LiDAR Quality Assurance (QA) Report
Louisiana LiDAR ARRA Project - Region 2
October 11, 2011

Submitted to:
USGS

Prepared by:
Dewberry

Table of contents

1 Executive Summary

Contract: Louisiana ARRA Region 2	**Production Contractor:** Woolpert Inc.	**Date Prepared:** 10/11/2011	**Delivery #:** 3	**Dewberry Recommendation:** Accept
Data History: • 1st delivery June, 2011. • 2nd delivery arrived September, 2011. • 3rd delivery arrived October, 2011.				

The following LiDAR quality assurance report documents Dewberry's third review of LiDAR data and derived products for the Florida-LA Region 1 & 2 –Texas Co.'s LiDAR Quality Assurance project. This document reviews the classification and derived products for the Louisiana Region 2 delivery by Woolpert Inc. (Woolpert). The delivery area consists of ~1683 square miles (4360 square kilometers) that amount to 2090 LAS tiles (1500 meters x 1500 meters) (Figure 1). Each tile contains LAS point cloud data classified according to the ASPRS classification scheme. The deliverables also include breakline shapefiles, the control (checkpoints used during LiDAR collection), hydro-enforced digital elevation models (DEMs), and metadata.

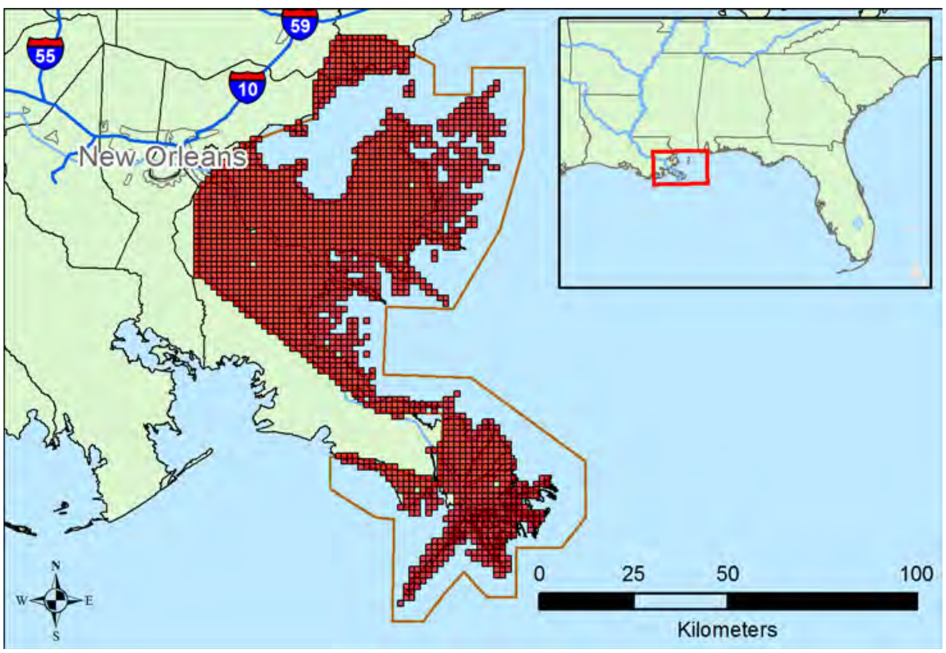

Figure 1 - Location of LAS tiles.

The LiDAR data and derived products were processed through Dewberry's comprehensive quantitative/qualitative review process. This multipart analysis determines the degree to which the data met expectations for completeness, relative accuracy, and conformity to specific project requirements for each data product. After thorough review of the third delivery materials, Dewberry recommends that the all deliverables be accepted by the USGS. All of the issues that Woolpert has addressed for the LiDAR, breakline collection, and DEM processing can be found in this report.

Both deliveries of the LiDAR data for the Louisiana Region 2 area were thoroughly examined by Dewberry for completeness and conformity to project specifications. The fundamental vertical accuracy of the data is 38.0 cm which exceeds project specifications. In the first delivery, Dewberry detected numerous misclassification issues, several vegetation artifacts and several instances of inconsistent editing. Dewberry also identified a few, minor data voids caused by intensity issues. Several flight line ridges that exceed project specifications were a concern in the original delivery. The large majority of these issues were addressed by Woolpert in the second delivery. Any remaining issues are small enough or localized enough to be considered insignificant.

In the first delivery, Dewberry identified breakline issues concerning water bodies not captured, breaklines not being clipped to the project boundary, unnecessary boundaries, floating water features, and topologic issues. No further issues exist in the breaklines in the 3rd delivery. Some floating water features exist in the DEM, but these are acceptable based on the way breaklines are compiled.

The hydro-enforced DEMs will improve once the breakline corrections are made. In the first delivery, Dewberry detected null pixels and water artifacts in the DEMs. These were corrected in the second delivery however three new areas of null pixels were identified which should be further addressed. These were addressed in the 3rd delivery. No further issues were found in the DEMs.

The metadata for both deliveries were of sufficient detail and do not contain any errors according to the USGS MP Tool in ArcGIS. Dewberry recommends the USGS accept the metadata.

1.1 Deliverables Summary for Woolpert Inc. Louisiana ARRA Region 2

Deliverable	Applicable Acceptance Criteria	Dewberry Recommendation
All-Return LAS Point Cloud Data	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 23, 24, 25, 26	☐ Accept ☑ Accept with Comments ☐ Return for Corrections ☐ Reject
Breaklines	30, 31, 32, 33, 34	☐ Accept ☑ Accept with Comments ☐ Return for Corrections ☐ Reject
Hydro-Enforced DEMs	20, 21	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject

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

The applicable acceptance criteria refer to the numbered criteria found in "Appendix B-Acceptance Criteria" on pages 12-13 of the Quality Plan.

1.2 Report Approval

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

Approved by: ______________________ Date: 10/11/2011
(sign & stamp)

Overview
The goal of the USGS Florida-LA Region 1 & 2 –Texas Co.'s LiDAR project Task Order is to provide high accuracy elevation datasets of multiple deliverable products including LiDAR, hydro enforced digital elevation models (DEMs), and 3D breaklines.

Dewberry's role is to provide Quality Assurance (QA) of the LiDAR data and supplemental deliverables provided by Woolpert Inc., Aerometric, and Woolpert including completeness checks, vertical accuracy testing, and a qualitative review of the bare earth surface. This document pertains solely to products delivered by Woolpert Inc. for the Louisiana Region 2 delivery area and describes the review of the second delivery data. Each product is reviewed independently and against the other products to verify the degree to which the data meets expectations.

2 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.

2.1 LiDAR Quantitative Review

One of the first steps in assessing the quality of the LiDAR would be a vertical accuracy analysis of the ground models in comparison to surveyed checkpoints. Dewberry & Davis, LLC provided 119 checkpoints for the entire project area extent (Figure 2).

Figure 2: Checkpoints distribution for Louisiana Region 2

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.

The $RMSE_Z$ in open terrain is 19.4 cm which exceeds the project specification of 12.5 cm. However, the CVA value for all points is 30.9 cm which meets project specifications of 36.3 cm. The SVA values for all three land cover types also all meet the project specifications of 36.3cm. Table 1 outlines the calculated RMSEz and associated statistics in meters while Table 2 outlines vertical accuracy and the statistics of the associated errors as computed by the different methods in meters.

100 % of Totals	$RMSE_Z$ (m) Spec=0.125 m[1]	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.172	-0.115	-0.128	0.418	0.128	119	-0.341	0.247
Open Terrain	0.194	-0.172	-0.179	0.403	0.091	41	-0.329	0.050
Weeds/Crop	0.155	-0.077	-0.072	-0.147	0.136	37	-0.340	0.140
Forest	0.162	-0.092	-0.098	0.413	0.135	41	-0.341	0.247

Table 1: The table shows the calculated RMSEz values in meters as well as associated statistics of the errors for Louisiana Region 2. [1]*In open terrain.*

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_Z$ x 1.9600) Spec= .245 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.363 m	SVA — Supplemental Vertical Accuracy (95th Percentile) Spec=0.363 m
Consolidated	119		0.309	
Open Terrain	41	0.380		
Weeds/Crop	37			0.278

Forest	41			0.274

Table 2: The table shows the calculated Accuracy$_z$ of the FVA in meters using FEMA/NSSDA guidelines (RMSEz x 1.9600) and the Accuracy$_z$ of the CVA in meters using NDEP/ASPRS guidelines (95th percentile) for Louisiana Region 2.

2.2 LiDAR Completeness Review

Dewberry received 2090 LiDAR tiles in the second delivery. 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 are named according to the United States National Grid and have the correct extents (1500m x 1500m).

All spatial projection information was correct and is as follows:

- Projection: NAD 1983 UTM Zone 16N
    - Horizontal and Vertical Units: Meters
- Vertical Datum: NAVD88, Geoid09

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

- 1,814 tiles had scan angles greater than 20° and 1,256 tiles had combined scan angle ranks greater than 40°. As discussed in the qualitative LiDAR QA/QC section, several flight line ridges were identified in the LiDAR data.

The LiDAR data has been classified to contain the appropriate classes as required:

- Class 1 (Unclassified)
- Class 2 (Bare Earth)
- Class 7 (Low point/Noise)
- Class 9 (Water)
- Class 10 (Overlap)

All points are classified into one of the aforementioned classes. There are no points existing in extraneous classes. All tiles meet the project requirement to have 10% overlap on adjoining swaths. It should be noted that there is no overlap between Class 2 (ground) from flight line to flight line. The overlap is all moved to Class 12 (overlap).

2.3 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. No issues were identified.

Each tile was queried to extract the number of LiDAR points. Woolpert Inc. collected the LiDAR at with a nominal point spacing of 2 pulses per square meter. The expected total number of points per tile should be approximately 4.5 million. The mean within the project area of each tile is approximately 1.57 million. The large discrepancy between the expected number of points per tile and the actual number of points per tile is due to the large areas of tidal water prevalent in almost every tile (Figure 3). Dewberry did not identify any issues with point density during the manual qualitative review of the LiDAR.

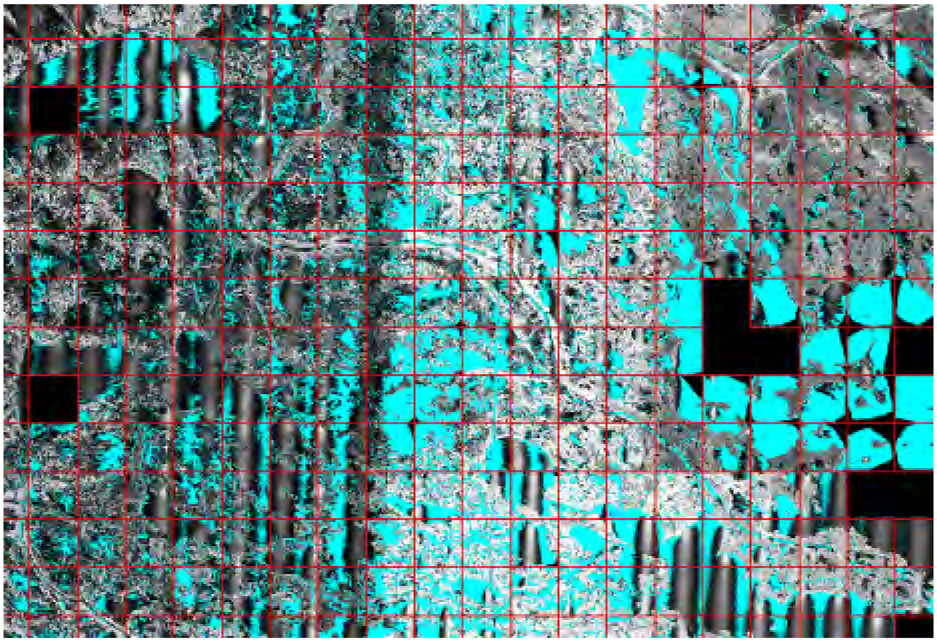

Figure 3 - Intensity images generated from full point cloud data. All areas that are bright blue indicate that there are no points in those areas because it is water. Large areas of water with no point returns will decrease the number of points per tile.

2.4 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%

Dewberry analysts performed a visual inspection of 100% of the bare earth data digital terrain model (DTM). 100% of the data was looked at the micro and macro levels. The DTMs 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.

In the 1st qualitative review of the LiDAR, Dewberry identified numerous issues that need to be addressed by Woolpert before the data should be accepted. These included numerous misclassification issues, several vegetation artifacts, areas of inconsistent editing, several flight line ridges, and a few, minor data voids caused by an intensity issue as well as missing LAS tiles not provided in the first delivery. All calls updated to include the status of the call for each delivery will be provided to the USGS and Woolpert in a GDB and shapefile format. The table below summarizes the calls (Table 3) both in the original delivery and in the second delivery. The amount of errors was greatly reduced by Woolpert. The remaining errors are not numerous enough to significantly degrade the ground model or DEMs, and therefore are not being recommended for further corrections.

Table 3 - LiDAR Visual QA Calls

Issue	Number of Occurrences	Issues left in Second Delivery
Misclassifications	511	6
Artifacts	53	2
Data Voids	7	6
Inconsistent Editing	36	1
Missing LAS Tiles	74	0
Flight Line Ridges	66	3
Total	747	18

2.4.1 Misclassification - Fixed

Misclassification calls in this document imply that LiDAR points are unclassified in the delivered dataset when they should be classified to ground. In other words, this call indicates that points that are unclassified (Class 1) should be moved to the ground (Class 2). One specific type of misclassification call is aggressive classification. This occurs when too many ground points are removed from the ground resulting in a loss of definition to the surface. This predominantly occurs along ridge tops or where there are significant changes in slope. Misclassification in the data was adequately corrected in the second delivery. Two examples of these calls and their corrections can be found below from Figure 4 to Figure 7.

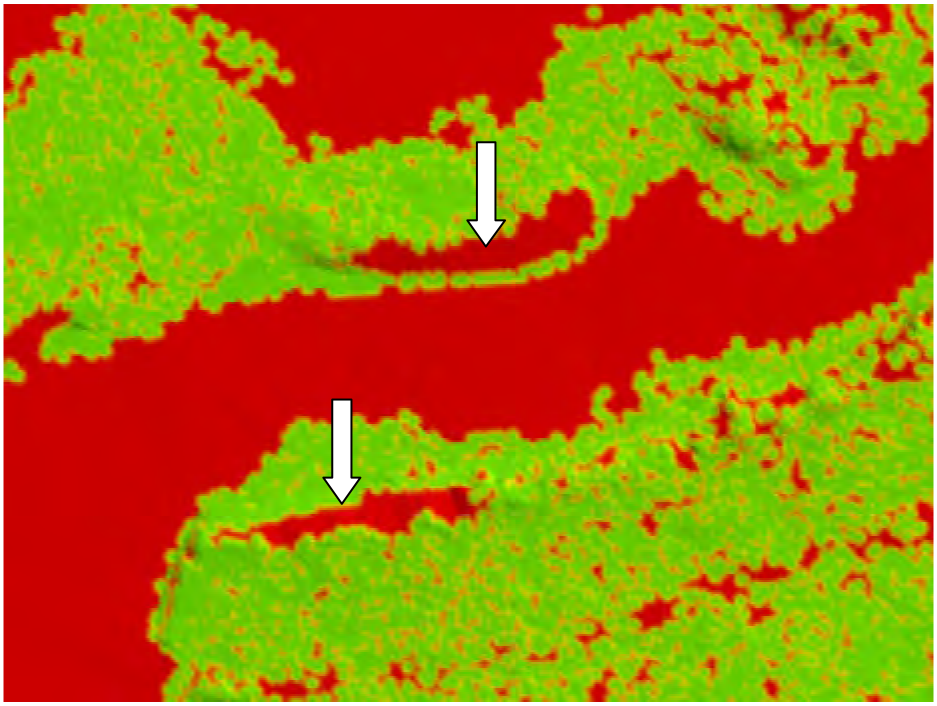

Figure 4 – 1st delivery. Ground density model of tile 16RBT715130 showing areas of red where points are removed from the ground model.

