Dewberry & Davis LLC
1000 N. Ashley Drive, Suite 801
Tampa, FL 33602-3718
813.225.1325
813.225.1385 fax
www.dewberry.com

Virginia FEMA NRCS South Central Lidar Project

Report Produced for U.S. Geological Survey

USGS Contract: G16PC00020

Task Order: G17PD01206

Report Date: 09/25/2019

SUBMITTED BY:

Dewberry
1000 North Ashley Drive Suite 801
Tampa, FL 33602
813.225.1325

SUBMITTED TO:

U.S. Geological Survey
1400 Independence Road
Rolla, MO 65401
573.308.3810

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 FEMA NRCS South Central 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 11495 tiles were produced for the project encompassing an area of approximately 9495 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 states of Virginia and West Virginia. Virginia counties include Carroll, Patrick, Floyd, Pulaski, Montgomery, Franklin, Henry, Roanoke, Halifax, Pittsylvania, Charlotte, Lunenburg, Mecklenburg, Brunswick, and Greensville. Coverage includes the cities of Radford, Roanoke, Salem, Martinsville, Danville, South Boston, and Emporia. In West Virginia coverage includes Mason, Putnam, Lincoln, Logan, Wayne, and Mercer Counties.

DATE OF SURVEY

The lidar aerial acquisition was conducted between April 14, 2017 and May 24, 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 meters, vertical units are meters.
Geiod Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

333 independent vertical accuracy checkpoints (191 non-vegetated and 142 vegetated) were collected for vertical accuracy testing. Two of these checkpoints—one non-vegetated and one vegetated—were not used in any testing due to survey errors. Seven additional non-vegetated points were removed from swath accuracy testing due to proximity to vegetation. For the Virginia FEMA NRCS South Central Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **5.7 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 **11.3 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 **21.1 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, including lists of excluded points, 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 11495 tiles were delivered for the project, covering the areas shown in Figure 1. Each tile's extent is 1500 m by 1500 m.

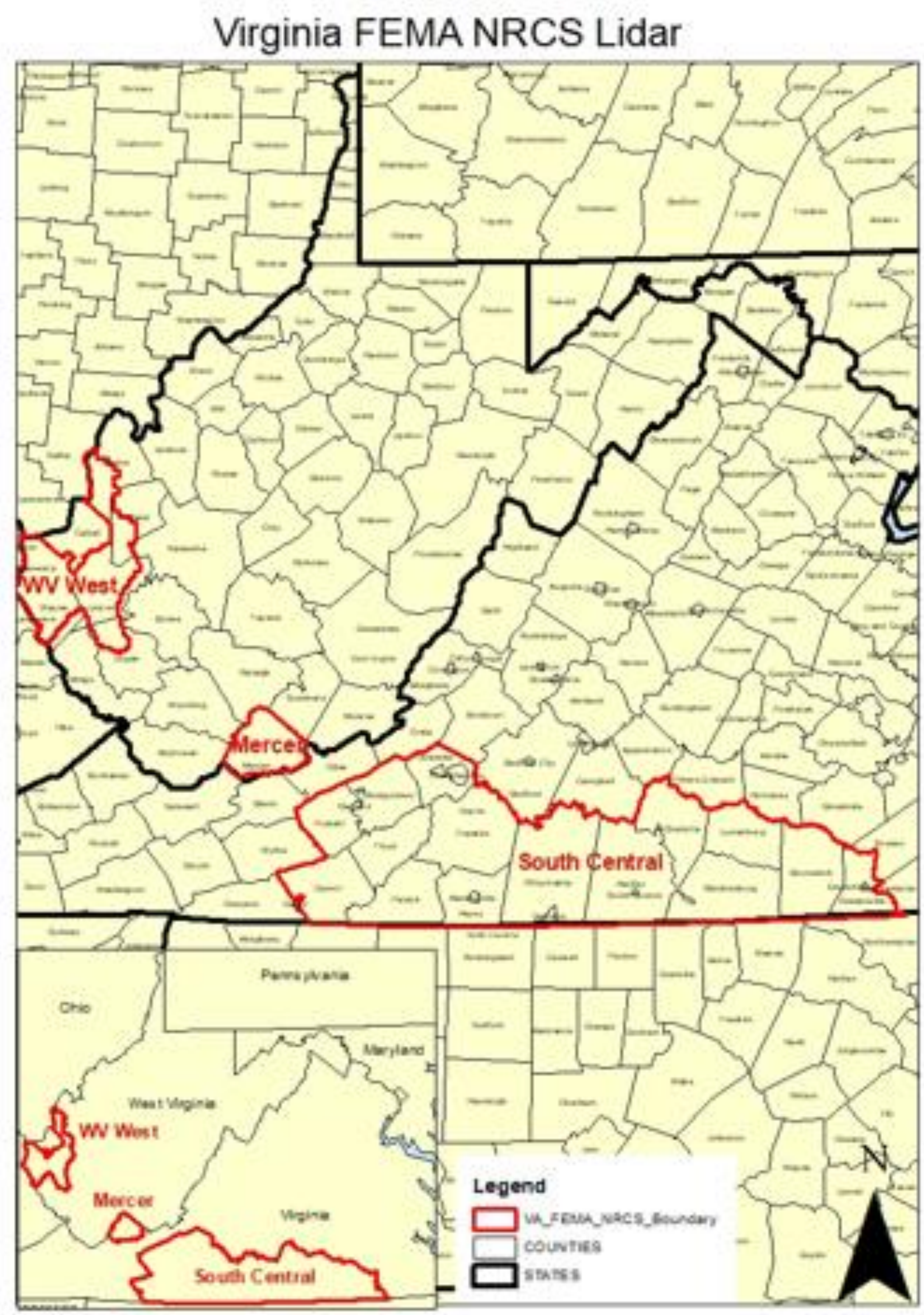

Figure 1 – Project Map

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 June 11, 2018 and LEG on September 16, 2018.

LIDAR ACQUISITION DETAILS

Axis planned 307 passes and LEG planned 631 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) for the project. Each of the 172s carried a Riegl VQ-780i scanner 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)
System	Riegl LMS-Q1560	Riegl VQ-1560i	Riegl VQ-780i
Altitude (AGL meters)	2087	2087	1600
Approx. Flight Speed (knots)	150	150	100
Scanner Pulse Rate (kHz)	687 (343.5 per channel)	687 (343.5 per channel)	300
Scan Frequency (hz)	153	153	74
Pulse Duration of the Scanner (nanoseconds)	3	3	3
Pulse Width of the Scanner (m)	0.90	0.90	0.90
Central Wavelength of the Sensor Laser (nanometers)	1064	1064	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes	Yes	Yes
Beam Divergence (milliradians)	0.25	0.25	0.25
Nominal Swath Width on the Ground (m)	2338	2338	1848
Swath Overlap (%)	15	15	55
Total Sensor Scan Angle (degree)	58.52	58.52	60
Computed Down Track spacing (m) per beam	0.73	0.73	0.70
Computed Cross Track Spacing (m) per beam	0.73	0.73	0.70
Nominal Pulse Spacing (single swath), (m)	0.70	0.70	1.0
Nominal Pulse Density (single swath) (ppsm), (m)	2.0	2.0	1.0
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
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
Maximum Number of Returns per Pulse	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.

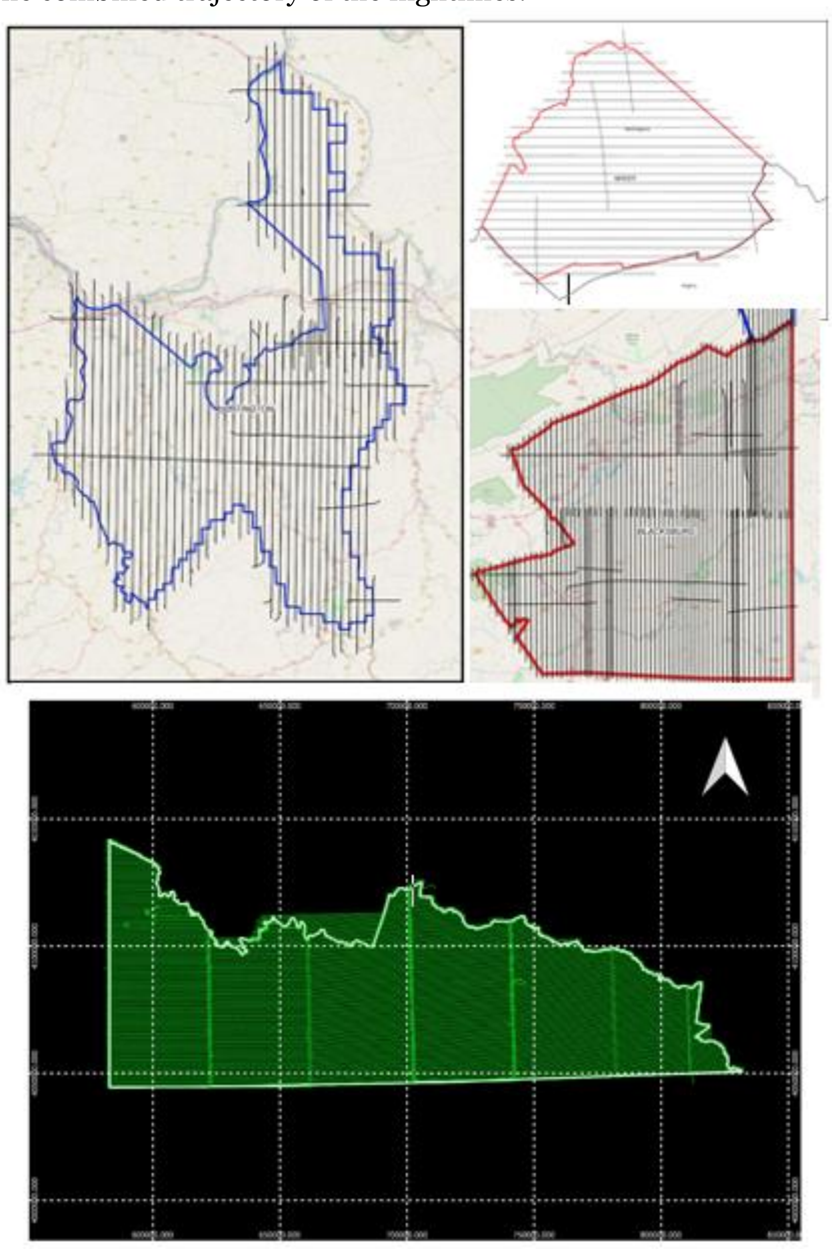

Figure 2 - Trajectories flown by Axis (top) and LEG (bottom)

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.

LEG CORS			
Name	NAD83(2011) UTM 17		Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)	
DOBS	4031171.940	525106.730	373.910
LOYH	4129769.660	648492.600	237.680
LOYI	4212418.270	718377.290	188.830
LOYO	4217683.300	820509.510	75.860
LOYP	4209942.970	673914.790	425.510
LOYU	4112970.370	550334.050	633.230
LOYV	4049294.110	644975.340	130.500
LOYX	4134228.180	881702.600	37.490
LS02	4130122.420	818278.900	27.270
LS04	4135662.540	592316.720	357.860
LS06	4055378.340	742124.150	104.040
NCGA	4040919.420	883600.890	15.640
NCJA	4035156.700	819469.250	47.660
NCMT	4037994.040	523375.040	375.510
NCNA	3984637.890	768739.140	68.970
NCPF	4006433.560	554635.400	301.130
NCRE	4024912.300	619708.230	266.710
NCRK	4045069.120	800399.600	61.910
NCRX	4029192.250	679510.890	225.650
NCWC	4025533.450	573117.440	309.540
NCWR	4031471.240	753770.640	109.500
UVFM	4194868.440	702835.290	546.410
VAAD	4178572.010	813252.850	67.460
VABR	4100321.550	684525.530	133.580
VABU	4160771.520	717257.800	142.750

LEG CORS			
Name	NAD83(2011) UTM 17		Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)	
VABV	4120169.020	747667.040	161.540
VADO	4079323.150	786245.270	109.650
VAPW	4172806.260	770203.890	100.740
VARY	4094983.210	598814.960	372.160
VAWK	4099749.220	856774.430	31.490
VAWY	4089339.370	492476.820	705.520
VAYL	4082001.950	833452.550	35.880
WVAT	4142412.730	493994.110	737.010
WVGB	4254201.870	603254.050	843.180
WVLE	4186254.180	550885.020	687.950
WVOH	4205629.800	488396.180	628.890

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

Axis CORS			
Name	NAD83(2011) UTM 17		Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)	
BLA1	551418.000	4118475.610	637.600
COLB	325264.540	4425295.110	218.930
GALP	389107.900	4300264.920	201.990
KYGB	336598.790	4260805.240	215.740
KYMH	286599.670	4229052.010	254.020
KYTI	259974.060	4256244.870	291.770
KYTK	254924.260	4115239.890	274.610
KYTL	364244.630	4149605.690	217.360
LS04	592316.120	4135663.390	356.540
NCWC	573116.840	4025534.280	308.200
NCWJ	457096.430	4027650.990	964.700
OHAD	277964.150	4296126.140	274.250

Axis CORS			
Name	NAD83(2011) UTM 17		Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)	
OHHI	275708.980	4342209.160	341.310
OHMO	491233.960	4402990.170	370.330
PKTN	324807.820	4323772.610	176.590
STKR	404572.310	4353546.310	211.010
TN18	394283.210	4025171.560	475.910
WVAT	493993.490	4142413.570	735.700
WVBR	562299.210	4351208.950	301.520
WVHA	496215.960	4344283.240	322.510
WVHU	375633.390	4253705.700	219.570
WVLE	550884.400	4186255.040	686.640
WVMZ	490559.190	4298905.990	328.810
WVNR	598998.180	4305822.160	612.480
WVOH	488395.550	4205630.650	627.600
WVRA	434884.980	4310537.500	182.090

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

AIRBORN GPS KINEMATIC

Axis and LEG used NGS CORS Base Stations to control the LiDAR acquisition for the Virginia FEMA NRCS South Central 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 B (Axis) and Appendix C (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.

