LiDAR Quality Assurance (QA) Report
Eastern Shore Virginia (ESVA) LiDAR Project
USGS
November 18, 2011

Submitted to:
USGS

Contract:
G10PC00013

Task Order:
G10PD01537

Prepared by:
Dewberry

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1 Executive Summary

Contract: Eastern Shore Virginia LiDAR QA Contract	**Production Contractor:** Sanborn Mapping Co.	**Date Prepared:** 11/18/2011	**Delivery #:** Full Delivery 4	**Dewberry Recommendation:** Accept all data
Data History: Pilot 1; Pilot 2; Pilot 3; Full Delivery 1; Full Delivery 2; Full Delivery 3; Full Delivery 4				

The following LiDAR quality assurance report documents Dewberry's fourth review of LiDAR data and derived products for the Eastern Shore Virginia LiDAR Quality Assurance Project. The report identifies areas where issues have been corrected as well as describing some end results of the data that may look unnatural but have been deemed acceptable by project participants. Each tile contains LAS point cloud data classified according to the USGS LiDAR Guidelines and Base Specifications, version 13 classification scheme. The final deliverables also include an ESRI Geodatabase containing hydrographic breaklines and tiled hydro-flattened digital elevation models (DEMs).

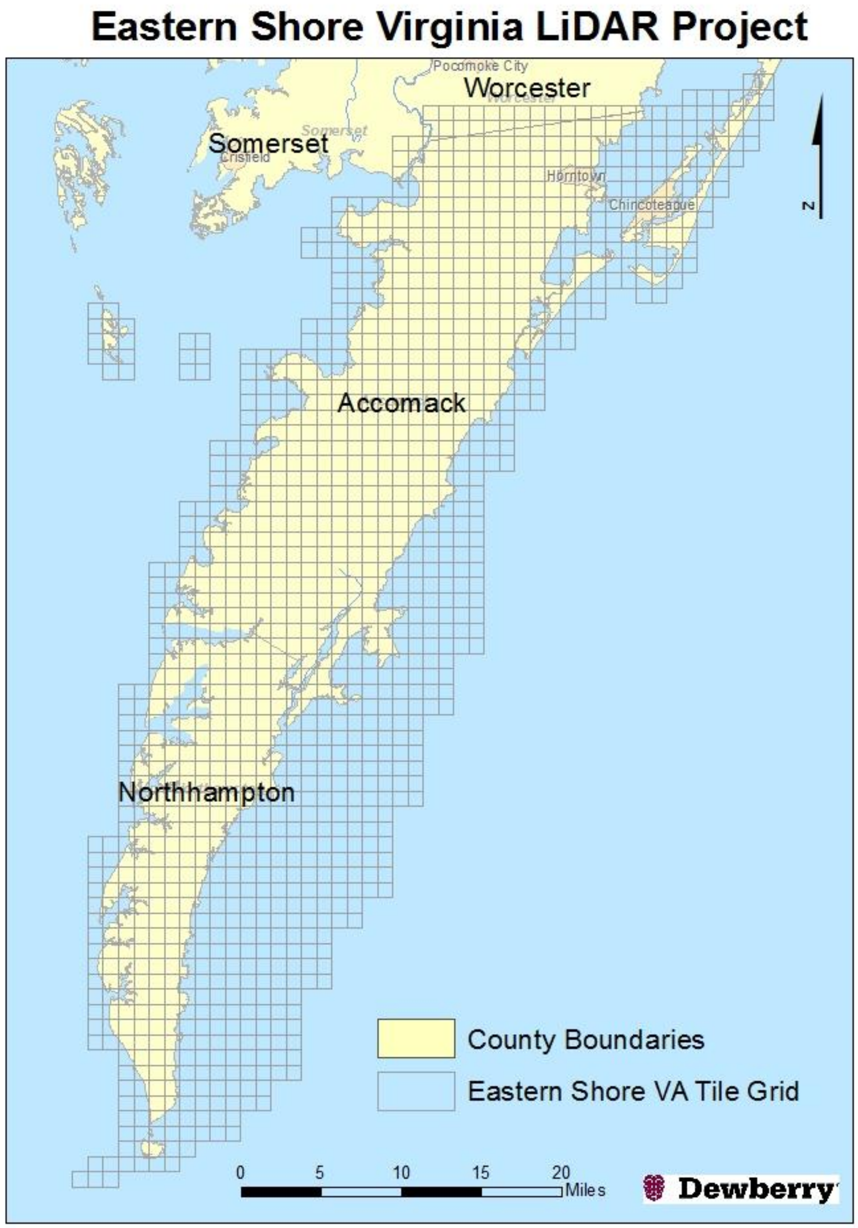

Figure 1-Location of Project Area

As this is the fourth delivery of the data Dewberry did not perform a complete analysis of the data, but reviewed the data to ensure corrections were made where necessary. After thorough review, Dewberry has determined that the LiDAR, breaklines, and DEMs should be accepted.

The LiDAR data for the ESVA project area were thoroughly examined by Dewberry for completeness and conformity to project specifications. The LiDAR passes vertical accuracy, re-calibration of the swath data has improved relative accuracy to within project specifications, and edit calls identifying areas of misclassification and aggressive classification that affected the final bare earth surface were corrected. The LiDAR is discussed in detail in section 3.

The breaklines were reviewed to ensure all project specifications have been met. Issues from previous deliveries, including floating or digging breaklines, topology issues, and missing or improper delineation of breaklines, have been corrected. The breaklines are discussed in detail in section 4.

The hydro-flattened DEMs were reviewed to ensure all project specifications have been met. The majority of DEM issues identified in previous deliveries related to artifacts remaining in the water, resulting in non-flattened DEMs. These issues and all other identified DEM issues have been corrected. The DEMs are discussed in detail in section 5.

Metadata has been delivered in XML format for the classified LAS data, raw LAS data, each day of LiDAR acquisition, masspoints, the terrain, DEMs, tidal water breaklines, inland streams and rivers breaklines, and inland lakes and ponds breaklines. While some files do contain metaparser warnings, there are no errors. The metadata files contain sufficient content. All previous issues noted with the metadata files have been corrected. The metadata is discussed in detail in section 6.

1.1 Deliverables Summary for the ESVA Project, Delivery 4

Deliverable	Applicable Acceptance Criteria (See Appendix A)	Dewberry Recommendation
All-Return LAS Point Cloud Data	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 18, 19, 23, 24, 25, and 26	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
Breakline Geodatabase	11, 12, 13, 14, 15, 30, 31, 32, and 33	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
Hydro-Flattened DEMs	11, 12, 13, 14, 15, 19, 20 and 21	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject

LAS Metadata	22 and 34	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
Breakline Metadata	22 and 34	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
DEM Metadata	22 and 34	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject

The applicable acceptance criteria refer to the numbered criteria found in "Appendix A-Acceptance Criteria" of the Technical Proposal for the Eastern Shore Virginia LiDAR Project. These acceptance criteria were provided to Sanborn with the pilot report.

1.2 Report Approval

Approved by: ______________________ Date: 11/18/2011

(sign & stamp)

American Society for Photogrammetry and Remote Sensing
BRIAN MAYFIELD
CERTIFIED
PHOTOGRAMMETRIST
(ASPRS) No. R1276
Exp. 11/2/2015

2 Overview

The goal of the USGS LiDAR Task Order is to evaluate high accuracy elevation datasets of multiple deliverable products including LiDAR, hydro-flattened digital elevation models (DEMs), and 3D breaklines delivered by the Sanborn Mapping Company for the Eastern Shore Virginia (ESVA) LiDAR project. The project area spans 663 square miles consisting of two Virginia counties, Accomack and Northhampton.

Dewberry's role is to provide Quality Assurance (QA) of the LiDAR data and supplemental deliverables provided by Sanborn that includes completeness checks, vertical accuracy testing, and a qualitative review of the bare earth surface. Each product is reviewed independently and against the other products to verify the degree to which the data meets expectations.

This report documents the quality of the deliverables for the Eastern Shore of Virginia provided by Sanborn. This report is organized into three sections: 3. LiDAR analysis, 4. Breakline analysis and 5. Hydro-flattened Digital Elevtion Model analysis.

3 LiDAR Analysis

The LiDAR data is reviewed on project, tile, and per point levels to determine the relative accuracy, proper classification and conformity to project requirements. This review begins with a computational analysis of the points for completeness and to determine point data format, projection, classification scheme, number of returns per pulse, and intensity values of the points.

The data were delivered in the proper tile size with the proper point cloud format, multiple returns per pulse and an intensity value for each point.

3.1 LiDAR Quantitative Review

One of the first steps in assessing the quality of the LiDAR is a vertical accuracy analysis of the ground models in comparison to surveyed checkpoints. Dewberry surveyed 68 checkpoints for the project area extent. One checkpoint was not used in the vertical accuracy testing because it was improperly located on sloped terrain. According to USGS LiDAR Guidelines and Base Specifications, v. 13, the consolidated vertical accuracy (CVA) must be 36.3 cm (1.2 ft) or less when computed with the 95th percentile method and the fundamental vertical accuracy (FVA) must be 24.5 cm (0.82 ft) or less when computed with RMSEz (12.5 cm or 0.4 ft) x 1.9600. In the first delivery, the CVA passed with a value of 0.61 ft, and the FVA failed with a value of 1.25 feet. Sanborn then performed numerous edits to the LiDAR data, including re-calibrations. The second delivery (and all subsequent deliveries) of ESVA data passed vertical accuracy. The final accuracy values and statistics are shown in the tables below.

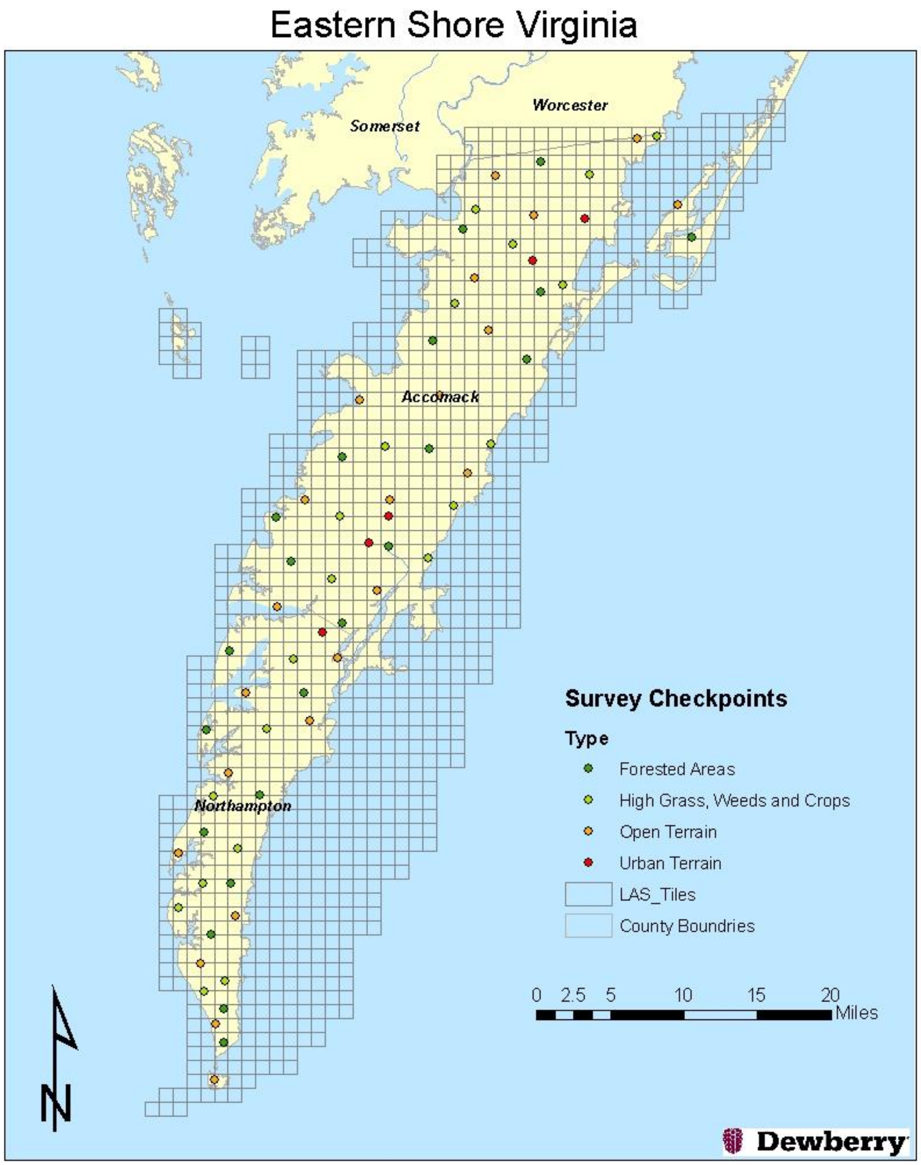

Figure 2: Checkpoint distribution for Eastern Shore Virginia

The vertical accuracy assessment compares the measured survey checkpoint elevations with those of the TIN as generated from the bare-earth LiDAR. The X/Y locations of the survey checkpoints are overlaid on the TIN and the interpolated Z values of the LiDAR are recorded. These interpolated Z values are then compared with the survey checkpoint Z values and this difference represents the amount of error between the measurements. Once all the Z values are recorded, the Root Mean Square Error (RMSE) is calculated and the vertical accuracy scores are interpolated from the RMSE value. The RMSE equals the square root of the average of the set of squared differences between the dataset coordinate values and the coordinate values from the survey checkpoints.