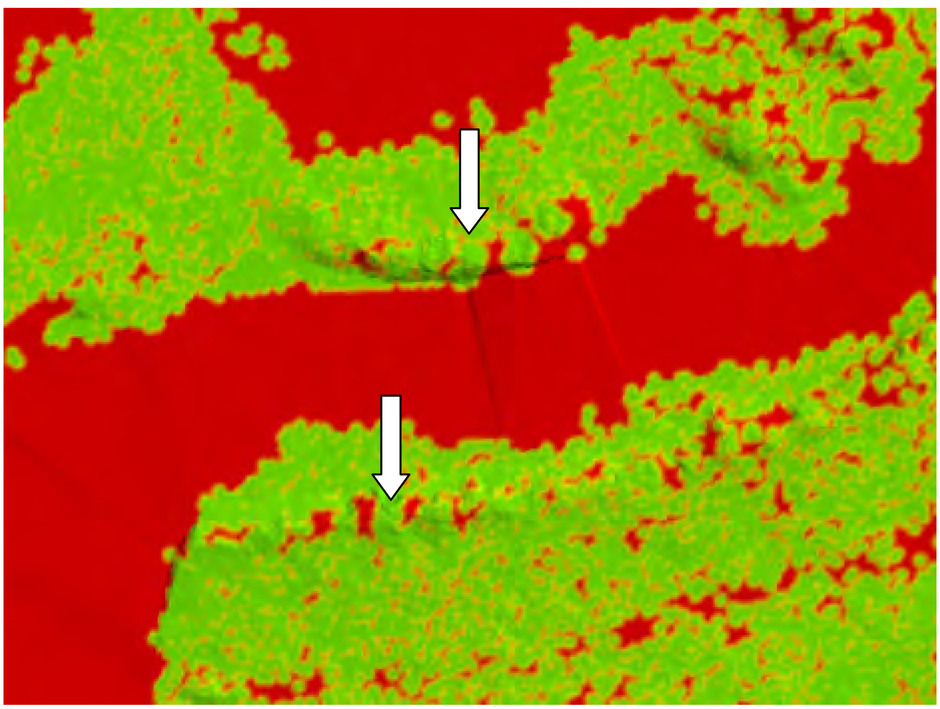

Figure 5 – 2nd delivery - corrected. Tile 16RBT715130, second delivery. As many ground points as possible were moved from unclassified into ground class. The ground density model displays significantly less red in the marked features and is a better depiction of the true ground surface.

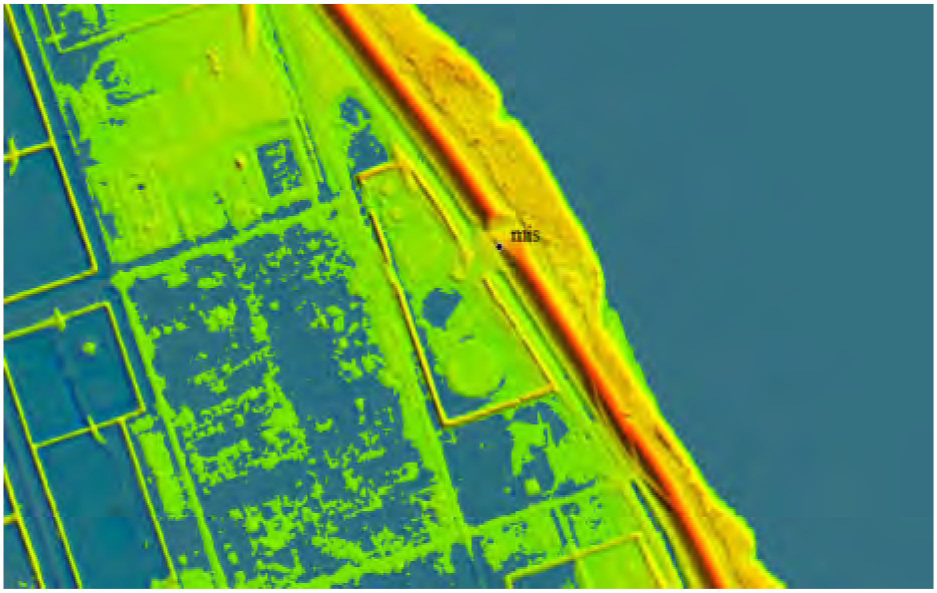

Figure 6 – 1st delivery. Ground elevation model DEM of tile 16RBT115865 showing an area that is misclassified (move Class1-unclassified to Class 2-ground).

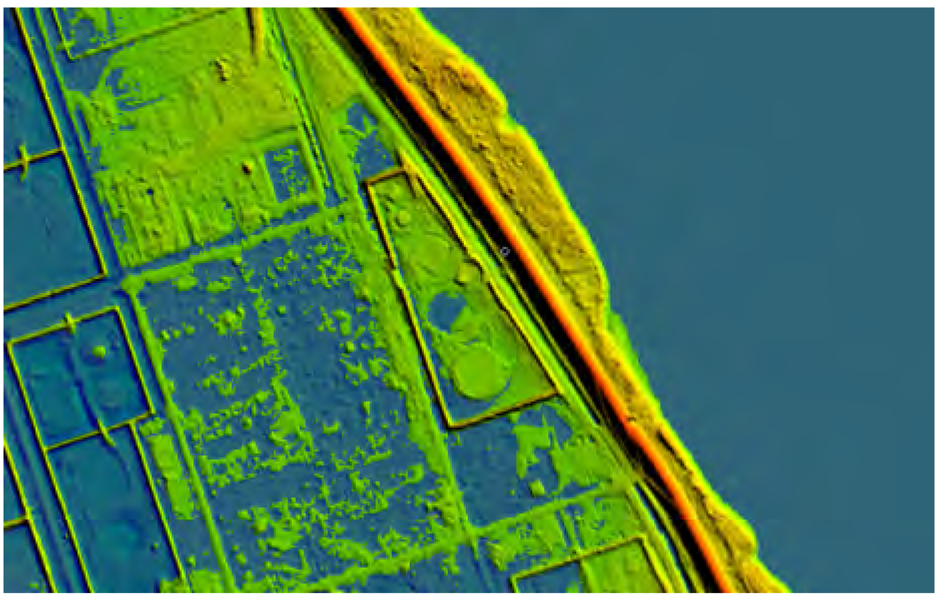

Figure 7 – 2nd delivery - corrected. Digital elevation model of tile 16RBT115865, second delivery. Missed ground points have been correctly classified for the second delivery. The feature no longer breaks at the point of the marker.

2.4.2 Artifacts - Fixed

Artifacts are features that are left in the ground model that should be removed. A few vegetation artifacts that were found in the project area where found in the original delivery and were corrected for the second delivery. Examples can be found below from Figure 8 to Figure 11.

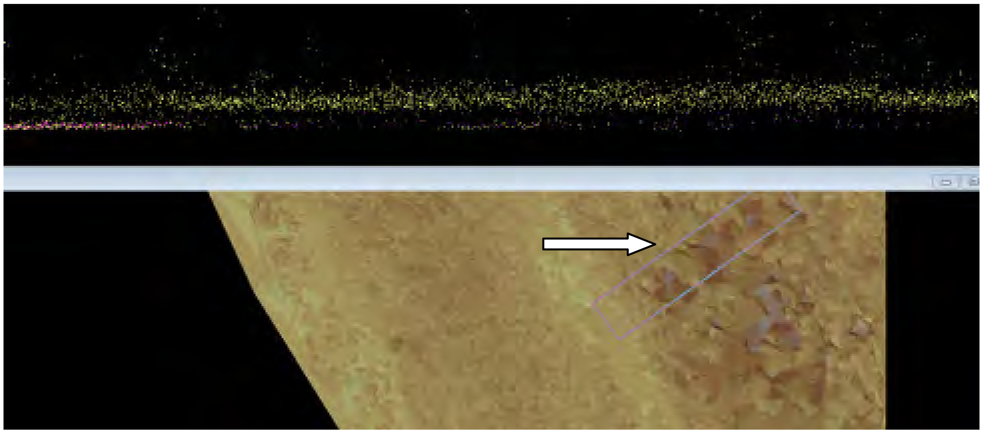

Figure 8 –1st delivery. Full point cloud of tile 16RBT115940.las showing a vegetation artifact that is left in the ground model.

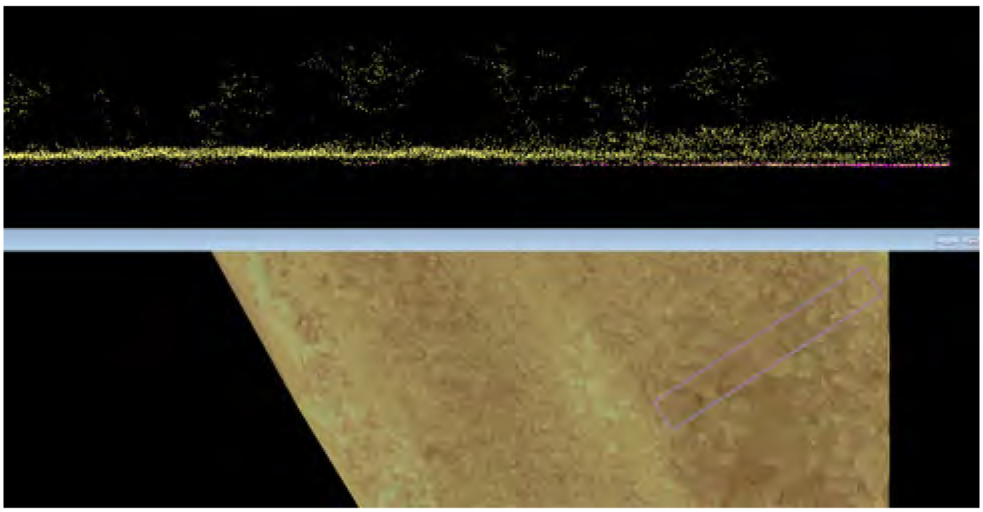

Figure 9 – 2nd delivery - corrected. LAS tile 16RBT115940, second delivery. Vegetation artifacts in the area of the profile have been removed. Ground points, shown in purple in the cross section, now contain only those points low enough to be considered ground. The ground model appears smoother.

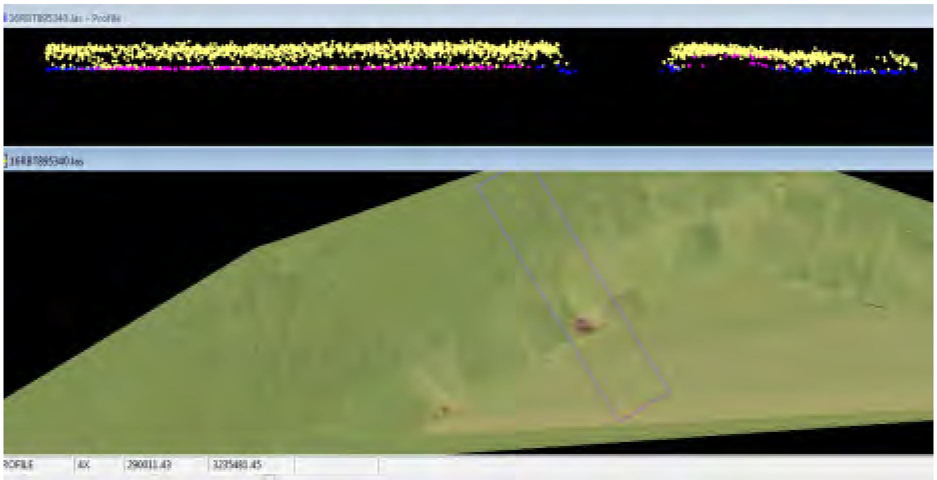

Figure 10 – 1st delivery. Full point cloud of tile 16RBT895340.las showing a vegetation artifact that is left in the ground model.

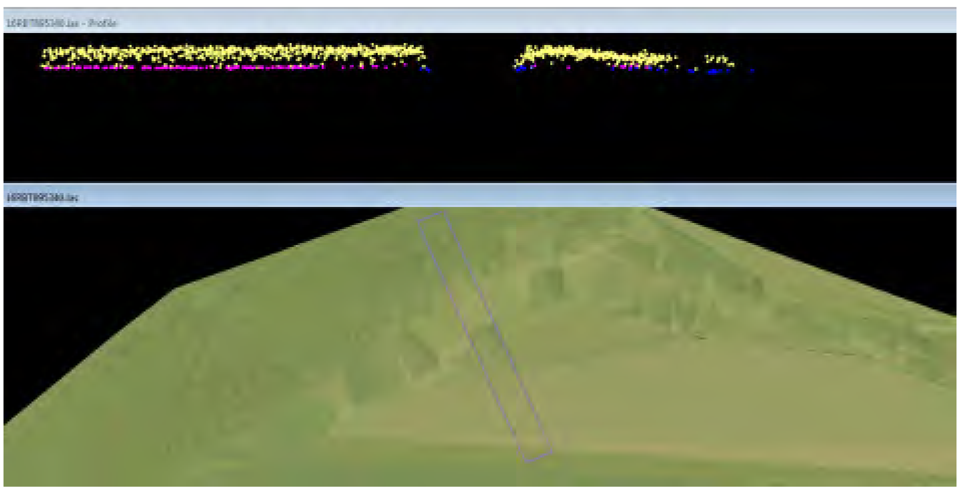

Figure 11 – 2nd delivery - corrected. Full point cloud LAS tile 16RBT895340. The vegetation artifact has been removed. No ground points (purple) are seen to be misclassified in the profile.

2.4.3 Data Voids

Data voids were identified in two areas resulting in 7 original calls. The voids seem to be related to areas where the intensity values are very dark (Figure 13). This error involves an anomaly with the LiDAR collection process. As seen in Figure 14 (the full LAS point cloud) no points were collected in the void areas. It would be costly and inefficient to fully correct for the void areas as the location would most likely need to be re-flown. Woolpert was unable to further correct the pictured tile below in the second delivery. However, Dewberry feels that because the voids are not widespread and are not of concerning size, they do not significantly impact the ground model. The void areas should be noted by the user but do not jeopardize the ground model or other LiDAR products.

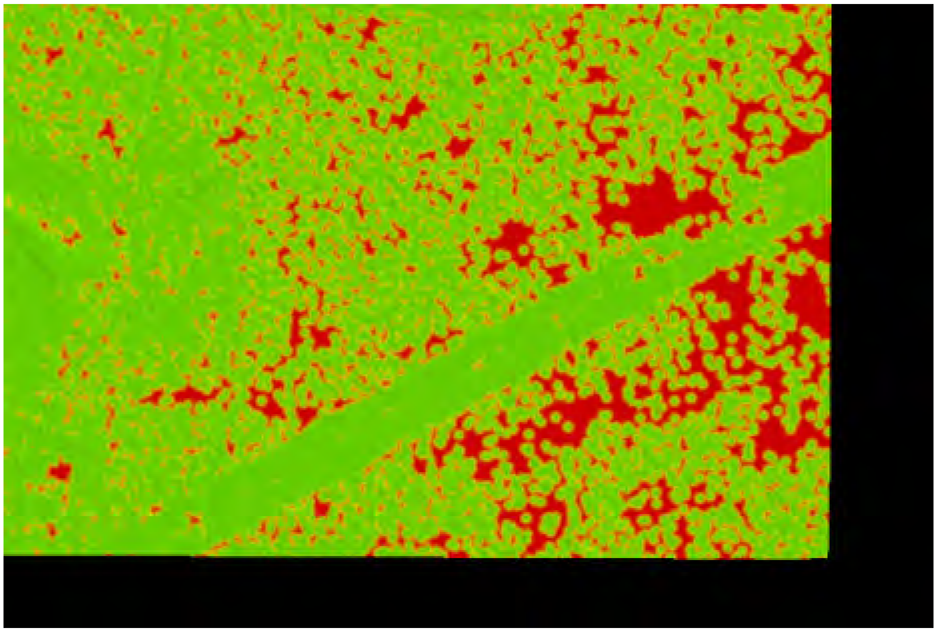

Figure 12 - Ground density model of tile 16RBU550480. The areas of red in this tile are data voids.

Figure 13 – Full point cloud intensity image of exact same area as image above. As evident, these voids are most likely related to the intensity which is too dark to make out the ground features.

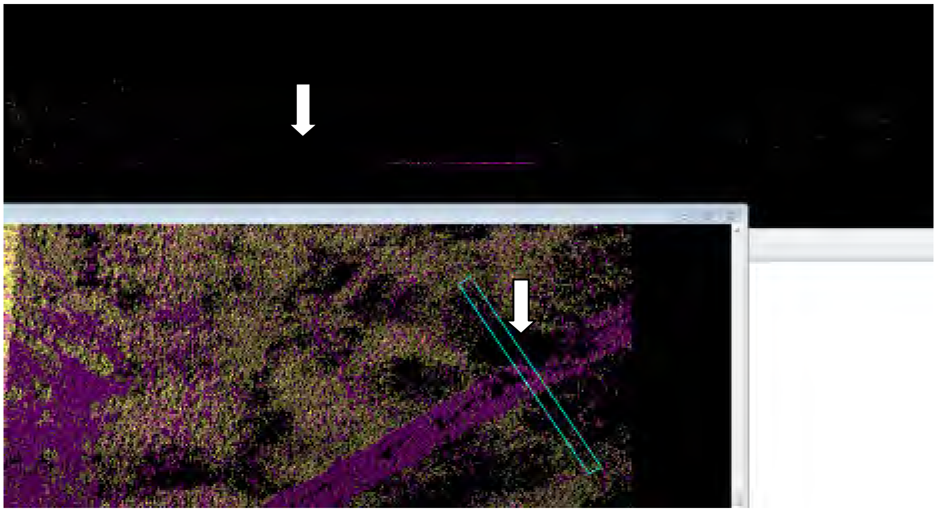

Figure 14 - Full point cloud image of tile 16RBU550480 colored by classification. The profile and map view both show the data voids.

