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# Virginia FEMA NRCS South Central 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 Virginia FEMA NRCS South Central Project Area.

The lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 1500 m by 1500 m. A total of 11495 tiles were produced for the project encompassing an area of approximately 9495 sq. mi.

### THE PROJECT TEAM

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

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

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

### SURVEY AREA

The project area addressed by this report falls within the states of Virginia and West Virginia. Virginia counties include Carroll, Patrick, Floyd, Pulaski, Montgomery, Franklin, Henry, Roanoke, Halifax, Pittsylvania, Charlotte, Lunenburg, Mecklenburg, Brunswick, and Greensville. Coverage includes the cities of Radford, Roanoke, Salem, Martinsville, Danville, South Boston, and Emporia. In West Virginia coverage includes Mason, Putnam, Lincoln, Logan, Wayne, and Mercer Counties.

### DATE OF SURVEY

The lidar aerial acquisition was conducted between April 4, 2017 and April 24, 2018.

### COORDINATE REFERENCE SYSTEM

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

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

## LIDAR VERTICAL ACCURACY

For the Virginia FEMA NRCS South Central Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **5.7 cm**, compared with the 10 cm specification; and the non-vegetated vertical accuracy (NVA) of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to **11.3 cm**, compared with the 19.6 cm specification.

The tested vegetated vertical accuracy (VVA) of the classified lidar data computed using the $95^{th}$ percentile was **21.1 cm,** compared with the 29.4 cm specification.

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

## PROJECT DELIVERABLES

The deliverables for the project are listed below.

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

## PROJECT TILING FOOTPRINT

A total of 11495 tiles were delivered for the project, covering the areas shown in Figure 1. Each tile's extent is 1500 m by 1500 m.

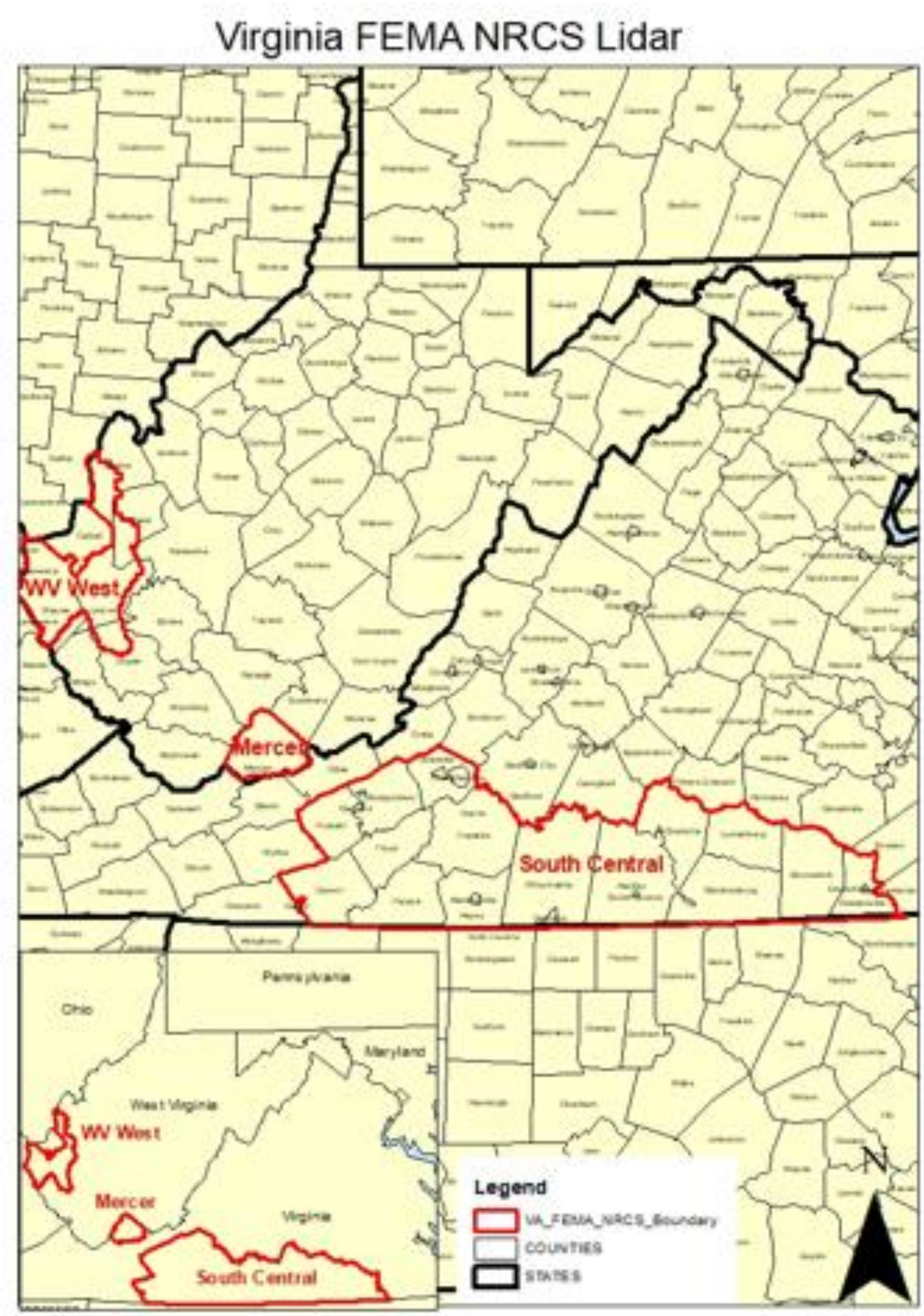


Figure 1 – Project Map

# Lidar Acquisition Report

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

Dewberry received final calibrated swath data from Axis on June 11, 2018 and LEG on September 16, 2018.

## LIDAR ACQUISITION DETAILS

Axis planned 307 passes and LEG planned 631 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent inertial measurement unit (IMU) drift associated with all IMU systems. In order to reduce potential errors in the data attributable to flight planning, Axis and LEG followed FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Survey*. The guidance includes the following minimum criteria:

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

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

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

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

## LIDAR SYSTEM PARAMETERS

Axis operated a Cessna 206H single engine aircraft (N223TC) and operated two dual-channel LiDAR sensors on separate missions during data collections: a Riegl LMS-Q1560 and a Riegl VQ-1560i. LEG operated two Cessna 172 aircraft (C-FUNB, C-FCAU) for the project. Each of the 172s carried a Riegl VQ-780i scanner during the collection of the study area. Table 1 illustrates Axis and LEG system parameters for lidar acquisition on this project.

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

**Table 1 – Axis and LEG lidar system parameters**

## ACQUISITION STATUS REPORT AND FLIGHTLINES

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

Figure 2 shows the combined trajectory of the flightlines.

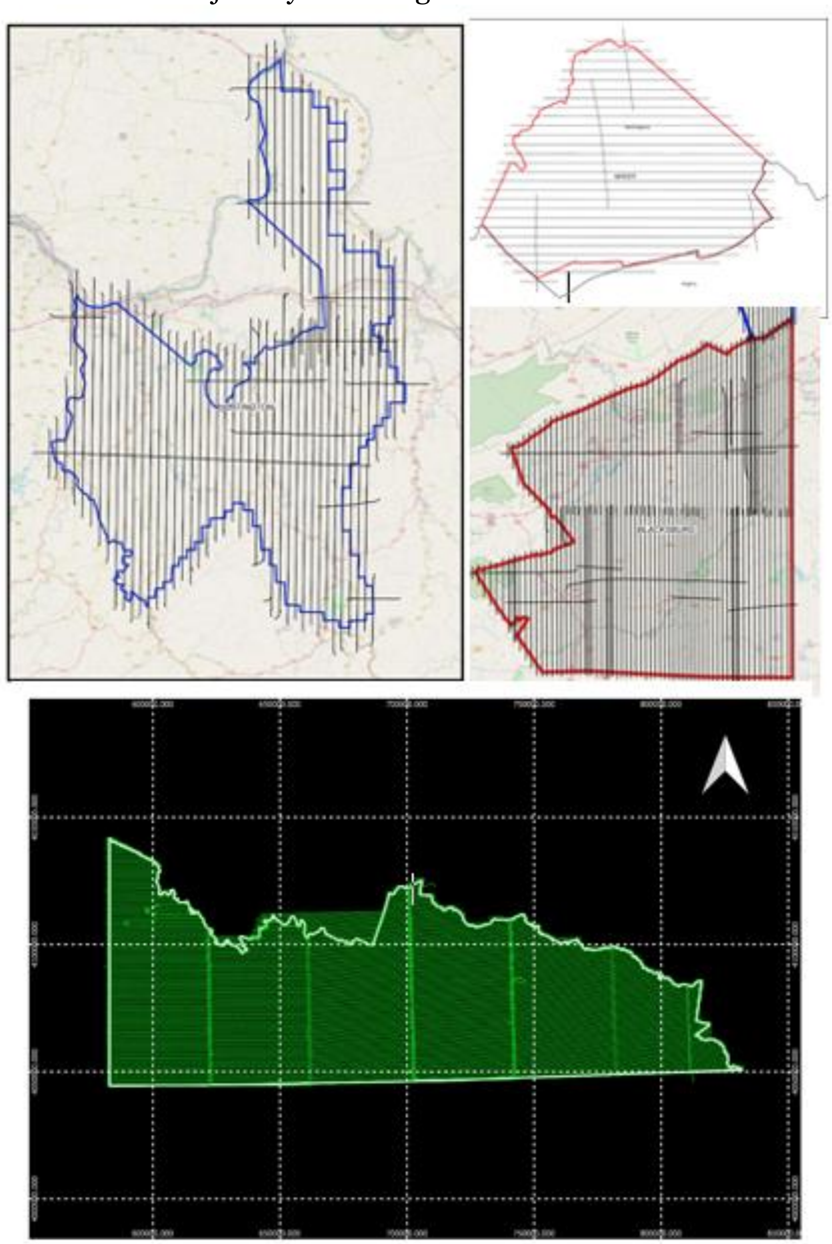

**Figure 2 - Trajectories flown by Axis (top) and LEG (bottom)**

## LIDAR CONTROL

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

| LEG CORS | | | |
|---|---|---|---|
| Name | NAD83(2011) UTM 17 | | Orthometric Ht (NAVD88 Geoid12B, m) |
| | Easting X (m) | Northing Y (m) | |
| DOBS | 4031171.940 | 525106.730 | 373.910 |
| LOYH | 4129769.660 | 648492.600 | 237.680 |
| LOYI | 4212418.270 | 718377.290 | 188.830 |
| LOYO | 4217683.300 | 820509.510 | 75.860 |
| LOYP | 4209942.970 | 673914.790 | 425.510 |
| LOYU | 4112970.370 | 550334.050 | 633.230 |
| LOYV | 4049294.110 | 644975.340 | 130.500 |
| LOYX | 4134228.180 | 881702.600 | 37.490 |
| LS02 | 4130122.420 | 818278.900 | 27.270 |
| LS04 | 4135662.540 | 592316.720 | 357.860 |
| LS06 | 4055378.340 | 742124.150 | 104.040 |
| NCGA | 4040919.420 | 883600.890 | 15.640 |
| NCJA | 4035156.700 | 819469.250 | 47.660 |
| NCMT | 4037994.040 | 523375.040 | 375.510 |
| NCNA | 3984637.890 | 768739.140 | 68.970 |
| NCPF | 4006433.560 | 554635.400 | 301.130 |
| NCRE | 4024912.300 | 619708.230 | 266.710 |
| NCRK | 4045069.120 | 800399.600 | 61.910 |
| NCRX | 4029192.250 | 679510.890 | 225.650 |
| NCWC | 4025533.450 | 573117.440 | 309.540 |
| NCWR | 4031471.240 | 753770.640 | 109.500 |
| UVFM | 4194868.440 | 702835.290 | 546.410 |
| VAAD | 4178572.010 | 813252.850 | 67.460 |
| VABR | 4100321.550 | 684525.530 | 133.580 |
| VABU | 4160771.520 | 717257.800 | 142.750 |
| VABV | 4120169.020 | 747667.040 | 161.540 |
| VADO | 4079323.150 | 786245.270 | 109.650 |

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

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

| Axis CORS | | | |
|---|---|---|---|
| Name | NAD83(2011) UTM 17 | | Orthometric Ht (NAVD88 Geoid12B, m) |
| | Easting X (m) | Northing Y (m) | |
| BLA1 | 551418.000 | 4118475.610 | 637.600 |
| COLB | 325264.540 | 4425295.110 | 218.930 |
| GALP | 389107.900 | 4300264.920 | 201.990 |
| KYGB | 336598.790 | 4260805.240 | 215.740 |
| KYMH | 286599.670 | 4229052.010 | 254.020 |
| KYTI | 259974.060 | 4256244.870 | 291.770 |
| KYTK | 254924.260 | 4115239.890 | 274.610 |
| KYTL | 364244.630 | 4149605.690 | 217.360 |
| LS04 | 592316.120 | 4135663.390 | 356.540 |
| NCWC | 573116.840 | 4025534.280 | 308.200 |
| NCWJ | 457096.430 | 4027650.990 | 964.700 |
| OHAD | 277964.150 | 4296126.140 | 274.250 |
| OHHI | 275708.980 | 4342209.160 | 341.310 |
| OHMO | 491233.960 | 4402990.170 | 370.330 |

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

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

## AIRBORN GPS KINEMATIC

Axis and LEG used NGS CORS Base Stations to control the LiDAR acquisition for the Virginia FEMA NRCS South Central Lidar project area.

Airborne GPS data was processed by Axis using the POSPac Mobile Mapping System (MMS) version 7.2 software suite. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 40km.

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

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

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

## GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

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

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

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

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

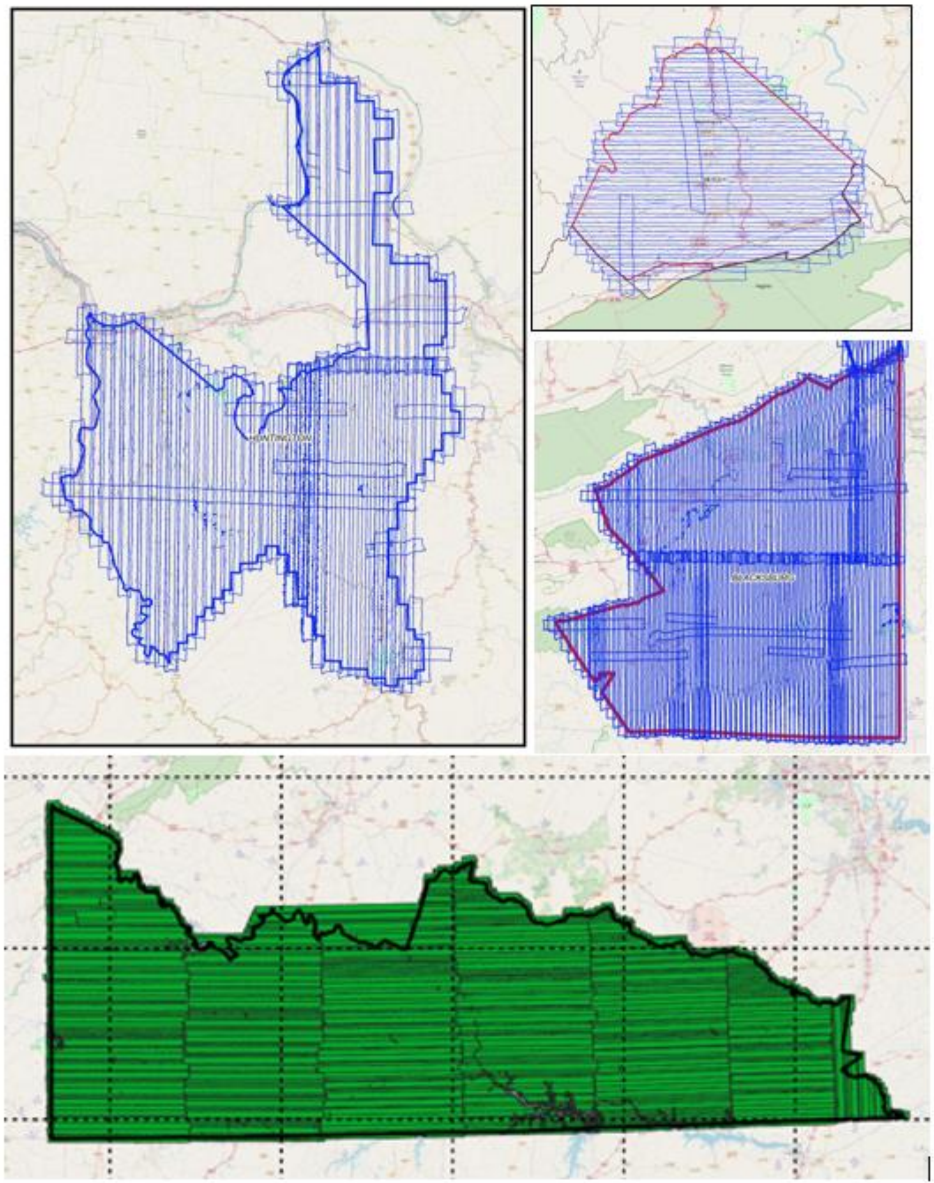

**Figure 3 – Lidar swath output showing complete coverage of the project area by Axis (top) and LEG (bottom)**

## BORESIGHT AND RELATIVE ACCURACY

The initial points for each mission calibration were inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the lidar unit or GPS. Roll, pitch and scanner scale were optimized during the calibration process until the relative accuracy was met.

