Dewberry Engineers Inc.
1000 North Ashley Drive, Suite 801
Tampa, FL 33602

813.225.1325
813.225.1385 fax
www.dewberry.com

Virginia Riverine Topobathy Project

Report Produced for NOAA

Client Contract: 1305M220DNCNL0062

Task Order: 1305M223FNCNL0331

Report Date: March 14, 2025

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

SUBMITTED TO:
NOAA NGS
1315 East-West Highway
Silver Spring, MD 20910

Table of Contents

Table of Tables

Table of Figures

ATTACHMENTS

Appendix A: Mission GPS and IMU Processing Reports

1. 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 Riverine project area.

This task order was for Planning, Acquisition, processing, and derivative products of lidar data to be collected at an aggregate nominal pulse spacing (ANPS) of ≤0.35 meters (QL1). Lidar data and derivative products were produced in compliance with this task order are based on the National Coastal Mapping Strategy 1.0 Document Lidar data were processed and classified according to project specifications. Detailed refraction extents and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Project components were formatted based on a tile grid with each lidar tile covering an area 500 m by 500 m, each ortho-mosaic tile covering an area of 3,000 m by 3,000 m, and each raster tile covering an area of 5,000 m by 5,000 m. A total of 14,284 lidar tiles were produced for the project encompassing an area of approximately 195 sq. miles.

1.1 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, digital elevation model (DEM) production, and quality assurance.

Dewberry completed the ground survey for the project and delivered surveyed checkpoints. Ground control points and checkpoints were surveyed for the project. Ground control points were used in calibration activities and checkpoints were used in independent testing of the vertical accuracy of the lidar-derived surface model.

Dewberry completed lidar data acquisition and data calibration for the project area.

1.2 Project Area

The project area is shown in Figure 1. The project DEM tile grid contains 344 5,000 m by 5,000 m tiles.

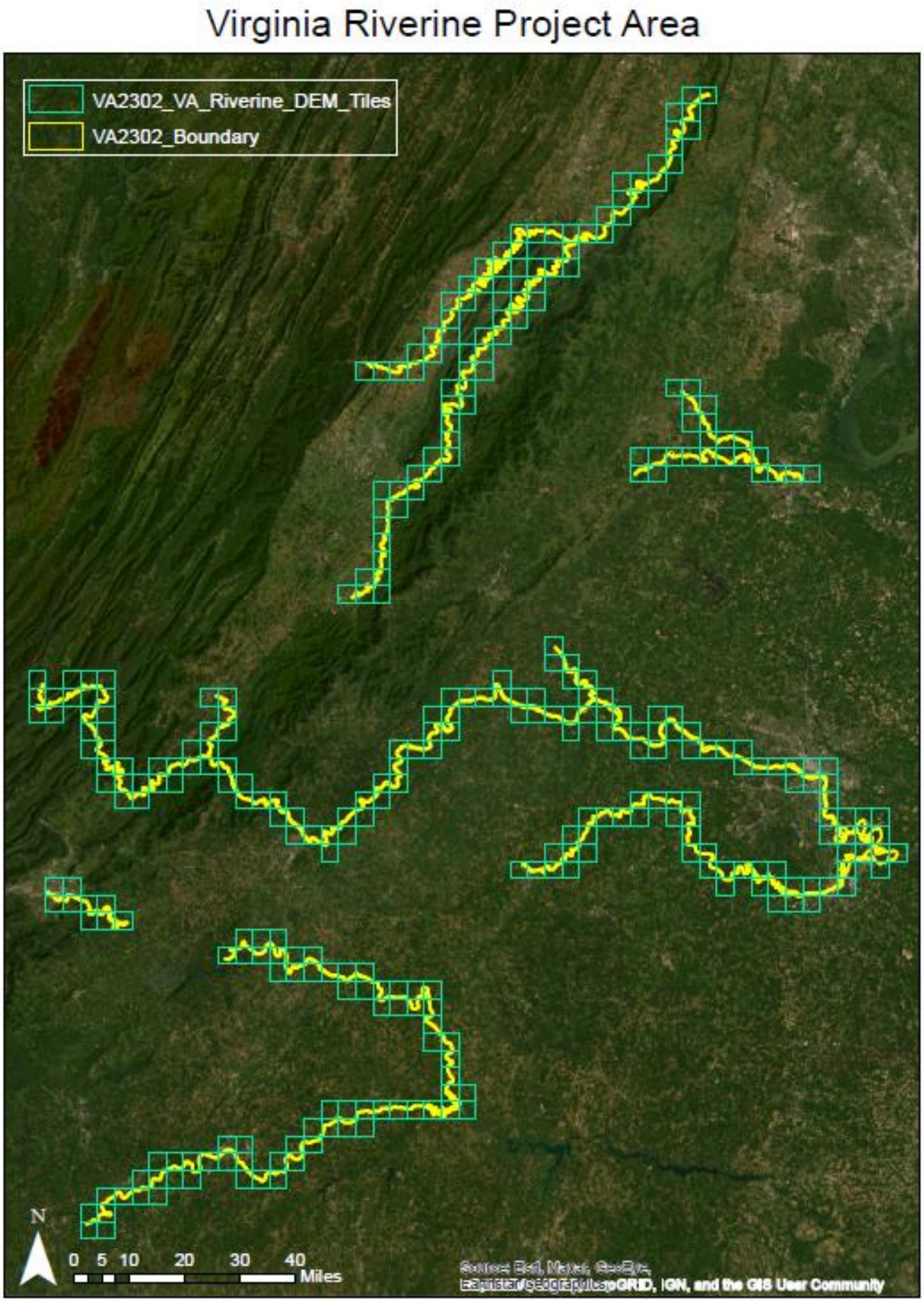


Figure 1. Project map and DEM tile grid.

1.3 Coordinate Reference System

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

Horizontal Datum: North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum, LAS: North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum, DEM: North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM zone 17
Units: Meters
Geoid Model: Geoid18

1.4 Project Deliverables

The deliverables for the project are listed below.

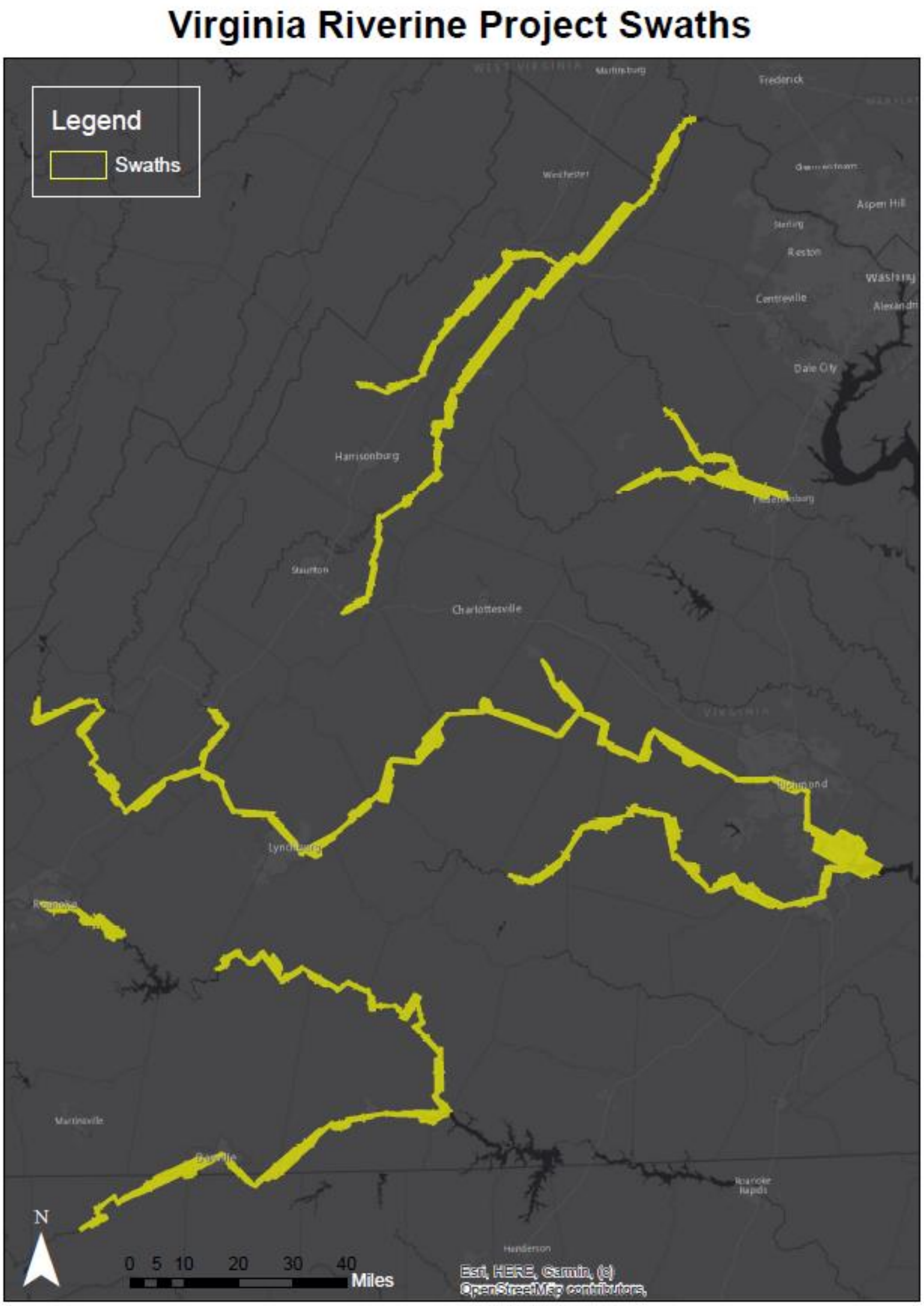
1. Classified Point Cloud (tiled LAS)
2. Bare Earth Surface (Raster DEM – Cloud Optimized GeoTIFF Format)
3. Normalized Seabed Intensity Images (tiled, 16-bit gray scale, GeoTIFF format)
4. Swath Separation Images (tiled raster, GeoTIFF format)
5. Standard Deviations (tiled raster, GeoTIFF format)
6. Independent Survey Checkpoint Data (report, photos, coordinates, Esri shapefile)
7. Calibration Points (coordinates, Esri shapefile)
8. Metadata (XML)
9. Project Report
10. Project Extents (Esri shapefile)
11. Flightline Extents (Esri shapefile)
12. Refraction Extents (Esri shapefile)
13. Void Polygons (Esri shapefile)
14. Trajectories

2. LIDAR ACQUISITION CONTROL

Dewberry was responsible for the lidar acquisition, calibration, and lidar data files. Acquisition was completed on November 28, 2024.

2.1 Acquisition Extents

Figure 2 shows flightline swaths.