The first method of evaluating vertical accuracy uses the FEMA specification which follows the methodology set forth by the National Standard for Spatial Data Accuracy. The accuracy is reported at the 95% confidence level using the Root Mean Square Error (RMSE) which is valid when errors follow a normal distribution. By this method, vertical accuracy at the 95% confidence level equals $RMSE_Z$ x 1.9600.

The second method of testing vertical accuracy, endorsed by the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) uses the same (RMSEZ x 1.9600) method in open terrain only; an alternative method uses the 95th percentile to report vertical accuracy in each of the other land cover categories (defined as Supplemental Vertical Accuracy – SVA) and all land cover categories combined (defined as Consolidated Vertical Accuracy – CVA). The 95th percentile method is used when vertical errors may not follow a normal error distribution, as in vegetated terrain.

The Fundamental Vertical Accuracy (FVA) is calculated in the same way when implementing FEMA/NSSDA and NDEP/ASPRS methodologies; both methods utilize the 95% confidence level (RMSEZ x 1.9600) in open terrain where there is no reason for LiDAR errors to depart from a normal error distribution.

Table 1 outlines the calculated RMSEz and associated statistics while Table 2 outlines vertical accuracy.

100 % of Totals	RMSE (ft) Open Terrain Spec= 0.4ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	# of Points	Min (ft)	Max (ft)
Consolidated		0.20	0.05	-0.33	0.26	67	-0.71	0.65
Open Terrain	0.22	0.16	0.00	0.20	0.22	21	-0.44	0.51
Vegetation		0.23	0.10	-0.81	0.29	20	-0.71	0.53
Forest		0.22	0.10	-0.63	0.28	21	-0.68	0.65
Urban		0.18	-0.18	1.00	0.20	5	-0.27	0.21

Table 1: The table shows the calculated RMSEz value for open terrain checkpoints as well as associated statistics of the errors for all land cover categories in Eastern Shore Virginia.

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.82 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=1.20 ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=1.20 ft
Consolidated	67		0.53	
Open Terrain	21	0.43		
Vegetation	20			0.54
Forest	21			0.65
Urban	5			0.26

Table 2: The table shows the FVA, calculated using FEMA/NSSDA guidelines (RMSEz x 1.9600) and the CVA/SVA, calculated using NDEP/ASPRS guidelines (95^{th} percentile) for Eastern Shore Virginia.

3.2 LiDAR Completeness Review

Dewberry received 1,330 LiDAR files within the ESVA Project Area. This number matches the number of DEM tiles provided. While the project tile grid has 1,341 tiles, the 11 tiles not included in the delivery are along the outer edges, well beyond the project boundary identified in the "vcr_land_area" shapefile. The LiDAR has coverage extending at least 100 meters beyond the boundary, as specified by USGS LiDAR Guideline and Base Specifications v.13.

The LiDAR was delivered in LAS format 1.2 that adheres to the ASPRS LAS 1.2 specifications. The Point Data Format 1 is used, with intensity values present. The LAS files match the Virginia Index Grid (VBMP_2009_all_tiles_SP_South_East) in both extent and naming. All spatial projection information is correct and is as follows:

- Horizontal Datum: NAD83 (HARN)
- Vertical Datum: NAVD88, processed with Geoid09
- Projection: Virginia State Plane Coordinate System, South Zone
- Horizontal and Vertical Units: Feet

Each record includes the following fields (among others):

- X, Y, Z coordinates
- Flight line data
- Intensity value
- Return number
- Number of returns
- Scan direction
- Edge of flight line
- Scan angle
- Classification
- GPSI time

Dewberry can confirm that the LiDAR sensor used recorded up to four returns per pulse. All files met the project specification to have at least 10% flightline overlap.

After the evaluation of the LAS header information, the following issues were discovered in the first delivery:

- 1240 tiles exceeded the project specifications for a maximum field of view of 40°. Scan angles that exceed the specified combined 40 degrees indicate that the data on the edge of flight lines could potentially be skewed but was used.
- 6 tiles have points in class 0. All points must follow the classification scheme outlined in the USGS LiDAR Guidelines and Base Specifications, v. 13. All points should be classified as either 1,2,7,9,or10.

In the fourth delivery of data, all points have been re-classified into an appropriate class, as defined by project specifications.

In the fourth delivery, tiles still exceed the maximum scan angle of 40° as re-flights would be necessary to change this attribute. Some LiDAR sensors will record a slightly larger field of view to ensure enough overlap is acquired between flight lines. This larger field of view is used to ensure flight lines properly overlap and align even though the airplane may have shifted from the optimal position. Data used in the ground surface that exceeds the 40° specification could potentially be skewed and not match the ground or surrounding flight lines very well. Dewberry creates a DeltaZ mosaicked MrSID image from the LiDAR data. This DeltaZ image compares adjoining flight line data. If the adjoining flight lines are within 6 cm, the overlapping or adjacent pixels are colored green. If the adjoining flight lines are between 6 cm and 12 cm of each other, the overlapping or adjacent pixels are colored yellow. If the adjoining flight lines are greater than 12 cm different from each other, the overlapping or adjacent pixels are colored red. When there are large portions of flight lines colored red, it is an indication that the flight lines do not match each other well, may not match the ground well, and may cause flight line ridges exceeding project specifications. The DeltaZ MrSID is created from the full point cloud so some discrepancy is expected due to vegetation. However, areas of open terrain or bare earth should not show large elevation discrepancies between adjacent flight lines.

While Dewberry identified relative accuracy and flight line ridge issues in the first delivery, Sanborn addressed these issues by re-calibrating the LiDAR data and moving points with high scan angles to class 1, unclassified, so that they were not used in the final ground surface. All data is now within specifications. Even though numerous tiles still have scan angles that exceed a total field of view of 40°, these scan angles do not correspond to flight line ridges, calibration, or relative accuracy issues in the final Eastern Shore dataset (delivery 4). Below is an example of the DZ orthos from the corrected dataset.

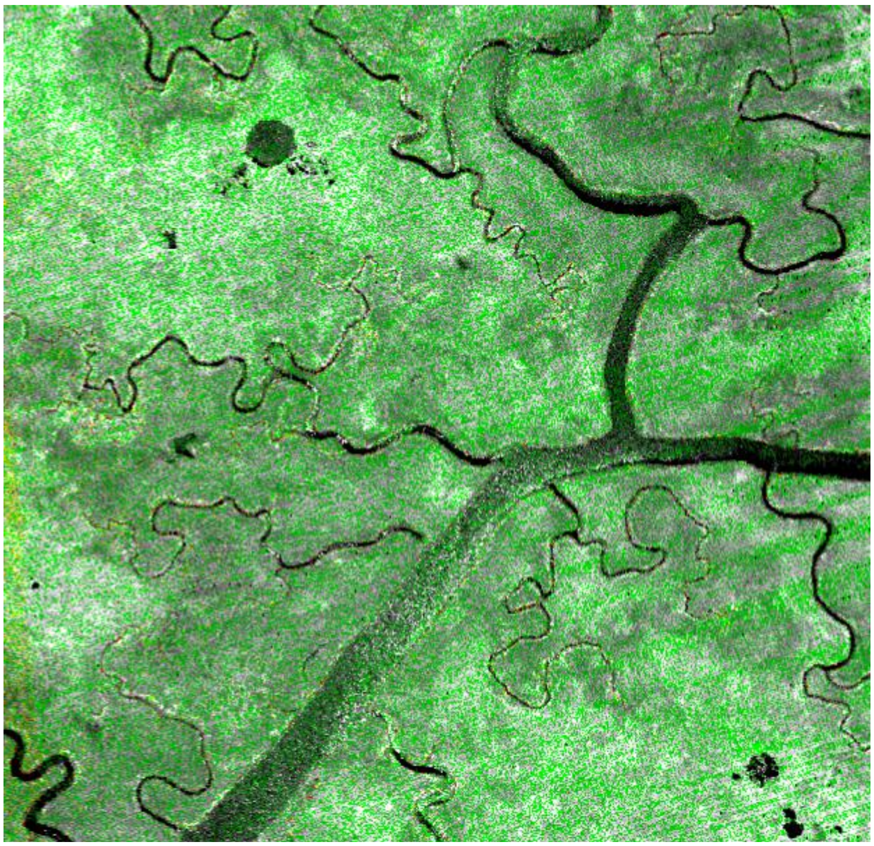

Figure 3-DeltaZ MrSID image where overlapping and adjacent flight lines are colored as green, yellow, or red based on set thresholds. Areas of green indicate adjacent flight lines are within project specifications for relative accuracy and that LAS files exceeding the maximum scan angles are not negatively impacting the dataset.

The LiDAR files are classified to USGS LiDAR Guidelines and Base Specifications, as follows:

- Class 1 (Unclassified)
- Class 2 (Bare Earth)
- Class 7 (Low point/Noise)
- Class 9 (Water)
- Class 10 (Ignored due to breakline proximity)

Figure 4 below shows that Class 10 was used correctly to identify ground points in close proximity to breaklines. A distance of approximately 10ft was used to classify ground points near breaklines.

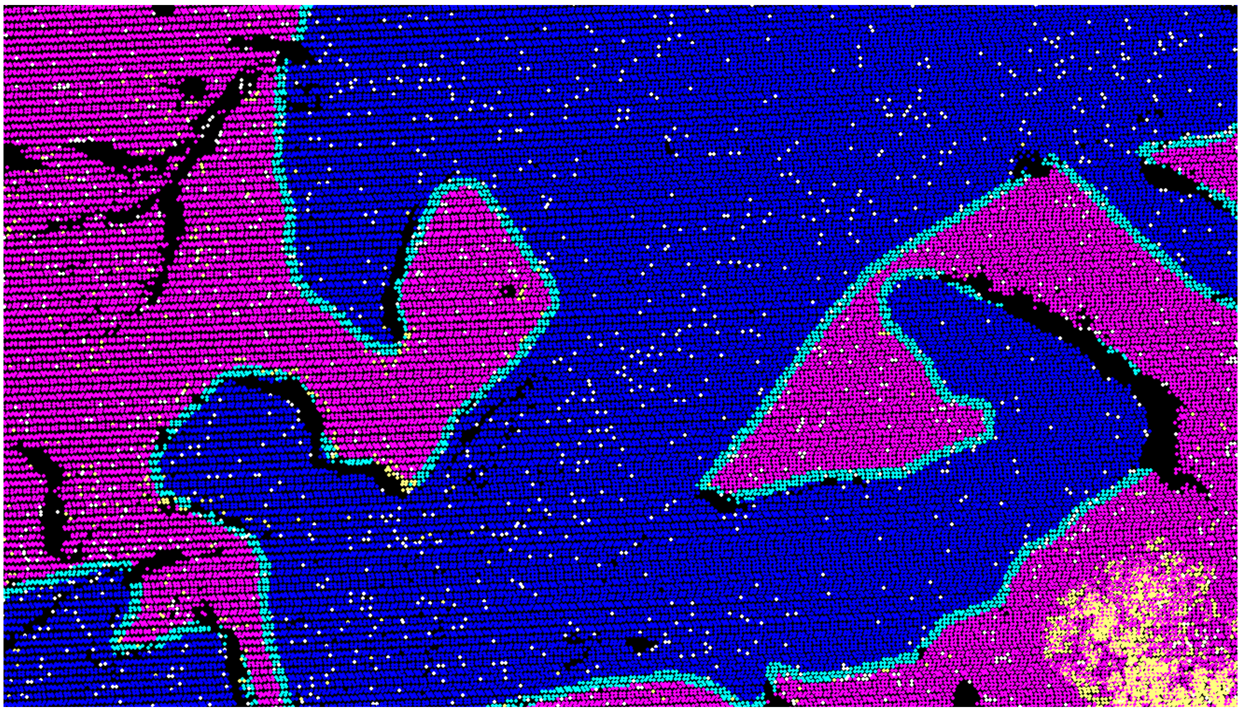

Figure 4-LAS_S23_2784_30. Class 10 points are shown in Turquoise, Class 9 points are blue, class 2 points are pink, and class 1 points are yellow.

