West Virginia FEMA HQ Lidar Project

Report Produced for U.S. Geological Survey

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Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (lidar) technology for the West Virginia FEMA HQ 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 1000 m by 1000 m. A total of 9145 tiles were produced for the project encompassing an area of approximately 3100 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 completed lidar data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report falls within the West Virginia counties of Mason, Putnam, Wirt, Roane, Tucker, Randolph, Webster, Pocahontas, Jackson, Kanawha, Calhoun, Wood, Ritchie, Upshur, Clay, Pendleton, Grant, Barbour and Preston.

DATE OF SURVEY

The lidar aerial acquisition was conducted between November 8, 2018 and May 5, 2019.

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: Albers Equal Area
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

170 independent vertical accuracy checkpoints (95 non-vegetated and 75 vegetated) were collected for vertical accuracy testing. For the West Virginia FEMA HQ Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **4.9 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 **9.6 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 **13.9 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 later 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 9145 tiles were delivered for the project, covering the areas shown in Figure 1. Each tile's extent is 1000 m by 1000 m.

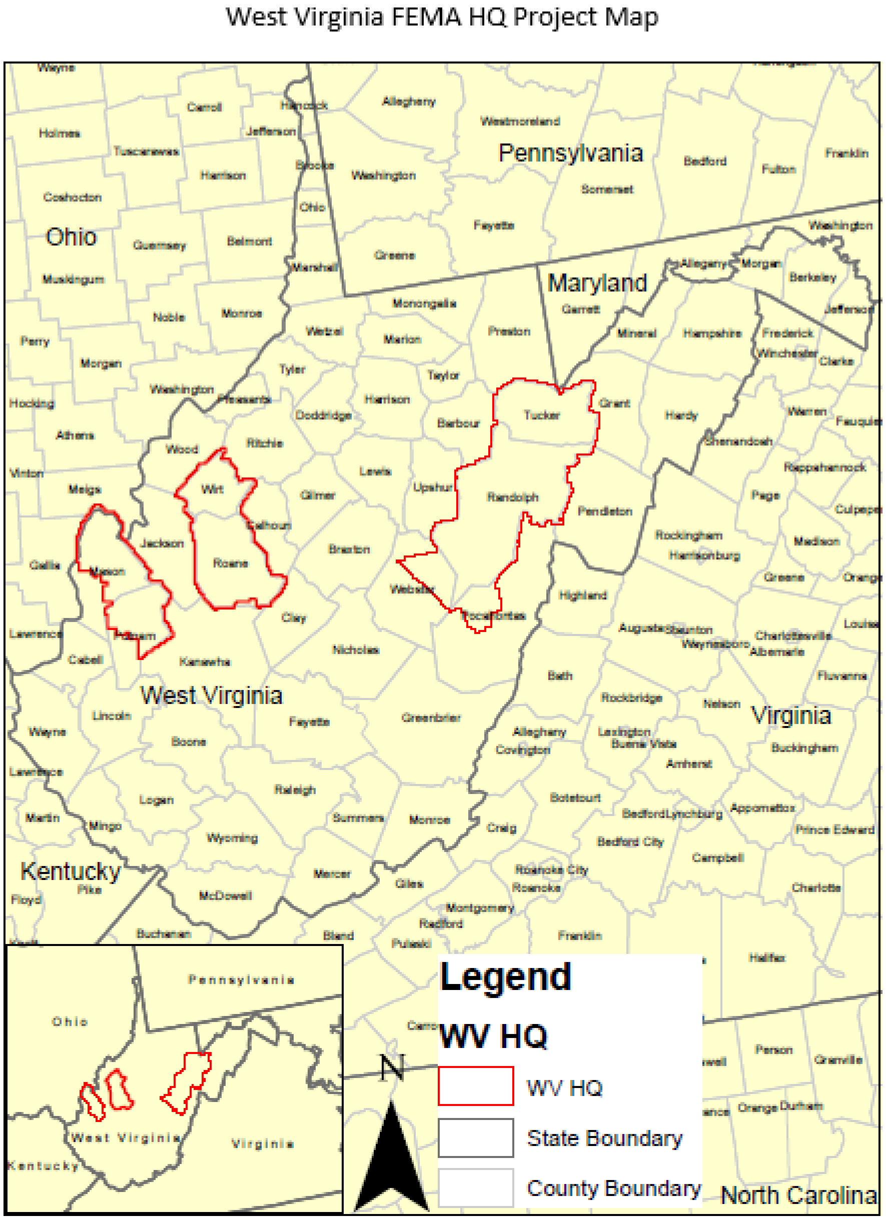

Figure 1 – Project Map

Lidar Acquisition Report

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

Dewberry received final calibrated swath data from Axis on May 29, 2019.

LIDAR ACQUISITION DETAILS

Axis Geospatial LLC. Planned a total of 172 lines to cover the area of interest. All 172 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. In order to reduce any margin for error in the flight plan, Axis Geospatial LLC followed USGS specifications for flight planning and, at a minimum, includes the following criteria:

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

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

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

Axis Geospatial LLC. lidar sensors are calibrated at a designated site located at Easton Airport in Easton Maryland and 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	Parameter
System	VQ-1560i	LMS Q1560
Maximum Number of Returns per Pulse	N/A	N/A
Nominal Pulse Spacing (single swath), (m)	0.68	.692
Nominal Pulse Density (single swath) (ppsm), (m)	*3.82*	*3.37*

Item	Parameter	Parameter
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.38	.692
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	4.36	3.37
Altitude (AGL meters)	1303	1524
Approx. Flight Speed (knots)	160	170
Total Sensor Scan Angle (degree)	58.52	58.52
Scan Frequency (hz)	700	2 x 400
Scanner Pulse Rate (kHz)	312	188
Pulse Duration of the Scanner (nanoseconds)	3 ns	3 ns
Pulse Width of the Scanner (m)	.06	.381
Central Wavelength of the Sensor Laser (nanometers)	614.8 nm	1064 nm
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes	Yes
Beam Divergence (milliradians)	≤ 0.25 mrad	≤ 0.25 mrad
Nominal Swath Width on the Ground (m)	1460	1707
Swath Overlap (%)	30	20
Computed Down Track spacing (m) per beam	0.42	.692
Computed Cross Track Spacing (m) per beam	0.42	.692
GNSS positional error (radial, in cm) *	0.05	0.05
IMU error (in decimal degrees) *	0.005	0.005
Maximum Baseline Length (mi)	47	47
Line Spacing (m)	.205	720

Table 1 – Axis 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.

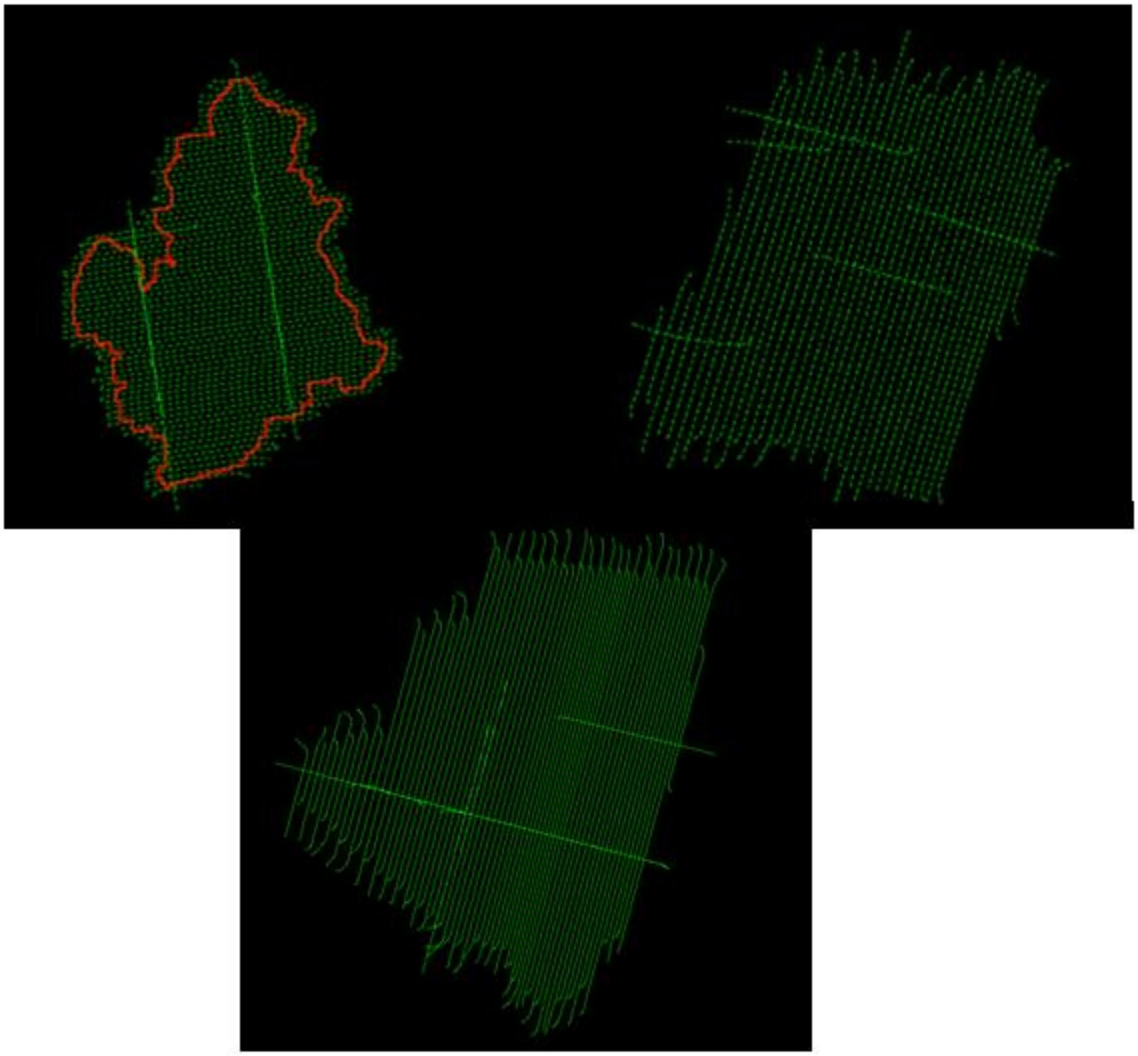

Figure 2 - Trajectories flown

LIDAR CONTROL

Axis Geospatial LLC. utilized CORS base stations during the acquisition of West Virginia FEMA HQ. These base sessions were then incorporated during the post-processing of aircraft position. The coordinates of these base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

Name	NAD83 (2011) Albers Equal Area		Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)	
GALP	1175815.77	1842486.4	169.456
KYGB	1130730.82	1794910.85	184.297
KYPA	1147379.05	1721379.38	160.427
LOYA	1471723.48	1843432.54	365.215
LOYY	1495421.47	1900496.4	222.19
LS08	1348127.33	1884892.56	407.318
MCON	1200377.36	1938636.06	272.658
PAGW	1336094.84	1987258.8	263.975
STKR	1182470.39	1898041.59	178.03
WVBR	1337197.78	1920301.28	270.245
WVBU	1451393.56	1943622.71	200.056
WVCH	1244987.98	1792586.53	168.512
WVCL	1289743.58	1819373.97	393.04
WVCV	1411970.12	1899831.58	969.234
WVFL	1315381.3	1847195.91	321.823
WVFR	1433391.7	1864528.47	580.203
WVGB	1392652.44	1829898.56	811.179
WVHA	1273621.56	1903116.67	290.153
WVHU	1170036.82	1793942.2	187.685
WVLA	1223279.22	1737539.07	480.445
WVMF	1455049.27	1914401.44	313.55
WVMZ	1275290.83	1856974.35	296.833
WVNR	1380305.22	1880725.92	582.775
WVOH	1287985.31	1763587.26	597.484
WVRA	1218967.84	1859890.17	149.245
WVRH	1214327.14	1814381.17	152.133
WVSH	1290903.34	1990918.55	384.55
WVTA	1398913.59	1945634.18	726.044

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

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the PosPac MMS 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 40 km.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 4 cm average or better but no larger than 6cm being recorded.