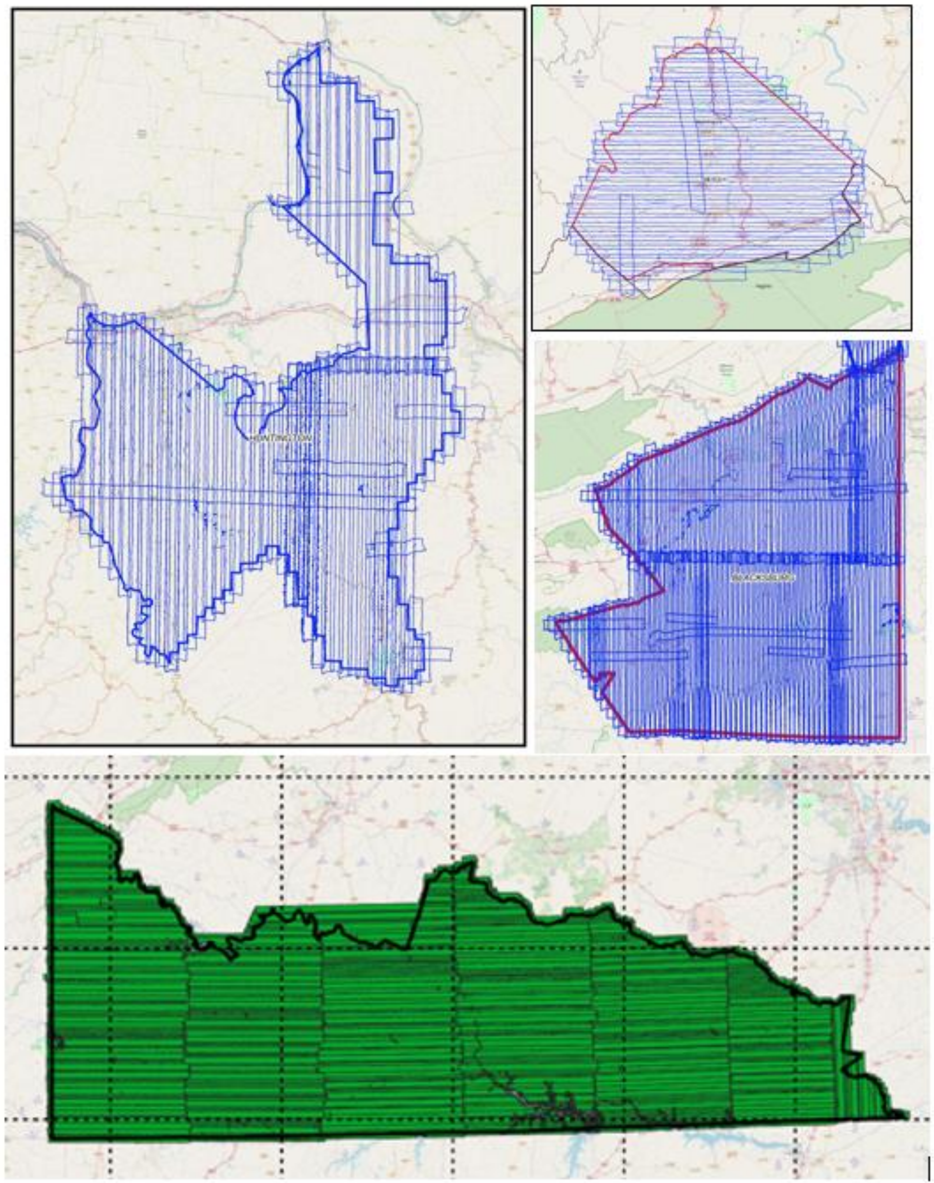

Figure 3 – Lidar swath output showing complete coverage of the project area by Axis (top) and LEG (bottom)

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.

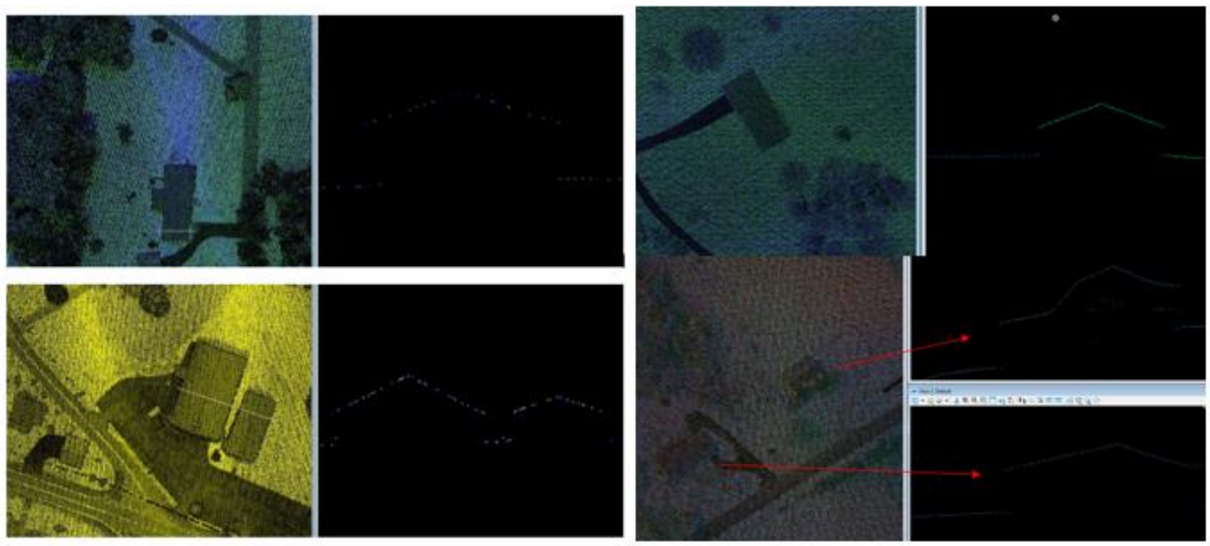

Figure 4 – Profile views showing correct roll and pitch adjustments from Axis (left) and LEG (right)

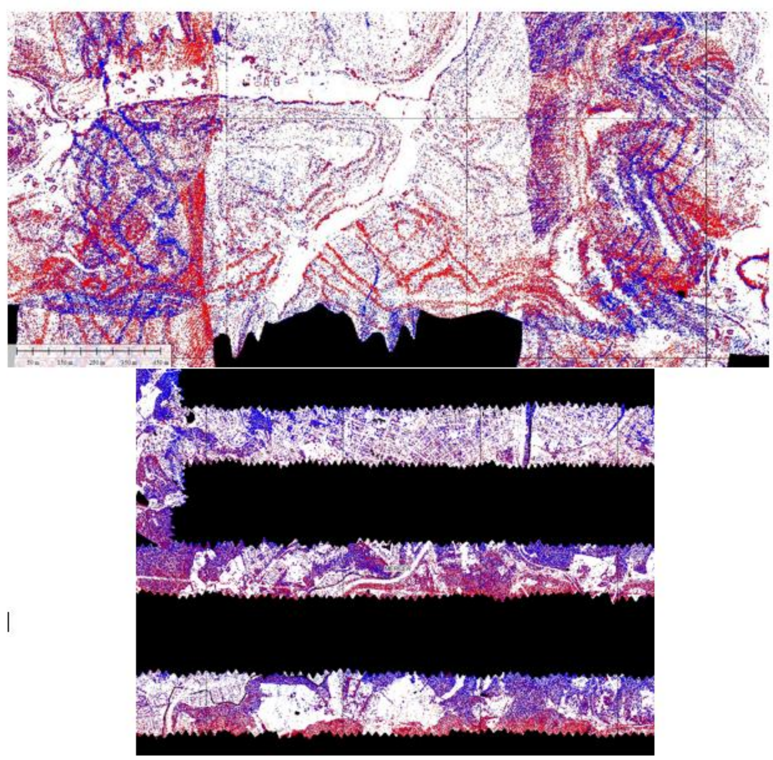

Figure 5 – QC block colored by distance to ensure accuracy at swath edges for Axis (top) and LEG (bottom) data

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 ($RMSE_z$ ≤ 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 0.1311 m (0.43 ft) vertical accuracy at 95% confidence level based on consolidated $RMSE_z$ (0.0669m x 1.9600) when compared to 1147 independently collected RTK checkpoints.

The following are the final statistics for the GPS static checkpoints used by Leading Edge Geomatics to internally verify vertical accuracy.

Average dz	0.055 m
Root mean square	0.067 m
Std deviation	0.046 m

Axis: The calibrated West Virginia West LiDAR dataset was tested to 0.129 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.066 m x 1.9600) when compared to 23 GPS static checkpoints.

The calibrated Mercer 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 checkpoints.

The calibrated South Central Block 1 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 28 GPS static checkpoints.

The final statistics for the GPS static checkpoints used by Axis to internally verify vertical accuracy per AOI are shown in tables 4-9.

Number	NAD83 (2011) UTM Zone 17N		NAVD88 (Geoid 12B)	Laser Z (M)	Delta Z
	Easting X (M)	Northing Y (M)	Known Z (M)		
GCP25	399443.740	4298576.317	171.825	171.800	-0.025
GCP26	394449.980	4295932.064	170.766	170.740	-0.026
GCP27	397279.955	4282002.861	179.692	179.670	-0.022
GCP28	360137.060	4232801.808	202.647	202.730	0.083
GCP29	411026.468	4275942.088	287.103	287.220	0.117
GCP30	406503.986	4269256.805	226.447	226.530	0.083
GCP31	392886.453	4271375.719	170.035	170.040	0.005
GCP32	418286.670	4261812.225	235.999	236.130	0.131
GCP33	413345.950	4255196.725	210.624	210.750	0.126
GCP34	423020.555	4234412.336	291.847	291.860	0.013
GCP35	418042.265	4228109.198	240.637	240.710	0.073
GCP36	403647.836	4237199.643	204.367	204.380	0.013
GCP37	394640.957	4231011.395	181.809	181.700	-0.109
GCP38	385645.893	4240681.451	186.68	186.700	0.020
GCP39	374019.709	4232298.582	184.715	184.720	0.005
GCP40	362154.105	4251405.942	166.95	166.970	0.020
GCP41	358589.881	4223940.783	178.307	178.280	-0.027
GCP42	372068.010	4220327.879	196.566	196.650	0.084
GCP43	396768.662	4217985.951	184.946	Slope	*
GCP44	402799.660	4209348.148	192.277	192.320	0.043
GCP45	413182.000	4191192.915	204.747	204.810	0.063
GCP46	372911.173	4196293.205	187.637	187.670	0.033
GCP47	384392.400	4216968.616	212.268	212.300	0.032

Table 4 – Axis static GPS points – West Virginia West

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	22	0.12936	0.131	+0.033	0.058	-0.109	0.131

Table 5 – Axis static GPS vertical accuracy results – West Virginia West

Number	NAD83 (2011) UTM Zone 17N		NAVD88 (Geoid 12B)	Laser Z (M)	Delta Z
	Easting X (M)	Northing Y (M)	Known Z (M)		
GCP48	384392.400	4159290.574	917.338	917.340	0.002
GCP49	485104.361	4147344.279	928.447	928.310	-0.137
GCP50	475434.181	4147486.753	658.227	658.290	0.063
GCP51	493992.284	4150158.575	770.953	770.970	0.017
GCP52	501741.199	4135651.444	465.945	465.960	0.015
GCP53	511685.862	4129174.940	674.245	674.290	0.045
GCP54	493107.081	4134891.136	729.403	729.480	0.077
GCP55	491093.781	4125508.560	779.465	779.530	0.065
GCP56	478118.157	4135294.684	772.837	772.780	-0.057
GCP57	470252.221	4141535.517	765.312	765.250	-0.062

Table 6 – Axis static GPS points – Mercer

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	10	0.065	0.127	0.003	0.069	-0.137	0.077

Table 7 – Axis static GPS vertical accuracy results – Mercer

Number	NAD83 (2011) UTM Zone 17N		NAVD88 (Geoid 12B)	Laser Z (M)	Delta Z
	Easting X (M)	Northing Y (M)	Known Z (M)		
GCLC10	581173.660	4185534.473	429.962	429.960	-0.002
GCLC11	567615.697	4181887.002	707.795	707.750	-0.045
GCLC12	572539.004	4177289.247	483.076	483.090	0.014
GCLC13	582629.410	4175721.219	404.229	404.240	0.011
GCLC14	575817.834	4167634.806	464.927	464.920	-0.007
GCLC15	566424.337	4164624.076	617.541	617.340	-0.201
GCLC16	564390.168	4154791.960	822.506	822.410	-0.096
GCLC17	578600.383	4151068.262	399.095	399.10	0.005
GCLC18	583616.025	4156924.216	403.536	403.360	-0.176
GCLC9	581241.683	4196424.794	680.635	680.580	-0.055
GCP1	511180.930	4100224.145	661.685	661.720	0.035

Number	NAD83 (2011) UTM Zone 17N		NAVD88 (Geoid 12B)	Laser Z (M)	Delta Z
	Easting X (M)	Northing Y (M)	Known Z (M)		
GCP10	535034.922	4087711.202	841.859	841.840	-0.019
GCP11	501040.616	4071954.598	710.225	710.200	-0.025
GCP12	522477.535	4067641.875	748.339	748.350	0.011
GCP13	518657.853	4046365.553	475.929	476.000	0.071
GCP14	548254.701	4045955.892	444.129	444.090	-0.039
GCP16	560556.405	4085510.351	758.860	758.790	-0.070
GCP17	581675.563	4084708.818	406.360	406.310	-0.050
GCP18	571625.258	4067956.590	461.149	461.090	-0.059
GCP19	582319.691	4050816.621	322.609	322.650	0.041
GCP2	534120.527	4117775.422	545.279	545.210	-0.069
GCP3	547078.523	4126423.277	670.994	671.020	0.026
GCP4	576672.903	4137163.453	585.161	585.070	-0.091
GCP5	582448.579	4136359.106	386.984	386.960	-0.024
GCP6	581470.113	4117092.101	414.749	414.710	-0.039
GCP7	568607.843	4121671.271	369.812	369.800	-0.012
GCP8	569470.825	4106632.781	467.764	467.740	-0.024
GCP9	551096.525	4108549.058	668.177	668.200	0.023

Table 8 – Axis static GPS points – South Central

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 9 – Axis static GPS vertical accuracy results – South Central

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 183 non-vegetated (open terrain and urban) independent survey checkpoints. 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 FEMA NRCS South Central 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 $RMSE_z$ = 6.0 cm, equating to +/- 11.7 cm 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	183	0.060	0.117	0.017	0.021	-0.382	0.057	-0.216	0.225	2.712

Table 10 - NVA at 95% confidence level for raw swaths

Eight checkpoints (NVA-10, 125, 127, 141, 143, 147, 153, and 157) were removed from the raw swath vertical accuracy testing due to proximity to vegetation. 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. Three of these points (NVA-10, 125, and 127) were located in open terrain, but were obscured by overhead branches or transient objects (vehicles). Points NVA- 141, 143, 153, and 157 were removed due to sensor noise 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, objects and high noise were removed from the final ground classification and these seven checkpoints were added back into the final vertical accuracy testing.