3.2.1 Point Count/Elevation Analysis

To verify the content of the data and validate the data integrity, a statistical analysis was performed on each tile. This process allows Dewberry to review 100% of the data at a macro level to identify any gross outliers. The statistical analysis consists of first extracting the header information and then reading the actual records and computing the number of points, minimum, maximum, and mean elevation for each class. Minimum and maximum for other relevant variables are also evaluated.

Each tile was queried to extract the number of LiDAR points. With a nominal point spacing of 1.0 meters, the expected total number of points per tile should be approximately 2.3 million. The mean in Sanborn's area is approximately 2.7 million. All tiles are within the anticipated size range except for those located within waterbody features, which are expected to have fewer points. The minimum and maximum elevations for class 2 were also evaluated and no major anomalies were identified.

3.3 LiDAR Qualitative Review

The goal of Dewberry's qualitative review is to assess the continuity and the level of cleanliness of the bare earth product. Each LiDAR tile is expected to meet the following acceptance criteria:

- ❑ The point density is homogenous and sufficient to meet the user's needs;
- ❑ The ground points have been correctly classified (no man-made structures or vegetation remains, no gaps except over water bodies);

- The ground surface model exhibits a correct definition (no aggressive classification, no over-smoothing, no inconsistency in the post-processing);
- No obvious anomalies due to sensor malfunction or systematic processing artifacts are present (data voids, spikes, divots, ridges between flight lines or tiles, cornrows, etc);
- Residual artifacts <5%

As this is the fourth delivery, Dewberry analysts reviewed the edit calls to ensure they were satisfactorily corrected. The DTMs used for LiDAR QC are built by first creating a fishnet grid of the LiDAR masspoints with a grid distance of 3x the full point cloud resolution. Then a triangulated irregular network is built based on this gridded DTM and displayed as a 3D surface. A shaded relief effect was applied which enhances 3D rendering. The software used for visualization allows the user to navigate, zoom and rotate models and to display elevation information with an adaptive color coding in order to better identify anomalies.

3.3.1 Aggressive Classification

The first review of the Eastern Shore of Virginia LiDAR dataset identified multiple areas of aggressive classification. Most of the areas of aggressive classification occurred where legitimate ground points on a slope, such as along the bank of a hydrographic feature or a road embankment, were removed from ground and resulted in the loss of ground definition. Sanborn addressed all edit calls that impacted the final bare earth surface. Edit calls for aggressive classification that were minor and did not impact the final bare earth surface may not have been corrected or modified. Examples from the first and last deliveries are shown below.

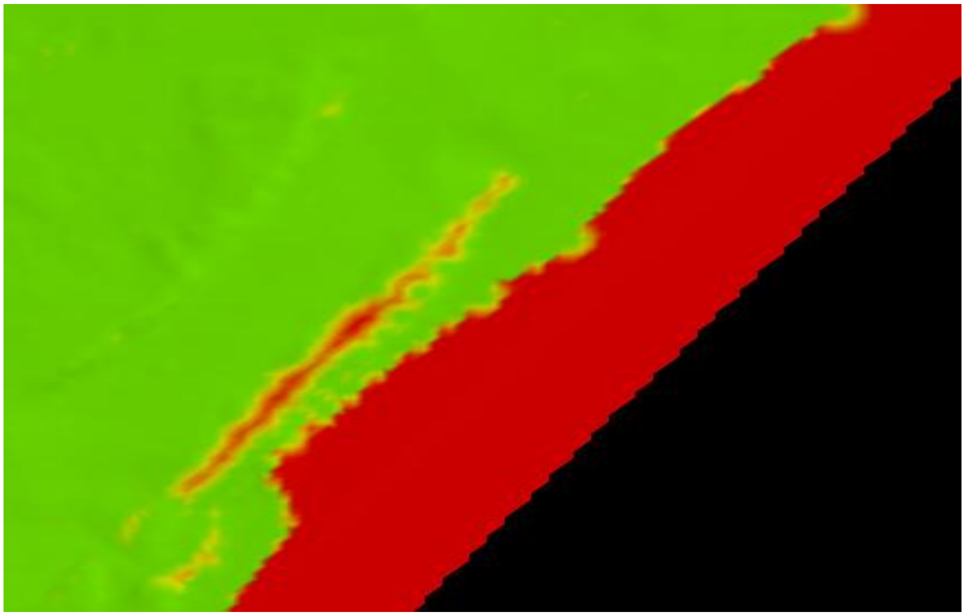

Figure 5-Tile LAS_S23_3853_20, Delivery 1. Ground density model showing an area of aggressive classification along the coast.

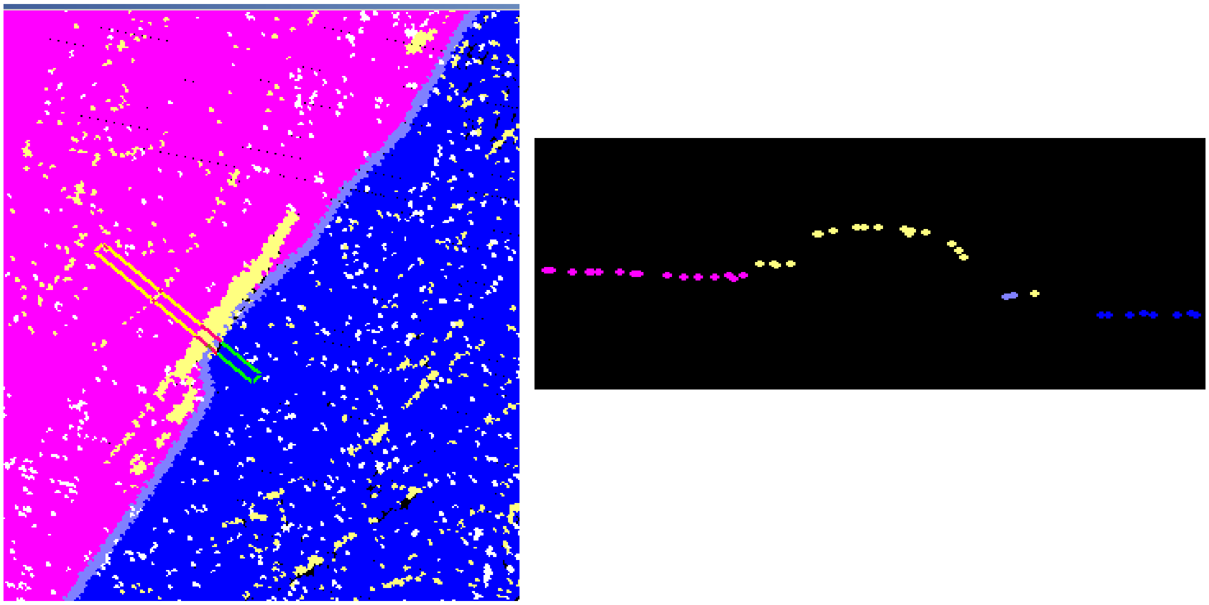

Figure 6-Tile LAS_S23_3853_20, Delivery 1. Profile view of an area along the coast that was aggressively classified. An embankment was missing from the ground surface because these points had been incorrectly classified as class 1 (unclassified, yellow) but should have been classified as class 2 (ground, pink).

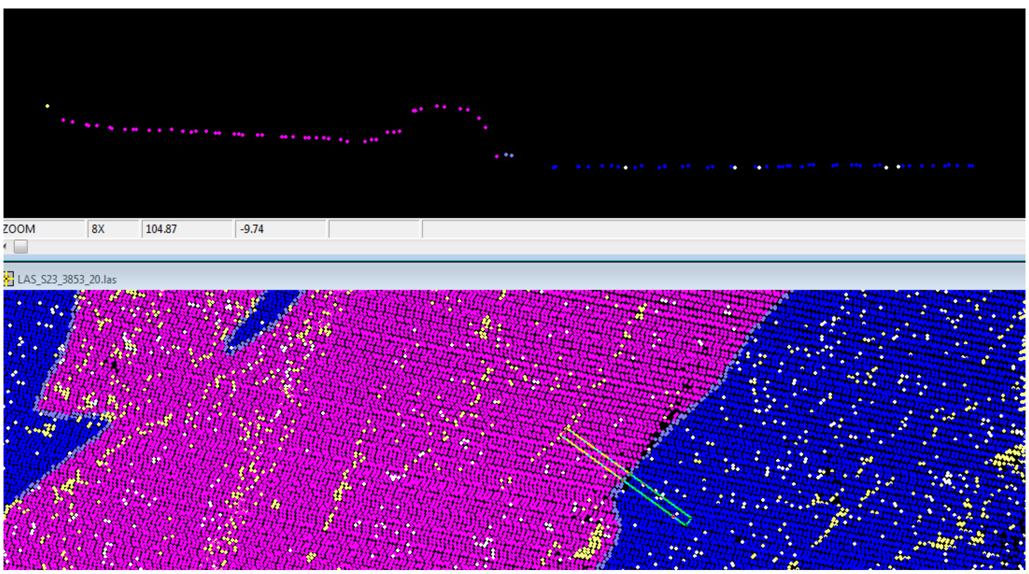

Figure 7-Tile LAS_S23_3853_20, Delivery 4. Profile view of an area along the coast that was aggressively classified, but has been corrected. Points representing an embankment had previously been classified as class 1 (yellow) but are now classified as class 2, ground (pink). This correction has added detail to the ground model.

3.3.2 Misclassification

The first review highlighted multiple areas where ground points (class 2, pink) were misclassified to unclassified (class 1, yellow) or ground points were misclassified to water (class 9, blue). Sanborn addressed all edit calls that impacted the final bare earth surface. Edit calls for misclassification that were minor and did not impact the final bare earth surface may not have been corrected or modified. Examples from the first and last deliveries are shown below.

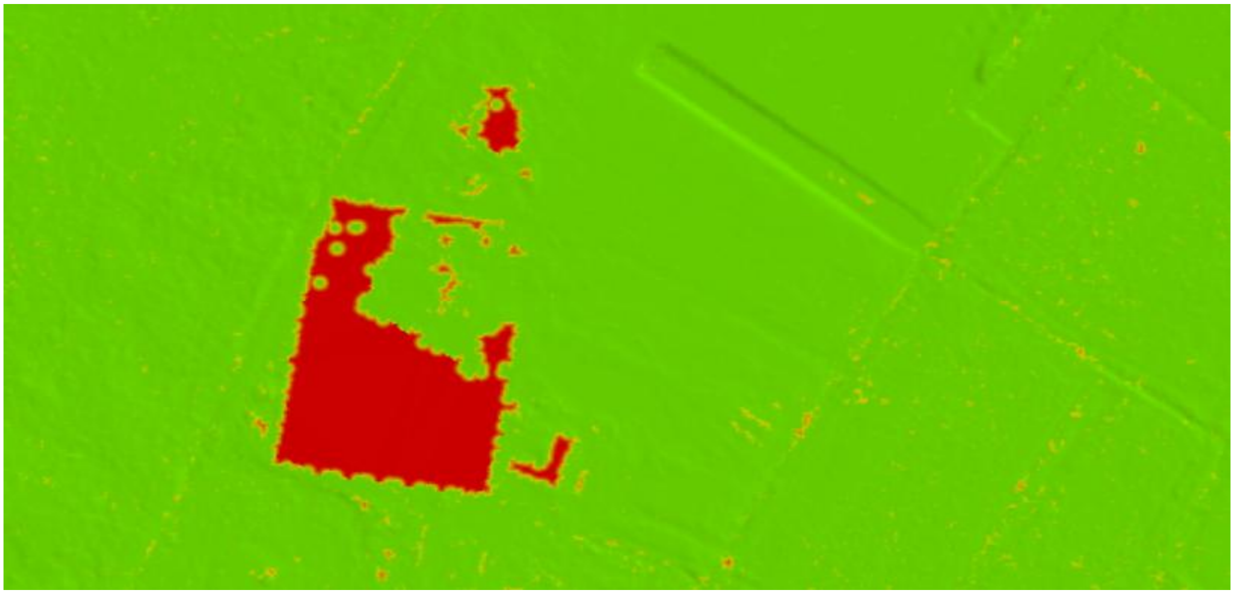

Figure 8-Tile LAS_S23_2786_40, Delivery 1. Ground density model showing a void was present in the bare earth surface model. As the profile below shows, this void was a result of ground points being misclassified as class 1, unclassified.