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

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

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

Subsequently the mission points are output using RiEGL's RiProcess software, initially with default values from RiEGL or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

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

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

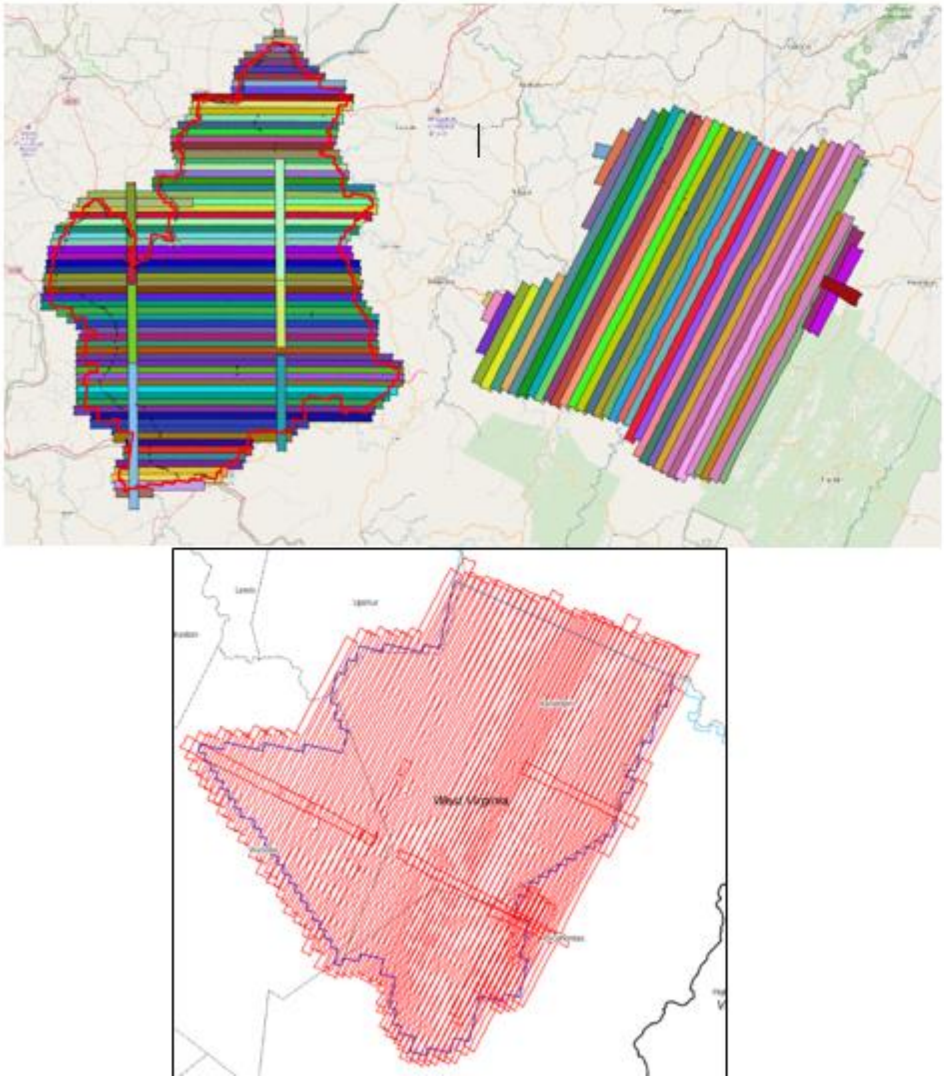

Figure 3 – Lidar swath output showing complete coverage of the project area

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.

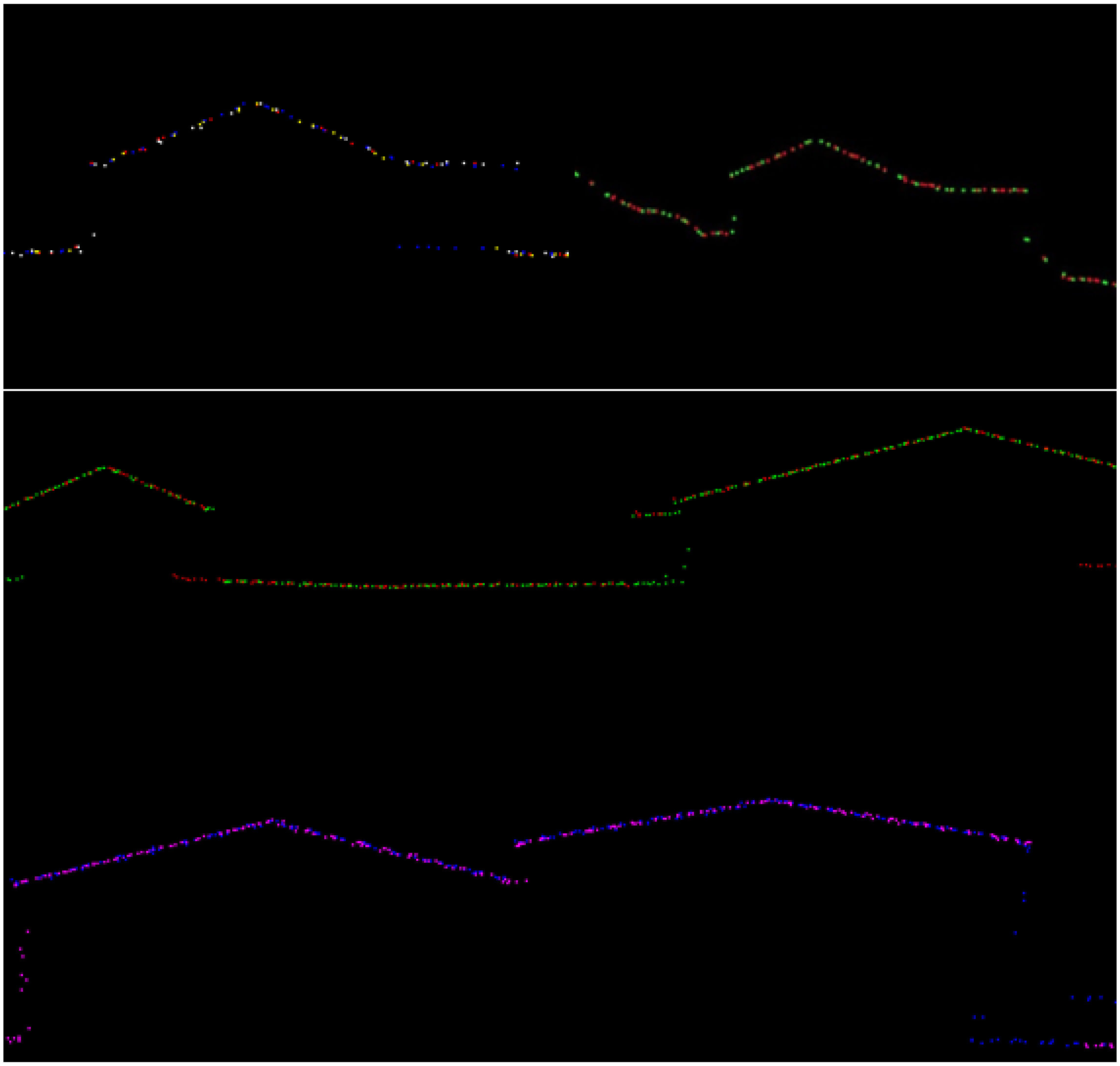

Figure 4 – Profile views showing correct roll and pitch adjustments

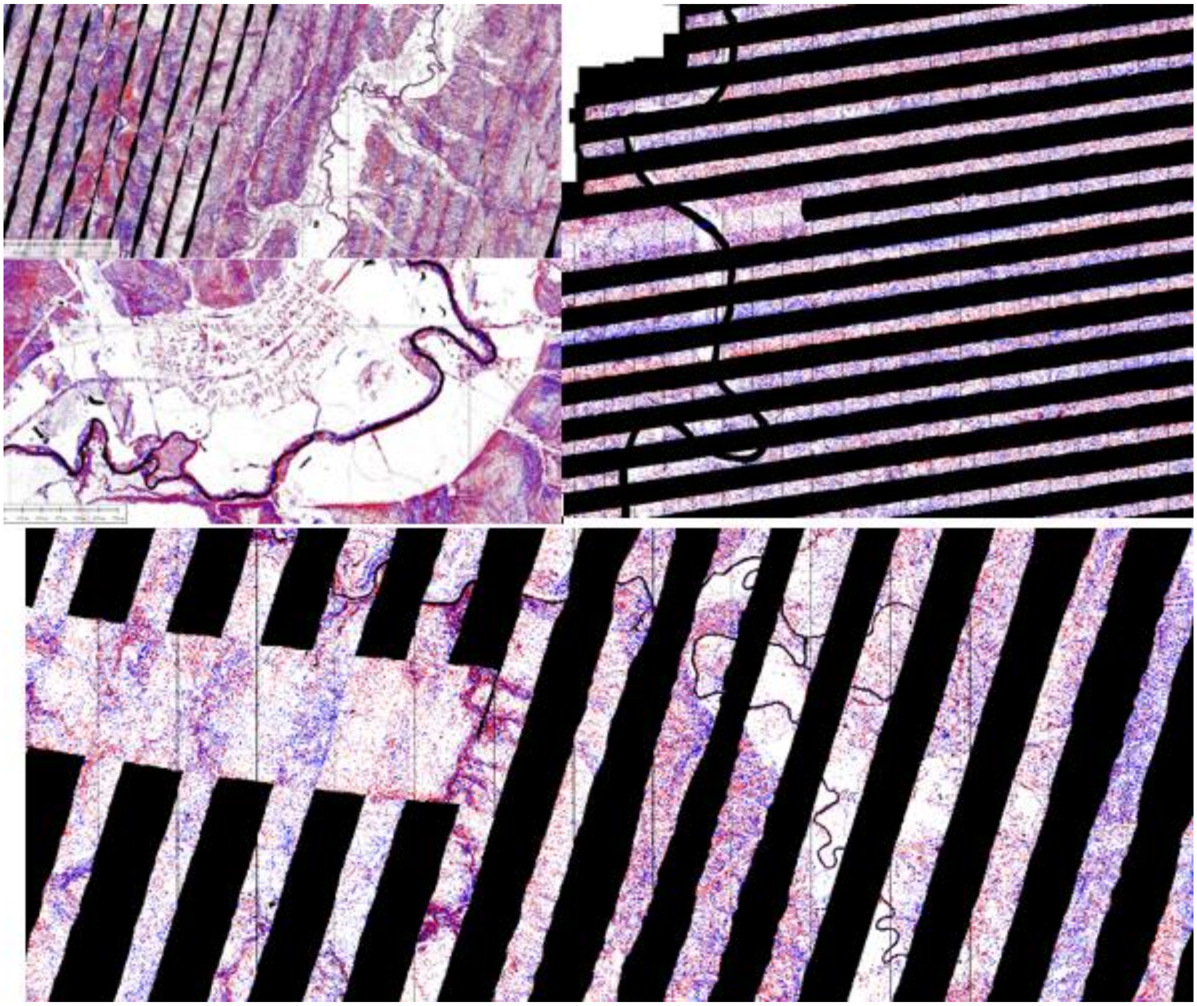

Figure 5 – QC block colored by distance to ensure accuracy at swath edges

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

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

Dewberry conducted the survey for 38 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 38 GCPs were available to use as control in case the swath data exhibited any biases which would need to be adjusted or removed. The coordinates of all GCPs are provided below and the accuracy results from testing the calibrated swath data against the GCPs is provided in table 4; no further adjustments to the swath data were required based on the accuracy results of the GCPs.