Esri, HERE, Garmin, (c) OpenStreetMap contributors,

Figure 2. Project swaths

2.2 Acquisition Summary

Dewberry planned 2702 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. To reduce any margin for error in the flight plan, Dewberry followed industry standards and best practices and, at a minimum, includes the following criteria:

- A digital flight plan layout using Teledyne Airborne Mission Manager (AMM) flight design software for direct integration into the sensor Flight Management System (FMS)
- Unique planned flight line numbers.
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas pre-coordinated so that required permissions can be obtained in a timely manner with respect to schedule.

NOAA provided support for the project and monitored foliage conditions and river levels prior to the authorization to fly aerial lidar. Within 72-hours prior to the planned day(s) of acquisition, Dewberry closely monitored the weather, checking all sources for forecasts at least twice daily. Upon permission to proceed, Dewberry then conducted lidar missions only when no conditions existed below the sensor that would affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist, or low clouds.

Before and during acquisition, Dewberry utilized the USGS National Water Dashboard to closely monitor the flow rate in the project rivers. Acquisition was paused during periods of above average streamflow. Despite these efforts to optimize conditions, differences in bathymetric coverage are still visible throughout the dataset. Differences in water levels, water clarity, and other environmental conditions (e.g. reflectivity of bottom, sediment in water, water currents, etc.) had direct impacts on how well the lidar pulses were able to travel through the water column.

Early in the acquisition, in November 2023, Dewberry encountered several delays due to wildfires causing excessive smoke and haze. This prevented safe flying and effective sensor performance. As acquisition neared completion in January 2024, snowy conditions slowed the pace of acquisition.

After acquisition completion, two sections of the Dan River were found to have been collected within 24 hours of a major rain event. Due to the heavy rain, the river had flooded its banks and inundated the surrounding areas with turbid water. This resulted in no bathymetric or topographic coverage along the river, with hard edges of coverage compared to neighboring missions. After discussion with NOAA, the decision was made to refly when conditions had improved. The reflights took place from November 8, 2024, through November 27, 2024.

2.3 Sensor Calibration and Boresight

Prior to the Virginia Riverine acquisition, Dewberry completed a sensor boresight for Supernova CZ11 from September 11, 2023, until September 12, 2023, in Fort Lauderdale, FL and for Supernova CZ12 on October 31, 2023, in Fort Lauderdale, FL. The boresight consisted of multiple opposing lines in an E-W direction as well as multiple opposing lines in a N-S direction. The swaths have a large overlap (>60%) with neighbors. The trajectory (.sbet) was processed using Applanix PosPac and raw swath data (.las) was produced using Caris Base Editor. The boresight was calibrated and then analyzed in Teledyne Lidar Mapping Suite (LMS). All deemed necessary corrections were then applied to the senor orientation internal files.

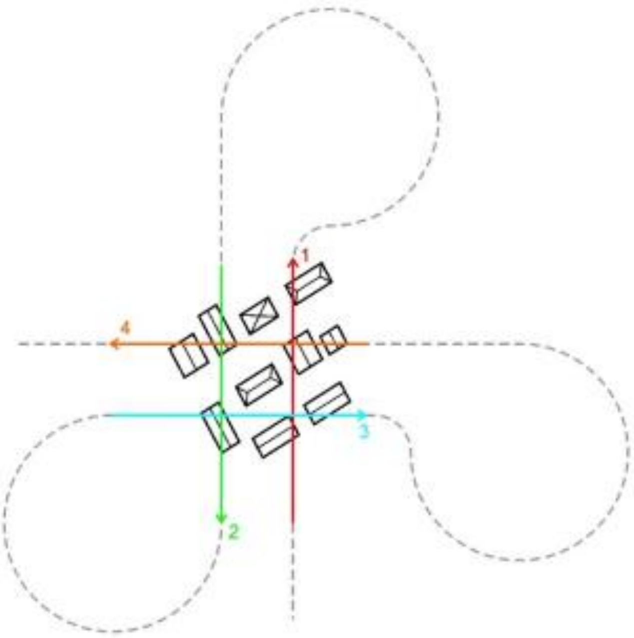


Figure 3. A typical calibration and boresight flight plan where above ground features are acquired from all four cardinal directions, any offsets of the above ground features between overlapping and other directional flight lines is analyzed, and corrections are applied as necessary to ensure proper configuration of the sensor

2.4 Lidar Acquisition and Processing Details

Table 1 outlines lidar acquisition details, including the project spatial reference system, and processing software used for this project.

Table 1. Lidar acquisition details

Parameter	Value
Number of Flight lines	2702
Approximate Area	195 sq. miles
Acquisition Dates	October 15, 2023 – November 27, 2024
Horizontal Datum	North American Datum of 1983 (NAD83)
Vertical Datum	North American Vertical Datum of 1988 (NAVD88)
Geoid Model	Geoid18
Coordinate Reference System	UTM Zone 17
Horizontal Units	Meters
Vertical Units	Meters
Kinematic Solution Processing Software:	Applanix Pospac
Point Cloud Generation Software	CARIS Base Editor
Calibration Software	BayesMap StripAlign

2.5 Lidar System Parameters

Dewberry operated two Cessna 208B Grand Caravans (Tail # N119RF and N126RF) outfitted with Teledyne CZMIL SuperNOVA lidar systems during data collection. Table 2 details the lidar system parameters used during acquisition for this project.

Table 2: Dewberry lidar system parameters

Parameter	Value
System	Teledyne CZMIL Supernova (SN# CZ11 & CZ12)
Altitude (m above ground level)	400
Nominal flight speed (kts)	120
Scanner pulse rate (kHz)	Proprietary
Scan frequency (Hz)	27
Pulse duration of the scanner (ns)	Proprietary
Pulse width of the scanner (m)	Proprietary
Central wavelength of the sensor laser (nm)	532
Multiple pulses in the air	Yes
Beam divergence (mrad)	5
Swath width (m)	290
Nominal swath width on the ground (m)	290
Swath overlap (%)	65
Total sensor scan angle (degrees)	40
Nominal pulse spacing (NPS) (single swath) (m)	0.36
Nominal Pulse Density (NPD) (single swath) (points per sq m)	7.8
Aggregate NPS (m) (if NPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.36
Aggregate NPD (m) (if NPD was designed to be met through single coverage, ANPD and NPD will be equal)	7.8
Maximum Number of Returns per Pulse	15

2.6 Acquisition Static Control

The airborne lidar data was post-processed by Dewberry with Applanix IN-Fusion PP-RTX, a Precise Point Position (PPP) processing solution. Therefore, no static base station control was required.

2.7 Airborne Kinematic Control

Airborne GPS data was processed using the PosPac kinematic On-The-Fly (OTF) software suite. Flights were flown with a minimum of six satellites in view (13° above the horizon) and with PDOP less 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 provided in Appendix A: Mission GPS and IMU Processing Reports.

2.8 ABGNSS-Inertial Processing

ABGNSS-Inertial processing was performed using the software identified in Table 1. The reference frame used for this processing does not always match the project spatial reference system and is shown in Table 3.

Appendix A contains additional mission GPS and IMU processing covering:

- POSPac graphics and processing
- Graphics of any reference stations used for differential correction
- Graphics of processing interface to show trajectory data and labeled reference stations for each lift (only graphics of trajectory when precise point position is used).
- Graphics of processed plots for each mission/flight/lift to include:
    1. Forward/reverse separation of trajectory
    2. Estimated accuracy of trajectory
    3. Any additional plots used in the analyses of trajectory quality

Table 3. Spatial reference system used for ABGNSS-Inertial processing

Parameter	Value
Horizontal Datum	North American Datum of 1983 (NAD83)
Vertical Datum	North American Vertical Datum of 1988 (NAVD88)
Geoid Model	Geoid18
Coordinate Reference System	UTM Zone 17
Horizontal Units	Meters
Vertical Units	Meters

2.9 Calibration Process (Project Mission Calibration)

Availability and staus of all required gps and laster data were verified against field reports and any data inconsistencies were addressed.

Subsequently the mission points were output using Teledyne Geospatial's CARIS software suite, initially with default values from Teledyne or the last mission calibrated for the system. The intial points (.las) for each mission calibration were inspected for flight line errors, spatial distribution, data voids, density, or issues with the lidar sensor. If a calibration error greater than specification was observed within the mission, the necessary roll, pitch, and scanner scale corrections were calculated and corrections were applied to each individual swath using the BayesMap StripAlign software. In addition, all GPS, aircraft trajectory, mission information, and ground control files were reviewed and logged into a database. The missions with the new calibratoin vlues were regenerated and validated internally once again to ensure quality.

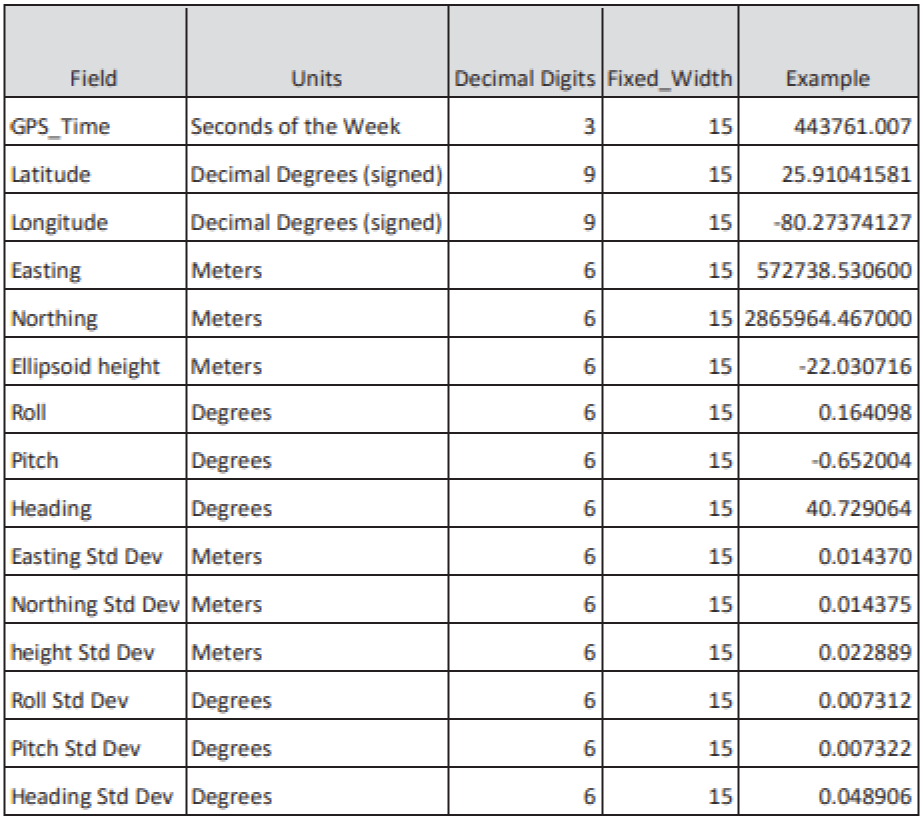
The methodology and assessment for the spatial distribution, density, and sensor anomaly reviews are outlined further in section 3.1.1 the Post Calibration Lidar Review.