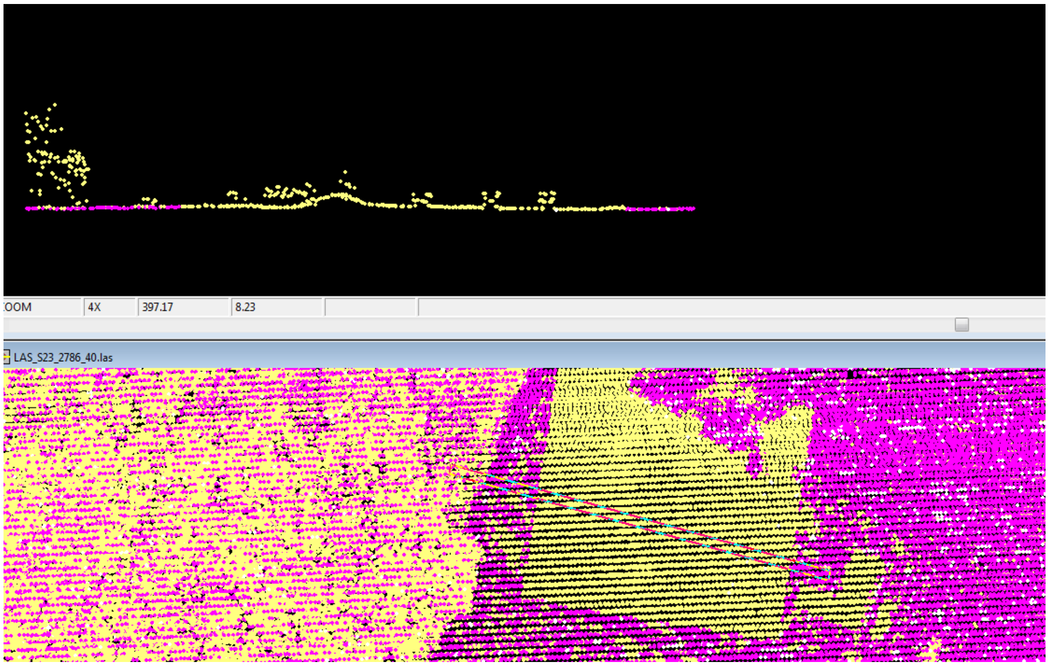

Figure 9-Tile LAS_S23_2786_40, Delivery 1. Profile view of points displayed by classification, showing points that were classified as unclassified (class 1, yellow) should have been classified as Bare Earth (class 2, Pink).

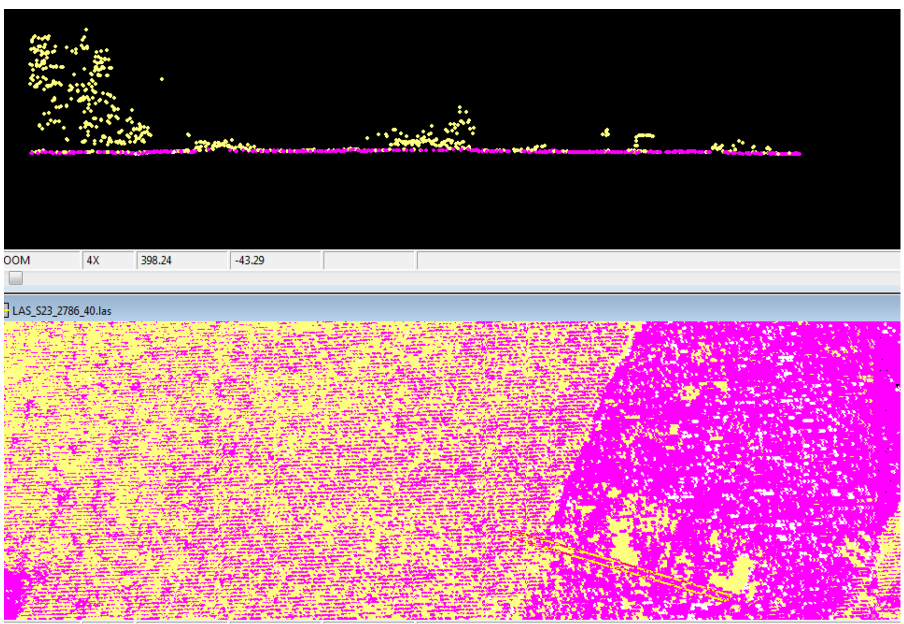

Figure 10-Tile LAS_S23_2786_40, Delivery 4. Profile view of points displayed by classification, showing legitimate points that were classified as unclassified (class 1, yellow) have been corrected by Sanborn and are now classified as Bare Earth (class 2, Pink).

3.3.3 Point Spreading

Dewberry identified several areas in the dataset with slightly uneven point spacing. The adjacent flight lines appear to diverge and converge, usually due to sudden changes in atmospheric conditions such as wind. This point spreading is somewhat visible in the density models. This issue does not affect the usability of the data but should be noted by the end user.

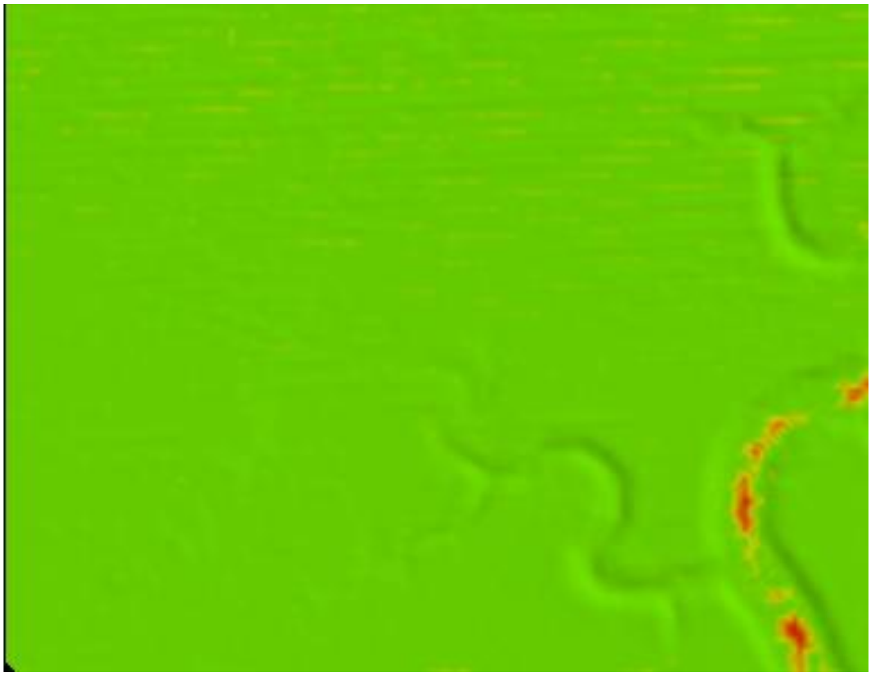

Figure 11-Tile LAS_S23_2653_30, all deliveries. The ground density model is predominantly green meaning there is sufficient coverage of ground points and does not affect the quality of the ground model.

Figure 12-Tile LAS_S23_2653_30, all deliveries. The image shows the distribution of the points is not even, which causes the low density stripes in the density model.

3.4 LiDAR Recommendation

Dewberry recommends that the LiDAR data delivered for ESVA is accepted. Sanborn re-calibrated much of the LiDAR data, resulting in improved relative accuracy and vertical accuracy. The vertical accuracy of the LiDAR is now passing project specifications. All major edit calls that impacted the final ground model, including aggressive classification, misclassification, inconsistent editing, and artifacts, have been addressed by Sanborn.

4 Breakline Analysis

A qualitative/quantitative review was completed on the breaklines. As this is the fourth delivery of the data, only edit calls were reviewed to ensure corrections and modifications were performed satisfactorily. Automated checks for topology, including ESRI PLTS tools and proprietary tools developed by Dewberry, were performed. The breakline review followed the Breakline QA/QC Checklist outlined in the Quality Plan.

4.1 Breakline Data Overview

The breakline qualitative review starts with an overview. First, the GDB is reviewed in ArcCatalog for correct spatial projections, data organization, and to ensure all necessary feature classes are present. The breakline GDB has the correct spatial projection information and is as follows:

- Horizontal Datum: NAD83 (HARN)
- Vertical Datum: NAVD88
- Projection: Virginia State Plane Coordinate System, South Zone
- Horizontal and Vertical Units: Feet

The feature classes are organized within an ESRI 9.3 Geodatabase. The GDB follows the standard USGS convention for feature names and organization. The feature classes located within the GDB are as follows:

- Inland Streams and Rivers
- Tidal Waters
- Inland Ponds and Lakes
- Boundary
- Masspoints
- Accomack Terrain

4.2 Breakline Completeness Review

The breakline completeness review includes ensuring all feature classes necessary are present and has the correct extents. The review area contained the correct feature classes, noted above. The breakline extents have coverage extending at least 100 meters beyond the boundary, the “vcr_land_area” shapefile, as specified by USGS LiDAR Guideline and Base Specifications v.13.

The entire coastline of this project area, which consisted of Accomack and Northhampton Counties, is tidally influenced. Differing tide levels can cause elevation changes within one flight line and can cause substantial elevation changes between flight lines. There are many low-lying islands off the coast of Accomack and Northhampton Counties. Many of these islands are only exposed at low tide. This caused some discontinuity in the data from one flight line to the next when an island is exposed in one flight line but inundated in the neighboring flight line.

This resulted in tidal breaklines that show abrupt changes between land and water interfaces. These breaklines often do not appear natural. However, this phenomenon is related to tidal fluctuations as Sanborn was not required to collect data at low tide.

Examples are shown below to inform end users of how some areas of the data appear.

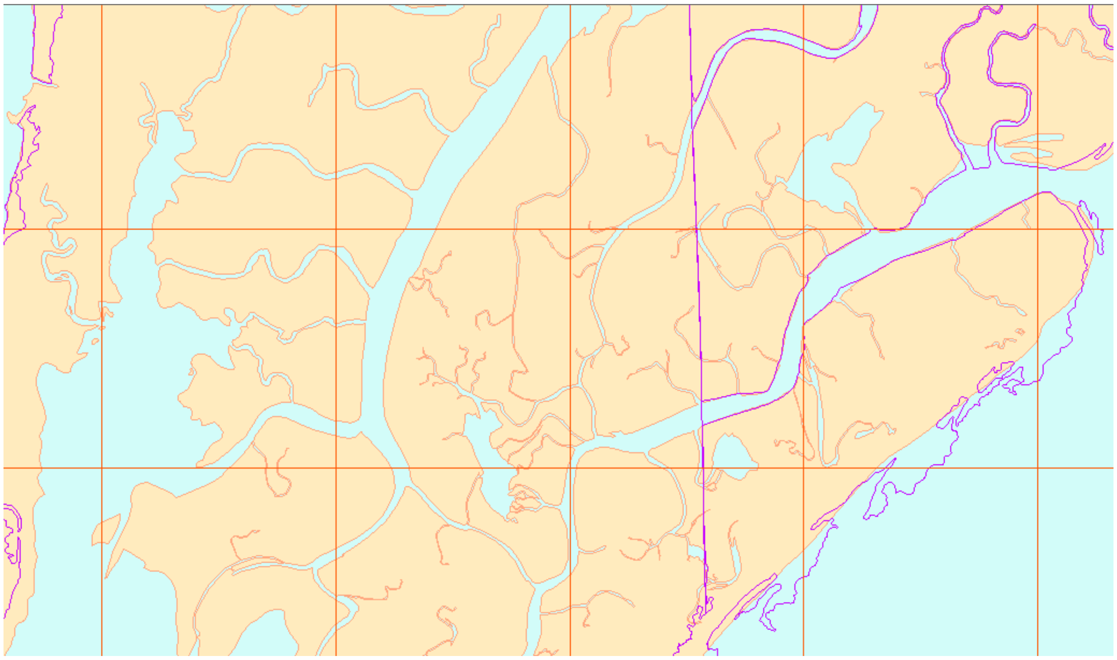

Figure 13, all deliveries-Tidal breaklines are shown in purple, overlaid on the vcr_land_area" shapefile that identifies the extent of land that is used as a boundary for the USGS ESVA project. As the screenshot shows, tidal breaklines run through the middle of islands and appear unnatural.

