West Virginia FEMA R3 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 R3 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 36,725 tiles were produced for the project encompassing an area of approximately 13,300 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, Eagle Mapping 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 West Virginia counties of Barbour, Boone, Braxton, Brooke, Cabell, Calhoun, Clay, Doddridge, Fayette, Gilmer, Grant, Greenbrier Handcock, Harrison, Jackson, Kanawha, Lewis, Logan, Marion, Marshall, Mason, McDowell, Mineral, Mingo, Monongalia, Nicholas, Ohio, Pleasants, Pocahontas, Preston, Raleigh, Ritchie, Taylor, Tyler Upshur, Webster, Wetzel, Wirt, Wood, and Wyoming.

DATE OF SURVEY

The lidar aerial acquisition was conducted between November 17, 2018 and March 13, 2020.

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

435 independent vertical accuracy checkpoints (254 non-vegetated and 181 vegetated) were collected for vertical accuracy testing. For the West Virginia FEMA R3 Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **5.1 cm**, compared with the 10 cm specification; and the non-vegetated vertical accuracy (NVA) of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to **10.1 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 **13.8 cm,** compared with the 30 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 36,725 tiles were delivered for the project, covering the area shown in Figure 1. Each tile's extent is 1000 m by 1000 m.

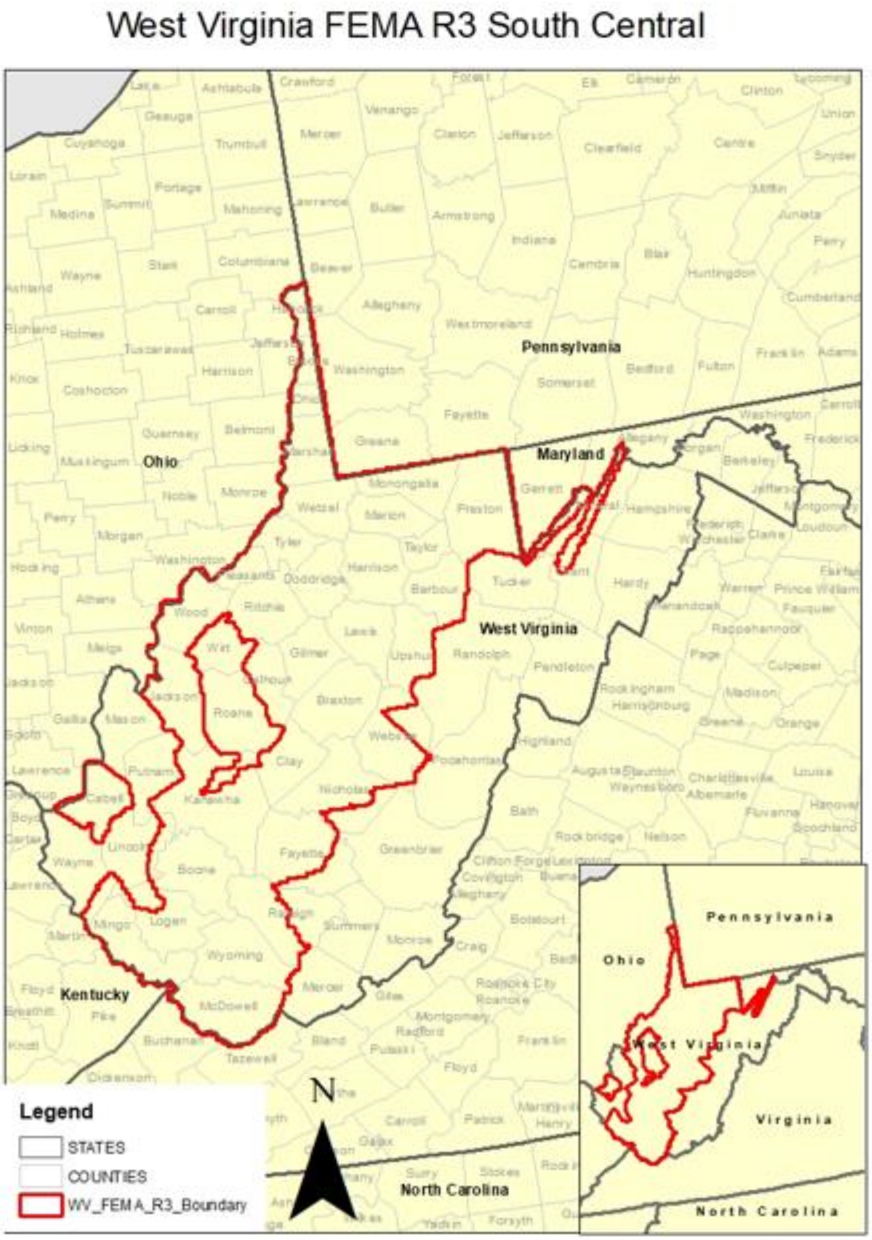

Figure 1 – Project Map

Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities to Axis Geospatial, LLC (Axis), Eagle Mapping (Eagle), and Leading Edge Geomatics (LEG). Axis, Eagle 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 May 24, 2019, Eagle data was received May 21, 2019, and final calibrated swaths from LEG were received May 29, 2020.

The acquisition reports with all details have been included as appendices.

Axis Acquisition Report: Appendix A
Axis Cabell Acquisition Report: Appendix B
Eagle Acquisition Report: Appendix C
LEG Acquisition Report: Appendix D

Overall the calibrated lidar data products collected by Axis, Eagle, and LEG meet or exceed the requirements set out in the Statement of Work. The quality control requirements of each acquisition provider's 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 each of the contracted acquisition providers, 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 252 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 R3 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 $RMSE_z$ = 7.4 cm, equating to +/-14.4cm 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	252	0.074	0.144	0.029	0.027	2.384	0.068	-0.160	0.550	16.712

Table 1: Raw Swath Vertical Accuracy Results

Two checkpoints (NVA-36 and NVA-60) were removed from the raw swath vertical accuracy testing due to their locations under a light pole and 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. While NVA-36 and NVA-60 located in open terrain, the overhead features are modeled by the lidar point cloud. These high points caused erroneous high values during the swath vertical accuracy testing so this point was removed from the final calculations. Once the data underwent the classification process, the power lines were removed from the final ground classification and this point could be used in the final vertical accuracy testing for the fully classified lidar data. Table 2, below, provides the coordinates for this checkpoint and the vertical accuracy results from the raw swath data. Table 3, below, provides the usable vertical accuracy results of this checkpoint from the fully classified lidar. The differences in the tables show how above ground features can cause erroneous vertical accuracy results in the raw swath data. Figure 2, below, shows a 3D model of the lidar point cloud and the location of the checkpoint beneath a power line.

Point ID	NAD83(2011) Conus Albers		NAVD88 (Geoid 12B)	Lidar Z (m)
	Easting X (m)	Northing Y (m)	Survey Z (m)	
NVA-36	1286077.223	1727964.163	797.596	slope
NVA-60	1184915.140	1743259.189	229.706	slope

Table 2: Checkpoints removed from raw swath vertical accuracy testing

Point ID	NAD83(2011) Conus Albers		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
NVA-36	1286077.223	1727964.163	797.596	797.680	0.084	0.084
NVA-60	1184915.140	1743259.189	229.706	229.760	0.054	0.054

Table 3: Final tested vertical accuracy for the removed checkpoints post ground classification

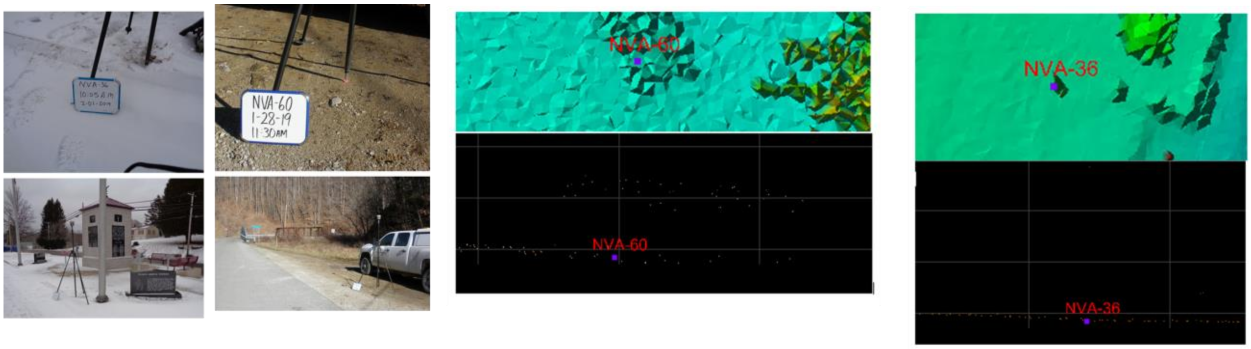

Figure 2 – NVA- 36 and NVA-60, as shown in the survey photos full point cloud TIN and point cloud.

Inter-Swath (Between Swath) Relative Accuracy

Dewberry verified inter-swath or between swath relative accuracy of the dataset by using proprietary software which measures offsets between overlapping flight lines. According to the SOW, USGS Lidar Base Specifications v1.3, 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 software and then binned for visual analysis. 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.

Flat, open areas are expected to be green, or within relative accuracy tolerances. 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 interswath accuracy analysis for West Virginia FEMA R3 is shown in the figure below; this project meets inter-swath relative accuracy specifications.