2.4.4 Inconsistent Editing - Fixed

Inconsistent editing occurs only along boundaries between tiles. In these areas, the same automated-classification routine was not applied consistently to the same feature or different LiDAR classification analysts interpreted the feature differently (Figure 15 and Figure 16). Calls were placed on the tile that required editing. These issues were addressed in the 2nd delivery.

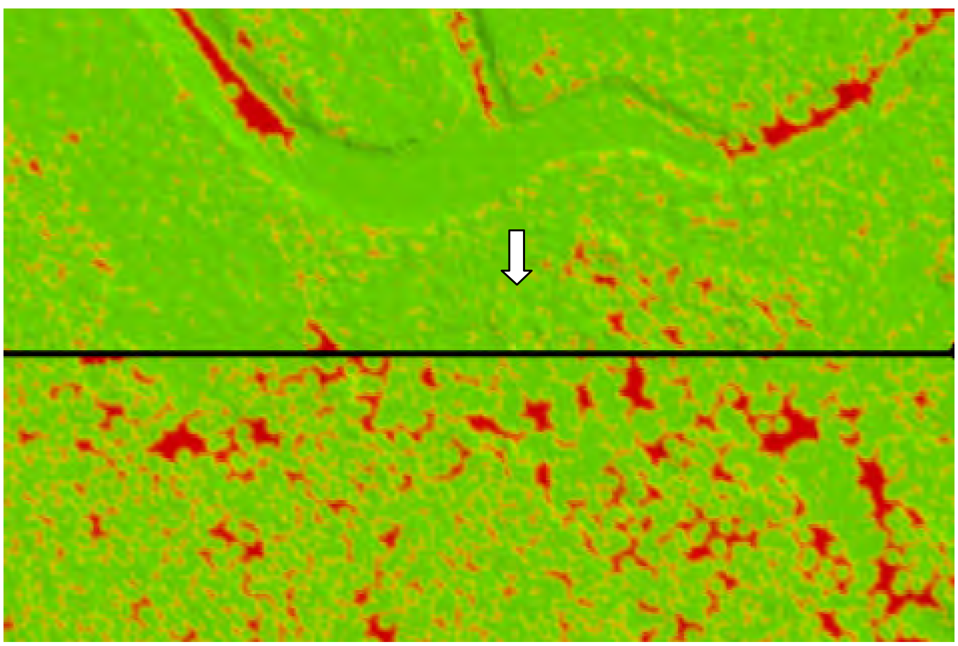

Figure 15 – 1st delivery. Ground density model of tiles 16RBT775265 and 16RBT775280 showing inconsistent editing between tiles. The tile on the right is more aggressively classified that the tile on the left.

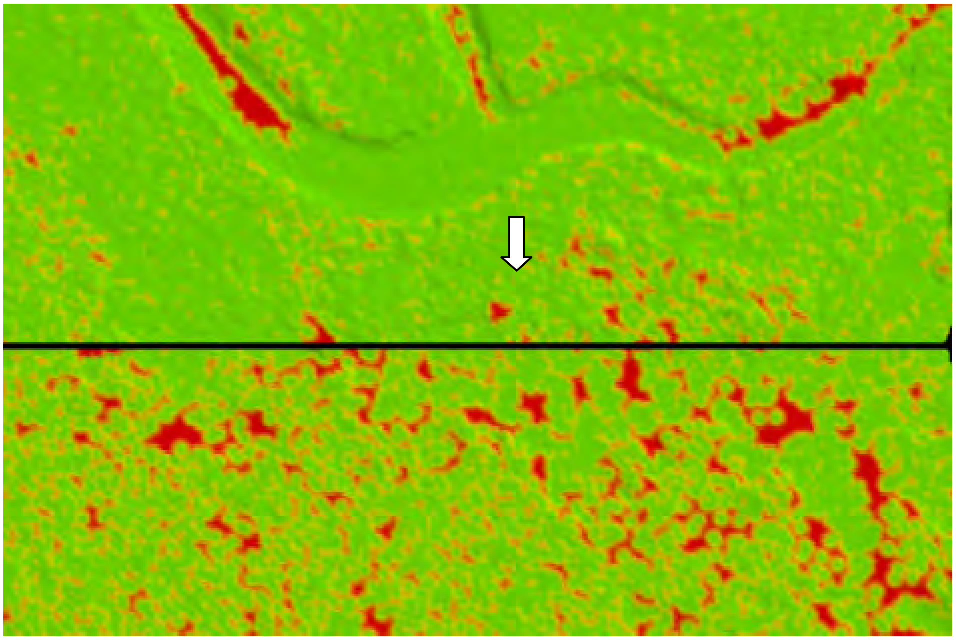

Figure 16 – 2nd delivery - corrected. Ground density model of tiles 16RBT775265 and 16RBT775280, second delivery. A moderate amount of artifact points were removed from the area shown by the arrow making the tiles more consistent.

2.4.5 Missing Tiles - Fixed

The data delivered to Dewberry in the first delivery appeared to be missing 74 tiles. Dewberry assumes all these tiles were not delivered because they Woolpert believed they contained no ground (i.e. are entirely water). Dewberry recommended that Woolpert send these tiles any subsequent deliveries so that Dewberry can confirm these tiles do not contain ground that is misclassified.

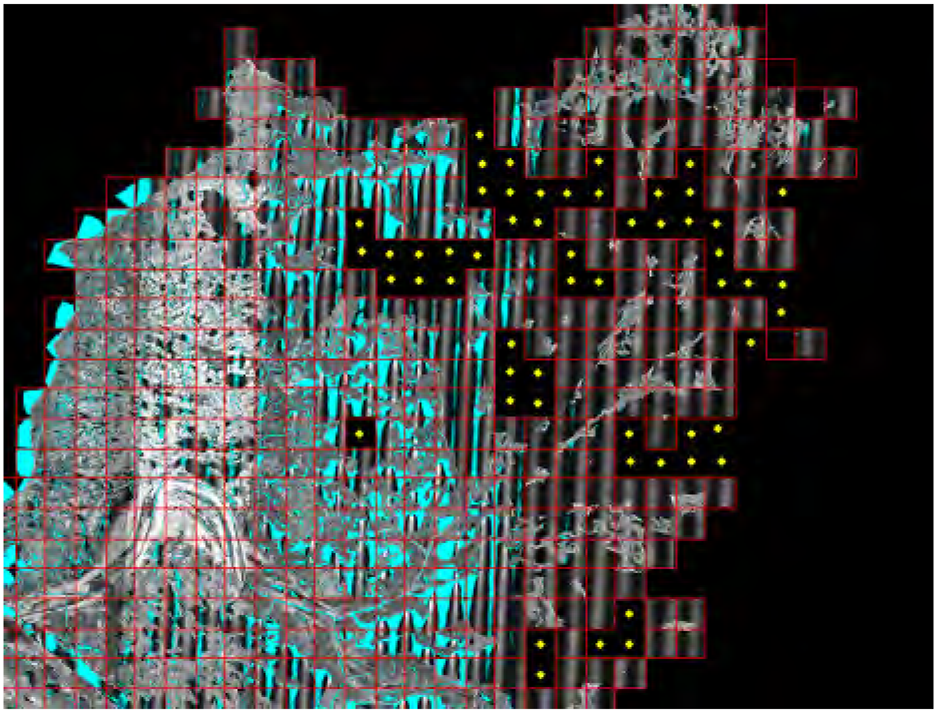

Figure 17 - Yellow dots show tiles that Dewberry recommends Woolpert deliver to ensure there is no ground.

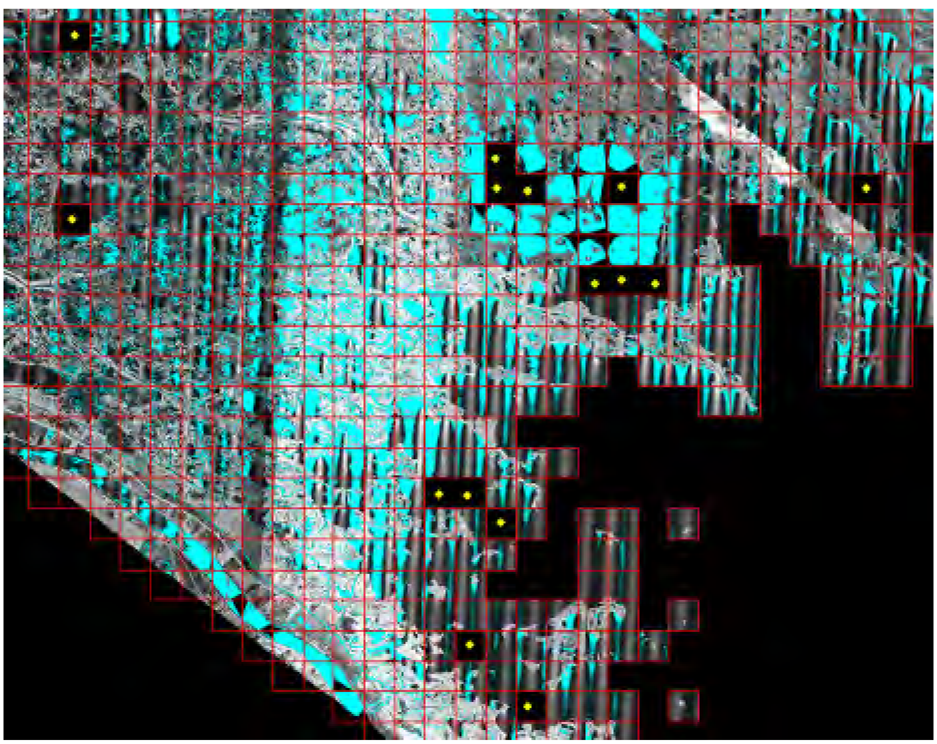

Figure 18 - Yellow dots show tiles that Dewberry recommends Woolpert deliver to ensure there is no ground.

Dewberry received the 74 additional LAS tiles and reviewed full point cloud models of each to assure no ground was overlooked. No ground which meets the requirements of being above zero elevation and greater than one half acre if an island was observed. It should be noted that significant amount of ground that is under the zero elevation does exists in a select few of the 74 tiles, particularly tiles 16RBT92310 and 16RBT535535.

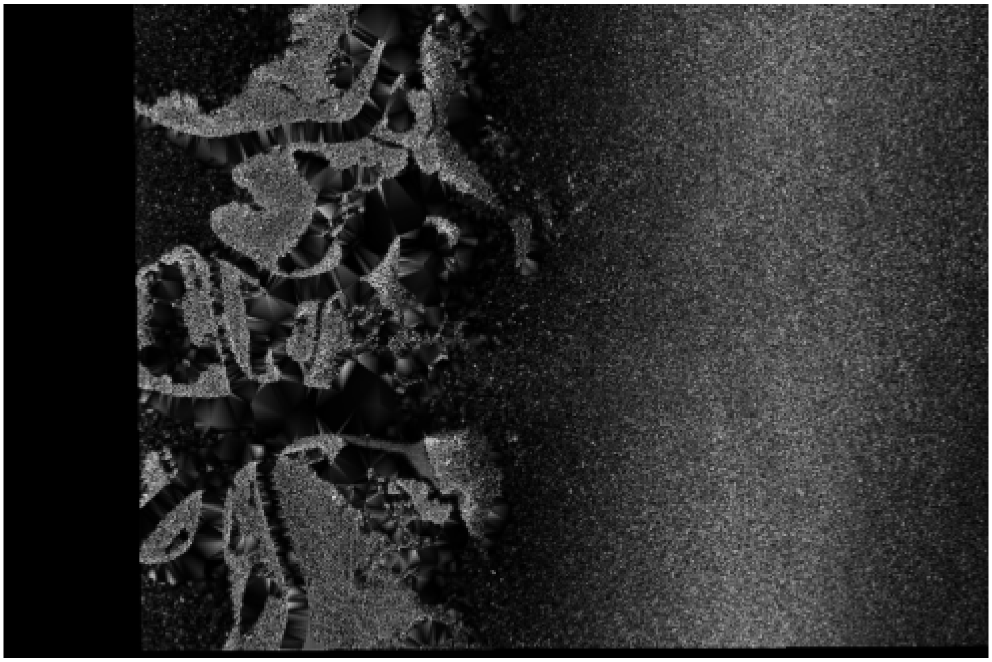

Figure 19 – Full point cloud model with LiDAR intensity values of tile 16RBT92310, second delivery. This tile was not included in the original delivery. Land clearly exists, however all the land seen above has an elevation that is below zero and is therefore not required to be classified as ground.

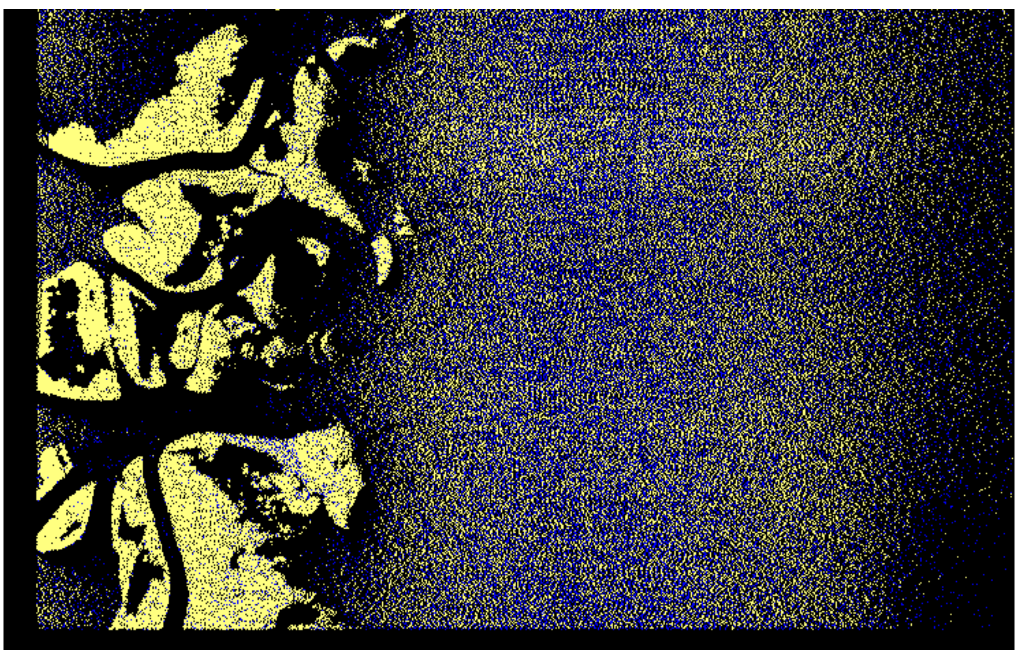

Figure 20 – LAS point cloud of tile 16RBT92310 colored by classification where blue is class 9, water, and yellow is class 1, unclassified. The below zero ground has been placed in class 1.

2.4.6 Flight Line Ridges - Fixed

Several flight line ridges were originally identified in the Louisiana Region 2 LiDAR dataset. The ridges are caused by a vertical mismatch between two adjacent flight lines. Elevation differences along adjoining flight lines range from 10 cm up to 50 cm. Figure 21 and Figure 22 show a flight line ridge before and after corrections. The scope of work indicates that the acceptable criterion for flightline ridges is 10 cm. Dewberry provided a polygon shapefile that delineates areas that exceed project specifications for flight line ridges. The majority of the flight line ridges were adequately corrected by Woolpert for the second delivery. Three flight line ridges ranging from 10 to 30 cm were not fully corrected and are still visible in ground models of tiles 16RBT340940, 16RBT445595 and 16RBU220045. While over the specification of 10 cm, these remaining ridges are localized and overall the data meets project specifications.