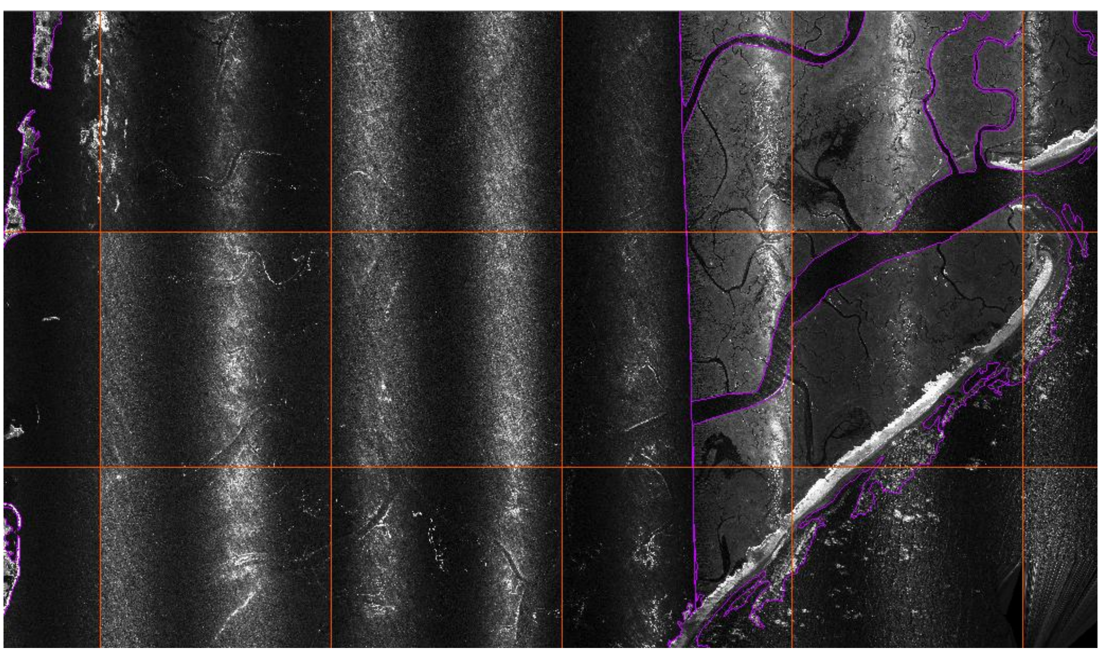

Figure 14, all deliveries-Tidal breaklines are shown in purple overlaid on intensity imagery. As the screenshot shows, the tidal breaklines follow the land water interface as seen in the intensity imagery.

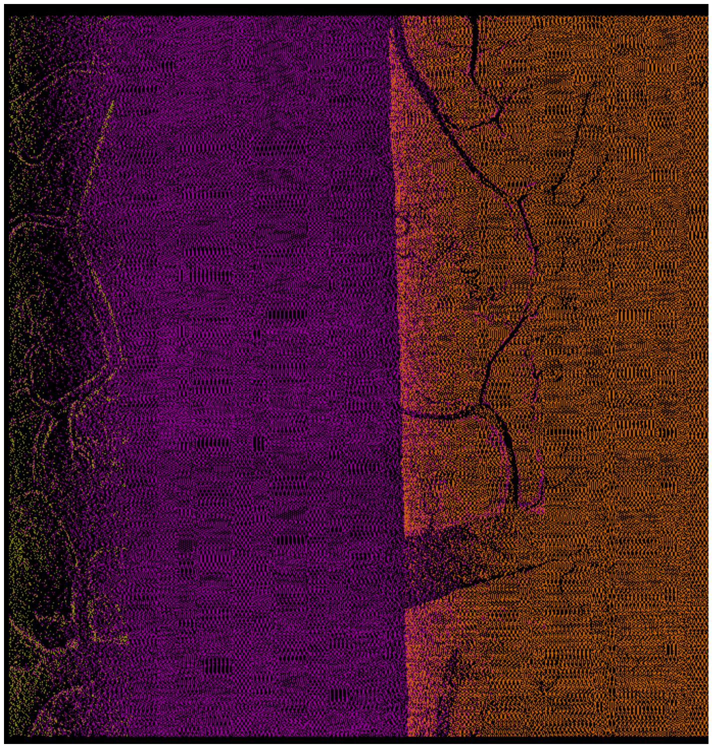

Figure 15, all deliveries-Tile LAS_S23_2559_20. Point cloud displayed by flight line source id. Flight line edges correspond to the land water interface seen in the intensity imagery and reflected in the breakline collection.

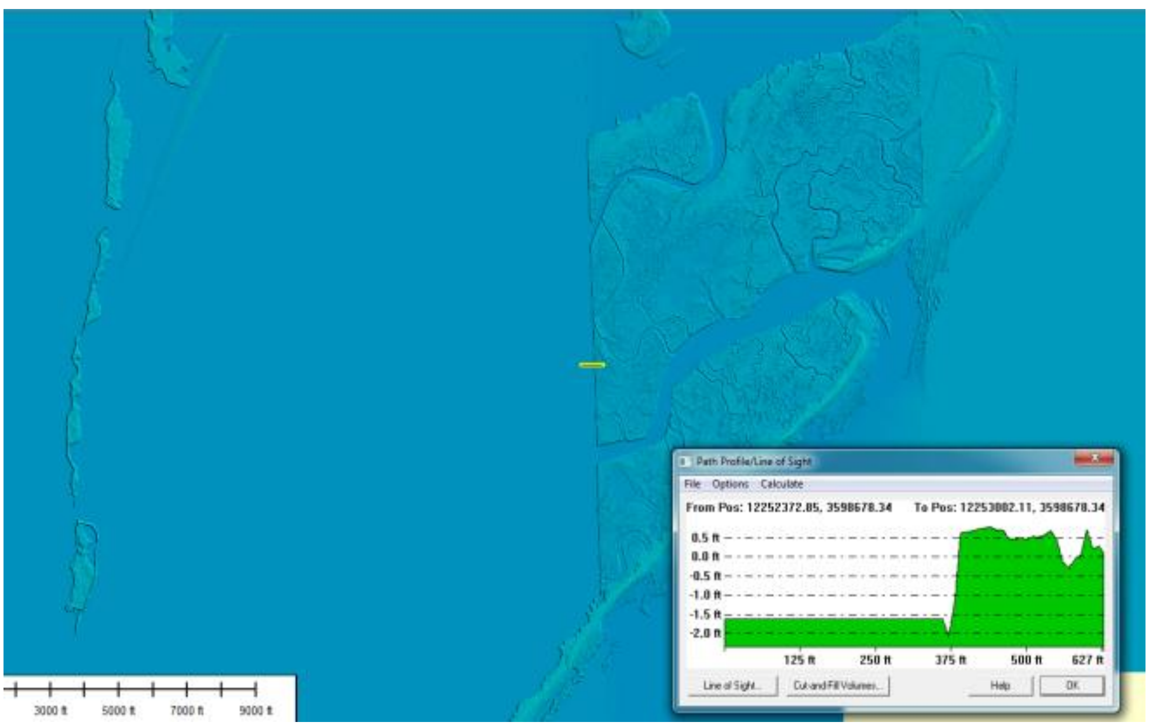

Figure 16, all deliveries-DEMs of the same area shown in the screenshots above. DEMs also seem to show an "unnatural" break between land and water interfaces due to large tidal variations between flight lines. While the water on the left side of this image is actually higher than the exposed island on the right side of this image, the water must be flattened and given a lower elevation. Otherwise, the water will appear as floating above surrounding land.

Normally, Dewberry asks that adjacent polygons be merged together into one feature. This is normally more organized and creates a cleaner line for the breakline data. However, due to tidal variations between adjoining flight lines, Sanborn has kept each tidal water area within a flight line as a separate polygon. Having Tidal Waters as separate polygons for each flight line helped immensely during the QA review as this area can be complicated, especially with tidal variations that can be drastic from one flight line to the next. Due to the usefulness of the separate polygons, Dewberry did not mark edit calls for “unnecessary polygon boundaries” in the Tidal Waters as is listed in the Breakline QA/QC Checklist. Below is a screenshot of the Tidal Water breaklines that are split at flight line boundaries.

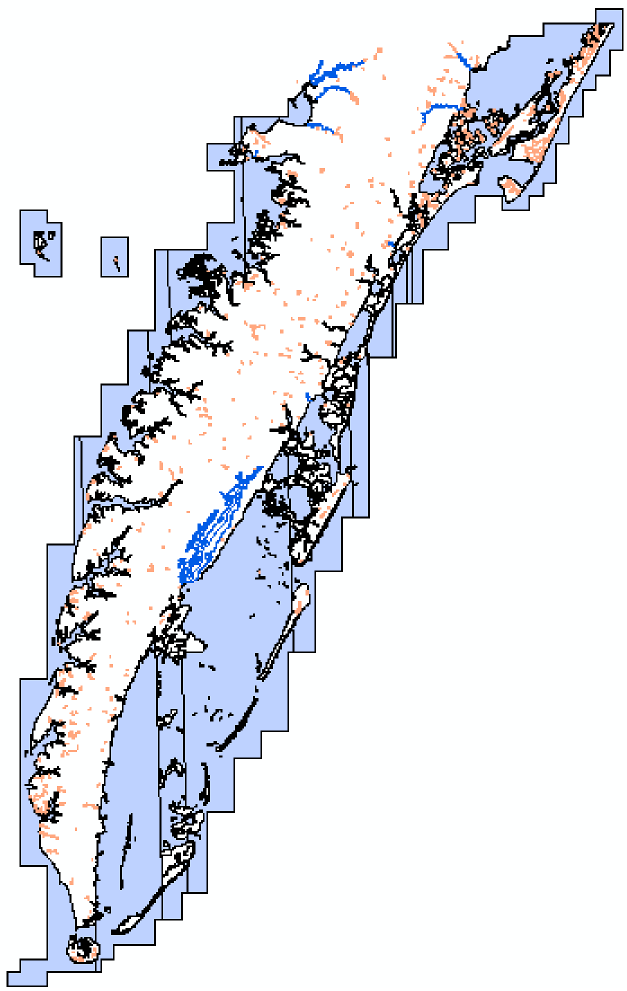

Figure 17, all deliveries-Tidal Water polygon breaklines are shown in light blue with a black outline. Normally Dewberry uses the PLTS “unnecessary polygon boundaries” check to identify adjacent polygons that should be merged into one. Due to the drastic tidal variations between flight lines, having the Tidal Waters split at those boundaries was very useful during the QA review. Because it could be useful for end users to have the Tidal Water breaklines split at flight line boundaries, Dewberry did not run the unnecessary polygon boundaries check on Tidal Waters.

4.3 Breakline Qualitative Review

As this is the fourth delivery of the data, only edit calls were reviewed to ensure corrections and modifications were performed satisfactorily. Numerous edit calls were placed during the review of the first delivery. Sanborn corrected most edit calls. Edit calls that were minor or would not affect the final bare earth surface may not have been corrected or modified. Examples from the first and last deliveries are shown below.

4.3.1 Missing Features

Islands that meet USGS capture specifications of .5 acres should be collected as "holes" and excluded from polygon layers, such as Inland Ponds and Lakes or Tidal Waters. Forty-eight (48) features were identified as missing in the first delivery. Sanborn has addressed these edit calls. An example is shown below.

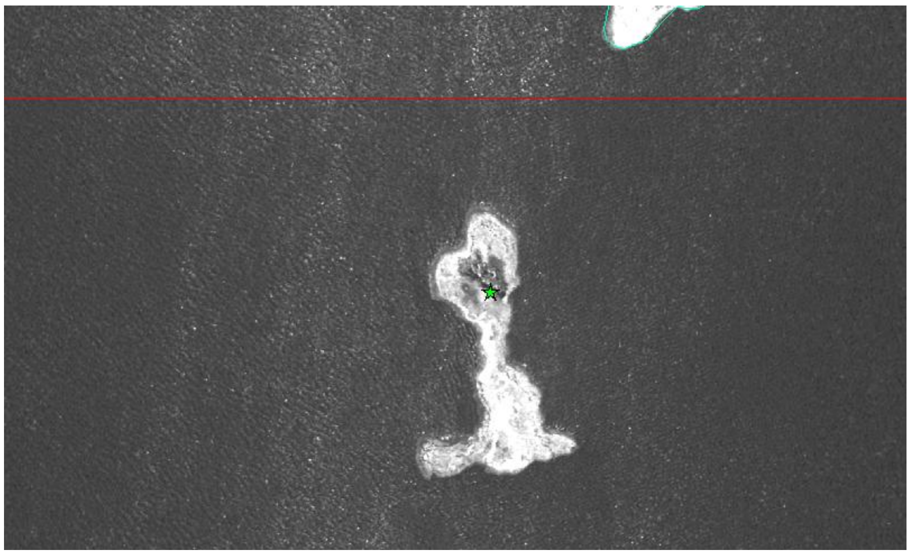

Figure 18-Tile S23_4900_40, Delivery 1. Island was not collected that is large enough to meet USGS specifications.