NVA-147 was positioned next to a steep mountain slope and close to mature trees. The erroneously high survey elevation is likely the result of multipathing errors, which result when vertical obstructions either partially block or "bounce" the GPS signal, producing incorrect position information. This point was removed from all testing.

Table 7, below, provides the coordinates for these checkpoints and the vertical accuracy results from the raw swath data. Table 12 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	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
NVA-125	770166.743	4053767.818	102.676	slope		
NVA-127	751004.129	4057370.164	100.172	slope		
NVA-10	511092.668	4060816.181	785.387	slope		
NVA-147	387030.474	4230875.020	210.094	slope		
NVA-141	395167.337	4236823.522	179.891	slope		
NVA-143	372970.188	4243948.016	170.837	slope		
NVA-153	396901.200	4225951.748	181.530	slope		
NVA-157	361147.604	4221977.832	195.088	slope		

Table 11 - 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-10	511092.668	4060816.181	785.387	785.450	0.063	0.063
NVA-125	770166.743	4053767.818	102.676	102.680	0.004	0.004
NVA-127	751004.129	4057370.164	100.172	100.160	-0.012	0.012
NVA-141	395167.337	4236823.522	179.891	179.900	0.009	0.009
NVA-143	372970.188	4243948.016	170.837	170.820	-0.017	0.017
NVA-153	396901.200	4225951.748	181.530	181.600	0.070	0.070
NVA-157	361147.604	4221977.832	195.088	195.110	0.022	0.022

Table 12 - Final tested vertical accuracy post ground classification

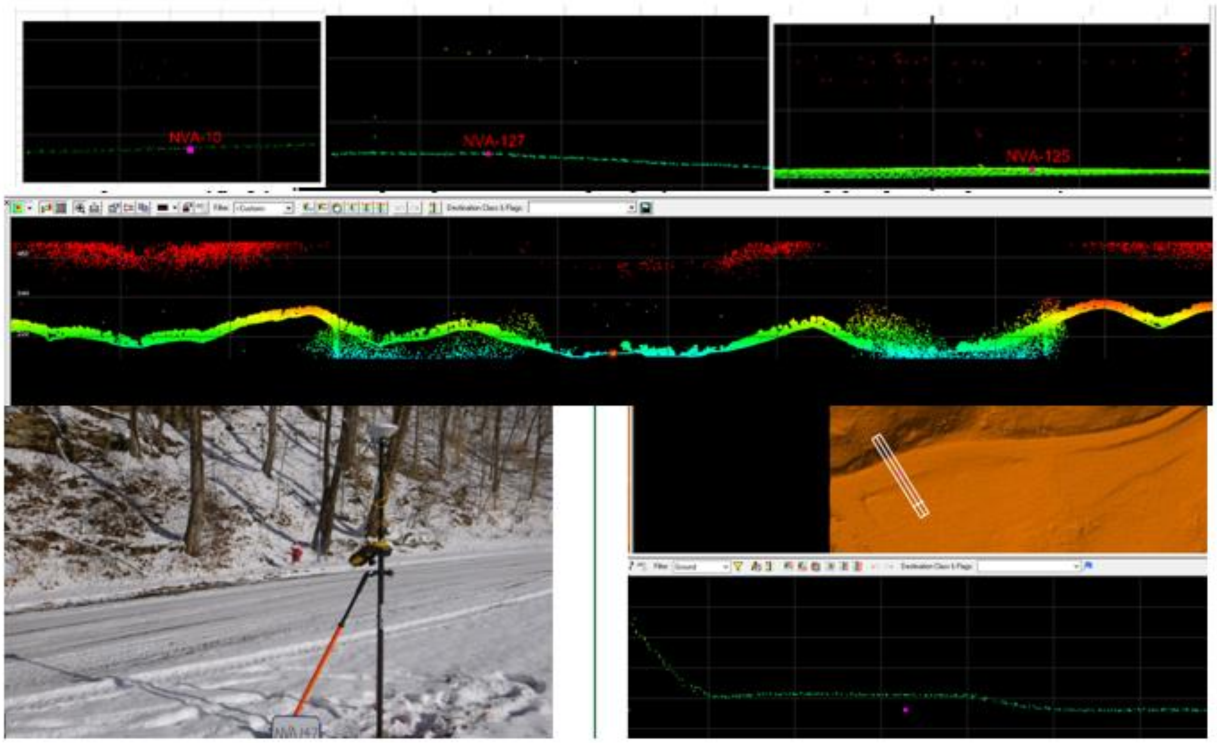

Figure 6 – Open terrain checkpoints (top row) NVA-10, 125, and 127, shown in pink, are located underneath powerlines or vegetation. These points were removed from raw swath vertical accuracy testing because above ground features had not been separated from the ground classification yet. The middle cross-section shows a representation of NVA points 141,143,153 and 157. The high noise from the sensor skews the results of the NVA point in open terrain. The Bottom images show NVA point -147, this point was removed from all testing due to multi-pathing issues caused by slope and trees.

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 FEMA NRCS South Central are shown in the figure below; this project meets inter-swath relative accuracy specifications.

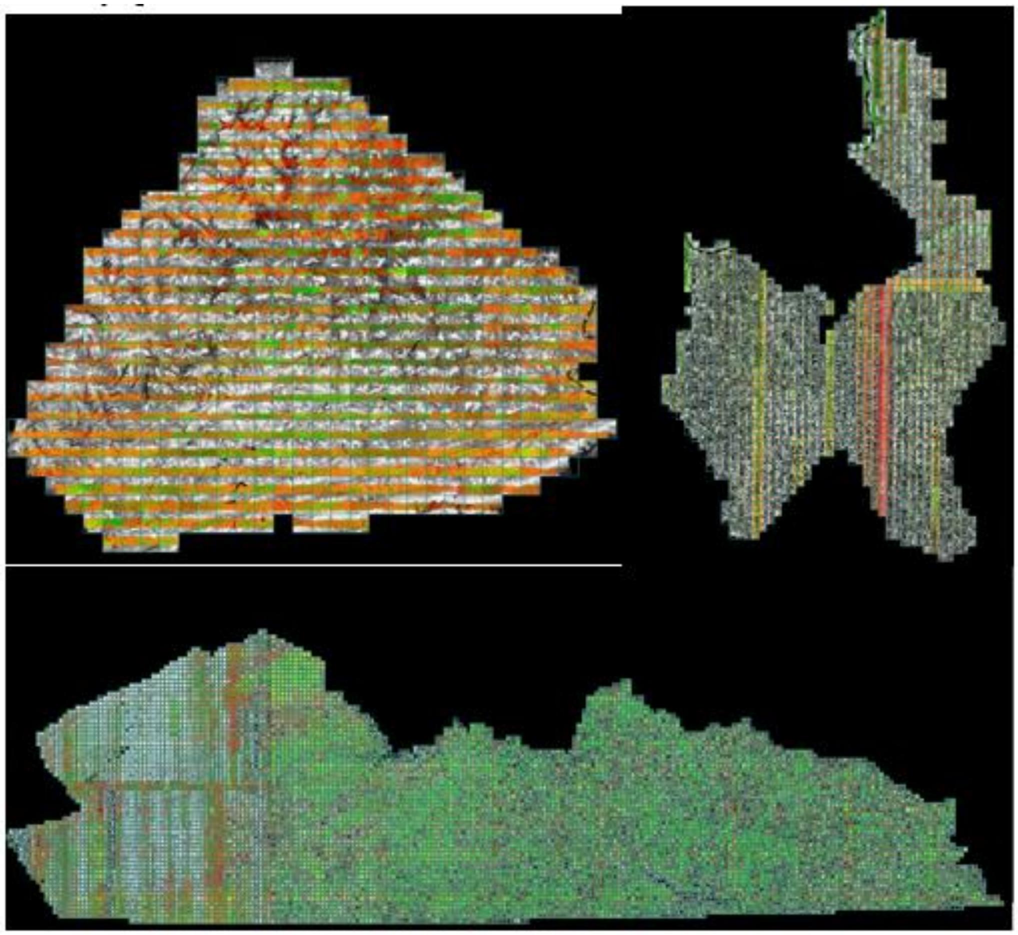

Figure 7 – Single return DZ Orthos for the Virginia FEMA NRCS South Central lidar project. Inter-swath relative accuracy passes specifications.

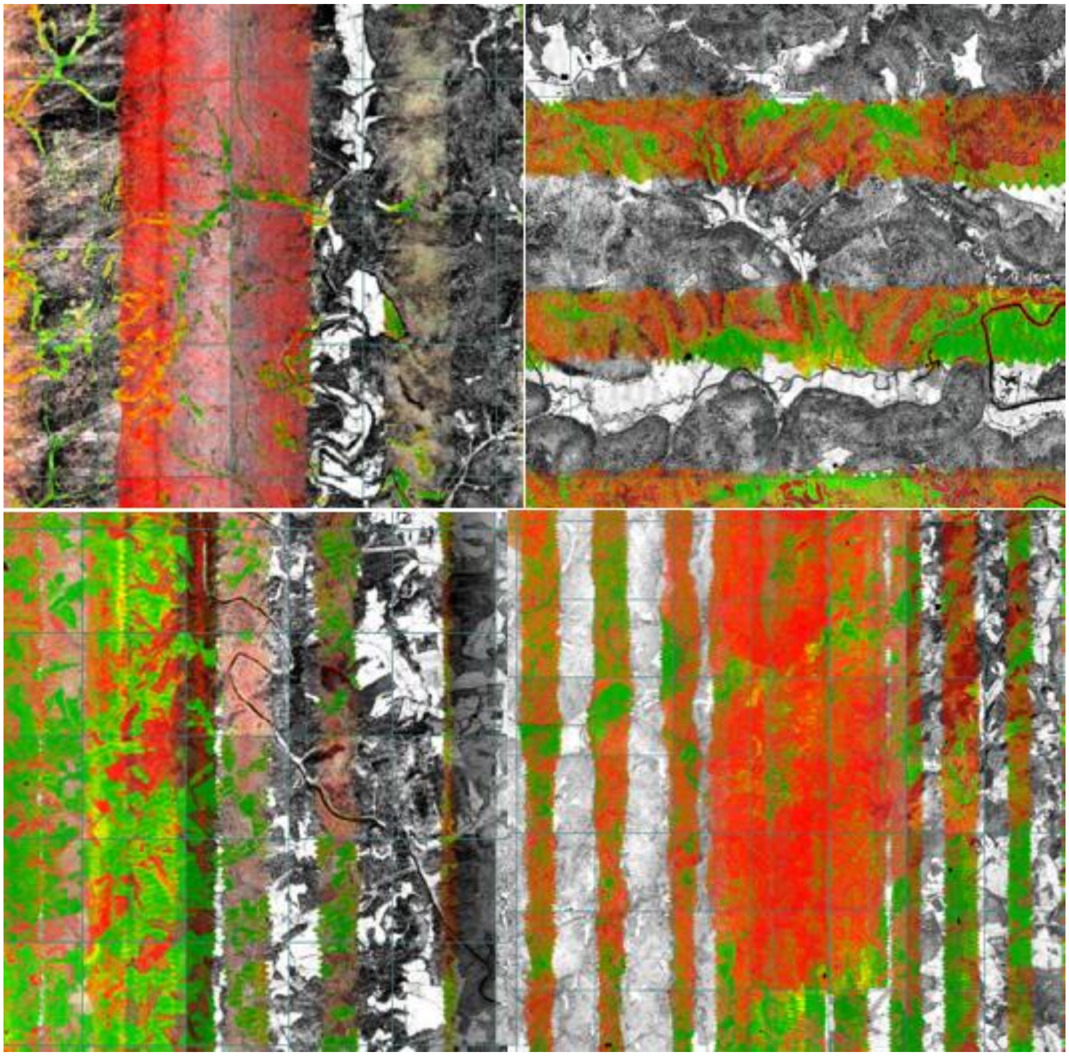

Figure 8 – These screenshots show close-ups of areas that may appear to exceed the threshold from a distance. These are mountainous forested regions but have threads of green where there are clearings spread throughout.

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 FEMA NRCS South Central; this project meets intra-swath relative accuracy specifications.

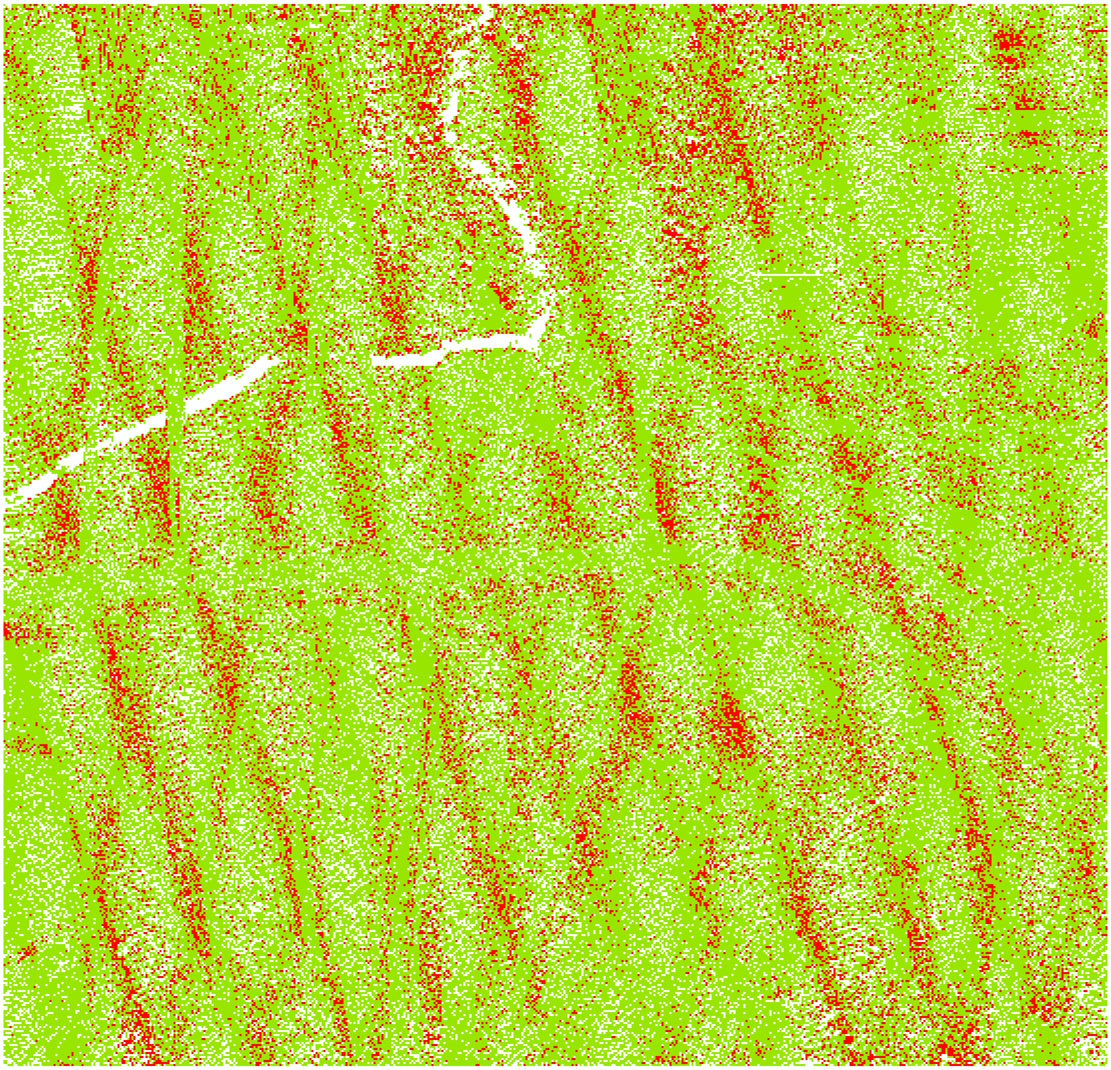

Figure 9 – Intra-swath relative accuracy. Areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The left image shows a large portion of the dataset; flat, open areas are colored green, whereas sloped terrain is colored red 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 FEMA NRCS South Central; no horizontal alignment issues were identified.