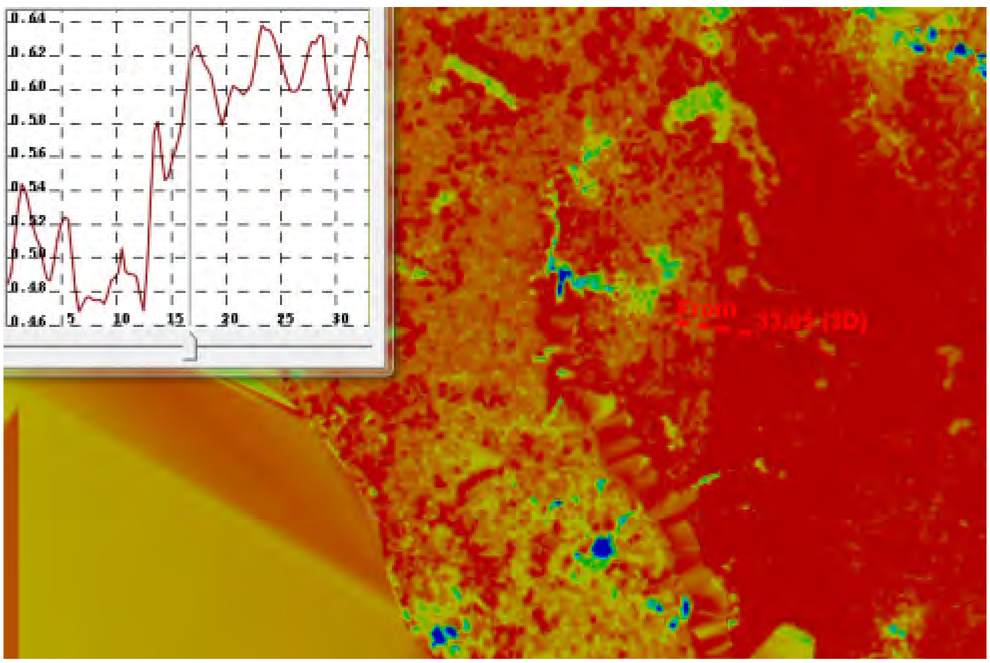

Figure 21- 1st delivery. Ground elevation model of tile 16RBT520940 showing a ~20 cm flight line ridge.

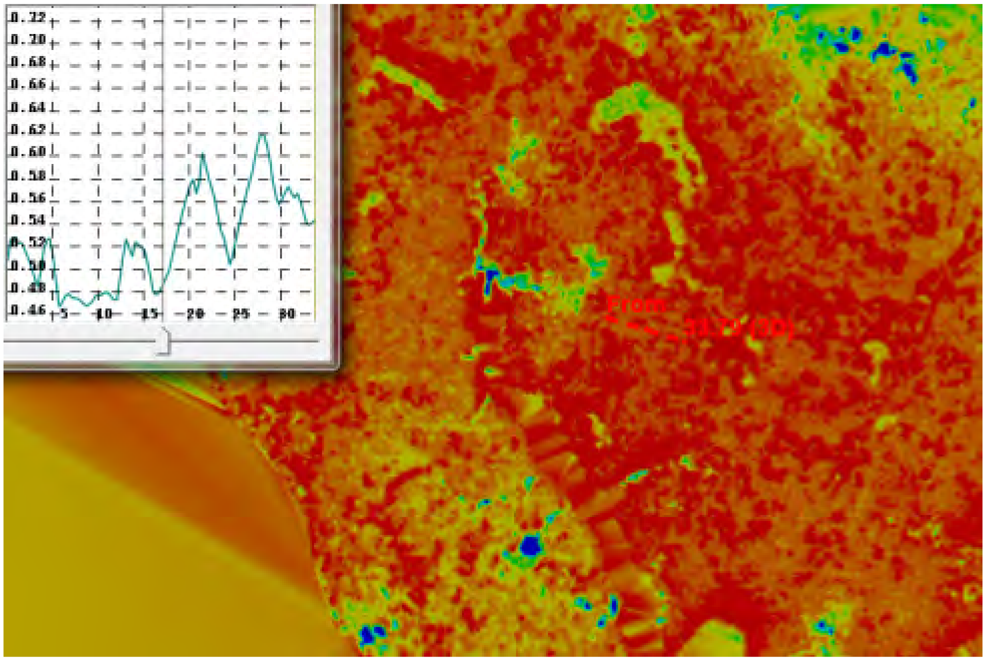

Figure 22 – 2nd delivery - corrected. Ground elevation model of tile 16RBT520940, second delivery. The flight line ridge has been corrected.

2.5 LiDAR Recommendation

Dewberry recommends that the USGS accept the second delivery LiDAR provided by Woolpert. A small number of issues remain however these are not great enough to warrant a third processing and review of the data and do not compromise the quality of the LiDAR as a whole.

3 Breakline Analysis

A qualitative/quantitative review was completed on the breaklines. The comprehensive qualitative review consisted of a visual review of the breaklines for completeness in compilation and horizontal placement as well as proper feature coding. This visual analysis was followed by several automated tests for hydro-enforcement and topology using ESRI PLTS tools and proprietary tools developed by Dewberry. The breakline review followed the Breakline QA/QC Checklist provided in the Quality Plan. Overall the breaklines are of good quality and, after the third review, should be accepted by the USGS.

3.1 Breakline Data Overview

The Woolpert breakline data was delivered as 14 shapefiles containing the following features:

1. Islands – Split into 6 shapefiles due to the large size of the data
2. Ponds and Lakes
3. Streams and Rivers
4. Tidal Waters – Split into 6 shapefiles due to the large size of the data.

This complies with project specifications.

The data is correctly projected horizontally and vertically:

- Horizontal Projection*: NAD_1983_UTM_Zone_16N*
- Vertical Datum: *NAVD88*
- Horizontal and Vertical Units: Meters and Meters

Lastly, all feature classes were verified to contain z-elevation values as specified by the data dictionary.

3.2 Breakline Completeness and Qualitative Review

The breakline completeness review includes ensuring all feature classes necessary are present, compiled accurately and has the correct extents. All feature classes were reviewed against intensity imagery Dewberry creates for its QC process. A review was performed on 100% of the data in an ESRI environment to validate data collection consistency and to validate all necessary features were collected.

3.2.1 Breakline Overview

Dewberry understands that these breaklines were compiled using automated methods. Woolpert and the USGS agreed that an elevation of zero (0) meters could be used to help delineate the placement of breaklines. Dewberry only called breakline issues on features that were above an elevation of zero meters.

During the completeness review, the quality of the collected breaklines is assessed. This includes validating the horizontal placement of breaklines as well as verifying the coding and attribution of breaklines. 67 issues were identified in the first delivery visual check. While most were corrected, 8 issues were found in the second breakline delivery. Examples of the types of issues found in the breakline visual QA can be found below. The table below summarizes the calls (Table 4):

Table 4: Breakline visual QA calls

Issue	Number of Occurrences	Issues Left in Second Delivery	Issues Left in Third Delivery
Area within 2 breaklines - streams/island	6	0	0
Breakline does not reach project bound	29	0	0
Breakline exists beyond project boundary.	3	0	0
Ground classified as water	1	0	0
Water body greater than 2 acres not captured	21	0	0
Water classified as ground	7	5	0
Total	67	5	0

3.2.2 Area within 2 breaklines – streams/islands - Fixed

In the first delivery, the islands breaklines were not clipped at the extent of the streams breakline. This issue was fixed in the second breakline delivery. An example of the error and its correction is below in Figure 23 and Figure 24.

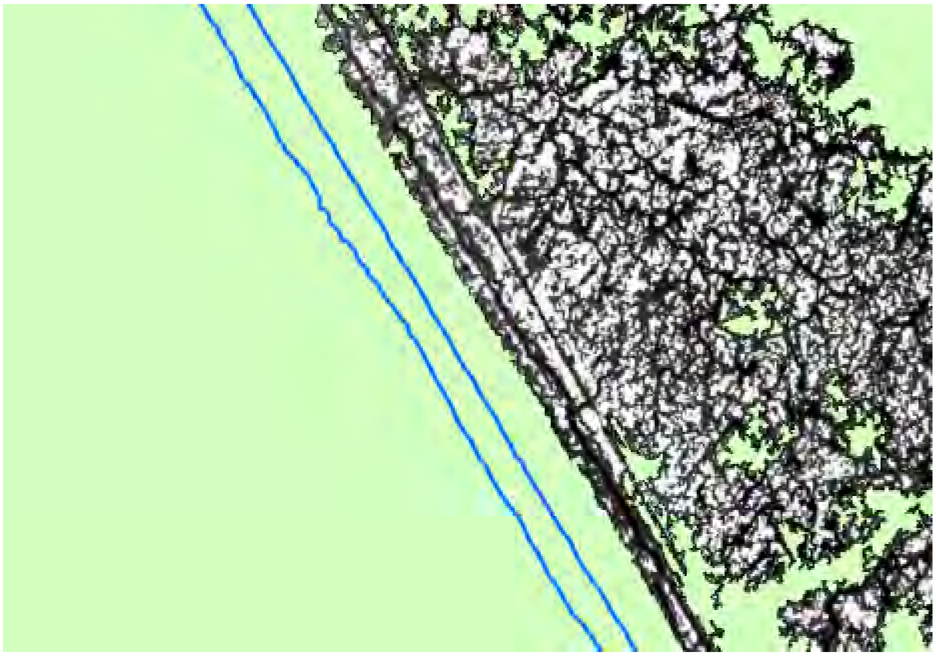

Figure 23 – 1st delivery. Full point cloud intensity image of tile 16RBU190135. The green area is the islands breakline and the two blue lines delineate a stream breakline. The islands should be clipped at the stream lines.

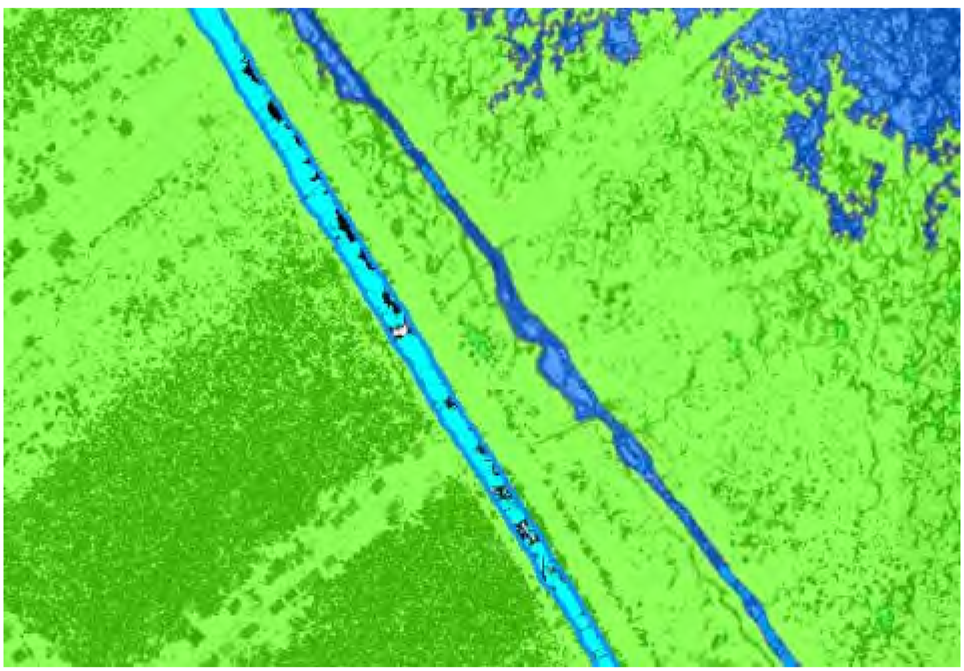

Figure 24- 2nd delivery - Corrected. Full point cloud intensity image of tile 16RBU190135 with the second delivery breaklines. The two blue lines delineate a stream breakline. The islands breakline has now been correctly clipped to the streams breakline.

3.2.3 Breakline does not reach project boundary - Fixed

In the first delivery, several areas where the breaklines do not extend to the project boundary were identified. (Figure 25 and Figure 27). These issues were addressed by Woolpert in the second delivery. Examples of the corrections made can be seen in Figure 26 and Figure 28.

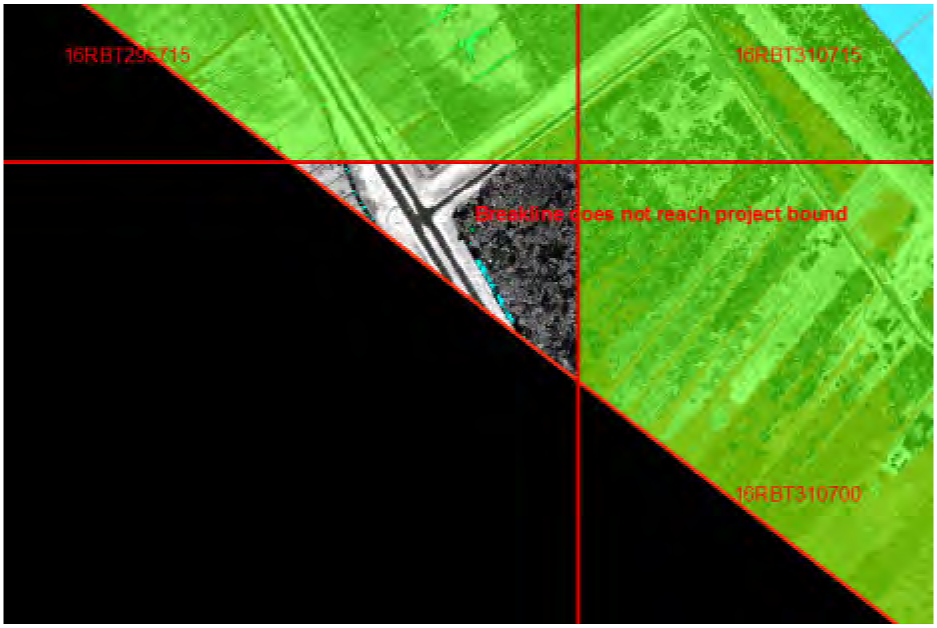

Figure 25 – 1st delivery. Full point cloud intensity image of a tile where the breaklines do not extend into. The green area is delineated as an island.

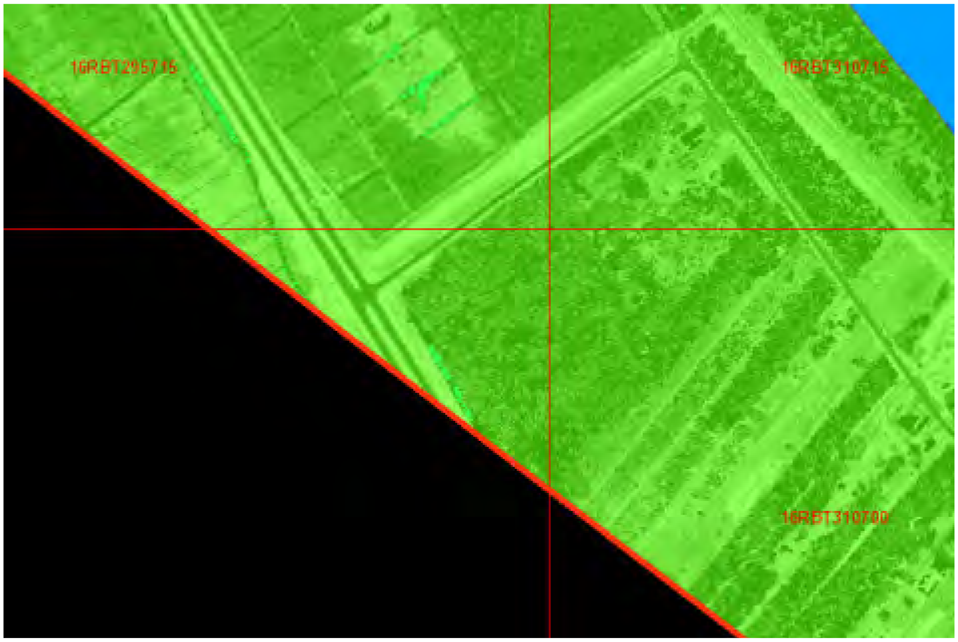

Figure 26 - 2nd delivery - Corrected. Full point cloud intensity of the same image as Figure 25 showing that the breaklines in the second delivery were extended to the project boundary.