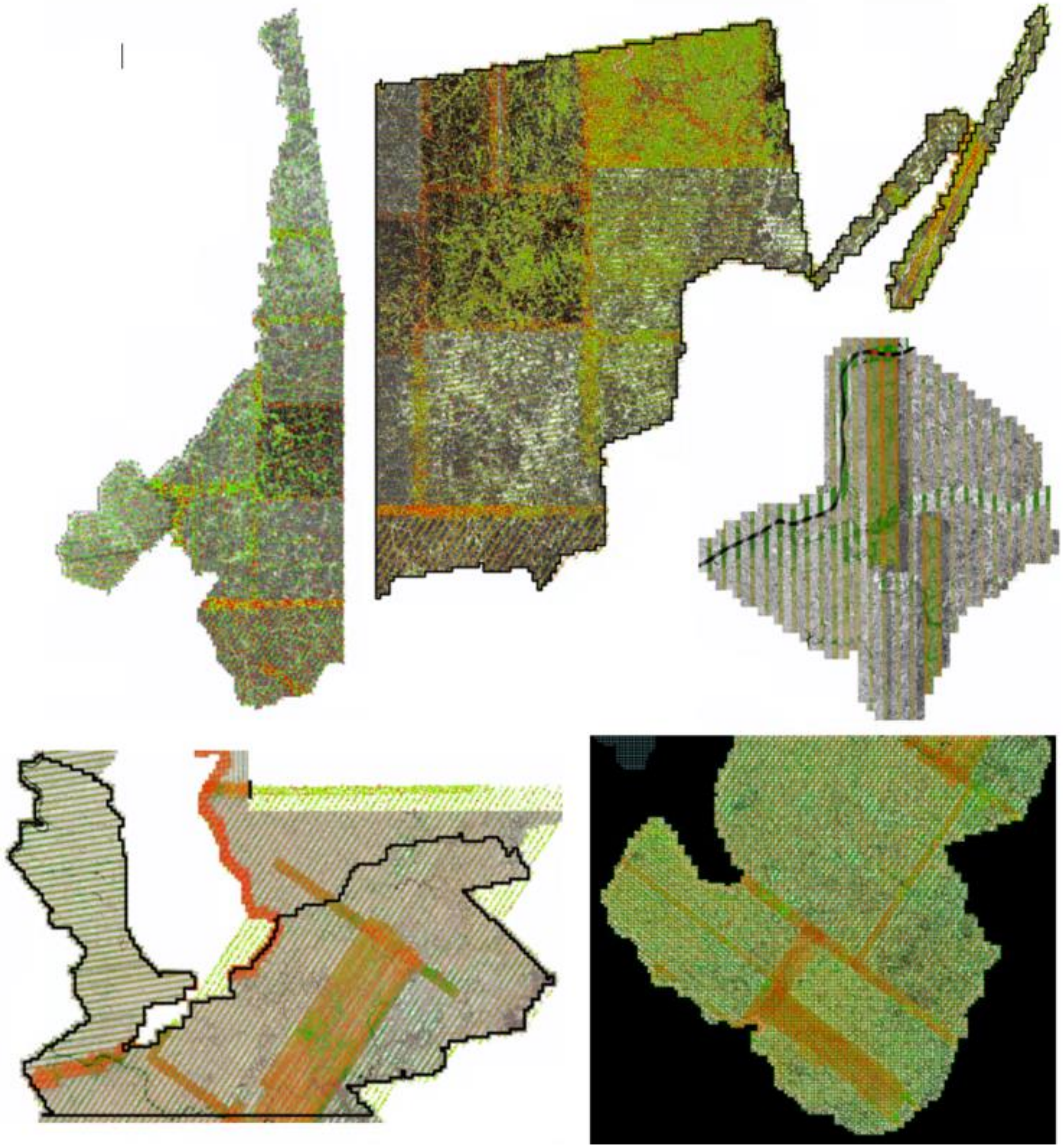

Figure 3 – Interswath accuracy analysis for the West Virginia FEMA R3 lidar project. Inter-swath relative accuracy passes specifications.

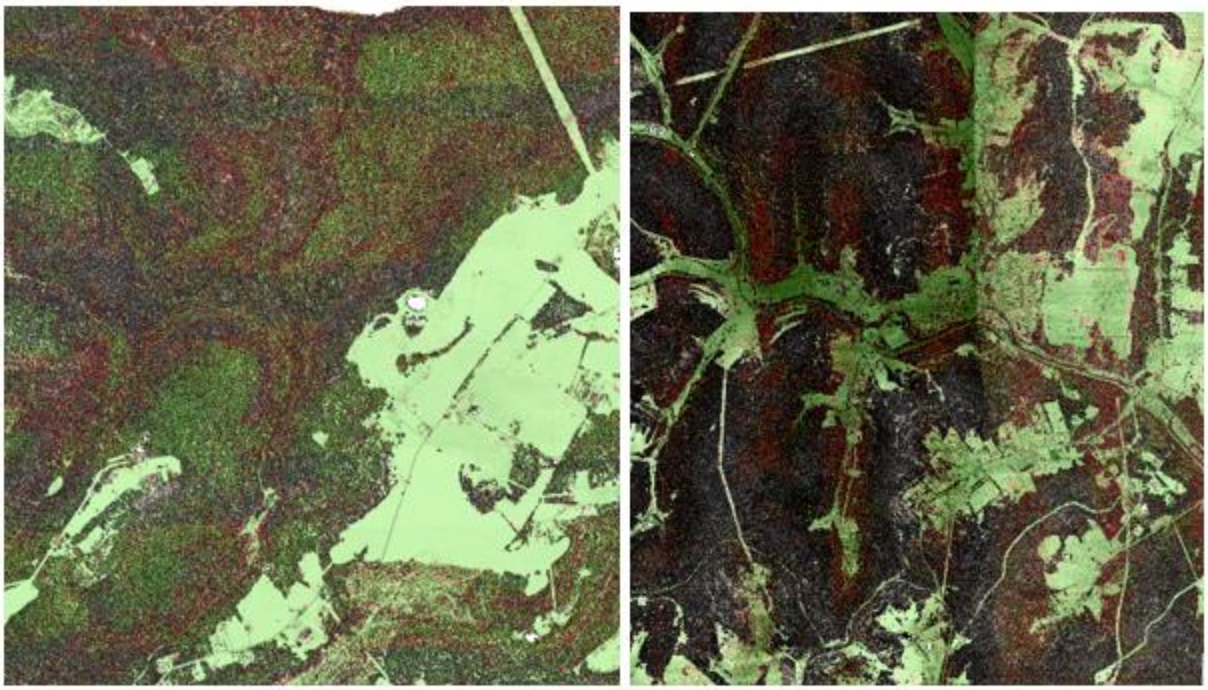

Figure 4 – These screenshots show close-ups of areas that may appear to exceed the threshold from a distance. These are mountainous forested regions but have threads of green where there are clearings spread throughout, the yellow area in the top right are agricultural fields.

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 an example of the intra-swath relative accuracy of West Virginia FEMA R3; this project meets intra-swath relative accuracy specifications.

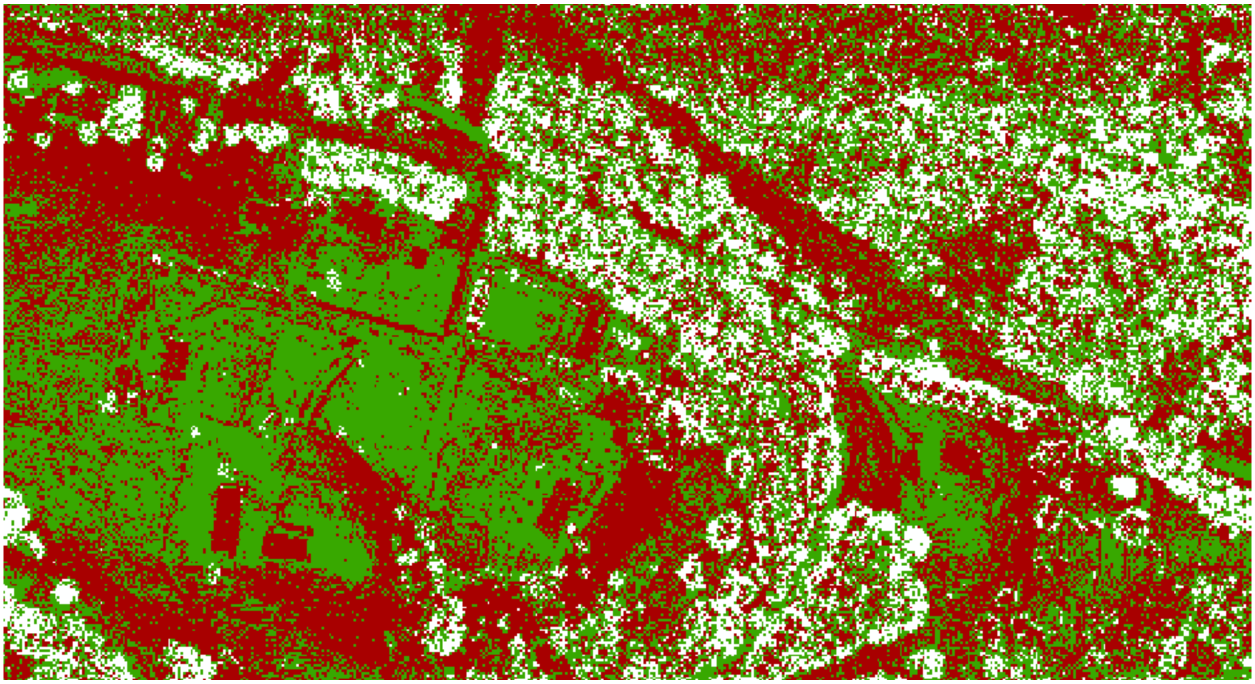

Figure 5 – Intra-swath relative accuracy. Areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The image shows a large portion of the dataset; flat, open areas are colored green, whereas sloped terrain is colored red because 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 R3; no horizontal alignment issues were identified.

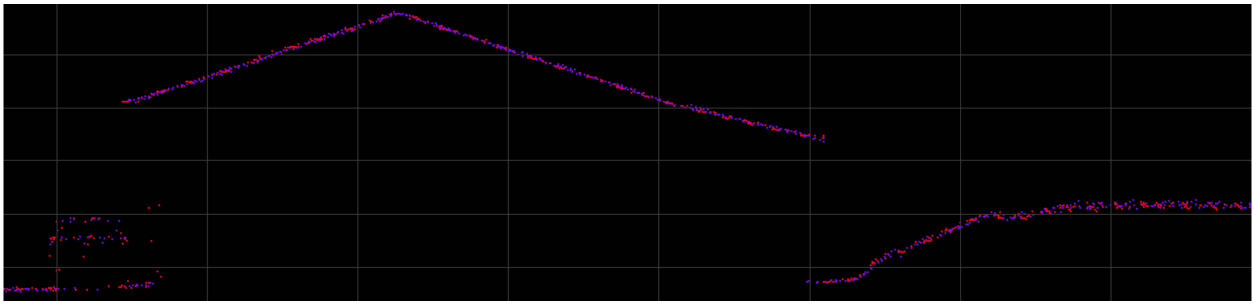

Figure 6 – Two separate flight lines differentiated by color (Red/Purple) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

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 0.47 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.