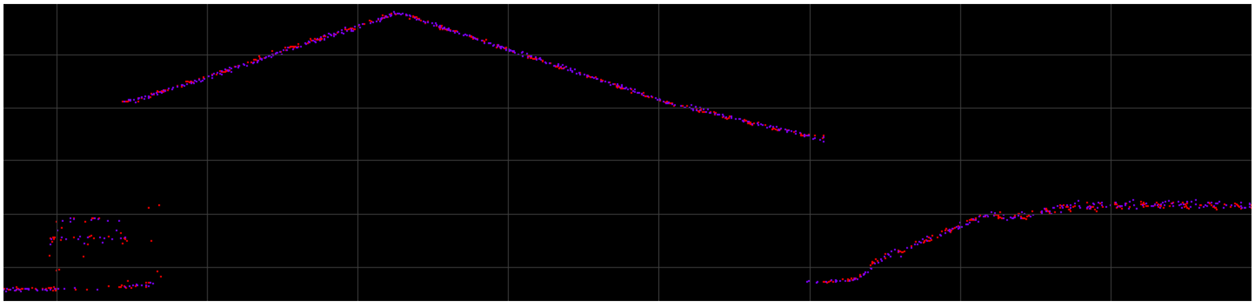

Figure 10 – Two separate flight lines differentiated by color (Blue/Yellow) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

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 0.5 meters and an ANPD of 3.65 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.

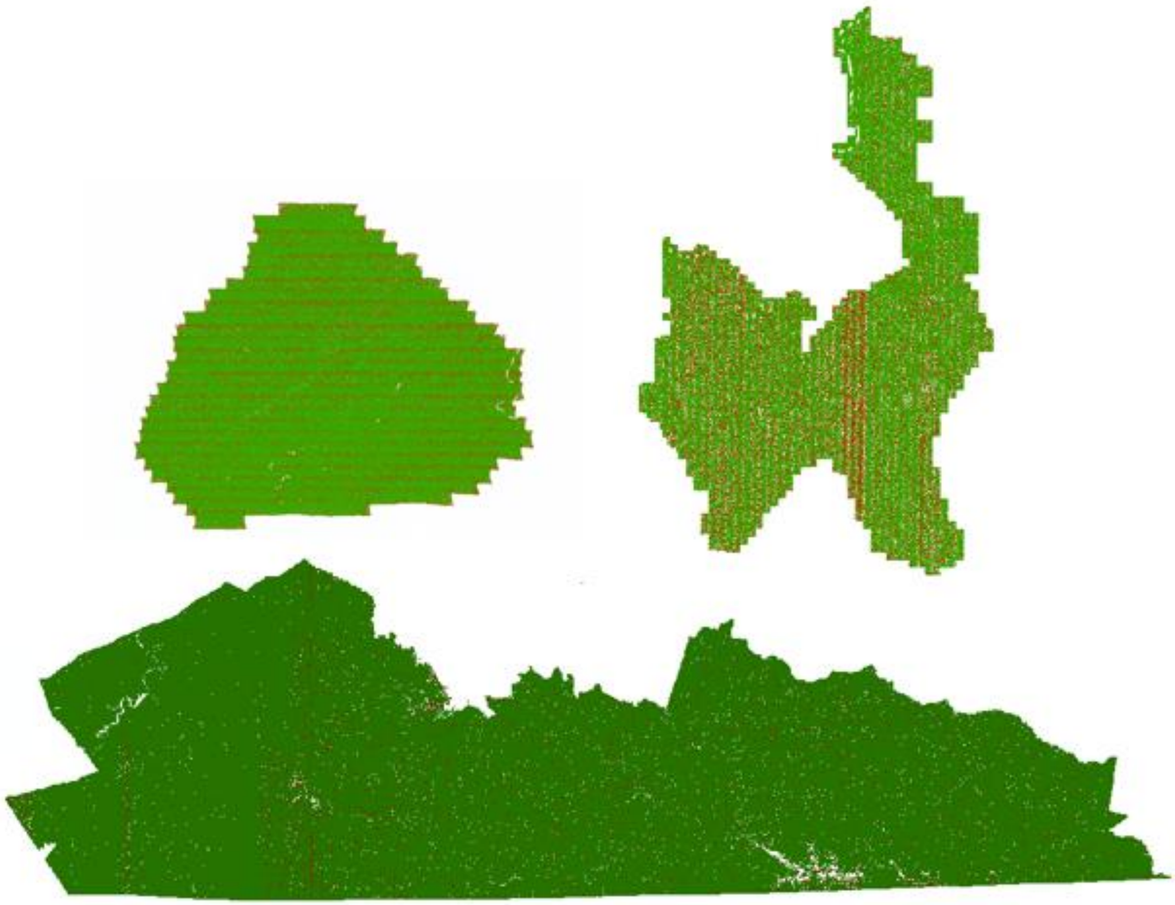

Figure 11 – 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-square meter cells contain at least 2 points per square meter (green areas) showing there are no systematic density 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.

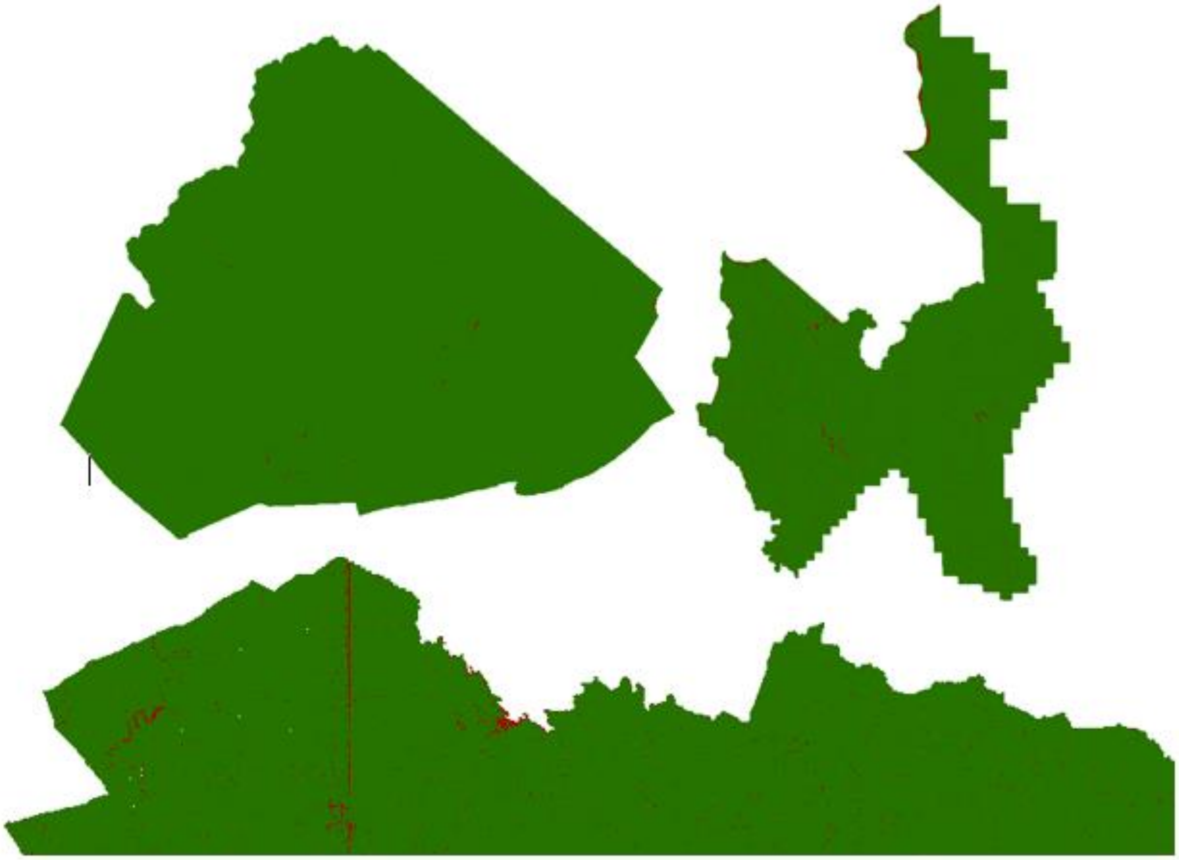

Figure 12 – All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies and other acceptable NoData areas, are colored red. Including acceptable NoData areas, 99.3% of cells contain at least one lidar point.

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 hydro flattening 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 FEMA NRCS South Central 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 FEMA NRCS South Central lidar project AOI. The issue is illustrated in Figure 13, below.

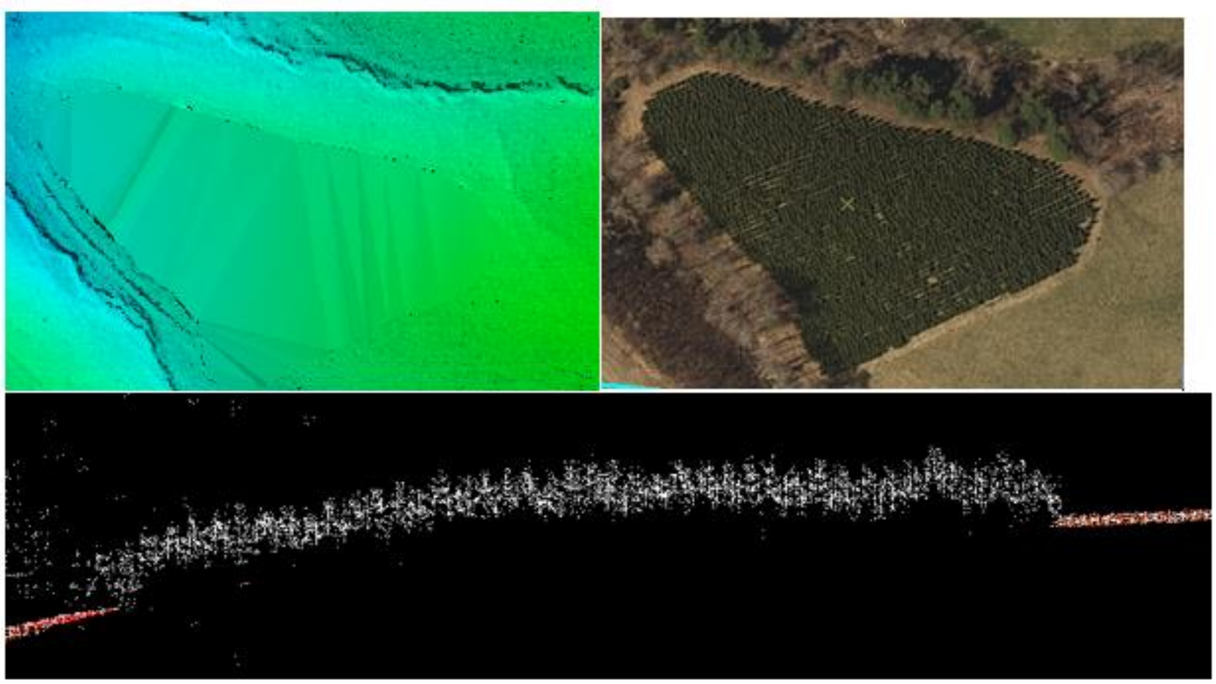

Figure 13 – 17SNA43008600. One atypical void exists in the dataset. This area contains a very dense tree farm. The lidar does not penetrate to the ground and no ground points can be added to create a better ground model.

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.

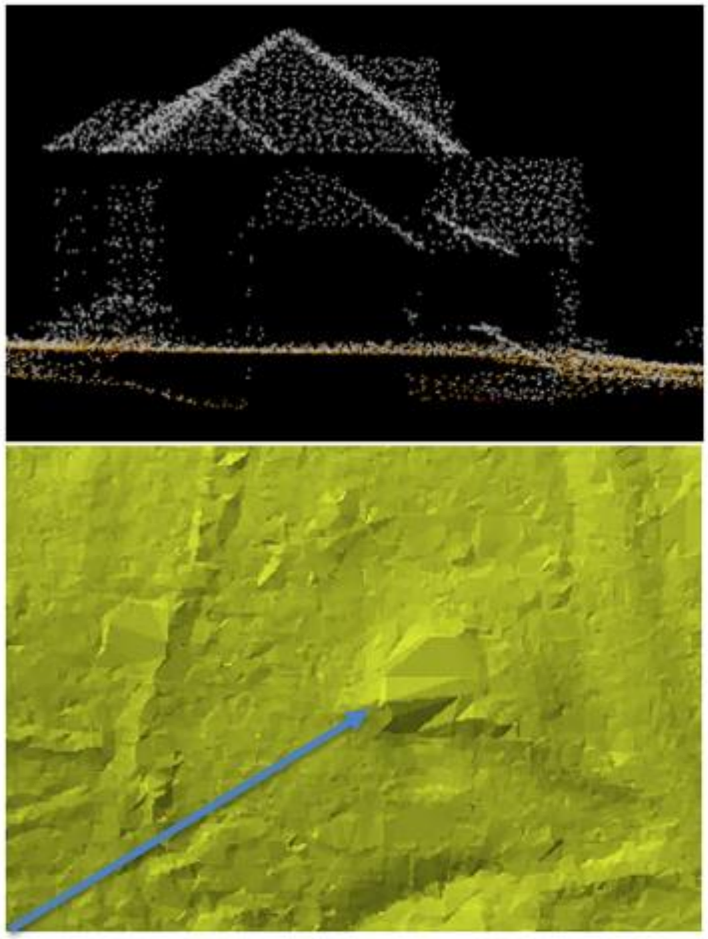

Figure 14 – 17SNB55002200. A profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but do not 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.