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

Point ID	NAD83 (2011) Albers Equal Area		NAVD88 (Geoid 12B)		Delta Z
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)	
GCP-01	1187740.241	1843018.700	171.413	171.370	-0.043
GCP-02	1218714.145	1801339.041	182.384	182.440	0.056

GCP-03	1214353.095	1813379.037	179.814	179.810	-0.004
GCP-04	1205625.313	1855226.495	176.558	176.520	-0.038
GCP-05	1193696.967	1864041.963	183.342	183.360	0.018
GCP-06	1201144.727	1851461.909	223.779	223.750	-0.029
GCP-07	1204350.079	1836072.348	173.796	173.780	-0.016
GCP-08	1204656.815	1820722.961	174.743	174.660	-0.083
GCP-09	1221456.456	1807468.934	178.999	179.030	0.031
GCP-10	1209746.318	1830171.769	184.142	184.140	-0.002
GCP-11	1218528.443	1818035.653	296.901	297.020	0.119
GCP-12	1266611.307	1824967.053	223.487	223.440	-0.047
GCP-13	1253830.630	1830879.803	216.471	216.480	0.009
GCP-14	1247386.875	1886685.282	196.274	196.240	-0.034
GCP-15	1215327.378	1797926.957	276.563	276.660	0.097
GCP-16	1233903.239	1874567.785	336.956	336.940	-0.016
GCP-17	1239985.667	1865490.354	216.300	216.290	-0.010
GCP-18	1253598.505	1850681.435	305.297	305.320	0.023
GCP-19	1248508.516	1846794.555	235.638	235.610	-0.028
GCP-20	1259729.433	1866870.199	205.356	205.260	-0.096
GCP-21	1278018.029	1826411.469	235.215	235.250	0.035
GCP-22	1255670.516	1881229.104	286.442	286.370	-0.072
GCP-23	1371307.569	1812218.585	1074.271	1074.280	0.009
GCP-24	1347131.782	1832667.344	935.601	935.610	0.009
GCP-25	1377803.930	1824885.854	1449.596	1449.600	0.004
GCP-26	1354833.812	1849078.942	818.333	818.330	-0.003
GCP-27	1384869.217	1849346.379	1098.903	1098.880	-0.023
GCP-28	1249962.857	1820256.417	327.118	327.100	-0.018
GCP-29	1262994.808	1840408.760	350.727	350.740	0.013
GCP-30	1217943.066	1827729.983	285.468	285.440	-0.028
GCP-31	1424104.977	1907761.924	1205.016	1205.000	-0.016
GCP-33	1371615.520	1884223.976	625.944	625.950	0.006
GCP-36	1409087.794	1894096.856	670.617	670.650	0.033
GCP-37	1365678.399	1840030.365	995.405	995.400	-0.005
GCP-38	1340496.777	1839821.625	749.985	750.060	0.075
GCP-39	1196002.613	1858565.824	195.118	195.000	-0.118
GCP-40	1215569.273	1841427.605	288.970	288.880	-0.090
GCP-41	1227437.057	1828128.483	312.984	312.990	0.006
GCP-42	1229820.010	1808230.289	179.635	179.660	0.025
GCP-43	1266003.907	1878052.241	303.305	303.330	0.025

GCP-44	1200738.039	1826947.687	177.247	177.250	0.003
GCP-45	1405974.121	1858944.391	1179.718	1179.720	0.002
GCP-46	1266176.658	1851435.461	219.020	219.000	-0.020
GCP-47	1254809.096	1867716.596	199.099	199.180	0.081
GCP-48	1200849.932	1845844.514	204.716	204.720	0.004
GCP-49	1362543.836	1861516.297	995.929	995.890	-0.039
GCP-50	1363407.053	1822864.365	1259.307	1259.310	0.003
GCP-50A	1369063.581	1829369.824	840.949	840.930	-0.019
GCP-52	1406109.002	1916457.511	908.356	908.390	0.034
GCP-53	1391558.641	1905647.623	501.174	501.180	0.006
GCP-54	1370734.161	1846656.678	664.417	664.470	0.053
GCP-55	1407997.091	1876380.800	840.984	841.000	0.016
GCP-56	1378937.346	1869457.245	599.639	599.670	0.031
GCP-56	1378937.346	1869457.245	599.639	599.610	-0.029
GCP-57	1391247.593	1884040.549	698.866	698.870	0.004
GCP58	1272260.970	1836286.619	264.963	264.970	0.007
GCP-59	1247173.775	1859436.377	206.454	206.490	0.036
GCP-60	1247204.738	1878109.161	194.969	194.990	0.021
GCP-61	1241233.807	1835628.979	315.826	315.810	-0.016

Table 3 – Axis swath against Dewberry's independent Ground Control Points

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.100 m	NVA-Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	59	0.043	0.084	-0.001	0.003	-0.054	0.043	-0.118	0.119	1.282

Table 4 – Axis Ground Control vertical accuracy results

Overall the calibrated lidar data products collected by Axis meet or exceed the requirements set out in the Statement of Work. The quality control requirements of Axis 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, 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 95 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 West Virginia FEMA HQ Lidar Project satisfies these 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	95	0.047	0.093	-0.001	-0.006	0.264	0.048	-0.127	0.136	0.463

Table 5 - NVA at 95% confidence level for raw swaths

Inter-Swath (Between Swath) Relative Accuracy

Dewberry verified inter-swath or between swath relative accuracy of the dataset by creating Delta-Z (DZ) orthos. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS

Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet inter-swath relative accuracy of 8 cm $RMSD_z$ 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 West Virginia FEMA HQ are shown in the figure below; this project meets inter-swath relative accuracy specifications.

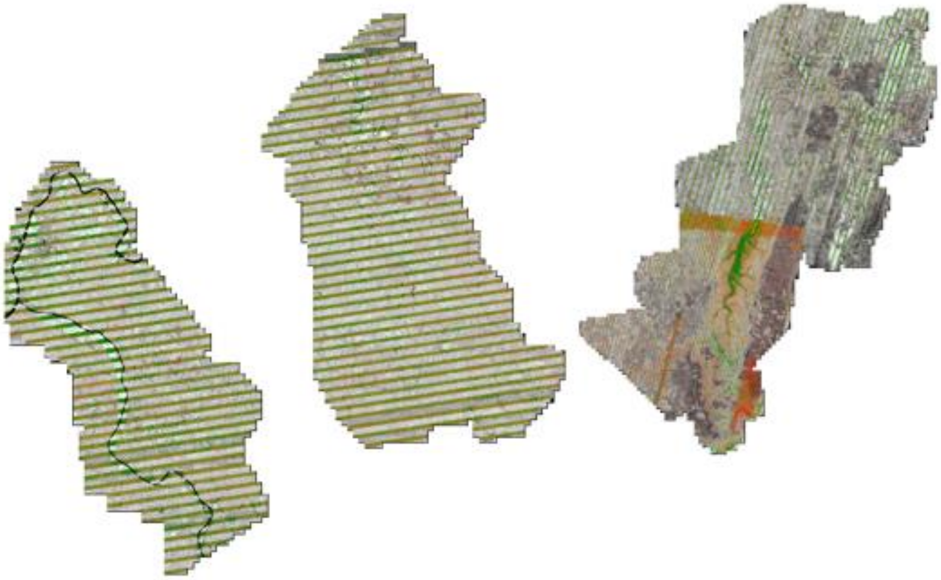

Figure 6 – Single return DZ Orthos for the West Virginia FEMA HQ lidar project. Inter-swath relative accuracy passes specifications.

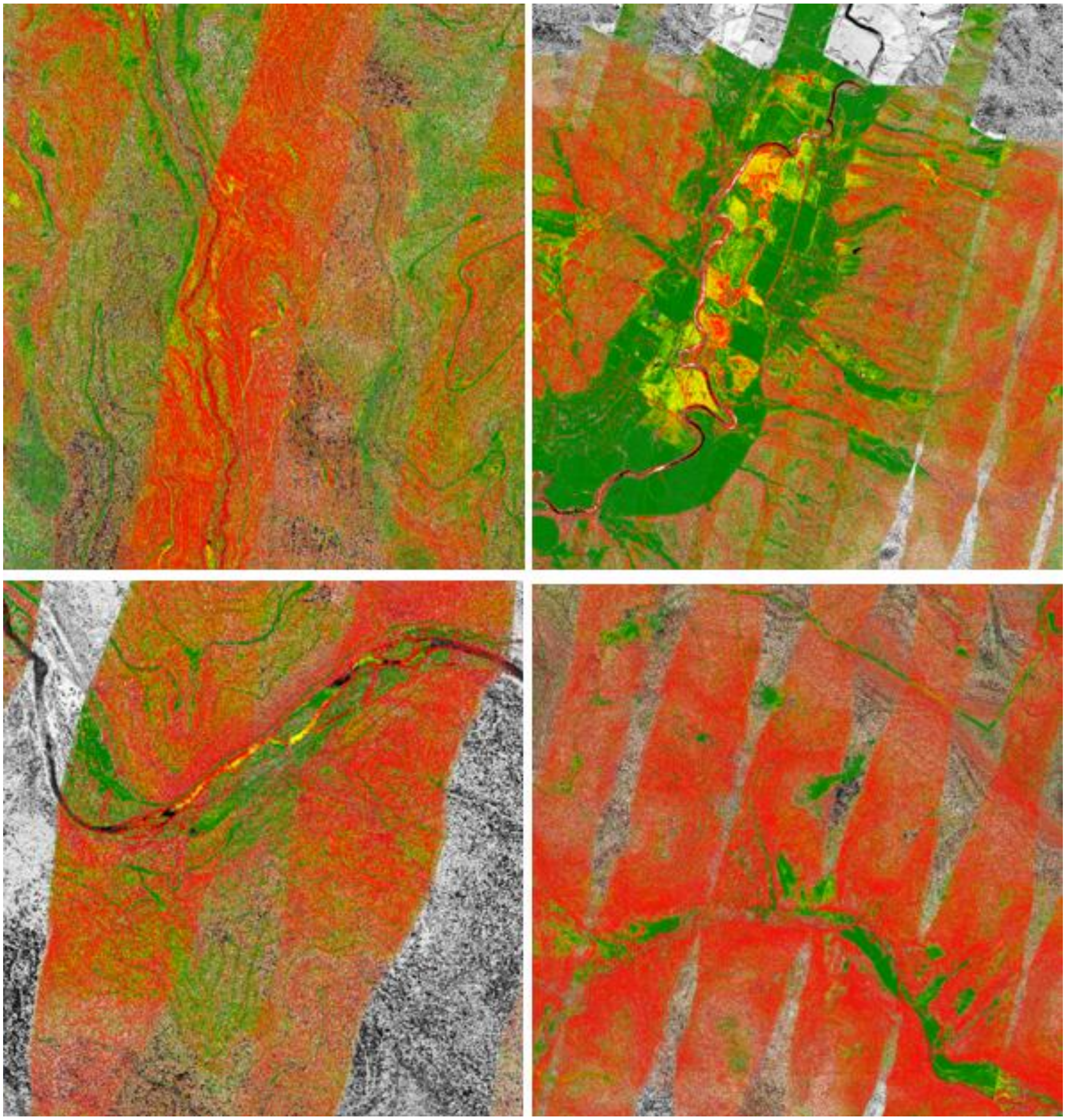

Figure 7 – These screenshots show close-ups of areas that may appear to exceed the threshold from a distance. These are mountainous forested regions but have threads of green where there are clearings spread throughout, the yellow area in the top right are agricultural fields

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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 West Virginia FEMA HQ; this project meets intra-swath relative accuracy specifications.