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

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

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

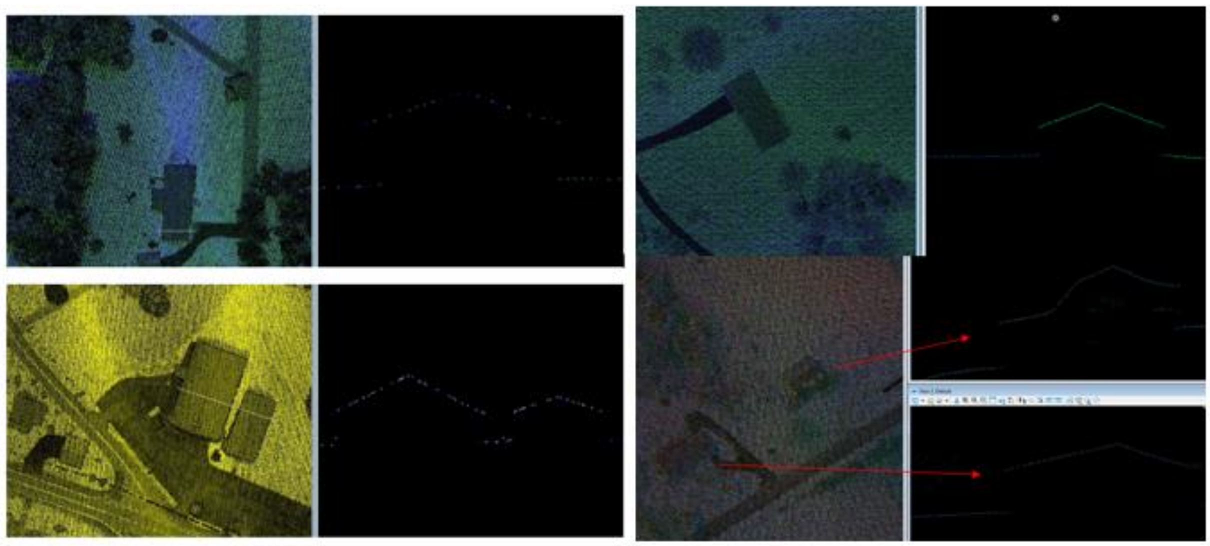

**Figure 4 – Profile views showing correct roll and pitch adjustments from Axis (left) and LEG (right)**

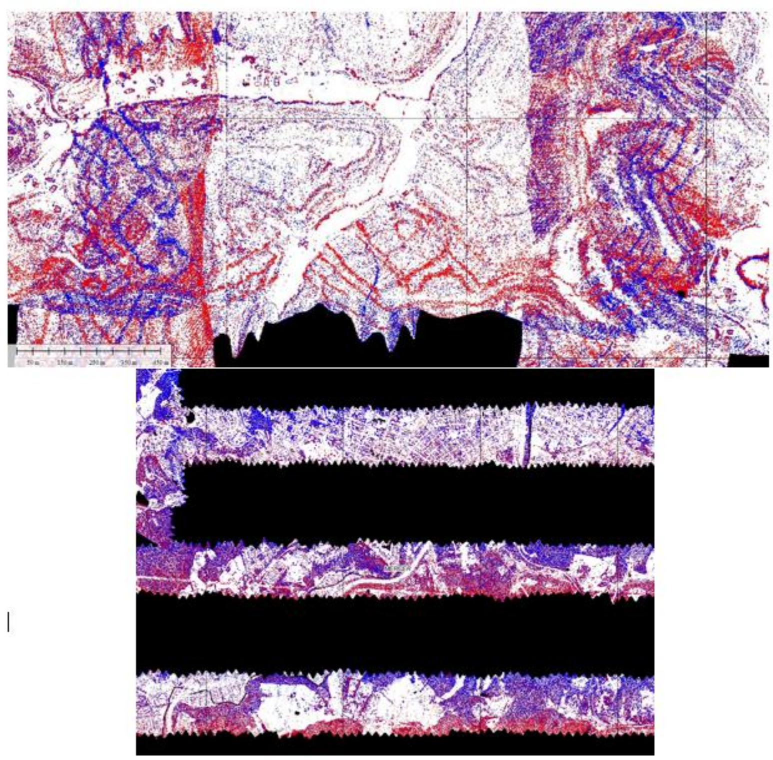

**Figure 5 – QC block colored by distance to ensure accuracy at swath edges for Axis (top) and LEG (bottom) data**

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

## PRELIMINARY VERTICAL ACCURACY ASSESSMENT

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

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

LEG: The calibrated LEG dataset was tested to 0.1311 m (0.43 ft) vertical accuracy at 95% confidence level based on consolidated $RMSE_z$ (0.0669m x 1.9600) when compared to 1147 independently collected RTK checkpoints.

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

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

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

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

The calibrated South Central Block 1 LiDAR dataset was tested to 0.127 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.065 m x 1.9600) when compared to 28 GPS static checkpoints.

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

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

Table 4 – Axis static GPS points – West Virginia West

| 100 % of Totals | # of Points | RMSEz (m) NVA Spec=0.1 m | NVA at 95% Spec=0.196 m | Mean (m) | Std Dev (m) | Min (m) | Max (m) |
|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 22 | 0.12936 | 0.131 | +0.033 | 0.058 | -0.109 | 0.131 |

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

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

Table 6 – Axis static GPS points – Mercer

| 100 % of Totals | # of Points | RMSEz (m) NVA Spec=0.1 m | NVA at 95% Spec=0.196 m | Mean (m) | Std Dev (m) | Min (m) | Max (m) |
|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 10 | 0.065 | 0.127 | 0.003 | 0.069 | -0.137 | 0.077 |

Table 7 – Axis static GPS vertical accuracy results – Mercer

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

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

**Table 8 – Axis static GPS points – South Central**

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

**Table 9 – Axis static GPS vertical accuracy results – South Central**

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

# Lidar Processing & Qualitative Assessment

## INITIAL PROCESSING

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

### Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Axis and LEG, Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using one hundred twenty five non-vegetated (open terrain and urban) independent survey checkpoints. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96. The dataset for Virginia FEMA NRCS South Central Lidar Project satisfies this criteria. The raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was calculated to be $RMSE_z$ = 6.0 cm, equating to +/- 11.7 cm at 95% confidence level. The table below shows calculated statistics for the raw swath data.

| 100 % of Totals | # of Points | $RMSE_z$ NVA Spec=0.10 m | NVA –Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m | Mean (m) | Median (m) | Skew | Std Dev (m) | Min (m) | Max (m) | Kurtosis |
|---|---|---|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 183 | 0.060 | 0.117 | 0.017 | 0.021 | -0.382 | 0.057 | -0.216 | 0.225 | 2.712 |

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

Four checkpoints (NVA-10, 125, 127, and 147) were removed from the raw swath vertical accuracy testing due to proximity to vegetation. Only non-vegetated terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation, structures, and other above ground features from the ground classification. While three of these points (NVA-10, 125, and 127) were located in open terrain, overhead branches or transient objects (vehicles) were also collected and modeled by the lidar point cloud. These high points caused erroneous high values during the swath vertical accuracy testing; therefore, these points were removed from the final calculations. Once the data underwent the classification process, the vegetation were removed from the final ground classification and these three checkpoints were added back into the final vertical accuracy testing for the fully classified lidar data.

The lidar around NVA-147 is consistent; the issue is a result of the survey. The road that NVA-147 is on is next to a mountain slope and under trees. So in this case, it is likely the GPS receivers produced multipathing errors in the survey data. Multipathing errors result when vertical obstructions either block or "bounce" the signal around and result in incorrect survey elevations.

Table 7, below, provides the coordinates for these checkpoints and the vertical accuracy results from the raw swath data. Table 12 provides the usable vertical accuracy results of this checkpoint from the fully classified lidar. Figure 6 shows a 3D model of the lidar point cloud and the location of the checkpoints beneath vegetation.

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | | Delta Z | AbsDeltaZ |
|---|---|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) | | |
| NVA-125 | 770166.743 | 4053767.818 | 102.676 | slope | | |
| NVA-127 | 751004.129 | 4057370.164 | 100.172 | slope | | |
| NVA-10 | 511092.668 | 4060816.181 | 785.387 | slope | | |
| NVA-147 | 387030.474 | 4230875.020 | 210.094 | slope | | |

Table 11 - Checkpoints removed from raw swath vertical accuracy testing

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | | Delta Z | AbsDelta Z |
|---|---|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) | | |
| NVA-10 | 511092.668 | 4060816.181 | 785.387 | 785.450 | 0.063 | 0.063 |
| NVA-125 | 770166.743 | 4053767.818 | 102.676 | 102.680 | 0.004 | 0.004 |
| NVA-127 | 751004.129 | 4057370.164 | 100.172 | 100.160 | -0.012 | 0.012 |

Table 12 - Final tested vertical accuracy post ground classification

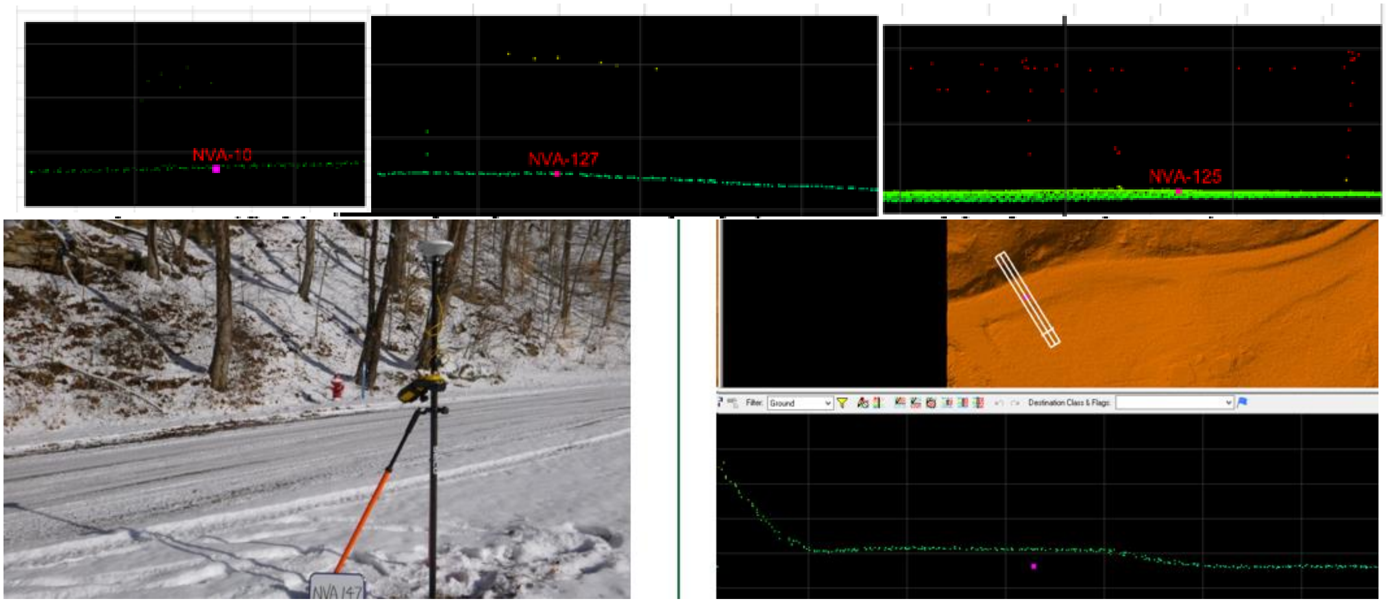


**Figure 6 – Open terrain checkpoints NVA-10, 125, and 127, shown in pink, are located underneath powerlines or vegetation. These points were removed from raw swath vertical accuracy testing because above ground features had not been separated from the ground classification yet. The Bottom images shows NVA point -147, removed due to multi-pathing issues caused by slope and trees.**

## Inter-Swath (Between Swath) Relative Accuracy

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

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

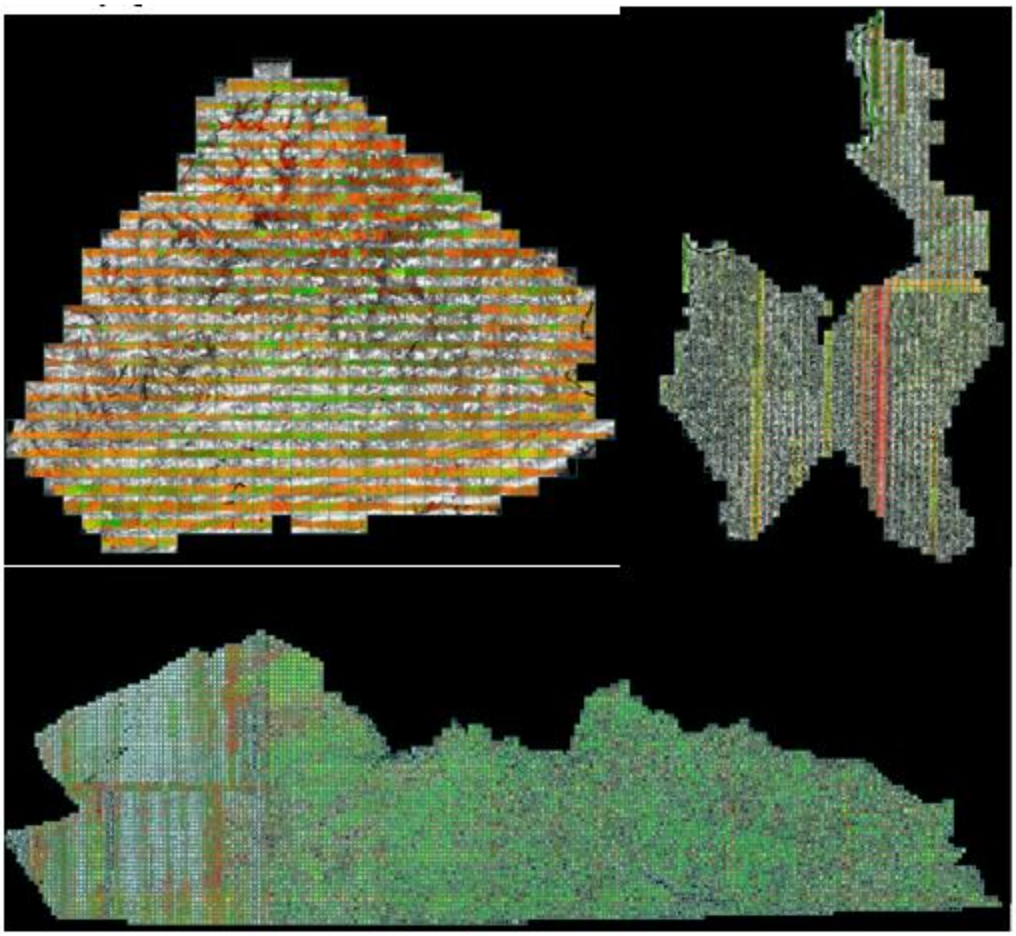

**Figure 7 – Single return DZ Orthos for the Virginia FEMA NRCS South Central lidar project. Inter-swath relative accuracy passes specifications.**

