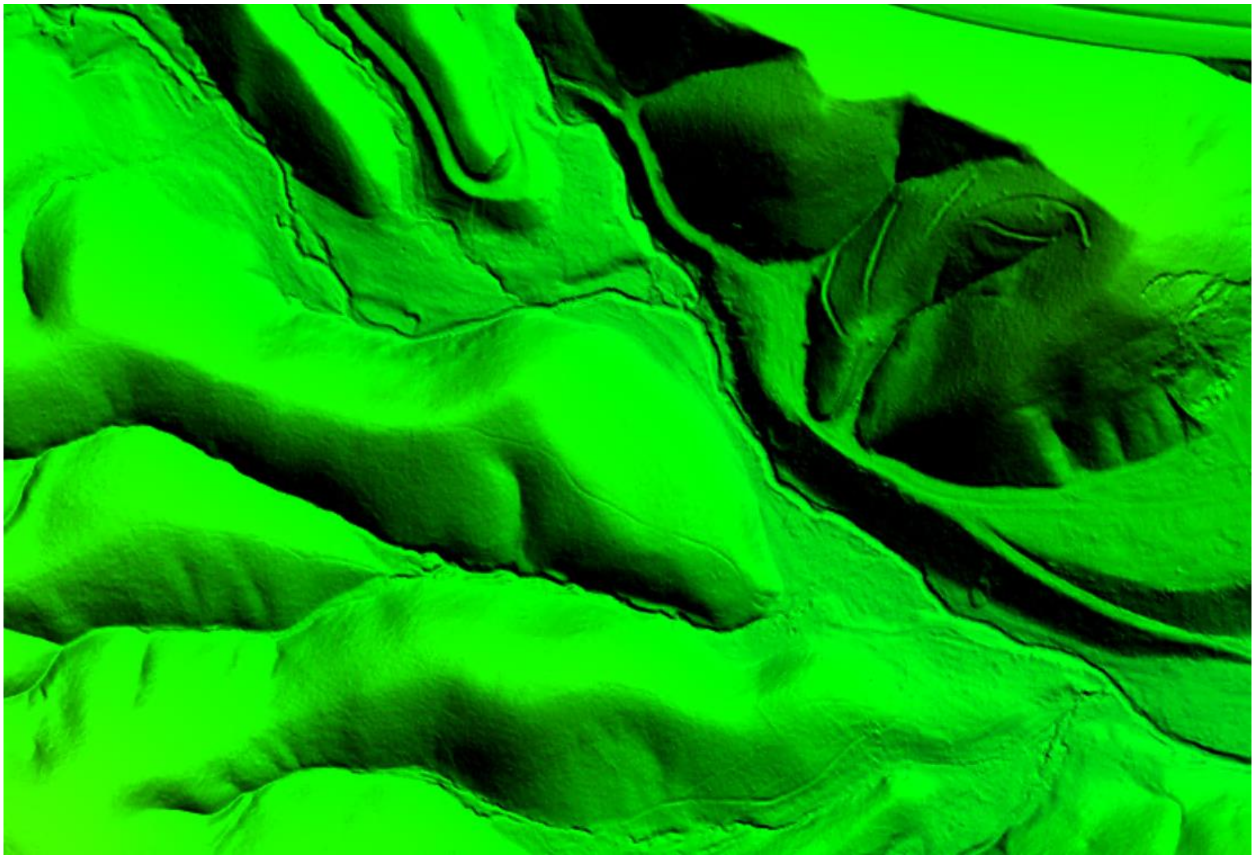


Figure 23 – LAS_17SPB045865. Bare Earth DEM

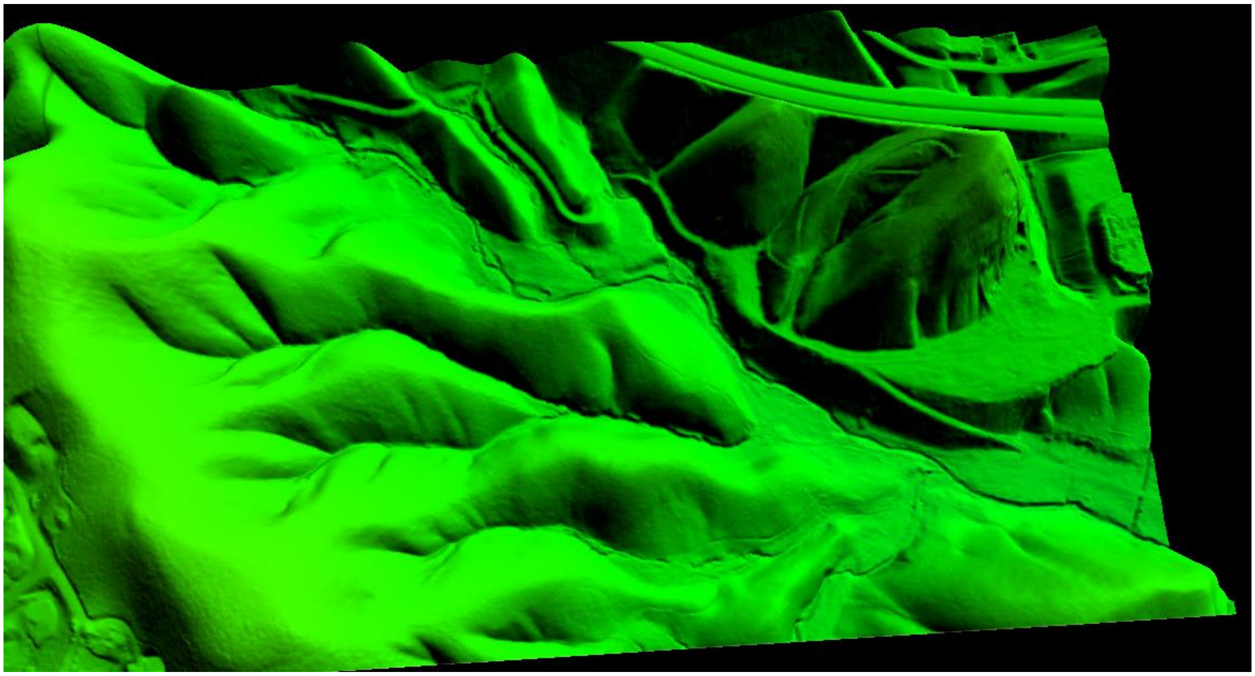


Figure 24 – LAS_17SPB045865. 3D Profile view of the bare earth DEM

When some bridges are removed from the ground surface, the distance from bridge abutment to bridge abutment is small enough that the DEM interpolates across the entire bridge opening, forming 'bridge saddles.' Dewberry collected 3D bridge breaklines in locations where bridge saddles were present and enforced these breaklines in the final DEM creation to help mitigate the bridge saddle artifacts. The image below shows an example of a bridge saddle that required bridge breaklines to enforce a better DEM surface.

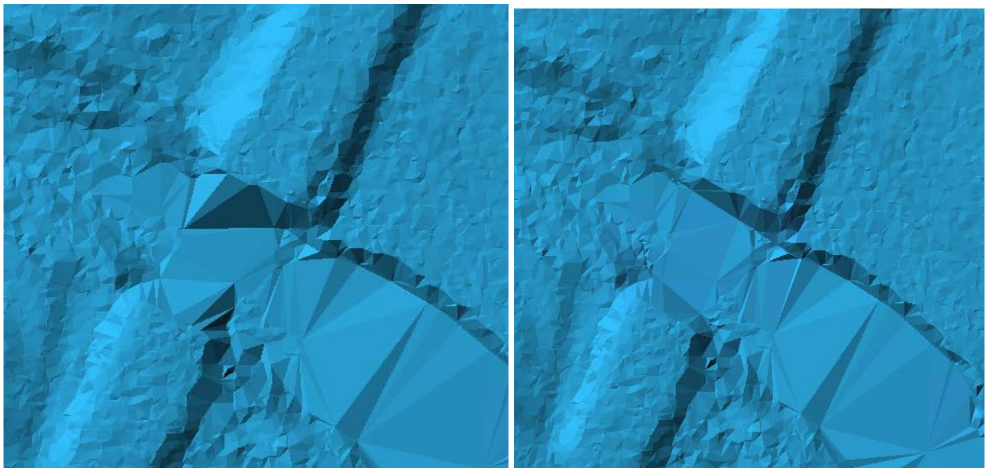


Figure 25 – LAS_17SPC420000. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced

DEM VERTICAL ACCURACY RESULTS

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

Table 16 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	128	0.141	
VVA	96		0.200

Table 16 – Tested DEM NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 5 cm, equating to ± 10 cm at 95% confidence level. Actual VVA accuracy was found to be ± 13 cm at the 95th percentile.

Table 17 lists the 5% outliers that are larger than the VVA 95th percentile and Table 18 shows the descriptive statistics of the VVA dataset.

Point ID	NAD83(2011) UTM Zone 17		NAVD88 (Geoid 12B)	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA-53	639128.945	4176858.887	343.958	344.166	0.208	0.208