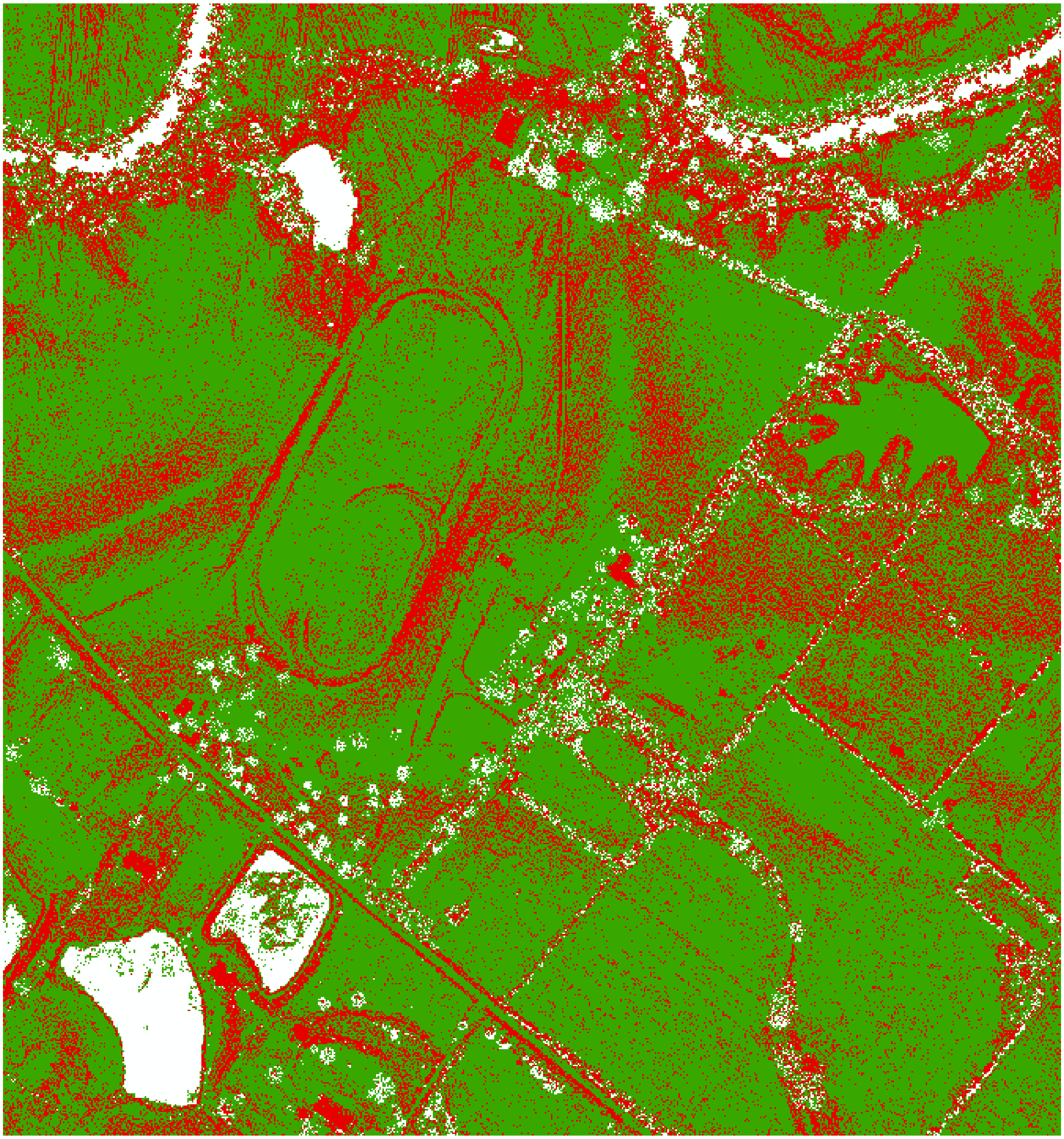

Figure 8 – Intra-swath relative accuracy. Areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The image shows a large portion of the dataset; flat, open areas are colored green, whereas sloped terrain is colored red because the terrain itself exceeds the 6 cm threshold. This is expected. 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 West Virginia FEMA HQ; no horizontal alignment issues were identified.

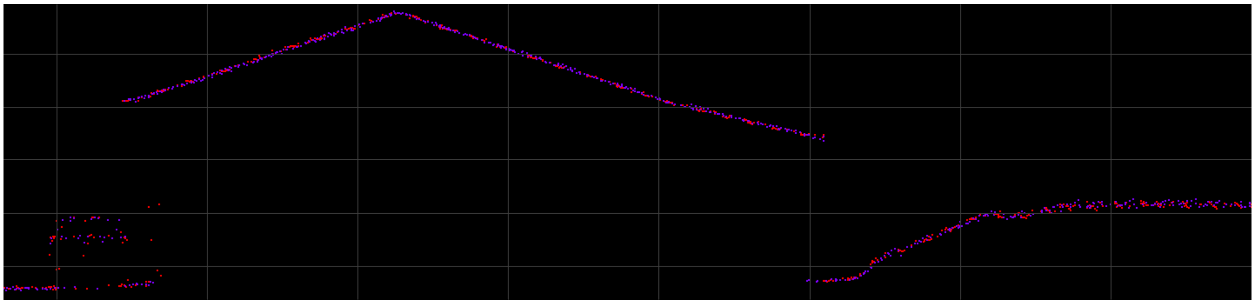

Figure 9 – Two separate flight lines differentiated by color (Blue/Yellow) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.71 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 2 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.5 meters and an ANPD of 4.5 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-square meter cells contain at least 2 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.

Figure 10 – 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-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.

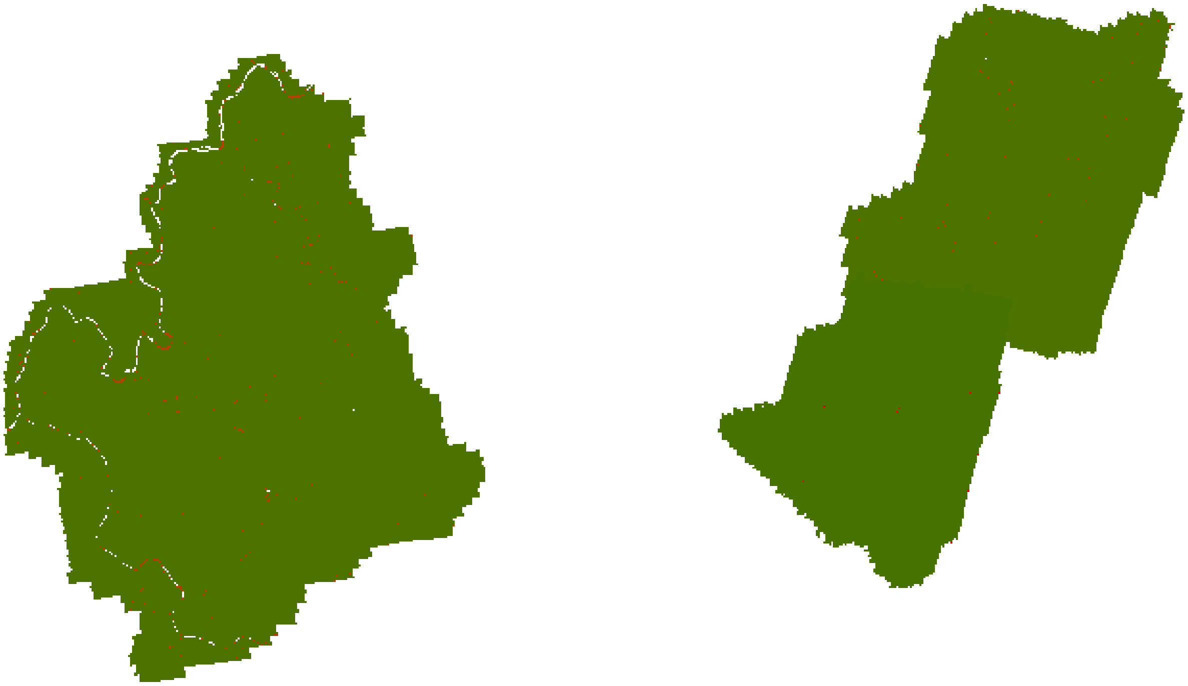

Figure 11 – All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies and other acceptable NoData areas, are colored red. Including acceptable NoData areas, 99.3% of cells contain at least one lidar point.

DATA CLASSIFICATION AND EDITING

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

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

This surface model is generated using four main parameters: building size, iteration angle, iteration distance, and maximum terrain angle. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. Points that do not relate to classified ground within the maximum terrain angle are not captured by the initial model.

After the initial automated ground routine, each tile was imported into Terrascan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry. Dewberry analysts employed 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. Bridge decks were classified to class 17 using bridge breaklines compiled by Dewberry. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that are within 1 NPS distance of the hydrographic feature boundaries are moved to class 10, ignored ground, to avoid 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 West Virginia FEMA HQ.

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 West Virginia FEMA HQ lidar project AOI. The issue is illustrated in Figure 13, below.