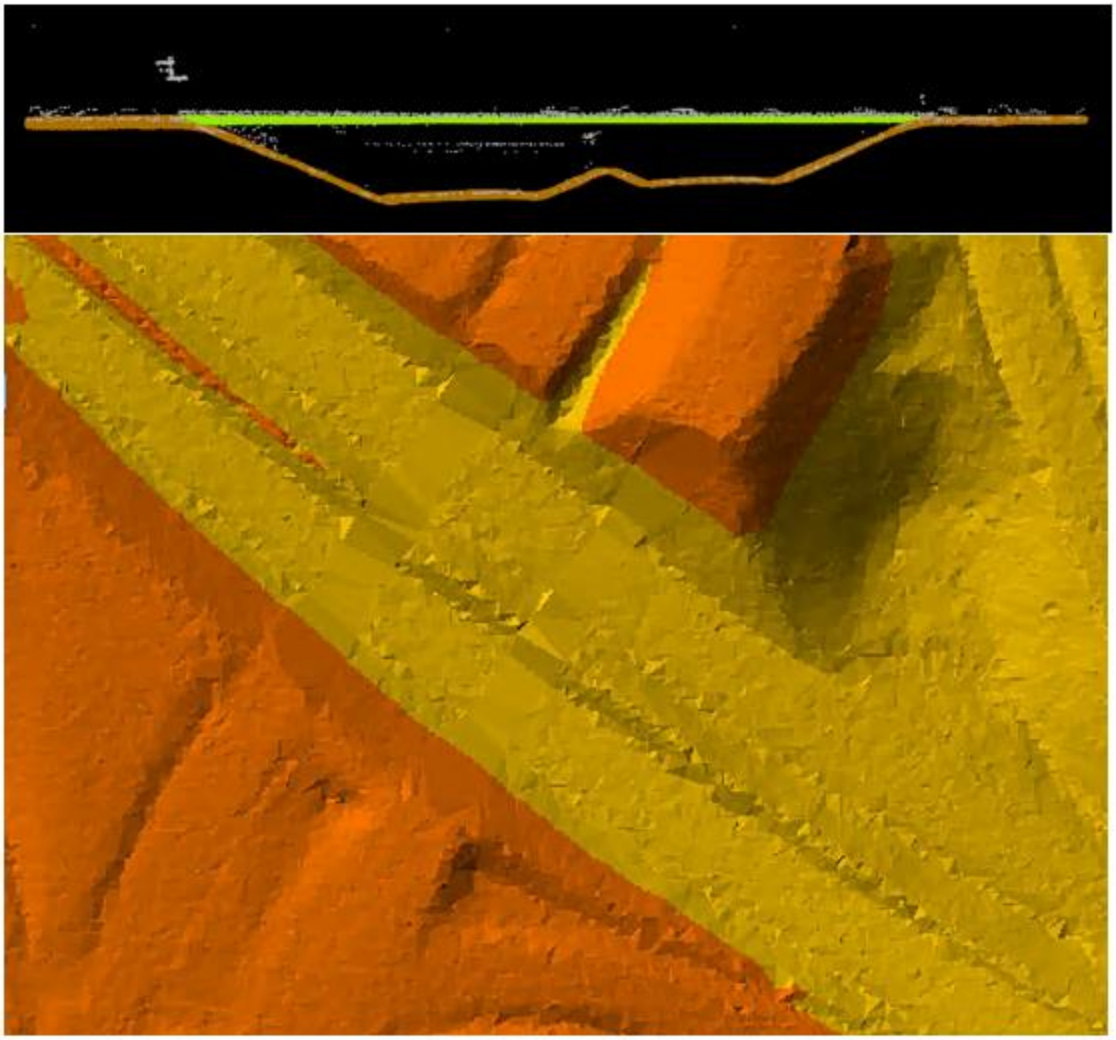

Figure 15 – 17SNB52001150. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile 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.

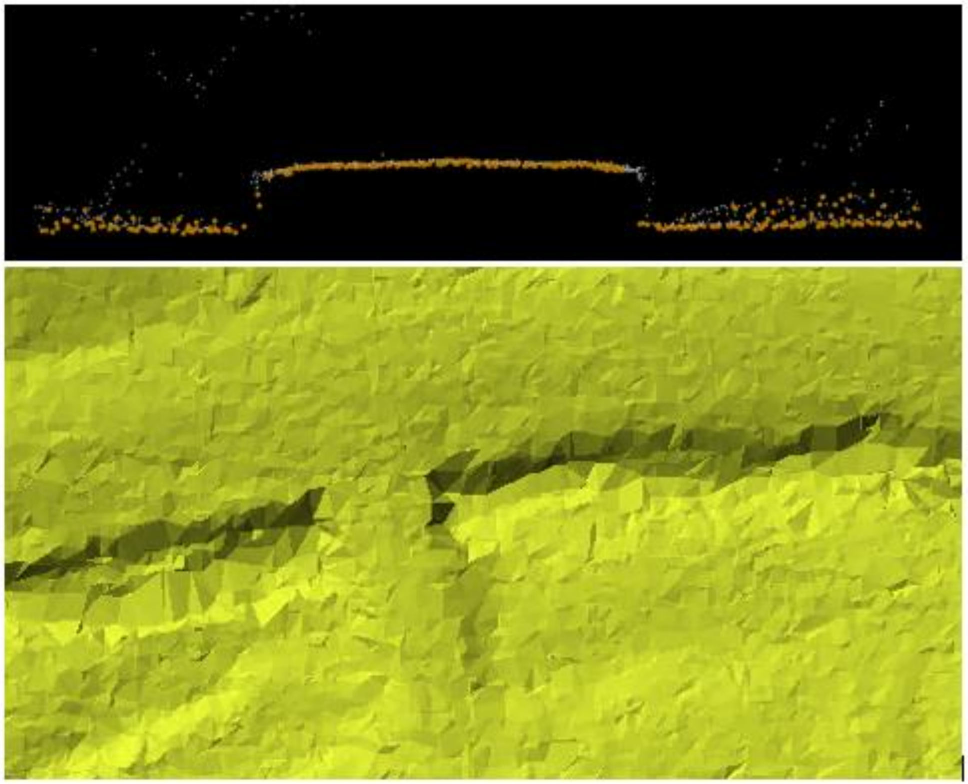

Figure 16– 17SNB43000850. A profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

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.

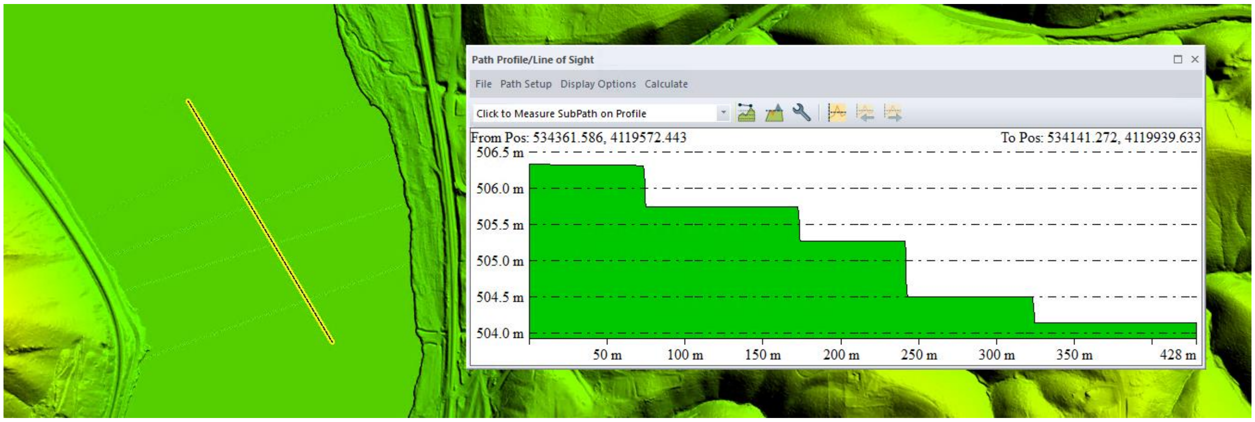

Figure 17 – LAS_17SNB34001900. The elevation change of approximately 0.35 m has been stair stepped. The steps are flat from bank to bank and are consistently monotonic.

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
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

Table 13 – Lidar header data that is updated and verified for correct formatting

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.

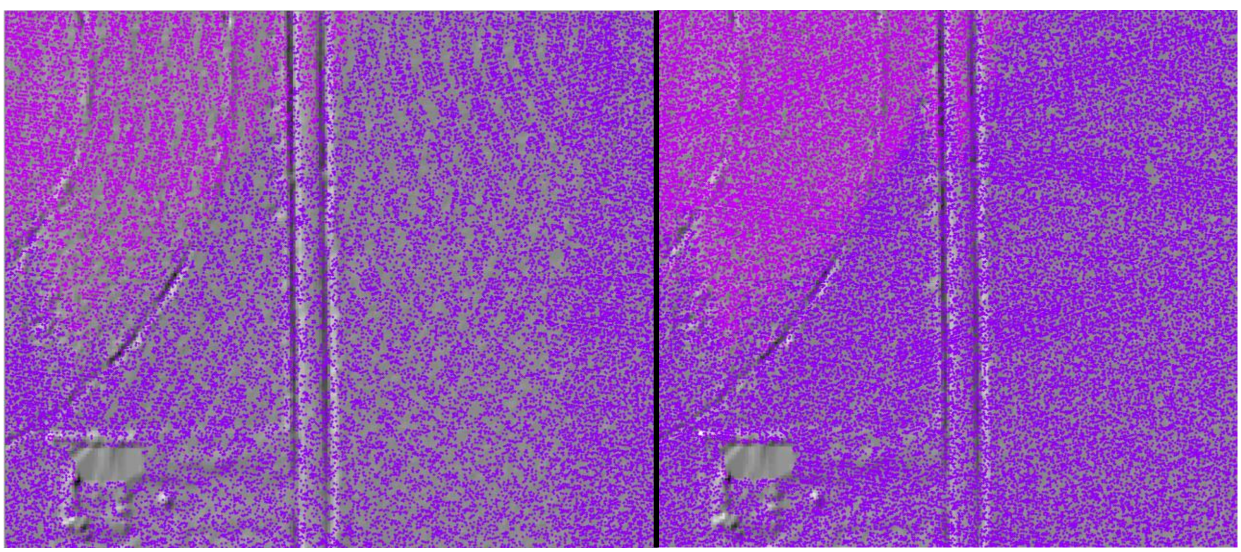

Figure 18 – The left image shows ground classified without synthetic points. The right image shows ground classified with synthetic points. Both images are overlaid on a hillshade of the example area

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, 333 checkpoints—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)	Elevation (m)
NVA-1	515801.927	4051635.773	883.930
NVA-10	511092.668	4060816.181	785.387
NVA-100	764176.277	4095504.232	127.813
NVA-101	747069.217	4096618.692	172.020
NVA-102	732821.796	4090983.066	159.969
NVA-103	730401.160	4083463.640	143.913
NVA-104	743677.382	4084662.295	141.555
NVA-105	760052.283	4087150.610	130.875
NVA-106	770916.764	4088101.983	126.278
NVA-107	789448.038	4092514.471	81.637
NVA-108	798906.292	4081149.116	75.689
NVA-109	784166.155	4083278.738	102.669
NVA-11	507343.469	4071162.295	722.797
NVA-110	768406.206	4078807.354	83.657
NVA-111	760371.547	4079003.913	127.883
NVA-112	745950.236	4074055.051	148.388
NVA-113	733141.655	4074266.672	132.143
NVA-114	733489.463	4061043.150	106.716
NVA-115	749611.920	4063493.331	104.099
NVA-116	767950.063	4065795.559	104.982
NVA-117	780066.791	4071467.379	68.961
NVA-118	795264.935	4073778.627	83.111
NVA-119	808436.147	4075785.322	52.558
NVA-12	516731.324	4074421.554	788.252
NVA-120	807969.853	4067406.056	40.612
NVA-121	820720.013	4055220.312	24.431
NVA-122	807696.153	4056798.189	36.092
NVA-123	796042.530	4063248.802	87.712
NVA-124	784297.214	4061034.068	98.709
NVA-125	770166.743	4053767.818	102.676
NVA-126	763083.569	4059441.666	115.064
NVA-127	751004.129	4057370.164	100.172
NVA-128	738979.216	4052635.959	95.009
NVA-129	396089.550	4291242.269	176.148
NVA-13	538176.102	4074320.006	776.427
NVA-130	397515.289	4286666.039	173.528
NVA-131	407323.746	4285379.256	205.073
NVA-132	398857.268	4278002.915	177.917
NVA-133	403361.275	4273716.089	173.332
NVA-134	399872.449	4267371.589	175.900