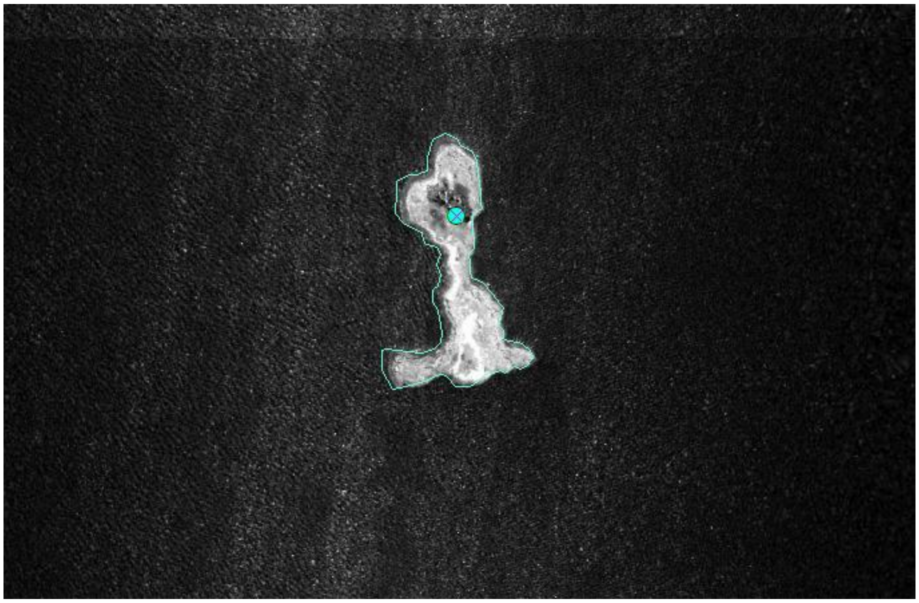

Figure 19-Tile S23_4900_40, Delivery 4. Island has been collected.

Figure 20-Tile S23_4900_40, Delivery 4. Island has been collected and is now visible in the DEM.

4.3.2 Improper Delineation of Features

The delineation of features (104) in some areas was identified in the first delivery as not correctly following the shoreline. These features were updated in subsequent deliveries to better reflect the land/water interface at the time of LiDAR collection. An example is shown below.

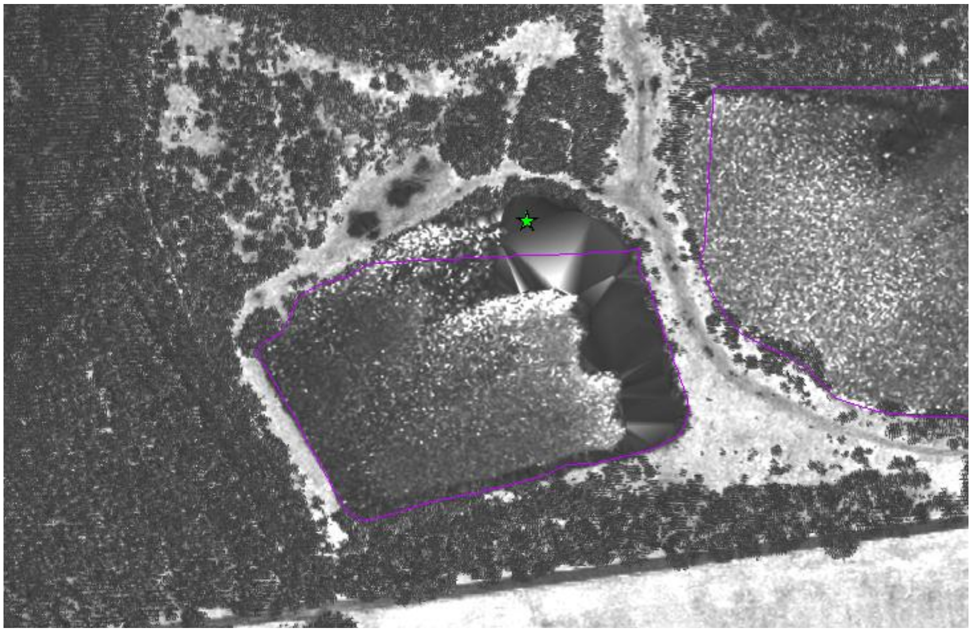

Figure 21-Tile S23_3930_10, Delivery 1. Delineation of water body did not correctly follow shoreline, leaving a large area of the feature missing.

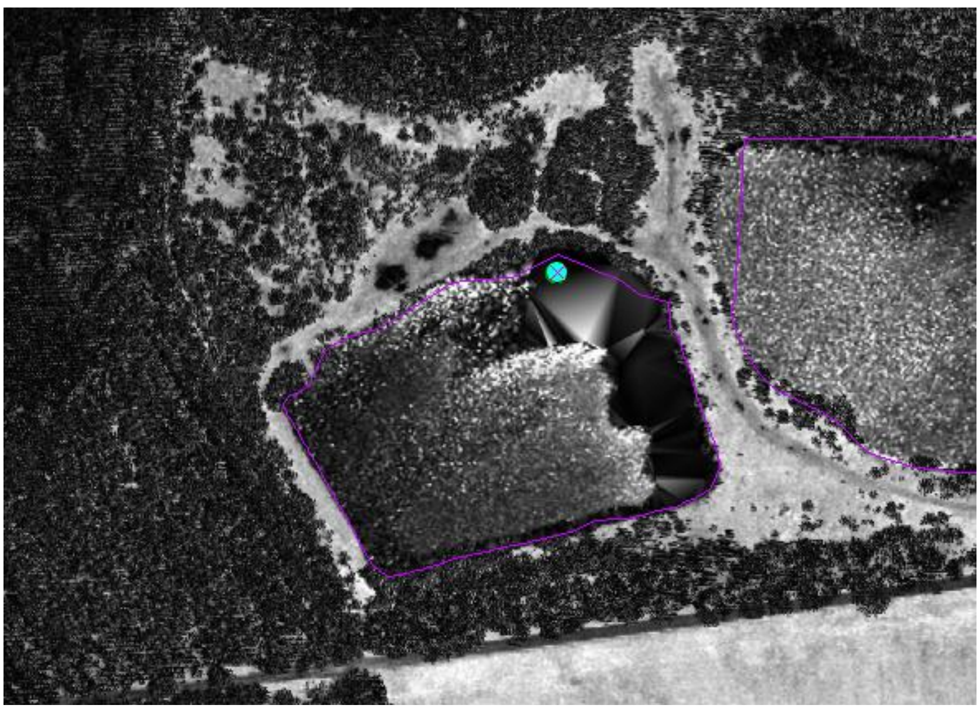

Figure 22-Tile S23_3930_10, Delivery 4. Delineation of water body has been corrected to fully capture feature.

4.3.3 Unnatural Appearance or Collection of Breaklines

During the first review it was noted that when some features became too small to meet minimum collection requirements, the breaklines (7) were abruptly stopped or appearred “cut off” as if a man-made structure was at that location. These breaklines were corrected to appear more natural and not mistaken for man-made features, such as dams. An example is shown below.

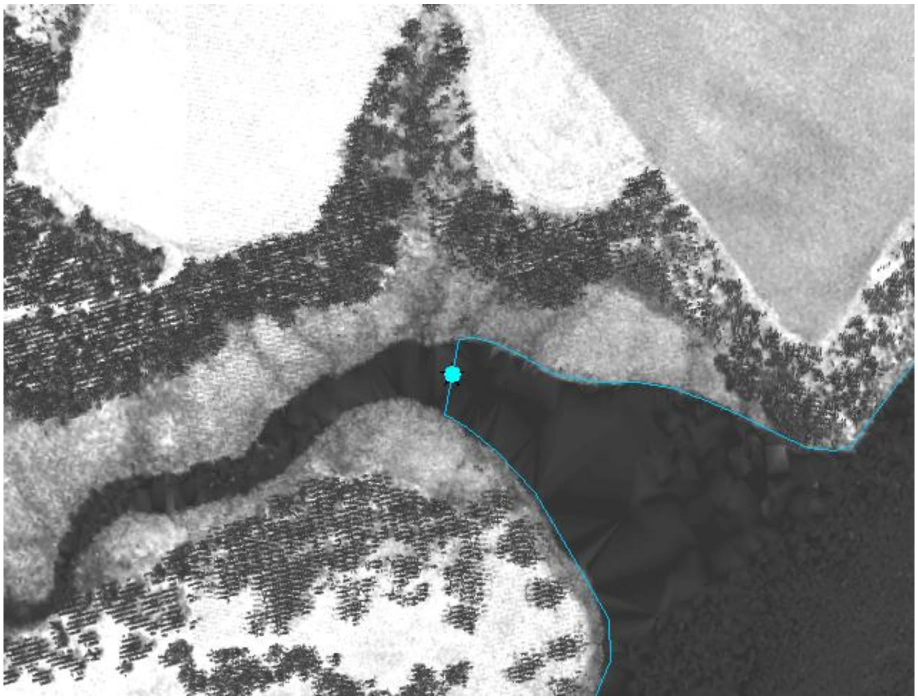

Figure 23-Tile S23_3858_10, Delivery 1. Unnatural appearance of Inland Stream, shown with blue line. Feature should have been rounded off where it becomes too narrow to meet specifications, so as not to appear to be "cut-off", or stopped by a man-made structure.

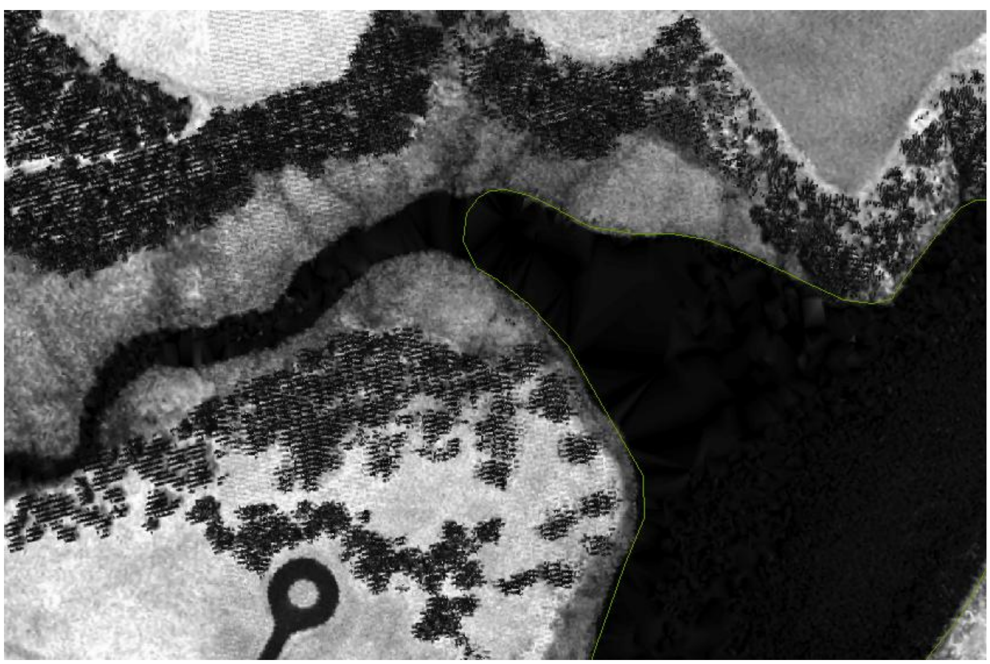

Figure 24-Tile S23_3858_10, Delivery 4. Unnatural appearance of Inland Stream, shown with green line, has been corrected by rounding it off. This feature no longer appears to be "cut-off", or stopped by a man-made structure.

4.4 Breakline Quantitative Review

The Quantitative Vertical Analysis compares the streams and rivers, ponds and lakes, and tidal water breakline vertices against the bare-earth LiDAR data. Dewberry begins this process by converting all breaklines to points. At the same time an ESRI GeoTerrain is created from the LiDAR using only the ground points. The elevation of the LiDAR is derived by extracting the Z-value of the terrain at the same X/Y-values of the points. Finally, an analysis of the elevation comparison between the points and the terrain is conducted to determine the accuracy of the breakline collection. LiDAR elevations are subtracted from breakline elevations to determine a ΔZ for every vertex.

Per USGS specification, all breaklines must be at or just below the surface of the surrounding terrain. To ensure this requirement is met, the ΔZ is reviewed for every vertex. Vertices floating above the surrounding terrain by more than 0.1ft are considered an error as 0.1ft is noticeable in the DEMs. Vertices digging by more than 1ft were also reviewed. Vertices digging due to LiDAR noise, holding pond and lake elevations constant, etc. are not considered to be errors. A few edit calls (23) were placed during the first review for water body features that were digging by several feet due to incorrect horizontal placement. Sanborn corrected these issues in subsequent deliveries by modifying the breaklines to show the actual land/water interface. Elevations for features that were identified as floating (2) or excessively digging (3) in the first review was corrected in subsequent deliveries.