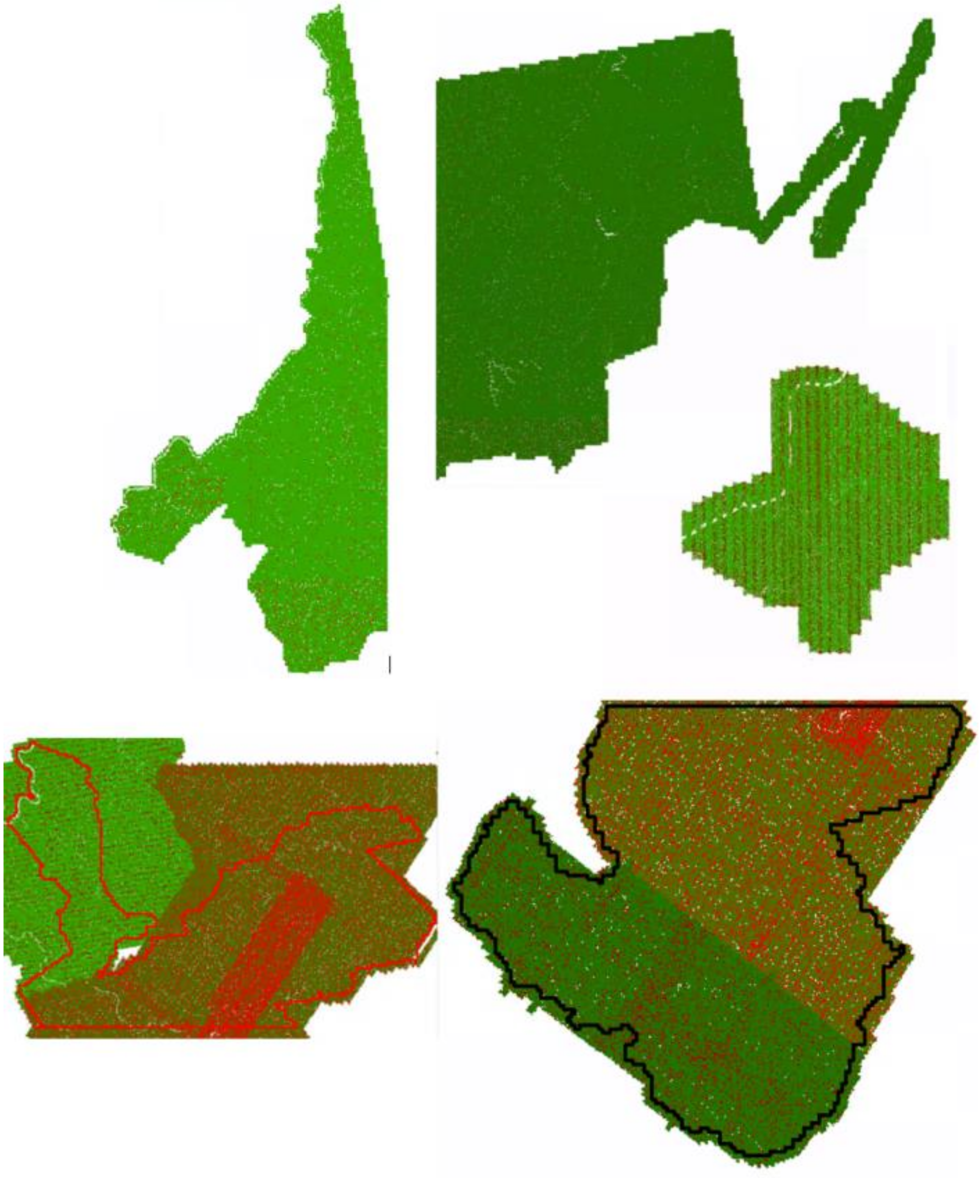

Figure 7 – 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-square meter cells contain at least 2 points per square meter (green areas) showing there are no systematic density 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.

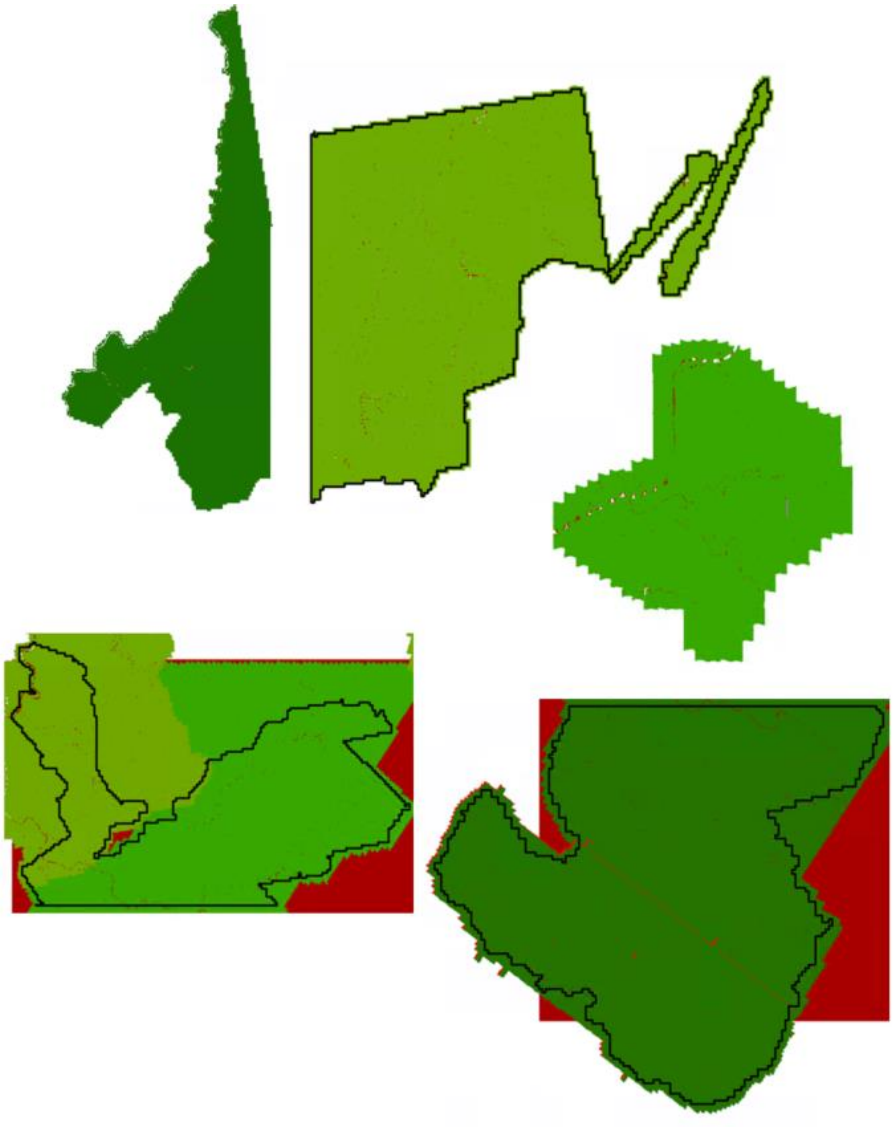

Figure 8 – All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies and other acceptable NoData areas, are colored red. Including acceptable NoData areas, 99.3% of cells contain at least one lidar point.

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, 17, 18, or 20, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 9 = Water
- Class 17 = Bridge Decks
- Class 18 = High Noise
- Class 20 = Ignored Ground

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 R3.

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.

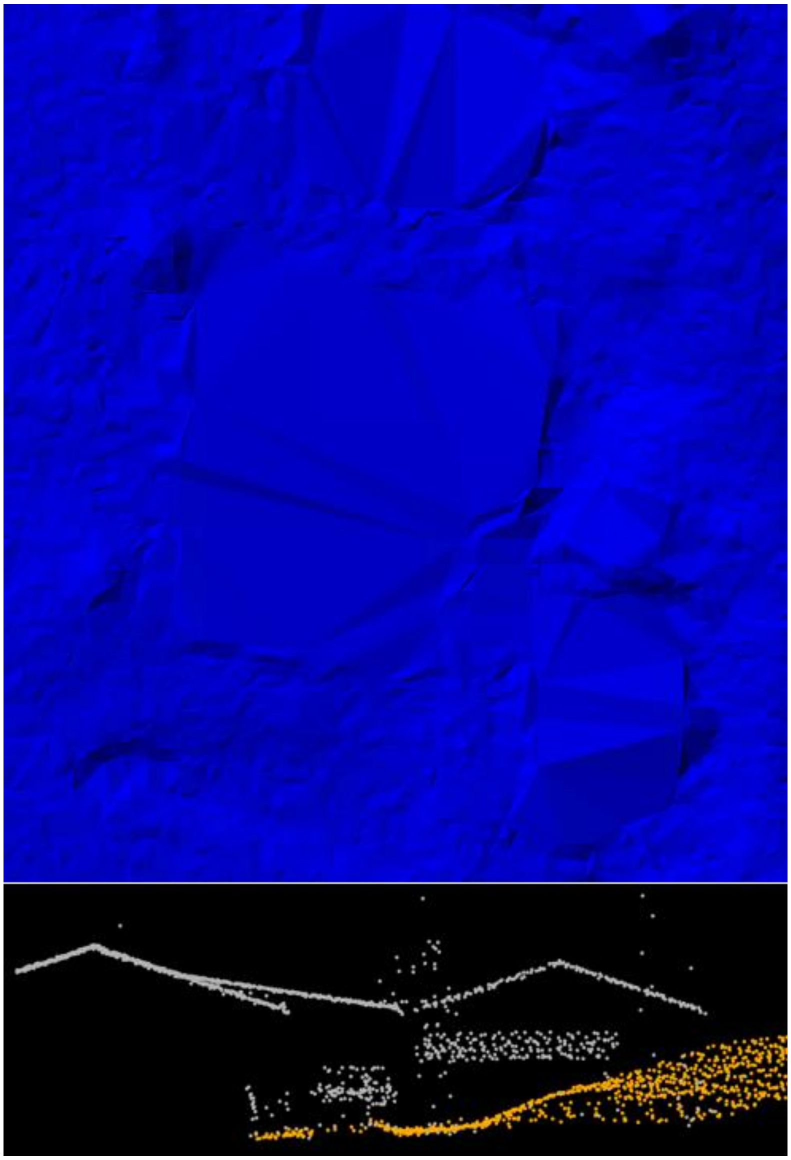

Figure 9 – e1311n1919. A profile with points colored by class (class 1=grey, class 2=orange) is shown in the top view and a TIN of the surface is shown in the bottom view. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

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.

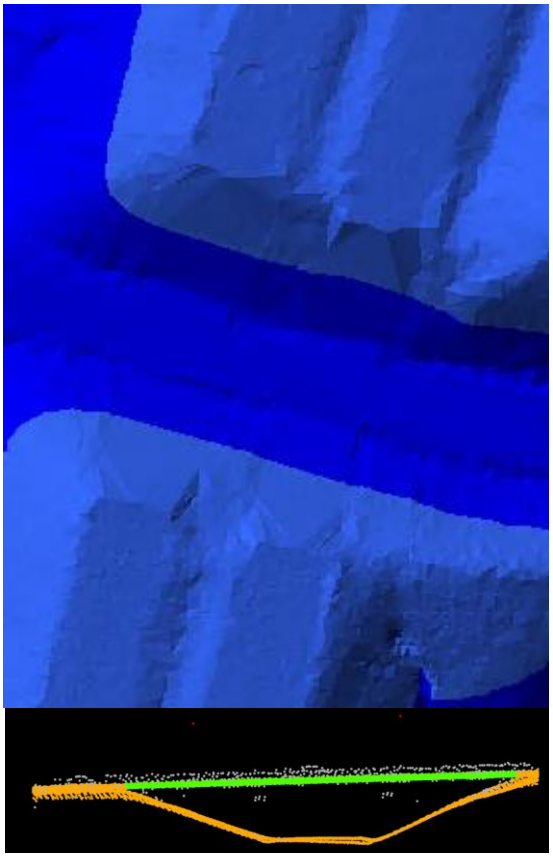

Figure 10 – Tile number e1341n1930. The DEM in the top view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. 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.