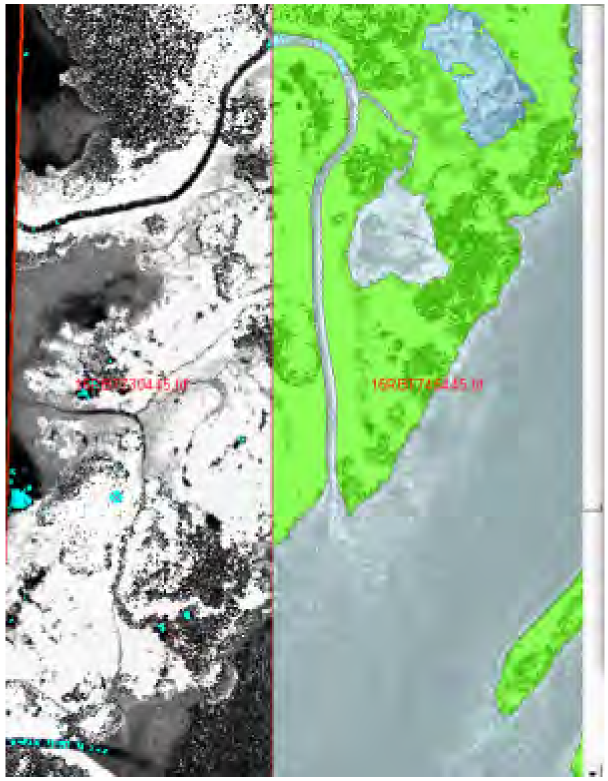

Figure 27 – 1st delivery. Full point cloud intensity image showing that breaklines do not extend into the tile on the left. The area in green are delineated as islands and the areas in blue are tidal waters.

Figure 28 – 2nd delivery - Corrected. Full point cloud intensity image showing that the breaklines in the second delivery have been corrected and now extend all the way to the project boundary.

3.2.4 Ground classified as water - Fixed

One serious issue was identified in the first delivery where ground points are classified to Class 9 (water). Issues with the data used to classify the points could cause ground, which was correctly identified during the breakline review, to be moved to Class 9. The issue and its correction in the second delivery are shown below.

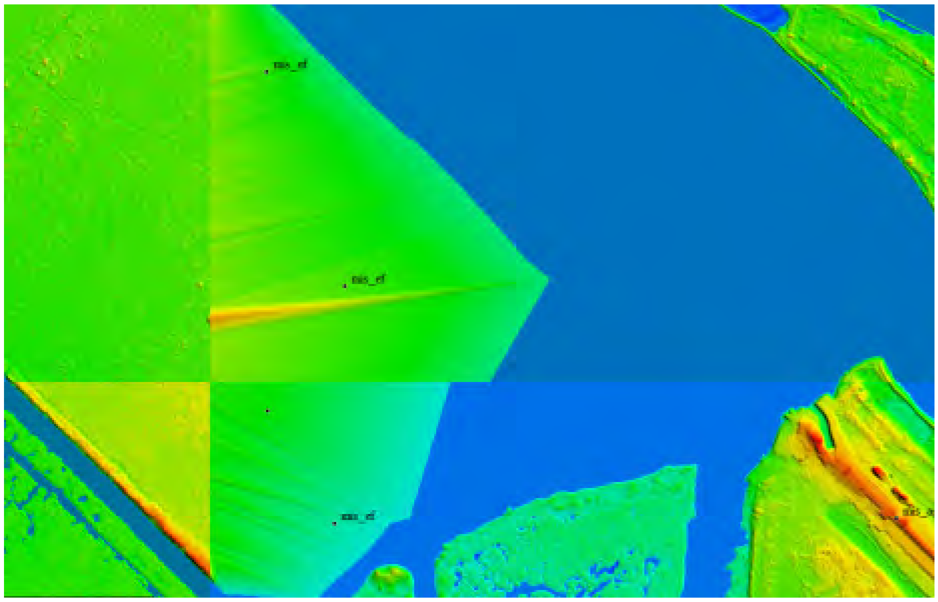

Figure 29 – 1st delivery. Ground elevation DEM of tiles 16RBU250150 and 16RBU250135 showing an area that contains no ground data. As evident below the points are classified as water when they are actually ground.

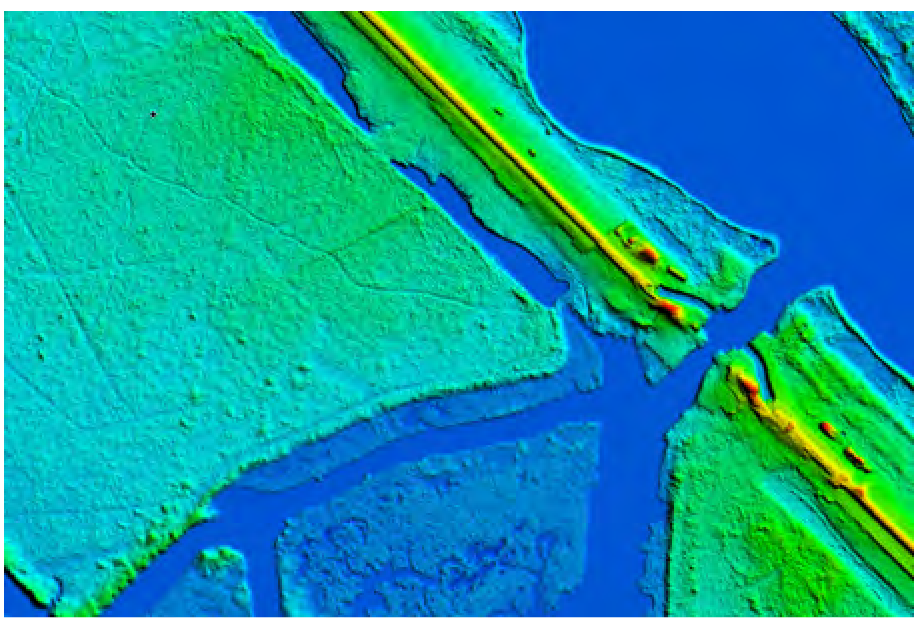

Figure 30 – 2nd delivery - Corrected. Ground elevation of DEM of tiles RBU250150 and RBU250135 showing that the ground has been correctly classified and added back to the ground model.

3.2.5 Water body greater than 2 acres not captured - Fixed

In the first review Dewberry identified 21 water bodies that are greater than 2 acres but not captured by the breaklines. During the second review all issues were addressed by Woolpert.

Figure 31 – 1st delivery. Full point cloud intensity image with tidal waters (blue) and islands (green) draped over showing a water body that was not captured.

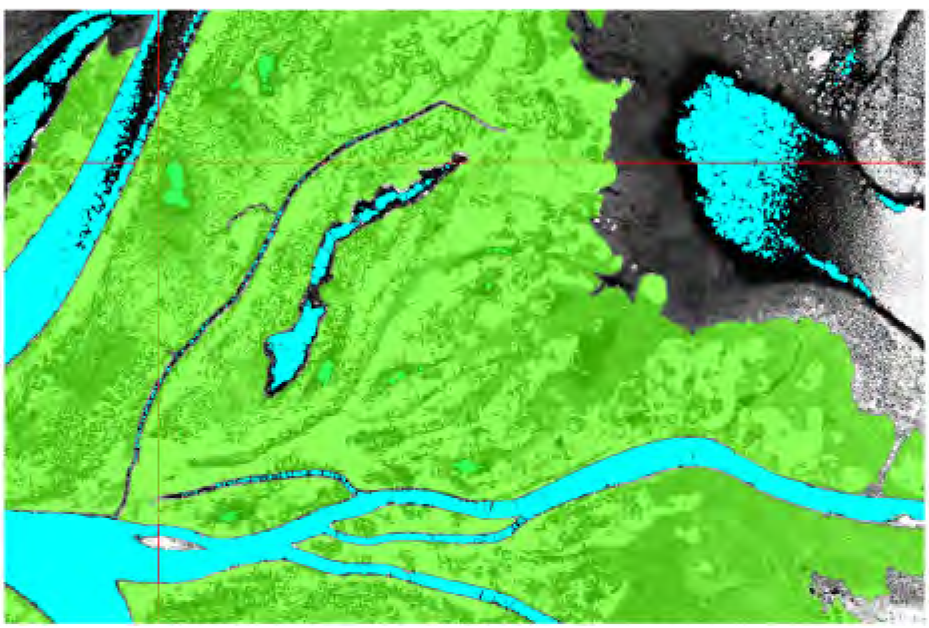

Figure 32 – 2nd delivery - Corrected. Full point cloud intensity image with tidal waters (blue) and islands (green) draped over showing a water body that not captured.

3.2.6 Water classified as ground - Fixed

Dewberry identified seven areas in the first delivery where the island breaklines delineated ground that was actually water. See below for an example of one of two errors that were resolved in the second delivery. Five issues remain in the data set, including areas where a very bright intensity return off water has been incorrectly captured as ground (Figure 35).

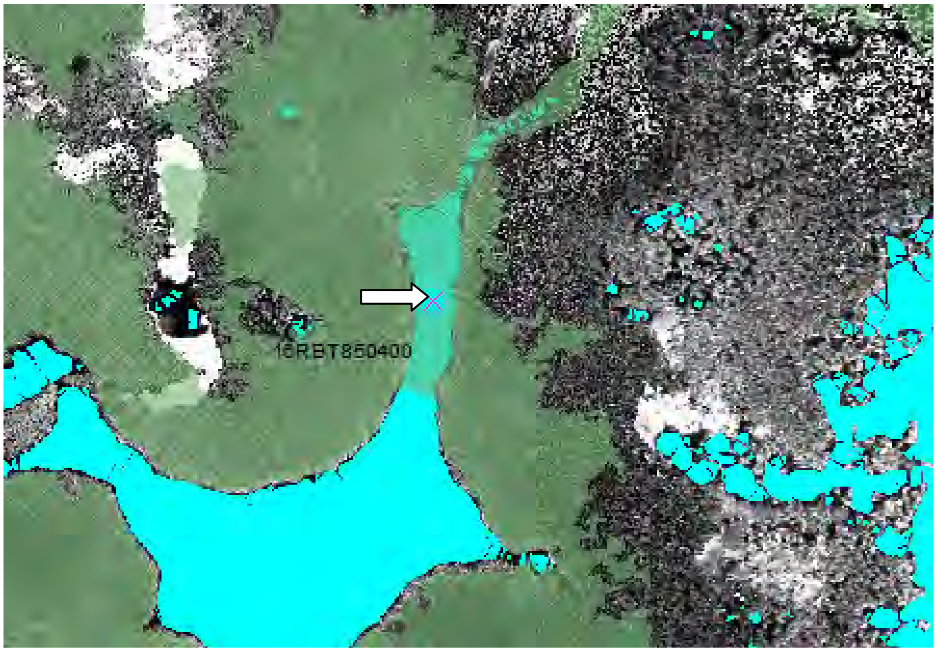

Figure 33 – 1st delivery. Full point cloud intensity image islands (green) draped over showing an area where water is classified as ground.

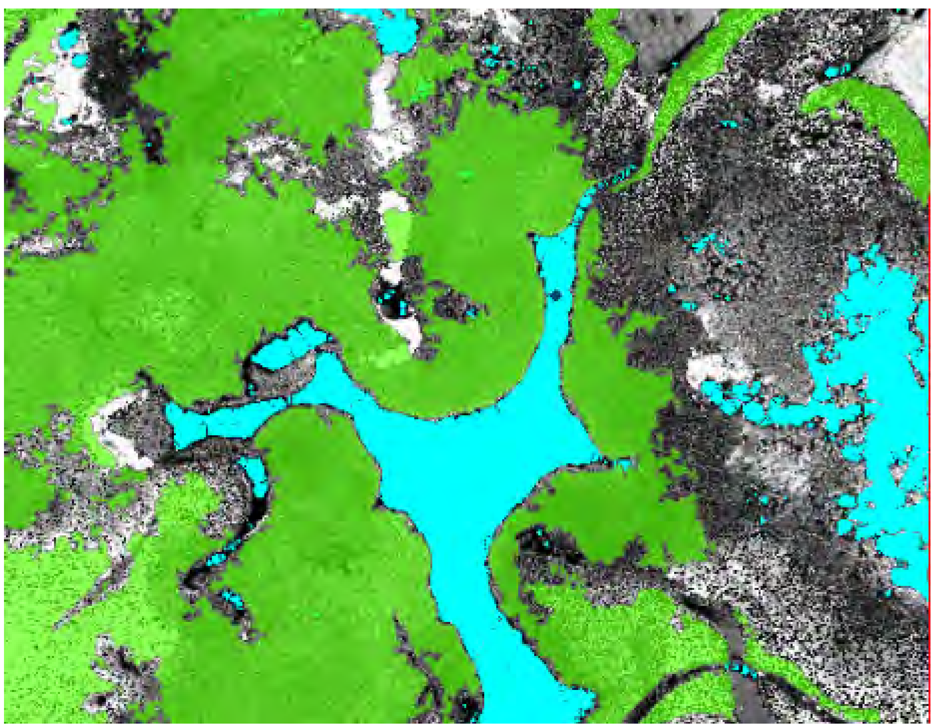

Figure 34- 2nd delivery - Corrected. Full point cloud intensity image shows that the islands (green) breakline has been adjusted to remove the water that was previous captured.

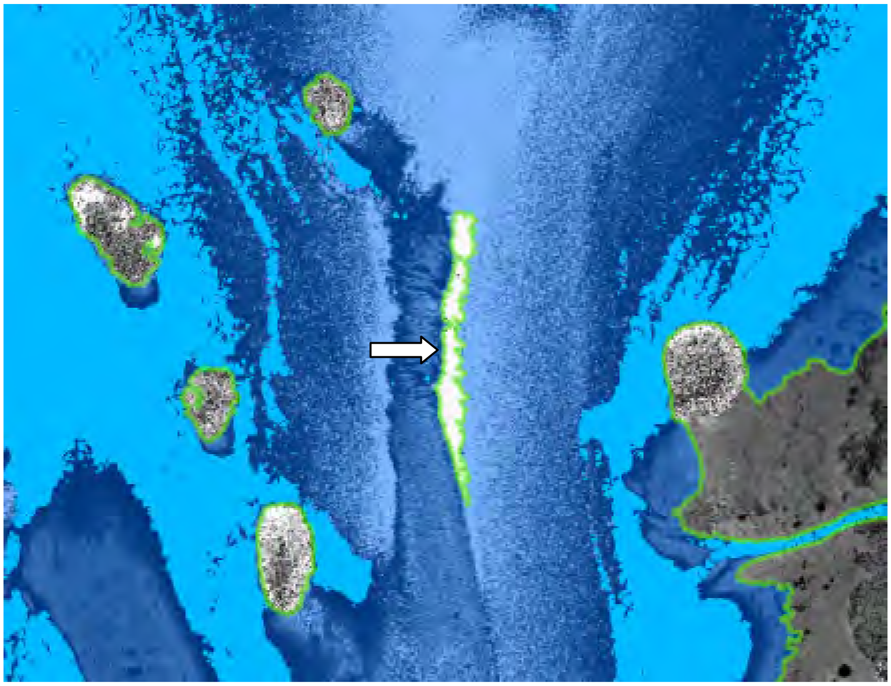

Figure 35 – Error Remains. Full point cloud for tile RBT790370, second delivery. A very bright return from in the LiDAR intensity has been incorrectly captured as an island. The island breakline indicated by the arrow should be removed and the area should be captured as water.

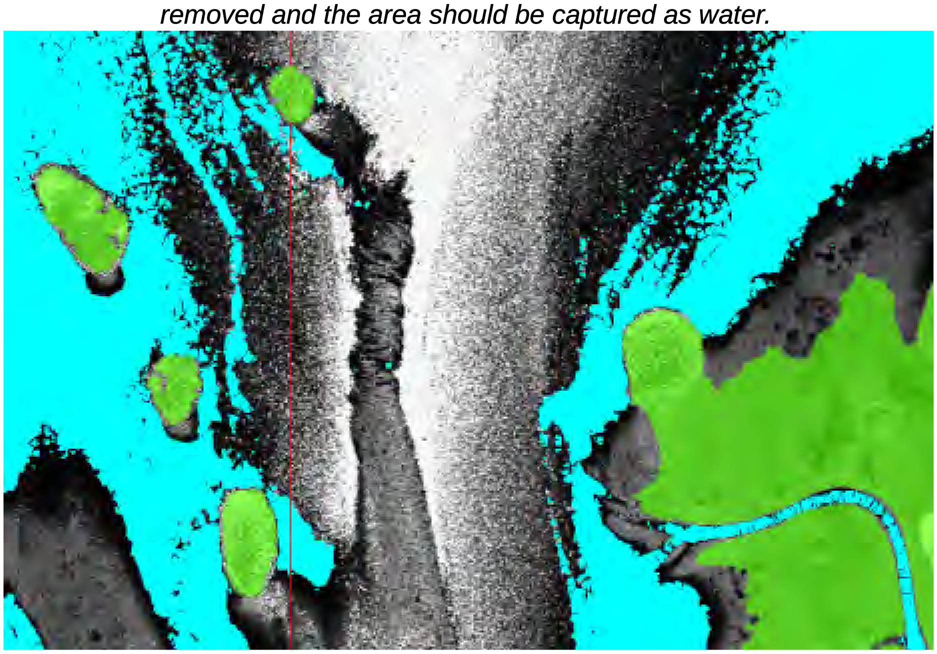

Figure 36 – Full point cloud for tile RBT790370, third delivery. The island breakline has been correctly removed and the area is now captured as water.