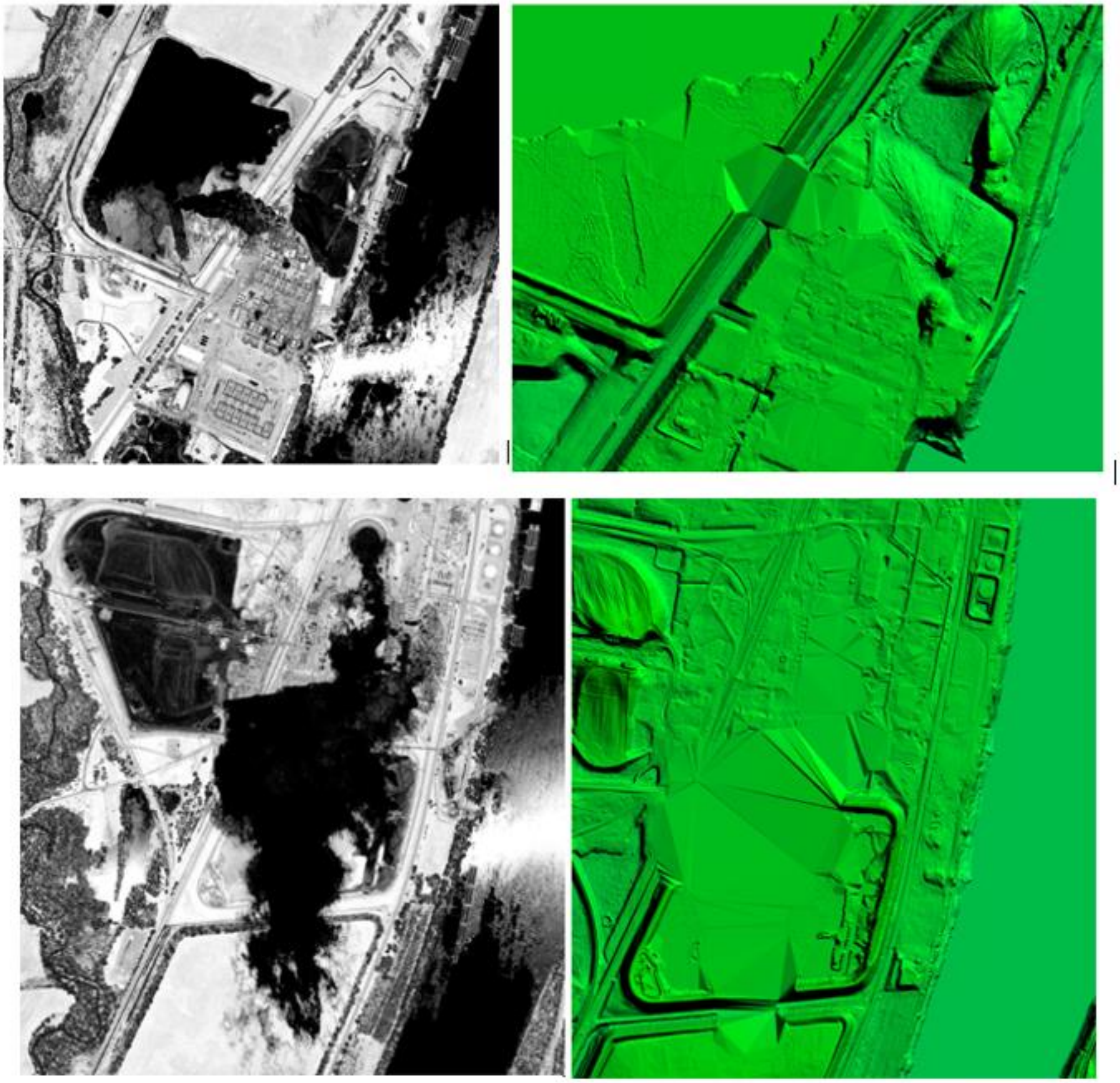

Figure 12 – e1187n1854, e1188n1854, e1187n1853, e1187n1852. 2 typical voids exist in the dataset. This area contains a power plant. The lidar does not penetrate to the ground and no ground points can be added to create a better ground model because of the steam/smoke from the plant.

Artifacts

Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches, or low vegetation used as landscaping in neighborhoods and other developed areas.

These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

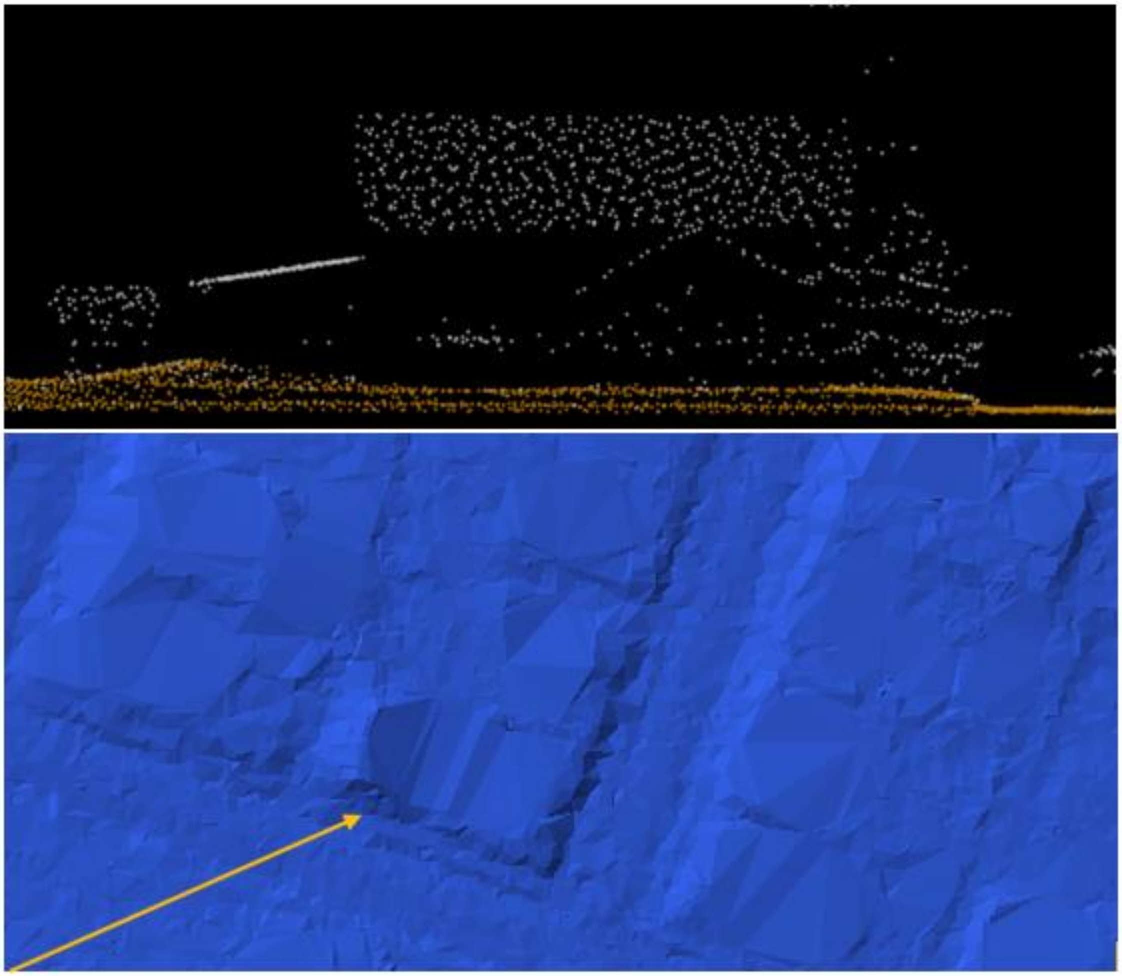

Figure 13 – e1192n1862. A profile with points colored by class (class 1=grey, class 2=orange) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

Bridge Removal Artifacts

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

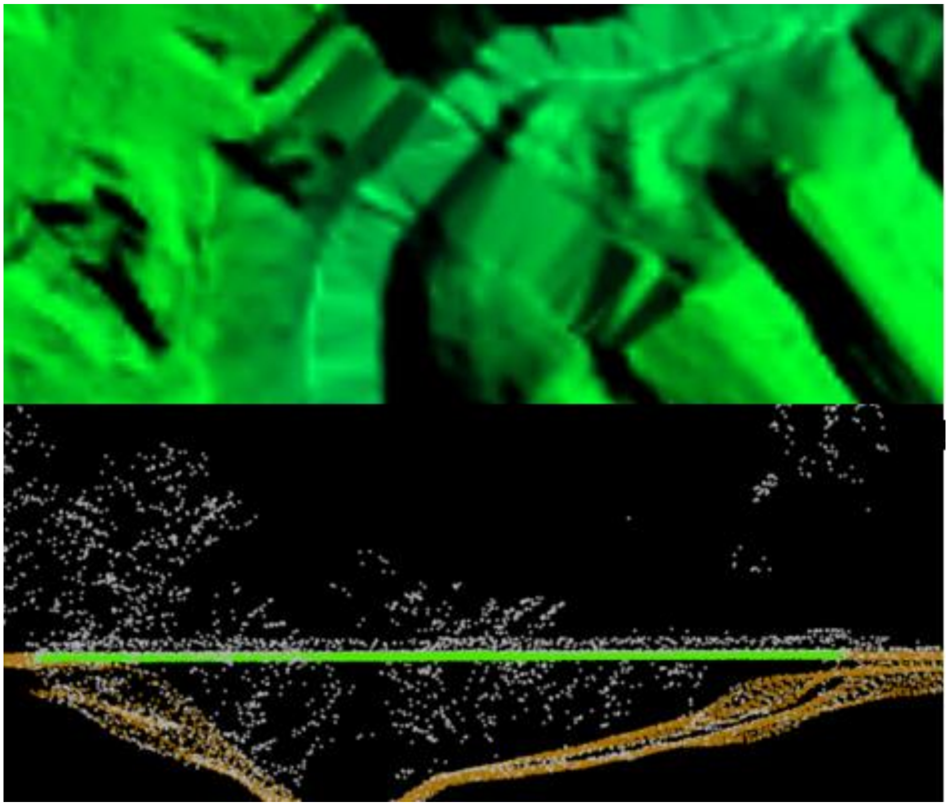

Figure 14 – Tile number e1197n1863. The DEM in the top view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the bottom view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (orange) and are unclassified (grey)/bridge deck (green).

Culverts and Bridges

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

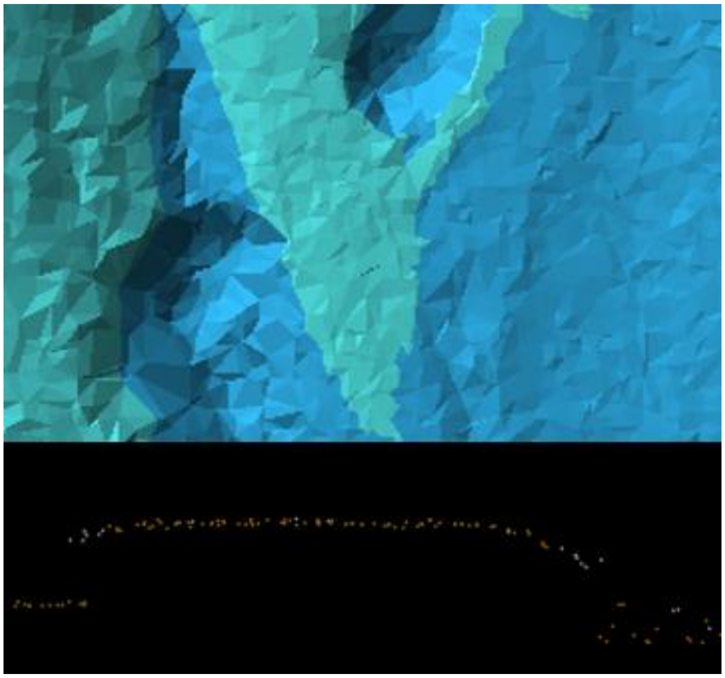

Figure 15– e1201n1856. A profile with points colored by class (class 1=grey, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

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

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Table 6– 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.