2.10 Refraction Correction

Bathymetric data must have a refraction correction applied. This process corrects the horizontal and vertical (depth) positions of each data point by accounting for the change in direction and speed of light as it enters and travels through water. The refraction correction for this dataset was performed by Dewberry using proprietary software.

2.11 Trajectories

A custom final lidar trajectory file is provided to calculate the total propagated uncertainty of bathymetric lidar data. Below are the file specifications used when creating the custom final lidar trajectory file:



Field	Units	Decimal Digits	Fixed_Width	Example
GPS_Time	Seconds of the Week	3	15	443761.007
Latitude	Decimal Degrees (signed)	9	15	25.91041581
Longitude	Decimal Degrees (signed)	9	15	-80.27374127
Easting	Meters	6	15	572738.530600
Northing	Meters	6	15	2865964.467000
Ellipsoid height	Meters	6	15	-22.030716
Roll	Degrees	6	15	0.164098
Pitch	Degrees	6	15	-0.652004
Heading	Degrees	6	15	40.729064
Easting Std Dev	Meters	6	15	0.014370
Northing Std Dev	Meters	6	15	0.014375
height Std Dev	Meters	6	15	0.022889
Roll Std Dev	Degrees	6	15	0.007312
Pitch Std Dev	Degrees	6	15	0.007322
Heading Std Dev	Degrees	6	15	0.048906

Figure 4. Trajectory file specifications.

Trajectory files are delivered as a tab delimited text (.txt) file, following the naming convention of YYYYMMDD, e.g., 20200810_lift01.txt.

2.12 Final Calibration Verification

Dewberry surveyed 28 ground control points (GCPs) in flat, non-vegetated areas to test the accuracy of the calibrated swath data. GCPs were located in open, non-vegetated terrain. To assess the accuracy of calibration, the heights of the ground control points were compared with a surface derived from the calibrated swath lidar. A full list of GCPs used for accuracy testing is included in the GCP Survey Report provided with project deliverables.

Table 4.Summary of calibrated swath vertical accuracy tested with ground control points.

Land Cover Type	# of Points	RMSE$_z$ (m)	NVA (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Ground Control Points (GCPs)	28	0.067	0.131	-0.016	0.006	-0.951	0.066	-0.158	0.098	0.309

3. LIDAR PROCESSING & QUALITATIVE ASSESSMENT

3.1 Initial Processing

Dewberry performed vertical accuracy validation of the swath data, inter-swath relative accuracy validation, intra-swath relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allowed Dewberry to determine whether the data were suitable for full-scale production.

The methodology and assessment for the absolute and relative accuracy, density, and spatial distribution reviews performed are outlined further in the Post Calibration Lidar Review table.

3.1.1 Post Calibration Lidar Review

The table below identifies requirements verified by Dewberry prior to tiling the swath data, running initial ground macros, and starting manual classification.

Table 5. Post calibration and initial processing data verification steps.

Methodology and Requirement	Description of Deliverables	Additional Comments
Using proprietary software it was determined the non-vegetated vertical accuracy (NVA) of the swath data meet required specifications of 19.6 cm at the 95% confidence level based on RMSEz (10 cm) x 1.96	The swath NVA was tested and passed specifications.	None
Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing density mean statistics output by proprietary tool, the project area was determined to meet the required specification of 3 ppsm or 0.35 m NPS.	The average calculated (A)NPD of this project is 19.9 ppsm. Density raster visualization also passed specifications.	None

A visual review of a 1-square meter density grid is also performed to confirm most 1-square meter cells satisfies the project requirements. Density is also viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds) to confirm density passes with no 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. Proprietary 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, i.e. some asphalt and roof composition materials. This project passes spatial distribution requirements, as shown in the image below.	98% of cells (2*NPS cell size) had at least 1 lidar point within the cell.	None
Within swath (Intra-swath or hard surface repeatability) relative accuracy must meet ≤ 6 cm maximum difference. Dewberry verifies the intra-swath or within swath relative accuracy by using proprietary scripting to output intra-swath rasters. Proprietary scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry performs a visual review of planar surfaces and ensures the data passes specification.	Within swath relative accuracy passed specification.	None

Between swath (Inter-swath or swath overlap) relative accuracy must meet 8 cm RMSDz maximum difference. These thresholds are tested in open, flat terrain. Dewberry verifies the inter-swath or between swath relative accuracy by using proprietary scripting to output inter-swath rasters and LP360 generated Swath Separation Images which are both reviewed visually at multiple stages of production to ensure the data passes specification.	Between swath relative accuracy passed specification, calculated from single return lidar points.	None
Horizontal Calibration-There should not be horizontal offsets (or vertical offsets) between overlapping swaths that would negatively impact the accuracy of the data or the overall usability of the data. Assessments made on rooftops or other hard planar surfaces where available.	Horizontal calibration met project requirements.	None
Ground Penetration-The missions were planned appropriately to meet project density requirements and achieve as much ground penetration beneath vegetation as possible	Ground penetration beneath vegetation was acceptable.	None
Sensor Anomalies-The sensor should perform as expected without anomalies that negatively impact the usability of the data, including issues such as excessive sensor noise and intensity gain or range-walk issues	No sensor anomalies were present.	None
Edge of Flightline bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath acquired, regardless of which type of sensor is used	Edge of Flightline bits were populated correctly	None

Scan Direction bits- These fields must show a minimum value of 0 and a maximum value of 1 for each swath. For the CZMIL Supernova sensor, which uses a circular scanner head, 0 and 1 scan direction bits will denote positive and negative directions, e.g. 360 degree scanning pattern is split into +180 and -180 degrees.	Scan Direction bits were populated correctly	None
Swaths are in LAS v1.4 formatting	Swaths were in LAS v1.4 as required by the project.	None
All swaths must have File Source IDs assigned (these should equal the Point Source ID or the flight line number)	File Source IDs were correctly assigned	None
GPS timestamps must be in Adjusted GPS time format and Global Encoding field must also indicate Adjusted GPS timestamps	GPS timestamps were Adjusted GPS time and Global Encoding field were correctly set to 17	None
Intensity values must be 16-bit, with values ranging between 0-65,535	Intensity values were 16-bit	None
Point Source IDs must be populated and swath Point Source IDs should match the File Source IDs	Point Source IDs were assigned and match the File Source IDs	None

3.2 Data Classification and Editing

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, Dewberry utilized proprietary and TerraScan software for processing. The acquired 3D laser point clouds were tiled according to the project tile grid using proprietary software. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classified 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 may be geometrically unusable were flagged as withheld and classified to a separate class so that they would be excluded from the initial ground algorithm. After points that could negatively affect the ground were removed from class 1, the ground layer was extracted from this remaining point cloud using an iterative surface model.

This surface model was generated using four main parameters: building size, iteration angle, iteration distance, and maximum terrain angle. The initial model was based on low points being selected by a "roaming window" with the assumption that these were the ground points. The size of this roaming window was determined by the building size parameter. The low points were triangulated and the remaining points were evaluated and subsequently added to the model if they met the iteration angle and distance constraints. This process was repeated until no additional points were added within iterations. Points that did not relate to classified ground within the maximum terrain angle were 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. Dewberry analysts employed 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points were removed from the ground classification. Bridge decks were classified to class 17. After the ground classification corrections were completed, the dataset was processed through a refraction extent creation to define the land/water interface and constrained void polygons.

The withheld bit was set on the withheld points previously identified in TerraScan before the ground classification routine was performed. The withheld bit was set on points classified as noise (classes 7 and 18) after manual clean-up. The synthetic bit was set on synthetic points previous identified by CARIS and TerraScan before the ground classification routine was performed. The synthetic bit was set on points classified was synthetic water surface (class 42).

After manual classification, the LAS tiles were peer reviewed and then underwent a final independent 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 and verified using proprietary Dewberry software.

3.2.1 Qualitative Review

Dewberry's qualitative assessment of lidar point cloud data utilized a combination of statistical analyses and visual interpretation. Methods and products used in the assessment included profile- and map view-based point cloud review, pseudo image products (e.g., intensity orthoimages), TINs, DEMs, DSMs, and point density rasters. This assessment looked for incorrect classification and other errors sourced in the LAS data. Lidar data are peer reviewed, reviewed by task leads (senior level analysts), and verified by an independent QA/QC team at key points within the lidar workflow.

The following table describes Dewberry's standard editing and review guidelines for specific types of features, land covers, and lidar characteristics.

Table 6. Lidar editing and review guidelines.

Category	Editing Guideline	Additional Comments
No Data Voids	The SOW for the project defines unacceptable data voids as voids greater than 4 x ANPS^2, or 1.96 m^2. Topographic areas should be free of voids unless related to low infrared	Please see section 6.1 Void Polygons for information regarding remaining bathymetric voids.

Category	Editing Guideline	Additional Comments
	reflectivity or appropriately filled by an adjacent/overlapping swath. Voids due to aircraft motion (topographic or bathymetric areas) must be reflown. Bathymetric voids may exist due to environmental conditions but best efforts should have been made to fill these voids through reflights. Remaining bathymetric voids, which could not be filled through reflights, must be geospatially identified and delivered as polygons.	
Topographic Artifacts	Artifacts in the point cloud are typically caused by misclassification of points in vegetation or man-made structures as ground. Low-lying vegetation and buildings are difficult for automated grounding algorithms to differentiate and often must be manually removed from the ground class. Dewberry identified these features during lidar editing and reclassified them to Class 1 (unassigned). Artifacts up to 0.3 m above the true ground surface may have been left as Class 2 because they do not negatively impact the usability of the dataset.	None
Bathymetric Artifacts	At or near laser extinction, bathymetric bottom tends to show diminishing returns and automated grounding can misclassify the water surface or water column as bathymetric bottom due to denser consistency of points. Dewberry identifies these features during lidar editing and reclassifies them to class 1 (unassigned), class 41 (water surface), or class 45 (water column) as appropriate while also looking to bring in any potential valid class 40 (bathymetric bottom).	None
Submerged Object	Submerged objects have been identified and manually classified as class 43 (Submerged Object).	Class 43 submerged objects have been identified and classified appropriately in this AOI.