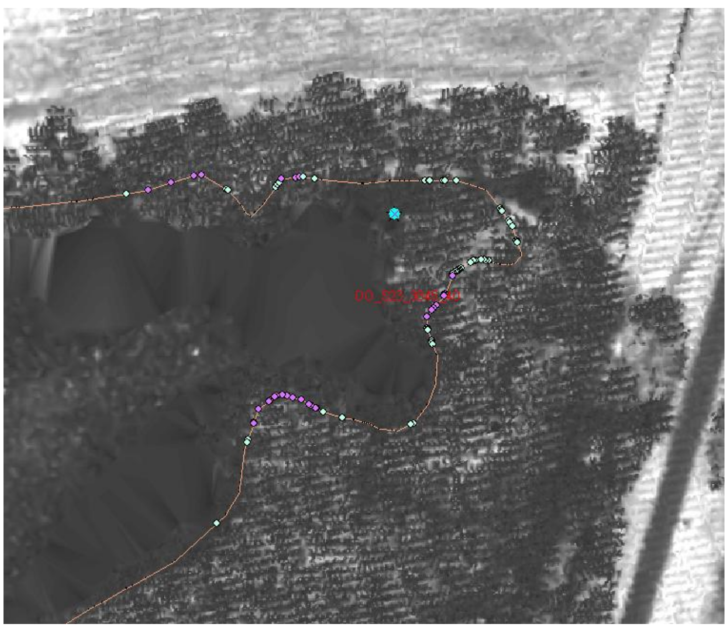

Figure 25-Tile S23_3845_40, Delivery 1. The incorrect horizontal placement of this feature along the bank was causing sections of it to be digging by several feet. Breaklines need to be adjusted to define the actual land/water interface.

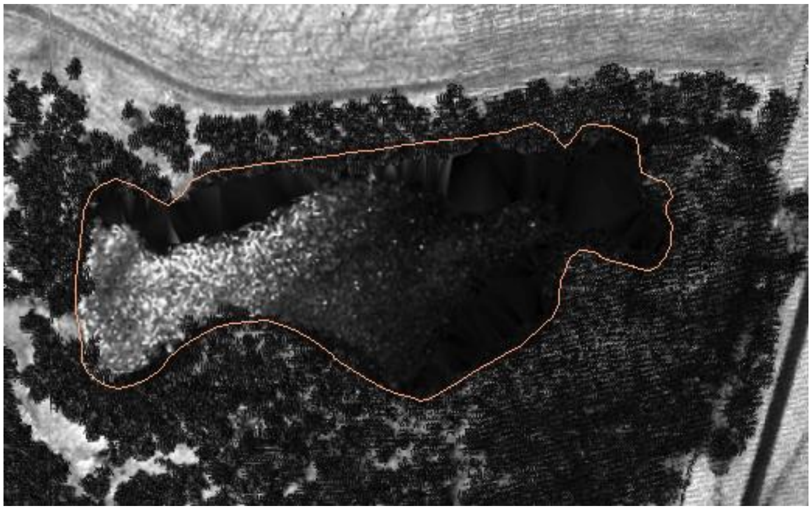

Figure 26-Tile S23_3845_40, Delivery 4. The horizontal placement of this feature was corrected to show the actual land/water interface.

4.5 Topology

One of the requirements of hydro breaklines intended for modeling is valid topology. Dewberry tested the topology using ESRI's PLTS extension and proprietary tools to ensure that the breakline vertices are snapped together, that hydro-lines fulfill monotonicity requirements within a specified tolerance, that all water bodies are flat within a tolerance, and that all breaklines have elevations defined. These data checks allow automated validation of 100% of the data. The data checks used are listed in detail in the Quality Plan under the "Breakline QA/QC Checklist."

No issues were identified with the automated checks.

The last automated data check used to ensure valid topology is to validate the ESRI GDB topology provided in the GDB shell or the rules defined in the Data Dictionary. All rules have been validated and there are no valid errors.

4.6 Breakline Recommendation

It is Dewberry's recommendation that the breakline data be accepted. Sanborn has corrected all edit calls that affect the final bare earth surface and there are no topology issues remaining in the dataset.

5 Hydro-flattened Digital Elevation Model Analysis

Dewberry reviewed the hydro-flattened DEMs in an ESRI and Global Mapper environment. When viewed in ESRI, hillshades were utilized that allow the analyst to review the data as if it were in 3D. This allows the analyst to identify potential issues at a higher confidence level. As the DEMs had to be re-processed to correct issues previously identified and re-processing can introduce new issues, all DEMs, 100% of the data, were reviewed at a micro level to check for artifacts, gaps, artificial smoothing, and any other errors or anomalies.

5.1 Completeness Review

Dewberry first verified that the number of DEMs delivered for the area, 1,330, is correct. This number matches the number of classified LiDAR tiles provided. While the project tile grid has 1,341 tiles, the 11 tiles not included in the delivery are along the outer edges, well beyond the project boundary identified in the "vcr_land_area" shapefile.

The DEMs have coverage to the full extent of the project boundary. Data was not clipped to this boundary, but extends well beyond the boundary. Data extending beyond the boundary may not always have full coverage and DEMs may not be flattened in these areas outside of the boundary. Some of this data outside of the boundary may have coverage gaps and be unusable. Sanborn is not required to clip the data. EROS has elected to receive all data and to perform the final clipping so that they control the final clipping boundary and selection of data that will ultimately be used in the NED program. An example of unusable data located outside of the project boundary is shown below.

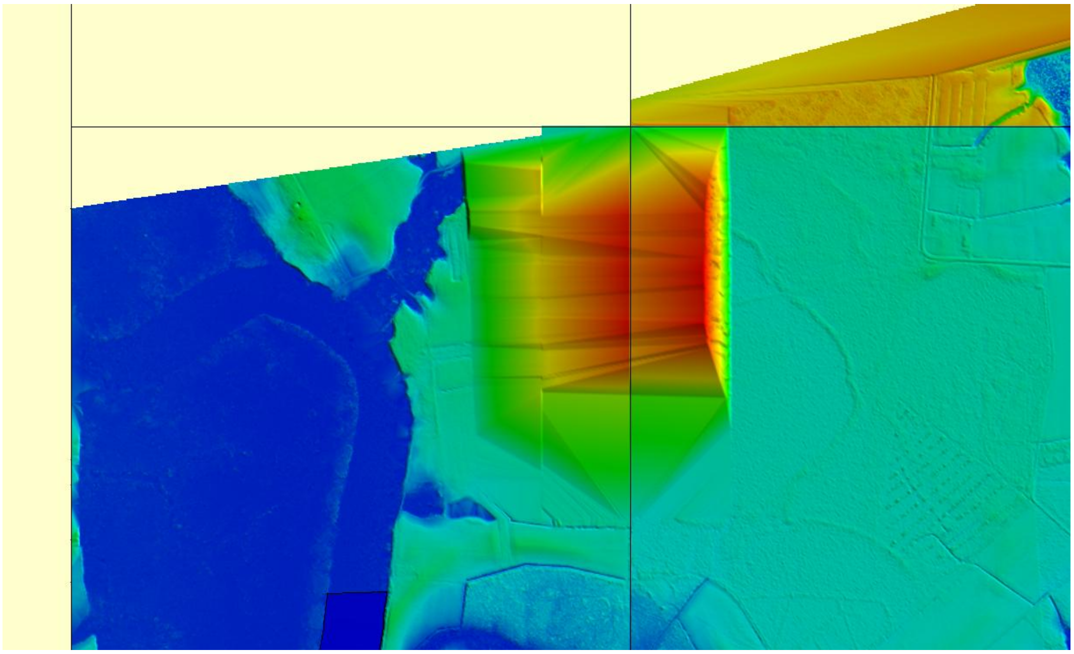

Figure 27-DEM_S23_3910_10, all deliveries. Some areas outside of the project boundary may be unusable. The identified area is a coverage gap well outside of the required project boundary, with an anomalous high ridge along the eastern side of the gap. This particular area is unusable even though it was delivered with the final DEMs. EROS will perform the final clipping of the data.

The DEMs have the correct spatial projection information, defined below:

- Horizontal Datum: NAD83 (HARN)
- Projection: Virginia South State Plane Coordinate System
- Horizontal Units: US_Feet

The DEMs are correctly named to match the tile grid with the identifier "DEM" appearing at the beginning of each tile name. The DEMs are in IMG format, with 10 foot resolution, and have 500 rows and columns of pixels each. The DEMs were visually verified to snap to the tile grid correctly with no overlap and spatially display in the correct location.

5.2 Qualitative Review

The majority of DEM edit calls placed by Dewberry in all previous deliveries were for artifacts within water features. Water should be flat except for gradual or stair-stepped elevations due to flow or tidal variations. While tidal variations are present in the final DEMs as this cannot be corrected post-processing, Sanborn has corrected all other DEM issues. Some examples from the first and last deliveries are shown in the sections below.

5.2.1 Artifacts

Numerous artifacts (315) were identified within water features in the first delivery. Sanborn modified their production process and the DEMs are now flat from bank to bank. Examples are shown below.

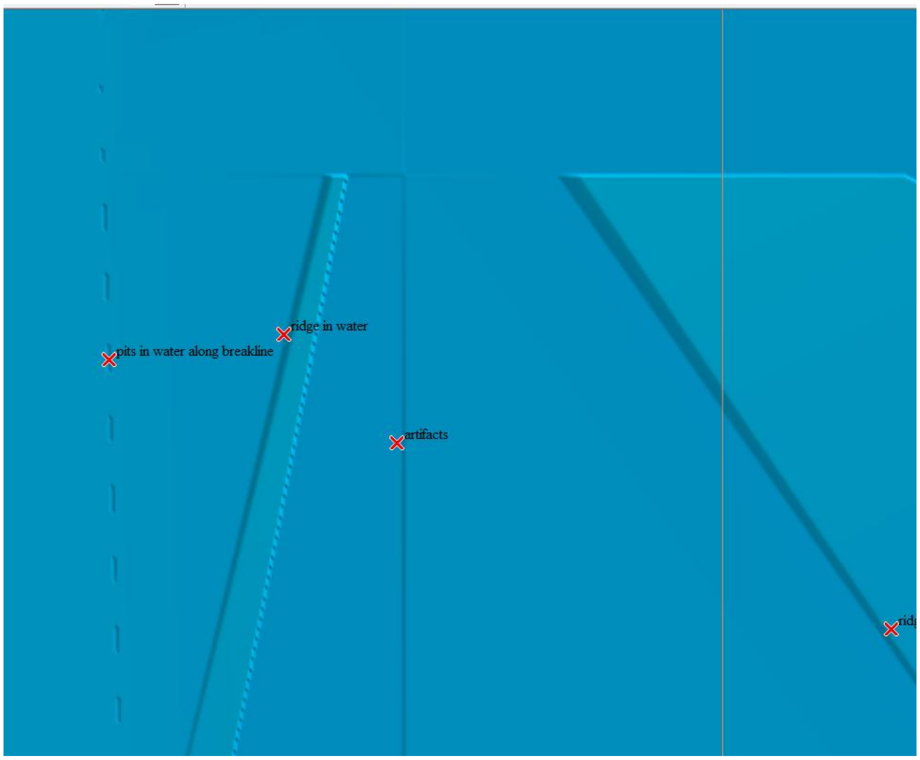

Figure 28-DEM_S23_2652_20, Delivery 1. Multiple artifacts with varying elevations were located within Tidal Waters.

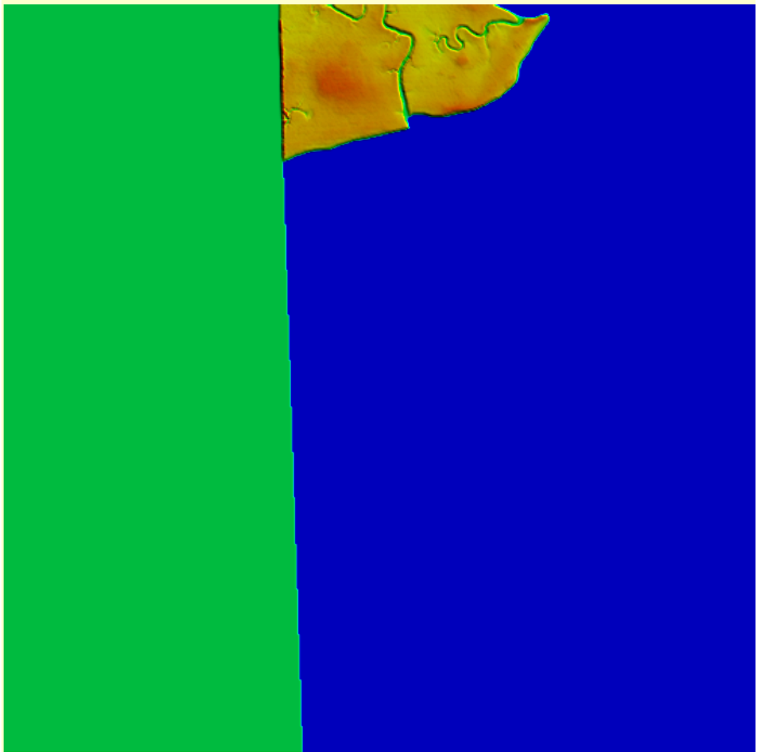

Figure 29-DEM_S23_2652_20, Delivery 4. The only elevation change in the water of this tile occurs along the flight line from tidal variations. This step is an acceptable way to show elevation change in water. The water is flat from bank to bank.