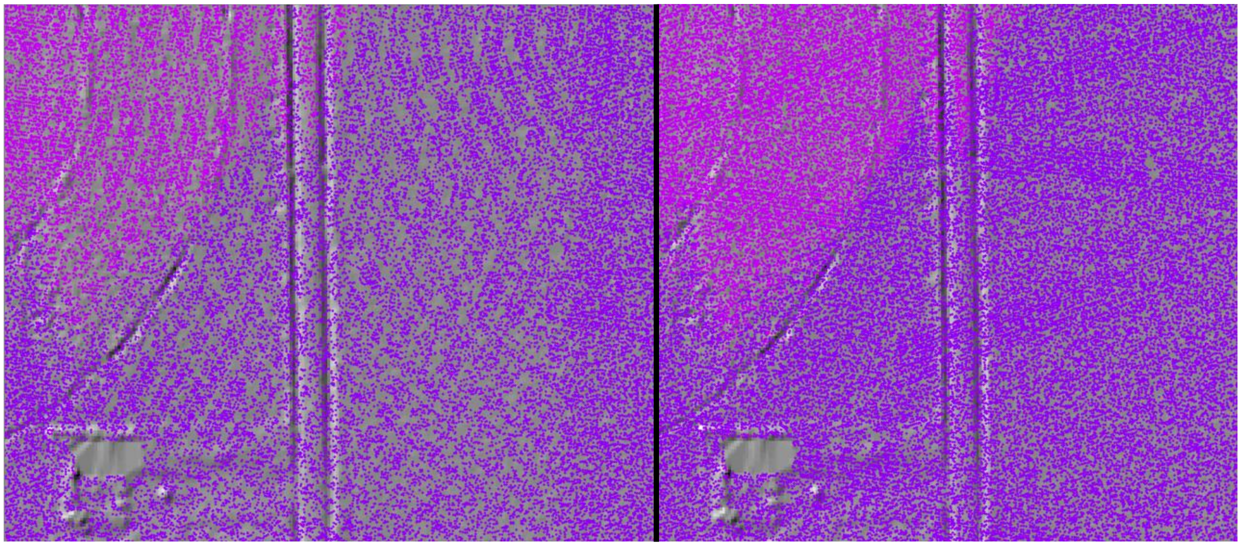

Figure 16 – The left image shows ground classified without synthetic points. The right image shows ground classified with synthetic points. Both images are overlaid on a hillshade of the example area

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, 170 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) Albers Equal Area		NAVD88 (Geoid 12B)
	Easting X (m)	Northing Y (m)	Elevation (m)
NVA-1	1199667.984	1862276.232	181.617
NVA-2	1192722.861	1860194.408	179.561
NVA-3	1188358.137	1851378.119	180.873
NVA-4	1197445.339	1854199.762	196.594
NVA-5	1206146.137	1846271.619	276.670
NVA-6	1191407.318	1844024.746	173.651
NVA-7	1194299.829	1838152.063	196.879
NVA-8	1204843.200	1839281.827	184.505
NVA-9	1215739.373	1835166.670	296.056
NVA-10	1204148.594	1832226.916	173.352
NVA-11	1206489.401	1824757.512	171.916
NVA-12	1202784.601	1815135.709	197.213
NVA-13	1215439.249	1822252.124	194.952
NVA-14	1224258.618	1826085.755	212.360
NVA-15	1222885.376	1819693.124	293.082
NVA-16	1210194.353	1812716.750	178.905
NVA-17	1225972.938	1806761.672	187.088
NVA-18	1218885.253	1804005.354	211.531
NVA-19	1255386.192	1886723.892	198.377
NVA-20	1244095.576	1881333.010	205.822
NVA-21	1239111.292	1873400.031	216.989
NVA-22	1254294.165	1879047.513	228.429
NVA-23	1260934.491	1873907.672	314.801
NVA-24	1253658.241	1864272.772	263.384
NVA-25	1246644.227	1874239.871	204.955
NVA-26	1240178.143	1862814.827	226.413
NVA-27	1242971.567	1856259.295	224.334
NVA-28	1253757.044	1858888.333	211.811
NVA-29	1263442.211	1858095.231	203.973
NVA-30	1262641.954	1847795.625	241.300
NVA-31	1255268.440	1849779.632	224.138
NVA-32	1242507.822	1843449.245	250.500
NVA-33	1252012.322	1838652.681	246.977
NVA-34	1268730.751	1842415.145	233.330
NVA-35	1278362.613	1832914.781	250.414
NVA-36	1267783.939	1831020.743	226.935
NVA-37	1255585.363	1832631.406	220.166
NVA-38	1245014.478	1831597.603	304.993
NVA-39	1247539.656	1822679.410	206.408
NVA-40	1261004.368	1827055.411	240.227
NVA-41	1273463.740	1828682.263	237.348

NVA-42	1391668.236	1921670.508	852.451
NVA-43	1396680.142	1916089.670	521.052
NVA-44	1411299.156	1915161.938	945.777
NVA-45	1417805.386	1921361.445	995.564
NVA-46	1412292.419	1908693.518	1072.238
NVA-47	1406876.811	1910030.465	951.114
NVA-48	1396701.149	1908193.102	788.811
NVA-49	1387400.837	1912815.662	472.106
NVA-50	1377629.225	1914170.980	595.325
NVA-51	1381113.125	1900488.808	607.733
NVA-52	1394638.663	1904530.470	525.619
NVA-53	1405639.515	1899278.768	757.602
NVA-54	1423232.922	1899209.655	1210.277
NVA-55	1412839.699	1896350.655	844.031
NVA-56	1407956.298	1888249.796	724.572
NVA-57	1400637.878	1891307.687	709.894
NVA-58	1386697.099	1889789.850	608.650
NVA-59	1390122.498	1897501.066	538.148
NVA-60	1380358.716	1884109.083	587.842
NVA-61	1385955.840	1884148.670	790.919
NVA-62	1393476.496	1884547.425	683.014
NVA-63	1404698.985	1882829.883	1027.182
NVA-64	1407299.665	1872936.489	897.062
NVA-65	1394563.801	1875940.732	874.361
NVA-66	1379917.526	1874410.125	597.007
NVA-67	1374477.902	1876364.088	935.240
NVA-68	1367842.901	1880867.586	741.654
NVA-69	1361778.550	1874818.981	593.479
NVA-70	1368887.300	1871926.304	664.681
NVA-71	1377304.434	1866350.583	616.022
NVA-72	1392382.783	1867624.108	923.732
NVA-73	1397084.536	1867793.649	1111.062
NVA-74	1397452.912	1866105.230	943.950
NVA-75	1382162.216	1859312.480	1187.719
NVA-76	1373960.113	1860867.993	623.267
NVA-77	1363399.648	1866768.957	760.919
NVA-78	1362323.780	1856934.466	894.247
NVA-79	1371885.034	1853434.683	644.981
NVA-80	1376387.817	1849184.680	753.054
NVA-81	1381716.031	1845180.773	1098.949
NVA-82	1380234.563	1839532.387	1176.824
NVA-83	1371850.124	1840398.443	713.066
NVA-84	1361772.766	1846492.798	1132.331
NVA-85	1354814.325	1854849.852	682.133
NVA-86	1354203.854	1844697.820	963.063
NVA-87	1360226.642	1838840.601	1167.967
NVA-88	1371204.923	1833213.764	821.415
NVA-89	1373695.496	1825340.328	902.524

NVA-90	1369900.571	1818411.785	896.099
NVA-91	1363600.537	1822527.669	1258.895
NVA-92	1350282.114	1829192.127	553.894
NVA-93	1351728.052	1834507.509	961.279
NVA-94	1348387.205	1838423.506	626.210
NVA-95	1338887.889	1836706.475	455.186
VVA-1	1199134.427	1858579.177	234.573
VVA-2	1192836.058	1848766.437	214.612
VVA-3	1204066.370	1849079.553	268.516
VVA-4	1198847.984	1842910.017	262.039
VVA-5	1210953.739	1841515.865	277.075
VVA-6	1198966.616	1834852.873	188.763
VVA-7	1211892.249	1833335.442	215.004
VVA-8	1221837.426	1829510.537	325.621
VVA-9	1211014.881	1822551.343	175.223
VVA-10	1205575.733	1813942.433	186.241
VVA-11	1211741.919	1817831.627	267.083
VVA-12	1223109.685	1822250.602	215.204
VVA-13	1224066.093	1811571.856	184.191
VVA-14	1213811.207	1809994.630	184.154
VVA-15	1249871.110	1883329.358	318.550
VVA-16	1240512.668	1876332.363	204.160
VVA-17	1246294.553	1868155.387	348.340
VVA-18	1255699.395	1875181.755	247.647
VVA-19	1260863.765	1870805.355	231.976
VVA-20	1257610.953	1861928.457	338.729
VVA-21	1246020.399	1854901.087	217.804
VVA-22	1244348.393	1847154.239	236.936
VVA-23	1259267.117	1853848.418	249.397
VVA-24	1262681.984	1844772.417	307.951
VVA-25	1254055.188	1842983.722	236.774
VVA-26	1245601.993	1837710.034	226.244
VVA-27	1254195.989	1832589.885	217.504
VVA-28	1265881.412	1838310.136	330.672
VVA-29	1271901.200	1832440.076	247.274
VVA-30	1261169.873	1830685.428	252.632
VVA-31	1251276.783	1825679.004	342.007
VVA-32	1271383.631	1822969.420	244.115
VVA-33	1381929.206	1917076.928	549.476
VVA-34	1391515.264	1916563.955	700.068
VVA-35	1402800.066	1918914.001	1006.806
VVA-36	1419925.030	1913156.911	1089.264
VVA-37	1423584.635	1903768.504	1181.131
VVA-38	1409484.064	1905933.504	1112.006
VVA-39	1399235.418	1910913.851	1050.781
VVA-40	1381268.122	1910531.997	780.098
VVA-41	1379654.312	1901023.310	624.945
VVA-42	1400659.121	1899363.241	556.913

VVA-43	1400688.867	1892695.217	695.090
VVA-44	1421328.435	1895030.581	1197.362
VVA-45	1402020.970	1887586.054	995.536
VVA-46	1384823.105	1894775.191	831.076
VVA-47	1373303.997	1886545.914	649.139
VVA-48	1387523.436	1881944.344	773.476
VVA-49	1399681.714	1877482.649	900.223
VVA-50	1404662.933	1875867.026	861.747
VVA-51	1403375.716	1864962.433	1058.692
VVA-52	1395972.031	1870896.172	890.869
VVA-53	1385497.390	1873463.519	668.990
VVA-54	1370140.175	1879014.889	664.537
VVA-55	1362492.457	1870933.918	642.501
VVA-56	1372204.355	1864795.502	865.397
VVA-57	1383957.912	1863525.110	1122.506
VVA-58	1394295.843	1860009.458	1159.113
VVA-59	1378804.123	1854157.313	800.004
VVA-60	1367498.348	1862704.014	688.764
VVA-61	1359353.329	1856080.497	932.019
VVA-62	1366715.693	1851253.441	912.556
VVA-63	1371709.326	1843509.081	684.429
VVA-64	1376154.663	1836634.327	1146.151
VVA-65	1368659.771	1838250.442	896.354
VVA-66	1359144.997	1845574.337	1076.221
VVA-67	1351854.365	1852253.688	714.020
VVA-68	1351051.552	1840609.658	963.356
VVA-69	1357149.346	1837984.131	1067.181
VVA-70	1366415.744	1830401.637	767.816
VVA-71	1374999.408	1825362.704	940.481
VVA-72	1371537.098	1817879.544	942.744
VVA-73	1354750.532	1823183.338	812.044
VVA-74	1352177.550	1830194.622	572.469
VVA-75	1342379.389	1836448.036	521.179