Category	Editing Guideline	Additional Comments
Culverts and Bridges	It is Dewberry's standard operating procedure to leave culverts in the bare earth surface model and remove bridges from the model. In instances where it is difficult to determine whether the feature was a culvert or bridge, Dewberry errs on the side of culverts, especially if the feature is on a secondary or tertiary road.	None
In-Ground Structures	In-ground structures typically occur on military bases and at facilities designed for munitions testing and storage. When present, Dewberry identifies these structures in the project and includes them in the ground classification.	No in-ground structures present in this dataset
Dirt Mounds	Irregularities in the natural ground, including dirt piles and boulders, are common and may be misinterpreted as artifacts that should be removed. To verify their inclusion in the ground class, Dewberry checked the features for any points above or below the surface that might indicate vegetation or lidar penetration and reviews ancillary layers in these locations as well. Whenever determined to be natural or ground features, Dewberry edits the features to class 2 (ground)	No dirt mounds or other irregularities in the natural ground were present in this dataset
Flight Line Ridges	Flight line ridges occur when there is a difference in elevation between adjacent flight lines or swaths. If ridges are visible in the final DEMs, Dewberry ensures that any ridges remaining after editing and QA/QC are within project relative accuracy specifications.	No flight line ridges are present in the data
Temporal Changes	If temporal differences are present in the dataset, the offsets are identified with a shapefile.	No temporal offsets are present in the data
Low NIR Reflectivity	Some materials, such as asphalt, tars, and other petroleum-based products, have low NIR reflectivity. Large-scale applications of these products,	No Low NIR Reflectivity is present in the data

Category	Editing Guideline	Additional Comments
	including roadways and roofing, may have diminished to absent lidar returns. USGS LBS allow for this characteristic of lidar but if low NIR reflectivity is causing voids in the final bare earth surface, these locations are identified with a shapefile.	
Refraction Extents (Land-Water Interface)	The DEM voids are enforced in bathymetric regions - areas where refraction has been applied. Refraction extents are auto-generated from refracted classes and later QC'd for any anomalies. Dewberry identifies missing features (e.g., small inland ponds) and incorrectly captured features (e.g., pools along shorelines) and manually adjusts the refraction extents. Refraction extents will also be manually adjusted to flow through/under manmade objects such as bridges or docks.	None.
Laser Shadowing	Shadows in the LAS can be caused when solid features like trees or buildings obstruct the lidar pulse, preventing data collection on one or more sides of these features. First return data is typically collected on the side of the feature facing toward the incident angle of transmission (toward the sensor), while the opposite side is not collected because the feature itself blocks the incoming laser pulses. Laser shadowing typically occurs in areas of single swath coverage because data is only collected from one direction. It can be more pronounced at the outer edges of the single coverage area where higher scanning angles correspond to more area obstructed by features. Building shadow in particular can be more pronounced in urban areas where structures are taller. Per specifications, reflights would occur if	No Laser Shadowing is present in the data

Category	Editing Guideline	Additional Comments
	voids are present due to excessive building shadow. Within dense vegetation, data are edited to the fullest extent possible within the point cloud.	

3.2.2 Formatting Review

After the final QA/QC was performed and all corrections were applied to the dataset, all lidar files were updated to the final format requirements and the final formatting, header information, point data records, and variable length records were verified using proprietary tools. The table below lists the primary lidar header fields that are updated and verified.

Table 7. Classified lidar formatting parameters

Parameter	Project Specification	Pass/Fail
LAS Version	1.4	Pass
Point Data Record Format	6	Pass
Horizontal Coordinate Reference System	NAD83 (2011) UTM Zone 17, meters in WKT format	Pass
Vertical Coordinate Reference System	NAD83 (2011) UTM Zone 17, meters in WKT format	Pass
Global Encoder Bit	17 for adjusted GPS time	Pass
Time Stamp	Adjusted GPS time (unique timestamps)	Pass
System ID	Sensor used to acquire data	Pass - CZMIL SuperNOVA
Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16-bit intensity values recorded for each pulse	Pass
Classification	Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 17: Bridge Decks Class 18: High Noise Class 40: Bathymetric Bottom, Submerged Topography Class 41: Water Surface Class 42: Derived Water Surface Class 45: Water Column, Neither surface nor bottom	Pass
Withheld Points	Withheld bits set for geometrically unreliable points and for noise points	Pass

Parameter	Project Specification	Pass/Fail
	in classes 7 and 18. Synthetic bits set for synthetic water surface in class 42.	
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Recorded for each pulse	Pass

3.2.3 Synthetic Points

Generally, class 42 represents synthetic water surface points which are those points that are artificially generated by the CARIS Base Editor processing software for the CZMIL SuperNOVA sensor. These are created during the detection of the water surface to ensure consistency in the refraction correction.

4. LIDAR POSITIONAL ACCURACY

4.1 Background

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discrete measurement of the survey checkpoints to that of the interpolated value within the three closest lidar points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the result is that only a small sample of the lidar data is actually tested. However, there is an increased level of confidence with lidar data due to the relative accuracy. This relative accuracy in turn is based on how well one lidar point "fits" in comparison to the next contiguous lidar measurement and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. For accuracy testing, Dewberry typically uses proprietary software, which utilizes both Esri and lastools software within its workflow, to test the swath lidar vertical accuracy and classified lidar vertical accuracy.

Horizontal accuracy testing requires survey checkpoints located such that the checkpoints are photo-identifiable in the intensity imagery. No photo-identifiable checkpoints were surveyed for this project, so the horizontal accuracy was not tested.

4.2 Survey Vertical Accuracy Checkpoints

The Virginia Riverine project encompasses approximately 195 square miles within the state of Virginia. The figure below shows the Virginia Riverine project area and the checkpoints that were collected. A complete list of survey checkpoints is contained in the project survey report, which is included as a project deliverable.

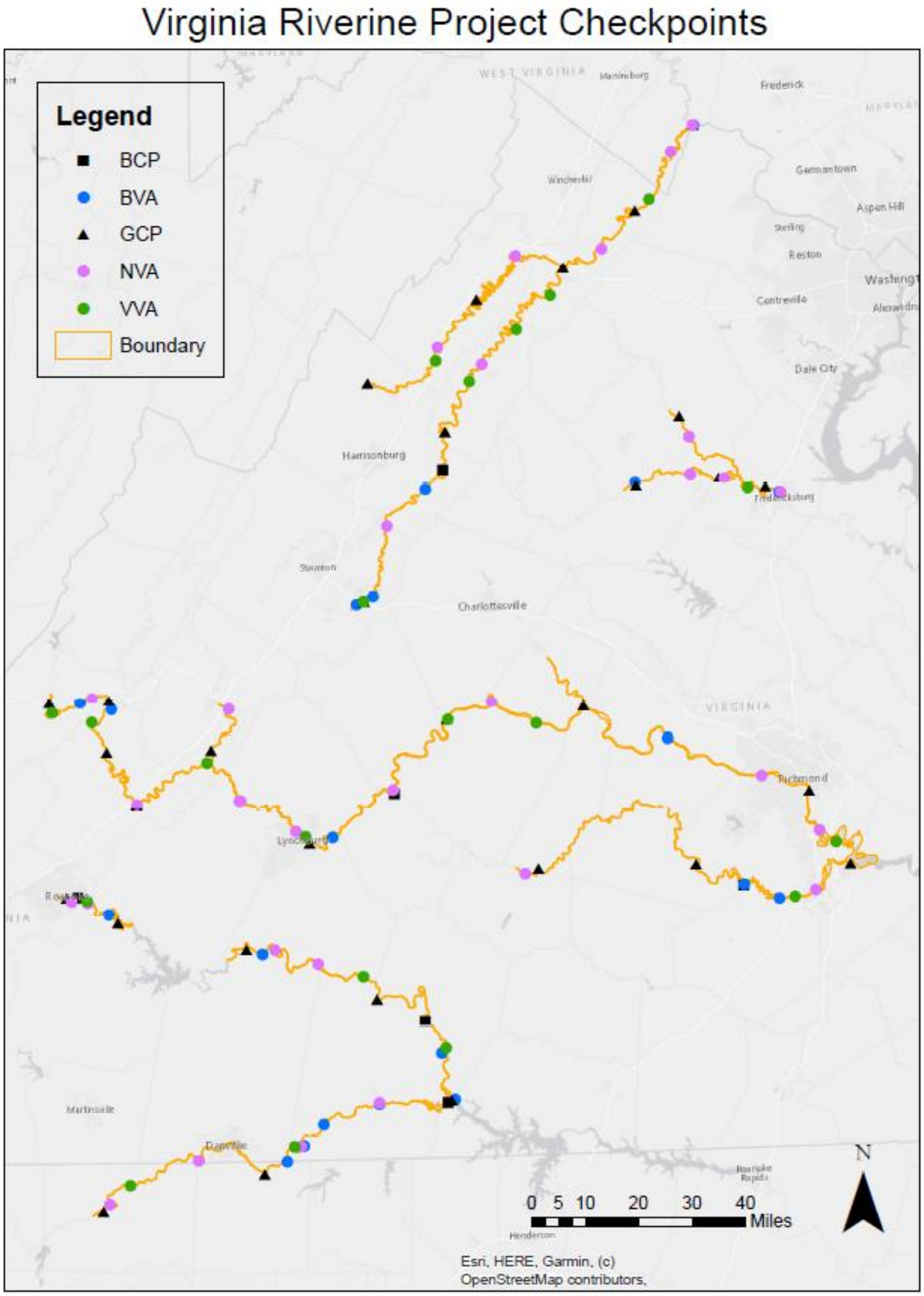


Figure 5. Project map with checkpoints.

4.3 Vertical Accuracy Test Procedures

NVA (Non-vegetated Vertical Accuracy) reflects the calibration and performance of the lidar sensor. NVA was determined with checkpoints located only in non-vegetated terrain, including open terrain (grass, dirt, sand,

and/or rocks) and urban areas. In these locations it is likely that the lidar sensor detected the bare-earth ground surface and random errors are expected to follow a normal error distribution. Assuming 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.

BVA (Bathymetric Vertical Accuracy) was determined with check points located only on submerged topography. The bathymetric portion of this lidar dataset was tested to meet $QL2_b$ vertical accuracy thresholds at a 95% confidence level, as specified in the Draft National Coastal Mapping Strategy 1.0 Document. Using the formula:

$$\text{Vertical Accuracy} = \sqrt{a^2 + (b \times d)^2}$$

where a is a coefficient representing the portion of uncertainty that does not vary with depth, equal to 0.30 for $QL2_b$, b is a coefficient which represents the portion of uncertainty that varies with depth, equal to 0.0130 for $QL2_b$, and d represents water depth. All BVA checkpoints for this AOI were surveyed in submerged areas ≤1 m depth.

VVA (Vegetated Vertical Accuracy) was determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas. In these locations there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA.

The relevant testing criteria are summarized in Table 8.

Table 8. Vertical accuracy acceptance criteria

Land Cover Type	Quantitative Criteria	Measure of Acceptability
NVA	Accuracy in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm
BVA	Accuracy in submerged topography using QL2b vertical accuracy coefficients a,b and the IHO S-44 standard formula	58.8 cm
VVA	Accuracy in vegetated land cover categories combined at the 95% percentile	30.0 cm

4.4 Final Swath Vertical Accuracy Assessment

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 the 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. Table 9 below summarizes the swath project accuracy specification, the amount of NVA points tested, and the final tested swath accuracy results.

Table 9. Tested NVA and descriptive statistics from unclassified lidar swaths

100 % of Totals	# of Points	RMSEz (m) NVA	NVA (m) Spec=0.196	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	28	0.073	0.143	-0.005	0.010	-1.184	0.074	2.249	-0.227	0.113

4.5 Classified Lidar Vertical Accuracy Results

Table 10 summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified lidar LAS files.