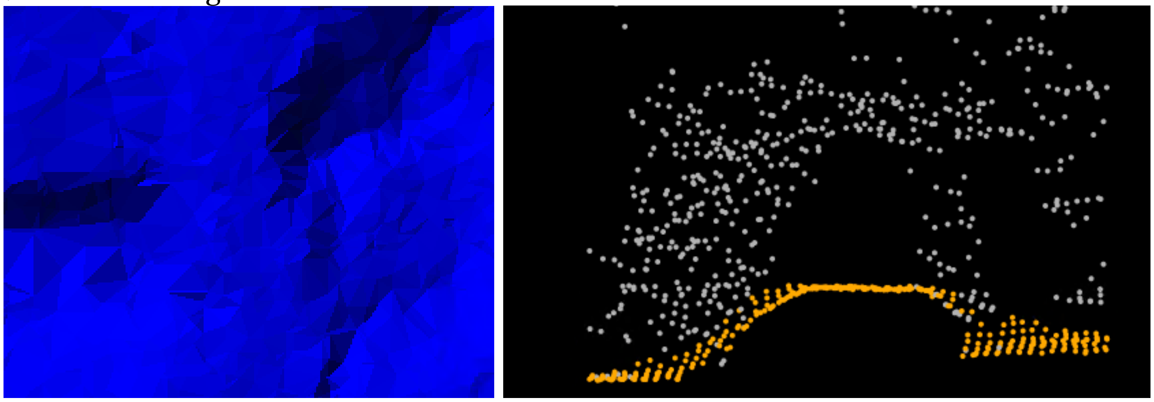

Figure 11– e1338n1933. A profile with points colored by class (class 1=grey, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

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) Conus Albers, 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 sensor type from acquisition	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 17: Bridge Decks Class 18: High Noise Class 20: Ignored Ground	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 4– 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.

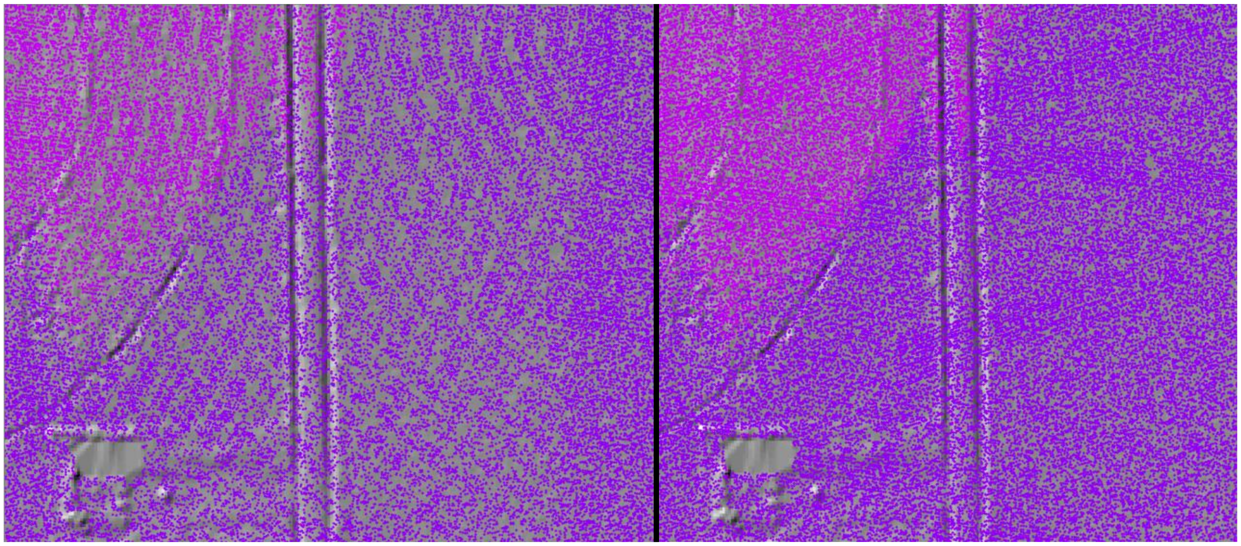

Figure 12 – The left image shows ground classified without synthetic points. The right image shows ground classified with synthetic points. Both images are overlaid on a hillshade of the example area

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. 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, 435 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..

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	1252989.595	1679554.387	414.802
NVA-10	1279046.379	1705817.277	577.591
NVA-100	1179627.764	1800536.852	170.693
NVA-101	1187573.959	1805785.465	293.205
NVA-102	1185807.003	1811839.489	174.820
NVA-103	1179841.535	1812089.698	178.456
NVA-104	1222003.212	1792308.959	201.838
NVA-105	1237932.166	1796938.599	181.132
NVA-106	1250320.505	1794657.705	194.666
NVA-107	1261995.832	1800681.483	225.394
NVA-108	1276832.912	1799955.764	321.281
NVA-109	1286473.081	1807925.248	274.341
NVA-11	1269482.897	1701564.803	718.741
NVA-110	1307581.989	1808588.487	565.047
NVA-111	1323424.147	1806596.521	699.796
NVA-112	1341364.007	1809244.174	766.256
NVA-113	1347803.730	1821964.774	718.343
NVA-114	1334224.789	1817434.801	720.386
NVA-115	1309530.671	1817852.749	659.057

NVA-116	1292484.306	1816549.108	253.010
NVA-117	1282503.741	1808137.608	259.511
NVA-118	1269418.099	1807367.480	301.603
NVA-119	1250955.943	1803534.741	213.953
NVA-12	1251914.487	1698995.504	360.729
NVA-120	1232203.779	1802049.788	206.751
NVA-121	1234553.740	1811160.447	201.483
NVA-122	1251649.186	1816867.454	207.934
NVA-123	1260932.597	1810818.201	217.562
NVA-124	1273219.247	1817206.627	203.269
NVA-125	1293907.713	1824397.687	401.344
NVA-126	1307687.254	1824828.973	455.249
NVA-127	1325182.222	1828718.066	463.320
NVA-128	1340736.094	1826644.037	443.638
NVA-129	1332268.199	1838993.915	320.560
NVA-13	1239813.956	1696159.524	308.891
NVA-130	1313798.960	1833729.079	339.512
NVA-131	1302772.688	1834106.816	320.171
NVA-132	1285714.445	1829827.279	258.069
NVA-133	1234138.085	1823347.181	200.472
NVA-134	1232299.101	1830836.548	283.267
NVA-135	1278439.527	1840216.678	244.857
NVA-136	1294903.785	1842006.531	262.442
NVA-137	1306860.023	1843407.099	264.424
NVA-138	1322203.245	1846329.670	346.715
NVA-139	1332220.412	1850390.866	540.705
NVA-14	1229111.834	1697815.243	286.147
NVA-140	1339878.685	1846171.289	453.751
NVA-141	1345675.105	1855567.606	715.988
NVA-142	1335634.248	1857731.143	309.621
NVA-143	1323340.443	1854850.077	372.251
NVA-144	1307935.682	1852148.495	278.575
NVA-145	1301453.025	1849734.287	414.545
NVA-146	1290964.473	1848632.953	234.031
NVA-147	1236989.515	1839976.381	309.632
NVA-148	1223079.093	1839473.669	228.620
NVA-149	1214180.421	1850590.354	184.953
NVA-15	1208887.785	1702060.793	221.830
NVA-150	1232874.062	1853201.316	311.921
NVA-151	1274088.530	1851037.653	224.835
NVA-152	1291203.364	1855827.053	367.043
NVA-153	1303420.651	1857968.905	250.566
NVA-154	1320302.136	1858770.632	251.774
NVA-155	1340365.477	1867445.936	525.111
NVA-156	1351214.431	1867214.761	550.821
NVA-157	1353114.216	1877746.549	501.800
NVA-158	1340064.947	1876513.961	463.017

NVA-159	1330987.825	1869946.288	332.750
NVA-16	1223948.387	1702396.639	255.480
NVA-160	1312930.836	1865282.330	233.855
NVA-161	1297740.849	1864368.751	233.950
NVA-162	1284777.021	1859791.038	217.349
NVA-163	1269608.861	1860029.089	354.861
NVA164	1229961.287	1864056.822	190.126
NVA-165	1217332.267	1861375.430	185.550
NVA-166	1267046.828	1868689.746	227.842
NVA-167	1275172.364	1866479.801	243.882
NVA-168	1286161.725	1869280.584	240.205
NVA-169	1298213.147	1872368.951	225.753
NVA-17	1236336.908	1708619.139	315.723
NVA-170	1310440.699	1876413.190	238.662
NVA-171	1323351.954	1878922.106	384.747
NVA-172	1338575.871	1886884.304	372.755
NVA-173	1359372.775	1886724.764	625.726
NVA-174	1371259.317	1893552.526	518.321
NVA-175	1370213.140	1910654.993	446.462
NVA-176	1364944.247	1902213.453	543.533
NVA-177	1347360.347	1895879.707	438.214
NVA-178	1331355.487	1896126.116	314.973
NVA-179	1317403.179	1888191.073	333.923
NVA-18	1245402.721	1703142.092	392.387
NVA-180	1305550.793	1881302.252	236.005
NVA-181	1288736.363	1879550.541	246.455
NVA-182	1274343.902	1876246.353	284.316
NVA-183	1218919.963	1872250.672	204.253
NVA-184	1233532.262	1877220.098	215.676
NVA-185	1264215.357	1882369.169	204.330
NVA-186	1283115.399	1890462.389	227.297
NVA-187	1303564.412	1898314.639	277.228
NVA-188	1321051.130	1899659.926	309.312
NVA-189	1334566.297	1904455.145	336.161
NVA-19	1260291.154	1702939.647	455.561
NVA-190	1349533.691	1906598.028	321.911
NVA-191	1358239.029	1910833.447	414.657
NVA-192	1432755.758	1923755.586	474.626
NVA-193	1433436.467	1928466.462	566.697
NVA-194	1441678.987	1944766.315	356.053
NVA-195	1444320.692	1953912.616	245.583
NVA-196	1450500.487	1966745.614	227.767
NVA-197	1457373.647	1977879.339	188.106
NVA-198	1434897.541	1951382.876	608.465
NVA-199	1427863.894	1945139.417	495.499
NVA-2	1270960.645	1682746.273	494.223
NVA-20	1283046.251	1712927.918	629.768