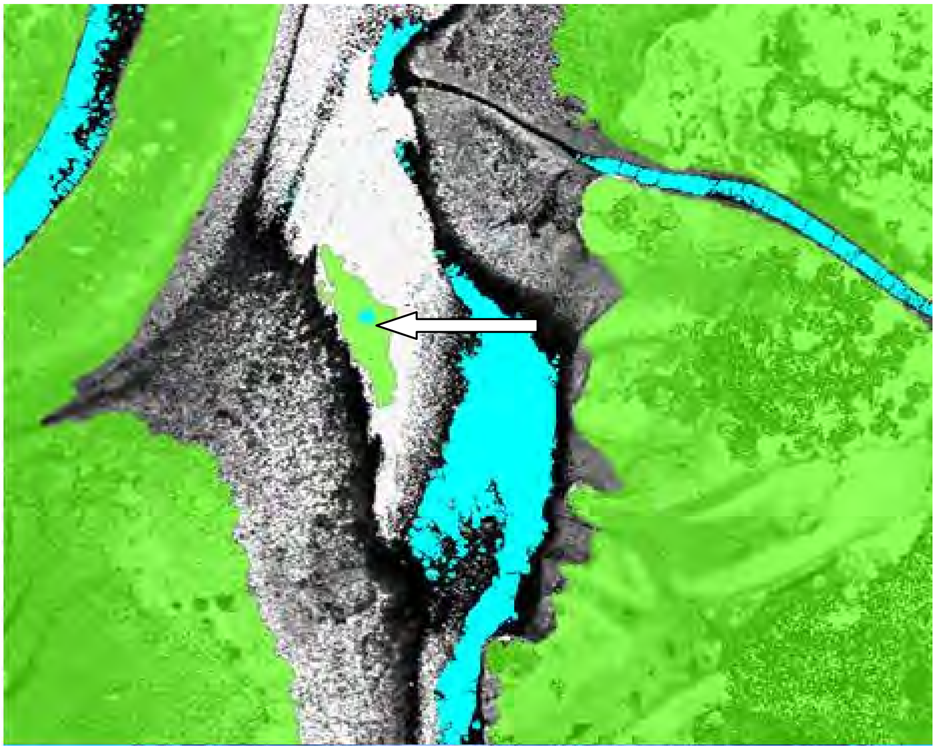

Figure 37 - Error Remains. Full point cloud for tile RBT820325, second delivery. Similar issue to image above. The island breaklines indicated by the arrow should be removed and the area should be captured as water.

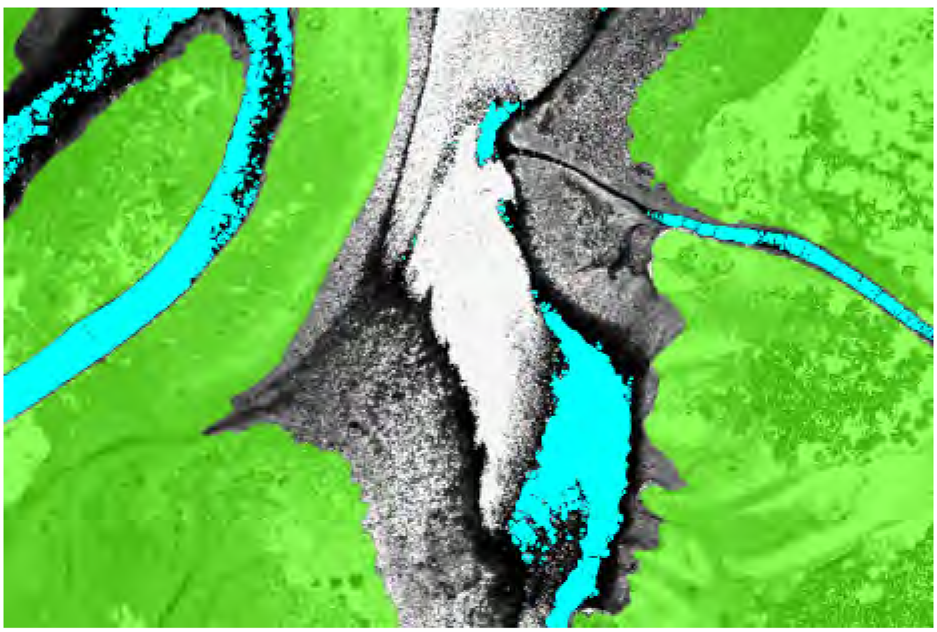

Figure 38 – Full point cloud for tile RBT820325, third delivery. Again the island breakline has been correctly removed and the area is now captured as water.

3.3 Breakline Quantitative Review

The Quantitative Vertical Analysis compares the island, streams, water bodies, and tidal waters 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.

Several vertices were discovered that float above the terrain surface. In the first delivery Dewberry reviewed and identified 30 water features that significantly float above the water. Of these 30 floating water bodies Dewberry identified 10 that were not corrected in the second delivery of the breaklines. Additionally, four new areas of floating water were detected. These issues may be caused by the predetermined “0” elevation for water body features. The land around these breaklines is lower than 0 meters causing raised water bodies in the area. Examples can be seen in Figure 39 to Figure 41. A point feature class will be provided that details where the vertices are that float. The previous digging water body was corrected in the second delivery (Figure 42 and Figure 43).

Woolpert responded to these floating water bodies in the 2nd delivery by writing, “Linework was automatically generated at the previously chosen "0" elevation. The data in this area was below 0, so it appears to float.” Dewberry discussed this issue with the USGS and because of the method used to collect breaklines it was determined that these floating areas would be acceptable in this delivery. The images below are provided to make the end-user aware of the issue.

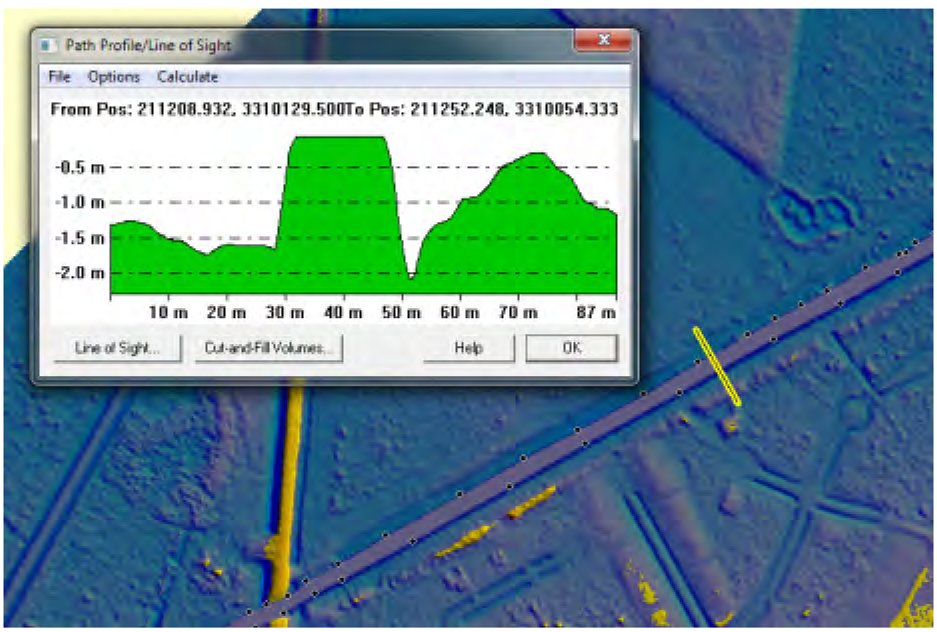

Figure 39 – Issue remains but no fix required. Ground elevation model of tile rbu100090 showing a floating water feature.

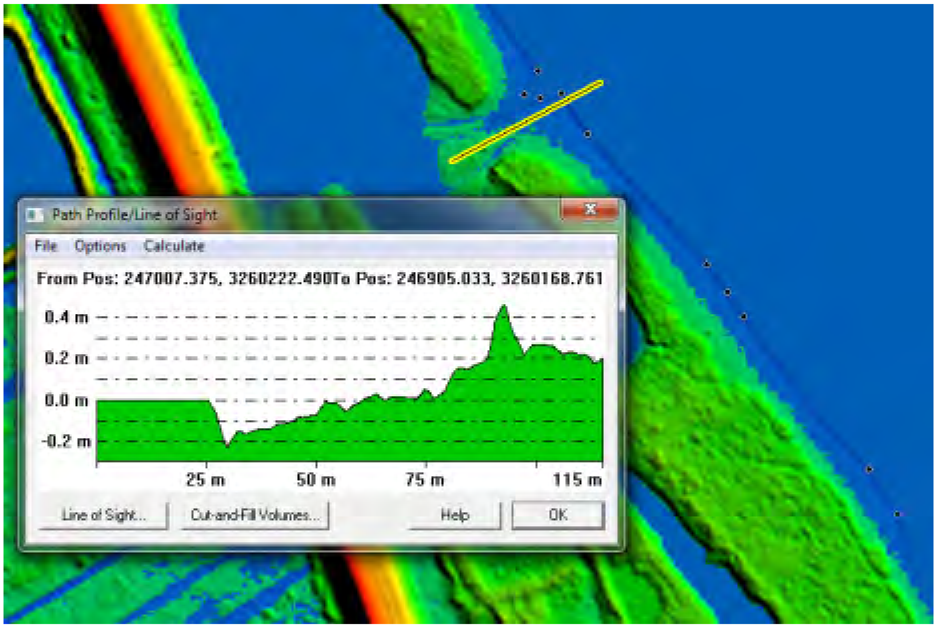

Figure 40 – Issue remains but no fix required. Ground elevation model of tile rbt475955 showing the tidal water breakline floats by ~22 cm.

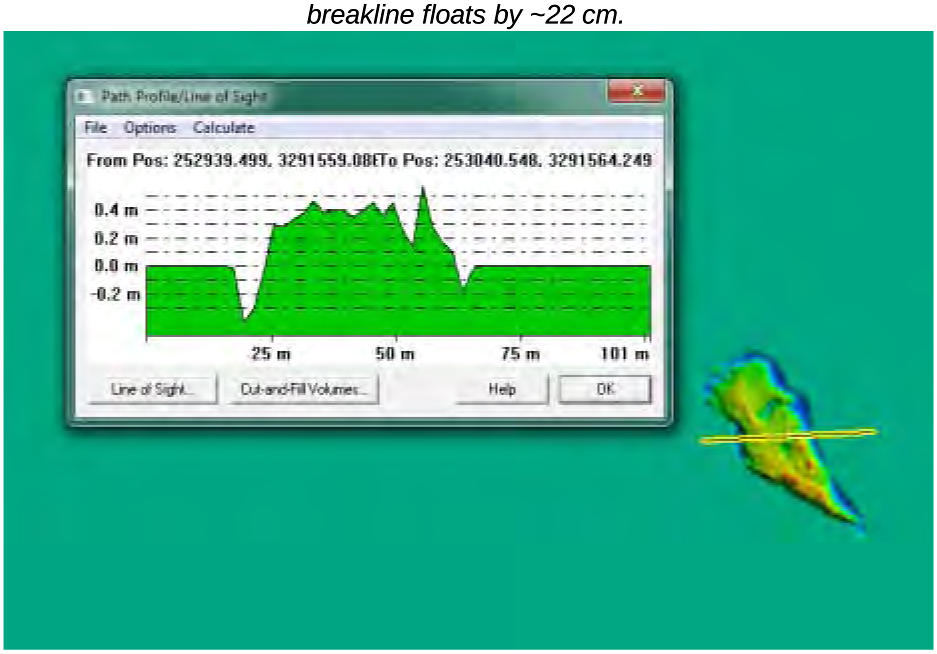

Figure 41 – Issue Remains but no fix required. Ground elevation model of tile rbt520910 showing that the tidal waters float by ~30cm around an island.

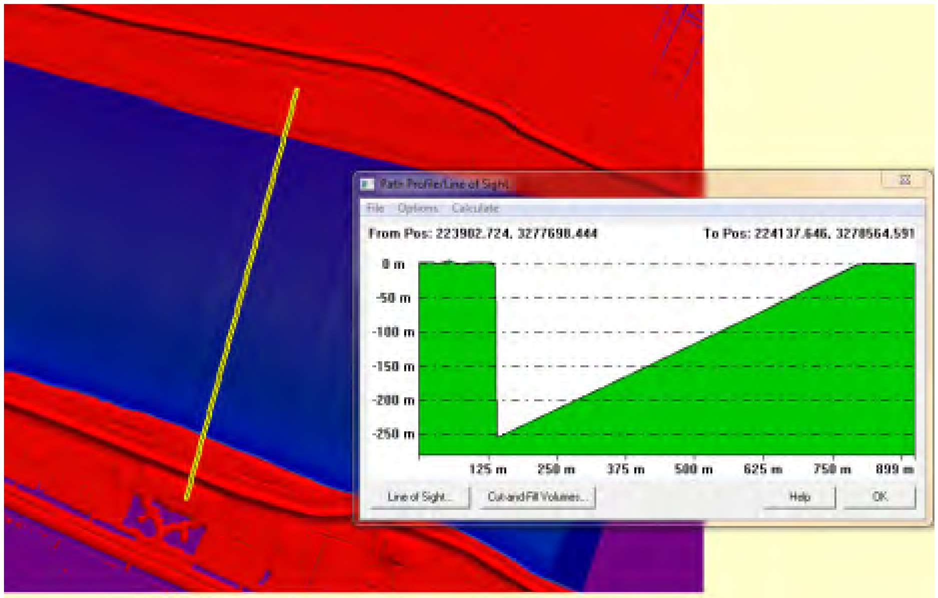

Figure 42 – 1st delivery. Ground elevation model of tile rbt235775, first delivery showing the water feature is digging by ~250m.

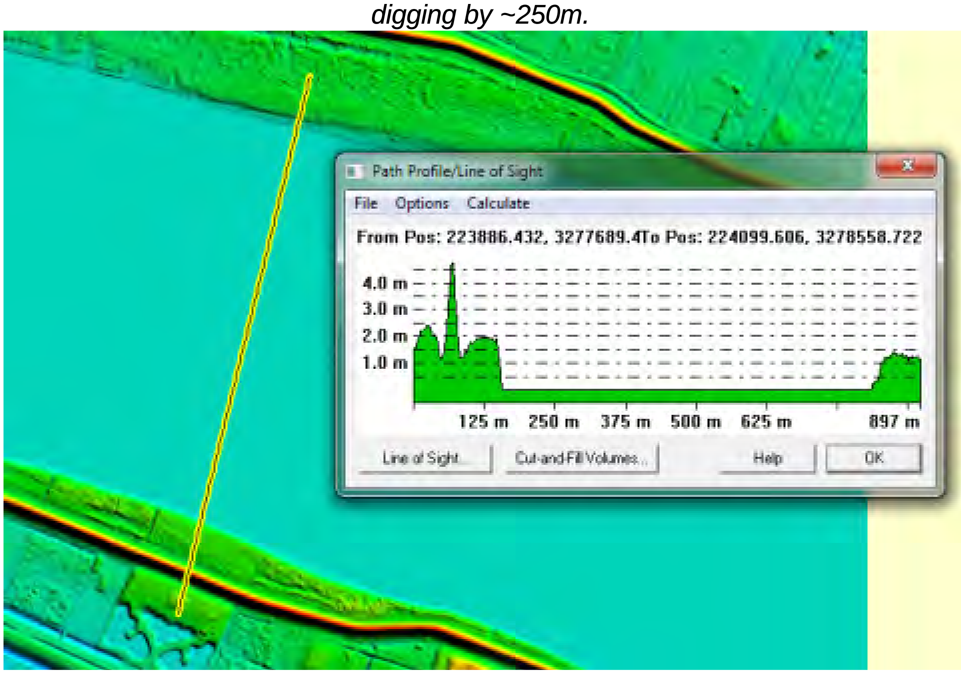

Figure 43 – 2nd delivery - Corrected. Ground elevation model of tile rbt235775, second delivery, showing that the digging water feature has been corrected in the second delivery.

3.4 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."

Due to the number of vertices contained with the tidal waters and islands shapefiles, Dewberry could not perform certain tests with the data as delivered. Dewberry performed a simplification process that removes vertices and allows <10cm shift in the delineation of the breaklines. Only tests where the data was compared to itself were performed using this modified data. Tests that compared one feature type to another were performed using the full data. The following issues were identified during the topology testing of the first delivery:

- Different Z-Value at intersection check – 1issue
- Features have duplicate geometry – 1 issue
- Geometry on Geometry - Tidal Waters_B to Islands_B – 13 issues
- Geometry on Geometry - Tidal Waters_C to Islands_C – 1 issue
- Geometry on Geometry - Tidal Waters_E to Islands_E – 7 issues
- Geometry on Geometry - Tidal Waters_E to Islands_E – 8 issues
- Vertices not identical – 9 issues

After reviewing the 2nd delivery breaklines, Dewberry confirms that all of these topology errors have corrected by Woolpert.