Table 10. Classified lidar vertical accuracy results

Land Cover Type	# of Points	NVA (m)	BVA (m)	VVA (m)
Project Specification		**0.196**	**0.588**	**0.300**
NVA	29	0.156		
BVA	15		0.297	
VVA	17			0.279

The topographic portion of this lidar 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 RMSEz = 8.0 cm, equating to ± 15.6 cm at 95% confidence level. The bathymetric portion of this lidar dataset was tested to meet QL2b vertical accuracy thresholds at a 95% confidence level, as specified in the Draft National Coastal Mapping Strategy 1.0 Document. All BVA checkpoints for this AOI were surveyed in submerged areas ≤1 m depth. The bathymetric portion of this lidar dataset was tested to meet 30 cm bathymetric vertical accuracy based on the depths of the surveyed submerged topography checkpoints. Bathymetric vertical accuracy was tested to be RMSEz = 15.1 cm, equating to ± 29.7 cm at 95% confidence level.

Nine checkpoints (BVA-03, BVA-09, BVA-19, VVA-07, VVA-15, VVA-16, and NVA-06) were removed from the classified lidar vertical accuracy testing and are listed in Table 11 below.

Table 11. Checkpoints removed from classified lidar vertical accuracy testing

Point ID	UTM Zone 17N NAD83(2011), m		NAVD88 Geoid18, m		Delta Z (m)
	Easting X (m)	Northing Y (m)	Survey Z (m)	Lidar Z (m)	
BVA-03	710329.613	4064251.722	58.663	N/A	N/A

BVA-04	687512.651	4062920.044	61.427	62.744	1.317
BVA-08	652274.573	4107959.628	120.838	121.320	0.482
BVA-09	597783.274	4183409.321	300.797	301.129	0.332
BVA-19	673359.423	4143195.742	106.827	109.300	2.473
VVA-07	714528.992	4280253.624	192.650	193.001	0.351
VVA-15	N/A	N/A	N/A	N/A	N/A
VVA-16	636021.048	4165582.522	186.586	186.950	0.364
NVA-06	645672.423	4154245.259	155.275	155.323	0.048

Points BVA-03, BVA-04, BVA-08, and BVA-09 were surveyed in areas of rough water with small waves caused by wind, therefore we have no bathymetric bottom return (40) in these locations. These points were removed from the classified lidar vertical testing due not having accurate bathymetric point values to compare the surveyed elevation against. Figure 6 and Figure 7, below, show suvery point BVA-09 and it's location in rough water.

Figure 6. BVA-09 is located in rough water that made it difficult to obtain valid bathymetric bottom returns.

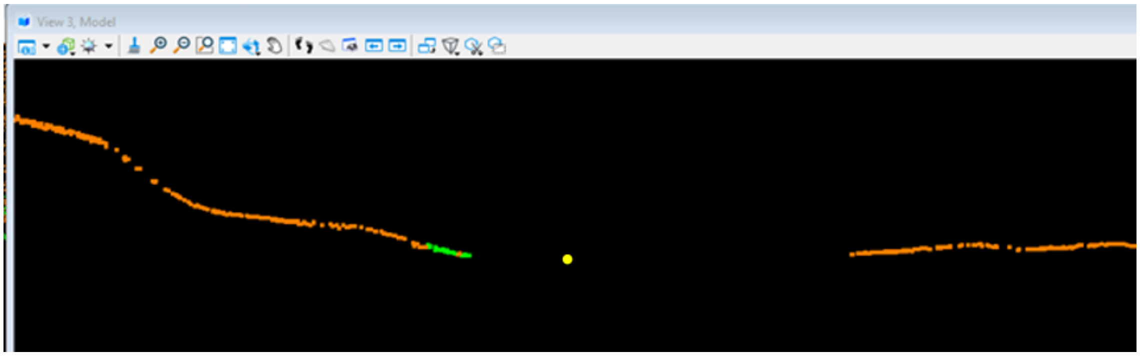


Figure 7. The yellow point in the profile above indicates that location of BVA-09 where there are no valid bathymetric (40) points.

Point BVA-19 was surveyed on a rocky feature in the river that had too much sediment build-up on it. This sediment build-up caused the classified bathymetric points (40) to have varying elevation values which caused erroneous high values during the classified lidar vertical testing. Figure 8 and Figure 9, below, show the suvery point and it's location in slightly turpid water with visible sediment build-up on the rock feature.

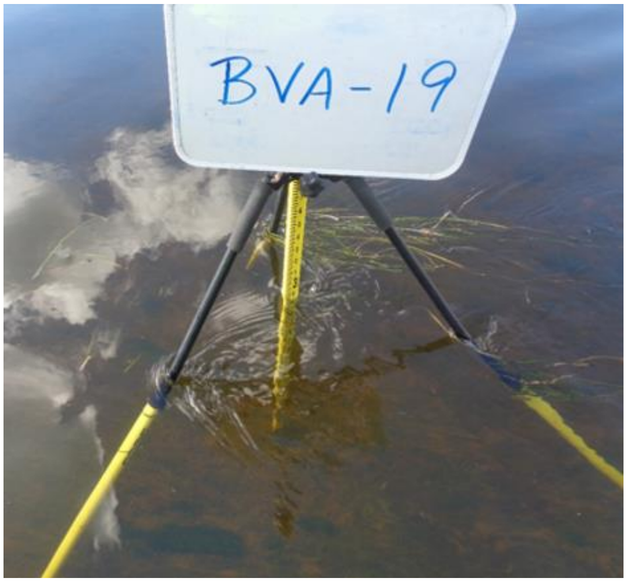


Figure 8. BVA-19 is located in turpid water with sediment build-up on rock features.

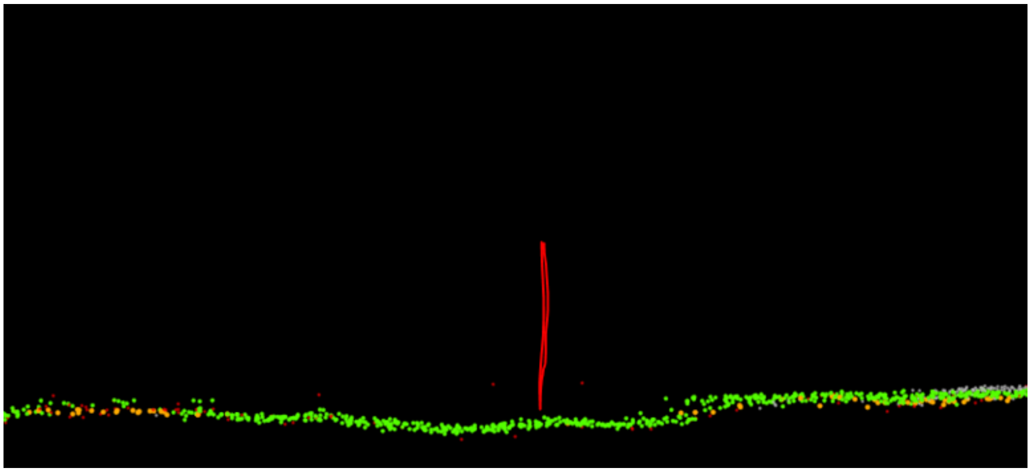


Figure 9. The red line indicates the location of BVA-19 in an area of bathymetric points that vary slightly in elevation.

Point VVA-07 was surveyed in a field of Foxtail grass and point VVA-16 was surveyed in a field of heavy, dense scrub brush. These two types of vegetation are difficult for sensors to penetrate, which means we are not able to classify any valid ground points (2) at ground elevation where the point was surveyed. These points were removed from the final calculation due to erroneous high values caused by the vegetation. Figure 10 and Figure 11, below, show suvery point VVA-07 and it's location in a Foxtail field.

Figure 10. VVA-07 is located in a Foxtail grass field making it difficult to obtain valid ground returns.

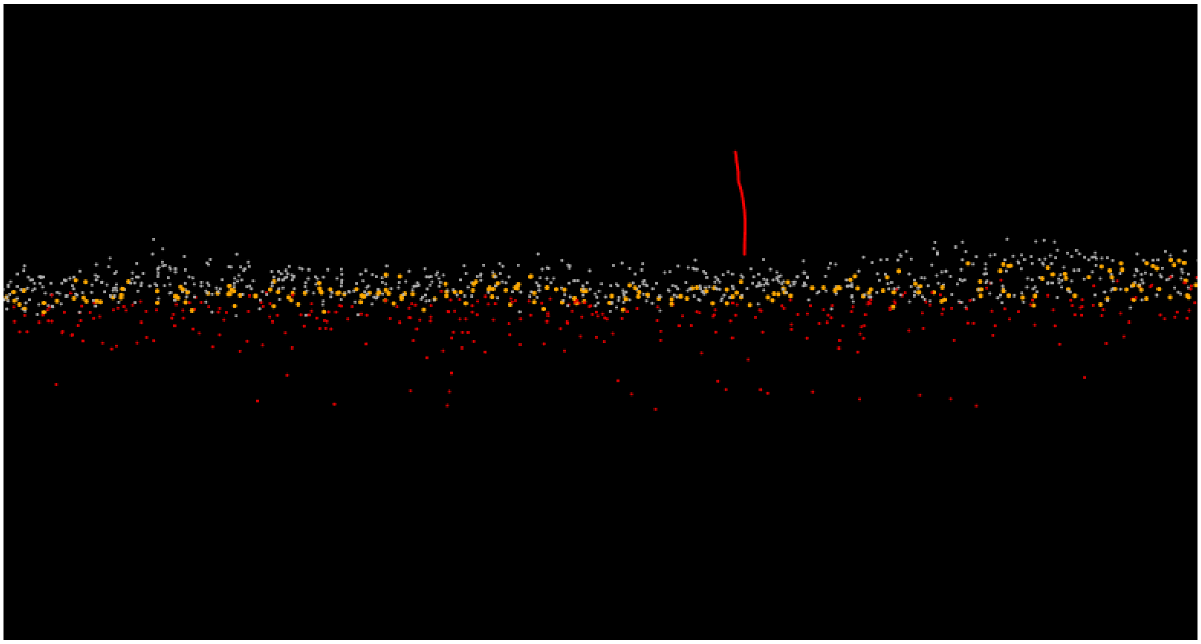
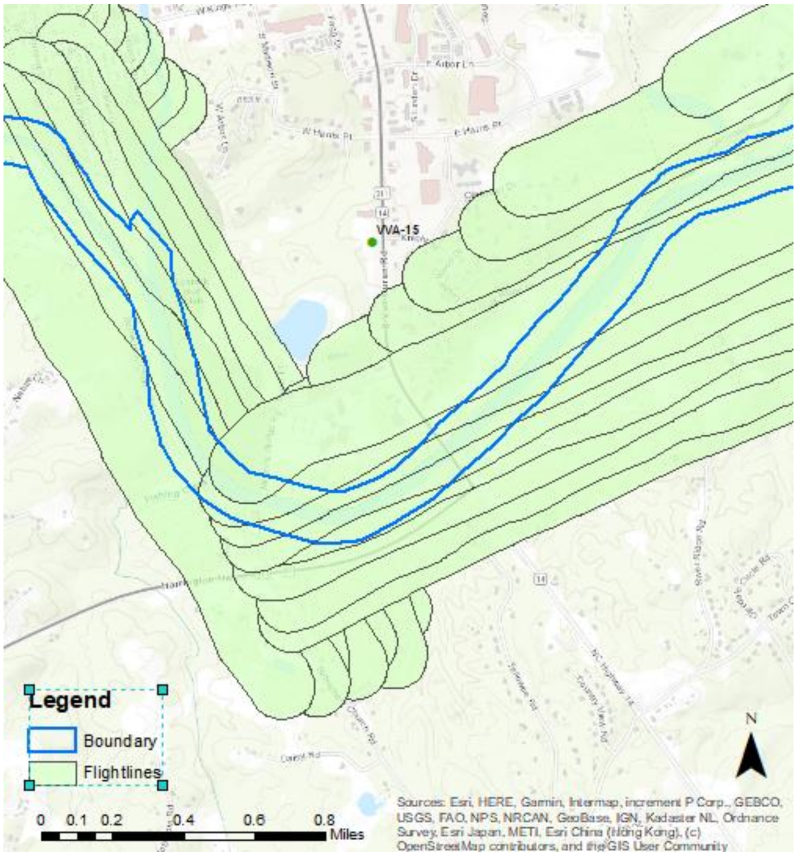


Figure 11. The red line indicates the location of VVA-07 in a field of vegetation.