Table 7 – West Virginia FEMA HQ lidar surveyed accuracy checkpoints

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

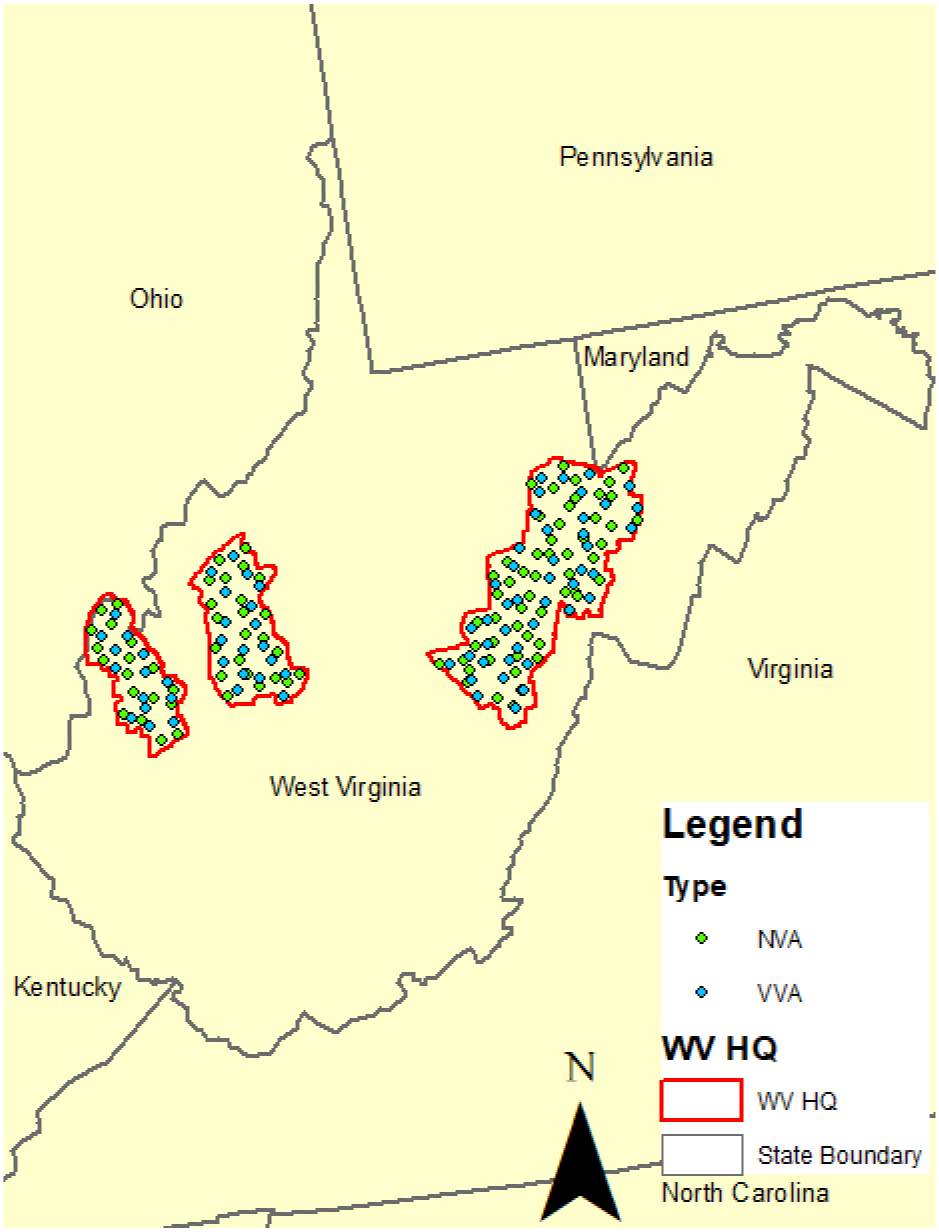

Figure 17 – Location of QA/QC Checkpoints

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 West Virginia FEMA HQ 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 West Virginia FEMA HQ 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 8.

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 8 — 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	95	0.096	
VVA	75		0.139

Table 9 – 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 $RMSE_z$ = 4.9cm, equating to ± 9.6 cm at 95% confidence level. Actual VVA accuracy was found to be ± 13.9 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 +27 cm.

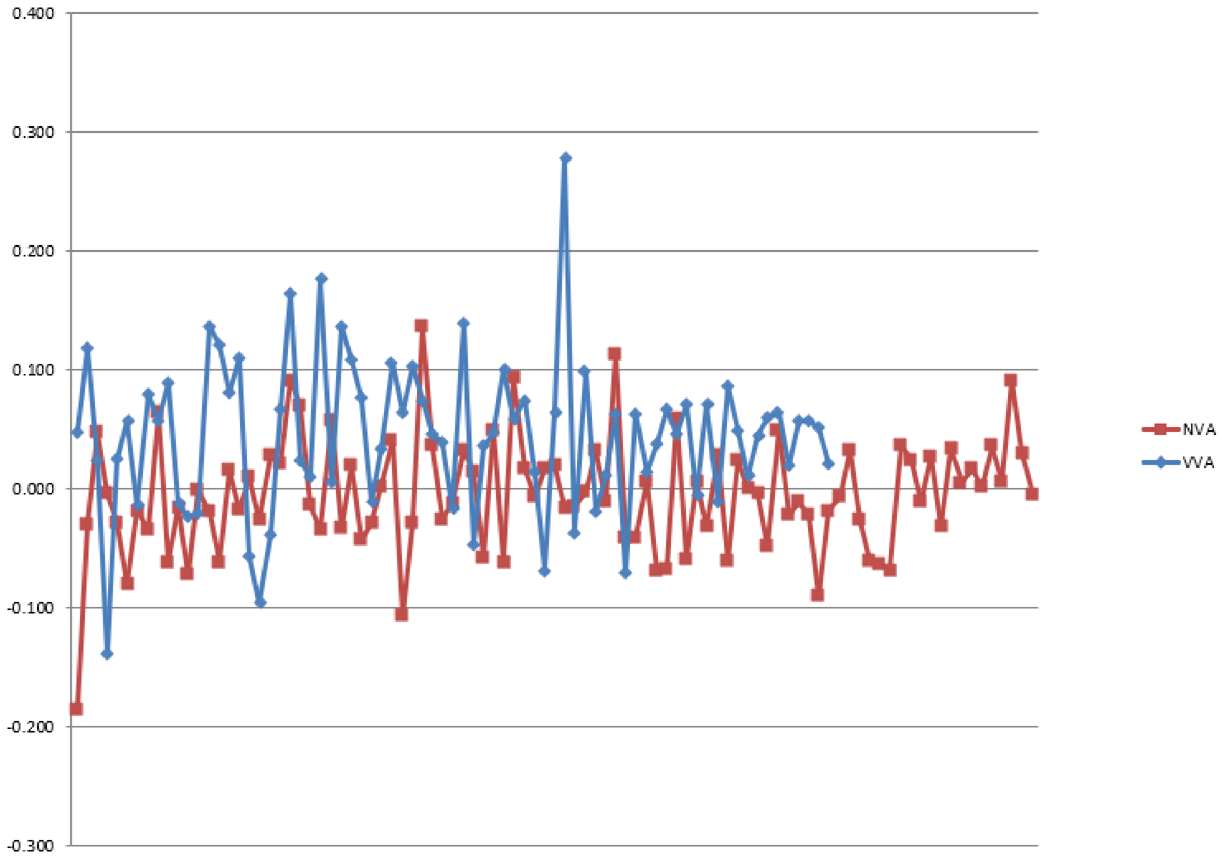

Figure 18 – Magnitude of elevation discrepancies per land cover category

Table 10 lists the 5% outliers that are larger than the VVA 95^{th} 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-22	1244348.393	1847154.239	236.936	237.100	0.164	0.164
VVA-25	1254055.188	1842983.722	236.774	236.950	0.176	0.176
VVA-49	1399681.714	1877482.649	900.223	900.500	0.277	0.277

Table 10— Lidar VVA 5% outliers

Table 11 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	95	0.049	-0.005	-0.007	-0.110	0.049	1.681	-0.187	0.136
VVA	75	N/A	0.045	0.049	0.217	0.065	1.881	-0.139	0.277

Table 11 — 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 -0.075 meters to +0.075 meters.

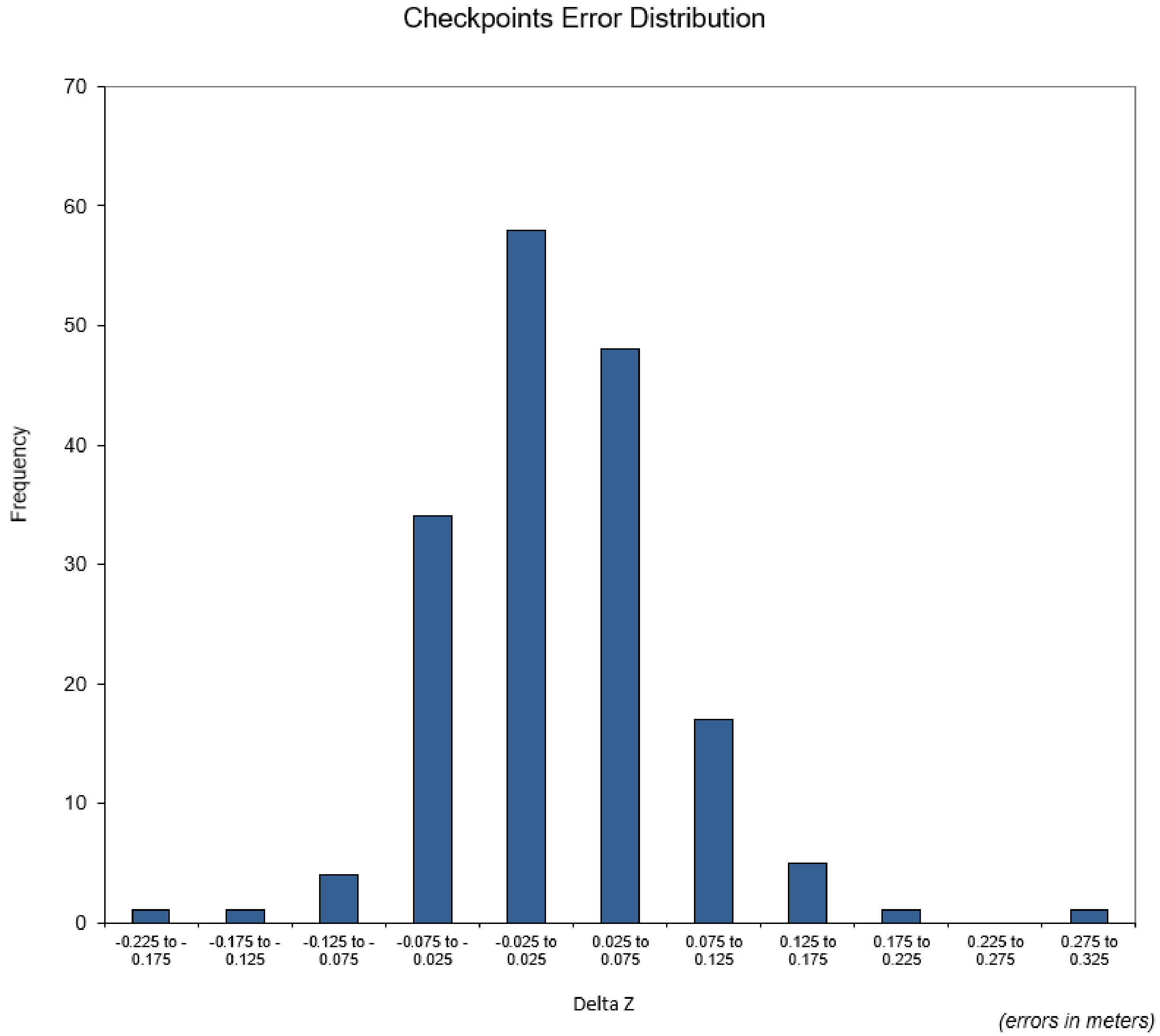

Figure 19 — Histogram of elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the USGS West Virginia FEMA HQ 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
19	0.280	0.481	0.557	0.964

Table 12 – 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. 19 checkpoints were used for horizontal accuracy testing. Actual positional accuracy of this dataset was found to be RMSE_x = 28 cm and RMSE_y = 48.1 cm, which equates to ± 96.4 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.