NVA-135	406809.793	4264936.668	276.768
NVA-136	418858.190	4257100.878	206.154
NVA-137	408732.098	4252913.153	215.242
NVA-138	419248.940	4250520.035	231.505
NVA-139	408745.136	4243755.447	192.161
NVA-14	560507.573	4077043.077	842.953
NVA-140	420288.765	4239959.874	207.470
NVA-141	395167.337	4236823.522	179.891
NVA-142	381514.201	4240878.284	186.769
NVA-143	372970.188	4243948.016	170.837
NVA-144	360972.066	4248076.647	172.756
NVA-145	365293.009	4240013.885	178.294
NVA-146	373178.476	4235367.660	178.386
NVA-147	387030.474	4230875.020	210.094
NVA-148	402613.049	4231003.752	204.230
NVA-149	412532.525	4236710.149	246.073
NVA-15	569826.576	4075036.242	419.401
NVA-150	419332.005	4231286.784	312.018
NVA-151	412468.126	4224237.875	237.941
NVA-152	404000.507	4226985.247	216.493
NVA-153	396901.200	4225951.748	181.530
NVA-154	379809.531	4226355.751	196.560
NVA-155	370227.402	4226540.786	188.015
NVA-156	360249.393	4229687.092	172.632
NVA-157	361147.604	4221977.832	195.088
NVA-158	364428.838	4216747.284	188.941
NVA-159	372260.062	4215608.898	203.519
NVA-16	584058.383	4081523.492	382.193
NVA-160	390016.930	4217199.802	265.174
NVA-161	399522.763	4213333.390	191.838
NVA-162	405115.440	4218662.309	331.249
NVA-163	409205.803	4210771.181	212.160
NVA-164	409694.414	4203539.201	195.629
NVA-165	413751.255	4198383.343	209.374
NVA-166	399191.539	4203236.034	199.531
NVA-167	383477.572	4208375.540	356.268
NVA-168	374334.782	4209335.841	211.041
NVA-169	368139.123	4206998.966	182.696
NVA-17	580016.841	4090085.892	473.686
NVA-170	372943.346	4197731.627	227.840
NVA-171	490476.006	4160212.371	989.362
NVA-172	482121.077	4155834.149	915.115
NVA-173	495027.278	4154320.087	655.299
NVA-174	504964.543	4146127.262	687.917
NVA-175	499240.931	4145322.939	782.990

NVA-176	491049.852	4149517.402	600.279
NVA-177	483508.263	4147781.753	811.576
NVA-178	474217.424	4138183.212	715.248
NVA-179	490408.871	4143201.630	630.940
NVA-18	564740.983	4088284.656	720.814
NVA-180	494322.234	4141455.386	769.772
NVA-181	503173.436	4143270.844	783.441
NVA-182	509550.169	4141521.264	743.780
NVA-183	507087.983	4133371.801	504.125
NVA-184	499990.976	4132780.110	619.460
NVA-185	489613.920	4135513.181	743.559
NVA-186	482011.753	4134884.631	790.100
NVA-187	474217.485	4138183.146	715.285
NVA-188	472858.914	4131582.375	685.976
NVA-189	477436.037	4128261.462	792.038
NVA-19	548738.254	4089103.409	808.300
NVA-190	487189.912	4128662.257	757.400
NVA-191	494780.587	4129654.773	613.305
NVA-2	530937.110	4047699.947	422.450
NVA-20	537046.932	4085474.786	856.521
NVA-21	522202.128	4090074.458	597.003
NVA-22	520042.990	4099369.758	602.734
NVA-23	542868.716	4100171.300	619.514
NVA-24	556756.759	4100887.490	694.417
NVA-25	570628.409	4099206.643	795.280
NVA-26	583996.974	4106545.785	421.161
NVA-27	565970.556	4113667.318	431.847
NVA-28	550011.963	4113436.233	639.623
NVA-29	532044.780	4113725.659	545.144
NVA-3	551992.993	4049518.218	443.755
NVA-30	517878.202	4112796.254	585.959
NVA-31	544684.403	4120279.085	569.113
NVA-32	562075.396	4121082.994	443.839
NVA-33	581529.049	4125879.104	359.513
NVA-34	579850.593	4138325.550	518.895
NVA-35	568492.506	4131332.610	585.580
NVA-36	555413.834	4130842.396	556.913
NVA-37	598807.867	4129052.844	354.524
NVA-38	595273.958	4121811.698	298.983
NVA-39	591501.892	4111239.377	378.906
NVA-4	569324.703	4051818.184	371.285
NVA-40	608050.151	4111744.776	348.655
NVA-41	618844.265	4101443.238	247.624
NVA-42	642513.458	4100379.447	189.583
NVA-43	645074.019	4090235.508	264.443

NVA-44	634304.749	4092442.964	204.286
NVA-45	621315.175	4089712.933	210.722
NVA-46	604771.852	4097446.102	343.816
NVA-47	593153.086	4097085.759	370.834
NVA-48	593219.204	4086633.775	394.425
NVA-49	609403.362	4080391.648	322.702
NVA-5	585501.925	4051902.690	277.520
NVA-50	629993.308	4081027.966	261.926
NVA-51	648405.576	4081272.829	223.237
NVA-52	646787.988	4070266.591	231.820
NVA-53	636425.584	4071648.032	231.299
NVA-54	621911.762	4071756.381	280.914
NVA-55	606979.262	4075446.354	343.724
NVA-56	592315.865	4071413.054	362.447
NVA-57	599798.508	4058644.088	232.992
NVA-58	616859.688	4059708.134	294.714
NVA-59	632762.104	4060228.308	249.065
NVA-6	579082.402	4062922.193	362.160
NVA-60	648512.651	4050400.350	176.917
NVA-61	633205.696	4049082.085	194.066
NVA-62	623835.891	4051609.691	234.771
NVA-63	612519.180	4050435.934	265.188
NVA-64	601743.543	4049672.257	266.208
NVA-65	593749.575	4048596.351	312.191
NVA-66	655675.642	4103908.656	247.633
NVA-67	665442.359	4098918.798	188.521
NVA-68	680310.648	4097181.146	142.344
NVA-69	691006.482	4103390.668	181.305
NVA-7	563065.031	4061418.440	480.525
NVA-70	695068.088	4116080.925	230.809
NVA-71	704139.945	4112861.145	200.175
NVA-72	718752.625	4108056.081	160.386
NVA-73	723707.187	4102178.914	192.368
NVA-74	709281.694	4103523.928	173.684
NVA-75	699187.883	4091975.243	150.400
NVA-76	676950.154	4089484.636	205.871
NVA-77	662177.505	4090284.488	186.355
NVA-78	659544.715	4080101.963	207.769
NVA-79	676190.262	4079364.580	116.108
NVA-8	549089.567	4061745.798	891.172
NVA-80	691280.634	4085525.497	171.909
NVA-81	704110.035	4083659.765	114.214
NVA-82	719644.862	4087004.209	162.413
NVA-83	726363.564	4075907.192	165.080
NVA-84	709090.942	4073621.840	138.934

NVA-85	697002.936	4074236.833	125.911
NVA-86	685376.999	4071515.812	136.051
NVA-87	673008.230	4071048.577	188.777
NVA-88	661494.591	4066306.157	235.200
NVA-89	659100.218	4060766.255	196.440
NVA-9	531967.964	4060210.384	781.387
NVA-90	675283.738	4054878.845	164.463
NVA-91	687948.447	4062214.441	102.968
NVA-92	703516.208	4059257.081	123.289
NVA-93	717718.449	4055595.341	97.675
NVA-94	705108.474	4049023.359	128.251
NVA-95	695588.881	4053233.728	142.855
NVA-96	680767.530	4051289.269	171.268
NVA-97	666359.497	4050379.010	154.430
NVA-98	735019.200	4102751.571	153.858
NVA-99	750306.774	4101914.235	160.025
VVA-1	818379.709	4054217.027	23.053
VVA-10	779325.325	4067131.089	56.309
VVA-100	410896.503	4260644.003	181.186
VVA-101	417585.873	4247042.945	338.332
VVA-102	412733.911	4241864.005	203.248
VVA-103	401660.667	4242154.572	218.430
VVA-104	395185.319	4237307.519	181.238
VVA-105	380017.168	4233226.793	192.882
VVA-106	375711.110	4241765.985	171.720
VVA-107	365629.309	4244837.176	189.245
VVA-108	367399.532	4235169.492	187.153
VVA-109	376738.002	4227929.616	202.735
VVA-11	791575.364	4066739.432	71.216
VVA-110	390099.800	4226630.225	208.922
VVA-111	399364.681	4226117.708	343.969
VVA-112	408499.642	4231394.180	225.166
VVA-113	416888.619	4236078.950	238.437
VVA-114	408056.524	4222456.881	221.044
VVA-115	396696.731	4224540.521	177.924
VVA-116	383946.171	4220051.195	346.141
VVA-117	375442.401	4220688.737	318.167
VVA-118	364279.468	4226998.142	191.461
VVA-119	368955.670	4214191.720	203.008
VVA-12	804011.260	4061565.243	51.384
VVA-120	381307.444	4212149.322	392.117
VVA-121	386029.969	4214326.230	206.415
VVA-122	394497.414	4218533.984	208.782
VVA-123	401236.545	4215608.729	186.598
VVA-124	408716.955	4215159.641	213.963

VVA-125	410857.551	4207046.736	191.047
VVA-127	380124.051	4207716.462	379.151
VVA-128	370787.287	4205514.287	182.511
VVA-129	371099.417	4200444.745	187.091
VVA-13	807851.726	4081382.381	62.989
VVA-130	401415.860	4201808.591	216.689
VVA-131	407662.368	4194005.611	378.244
VVA-132	413314.699	4192944.067	200.747
VVA-133	489937.581	4157360.771	893.123
VVA-134	479340.784	4148649.156	922.948
VVA-135	497606.018	4150283.397	716.051
VVA-136	504870.677	4144468.465	707.725
VVA-137	488888.693	4147333.017	635.578
VVA-138	477301.998	4142012.943	726.807
VVA-139	473370.250	4133792.184	803.070
VVA-14	793821.393	4080975.628	86.748
VVA-140	485952.970	4136478.583	844.952
VVA-141	502171.612	4135114.442	617.642
VVA-142	504339.504	4130861.053	572.111
VVA-143	485432.086	4128006.646	766.718
VVA-15	778432.524	4080799.760	79.164
VVA-16	765923.667	4083856.054	126.480
VVA-17	752563.105	4085617.794	129.091
VVA-18	741947.901	4089181.776	137.878
VVA-19	733791.010	4097767.215	148.830
VVA-2	787902.337	4052934.399	100.291
VVA-20	744967.094	4106698.819	176.236
VVA-21	755975.999	4097964.659	122.143
VVA-22	769923.092	4095092.391	126.229
VVA-23	778795.614	4094334.027	111.559
VVA-24	793439.402	4085106.251	81.523
VVA-25	716058.038	4051751.709	127.816
VVA-26	704275.941	4054551.916	112.162
VVA-27	693575.150	4056292.740	123.620
VVA-28	679995.767	4053711.655	169.095
VVA-29	674097.463	4050365.568	169.417
VVA-3	777178.788	4055314.528	105.101
VVA-30	660623.419	4052885.832	164.898
VVA-31	661208.438	4072469.661	176.074
VVA-32	675475.820	4065084.215	154.650
VVA-33	688837.160	4070816.908	123.629
VVA-34	701271.226	4068943.179	160.006
VVA-35	717398.838	4067992.518	107.339
VVA-36	717923.501	4077651.005	140.587
VVA-37	717201.837	4088888.221	167.827

VVA-38	699828.519	4084623.270	119.746
VVA-39	684933.458	4082843.393	167.543
VVA-4	760047.812	4050567.811	95.694
VVA-40	672190.958	4085381.008	173.872
VVA-41	658911.043	4086033.650	166.986
VVA-42	660966.420	4097416.161	207.923
VVA-43	673997.135	4094191.446	180.956
VVA-44	688756.399	4093918.626	153.502
VVA-45	704464.619	4099549.726	165.187
VVA-46	717356.557	4105003.627	128.113
VVA-47	706407.604	4109595.427	169.137
VVA-48	694792.151	4109339.464	177.921
VVA-49	648627.744	4055334.922	208.482
VVA-5	746006.568	4053578.472	86.213
VVA-50	637413.992	4054887.119	185.384
VVA-51	622455.555	4048071.596	202.479
VVA-52	617138.406	4051224.846	235.448
VVA-53	606991.853	4048622.048	260.557
VVA-54	594942.651	4050994.107	265.621
VVA-55	589842.190	4057620.854	311.514
VVA-56	600285.546	4071389.216	326.999
VVA-57	608348.542	4066271.644	253.675
VVA-58	616532.868	4068434.570	319.370
VVA-59	626197.569	4065833.266	261.863
VVA-6	729675.626	4050413.852	111.149
VVA-60	647669.229	4067708.055	227.045
VVA-61	648883.827	4087408.265	231.750
VVA-62	635966.624	4084811.805	270.769
VVA-63	620792.135	4083663.117	252.466
VVA-64	605215.189	4086577.418	346.506
VVA-65	591420.260	4080313.915	389.078
VVA-66	591248.873	4102551.963	362.658
VVA-67	611563.978	4097169.979	332.971
VVA-68	625561.278	4094331.591	313.499
VVA-69	640540.755	4094789.367	287.834
VVA-7	735439.774	4068471.088	130.814
VVA-70	645949.726	4106318.438	253.881
VVA-71	603903.844	4108861.654	337.068
VVA-72	598918.731	4117320.914	430.162
VVA-73	575383.869	4132207.205	503.852
VVA-74	559989.989	4128744.506	608.853
VVA-75	574795.127	4116571.158	1141.919
VVA-76	582708.547	4098478.933	415.964
VVA-77	566319.188	4109599.680	461.334
VVA-78	539017.631	4122700.627	639.304

VVA-79	525046.817	4114657.134	690.488
VVA-8	747402.962	4068168.544	128.137
VVA-80	510154.001	4106161.105	669.967
VVA-81	528819.512	4099229.398	615.707
VVA-82	530058.070	4091193.107	653.121
VVA-83	549132.898	4093424.421	740.472
VVA-84	563427.839	4094914.675	731.615
VVA-85	572289.905	4080409.058	434.537
VVA-86	549568.274	4076406.189	834.722
VVA-87	531303.938	4077379.737	688.799
VVA-88	511634.399	4067854.113	791.587
VVA-89	516128.502	4053567.144	893.938
VVA-9	763081.931	4061419.585	121.528
VVA-90	530322.953	4052647.902	467.403
VVA-91	534756.487	4065852.173	769.623
VVA-92	544693.337	4052194.729	422.856
VVA-93	560894.496	4066573.886	486.088
VVA-94	573014.603	4061028.188	416.157
VVA-95	557935.708	4052830.873	591.689
VVA-96	571730.631	4047927.270	301.887
VVA-97	402075.124	4292142.941	267.675
VVA-98	403645.888	4282630.397	181.399
VVA-99-1	402201.119	4272569.784	187.912

Table 14 – Virginia FEMA NRCS South Central lidar surveyed accuracy checkpoints

Two checkpoints (NVA-147, VVA-28) were removed from the vertical accuracy testing for the classified lidar. The lidar around NVA-147 is consistent; the issue is a result of the survey. The road that NVA-147 is on is next to a mountain slope and under trees. So in this case, it is likely the GPS receivers produced multipathing errors in the survey data. Multipathing errors result when vertical obstructions either block or "bounce" the signal around and result in incorrect survey elevations. VVA-28 was collected in close proximity to trees.