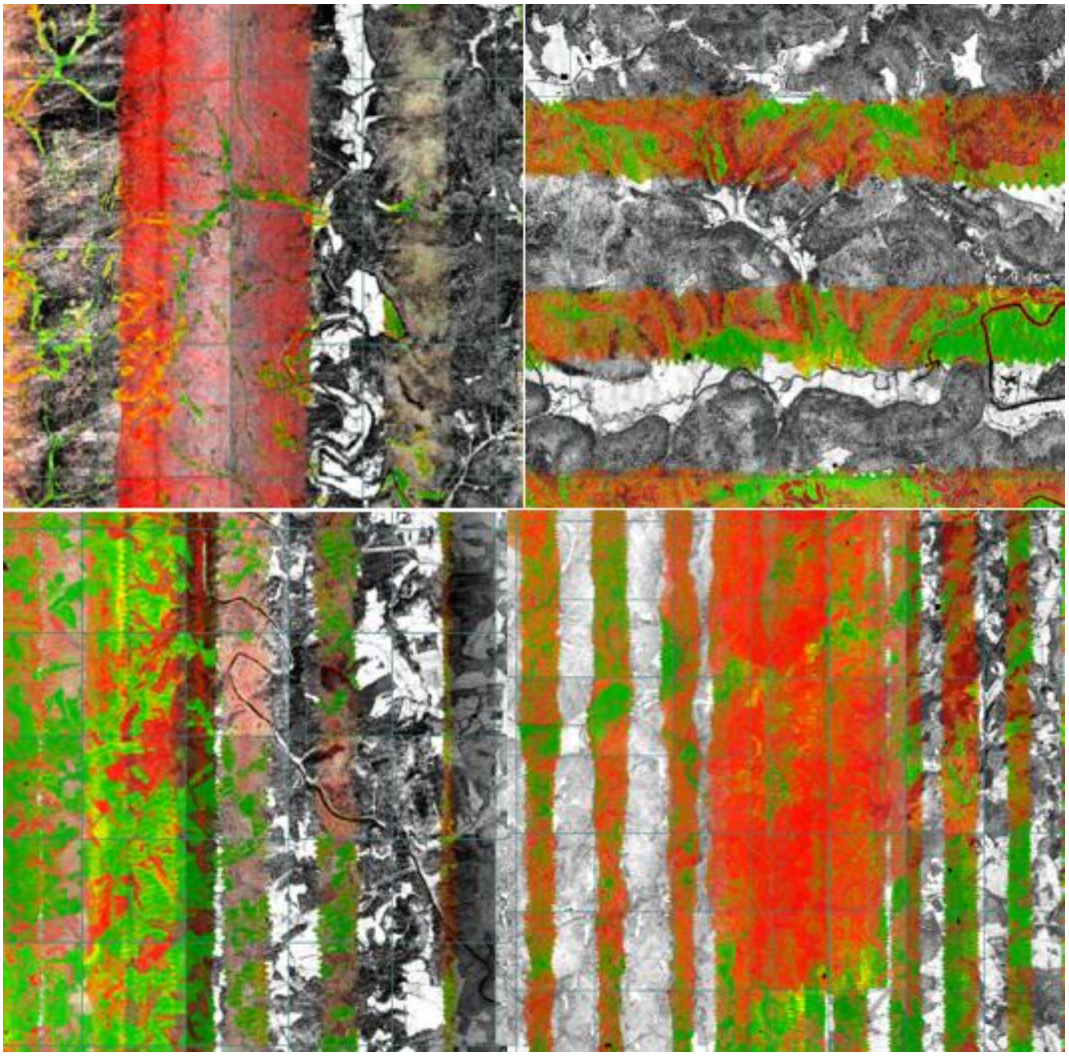

**Figure 8 – These screenshots show close-ups of areas that may appear to exceed the threshold from a distance. These are mountainous forested regions but have threads of green where there are clearings spread throughout.**

## Intra-Swath (Within a Single Swath) Relative Accuracy

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

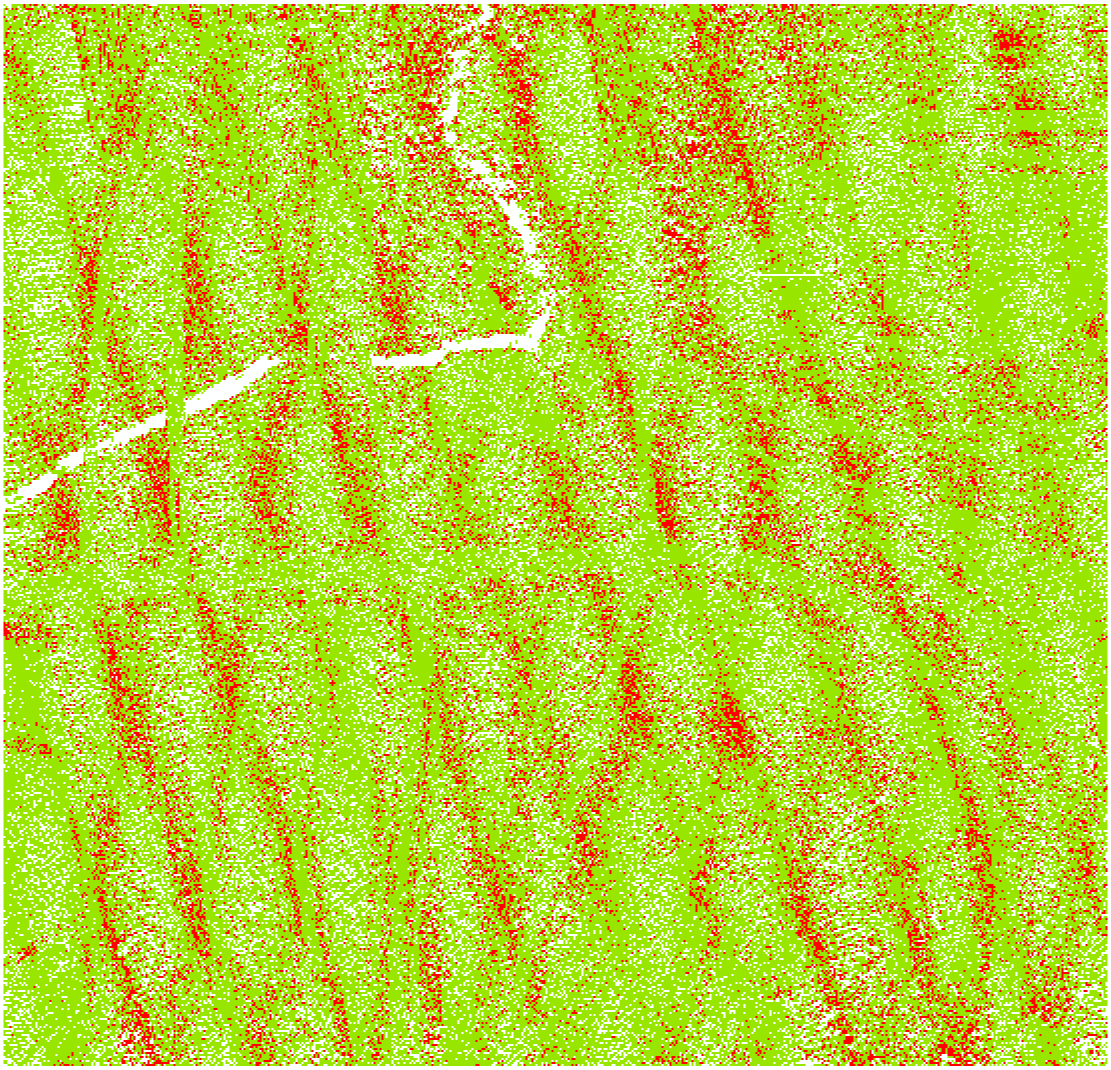

**Figure 9 – Intra-swath relative accuracy. Areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red. The left image shows a large portion of the dataset; flat, open areas are colored green, whereas sloped terrain is colored red because the terrain itself exceeds the 6 cm threshold. This is expected. The right image is an inset showing a flat area. With the exception of a few trees (shown in red as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.**

## Horizontal Alignment

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

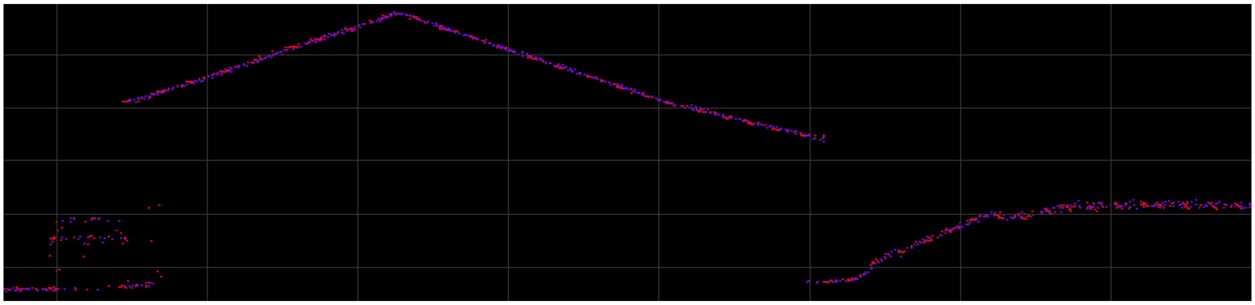

**Figure 10 – Two separate flight lines differentiated by color (Blue/Yellow) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.**

## Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.71 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 2 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.5 meters and an ANPD of 3.65 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-square meter cells contain at least 2 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds), density passes with no issues.

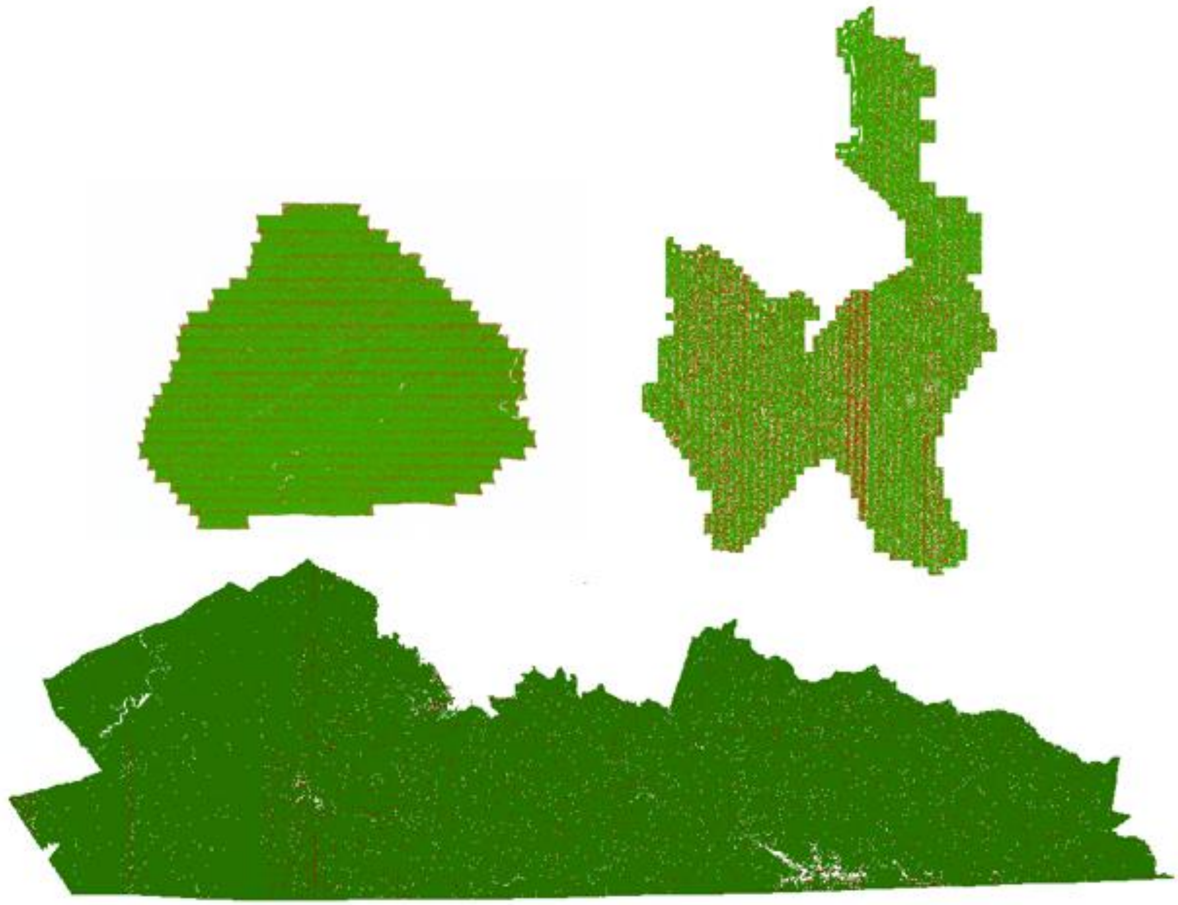

**Figure 11 – 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-square meter cells contain at least 2 points per square meter (green areas) showing there are no systematic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

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

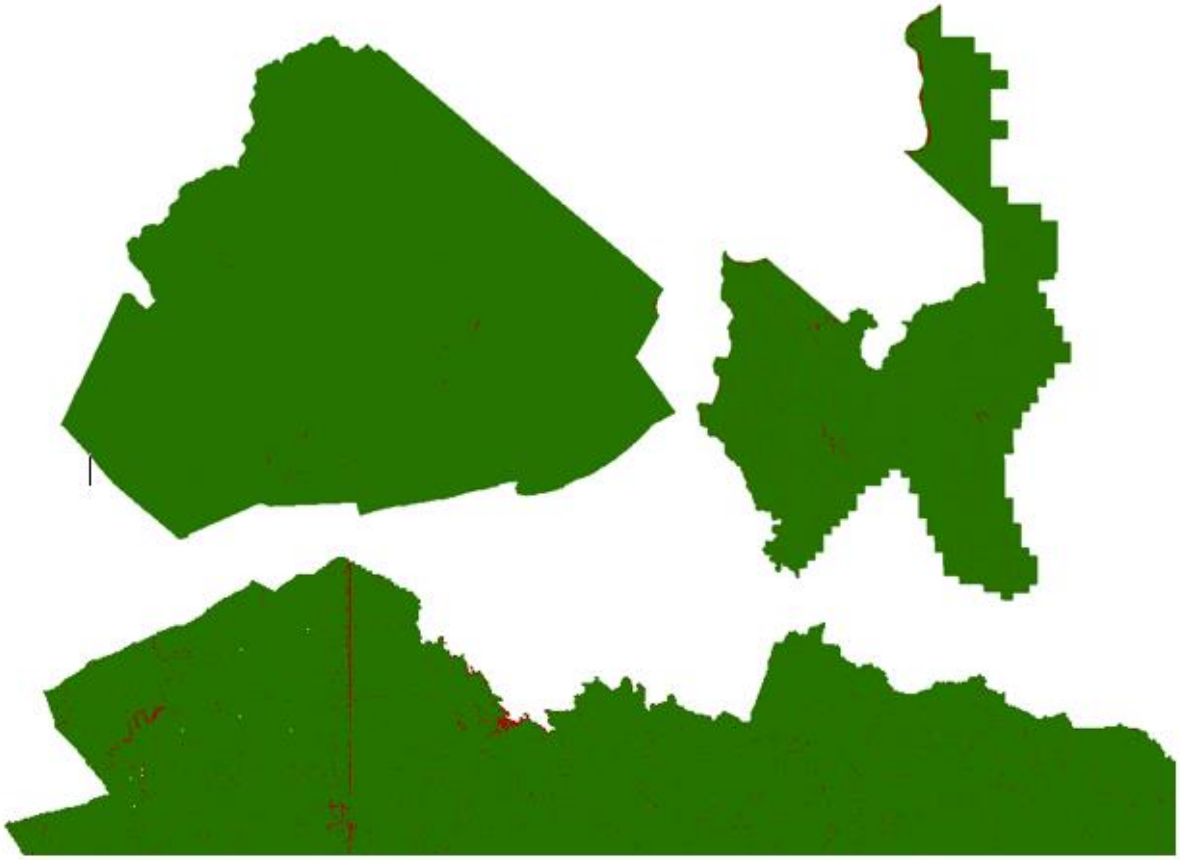

**Figure 12 – All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point, including water bodies and other acceptable NoData areas, are colored red. Including acceptable NoData areas, 99.3% of cells contain at least one lidar point.**

## DATA CLASSIFICATION AND EDITING

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

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

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

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

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

The lidar tiles were classified to the following classification schema:

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

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

## Lidar Qualitative Assessment

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

## VISUAL REVIEW

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

### Data Voids

The LAS files are used to produce density grids with the commercial software package QT Modeler (QTM), which creates a 3-dimensional data model derived from Class 2 (ground) points. Grid spacing is based on the project density deliverable requirement for un-obscured areas. Acceptable voids (areas with no lidar returns in the LAS files) that are present in the majority of lidar projects include voids caused by bodies of water. One atypical void was found in the Virginia FEMA NRCS South Central lidar project AOI. The issue is illustrated in Figure 13, below.