Point VVA-15 was surveyed in an area outside of our Flightline Index and boundary. This point was removed from the final calculation due to not having any classified lidar points to compare the surveyed lidar point against. Figure 12, below, shows VVA-15 outside of the project flightline extents.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 12. VVA-15 is shown outside of the project flightline extents.

Point NVA-06 was surveyed on a paved road on top of a bridge deck. The point being located on a bridge caused the DEM vertical accuracy to fail since bridges are removed from the DEM. Therefore, our DEM elevation at survey point NVA-06 was taken from the ground underneath the bridge verses the surveyed point elevation being on top of the bridge, causing erroneous low values during the DEM veritical accuracy testing. This point was removed from the final calculations for both the DEM accuracy testing as well as the classified lidar accuracy testing for consistency purposes. Figure 13 and Figure 14, below, show the suvery point and it’s location on the bridge deck compared to our DEM where the point is located on the earth’s surface underneath the bridge.

Figure 13. NVA-06 is located on a birdge deck which has been removed from the DEM, which can be seen on the right. The blue point represents NVA-06 on the DEM.

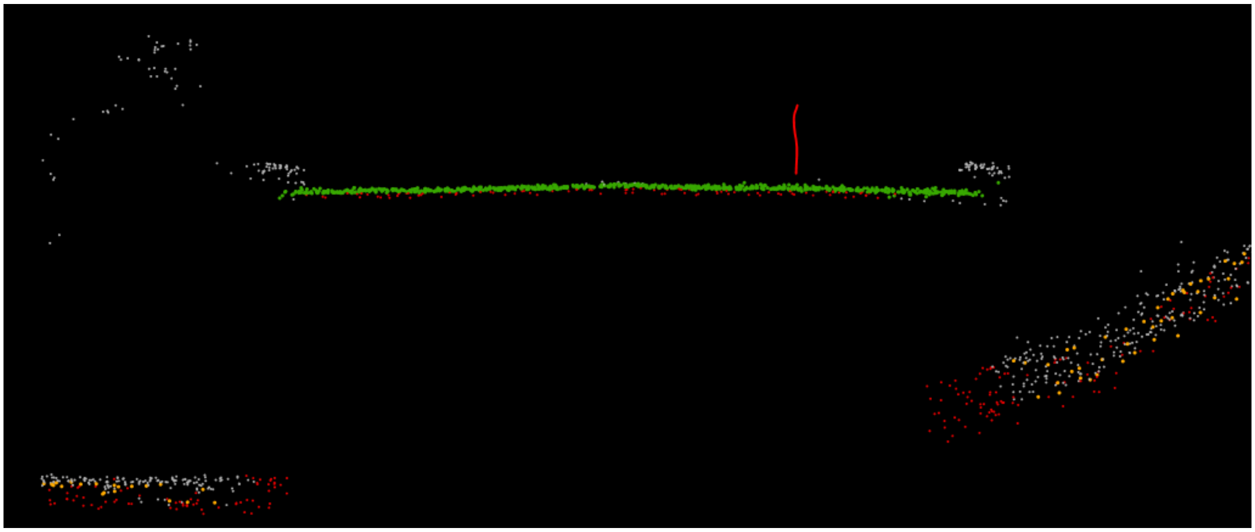


Figure 14. The red lines indicates where NVA-06 is located on the bridge deck.

Descriptive statistics for all categories are presented in Table 12. Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the Virginia Riverine Project satisfies the project's pre-defined vertical accuracy criteria.

Table 12. Classified lidar vertical accuracy descriptive statistics

Land Cover Type	# of Points	RMSE$_z$ (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	29	0.080	-0.019	-0.003	-1.012	0.079	-0.222	0.113	1.494
BVA	15	0.151	0.026	0.013	0.000	0.154	-0.249	0.279	-0.436
VVA	17	N/A	0.068	0.052	0.156	0.119	-0.137	0.288	-0.219

4.6 Horizontal Accuracy Test Procedures

Horizontal accuracy testing requires well-defined checkpoints that can be visually identified in the dataset. Elevation datasets, including lidar datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. Dewberry reviewed all NVA checkpoints to determine which, if any, of these checkpoints were located on photo-identifiable features in the intensity imagery. This subset of checkpoints was used for horizontal accuracy testing.

The horizontal accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed X, Y, and Z coordinates for discrete checkpoints in accordance with project specifications. Dewberry targeted half of the NVA checkpoints for location on features that would photo-identifiable in the intensity imagery.
2. Following initial processing, Dewberry located the photo-identifiable features in the intensity imagery.
3. Dewberry computed the differences in X and Y values between the surveyed coordinates and the lidar coordinates of the photo-identifiable feature.
4. Horizontal accuracy was assessed based on these data using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level.

4.7 Horizontal Accuracy Results

No checkpoints were photo-identifiable in the intensity imagery; horizontal accuracy could not be tested on this dataset.

4.8 Ortho-Mosaic Horizontal Accuracy

No checkpoints were photo-identifiable in the intensity imagery; horizontal accuracy could not be tested on this dataset.

4.9 Positional Accuracy Validation

4.9.1 Interswath Accuracy

The Interswath accuracy, or overlap consistency, measures the variation in the lidar data within the swath overlap. Interswath accuracy measures the quality of the calibration and boresight adjustment of the data in each lift. Dewberry reviews the overlap consistency of the lidar dataset during multiple stages of production. Each review is performed by an initial reviewer and then reviewed by a second reviewer to verify the overlap consistency meets expectations. After calibration, Dewberry uses a proprietary software to generate a point statistics interswath raster. The interswath raster is reviewed for any systematic interswath errors that should be considered of concern. If issues are identified it will be corrected by the calibration team. The interswath rasters are symbolized by the following ranges:

- +/- 0-8 cm: **Green**
- +/- 8-16 cm: **Yellow**
- +/- 16 cm: **Red**

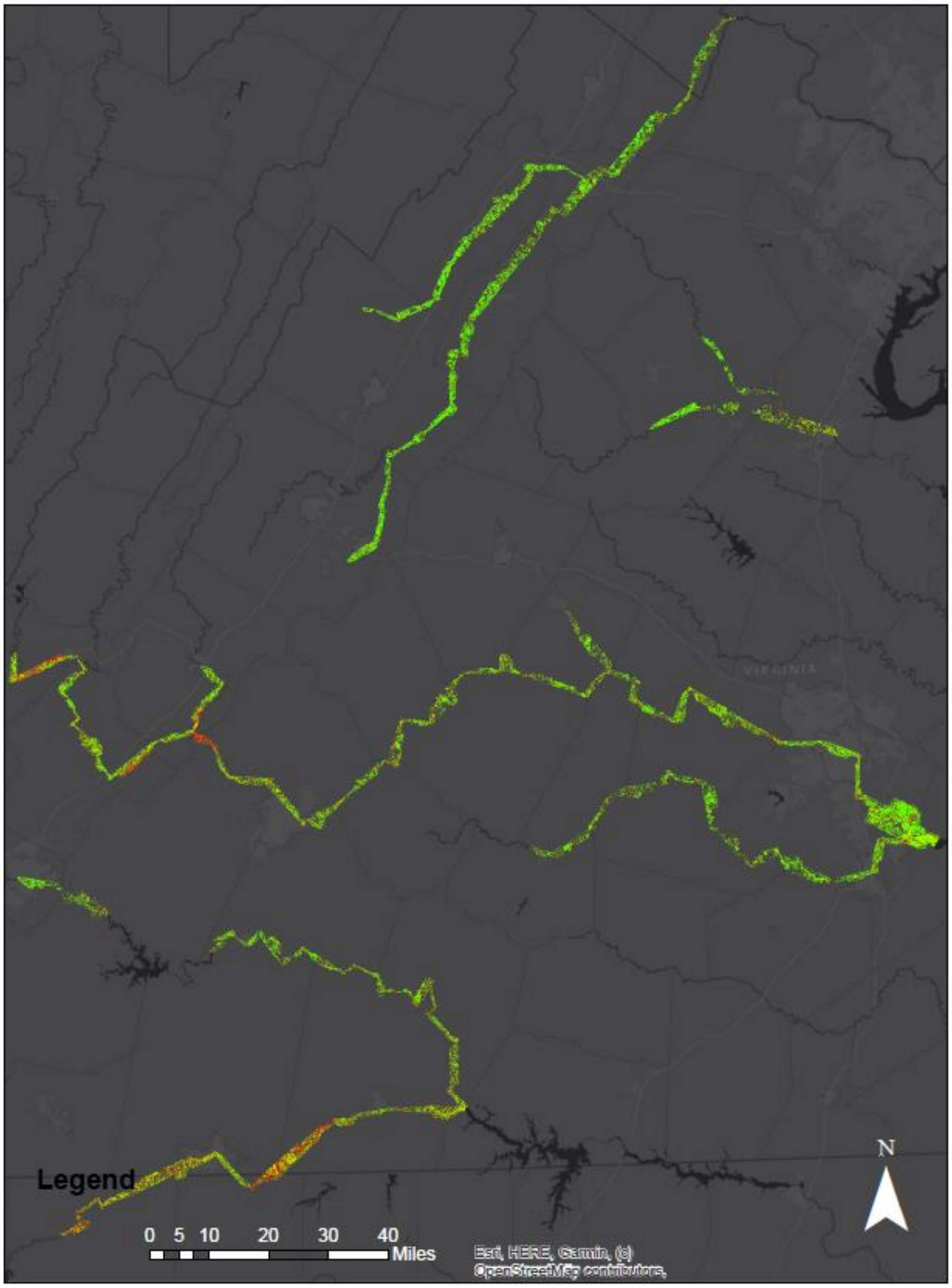


Figure 15. Interswath raster generated using proprietary software and symbolized according to the ranges specified above. Inter-swath relative accuracy passes specifications.