Even with the removal of these two points, there are enough total checkpoints and enough checkpoints per land cover category to satisfy project requirements. The image below shows the two checkpoints removed from final vertical accuracy testing.

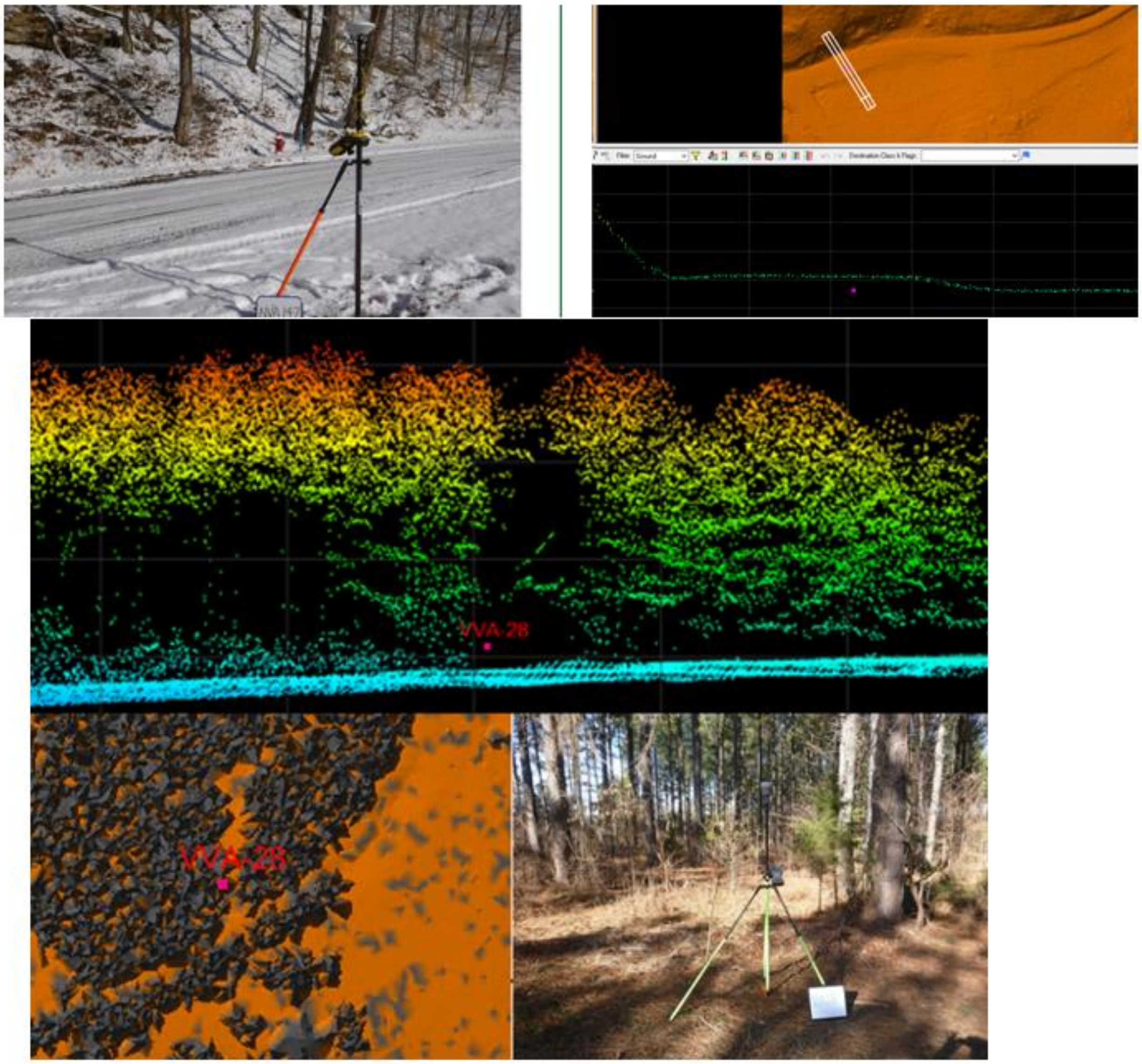

Figure 19 – The top images show NVA point -147, which was removed due to multipathing issues caused by slope and trees. The bottom images displays VVA-28. The close proximity to the trees and the overhanging branches make this point unsuitable for vertical accuracy testing (bottom).

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

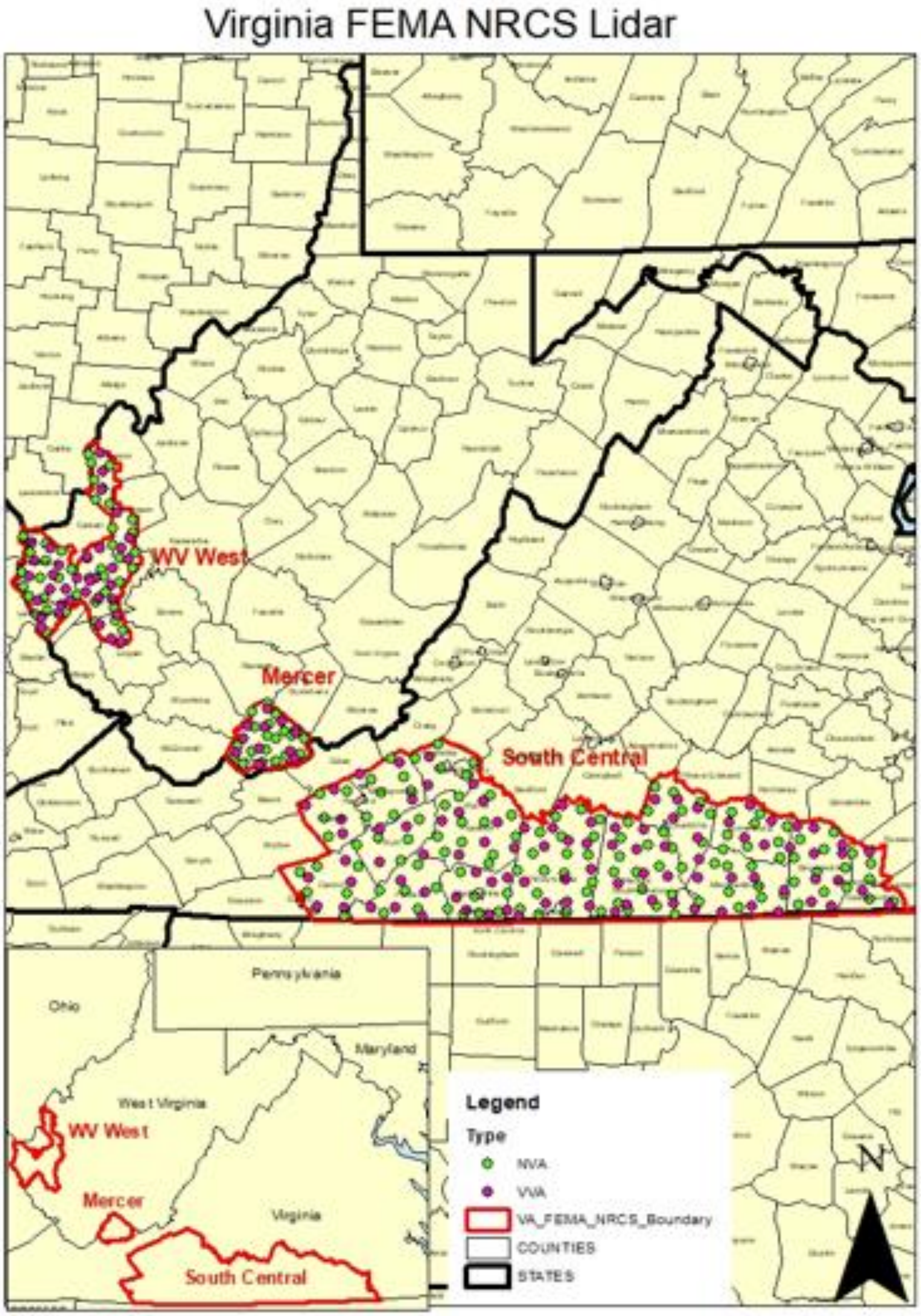

Figure 20 – Location of QA/QC Checkpoints

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 FEMA NRCS South Central 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 FEMA NRCS South Central 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 15.

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 15 — 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	190	0.113	
VVA	141		0.211

Table 16 — 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 $RMSE_z$ = 5.7cm, equating to ± 11.3 cm at 95% confidence level. Actual VVA accuracy was found to be ± 21.1 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 +45 cm.

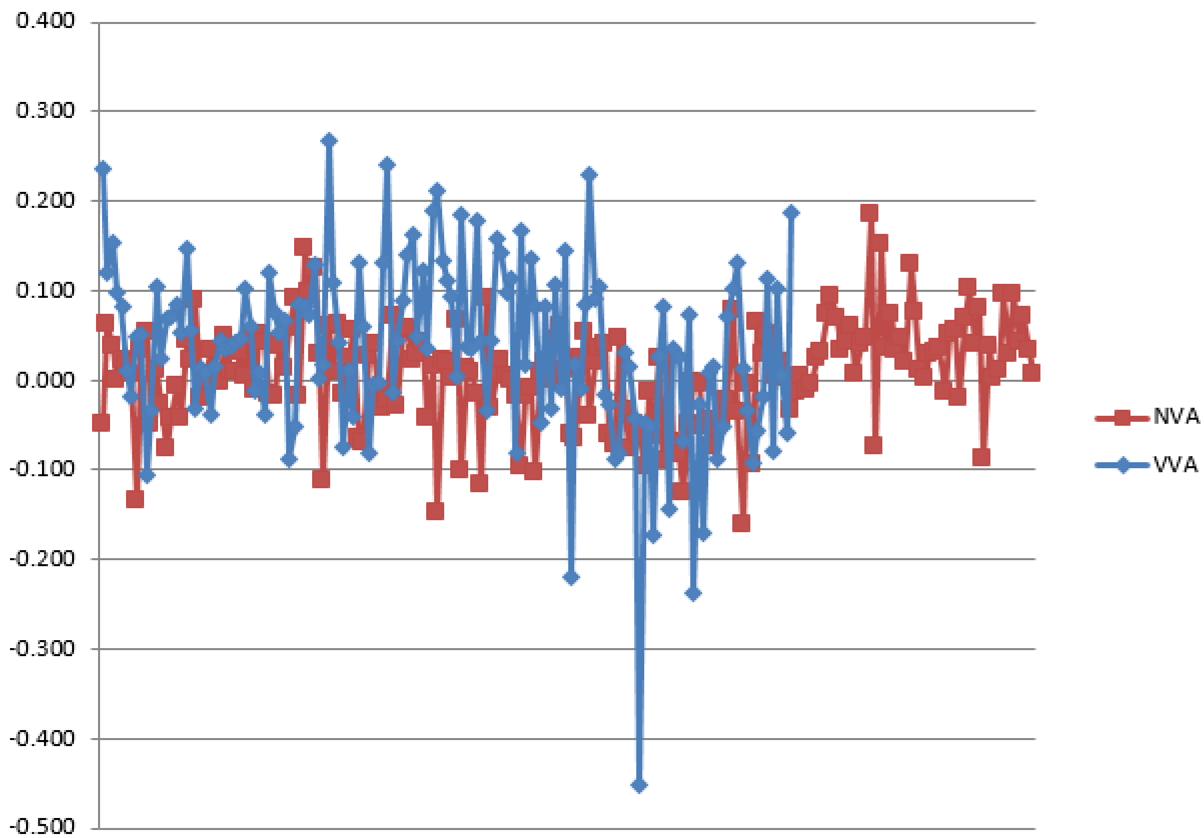

Figure 21 – Magnitude of elevation discrepancies per land cover category

Table 17 lists the 5% outliers that are larger than the VVA 95th percentile.

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)		
VVA-58	616532.868	4068434.570	319.370	319.150	-0.220	0.220
VVA-61	648883.827	4087408.265	231.750	231.980	0.230	0.230
VVA-80	510154.001	4106161.105	669.967	669.730	-0.237	0.237
VVA-1	818379.709	4054217.027	23.053	23.290	0.237	0.237
VVA-23	778795.614	4094334.027	111.559	111.800	0.241	0.241
VVA-141	502171.612	4135114.442	617.642	617.910	0.268	0.268
VVA-70	645949.726	4106318.438	253.881	253.430	-0.451	0.451

Table 17— Lidar VVA 5% outliers

Table 18 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	190	0.057	0.007	0.011	-0.247	0.057	0.548	-0.162	0.185
VVA	141	N/A	0.036	0.042	-0.932	0.099	3.702	-0.451	0.268

Table 18 — Lidar NVA and VVA descriptive statistics

The figure below shows 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.

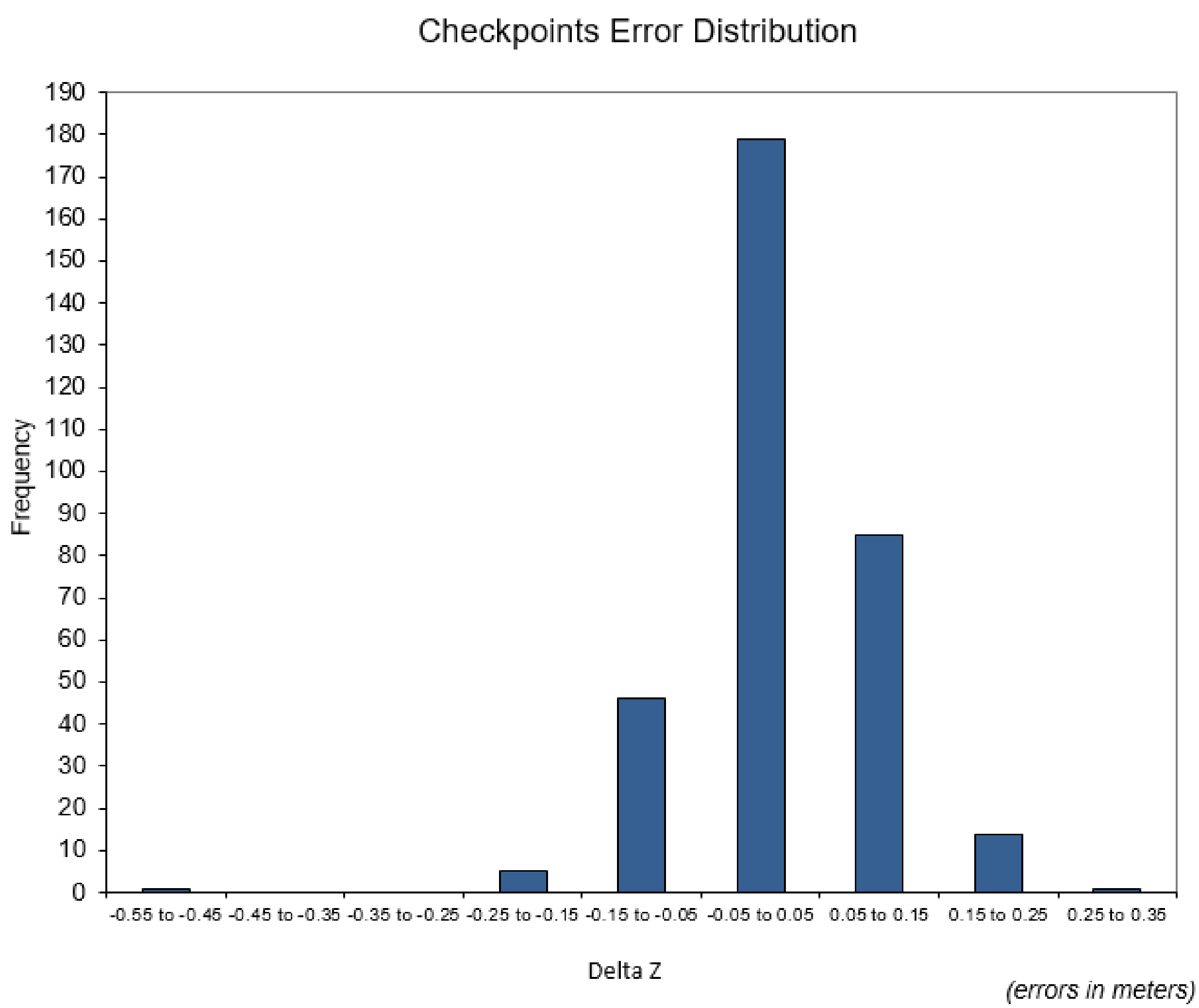

Figure 22 — Histogram of elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the USGS Virginia FEMA NRCS South Central 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 checkpoints 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 checkpoints.