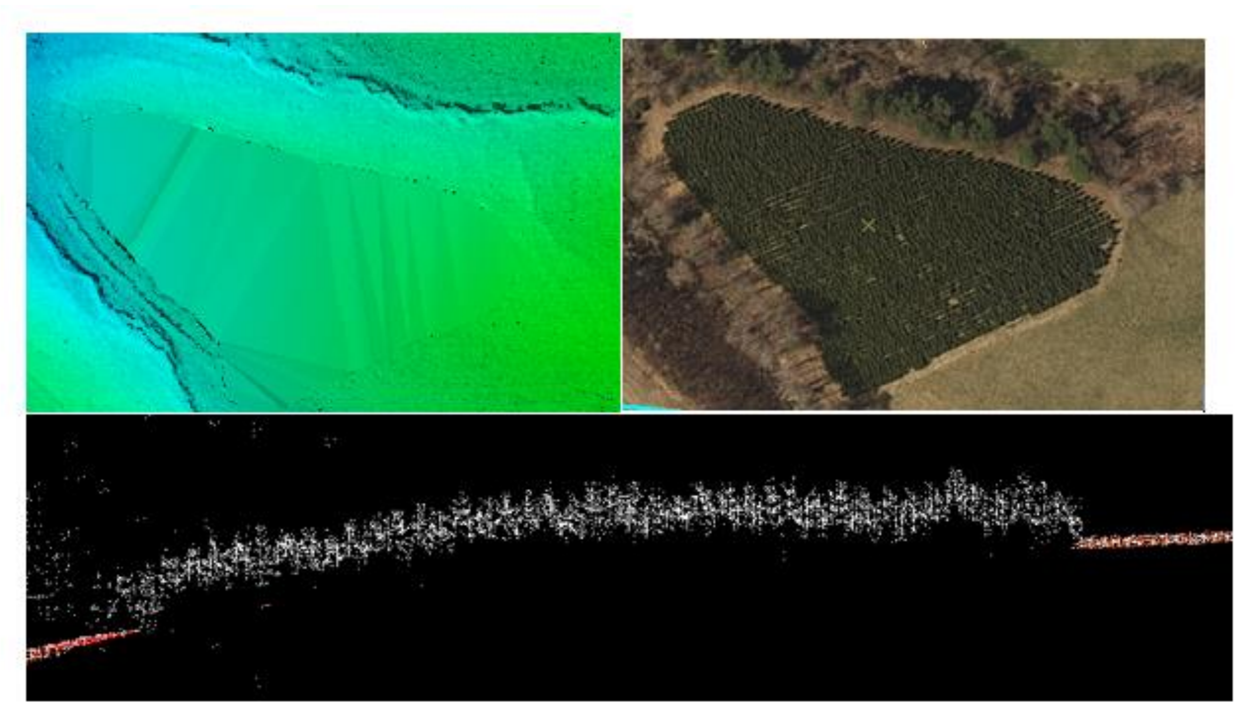

**Figure 13 – 17SNA43008600. One atypical void exists in the dataset. This area contains a very dense tree farm. The lidar does not penetrate to the ground and no ground points can be added to create a better ground model.**

### Artifacts

Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches, or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

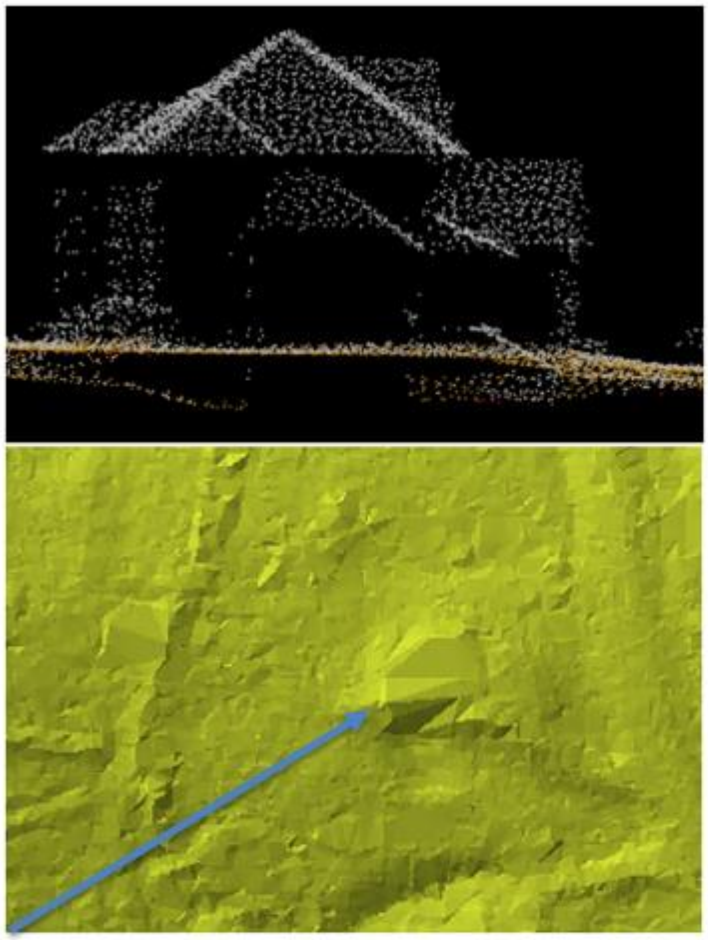

**Figure 14 – 17SNB55002200. A profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground but do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

## Bridge Removal Artifacts

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

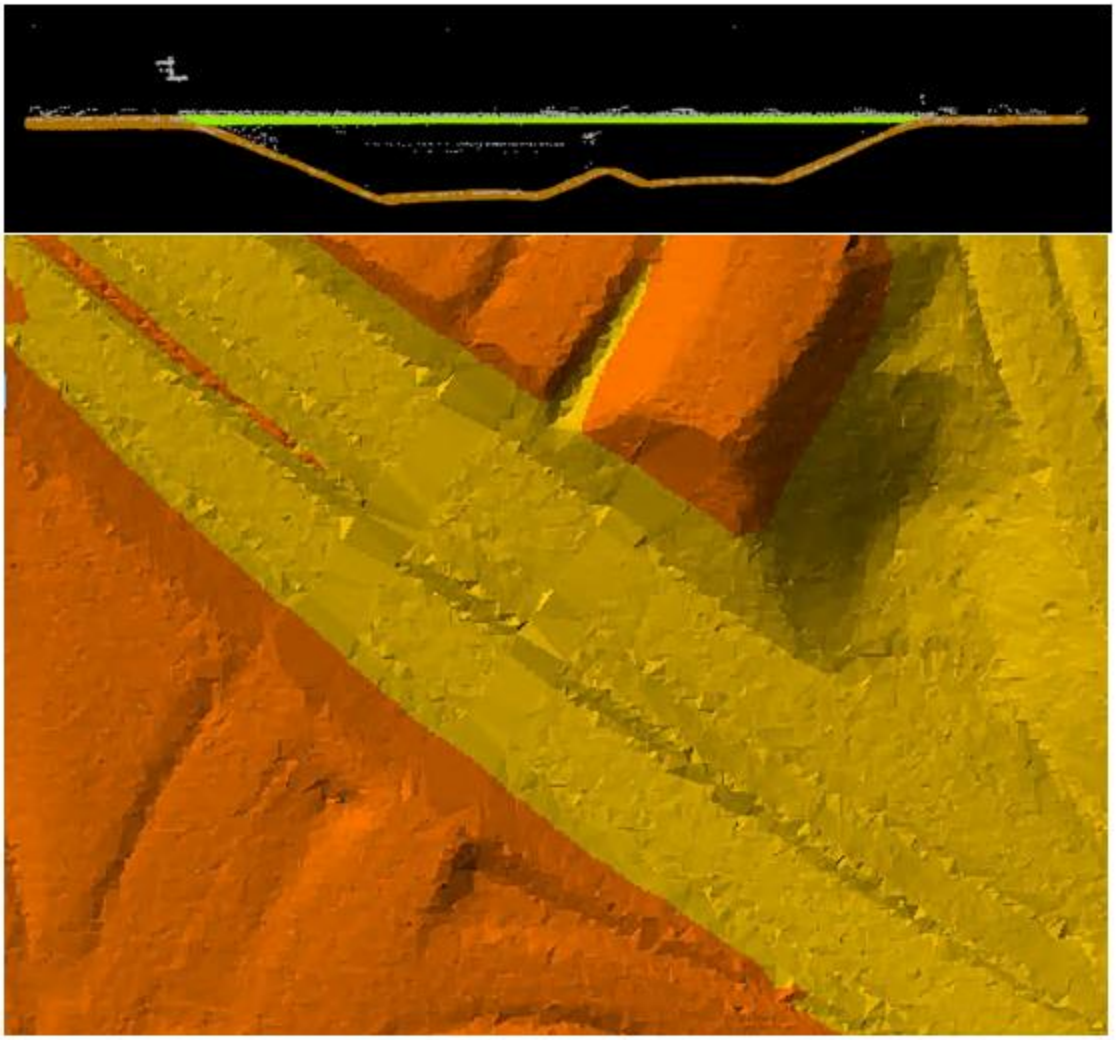

**Figure 15 – 17SNB52001150. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (orange) and are unclassified (white)/bridge deck (green).**

## Culverts and Bridges

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

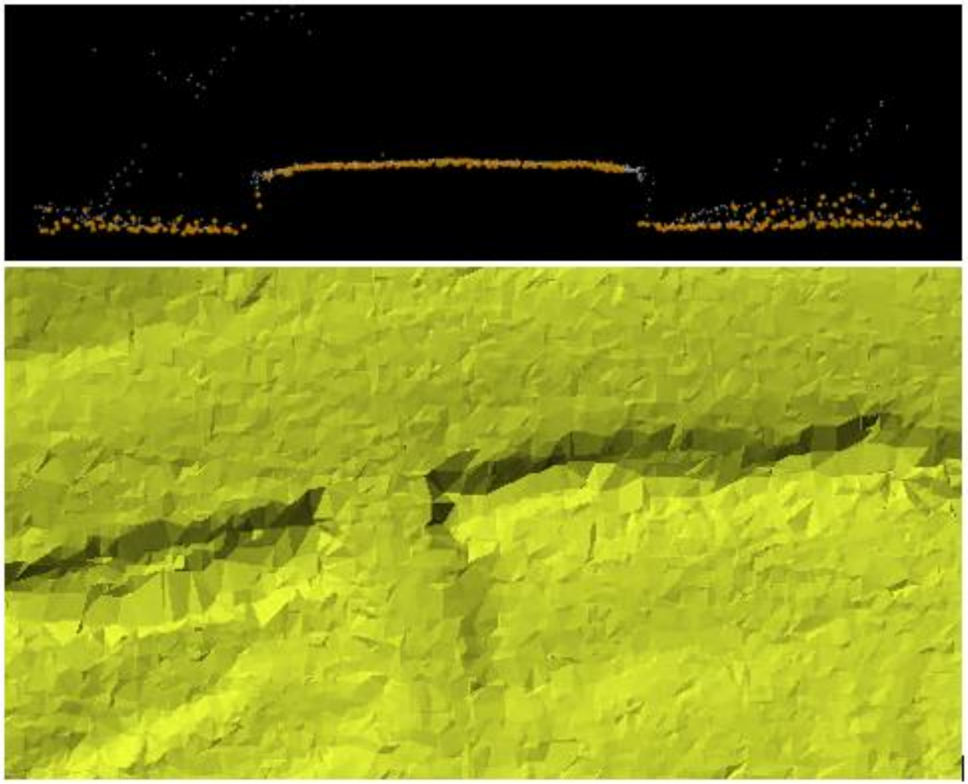

**Figure 16– 17SNB43000850. A profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.**

## Elevation Change within Breaklines

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

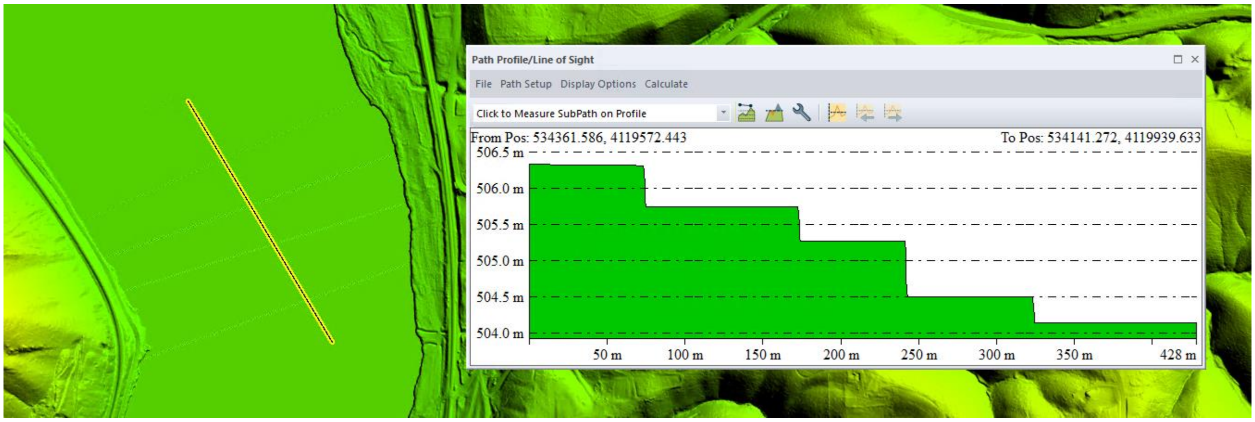


**Figure 17 – LAS_17SNB34001900. The elevation change of approximately 0.35 m has been stair stepped. The steps are flat from bank to bank and are consistently monotonic.**

## FORMATTING

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

| Classified Lidar Formatting | | |
|---|---|---|
| **Parameter** | **Requirement** | **Pass/Fail** |
| LAS Version | 1.4 | Pass |
| Point Data Format | 6 | Pass |
| Coordinate Reference System | NAD83 (2011) UTM Zone 17, meters and NAVD88 (Geoid 12B), meters in WKT format | Pass |
| Global Encoder Bit | 17 (adjusted GPS time) | Pass |
| Time Stamp | Adjusted GPS time (unique timestamps) | Pass |
| System ID | Set to the processing system/software (NIIRS10 for GeoCue software) | Pass |
| Multiple Returns | Yes, and the return numbers are recorded | Pass |
| Intensity | 16 bit intensity values for each pulse | Pass |
| Classification | Class 1: Unclassified<br>Class 2: Ground<br>Class 7: Low Noise<br>Class 9: Water<br>Class 10: Ignored Ground<br>Class 17: Bridge Decks<br>Class 18: High Noise | Pass |
| Overlap and Withheld Points | Set to the Overlap and Withheld bits | Pass |
| Scan Angle | Recorded for each pulse | Pass |
| XYZ Coordinates | Unique Easting, Northing, and Elevation coordinates are recorded for each pulse | Pass |