3.5 Breakline Recommendation

Woolpert has addressed all issues raised during the review. The floating water issue will be accepted due to the method used to collect the breaklines. Dewberry recommends that the USGS accept the breaklines delivered by Woolpert.

4 Hydro-enforced Digital Elevation Model Analysis

Dewberry received hydro-enforced bare earth DEMs as part of the deliverables for the project area. The DEMs are in ESRI ArcGRID format and are 1500 meters by 1500 meters and are at a 2 meter resolution. The naming convention follows the same parameters as the LAS naming, but cuts off the "16" in front of the tile name and uses lower case rather than upper case letters (e.g. 15RBT085925 → rbt085925).

4.1 Missing DEM tiles - Fixed

The first delivery of DEMs was missing 27 tiles that had LAS data (in addition to the 74 tiles Dewberry recommended be delivered to ensure no ground was overlooked). All missing DEMs were delivered in the second delivery. There are now 1290 DEMs which is consistent with the number of LAS tiles for the project.

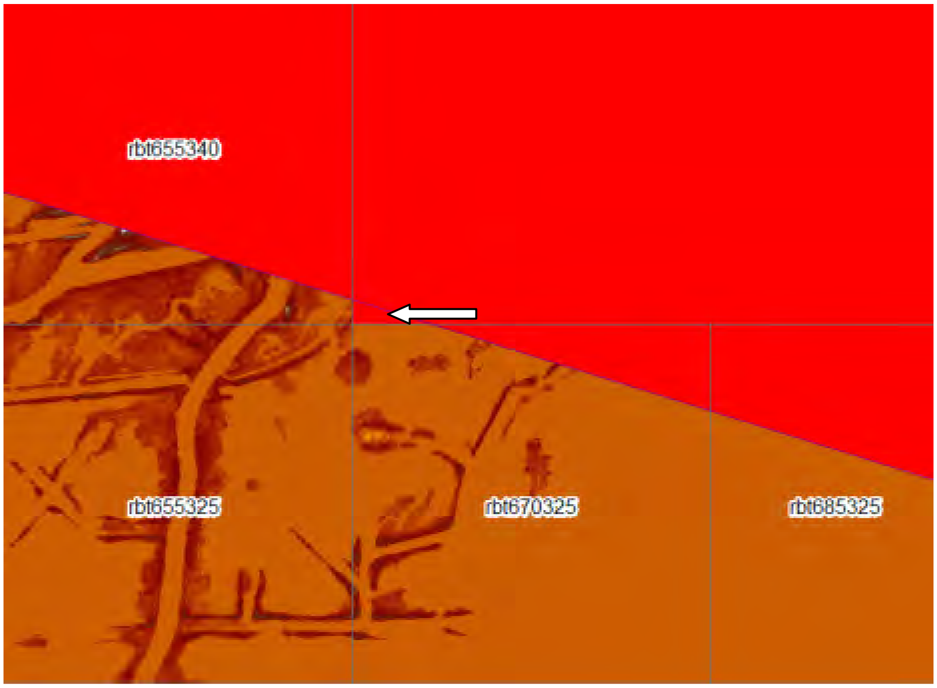

Figure 44 – 1st delivery. Example of missing DEM tile (white arrow). Dewberry received LAS data for this area.

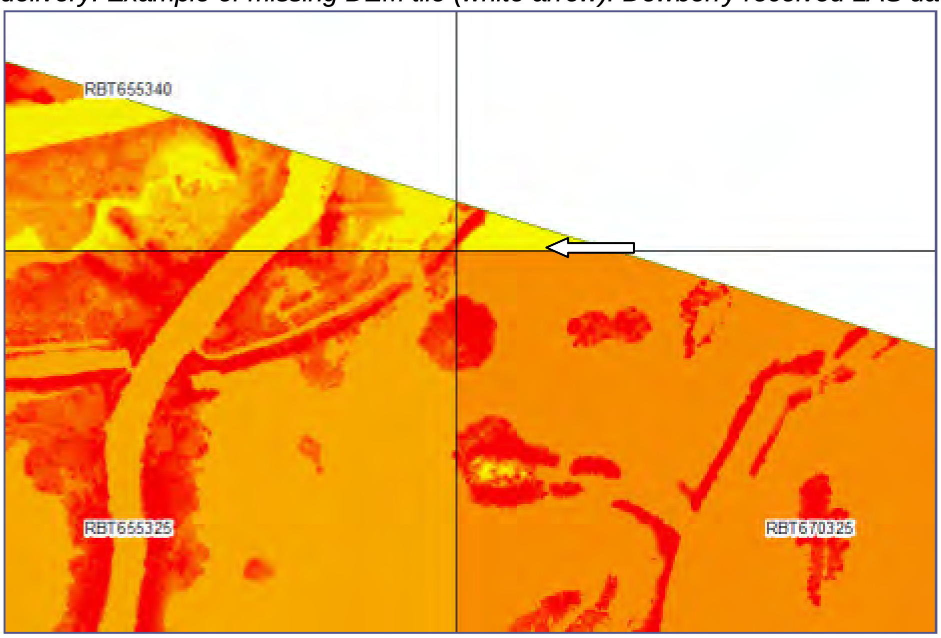

Figure 45- 2nd delivery - Corrected. The missing DEM was included in the second delivery.

4.2 Issues with DEM files - Fixed

The original DEMs that were delivered to Dewberry appeared to have extraneous files that were likely artifacts from deleted GRID files or created by issues during transfer. This was corrected in the second delivery.

4.3 Qualitative Review

Dewberry used a proprietary tool to validate the resolution and spatial projection on all DEMs. All DEMs have the correction resolution of 2 meters. All projection information was correct and is as follows:

- Projection: NAD 1983 UTM Zone 16N
- Horizontal and Vertical Units: Meters

Dewberry performed a visual analysis on each tile. Each tile was viewed in Global Mapper. Global Mapper colors the DEMs by elevation and creates an artificial Hillshade. This helps errors or anomalies to be identified. The aforementioned issues with the breaklines and LiDAR classification are visible in the DEMs. In addition to those issues, several instances of null pixels were found in the DEMs and some water issues were also identified. All of the issues have been corrected in the third delivery. The table below summarizes the calls (Table 5).

Table 5 - DEM calls

Issue	Number of Occurrences	Errors Remaining After Second Deliver	Errors Remaining After Third Delivery
Null pixels in DEMs	11	3	0
Water Issues	20	6	0
Missing DEM (mentioned above)	31	0	0
Total	62	9	0

4.3.1 Null Pixels in DEMs - Fixed

Dewberry also identified 11 tiles that have null pixels in the DEM that are not outside of the project boundary. Woolpert corrected all of these issues identified in the first delivery; however, Dewberry discovered 3 new DEMs with null pixels in the second delivery. Dewberry recommends these DEMs be reprocessed. Examples of the fixes and the new issues can be found below.

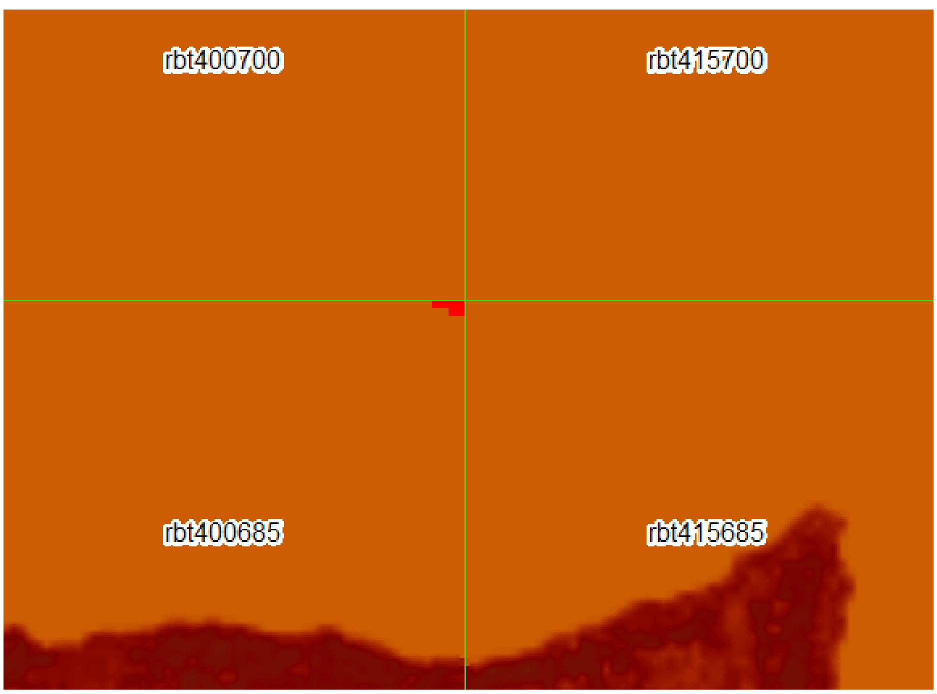

Figure 46 – 1st delivery. Ground elevation model of several first delivery tiles. Tile rbt400685 has several null pixel values in the upper-right corner (In red).

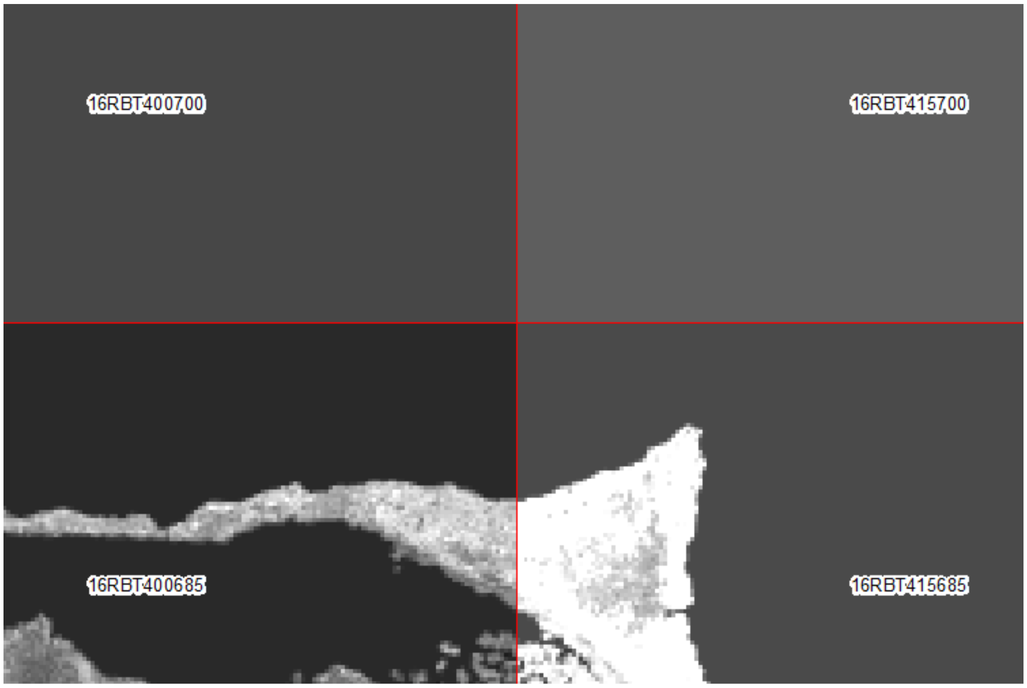

Figure 47 – 2nd delivery - Corrected. Ground elevation model of the second delivery of tile rbt400685. The null pixel values have been corrected.

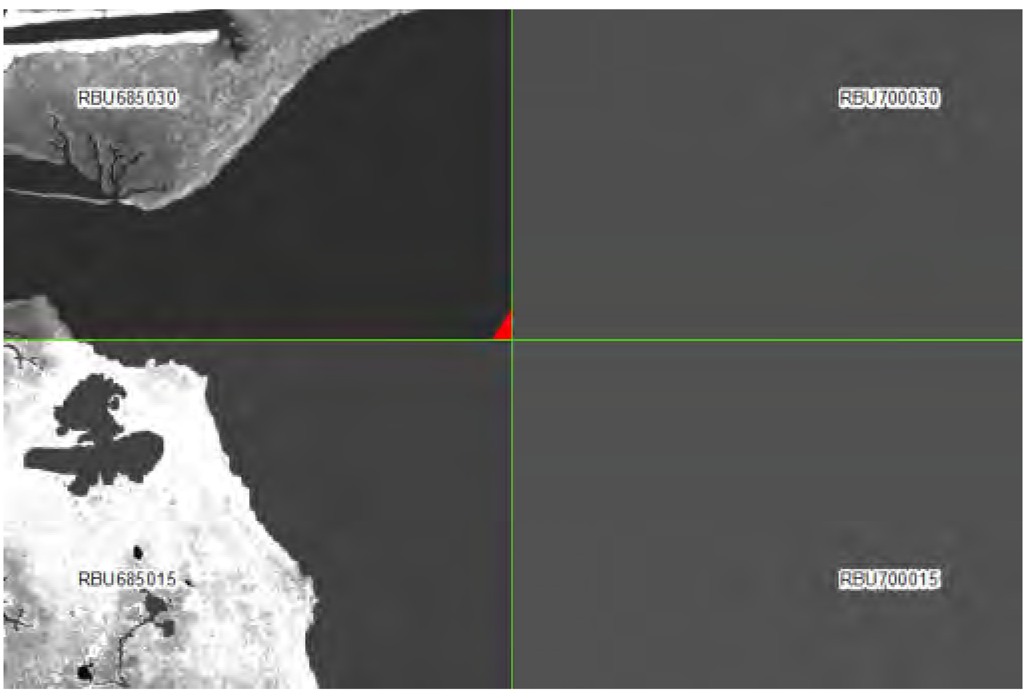

Figure 48 – Error Remains. Ground elevation model of several tiles in the second delivery. Tile rbu685030 shows several null pixels (red) in the bottom right corner of the tile.

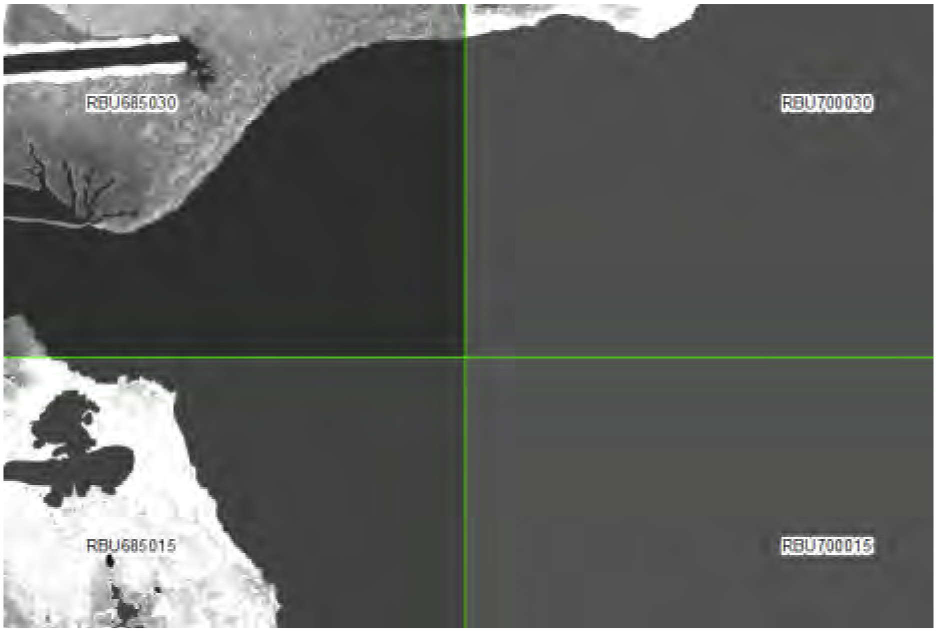

Figure 49 – The null pixels in the corner of tile rbu685030 have been corrected in the third delivery

4.3.2 Water Issues in DEMs - Fixed

These issues are likely related to the breaklines and the classification to water step, but they are clearly identified in the DEMs and therefore mentioned here. In the first delivery, Dewberry identified several areas of artifacts appearing in water. Water artifacts called out by Dewberry in the first delivery were corrected; however, six new water artifacts were detected during the visual DEM QA of the second delivery. All six of these water artifacts were corrected in the third delivery. See figures below.