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
51	0.264	0.285	0.388	0.672

Table 19 – 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. 51 checkpoints were used for horizontal accuracy testing. Actual positional accuracy of this dataset was found to be $RMSE_x$ = 26.4 cm and $RMSE_y$ = 28.5 cm, which equates to ± 67.2 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.

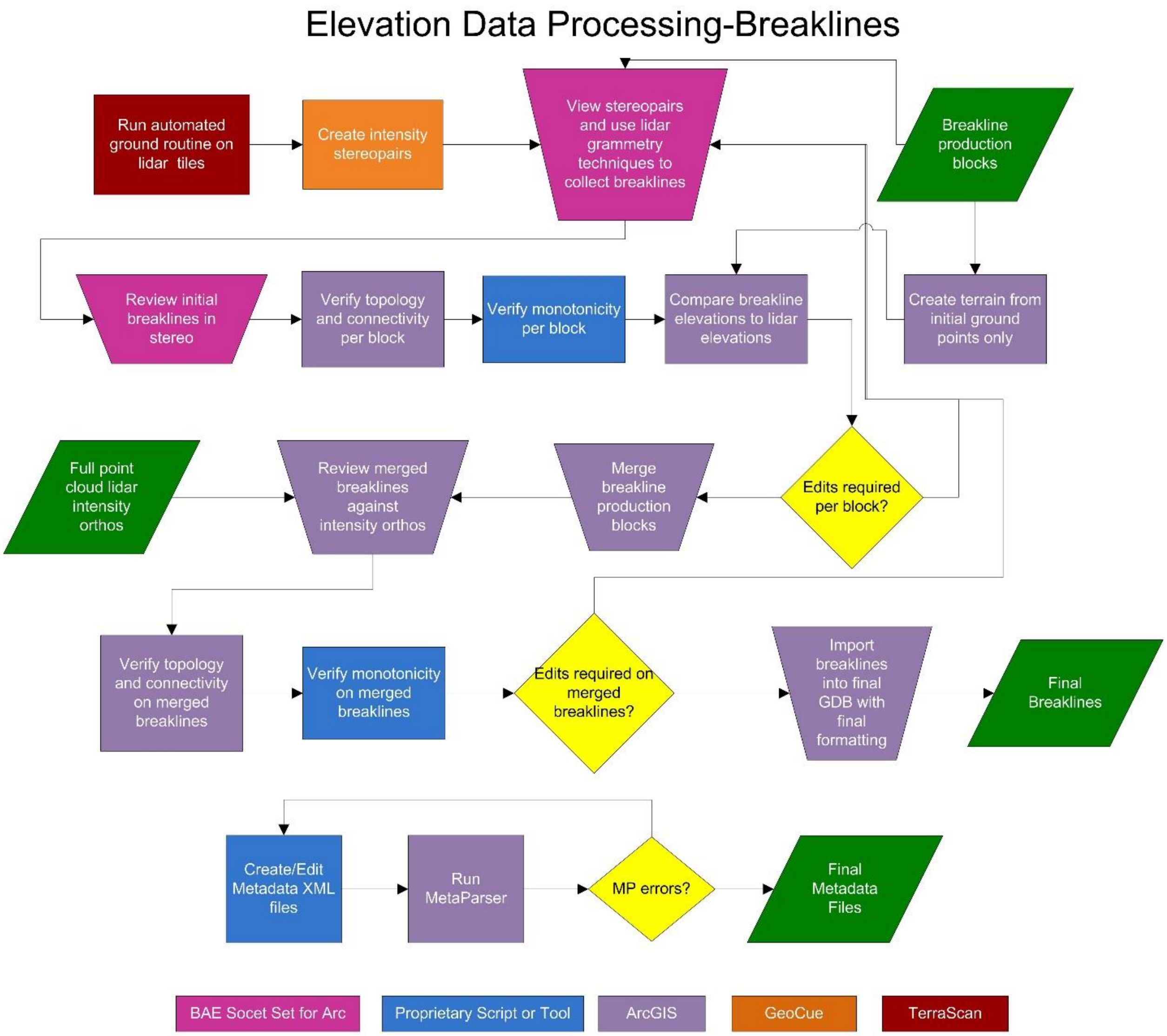

Figure 23 – Breakline QA/QC workflow

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 20 – 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 24 – 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.

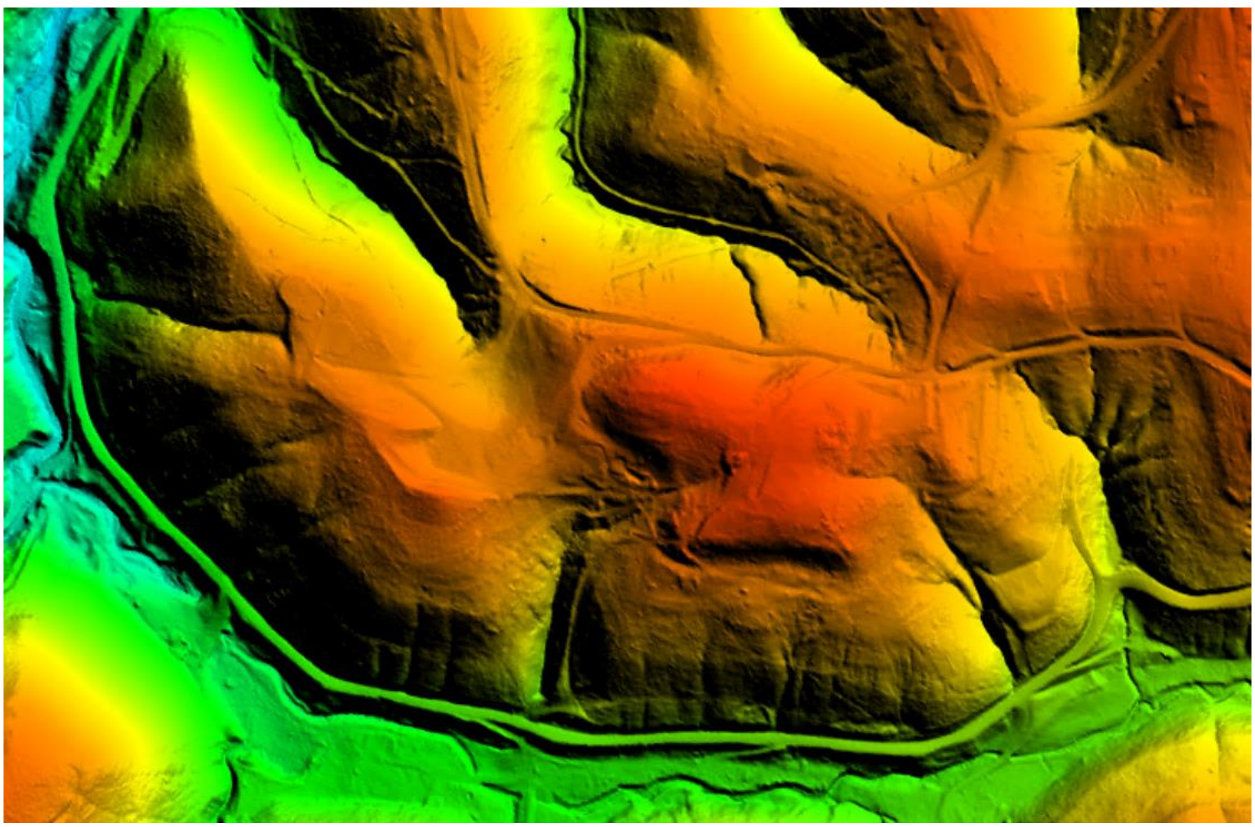

Figure 25 – 17SLC64504950. Map view of the bare Earth DEM with hillshade

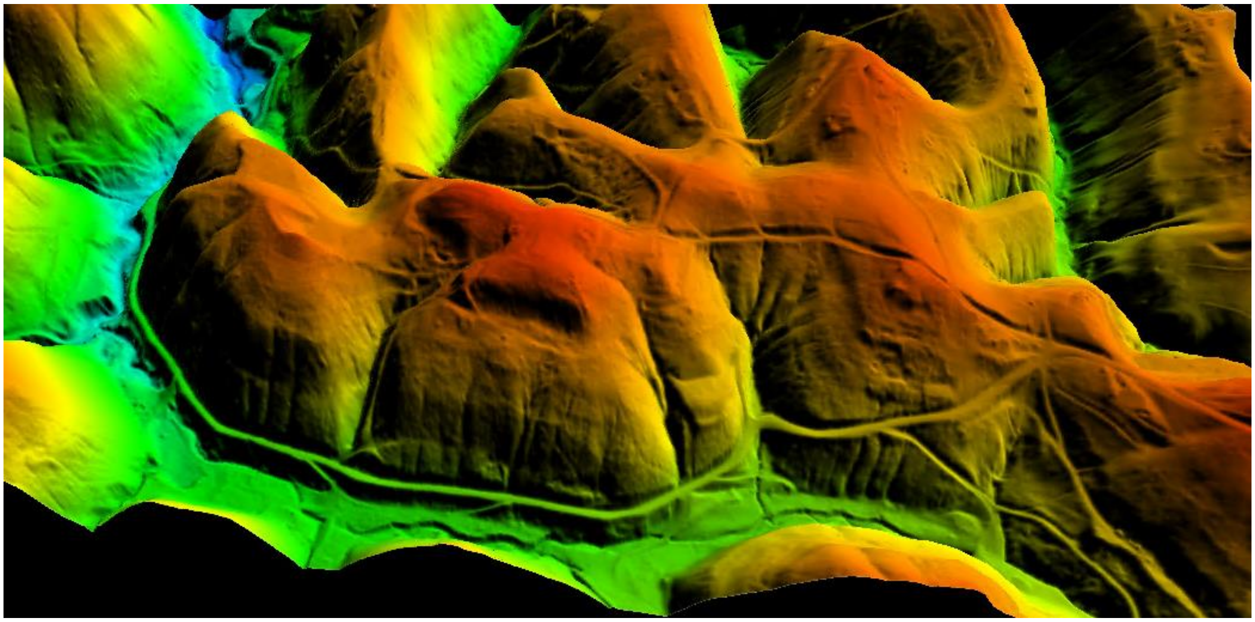

Figure 26 – 17SLC64504950. 3D profile view of the bare earth DEM

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.

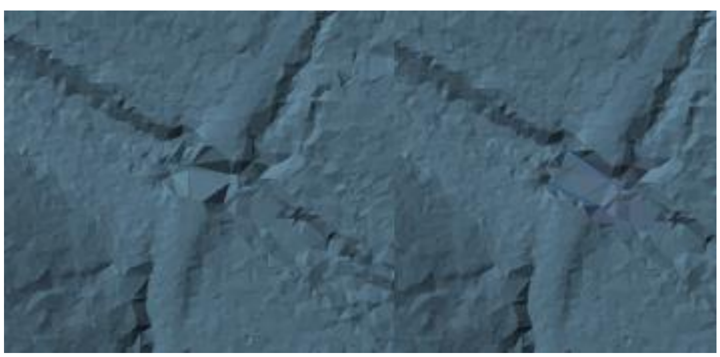

Figure 27 – 17SNA86507400. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced

DEM VERTICAL ACCURACY RESULTS

The same 331 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 21 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	190	0.113	
VVA	141		0.199

Table 21 — 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 $RMSE_z$ = 5.7 cm, equating to ± 11.3 cm at 95% confidence level. Actual VVA accuracy was found to be ± 19.9 cm at the 95th percentile.

Table 22 lists the 5% outliers that are larger than the VVA 95th percentile and Table 23 shows the descriptive statistics of the VVA dataset.

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-99-1	402201.119	4272569.784	187.912	188.125	0.213	0.213
VVA-32	675475.820	4065084.215	154.650	154.884	0.234	0.234
VVA-80	510154.001	4106161.105	669.967	669.731	-0.236	0.236
VVA-141	502171.612	4135114.442	617.642	617.901	0.259	0.259
VVA-23	778795.614	4094334.027	111.559	111.856	0.297	0.297
VVA-1	818379.709	4054217.027	23.053	23.362	0.309	0.309
VVA-70	645949.726	4106318.438	253.881	253.455	-0.426	0.426

Table 22 — 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	190	0.057	0.008	0.011	-0.178	0.057	0.377	-0.158	0.180
VVA	141	N/A	0.039	0.042	-0.654	0.099	3.273	-0.426	0.309

Table 23 — DEM NVA and VVA descriptive statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the USGS Virginia FEMA NRCS South Central 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 24– 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: Axis GPS and IMU Reports

Appendix B has been included as an attachment.

Appendix C: LEG GPS and IMU Reports

Appendix C has been included as an attachment.