NVA-200	1415993.439	1932130.136	709.351
NVA-201	1396987.213	1931858.318	832.940
NVA-202	1376223.525	1928080.685	512.897
NVA-203	1356923.490	1927050.081	301.393
NVA-204	1337259.403	1916218.497	381.132
NVA-205	1314305.061	1913593.223	328.195
NVA-206	1289217.591	1904171.011	263.032
NVA-207	1274263.967	1898591.683	253.884
NVA-208	1255621.428	1893802.059	212.456
NVA-209	1241615.172	1890296.722	191.588
NVA-21	1287680.760	1720235.700	649.899
NVA-210	1222429.708	1891506.859	222.791
NVA-211	1231775.798	1903734.894	224.908
NVA-212	1243224.564	1905754.626	235.277
NVA-213	1267778.604	1911130.999	305.402
NVA-214	1282884.502	1917557.119	264.311
NVA-215	1299210.993	1920052.007	252.120
NVA-216	1315111.598	1923550.607	325.433
NVA-217	1333233.196	1928101.877	322.541
NVA-218	1348281.346	1930851.155	413.706
NVA-219	1365532.181	1936789.372	516.531
NVA-22	1270689.090	1712756.873	425.522
NVA-220	1383738.233	1946352.667	552.024
NVA-221	1396129.084	1958093.277	772.379
NVA-222	1373350.357	1948927.898	523.389
NVA-223	1353417.314	1943358.701	409.806
NVA-224	1342001.691	1939976.567	312.640
NVA-225	1323078.686	1936606.187	313.453
NVA-226	1304143.328	1931631.915	291.762
NVA-227	1288718.824	1928086.893	217.813
NVA-228	1264716.325	1927516.937	190.301
NVA-229	1275949.720	1936183.606	236.433
NVA-23	1258130.224	1713760.633	533.039
NVA-230	1290289.033	1939715.355	389.937
NVA-231	1309761.429	1944100.766	269.646
NVA-232	1324506.481	1948945.853	303.772
NVA-233	1349185.808	1956055.222	306.971
NVA-234	1359492.761	1955180.023	406.146
NVA-235	1383060.720	1963669.142	568.550
NVA-236	1392974.566	1975020.118	646.430
NVA-237	1366632.734	1967456.109	311.727
NVA-238	1352811.690	1968349.589	288.198
NVA-239	1336003.610	1960880.771	307.262
NVA-24	1248431.019	1711119.669	352.075
NVA-240	1315813.516	1958300.151	315.355
NVA-241	1295529.654	1954667.381	419.170
NVA-242	1281757.313	1953210.366	205.531

NVA-243	1288935.629	1967241.357	210.323
NVA-244	1301959.255	1973628.702	314.214
NVA-245	1295926.099	1983985.768	353.852
NVA-246	1303311.150	1994979.209	432.252
NVA-247	1285894.629	1996864.658	197.702
NVA-248	1294530.878	2010294.396	328.908
NVA-249	1293403.893	2022222.594	305.417
NVA-25	1227037.983	1713151.600	288.553
NVA-250	1295993.753	2033685.348	242.776
NVA-251	1292510.436	2043663.184	339.674
NVA-252	1290146.649	2052493.403	309.590
NVA-253	1285509.802	2060518.545	228.731
NVA-26	1218069.920	1708149.707	349.230
NVA-27	1205018.232	1708390.095	213.257
NVA-28	1195070.699	1713251.099	263.412
NVA-29	1202307.124	1717895.373	226.065
NVA-3	1274300.028	1691934.100	575.765
NVA-30	1211974.063	1718391.454	528.282
NVA-31	1231017.252	1719842.728	231.893
NVA-32	1239041.313	1716563.702	338.794
NVA-33	1246884.279	1715538.346	384.541
NVA-34	1266254.621	1719391.678	590.333
NVA-35	1278364.896	1723292.710	514.844
NVA-36	1286077.223	1727964.163	797.596
NVA-37	1278158.821	1732216.538	618.410
NVA-38	1271943.701	1732222.072	585.529
NVA-39	1264226.174	1724103.136	552.034
NVA-4	1262707.846	1687970.822	428.563
NVA-40	1250088.640	1722890.727	382.226
NVA-41	1235664.152	1724951.406	267.539
NVA-42	1217430.025	1725408.035	247.285
NVA-43	1207596.638	1724759.461	490.030
NVA-44	1195568.975	1724639.005	218.801
NVA-45	1186884.731	1724969.757	194.498
NVA-46	1183034.798	1731943.042	186.595
NVA-47	1198470.977	1733194.934	268.684
NVA-48	1211505.725	1732448.375	267.342
NVA-49	1225714.233	1733167.507	252.685
NVA-5	1241682.471	1690207.081	316.126
NVA-50	1242226.092	1734713.568	392.600
NVA-51	1256654.853	1734778.097	859.242
NVA-52	1273905.026	1741544.833	543.148
NVA-53	1273137.396	1747598.982	493.395
NVA-54	1262716.818	1743305.940	399.946
NVA-55	1246819.791	1742752.060	330.378
NVA-56	1236484.421	1746917.198	301.398
NVA-57	1223096.597	1738655.836	251.765

NVA-58	1200449.408	1739549.242	286.487
NVA-59	1190219.016	1737796.092	284.577
NVA-6	1232809.847	1692698.871	318.174
NVA-60	1184915.140	1743259.189	229.706
NVA-60-2	1184902.275	1743264.152	229.513
NVA-61	1192436.056	1751379.738	237.904
NVA-62	1222972.819	1745821.629	294.857
NVA-63	1238631.292	1753022.192	248.578
NVA-64	1254156.844	1753583.360	261.114
NVA-65	1275352.176	1758832.661	441.268
NVA-66	1287130.978	1761939.950	594.651
NVA-67	1304043.890	1766797.207	699.222
NVA-68	1296987.986	1778261.636	659.449
NVA-69	1285107.809	1773848.091	409.160
NVA-7	1253600.277	1689043.427	443.312
NVA-70	1269416.421	1767558.407	355.563
NVA-71	1259527.165	1767010.420	268.690
NVA-72	1245454.113	1762235.414	259.144
NVA-73	1227721.227	1761110.614	236.876
NVA-74	1217177.637	1759888.450	268.742
NVA-75	1223327.041	1773500.694	209.031
NVA-76	1241529.784	1772336.227	208.969
NVA-77	1258089.230	1777192.268	204.074
NVA-78	1268246.208	1781148.137	196.234
NVA-79	1284812.000	1786843.769	266.481
NVA-8	1264164.630	1693456.402	441.286
NVA-80	1303074.477	1791628.590	506.458
NVA-81	1322060.697	1794605.340	836.974
NVA-82	1307228.479	1798697.898	569.887
NVA-83	1293248.055	1794690.950	331.488
NVA-84	1277409.263	1793406.416	259.694
NVA-85	1262727.181	1790067.302	245.450
NVA-86	1249296.640	1784042.666	188.740
NVA-87	1237281.736	1785686.778	246.251
NVA-88	1225540.282	1784395.945	204.861
NVA-89	1184755.131	1780514.964	201.304
NVA-9	1279271.704	1699602.743	657.732
NVA-90	1189619.409	1785530.473	179.823
NVA-91	1177938.452	1785529.318	289.922
NVA-92	1171328.361	1787570.813	262.800
NVA-93	1184442.892	1789648.794	185.144
NVA-94	1190989.427	1791523.014	241.940
NVA-95	1196250.871	1797711.107	197.459
NVA-96	1196307.929	1804300.768	207.001
NVA-97	1188501.925	1796987.847	188.514
NVA-98	1178771.057	1793955.542	209.200
NVA-99	1170174.229	1793894.890	169.140

VVA-1	1289402.090	2058401.554	383.454
VVA-10	1288102.579	1956115.083	324.850
VVA-100	1317659.031	1829649.647	626.743
VVA101	1304846.354	1838111.659	299.873
VVA-102	1302337.516	1827442.755	409.160
VVA-103	1292442.854	1834592.650	271.856
VVA-104	1295080.444	1831457.390	240.586
VVA-105	1282808.421	1824292.200	392.624
VVA-106	1239944.844	1818800.620	197.952
VVA-107	1229308.220	1819360.440	279.128
VVA-108	1184619.107	1807773.317	298.245
VVA-109	1183500.261	1801752.179	292.791
VVA-11	1309472.978	1952612.514	444.825
VVA-110	1174988.500	1789806.367	189.554
VVA-111	1194670.397	1792865.388	192.222
VVA-112	1236256.276	1811765.410	192.989
VVA-113	1277618.285	1812459.304	210.143
VVA-114	1290164.577	1819946.391	408.047
VVA-115	1302022.072	1819789.929	480.060
VVA-116	1316066.339	1819785.906	426.016
VVA-117	1329604.274	1819683.256	681.724
VVA-118	1346427.586	1821085.474	711.320
VVA-119	1342722.070	1813061.868	695.169
VVA-12	1330165.774	1955820.461	500.377
VVA-120	1337089.255	1810285.379	942.669
VVA-121	1310201.105	1808904.185	567.570
VVA-122	1299971.854	1802044.930	436.864
VVA-123	1287114.777	1809858.158	441.810
VVA-124	1266342.822	1803504.395	436.463
VVA-125	1259975.109	1804941.150	282.324
VVA-126	1253491.565	1796561.647	214.030
VVA-127	1236212.606	1800828.475	184.409
VVA-128	1218693.350	1793034.150	183.839
VVA-129	1223937.371	1778927.594	209.531
VVA-13	1365600.362	1961589.163	410.459
VVA-130	1237360.204	1776509.997	226.710
VVA-131	1269928.509	1783962.916	228.248
VVA-132	1282201.600	1794154.027	246.485
VVA-133	1298734.791	1798353.022	385.423
VVA-134	1312007.659	1796120.971	675.645
VVA-135	1325261.127	1802204.332	584.916
VVA-136	1293842.095	1782370.452	551.257
VVA-136	1293842.095	1782370.452	551.257
VVA-137	1278497.413	1778868.756	193.985
VVA-138	1263633.104	1774886.300	219.122
VVA-139	1252195.357	1771443.434	495.596
VVA-14	1383610.687	1971149.899	544.548

VVA-140	1230743.447	1765742.294	259.000
VVA-141	1222352.672	1754472.956	297.029
VVA-142	1244867.844	1758540.250	299.816
VVA-143	1262681.722	1761183.230	355.449
VVA-144	1275406.632	1767856.221	337.134
VVA-145	1297134.768	1770606.776	644.010
VVA-146	1290614.425	1759066.532	507.493
VVA-147	1269850.127	1753055.056	413.731
VVA-148	1255295.294	1745663.830	300.921
VVA-149	1242112.748	1747770.768	283.470
VVA-15	1393073.007	1963453.446	680.132
VVA-150	1228415.202	1744222.069	274.934
VVA-151	1192722.002	1746644.847	363.858
VVA-152	1184343.131	1736121.807	214.095
VVA-153	1191069.963	1731154.416	409.862
VVA-154	1213898.983	1729798.941	250.490
VVA-155	1230815.093	1733623.157	383.805
VVA-156	1245423.739	1734499.236	461.711
VVA-157	1268941.706	1738294.983	573.752
VVA-158	1276084.364	1735755.539	585.676
VVA-159	1285162.834	1721926.982	566.623
VVA-16	1382667.575	1956532.436	671.998
VVA-160	1253297.436	1720371.491	408.743
VVA-161	1241686.346	1718157.409	381.137
VVA-162	1231378.861	1724466.563	238.274
VVA-164	1192403.014	1715673.036	198.700
VVA-165	1211470.166	1710475.692	299.888
VVA-166	1224057.764	1708582.713	501.699
VVA-167	1233150.949	1700171.778	338.307
VVA-168	1252333.567	1708721.577	372.948
VVA-169	1277316.862	1711504.813	700.472
VVA-17	1362829.850	1949806.299	558.180
VVA-170	1272395.244	1696382.508	563.260
VVA-171	1260277.804	1696954.597	439.777
VVA-172	1246806.493	1690473.450	650.444
VVA-173	1229493.240	1694872.005	323.718
VVA-174	1236954.472	1686734.244	603.435
VVA-175	1244386.250	1680949.549	401.971
VVA-176	1254070.365	1685677.460	601.102
VVA-177	1272737.240	1687020.315	514.450
VVA-178	1264046.820	1682358.190	532.866
VVA-179	1257362.816	1672487.476	475.977
VVA-18	1336563.166	1945073.548	301.716
VVA-180	1264655.618	1674978.192	537.999
VVA-19	1319349.886	1940908.716	310.004
VVA-2	1290940.801	2047274.535	364.154
VVA-20	1299858.424	1941606.304	219.059