VVA-43	628279.735	4191941.163	398.732	398.955	0.223	0.223
VVA-87	571742.219	4163714.994	527.822	527.449	-0.373	0.373
VVA-69	628512.853	4158743.455	415.206	414.820	-0.386	0.386
VVA-05	670894.235	4287149.871	593.308	592.819	-0.489	0.489

Table 17 – DEM 5% Outliers

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	128	0.072	-0.028	-0.028	-0.326	0.066	0.289	-0.221	0.119
VVA	96	N/A	0.011	0.028	-1.589	0.115	4.750	-0.489	0.223

Table 18 — DEM NVA and VVA descriptive statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the USGS Virginia West Chesapeake Bay Watershed Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

DEM CHECKLIST

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

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

Table 19 – A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project

Appendix A: Checkpoint Survey Report

Appendix A has been included as an attachment.

Appendix B: Complete List of Delivered Tiles

17SPC615615
17SPC630615
17SPC645615
17SPC660615
17SPC675615
17SPC555630
17SPC570630
17SPC600630
17SPC615630
17SPC630630
17SPC645630
17SPC660630
17SPC675630
17SPC690630
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17SPC570645
17SPC585645
17SPC600645
17SPC615645
17SPC630645
17SPC645645
17SPC660645
17SPC675645
17SPC690645
17SPC705645
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Appendix C: Axis GPS and IMU Reports

Appendix D has been included as an attachment.

Appendix D: LEG GPS and IMU Reports

Appendix E has been included as an attachment.