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

## Synthetic Points

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

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

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

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

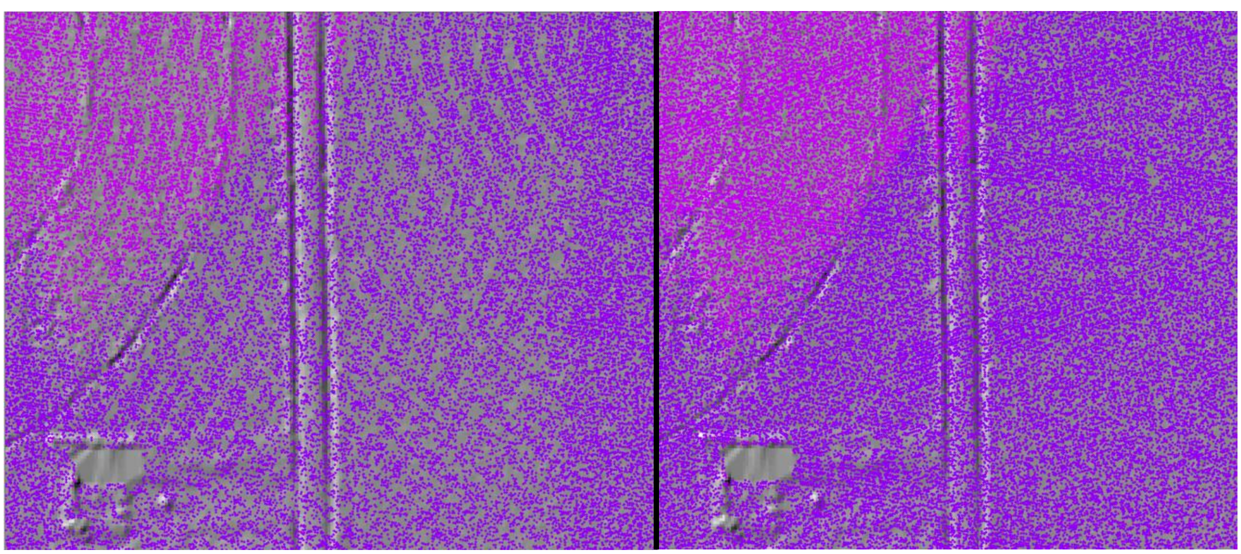

**Figure 18 – The left image shows ground classified without synthetic points. The right image shows ground classified with synthetic points. Both images are overlaid on a hillshade of the example area**

# Derivative Lidar Products

## CONTOURS

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

# Lidar Positional Accuracy

## BACKGROUND

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

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

## SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, 333 checkpoints—located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories—were surveyed. Survey details and validation are included in the survey report, attached as Appendix A.
Checkpoints were evenly distributed throughout the project area to cover as many flight lines as possible using the "dispersed method" of placement.

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

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| NVA-1 | 515801.927 | 4051635.773 | 883.930 | 883.880 |
| NVA-10 | 511092.668 | 4060816.181 | 785.387 | 785.450 |
| NVA-100 | 764176.277 | 4095504.232 | 127.813 | 127.850 |
| NVA-101 | 747069.217 | 4096618.692 | 172.020 | 172.020 |
| NVA-102 | 732821.796 | 4090983.066 | 159.969 | 159.990 |
| NVA-103 | 730401.160 | 4083463.640 | 143.913 | 143.930 |
| NVA-104 | 743677.382 | 4084662.295 | 141.555 | 141.560 |
| NVA-105 | 760052.283 | 4087150.610 | 130.875 | 130.740 |
| NVA-106 | 770916.764 | 4088101.983 | 126.278 | 126.310 |
| NVA-107 | 789448.038 | 4092514.471 | 81.637 | 81.690 |
| NVA-108 | 798906.292 | 4081149.116 | 75.689 | 75.640 |
| NVA-109 | 784166.155 | 4083278.738 | 102.669 | 102.680 |
| NVA-11 | 507343.469 | 4071162.295 | 722.797 | 722.770 |
| NVA-110 | 768406.206 | 4078807.354 | 83.657 | 83.580 |
| NVA-111 | 760371.547 | 4079003.913 | 127.883 | 127.840 |
| NVA-112 | 745950.236 | 4074055.051 | 148.388 | 148.380 |
| NVA-113 | 733141.655 | 4074266.672 | 132.143 | 132.100 |
| NVA-114 | 733489.463 | 4061043.150 | 106.716 | 106.760 |
| NVA-115 | 749611.920 | 4063493.331 | 104.099 | 104.120 |
| NVA-116 | 767950.063 | 4065795.559 | 104.982 | 105.070 |
| NVA-117 | 780066.791 | 4071467.379 | 68.961 | 68.940 |
| NVA-118 | 795264.935 | 4073778.627 | 83.111 | 83.110 |
| NVA-119 | 808436.147 | 4075785.322 | 52.558 | 52.590 |
| NVA-12 | 516731.324 | 4074421.554 | 788.252 | 788.250 |
| NVA-120 | 807969.853 | 4067406.056 | 40.612 | 40.610 |
| NVA-121 | 820720.013 | 4055220.312 | 24.431 | 24.480 |
| NVA-122 | 807696.153 | 4056798.189 | 36.092 | 36.100 |
| NVA-123 | 796042.530 | 4063248.802 | 87.712 | 87.720 |
| NVA-124 | 784297.214 | 4061034.068 | 98.709 | 98.740 |
| NVA-125 | 770166.743 | 4053767.818 | 102.676 | 102.680 |
| NVA-126 | 763083.569 | 4059441.666 | 115.064 | 115.110 |
| NVA-127 | 751004.129 | 4057370.164 | 100.172 | 100.160 |
| NVA-128 | 738979.216 | 4052635.959 | 95.009 | 95.060 |
| NVA-129 | 396089.550 | 4291242.269 | 176.148 | 176.190 |
| NVA-13 | 538176.102 | 4074320.006 | 776.427 | 776.410 |

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| NVA-130 | 397515.289 | 4286666.039 | 173.528 | 173.510 |
| NVA-131 | 407323.746 | 4285379.256 | 205.073 | 205.110 |
| NVA-132 | 398857.268 | 4278002.915 | 177.917 | 177.930 |
| NVA-133 | 403361.275 | 4273716.089 | 173.332 | 173.390 |
| NVA-134 | 399872.449 | 4267371.589 | 175.900 | 175.990 |
| NVA-135 | 406809.793 | 4264936.668 | 276.768 | 276.750 |
| NVA-136 | 418858.190 | 4257100.878 | 206.154 | 206.300 |
| NVA-137 | 408732.098 | 4252913.153 | 215.242 | 215.340 |
| NVA-138 | 419248.940 | 4250520.035 | 231.505 | 231.630 |
| NVA-139 | 408745.136 | 4243755.447 | 192.161 | 192.190 |
| NVA-14 | 560507.573 | 4077043.077 | 842.953 | 842.840 |
| NVA-140 | 420288.765 | 4239959.874 | 207.470 | 207.530 |
| NVA-141 | 395167.337 | 4236823.522 | 179.891 | 179.900 |
| NVA-142 | 381514.201 | 4240878.284 | 186.769 | 186.830 |
| NVA-143 | 372970.188 | 4243948.016 | 170.837 | 170.820 |
| NVA-144 | 360972.066 | 4248076.647 | 172.756 | 172.780 |
| NVA-145 | 365293.009 | 4240013.885 | 178.294 | 178.350 |
| NVA-146 | 373178.476 | 4235367.660 | 178.386 | 178.320 |
| NVA-148 | 402613.049 | 4231003.752 | 204.230 | 204.160 |
| NVA-149 | 412532.525 | 4236710.149 | 246.073 | 246.100 |
| NVA-15 | 569826.576 | 4075036.242 | 419.401 | 419.440 |
| NVA-150 | 419332.005 | 4231286.784 | 312.018 | 312.000 |
| NVA-151 | 412468.126 | 4224237.875 | 237.941 | 237.910 |
| NVA-152 | 404000.507 | 4226985.247 | 216.493 | 216.470 |
| NVA-153 | 396901.200 | 4225951.748 | 181.530 | 181.600 |
| NVA-154 | 379809.531 | 4226355.751 | 196.560 | 196.530 |
| NVA-155 | 370227.402 | 4226540.786 | 188.015 | 188.070 |
| NVA-156 | 360249.393 | 4229687.092 | 172.632 | 172.690 |
| NVA-157 | 361147.604 | 4221977.832 | 195.088 | 195.110 |
| NVA-158 | 364428.838 | 4216747.284 | 188.941 | 188.970 |
| NVA-159 | 372260.062 | 4215608.898 | 203.519 | 203.560 |
| NVA-16 | 584058.383 | 4081523.492 | 382.193 | 382.150 |
| NVA-160 | 390016.930 | 4217199.802 | 265.174 | 265.190 |
| NVA-161 | 399522.763 | 4213333.390 | 191.838 | 191.690 |
| NVA-162 | 405115.440 | 4218662.309 | 331.249 | 331.270 |

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| NVA-163 | 409205.803 | 4210771.181 | 212.160 | 212.180 |
| NVA-164 | 409694.414 | 4203539.201 | 195.629 | 195.630 |
| NVA-165 | 413751.255 | 4198383.343 | 209.374 | 209.440 |
| NVA-166 | 399191.539 | 4203236.034 | 199.531 | 199.430 |
| NVA-167 | 383477.572 | 4208375.540 | 356.268 | 356.280 |
| NVA-168 | 374334.782 | 4209335.841 | 211.041 | 211.050 |
| NVA-169 | 368139.123 | 4206998.966 | 182.696 | 182.680 |
| NVA-17 | 580016.841 | 4090085.892 | 473.686 | 473.570 |
| NVA-170 | 372943.346 | 4197731.627 | 227.840 | 227.930 |
| NVA-171 | 490476.006 | 4160212.371 | 989.362 | 989.330 |
| NVA-172 | 482121.077 | 4155834.149 | 915.115 | 915.120 |
| NVA-173 | 495027.278 | 4154320.087 | 655.299 | 655.320 |
| NVA-174 | 504964.543 | 4146127.262 | 687.917 | 687.920 |
| NVA-175 | 499240.931 | 4145322.939 | 782.990 | 782.990 |
| NVA-176 | 491049.852 | 4149517.402 | 600.279 | 600.260 |
| NVA-177 | 483508.263 | 4147781.753 | 811.576 | 811.480 |
| NVA-178 | 474217.424 | 4138183.212 | 715.248 | 715.230 |
| NVA-179 | 490408.871 | 4143201.630 | 630.940 | 630.930 |
| NVA-18 | 564740.983 | 4088284.656 | 720.814 | 720.710 |
| NVA-180 | 494322.234 | 4141455.386 | 769.772 | 769.780 |
| NVA-181 | 503173.436 | 4143270.844 | 783.441 | 783.460 |
| NVA-182 | 509550.169 | 4141521.264 | 743.780 | 743.780 |
| NVA-183 | 507087.983 | 4133371.801 | 504.125 | 504.170 |
| NVA-184 | 499990.976 | 4132780.110 | 619.460 | 619.520 |
| NVA-185 | 489613.920 | 4135513.181 | 743.559 | 743.570 |
| NVA-186 | 482011.753 | 4134884.631 | 790.100 | 790.040 |
| NVA-187 | 474217.485 | 4138183.146 | 715.285 | 715.220 |
| NVA-188 | 472858.914 | 4131582.375 | 685.976 | 686.000 |
| NVA-189 | 477436.037 | 4128261.462 | 792.038 | 792.090 |
| NVA-19 | 548738.254 | 4089103.409 | 808.300 | 808.260 |
| NVA-190 | 487189.912 | 4128662.257 | 757.400 | 757.420 |
| NVA-191 | 494780.587 | 4129654.773 | 613.305 | 613.340 |
| NVA-2 | 530937.110 | 4047699.947 | 422.450 | 422.490 |
| NVA-20 | 537046.932 | 4085474.786 | 856.521 | 856.460 |
| NVA-21 | 522202.128 | 4090074.458 | 597.003 | 596.930 |

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| NVA-22 | 520042.990 | 4099369.758 | 602.734 | 602.780 |
| NVA-23 | 542868.716 | 4100171.300 | 619.514 | 619.480 |
| NVA-24 | 556756.759 | 4100887.490 | 694.417 | 694.340 |
| NVA-25 | 570628.409 | 4099206.643 | 795.280 | 795.230 |
| NVA-26 | 583996.974 | 4106545.785 | 421.161 | 421.100 |
| NVA-27 | 565970.556 | 4113667.318 | 431.847 | 431.750 |
| NVA-28 | 550011.963 | 4113436.233 | 639.623 | 639.610 |
| NVA-29 | 532044.780 | 4113725.659 | 545.144 | 545.080 |
| NVA-3 | 551992.993 | 4049518.218 | 443.755 | 443.780 |
| NVA-30 | 517878.202 | 4112796.254 | 585.959 | 585.870 |
| NVA-31 | 544684.403 | 4120279.085 | 569.113 | 569.140 |
| NVA-32 | 562075.396 | 4121082.994 | 443.839 | 443.770 |
| NVA-33 | 581529.049 | 4125879.104 | 359.513 | 359.430 |
| NVA-34 | 579850.593 | 4138325.550 | 518.895 | 518.770 |
| NVA-35 | 568492.506 | 4131332.610 | 585.580 | 585.530 |
| NVA-36 | 555413.834 | 4130842.396 | 556.913 | 556.910 |
| NVA-37 | 598807.867 | 4129052.844 | 354.524 | 354.520 |
| NVA-38 | 595273.958 | 4121811.698 | 298.983 | 298.930 |
| NVA-39 | 591501.892 | 4111239.377 | 378.906 | 378.860 |
| NVA-4 | 569324.703 | 4051818.184 | 371.285 | 371.210 |
| NVA-40 | 608050.151 | 4111744.776 | 348.655 | 348.600 |
| NVA-41 | 618844.265 | 4101443.238 | 247.624 | 247.580 |
| NVA-42 | 642513.458 | 4100379.447 | 189.583 | 189.560 |
| NVA-43 | 645074.019 | 4090235.508 | 264.443 | 264.520 |
| NVA-44 | 634304.749 | 4092442.964 | 204.286 | 204.250 |
| NVA-45 | 621315.175 | 4089712.933 | 210.722 | 210.560 |
| NVA-46 | 604771.852 | 4097446.102 | 343.816 | 343.810 |
| NVA-47 | 593153.086 | 4097085.759 | 370.834 | 370.740 |
| NVA-48 | 593219.204 | 4086633.775 | 394.425 | 394.490 |
| NVA-49 | 609403.362 | 4080391.648 | 322.702 | 322.730 |
| NVA-5 | 585501.925 | 4051902.690 | 277.520 | 277.570 |
| NVA-50 | 629993.308 | 4081027.966 | 261.926 | 261.970 |
| NVA-51 | 648405.576 | 4081272.829 | 223.237 | 223.240 |
| NVA-52 | 646787.988 | 4070266.591 | 231.820 | 231.840 |
| NVA-53 | 636425.584 | 4071648.032 | 231.299 | 231.300 |