VVA-21	1280235.832	1942579.700	231.122
VVA-22	1271719.247	1928233.040	197.135
VVA-23	1287448.557	1933593.705	383.834
VVA-24	1311323.596	1936721.024	262.660
VVA-25	1330497.390	1935579.579	294.205
VVA-26	1347528.203	1940598.905	332.916
VVA-27	1374571.105	1940802.688	443.653
VVA-28	1398468.165	1945418.258	785.408
VVA-29	1431628.052	1948147.819	467.422
VVA-3	1293306.563	2039754.405	335.292
VVA-30	1424951.546	1936429.408	835.185
VVA-31	1412554.242	1927202.773	777.121
VVA-32	1431572.558	1921189.654	534.655
VVA-33	1439487.570	1936582.277	430.347
VVA-34	1451002.212	1963052.558	513.257
VVA-35	1386571.182	1929996.813	431.986
VVA-36	1371506.523	1929288.989	406.236
VVA-37	1350459.723	1924499.024	337.735
VVA-38	1330956.889	1920720.509	326.086
VVA-39	1316325.797	1919967.304	326.517
VVA-4	1294825.215	2028355.608	353.534
VVA-40	1306806.631	1924128.066	245.288
VVA-41	1286825.994	1922755.239	218.313
VVA-42	1270910.785	1922124.358	251.425
VVA-43	1258565.323	1917094.381	262.764
VVA-44	1249549.817	1905167.898	195.646
VVA-45	1233545.276	1907353.944	285.872
VVA-46	1221422.014	1886653.147	280.913
VVA-47	1245157.600	1894742.139	273.402
VVA-48	1260708.175	1896543.901	297.678
VVA-49	1274500.871	1907469.569	249.243
VVA-5	1292132.966	2014943.576	339.890
VVA-50	1284637.463	1897990.512	259.220
VVA-51	1294607.959	1909741.257	361.746
VVA-52	1307050.653	1903723.953	301.214
VVA-53	1321497.588	1908087.696	397.703
VVA-54	1343105.282	1911443.264	312.807
VVA-55	1357123.689	1916142.567	350.097
VVA-56	1367001.566	1921838.593	497.030
VVA-57	1375727.342	1914359.281	498.950
VVA-58	1368127.201	1899490.697	514.251
VVA-59	1351618.411	1898066.892	432.352
VVA-6	1297607.630	2000254.799	294.377
VVA-60	1344201.599	1891658.634	438.435
VVA-61	1324510.224	1894208.786	318.032
VVA-62	1313964.796	1893286.501	279.581
VVA-63	1299279.993	1888823.347	239.378

VVA-64	1290287.492	1882912.681	266.292
VVA-65	1277250.938	1885894.159	212.757
VVA-66	1261558.687	1884603.187	231.630
VVA-67	1225665.471	1874552.835	202.029
VVA-67	1225665.471	1874552.835	202.029
VVA-68	1219788.060	1865430.664	174.650
VVA-69	1233252.061	1857853.899	195.625
VVA-7	1302762.942	1988463.567	248.987
VVA-70	1271972.163	1871072.607	319.714
VVA-71	1285004.407	1875861.081	322.107
VVA-72	1298207.582	1879218.170	235.356
VVA-73	1306373.756	1872546.764	225.742
VVA-74	1316461.444	1881001.925	358.644
VVA-75	1328825.991	1876798.622	386.244
VVA-76	1344364.033	1879000.642	456.331
VVA-77	1364515.822	1890126.866	704.983
VVA-78	1354822.294	1871527.254	664.484
VVA-79	1338599.364	1861227.775	587.275
VVA-8	1289160.129	1978007.494	206.974
VVA-80	1324785.381	1863359.290	252.722
VVA-81	1313773.536	1860186.172	236.466
VVA-82	1301389.637	1863973.577	277.154
VVA-83	1291069.805	1859886.196	229.781
VVA-84	1279907.751	1854002.848	366.547
VVA-85	1273342.818	1859287.242	356.158
VVA-86	1234316.131	1844911.149	199.187
VVA-87	1217972.752	1848199.169	185.162
VVA-88	1226079.411	1835367.745	208.149
VVA-89	1237186.243	1831875.033	312.066
VVA-9	1298002.780	1966033.670	233.329
VVA-90	1277692.391	1847230.988	231.749
VVA-91	1287342.911	1841745.049	276.006
VVA-92	1295890.074	1847447.244	257.798
VVA-93	1306885.700	1847259.122	294.368
VVA-94	1314673.221	1840256.953	462.644
VVA-95	1326397.431	1850911.437	479.109
VVA-96	1340125.991	1850670.988	507.608
VVA-97	1349222.273	1859675.196	731.393
VVA-98	1334541.451	1831069.859	355.237
VVA-99	1324247.794	1836546.545	328.023

Table 5 – West Virginia FEMA R3 lidar surveyed accuracy checkpoints

One checkpoints (VVA-163) was removed from the vertical accuracy testing for the classified lidar due to the proximity to a break in the terrain. As per the task order, checkpoints should not be located within five (5) meters of any breakline where there is a change in slope. Breaks in the terrain may cause erroneous vertical accuracy results due to interpolation of the surface, which does not adequately test how well a sensor performed or how well a vegetation filtering technique performed. The coordinates of this checkpoint is provided in the table below and profile showing the checkpoint located near breaks in the terrain are provided in the figures below.

Point ID	NAD83(2011) Conus Albers		NAVD88 (Geoid 12B)	Lidar Z (m)
	Easting X (m)	Northing Y (m)	Survey Z (m)	
VVA-163	1219219.062	1720117.043	308.302	slope

Table 6: Checkpoint removed from vertical accuracy testing due to the location near breaks in the terrain

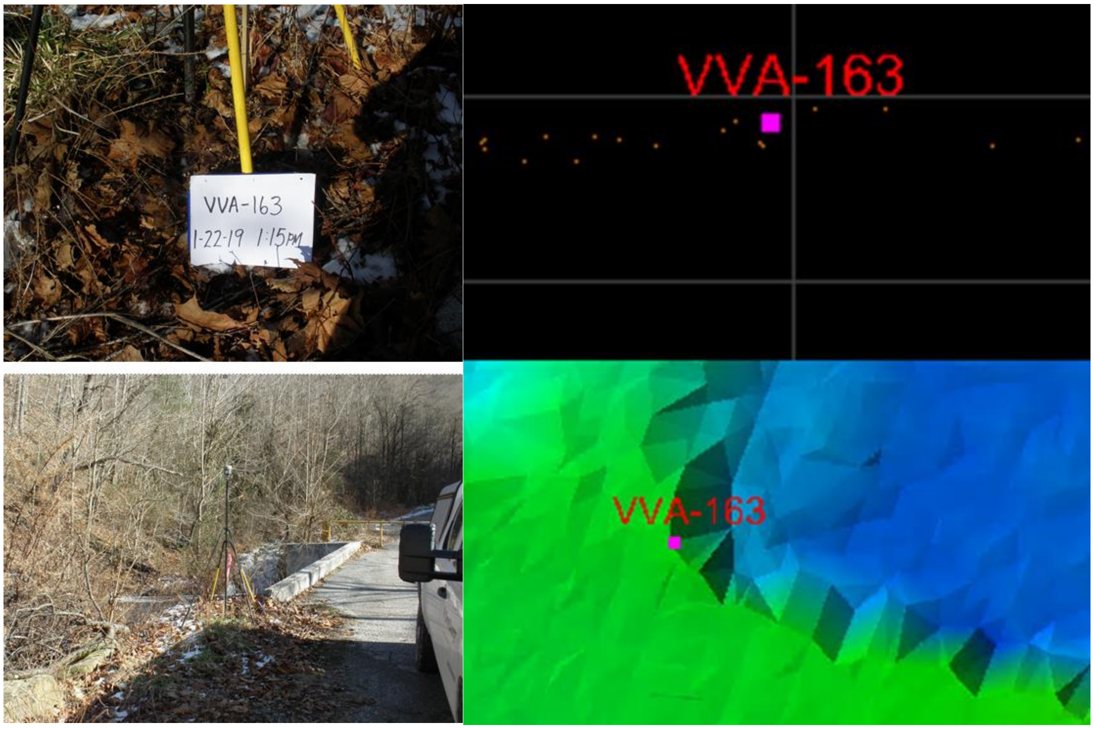

Figure 13 – VVA-163, shown as the purple square in the profile, is located on the edge of an embankment. This checkpoint was removed from all vertical accuracy calculations due to its proximity to breaks in the terrain.