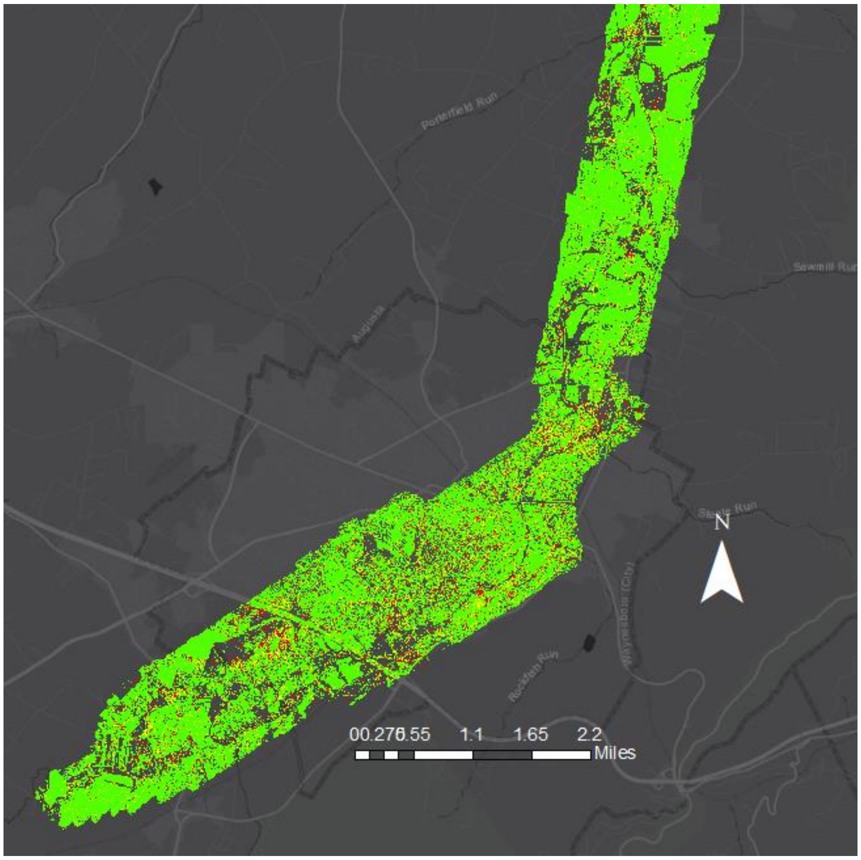


Figure 16. Shows the interswath of a zoomed-in area of the Shenandoah River.

Once the initial ground macro has been run on the dataset, Dewberry uses LP360 to generate swath separation images. The swath separation images are generated using the same settings as the final deliverable swath separation images outlined in 6.6 DZ Orthoimages and in accordance with USGS Lidar Base Specification v2024 A. If the lidar dataset is heavily vegetated, Dewberry will generate swath separation images using the last return of ground points only to better confirm no offsets are present in the bare earth DEM. If issues are identified, dependent on the cause of the issue, it will be corrected by recalibrating the affected data or classifying the impacting points to withheld.

Lastly, the final deliverable swath separation images are generated using LP360. A final review is performed by the final product producer and then verified by a member of the quality management team prior to sending to NOAA.

4.9.2 Intraswath Accuracy

The intraswath accuracy, or the precision of lidar, measures variations on a surface expected to be flat and without variation. Precision is evaluated to confirm that the lidar system is performing properly and without gross internal error that may not be otherwise apparent. Dewberry reviews the precision of the lidar dataset during multiple stages of production. Each review is performed by an initial reviewer and then reviewed by a second reviewer to verify the precision of the lidar meets expectations. Dewberry performs an intraswath accuracy review for each mission within 1-2 days of collection. The precision of the lidar dataset is then reviewed before calibration on the lidar dataset to ensure no systematic errors.

Dewberry uses a proprietary software to generate point statistics intraswath rasters. Swath data in non-overlap areas were assessed using only first returns in non-vegetated areas. To measure the precision of a lidar dataset, level or flat surfaces were assessed. If the lidar dataset is located in area with sloped or steep terrain, a slope raster will be used in conjunction with the intraswath raster to ensure only level or flat surfaces are being assessed. The intraswath raster is reviewed for any systematic intraswath errors that should be considered of concern.

The intraswath rasters are symbolized by the following ranges:

- 0-6 cm: **Green**
- >6 cm: **Red**

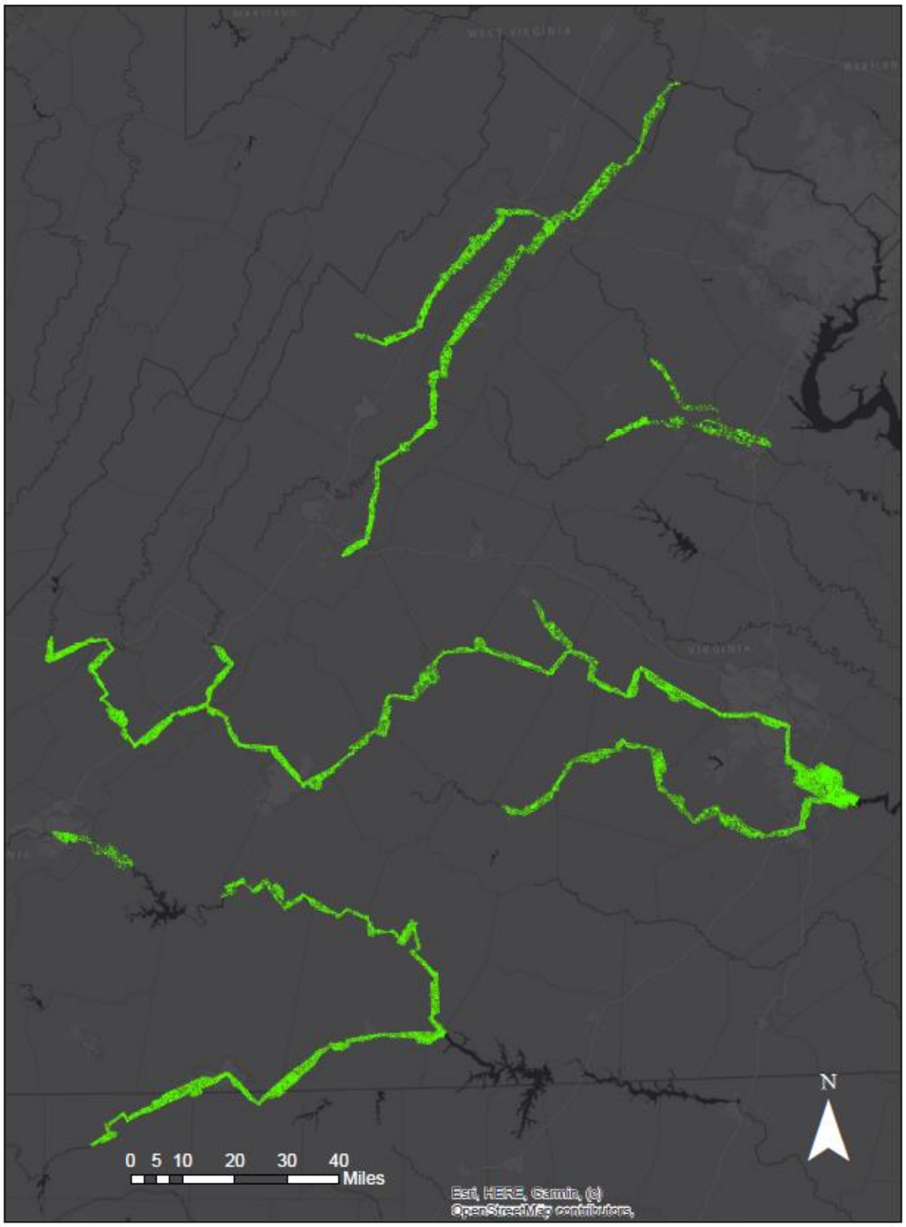


Figure 17. Intra-swath relative accuracy. The top image shows the full project area; areas where the maximum difference is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm are colored red.

Figure 18. Shows the intraswath of a zoomed-in area of the Shenandoah River.

5. DEM PROCESSING & QUALITATIVE ASSESSMENT

5.1 DEM Production Methodology

Dewberry utilized LP360 to generate DEMs. LP360 uses TIN (Triangulated Irregular Network) as the interpolated surface method. A TIN divides a surface into a set of contiguous, non-overlapping, Delaunay triangles. The height of each triangle vertex interpolates together to construct the surface. Dewberry utilized both ArcGIS and Global Mapper for QA/QC.

The DEM bare earth surface was sourced from the final classified lidar points in bare earth classes—class 2 for bare-earth ground, class 40 for submerged topography (bathymetry), and class 43 for submerged objects. Void polygons were enforced in the final raster to delineate areas larger than 9 square meters where no valid bathymetric returns were received. The DEM was reviewed for any issues requiring corrections, including lidar point misclassification, and processing artifacts. After corrections were applied, the DEM was split into tiles per the project tiling scheme. The formatting of the DEM tiles was verified before a final qualitative review was conducted by an independent review department within Dewberry.

5.2 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. Dewberry conducted the review in ArcGIS using a hillshade model of the full dataset with a partially transparent colorized elevation model overlaid. The tiled DEMs were reviewed at a scale of 1:5,000 to look for artifacts caused by the DEM generation process and to verify correct enforcement of void areas. Upon correction of any outstanding issues, the DEM data was loaded into ESRI's ArcMap for its second review and to verify corrections.

Table 13 below outlines high level steps verified for every DEM dataset.

Table 13. DEM verification steps.

Parameter	Requirement	Pass/Fail
Digital Elevation Model (DEM)	Topobathymetric DEM (1 m) is created from bare-earth lidar ground and bathymetric bottom points and void polygons. DEMs are tiled without overlaps or gaps, show no edge artifact or mismatch, DEM deliverables are COG GeoTiff format	Pass
DEM Compression	DEMs are not compressed	Pass
DEM NoData	Areas outside survey boundary are coded as NoData. Internal voids are coded as NoData (-999999)	Pass
Bridge Removal	Verify removal of bridges from bare-earth DEMs	Pass
DEM Artifacts	Correct any issues in the lidar classification that were visually expressed in the DEMs. Reprocess the DEMs following lidar corrections.	Pass
DEM Voids	Bathymetric voids greater than 9 sq mi are enforced in the DEM.	Pass
DEM Tiles	Split the DEMs into tiles according to the project tiling scheme	Pass
DEM Formatting	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression is not applied to the tiled DEMs. GDAL version 3.6.3 used for all DEM formatting.	Pass
DEM Extents	Load all tiled DEMs into ArcMap and verify complete coverage within the (buffered) project boundary and verify that no tiles are corrupt	Pass

5.3 DEM Vertical Accuracy

The same 70 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 linearly interpolated TIN created from the source LAS. The vertical accuracy of the DEM was tested by comparing the elevation of a given surveyed checkpoint with the elevation of the horizontally coincident pixel in the DEM. Dewberry used Esri software to test the DEM vertical accuracy.