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| NVA-54 | 621911.762 | 4071756.381 | 280.914 | 280.880 |
| NVA-55 | 606979.262 | 4075446.354 | 343.724 | 343.710 |
| NVA-56 | 592315.865 | 4071413.054 | 362.447 | 362.450 |
| NVA-57 | 599798.508 | 4058644.088 | 232.992 | 232.980 |
| NVA-58 | 616859.688 | 4059708.134 | 294.714 | 294.710 |
| NVA-59 | 632762.104 | 4060228.308 | 249.065 | 249.090 |
| NVA-6 | 579082.402 | 4062922.193 | 362.160 | 362.190 |
| NVA-60 | 648512.651 | 4050400.350 | 176.917 | 176.990 |
| NVA-61 | 633205.696 | 4049082.085 | 194.066 | 194.160 |
| NVA-62 | 623835.891 | 4051609.691 | 234.771 | 234.840 |
| NVA-63 | 612519.180 | 4050435.934 | 265.188 | 265.220 |
| NVA-64 | 601743.543 | 4049672.257 | 266.208 | 266.250 |
| NVA-65 | 593749.575 | 4048596.351 | 312.191 | 312.250 |
| NVA-66 | 655675.642 | 4103908.656 | 247.633 | 247.640 |
| NVA-67 | 665442.359 | 4098918.798 | 188.521 | 188.560 |
| NVA-68 | 680310.648 | 4097181.146 | 142.344 | 142.390 |
| NVA-69 | 691006.482 | 4103390.668 | 181.305 | 181.490 |
| NVA-7 | 563065.031 | 4061418.440 | 480.525 | 480.450 |
| NVA-70 | 695068.088 | 4116080.925 | 230.809 | 230.960 |
| NVA-71 | 704139.945 | 4112861.145 | 200.175 | 200.210 |
| NVA-72 | 718752.625 | 4108056.081 | 160.386 | 160.460 |
| NVA-73 | 723707.187 | 4102178.914 | 192.368 | 192.400 |
| NVA-74 | 709281.694 | 4103523.928 | 173.684 | 173.730 |
| NVA-75 | 699187.883 | 4091975.243 | 150.400 | 150.420 |
| NVA-76 | 676950.154 | 4089484.636 | 205.871 | 206.000 |
| NVA-77 | 662177.505 | 4090284.488 | 186.355 | 186.430 |
| NVA-78 | 659544.715 | 4080101.963 | 207.769 | 207.780 |
| NVA-79 | 676190.262 | 4079364.580 | 116.108 | 116.110 |
| NVA-8 | 549089.567 | 4061745.798 | 891.172 | 891.200 |
| NVA-80 | 691280.634 | 4085525.497 | 171.909 | 171.940 |
| NVA-81 | 704110.035 | 4083659.765 | 114.214 | 114.250 |
| NVA-82 | 719644.862 | 4087004.209 | 162.413 | 162.400 |
| NVA-83 | 726363.564 | 4075907.192 | 165.080 | 165.130 |
| NVA-84 | 709090.942 | 4073621.840 | 138.934 | 138.990 |
| NVA-85 | 697002.936 | 4074236.833 | 125.911 | 125.890 |

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| NVA-86 | 685376.999 | 4071515.812 | 136.051 | 136.120 |
| NVA-87 | 673008.230 | 4071048.577 | 188.777 | 188.880 |
| NVA-88 | 661494.591 | 4066306.157 | 235.200 | 235.240 |
| NVA-89 | 659100.218 | 4060766.255 | 196.440 | 196.520 |
| NVA-9 | 531967.964 | 4060210.384 | 781.387 | 781.300 |
| NVA-90 | 675283.738 | 4054878.845 | 164.463 | 164.500 |
| NVA-91 | 687948.447 | 4062214.441 | 102.968 | 102.970 |
| NVA-92 | 703516.208 | 4059257.081 | 123.289 | 123.300 |
| NVA-93 | 717718.449 | 4055595.341 | 97.675 | 97.770 |
| NVA-94 | 705108.474 | 4049023.359 | 128.251 | 128.280 |
| NVA-95 | 695588.881 | 4053233.728 | 142.855 | 142.950 |
| NVA-96 | 680767.530 | 4051289.269 | 171.268 | 171.310 |
| NVA-97 | 666359.497 | 4050379.010 | 154.430 | 154.500 |
| NVA-98 | 735019.200 | 4102751.571 | 153.858 | 153.890 |
| NVA-99 | 750306.774 | 4101914.235 | 160.025 | 160.030 |
| VVA-1 | 818379.709 | 4054217.027 | 23.053 | 23.290 |
| VVA-10 | 779325.325 | 4067131.089 | 56.309 | 56.430 |
| VVA-100 | 410896.503 | 4260644.003 | 181.186 | 181.340 |
| VVA-101 | 417585.873 | 4247042.945 | 338.332 | 338.430 |
| VVA-102 | 412733.911 | 4241864.005 | 203.248 | 203.330 |
| VVA-103 | 401660.667 | 4242154.572 | 218.430 | 218.440 |
| VVA-104 | 395185.319 | 4237307.519 | 181.238 | 181.220 |
| VVA-105 | 380017.168 | 4233226.793 | 192.882 | 192.930 |
| VVA-106 | 375711.110 | 4241765.985 | 171.720 | 171.770 |
| VVA-107 | 365629.309 | 4244837.176 | 189.245 | 189.140 |
| VVA-108 | 367399.532 | 4235169.492 | 187.153 | 187.120 |
| VVA-109 | 376738.002 | 4227929.616 | 202.735 | 202.840 |
| VVA-11 | 791575.364 | 4066739.432 | 71.216 | 71.240 |
| VVA-110 | 390099.800 | 4226630.225 | 208.922 | 208.990 |
| VVA-111 | 399364.681 | 4226117.708 | 343.969 | 344.040 |
| VVA-112 | 408499.642 | 4231394.180 | 225.166 | 225.250 |
| VVA-113 | 416888.619 | 4236078.950 | 238.437 | 238.490 |
| VVA-114 | 408056.524 | 4222456.881 | 221.044 | 221.190 |
| VVA-115 | 396696.731 | 4224540.521 | 177.924 | 177.980 |
| VVA-116 | 383946.171 | 4220051.195 | 346.141 | 346.110 |

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| VVA-117 | 375442.401 | 4220688.737 | 318.167 | 318.180 |
| VVA-118 | 364279.468 | 4226998.142 | 191.461 | 191.470 |
| VVA-119 | 368955.670 | 4214191.720 | 203.008 | 202.970 |
| VVA-12 | 804011.260 | 4061565.243 | 51.384 | 51.400 |
| VVA-120 | 381307.444 | 4212149.322 | 392.117 | 392.160 |
| VVA-121 | 386029.969 | 4214326.230 | 206.415 | 206.450 |
| VVA-122 | 394497.414 | 4218533.984 | 208.782 | 208.820 |
| VVA-123 | 401236.545 | 4215608.729 | 186.598 | 186.640 |
| VVA-124 | 408716.955 | 4215159.641 | 213.963 | 214.010 |
| VVA-125 | 410857.551 | 4207046.736 | 191.047 | 191.150 |
| VVA-127 | 380124.051 | 4207716.462 | 379.151 | 379.210 |
| VVA-128 | 370787.287 | 4205514.287 | 182.511 | 182.500 |
| VVA-129 | 371099.417 | 4200444.745 | 187.091 | 187.100 |
| VVA-13 | 807851.726 | 4081382.381 | 62.989 | 62.950 |
| VVA-130 | 401415.860 | 4201808.591 | 216.689 | 216.810 |
| VVA-131 | 407662.368 | 4194005.611 | 378.244 | 378.320 |
| VVA-132 | 413314.699 | 4192944.067 | 200.747 | 200.800 |
| VVA-133 | 489937.581 | 4157360.771 | 893.123 | 893.190 |
| VVA-134 | 479340.784 | 4148649.156 | 922.948 | 922.860 |
| VVA-135 | 497606.018 | 4150283.397 | 716.051 | 716.000 |
| VVA-136 | 504870.677 | 4144468.465 | 707.725 | 707.810 |
| VVA-137 | 488888.693 | 4147333.017 | 635.578 | 635.660 |
| VVA-138 | 477301.998 | 4142012.943 | 726.807 | 726.880 |
| VVA-139 | 473370.250 | 4133792.184 | 803.070 | 803.200 |
| VVA-14 | 793821.393 | 4080975.628 | 86.748 | 86.750 |
| VVA-140 | 485952.970 | 4136478.583 | 844.952 | 844.970 |
| VVA-141 | 502171.612 | 4135114.442 | 617.642 | 617.910 |
| VVA-142 | 504339.504 | 4130861.053 | 572.111 | 572.220 |
| VVA-143 | 485432.086 | 4128006.646 | 766.718 | 766.760 |
| VVA-15 | 778432.524 | 4080799.760 | 79.164 | 79.090 |
| VVA-16 | 765923.667 | 4083856.054 | 126.480 | 126.490 |
| VVA-17 | 752563.105 | 4085617.794 | 129.091 | 129.050 |
| VVA-18 | 741947.901 | 4089181.776 | 137.878 | 138.010 |
| VVA-19 | 733791.010 | 4097767.215 | 148.830 | 148.890 |
| VVA-2 | 787902.337 | 4052934.399 | 100.291 | 100.210 |

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| VVA-20 | 744967.094 | 4106698.819 | 176.236 | 176.230 |
| VVA-21 | 755975.999 | 4097964.659 | 122.143 | 122.140 |
| VVA-22 | 769923.092 | 4095092.391 | 126.229 | 126.360 |
| VVA-23 | 778795.614 | 4094334.027 | 111.559 | 111.800 |
| VVA-24 | 793439.402 | 4085106.251 | 81.523 | 81.510 |
| VVA-25 | 716058.038 | 4051751.709 | 127.816 | 127.860 |
| VVA-26 | 704275.941 | 4054551.916 | 112.162 | 112.250 |
| VVA-27 | 693575.150 | 4056292.740 | 123.620 | 123.760 |
| VVA-29 | 674097.463 | 4050365.568 | 169.417 | 169.580 |
| VVA-3 | 777178.788 | 4055314.528 | 105.101 | 105.150 |
| VVA-30 | 660623.419 | 4052885.832 | 164.898 | 165.020 |
| VVA-31 | 661208.438 | 4072469.661 | 176.074 | 176.110 |
| VVA-32 | 675475.820 | 4065084.215 | 154.650 | 154.840 |
| VVA-33 | 688837.160 | 4070816.908 | 123.629 | 123.840 |
| VVA-34 | 701271.226 | 4068943.179 | 160.006 | 160.140 |
| VVA-35 | 717398.838 | 4067992.518 | 107.339 | 107.450 |
| VVA-36 | 717923.501 | 4077651.005 | 140.587 | 140.680 |
| VVA-37 | 717201.837 | 4088888.221 | 167.827 | 167.830 |
| VVA-38 | 699828.519 | 4084623.270 | 119.746 | 119.930 |
| VVA-39 | 684933.458 | 4082843.393 | 167.543 | 167.580 |
| VVA-4 | 760047.812 | 4050567.811 | 95.694 | 95.730 |
| VVA-40 | 672190.958 | 4085381.008 | 173.872 | 174.050 |
| VVA-41 | 658911.043 | 4086033.650 | 166.986 | 167.030 |
| VVA-42 | 660966.420 | 4097416.161 | 207.923 | 207.890 |
| VVA-43 | 673997.135 | 4094191.446 | 180.956 | 181.000 |
| VVA-44 | 688756.399 | 4093918.626 | 153.502 | 153.660 |
| VVA-45 | 704464.619 | 4099549.726 | 165.187 | 165.330 |
| VVA-46 | 717356.557 | 4105003.627 | 128.113 | 128.210 |
| VVA-47 | 706407.604 | 4109595.427 | 169.137 | 169.250 |
| VVA-48 | 694792.151 | 4109339.464 | 177.921 | 177.840 |
| VVA-49 | 648627.744 | 4055334.922 | 208.482 | 208.650 |
| VVA-5 | 746006.568 | 4053578.472 | 86.213 | 86.230 |
| VVA-50 | 637413.992 | 4054887.119 | 185.384 | 185.520 |
| VVA-51 | 622455.555 | 4048071.596 | 202.479 | 202.560 |
| VVA-52 | 617138.406 | 4051224.846 | 235.448 | 235.400 |

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| VVA-53 | 606991.853 | 4048622.048 | 260.557 | 260.640 |
| VVA-54 | 594942.651 | 4050994.107 | 265.621 | 265.590 |
| VVA-55 | 589842.190 | 4057620.854 | 311.514 | 311.620 |
| VVA-56 | 600285.546 | 4071389.216 | 326.999 | 326.990 |
| VVA-57 | 608348.542 | 4066271.644 | 253.675 | 253.820 |
| VVA-58 | 616532.868 | 4068434.570 | 319.370 | 319.150 |
| VVA-59 | 626197.569 | 4065833.266 | 261.863 | 261.880 |
| VVA-6 | 729675.626 | 4050413.852 | 111.149 | 111.140 |
| VVA-60 | 647669.229 | 4067708.055 | 227.045 | 227.130 |
| VVA-61 | 648883.827 | 4087408.265 | 231.750 | 231.980 |
| VVA-62 | 635966.624 | 4084811.805 | 270.769 | 270.860 |
| VVA-63 | 620792.135 | 4083663.117 | 252.466 | 252.570 |
| VVA-64 | 605215.189 | 4086577.418 | 346.506 | 346.490 |
| VVA-65 | 591420.260 | 4080313.915 | 389.078 | 389.050 |
| VVA-66 | 591248.873 | 4102551.963 | 362.658 | 362.570 |
| VVA-67 | 611563.978 | 4097169.979 | 332.971 | 332.890 |
| VVA-68 | 625561.278 | 4094331.591 | 313.499 | 313.530 |
| VVA-69 | 640540.755 | 4094789.367 | 287.834 | 287.850 |
| VVA-7 | 735439.774 | 4068471.088 | 130.814 | 130.770 |
| VVA-70 | 645949.726 | 4106318.438 | 253.881 | 253.430 |
| VVA-71 | 603903.844 | 4108861.654 | 337.068 | 337.020 |
| VVA-72 | 598918.731 | 4117320.914 | 430.162 | 430.110 |
| VVA-73 | 575383.869 | 4132207.205 | 503.852 | 503.680 |
| VVA-74 | 559989.989 | 4128744.506 | 608.853 | 608.880 |
| VVA-75 | 574795.127 | 4116571.158 | 1141.919 | 1142.000 |
| VVA-76 | 582708.547 | 4098478.933 | 415.964 | 415.820 |
| VVA-77 | 566319.188 | 4109599.680 | 461.334 | 461.370 |
| VVA-78 | 539017.631 | 4122700.627 | 639.304 | 639.330 |
| VVA-79 | 525046.817 | 4114657.134 | 690.488 | 690.420 |
| VVA-8 | 747402.962 | 4068168.544 | 128.137 | 128.210 |
| VVA-80 | 510154.001 | 4106161.105 | 669.967 | 669.730 |
| VVA-81 | 528819.512 | 4099229.398 | 615.707 | 615.680 |
| VVA-82 | 530058.070 | 4091193.107 | 653.121 | 652.950 |
| VVA-83 | 549132.898 | 4093424.421 | 740.472 | 740.480 |
| VVA-84 | 563427.839 | 4094914.675 | 731.615 | 731.630 |

| Point ID | NAD83(2011) UTM Zone 17N | | NAVD88 (Geoid 12B) | |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) |
| VVA-85 | 572289.905 | 4080409.058 | 434.537 | 434.450 |
| VVA-86 | 549568.274 | 4076406.189 | 834.722 | 834.670 |
| VVA-87 | 531303.938 | 4077379.737 | 688.799 | 688.870 |
| VVA-88 | 511634.399 | 4067854.113 | 791.587 | 791.690 |
| VVA-89 | 516128.502 | 4053567.144 | 893.938 | 894.070 |
| VVA-9 | 763081.931 | 4061419.585 | 121.528 | 121.540 |
| VVA-90 | 530322.953 | 4052647.902 | 467.403 | 467.370 |
| VVA-91 | 534756.487 | 4065852.173 | 769.623 | 769.530 |
| VVA-92 | 544693.337 | 4052194.729 | 422.856 | 422.800 |
| VVA-93 | 560894.496 | 4066573.886 | 486.088 | 486.070 |
| VVA-94 | 573014.603 | 4061028.188 | 416.157 | 416.270 |
| VVA-95 | 557935.708 | 4052830.873 | 591.689 | 591.610 |
| VVA-96 | 571730.631 | 4047927.270 | 301.887 | 301.990 |
| VVA-97 | 402075.124 | 4292142.941 | 267.675 | 267.680 |
| VVA-98 | 403645.888 | 4282630.397 | 181.399 | 181.340 |
| VVA-99-1 | 402201.119 | 4272569.784 | 187.912 | 188.100 |