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

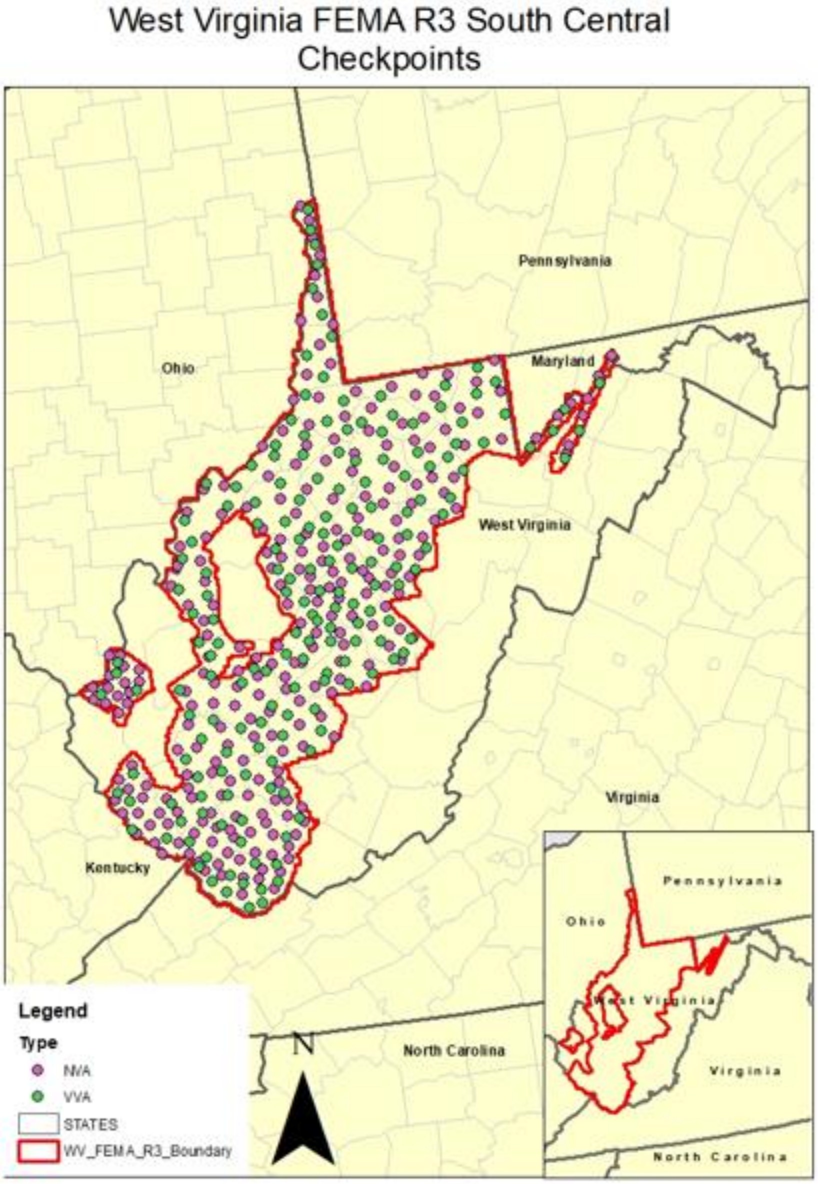

Figure 14 – Location of QA/QC Checkpoints

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 R3 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 R3 Lidar Project VVA standard is 30 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 7.

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	30 cm (based on combined 95th percentile)

Table 7 — 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=30 cm
NVA	254	10.1	
VVA	181		13.8

Table 8 – 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$_z$ = 5.1cm, equating to ± 10.1 cm at 95% confidence level. Actual VVA accuracy was found to be ± 13.8 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 ± 10 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +28 cm.

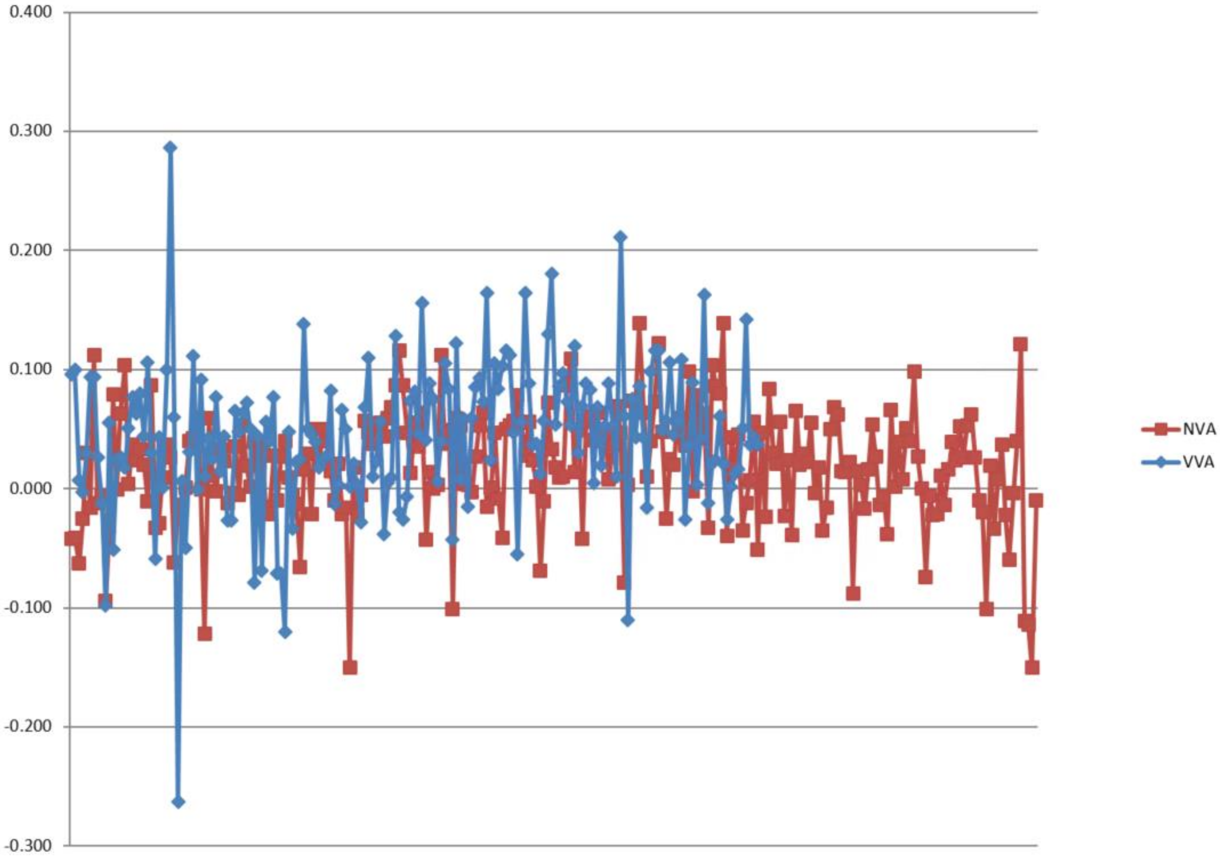

Figure 15– Magnitude of elevation discrepancies per land cover category

Table 9 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	**NAD83(2011)** Albers Equal Area		**NAVD88 (Geoid 12B)**		**DeltaZ**	**AbsDeltaZ**
	Easting X (m)	**Northing Y (m)**	**Z-Survey (m)**	**Z-LiDAR (m)**		
VVA-96	1340125.991	1850670.988	507.608	507.750	-0.142	0.142
VVA-2	1290940.801	2047274.535	364.154	364.310	-0.156	0.156
VVA-86	1234316.131	1844911.149	199.187	199.350	-0.163	0.163
VVA-35	1386571.182	1929996.813	431.986	432.150	-0.164	0.164
VVA-44	1249549.817	1905167.898	195.646	195.810	-0.164	0.164
VVA-50	1284637.463	1897990.512	259.220	259.400	-0.180	0.180
VVA-67	1225665.471	1874552.835	202.029	202.240	-0.211	0.211
VVA-124	1266342.822	1803504.395	436.463	436.200	0.263	0.263
VVA-122	1299971.854	1802044.930	436.864	437.150	-0.286	0.286

Table 9 — Lidar VVA 5% outliers

Table 10 provides overall descriptive statistics for NVA and VVA assessments.

100 % of Totals	**# of Points**	**RMSEz (m) Spec=0.100 m NVA**	**Mean (m)**	**Median (m)**	**Skew**	**Std Dev (m)**	**Kurtosis**	**Min (m)**	**Max (m)**
NVA	254	0.051	0.019	0.023	-0.566	0.048	1.225	-0.150	0.139
VVA	181	N/A	0.044	0.045	-0.453	0.062	4.006	-0.263	0.286

Table 10 — 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.

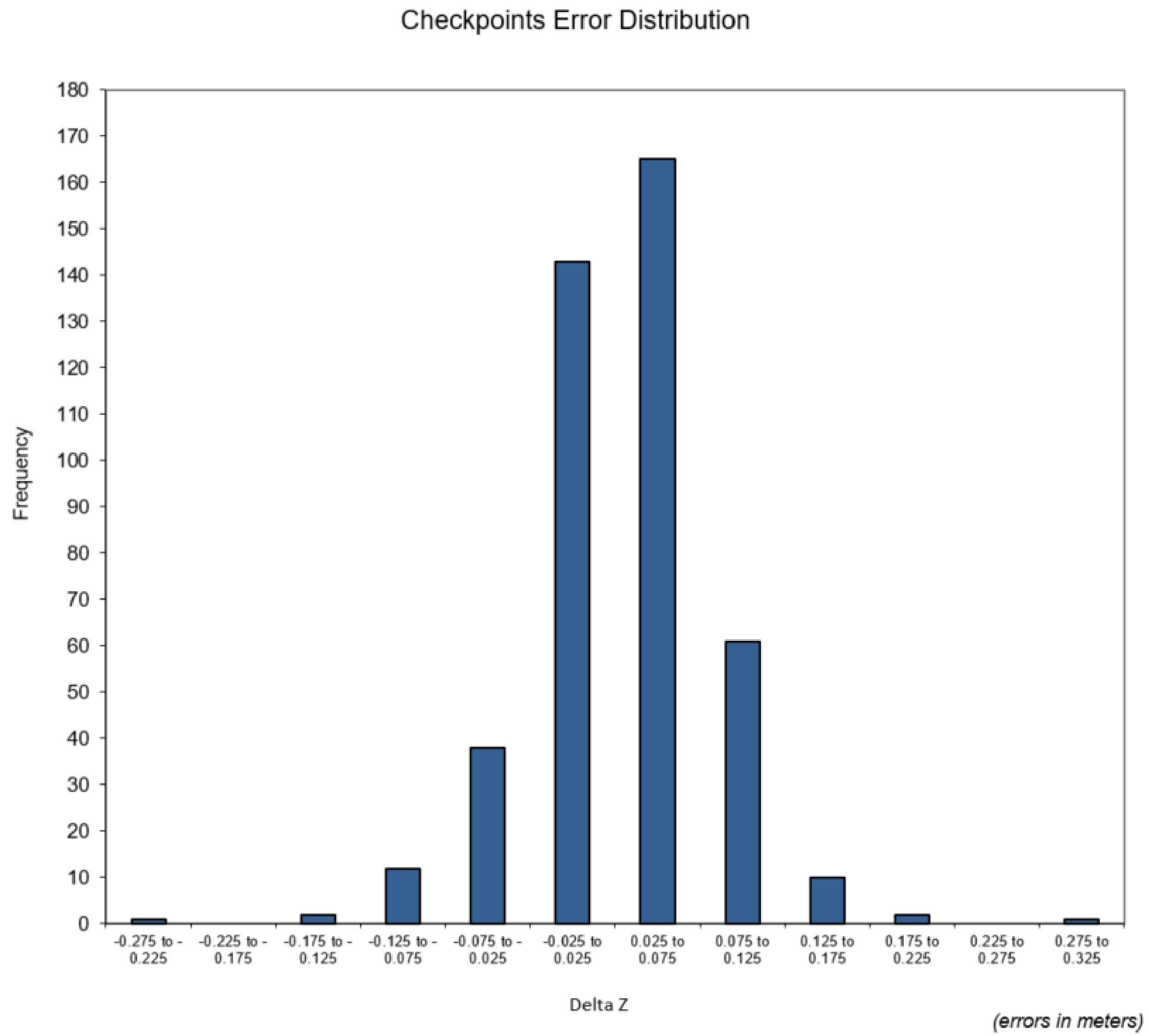

Figure 16— Histogram of elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the USGS West Virginia FEMA R3 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

Fifty-Three 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
53	26.1	28	38.8	66.3

Table 11 – 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. Fifty-three checkpoints were used for horizontal accuracy testing. Actual positional accuracy of this dataset was found to be RMSE$_x$ = 26.1 cm and RMSE$_y$ = 28 cm, which equates to ± 66.3 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.