Out of the 70 checkpoints surveyed by Dewberry, one (NVA-06) was determined to be located on a bridge deck. This checkpoint showed a large difference between the DEM z value and surveyed checkpoint z value, due to the elevation of the surveyed point being on the bridge and the elevation of the DEM being located on the earth's surface underneath the bridge. Checkpoing BVA-03 was located in an area of no bathymetric bottom (40) return due to rough water. These checkpoints were omitted from the DEM accuracy testing. The coordinates for the removed checkpoints are provided in Table 14.

Table 14. Checkpoint omitted from DEM vertical accuracy testing

Point ID	UTM Zone 17N NAD83(2011), m		NAVD88 Geoid18, m		Delta Z (m)
	Easting X (m)	Northing Y (m)	Survey Z (m)	Lidar Z (m)	
NVA-06	645672.421	4154245.254	187.546	182.333	-5.213
BVA-03	710329.613	4064251.722	58.663	N/A	N/A

Table 15 summarizes the tested vertical accuracy results from the final DEM dataset.

Table 15. DEM vertical accuracy results

Land Cover Type	# of Points	NVA (m)	BVA (m)	VVA (m)
Project Specification		**0.196**	**0.588**	**0.300**
NVA	29	0.143		
BVA	15		0.306	
VVA	17			0.226

The topographic portion of this lidar 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 RMSEz = 7.3 cm, equating to ± 14.3 cm at 95% confidence level. The bathymetric portion of this lidar dataset was tested to meet QL2b vertical accuracy thresholds at a 95% confidence level, as specified in the Draft National Coastal Mapping Strategy 1.0 Document. All BVA checkpoints for this AOI were surveyed in submerged areas ≤1 m depth. The bathymetric portion of this lidar dataset was tested to meet 30 cm bathymetric vertical accuracy based on the depths of the surveyed submerged topography checkpoints. Bathymetric vertical accuracy was tested to be RMSEz = 15.6 cm, equating to ± 30.6 cm at 95% confidence level.

Table 16. Classified lidar vertical accuracy descriptive statistics

Land Cover Type	# of Points	$RMSE_z$ (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	29	0.073	-0.027	-0.001	-1.643	0.069	-0.218	0.056	2.432
BVA	15	0.156	-0.008	-0.010	0.161	0.162	-0.271	0.281	-0.658
VVA	17	N/A	0.051	0.045	0.131	0.114	-0.160	0.291	0.201

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for Virginia Riverine Project satisfies the project's pre-defined vertical accuracy criteria.

6. DERIVATIVE LIDAR PRODUCTS

NOAA required several derivative lidar products to be created. Each type of derived product is described below.

6.1 Void Polygons

Void polygons delineating areas of extremely sparse or no valid bathymetric returns have been created for this project area. The polygons reflect void areas greater than or equal to 9 square meters in area and were utilized to constrain interpolation in the bathymetry domain in the final merged topo-bathymetric DEM.

6.2 Refraction Extents

The refraction extent layer was created by using rasterized aggregate extents of refracted points to create automated, smoothed 2-D refraction extent vectors with LASTools. These refraction extents delineate areas where the refraction correction was applied to the lidar data by CZMIL's automated refraction correction software based on the software's detection of water.

6.3 Standard Deviations

A confidence layer that reports the standard deviation of all ground and submerged topography points within each 1-meter grid cell has been created for the entire project area on a per-tile basis. Each 1-meter grid cell has an associated standard deviation value, in meters. The confidence layer extents are the same as the extents for the final topo-bathymetric DEMs so that the pixels align, showing the confidence of each topobathymetric DEM grid cell. The standard deviation rasters are tiled according to the DEM tile grid.

6.4 Intensity Imagery

Intensity orthoimages representing normalized seabed reflectance have been created for the entire project area on a per-tile basis. Each 1-meter grid cell has an associated 16-bit intensity value, 256 color gray scale that has been normalized to account for attenuation due to depth and swath-to-swath variability in acquisition. The intensity layer extents are the same as the extents for the final classified topo-bathymetric LAS and DEMs.

6.5 Swath Separation Images (SSIs)

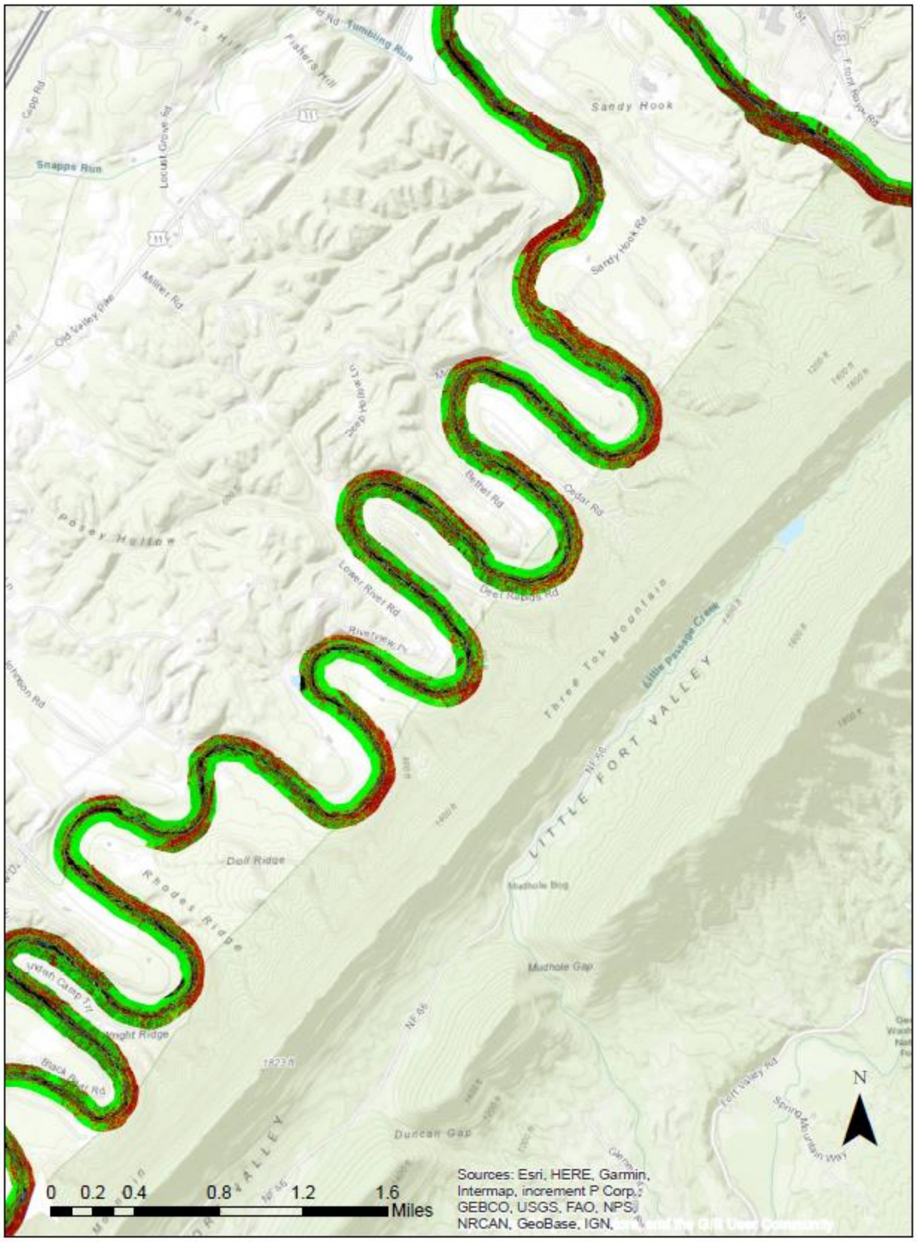
Dewberry verified inter-swath or between swath relative accuracy of the dataset by generating swath separation images in conjunction with interswath polygons. Color-coding is used to help visualize elevation differences between overlapping swaths. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values.

The swath separation images are symbolized by the following ranges:

- 0-8 cm: **Green**
- 8-16 cm: **Yellow**
- >16 cm: **Red**

Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across one raster pixel) are expected to appear yellow or red in the SSIs. Flat, open areas are expected to be green in the SSIs. Large or continuous sections of yellow or red pixels following flight line patterns and not the terrain or vegetation can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data.

Dewberry generated swath separation images using LP360 software. These images were created from the last return of all points except points classified as noise and/or flagged as withheld. Point Insertion was used as the Surface Method and the cell size was set to the deliverable DEM cell size. The three interval bins used are bulleted above and the parameter to “Modulate source differences by Intensity” was set to 50%. The output GeoTIFF rasters are tiled to the project tile grid, clipped to the master DPA, and formatted (including defining the CRS which matches the project CRS) using GDAL software, version 3.6.3.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN,

Figure 19. DZ Orthoimage from a section of the Shenandoah River generated for the Virginia Riverine Project.

6.6 Flightline Extents Shapefile

Flightline extents are delivered as polygons in an Esri shapefile, delineating actual coverage of each swath used in the project deliverables. Dewberry delivered this shapefile using NOAA’s provided template so that each polygon contains the following attributes:

- Lift ID (unique per lift/mission)
- Point Source ID (unique per swath)
- Type of Swath (project, cross-tie, fill-in, calibration, or other)
- Start time in adjusted GPS seconds

- End time in adjusted GPS seconds

Prior to delivery, a final flightline shapefile is created from the final, tiled point cloud deliverables to ensure all correct swaths are represented in the flightline shapefile. The flightline shapefile is then reviewed for complete coverage and correct formatting.

6.7 Direct-Georeferenced Imagery

Three-band (Red, Green, Blue) digital imagery was collected over the project area using a PhaseOne iXM-RS150F digital camera. The 25 cm pixel imagery was georeferenced using using the raw positional and orientation files from the on-board INS-GNSS system. Additional bundle adjustments were done to improve the horizontal positioning using two methods:

- Using Hexagon ISAT and control points chosen from either lidar intensity fromx this project or from reference ortho imagery.
- Using Simactive Correlator3D without control points and mosaicked using orthomoasaic processing with a 3DEP DEM.

Seamlines for mosaicking were auto generated and minimal or no color balancing was done on the mosaics. Three-band (RGB) mosaic tiles (3,000 m x 3,000 m) in Cloud Optimized GeoTIFF format with 25 cm Ground Sample Distance were created for the project area. Offsets found that were greater than 10m were marked in shapefiles and delivered with the mosaic tiles:

- VA2303_DG_imagery_James_Appomattox.shp
- VA2303_DG_imagery_Dan_Roanoke.shp