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

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

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

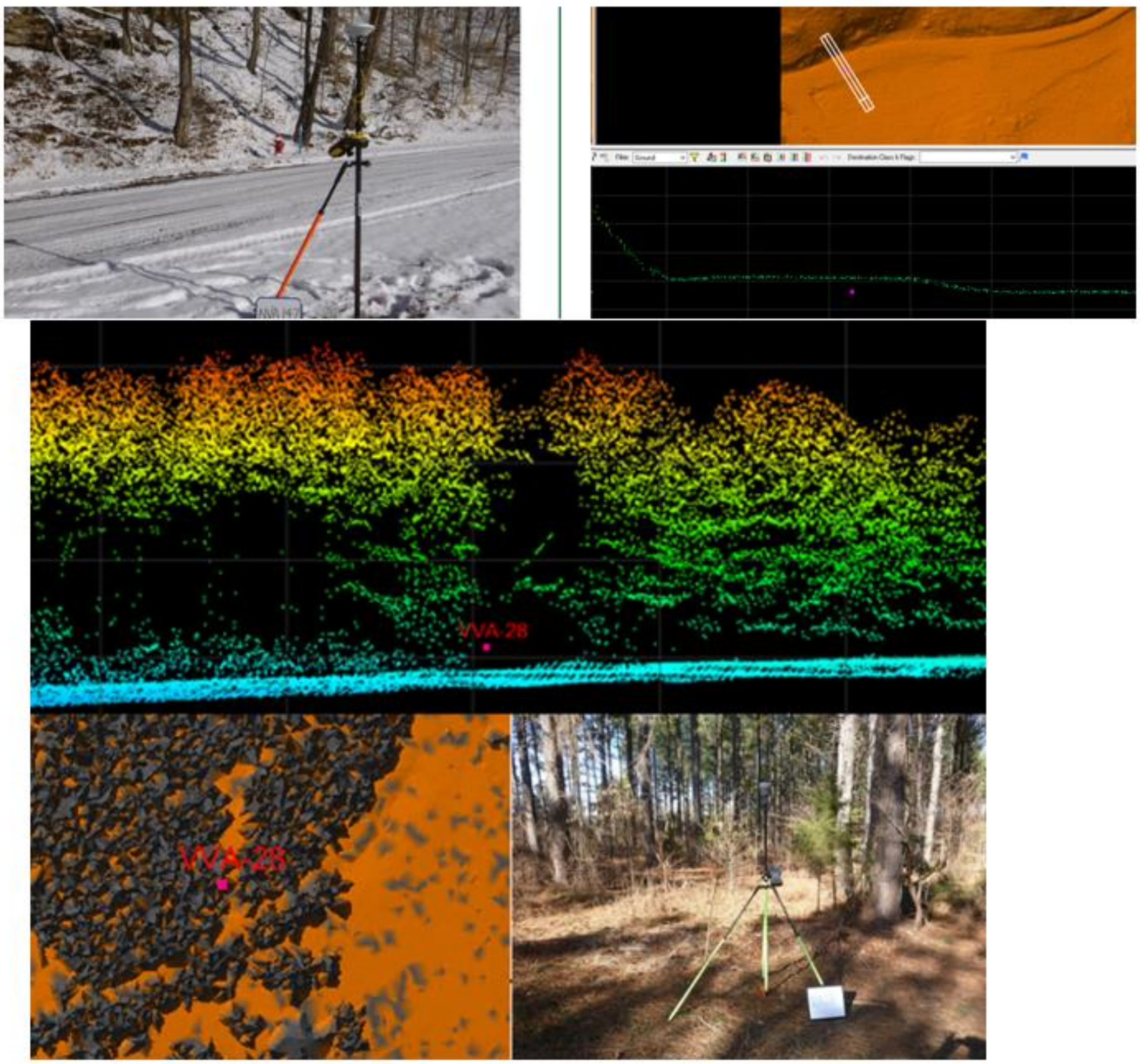


**Figure 19 – The top images show NVA point -147, which was removed due to multipathing issues caused by slope and trees. The bottom images displays VVA-28. The close proximity to the trees and the overhanging branches make this point unsuitable for vertical accuracy testing (bottom).**

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

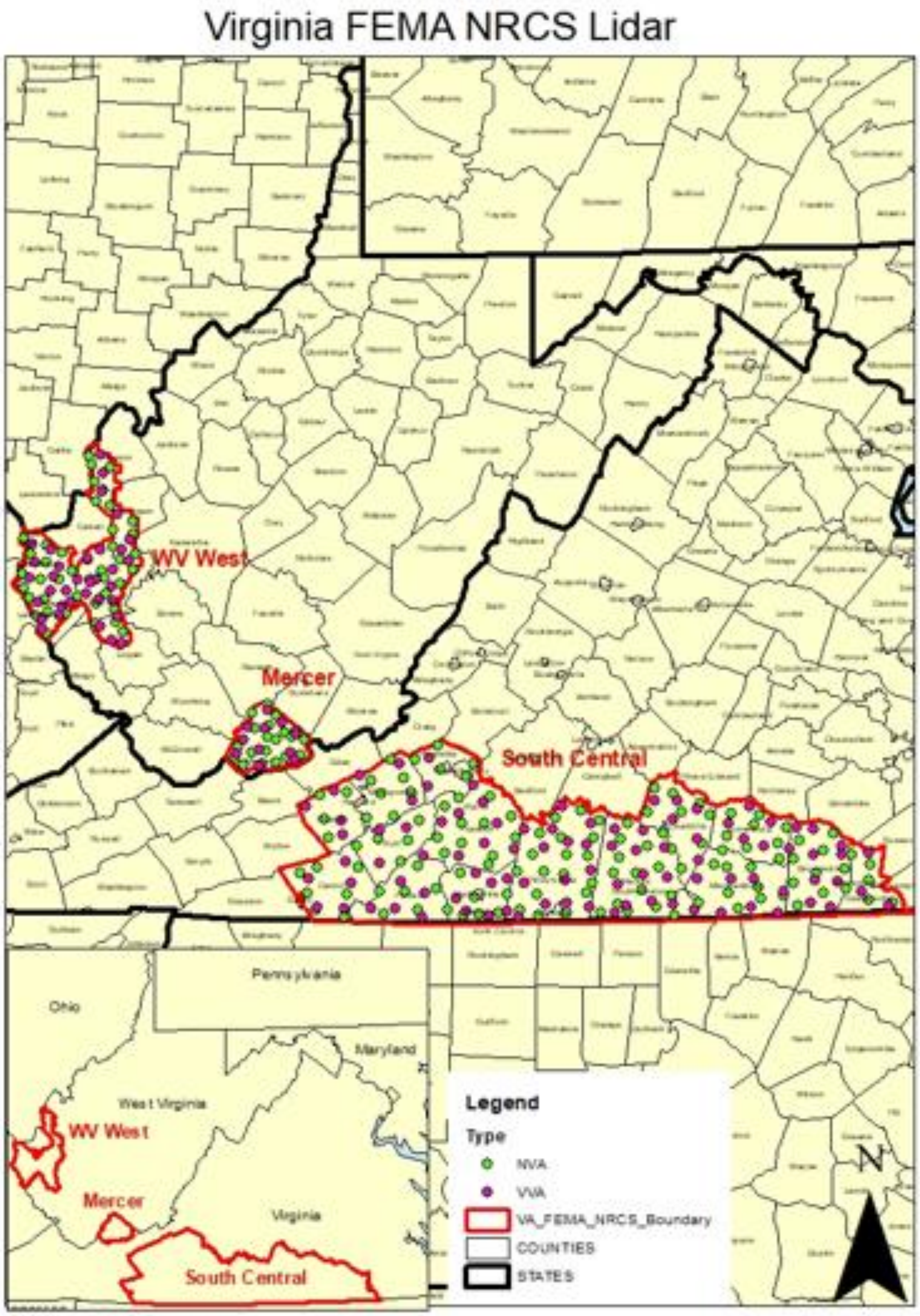


**Figure 20 – Location of QA/QC Checkpoints**

# VERTICAL ACCURACY TEST PROCEDURES

## Non-Vegetated Vertical Accuracy

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

## Vegetated Vertical Accuracy

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

The relevant testing criteria are summarized in Table 15.

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

**Table 15 — Acceptance criteria**

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

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

## VERTICAL ACCURACY RESULTS

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

| Land Cover Category | # of Points | NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm | VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm |
|---|---|---|---|
| NVA | 190 | 0.113 | |
| VVA | 141 | | 0.211 |

Table 16 — Tested lidar NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 5.7cm, equating to ± 11.3 cm at 95% confidence level. Actual VVA accuracy was found to be ± 21.1 cm at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within ± 20 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +45 cm.

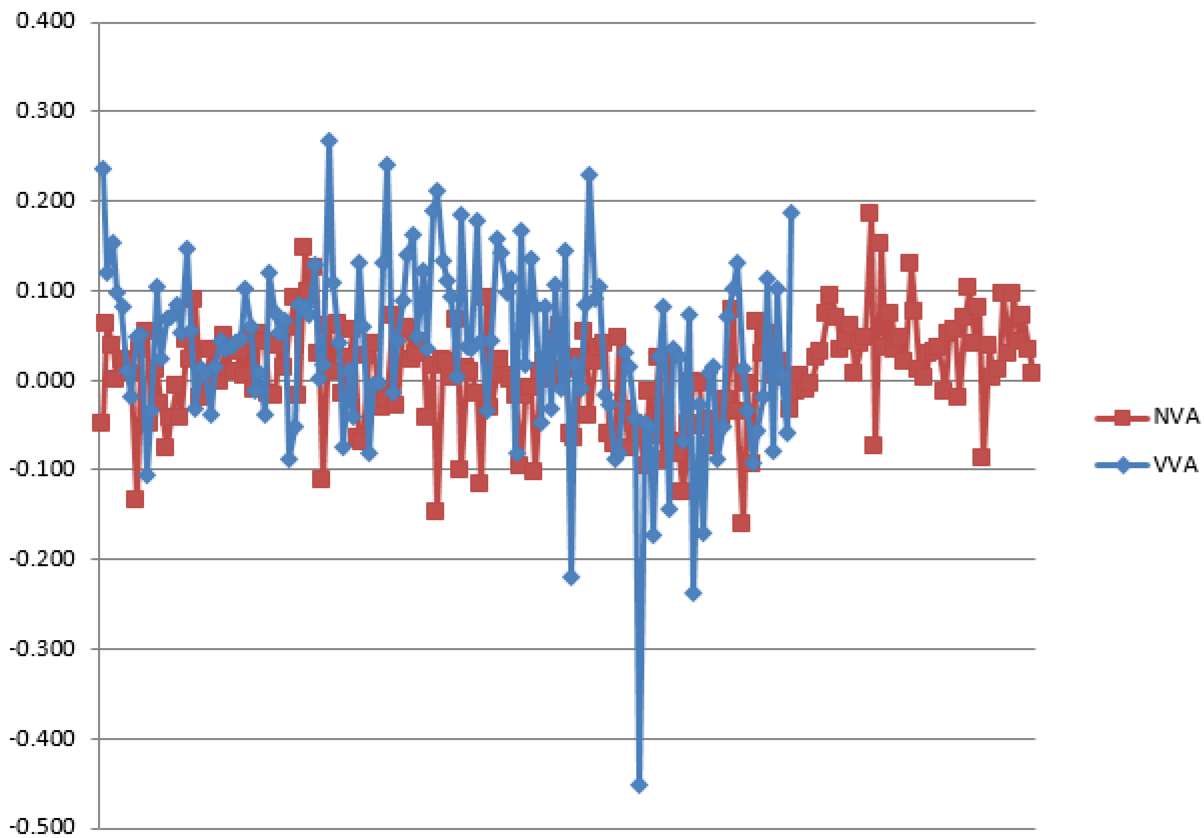


**Figure 21 – Magnitude of elevation discrepancies per land cover category**

Table 17 lists the 5% outliers that are larger than the VVA 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-58 | 616532.868 | 4068434.570 | 319.370 | 319.150 | -0.220 | 0.220 |
| VVA-61 | 648883.827 | 4087408.265 | 231.750 | 231.980 | 0.230 | 0.230 |
| VVA-80 | 510154.001 | 4106161.105 | 669.967 | 669.730 | -0.237 | 0.237 |
| VVA-1 | 818379.709 | 4054217.027 | 23.053 | 23.290 | 0.237 | 0.237 |
| VVA-23 | 778795.614 | 4094334.027 | 111.559 | 111.800 | 0.241 | 0.241 |
| VVA-141 | 502171.612 | 4135114.442 | 617.642 | 617.910 | 0.268 | 0.268 |
| VVA-70 | 645949.726 | 4106318.438 | 253.881 | 253.430 | -0.451 | 0.451 |

**Table 17— Lidar VVA 5% outliers**

Table 18 provides overall descriptive statistics for NVA and VVA assessments.

| 100 % of Totals | # of Points | RMSEz (m) Spec=0.100 m NVA/ 0.180 m Submerged Topography | Mean (m) | Median (m) | Skew | Std Dev (m) | Kurtosis | Min (m) | Max (m) |
|---|---|---|---|---|---|---|---|---|---|
| NVA | 190 | 0.057 | 0.007 | 0.011 | -0.247 | 0.057 | 0.548 | -0.162 | 0.185 |
| VVA | 141 | N/A | 0.036 | 0.042 | -0.932 | 0.099 | 3.702 | -0.451 | 0.268 |

**Table 18 — Lidar NVA and VVA descriptive statistics**

The figure below shows a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. The vast majority of points are within the ranges of -0.05 meters to +0.05 meters.

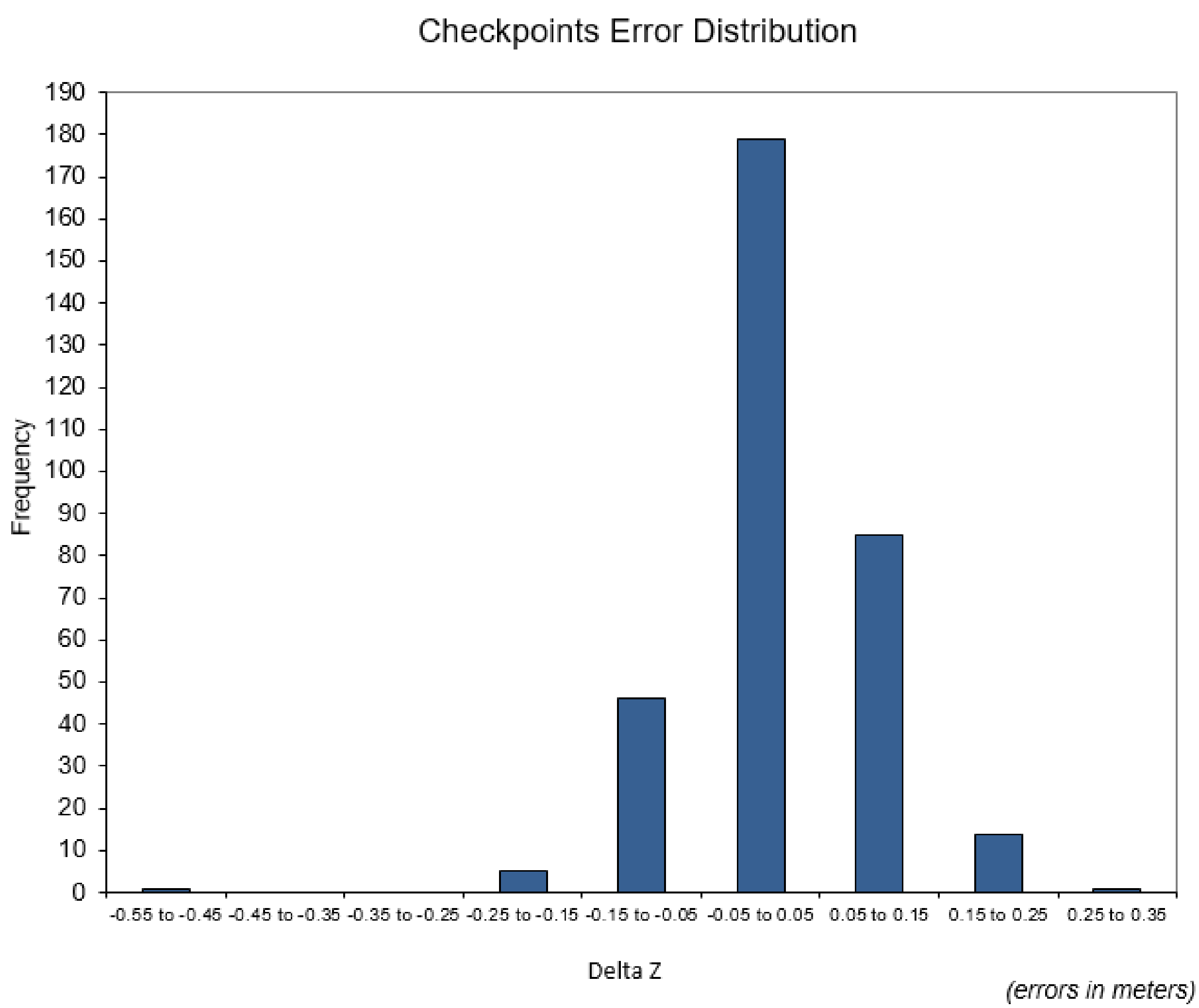


**Figure 22 — Histogram of elevation Discrepancies with errors in meters**

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the USGS Virginia FEMA NRCS South Central Lidar Project satisfies the project's defined vertical accuracy criteria.