Figure 30-DEM_S23_2759_20 and DEM_S23_2759_30, Delivery 1. Multiple artifacts with varying elevations were located within Tidal Waters.

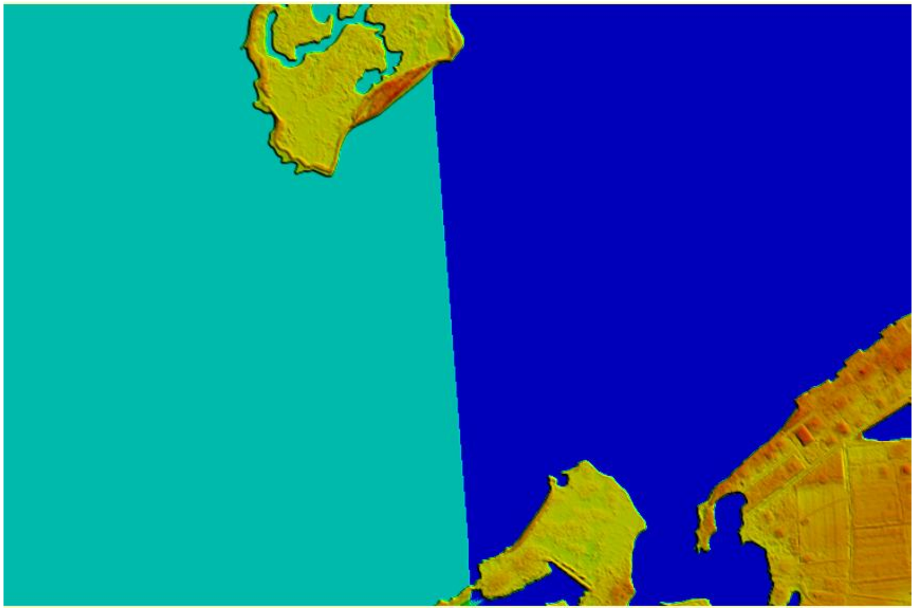

Figure 31-DEM_S23_2759_20 and DEM_S23_2759_30, Delivery 4. Now, the only elevation change in the water of these tiles occur along the flight line from tidal variations. This step is an acceptable way to show elevation change in water. The water is flat from bank to bank.

5.2.2 Floating Water Features

A few features (9) were identified in the first delivery as floating in the DEMs. These features were adjusted to be at or below the surrounding terrain. An example of the corrections is shown below.

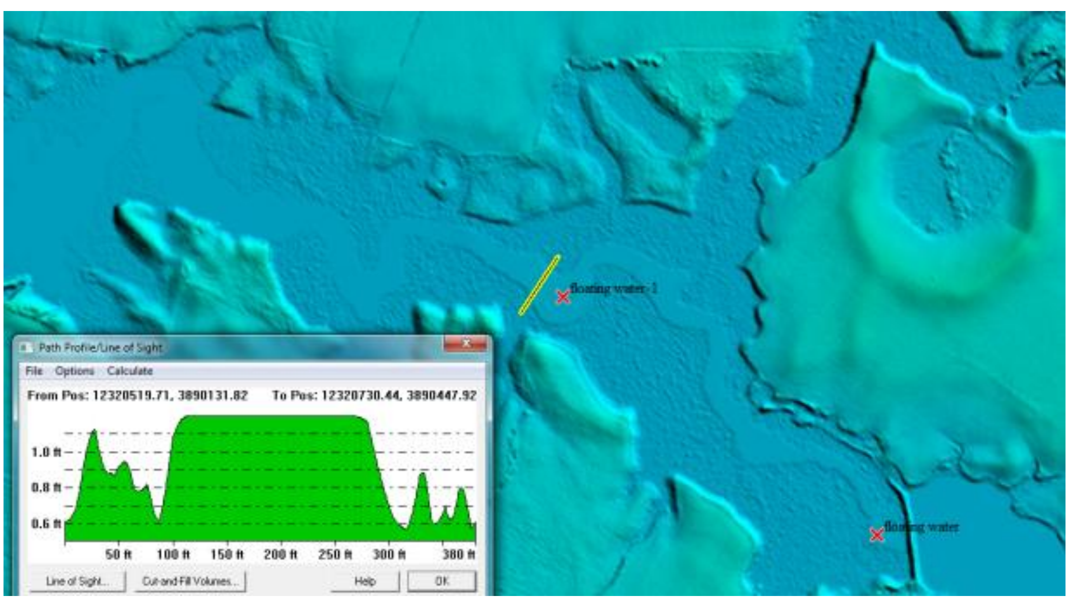

Figure 32-DEM_S23_3829_10, delivery 1. Tidal waters were floating above the surrounding terrain.

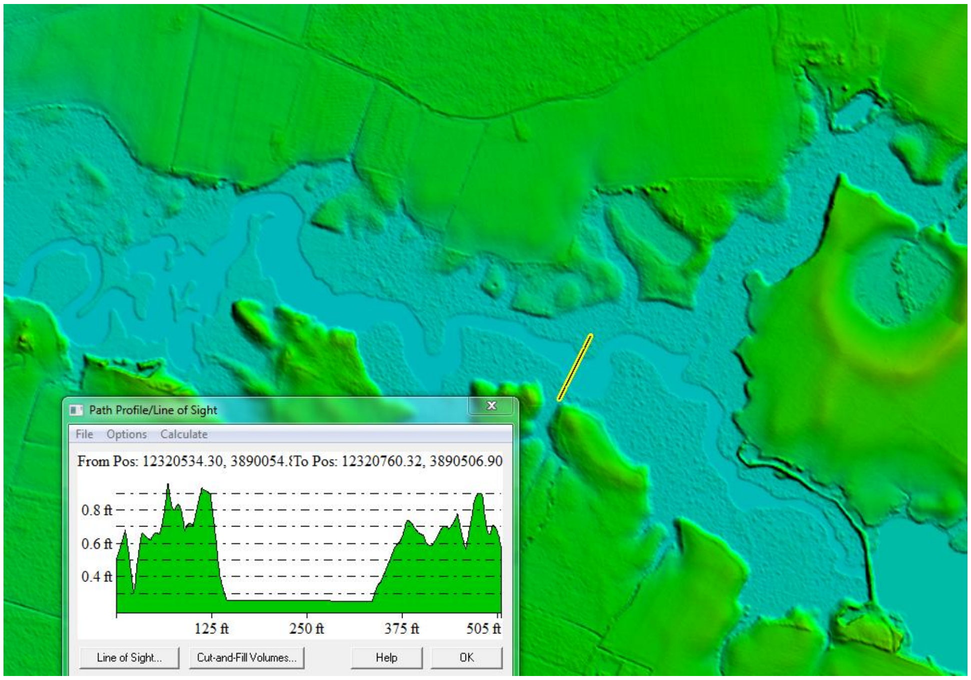

Figure 33-DEM_S23_3829_10, delivery 4. Tidal waters that were floating above the surrounding terrain have been corrected and are now at or below the surrounding terrain.

5.2.3 Flight line Ridges

Numerous edit calls (23) were placed in the first delivery where flight line ridges between two adjoining swaths exceeded 12 cm or 0.4 ft as outlined in the Quality Plan. These issues were corrected when Sanborn re-calibrated the LiDAR data. A few flight line ridges were identified in previous deliveries. Most of these were corrected when Sanborn re-calibrated the LiDAR data. However, varying water levels in marsh or vegetated areas can affect the return of LiDAR signals to the sensor. Some LiDAR signals may show a greater absorption in wetter marsh areas compared to drier marsh areas. This greater absorption before the LiDAR signal is transmitted back to the sensor can translate into lower elevations. Or, some LiDAR signals may reflect off of the thin water layer covering or partially covering an island rather than reflecting off of the "ground" surface. The LiDAR could potentially show different responses between adjoining flight lines in marsh or wet areas such as tidally exposed islands, depending on the tide levels. Some of this variance in the LiDAR return signals may result in an elevation step between adjacent flight lines. These flight line ridges that occur in marsh like land cover types were not held to the USGS 10 cm relative accuracy specification for adjoining swaths as the flight line ridges do not occur over "true" ground. An example of flight line ridges that may still appear in the dataset is shown below.

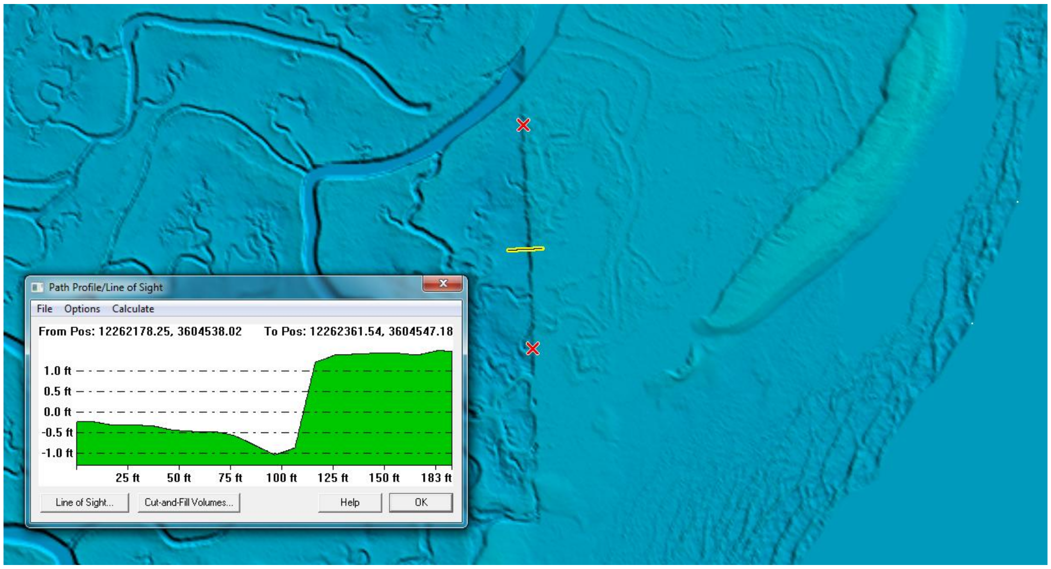

Figure 34-DEM_S23_2660_20 and DEM_S23_2660_10, All deliveries. Flight line ridges are more prominent on tidally exposed ground. These tidal flats can be very marshy with varying levels of water present. As these areas are not "true" ground, they were not held to the same relative accuracy specifications outlined for actual ground.

5.3 DEM Recommendation

It is Dewberry's recommendation that the DEMs delivered by Sanborn be accepted. Flight line ridges, with the exception of those located in tidally influenced areas, were corrected when Sanborn re-calibrated the LiDAR data. Sanborn modified their production process. This corrected all other DEM issues, including artifacts in water that needed to be flattened.

6 Metadata

Metadata has been delivered in XML format for the classified LAS data, raw LAS data, each day of LiDAR acquisition, masspoints, the terrain, DEMs, tidal water breaklines, inland streams and rivers breaklines, and inland lakes and ponds breaklines. While some files do contain metaparser warnings, there are no errors. The metadata files contain sufficient content. All previous issues noted with the metadata files, including date inconsistencies, incorrect processing steps, and metaparser errors, have been corrected. The vertical accuracy listed in the metadata files is the accuracy as tested by Sanborn, not the independent accuracy assessment completed by Dewberry.

7 Other Comments

The raw LiDAR swath data was not delivered as part of the final deliverables.

8 Recommendation Summary

The following represents a summary of Dewberry's recommendations for the ESVA Project Deliverables. These recommendations can be found throughout the various sections of this report but are summarized here for convenience.

8.1 Issues Requiring Modifications by Sanborn Mapping Company

There are no issues requiring corrections or modifications by Sanborn.

8.2 Issues for USGS Comments

There are no issues requiring USGS resolution.