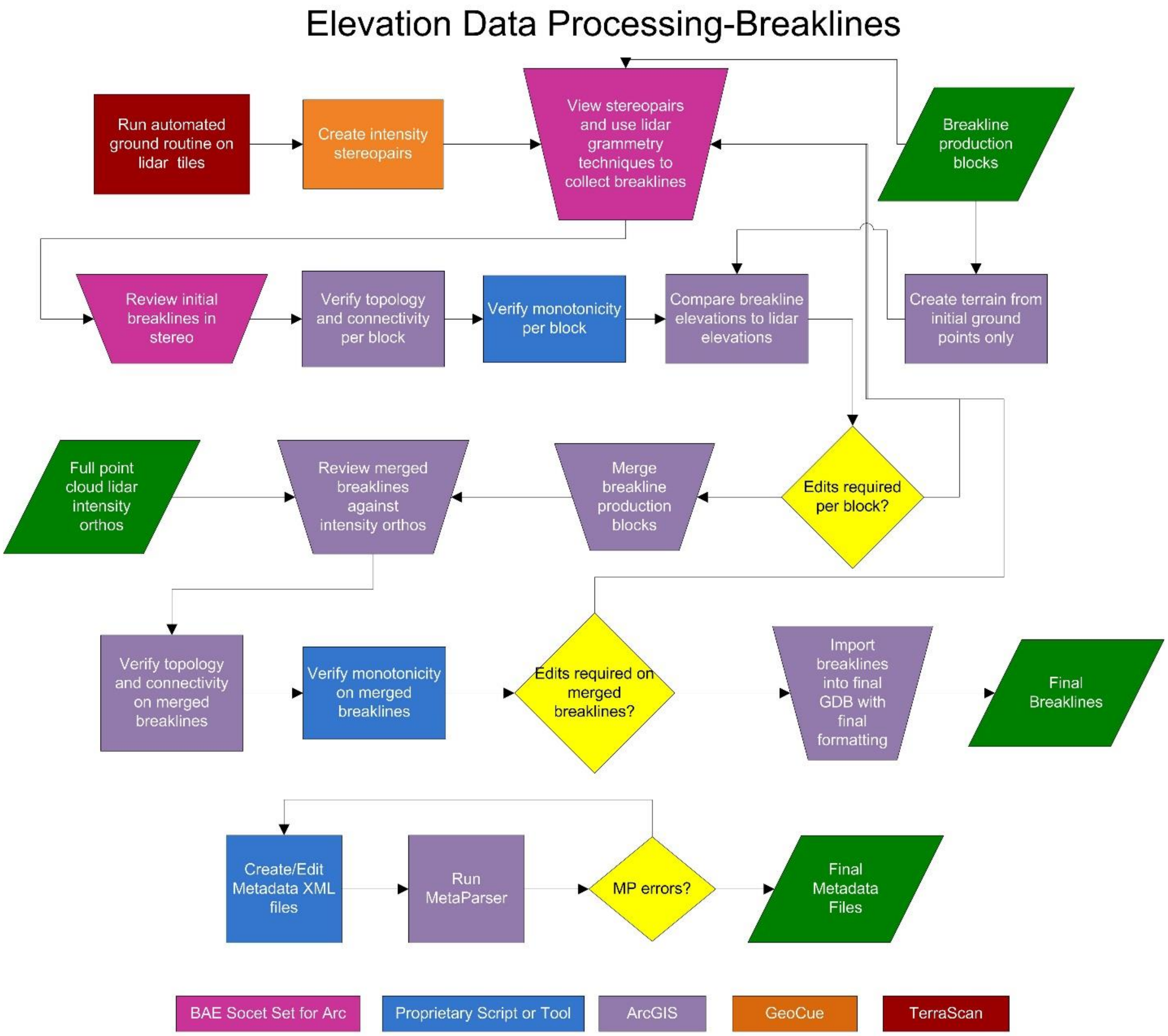

Figure 17 – Breakline QA/QC workflow

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 20) 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 12 – 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 18 – 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.

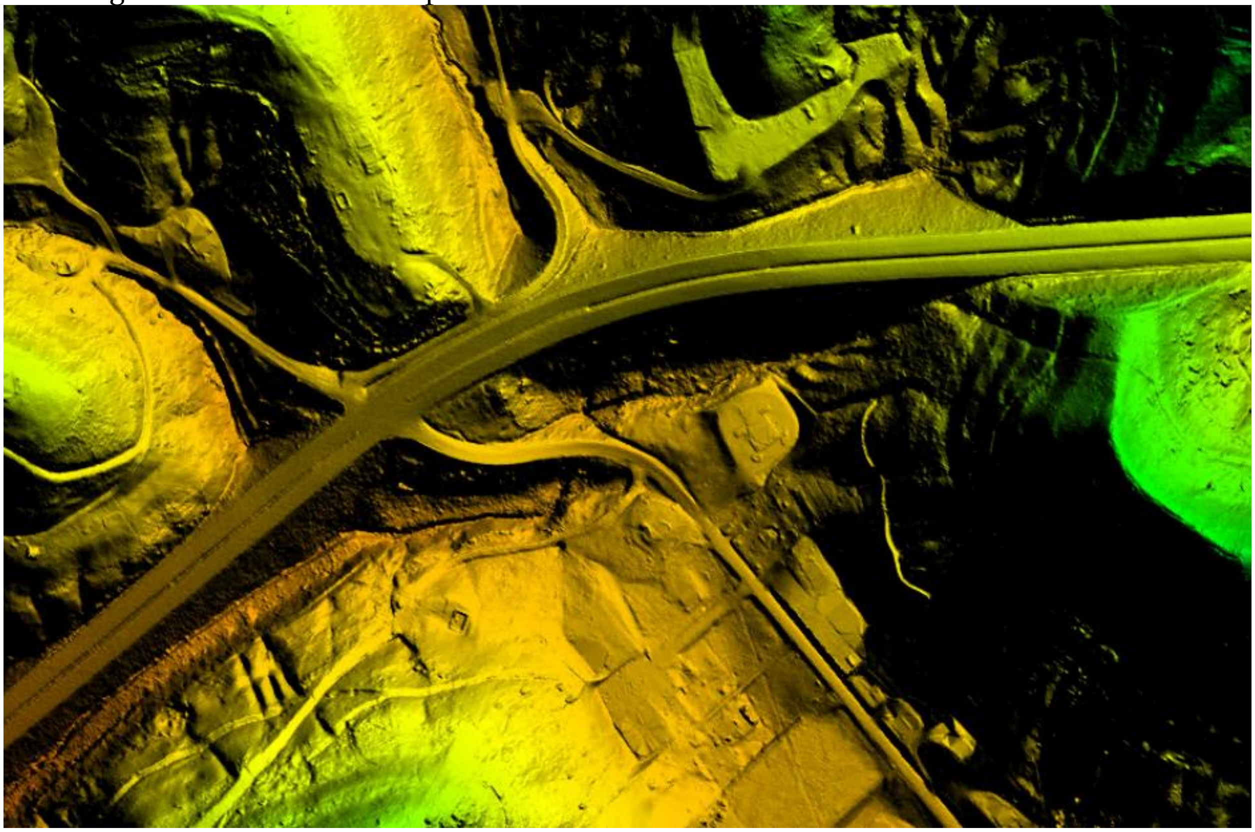

Figure 19- Tile e1310n1914. Map view of the bare Earth DEM with hillshade

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.

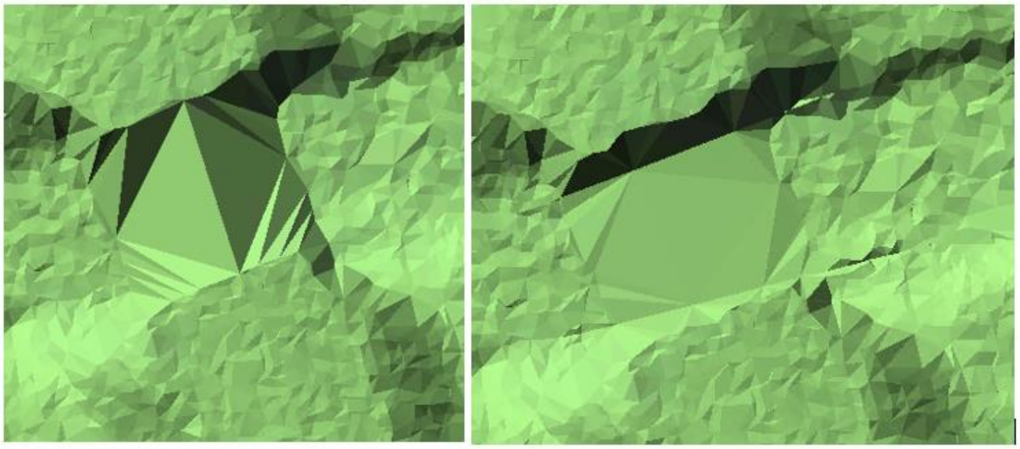

Figure 20 – e1384n1970. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced

DEM VERTICAL ACCURACY RESULTS

The same 435 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 13 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=30 cm
NVA	254	9.9	
VVA	181		14.5

Table 13 — 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$_z$ = 5.0 cm, equating to ± 9.9 cm at 95% confidence level. Actual VVA accuracy was found to be ± 14.5 cm at the 95th percentile.

Table 14 lists the 5% outliers that are larger than the VVA 95th percentile and Table 15 shows the descriptive statistics of the VVA dataset.

Point ID	NAD83(2011) Conus Albers		NAVD88 (Geoid 12B)		DeltaZ	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
VVA-35	1386571.182	1929996.813	431.986	432.141	-0.155	0.155
VVA-2	1290940.801	2047274.535	364.154	364.323	-0.169	0.169
VVA-50	1284637.463	1897990.512	259.220	259.401	-0.181	0.181
VVA-44	1249549.817	1905167.898	195.646	195.827	-0.181	0.181
VVA-86	1234316.131	1844911.149	199.187	199.374	-0.187	0.187
VVA-67	1225665.471	1874552.835	202.029	202.245	-0.216	0.216
VVA-124	1266342.822	1803504.395	436.463	436.208	0.255	0.255
VVA-122	1299971.854	1802044.930	436.864	437.148	-0.284	0.284
VVA-5	1292132.966	2014943.576	339.890	340.042	0.152	0.152

Table 14 – 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	254	0.050	0.018	0.021	-0.439	0.047	0.901	-0.133	0.140
VVA	181	N/A	0.048	0.051	-0.456	0.064	3.222	-0.255	0.284

Table 15– DEM NVA and VVA descriptive statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the USGS West Virginia FEMA R3 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 16– A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project

Appendix A-D: Acquisition Reports from Each Provider

Appendix 1-4: IMU and Processing Reports from Each Provider