## HORIZONTAL ACCURACY TEST PROCEDURES

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

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

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

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

## HORIZONTAL ACCURACY RESULTS

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

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

| # of Points | $RMSE_x$ (Target=41 cm) | $RMSE_y$ (Target=41 cm) | $RMSE_r$ (Target=58 cm) | $ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=100 cm |
|---|---|---|---|---|
| 51 | 0.264 | 0.285 | 0.388 | 0.672 |

**Table 19 – Tested horizontal accuracy at the 95% confidence level**

This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm $RMSE_x$/$RMSE_y$ Horizontal Accuracy Class which equates to a positional horizontal accuracy of ± 1 meter at a 95% confidence level. 51 checkpoints were used for horizontal accuracy testing. Actual positional accuracy of this dataset was found to be $RMSE_x$ = 26.4 cm and $RMSE_y$ = 28.5 cm, which equates to ± 67.2 cm at 95% confidence level.

# Breakline Production & Qualitative Assessment Report

## BREAKLINE PRODUCTION METHODOLOGY

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

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

## BREAKLINE QUALITATIVE ASSESSMENT

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

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

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

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

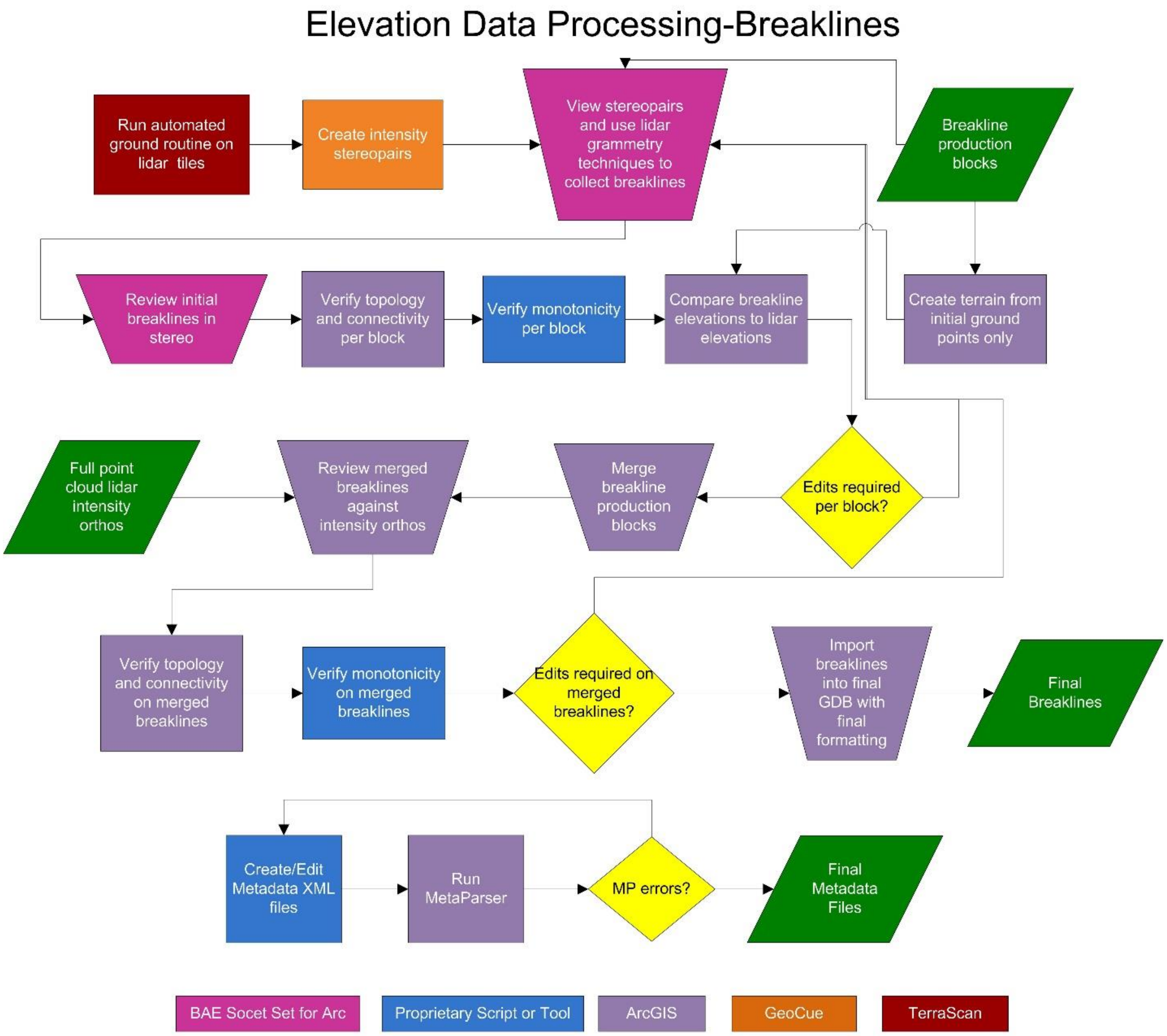


**Figure 23 – Breakline QA/QC workflow**

## BREAKLINE CHECKLIST

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

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

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

**Table 20 – A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.**

# DATA DICTIONARY

The following data dictionary was used for this project.

## Horizontal and Vertical Datum

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

## Coordinate System and Projection

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

## Inland Streams and Rivers

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

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

### Description

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

## Table Definition

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

## Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| Streams and Rivers | Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project. | Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present.<br><br>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.<br><br>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.<br><br>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.<br><br>Every effort should be made to avoid breaking a stream or river into segments.<br><br>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.<br><br>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.<br><br>"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.<br><br>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.<br><br>An Island within a Closed Water Body Feature that is 1 acre in size or greater will also have a "donut polygon" compiled.<br><br>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.<br><br>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.<br><br>The endpoints of the bridge breaklines will match the elevation of the ground at their xy position to enforce the ground/bare earth elevations beneath the bridge deck and prevent bridge saddles from forming. |

# DEM Production & Qualitative Assessment

## DEM PRODUCTION METHODOLOGY

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

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


Figure 24 – DEM production workflow

## DEM QUALITATIVE ASSESSMENT

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

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

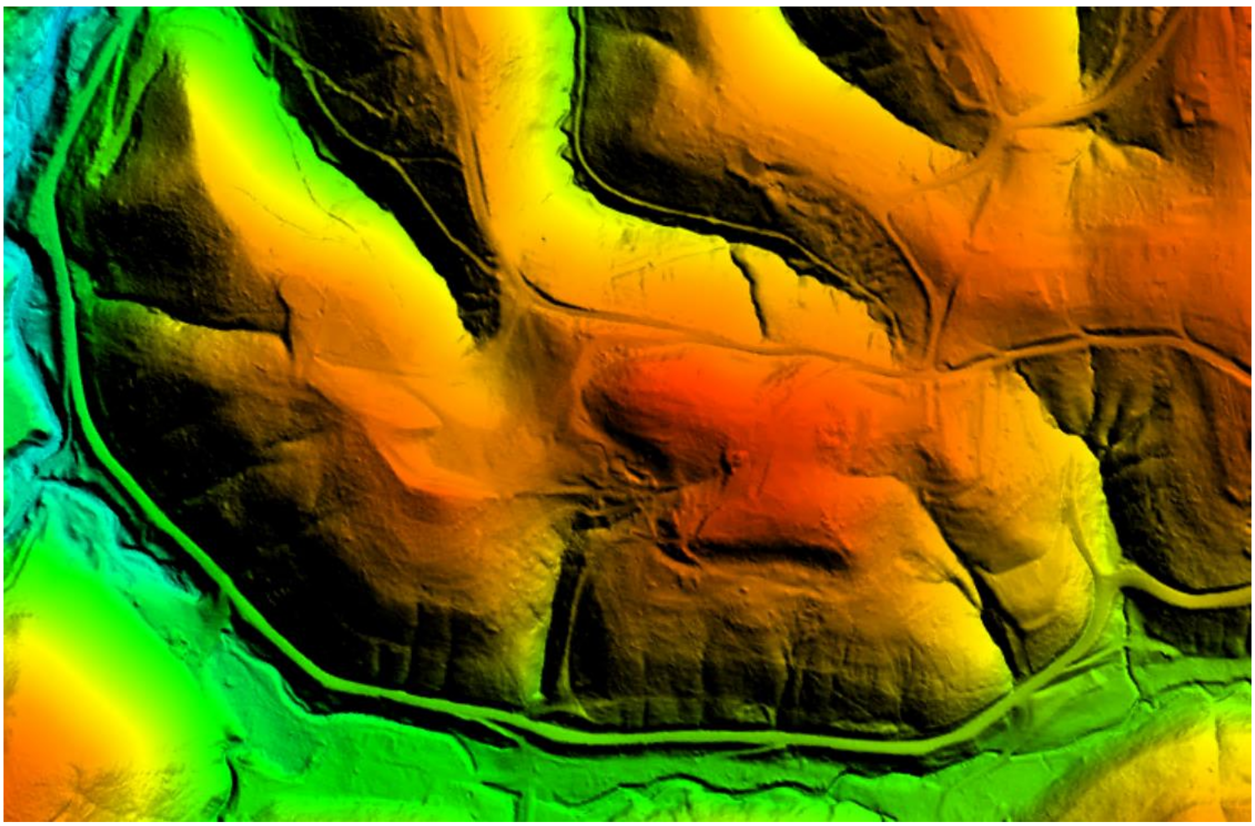

**Figure 25 – 17SLC64504950. Map view of the bare Earth DEM with hillshade**

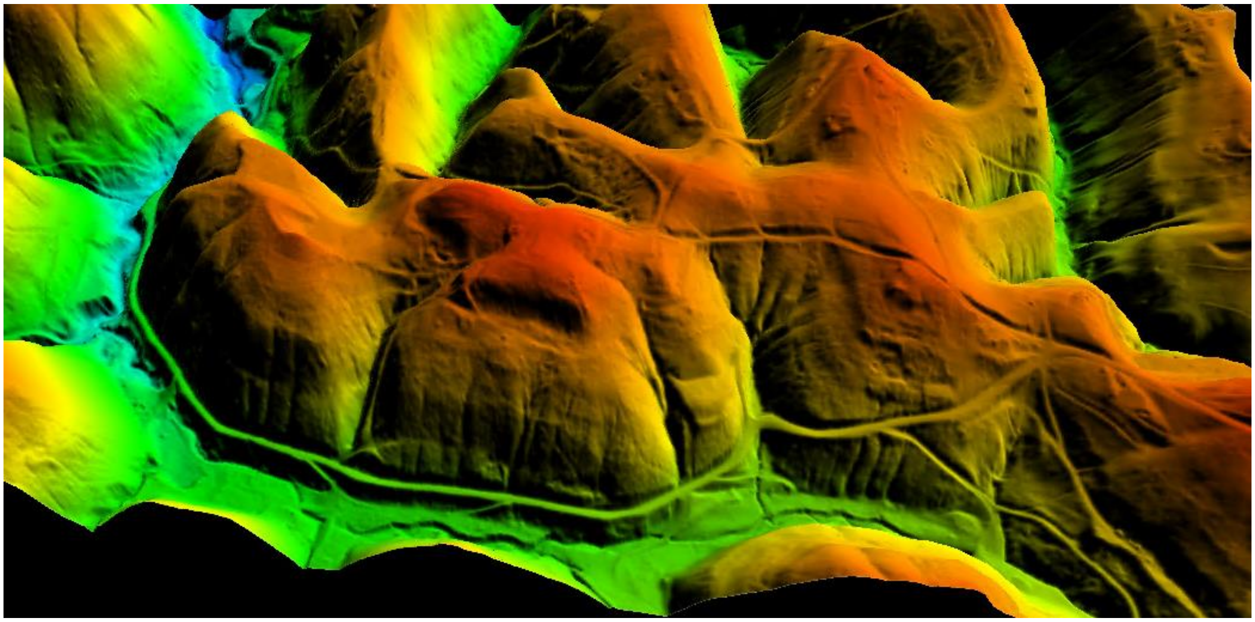

**Figure 26 – 17SLC64504950. 3D profile view of the bare earth DEM**

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

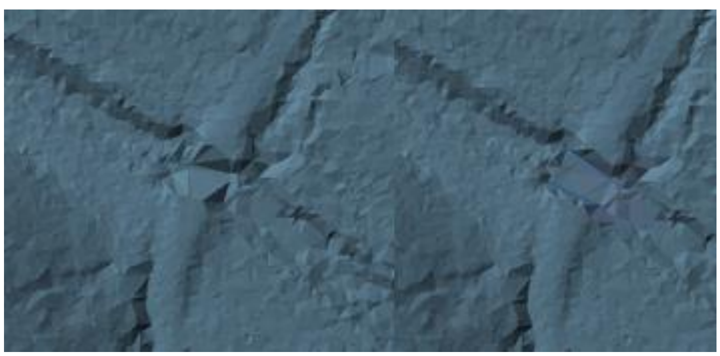

**Figure 27 – 17SNA86507400. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced**

## DEM VERTICAL ACCURACY RESULTS

The same 331 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 21 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

| Land Cover Category | # of Points | NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm | VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm |
|---|---|---|---|
| NVA | 190 | 0.113 | |
| VVA | 141 | | 0.199 |

Table 21 — Tested DEM NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 5.7 cm, equating to ± 11.3 cm at 95% confidence level. Actual VVA accuracy was found to be ± 19.9 cm at the 95th percentile.

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

| Point ID | NAD83(2011) UTM Zone 18N | | NAVD88 (Geoid 12B) | | Delta Z | AbsDelta Z |
|---|---|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | Z-Survey (m) | Z-LiDAR (m) | | |
| VVA-99-1 | 402201.119 | 4272569.784 | 187.912 | 188.125 | 0.213 | 0.213 |
| VVA-32 | 675475.820 | 4065084.215 | 154.650 | 154.884 | 0.234 | 0.234 |
| VVA-80 | 510154.001 | 4106161.105 | 669.967 | 669.731 | -0.236 | 0.236 |
| VVA-141 | 502171.612 | 4135114.442 | 617.642 | 617.901 | 0.259 | 0.259 |
| VVA-23 | 778795.614 | 4094334.027 | 111.559 | 111.856 | 0.297 | 0.297 |
| VVA-1 | 818379.709 | 4054217.027 | 23.053 | 23.362 | 0.309 | 0.309 |
| VVA-70 | 645949.726 | 4106318.438 | 253.881 | 253.455 | -0.426 | 0.426 |

Table 22 — DEM 5% Outliers

| 100 % of Totals | # of Points | RMSEz (m) NVA Spec=0.1 m | Mean (m) | Median (m) | Skew | Std Dev (m) | Kurtosis | Min (m) | Max (m) |
|---|---|---|---|---|---|---|---|---|---|
| NVA | 190 | 0.057 | 0.008 | 0.011 | -0.178 | 0.057 | 0.377 | -0.158 | 0.180 |
| VVA | 141 | N/A | 0.039 | 0.042 | -0.654 | 0.099 | 3.273 | -0.426 | 0.309 |

Table 23 — DEM NVA and VVA descriptive statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the USGS Virginia FEMA NRCS South Central Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

## DEM CHECKLIST

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

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

Table 24– A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project

# Appendix A: Checkpoint Survey Report

Appendix A has been included as an attachment.

## Appendix B: Axis GPS and IMU Reports

Appendix B has been included as an attachment.

# Appendix C: LEG GPS and IMU Reports

Appendix C has been included as an attachment.