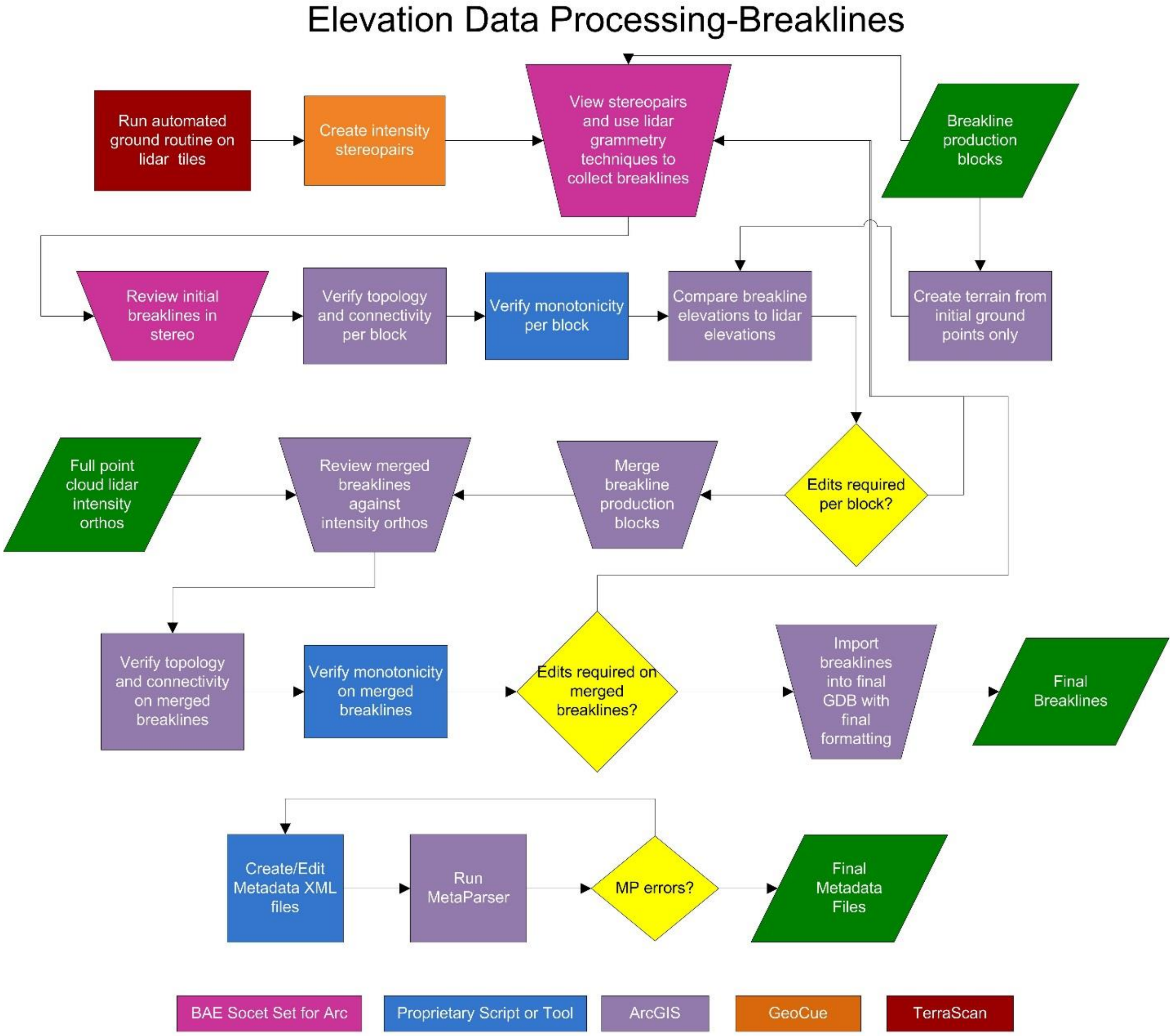

Figure 20 – Breakline QA/QC workflow

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	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/Fail	Validation Step
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 13 – 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 Conus Albers, 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 21 – 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.

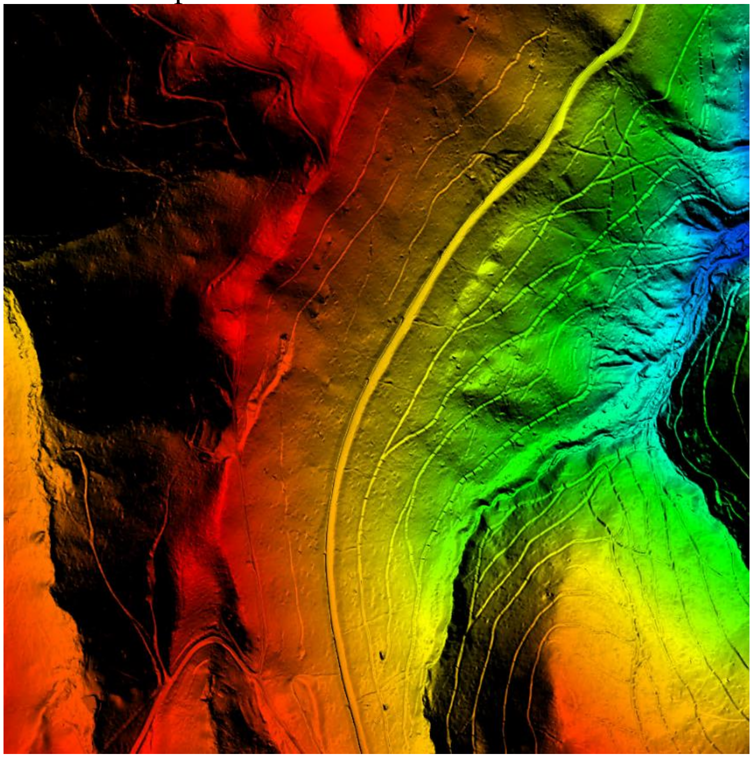

Figure 22- Tile e1340n1840. Map view of the bare Earth DEM with hillshade

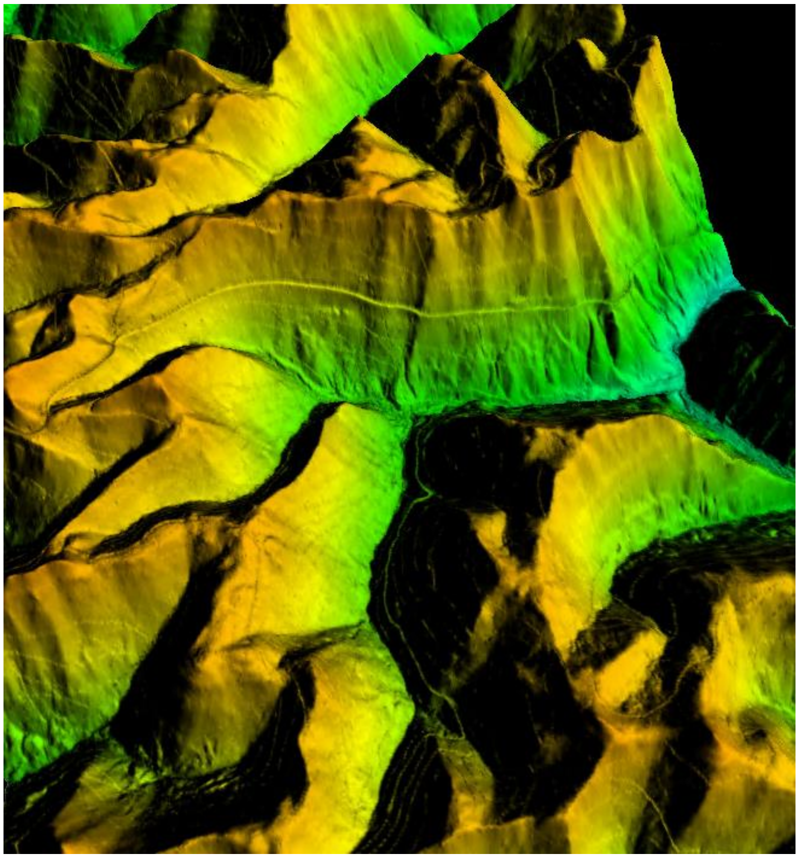

Figure 23 – Tile e1340n1840. 3D profile view of the bare earth DEM

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.

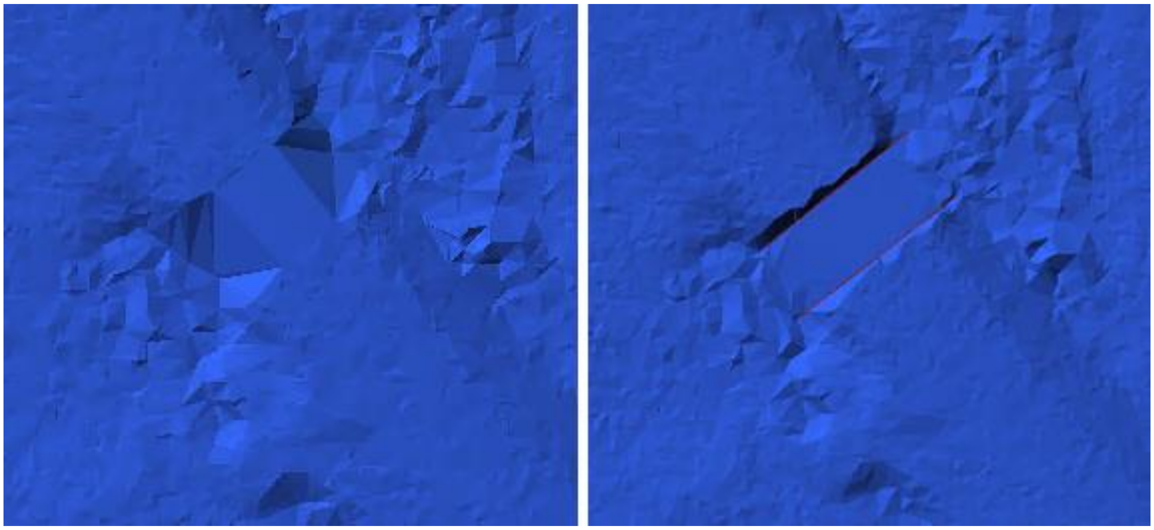

Figure 24 – e1379n1886. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced

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 14 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	95	0.099	
VVA	75		0.140

Table 14 — 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 15 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-15	1249871.110	1883329.358	318.550	318.698	0.148	0.148
VVA-25	1254055.188	1842983.722	236.774	236.992	0.218	0.218
VVA-49	1399681.714	1877482.649	900.223	900.500	0.277	0.277

Table 15 — 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	95	0.050	-0.006	-0.007	-0.230	0.050	1.734	-0.193	0.134
VVA	75	N/A	0.046	0.050	0.470	0.063	2.054	-0.101	0.277

Table 16— DEM NVA and VVA descriptive statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the USGS West Virginia FEMA HQ 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 17– 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

See attached document.

Appendix B: GPS and IMU Reports

See attached folder.