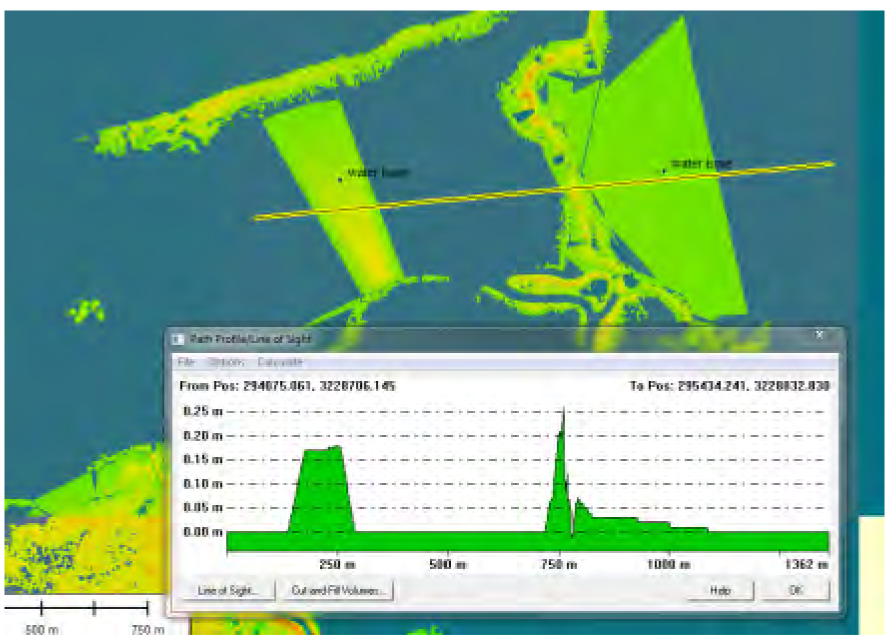

Figure 50 – 1st delivery. Ground elevation model of tile 16RBT940280,first delivery. The areas in between the islands are delineated in the breaklines as water, but this is not reflected in the DEM.

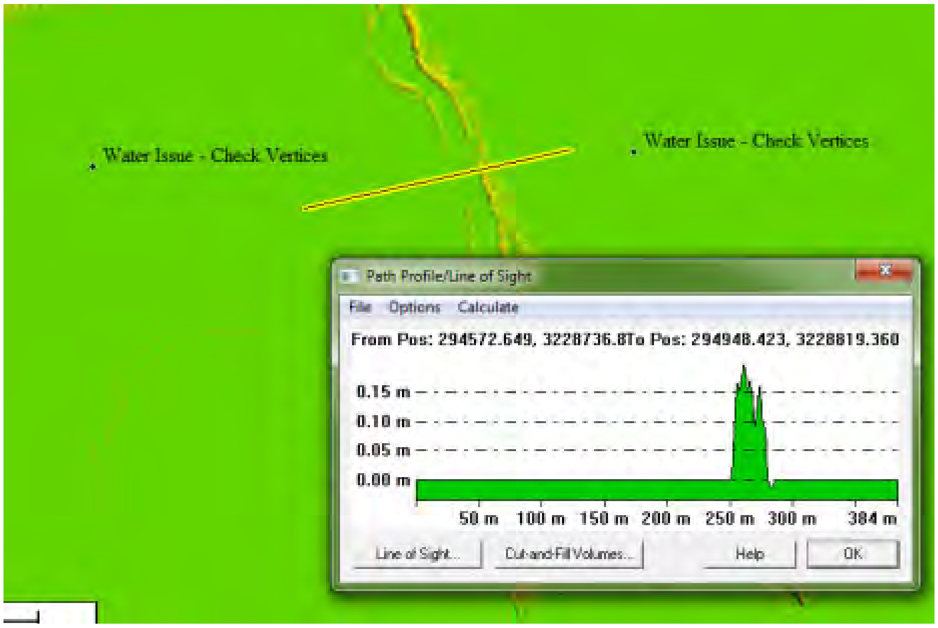

Figure 51- 2nd delivery – Corrected. Ground elevation model of tile 16RBT940280, second delivery. The water artifacts have been removed in the second delivery.

4.4 DEM Recommendation

After the third delivery Woolpert has corrected all issues that arouse during the review. Dewberry recommends that the USGS accepts the DEMs delivered.

5 Metadata

Project level metadata were delivered for the DEMs, breaklines, bare-earth LAS, raw LAS, QC Points, and the tile layout. The metadata are sufficient in detail and no errors were found using the USGS MP Tool in ArcGIS.

6 GDB

Dewberry will provide to the USGS and Woolpert a GDB that contains all the LiDAR and breakline calls. Each deliverable will contain a separate feature class with at least the following fields:

1. MainCall – A brief, generalized description of the call
2. Software – the software and test used to identify the issue
3. Description – A more detailed explanation of the identified issue
4. CallType – States whether the issue should be addressed or if it is for reference.

7 Recommendation Summary

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

LiDAR Calls

- Dewberry finds no issues with the LiDAR data as classified. The issue of the vertical RMSE still remains, but this has been discussed with the USGS. No further modifications were deemed necessary.

Breakline Calls

- No issues, Dewberry recommends the USGS accept the Breaklines.

DEM Calls

- No issues, Dewberry recommends the USGS accept the DEMs.

Metadata Calls

- No issues, Dewberry recommends the USGS accept the Metadata.

LiDAR Quality Assurance (QA) Report
Louisiana LiDAR ARRA Project - Region 1
November 15, 2011

Submitted to:
USGS

Prepared by:
Dewberry

Table of contents

1 Executive Summary

Contract: Louisiana ARRA Region 1	Production Contractor: Woolpert Inc.	Date Prepared: 11/15/2011	Delivery #: 3	Dewberry Recommendation: Accept
Data History: ❑ N/A – First review of the data ❑ Second review of the data ❑ Nov. 5th – 3rd review of data ❑ Nov. 14th – FTP delivery of partial data				

The following LiDAR quality assurance report documents Dewberry's final review of LiDAR data and derived products for the Florida-LA Region 1 & 2 –Texas Co.'s LiDAR Quality Assurance project. This document reviews the classification and derived products for the Louisiana Region 1 delivery by Woolpert Inc. (Woolpert). The delivery area consists of ~2575 square miles (6669 square kilometers) that amount to 1580 LAS tiles (1500 meters x 1500 meters) (Figure 1). Each tile contains LAS point cloud data classified according to the ASPRS classification scheme. The deliverables also include breakline shapefiles, the control (checkpoints used during LiDAR collection), hydro-enforced digital elevation models (DEMs), and metadata.

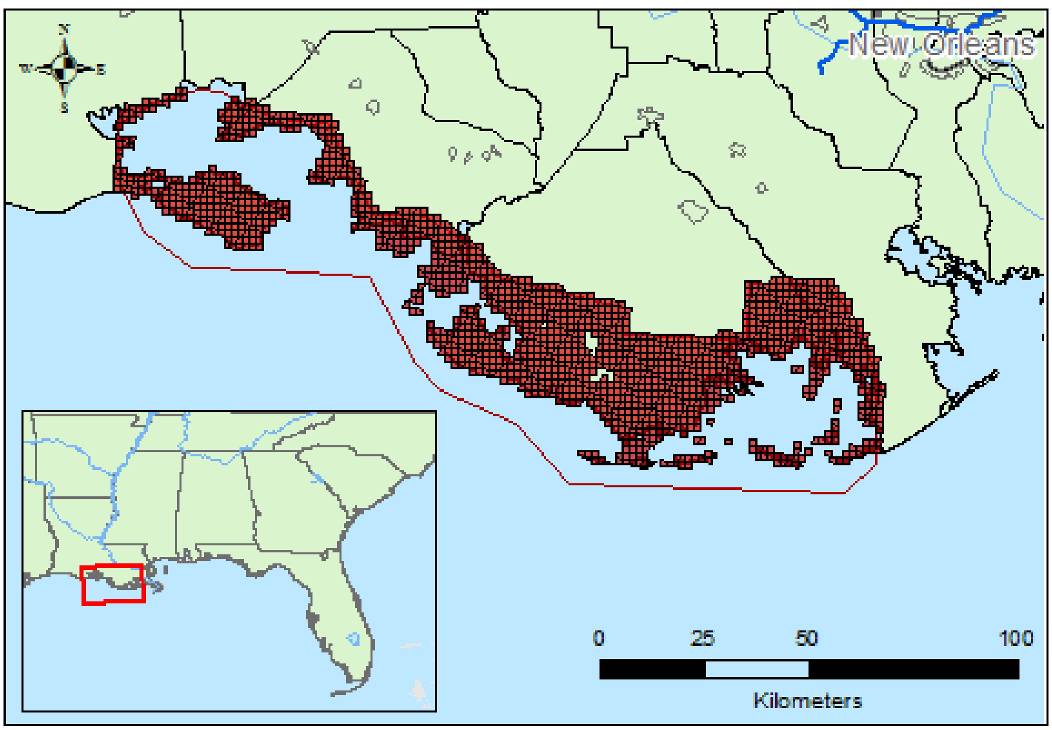

Figure 1 - Location of LAS tiles.

The LiDAR data and derived products were processed through Dewberry's comprehensive quantitative/qualitative review process. This multipart analysis determines the degree to which the data met expectations for completeness, relative accuracy, and conformity to specific project requirements for each data product. After thorough review, Dewberry recommends that the data be accepted by the USGS. All issues previously identified and their fixes can be found in this report.

The LiDAR data for the Louisiana Region 1 area were thoroughly examined by Dewberry for completeness and conformity to project specifications. The fundamental vertical accuracy of the data is 16.2 cm which meets project specifications. In the second delivery there remain no significant misclassification issues or flight line ridges, but there is one data void that remains in the dataset. Dewberry believes that the LiDAR data provided by Woolpert in the second delivery is satisfactory and should be accepted.

Dewberry identified a few issues concerning water bodies not captured, ground captured as water, and water captured as ground. Woolpert corrected the majority of these issues in the second delivery. Additionally, several breakline features were identified to float above the ground mode. All of these issues were fully corrected by Woolpert in the third delivery.

All changes in the LAS and breaklines have been appropriately adjusted in the DEMs and Dewberry belives that the USGS should accept the DEMs delivered by Woolpert.

The metadata do not contain any errors according to the USGS MP Tool in ArcGIS and are sufficient in detail. Dewberry recommends the USGS accept this deliverable.

1.1 Deliverables Summary for Woolpert Inc. Louisiana ARRA Region 2

Deliverable	Applicable Acceptance Criteria	Dewberry Recommendation
All-Return LAS Point Cloud Data	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 23, 24, 25, 26	☐ Accept ☑ Accept with Comments ☐ Return for Corrections ☐ Reject
Breaklines	30, 31, 32, 33, 34	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
Hydro-Enforced DEMs	20, 21	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
LAS Metadata	22	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject

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

The applicable acceptance criteria refer to the numbered criteria found in "Appendix B-Acceptance Criteria" on pages 12-13 of the Quality Plan.

1.2 Report Approval

Approved by: ______________________ Date: 11/15/2011
(sign & stamp)

Overview
The goal of the USGS Florida-LA Region 1 & 2 –Texas Co.'s LiDAR project Task Order is to provide high accuracy elevation datasets of multiple deliverable products including LiDAR, hydro enforced digital elevation models (DEMs), and 3D breaklines.

Dewberry's role is to provide Quality Assurance (QA) of the LiDAR data and supplemental deliverables provided by Woolpert Inc., Aerometric, and Woolpert including completeness checks, vertical accuracy testing, and a qualitative review of the bare earth surface. This document pertains solely to products delivered by Woolpert Inc. for the Louisiana Region 1 delivery area. Each product is reviewed independently and against the other products to verify the degree to which the data meets expectations.

2 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.

2.1 LiDAR Quantitative Review

One of the first steps in assessing the quality of the LiDAR would be a vertical accuracy analysis of the ground models in comparison to surveyed checkpoints. Dewberry & Davis, LLC provided 52 checkpoints for the entire project area extent (Figure 2).

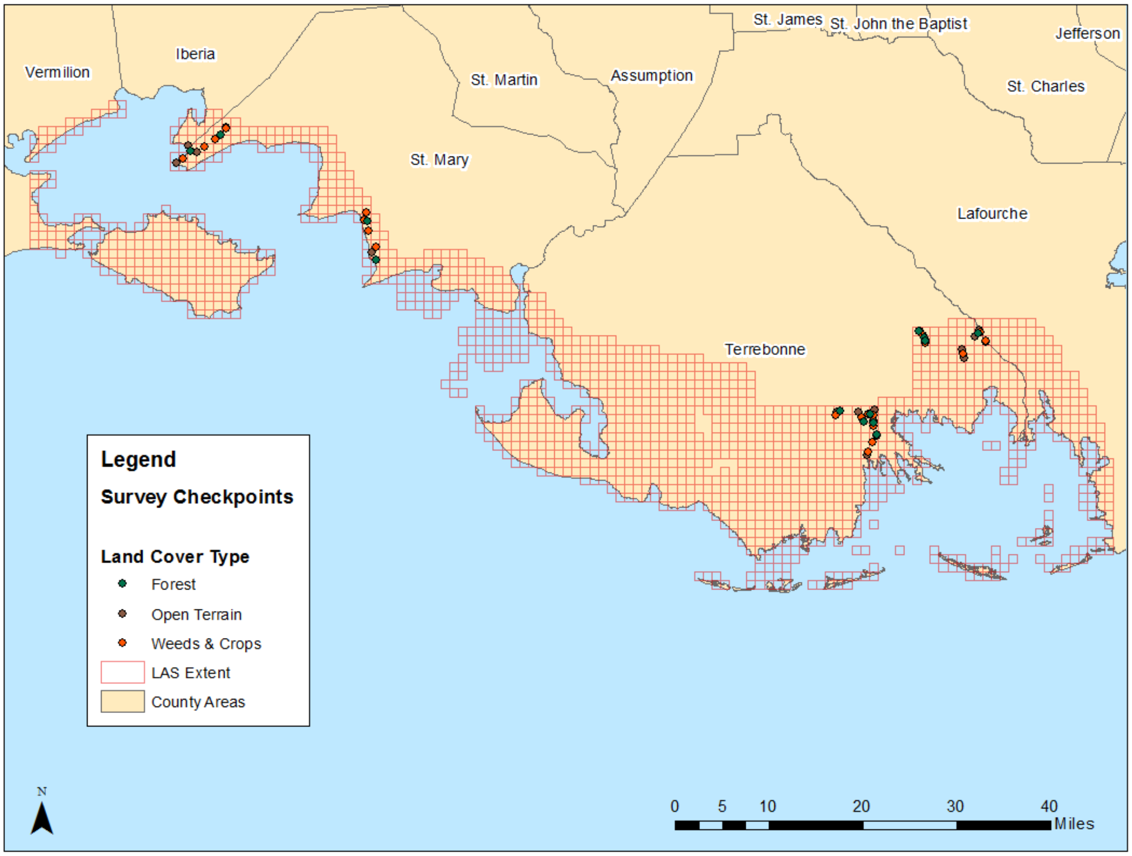

Figure 2: Checkpoints distribution for Louisiana Region 1

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.

The $RMSE_Z$ in open terrain is 8.30 cm which exceeds the project specification of 12.5 cm. The CVA value for all points is 32.5 cm which meets project specifications of 36.3 cm. The SVA values for all three land cover types also all meet the project specifications of 36.3 cm. Table 1 outlines the calculated RMSEz and associated statistics in meters while Table 2 outlines vertical accuracy and the statistics of the associated errors as computed by the different methods in meters. It should be noted that the typical ASPRS standards specifying 20 points per land cover category were not met in this RMSE assessment. Dewberry believes that given the difficult topology of the project area (which necessitated the use of clustered survey points) and in light of the favorable SVA scores, the amount of checkpoints used is acceptable.

100 % of Totals	$RMSE_Z$ (m) Spec=0.125 m[1]	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.173	0.103	0.099	-0.056	0.140	47	-0.222	0.376
Open Terrain	0.083	0.025	0.028	-0.473	0.081	18	-0.130	0.140
Weeds/Crop	0.211	0.181	0.192	-0.407	0.112	19	-0.066	0.364
Forest	0.207	0.094	0.112	-0.237	0.195	10	-0.222	0.376

Table 1: The table shows the calculated RMSEz values in meters as well as associated statistics of the errors for Louisiana Region 1. [1]*In open terrain.*

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_Z$ x 1.9600) Spec= .245 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.363 m	SVA — Supplemental Vertical Accuracy (95th Percentile) Spec=0.363 m
Consolidated	47		0.325	
Open Terrain	18	0.162		
Weeds/Crop	19			0.315
Forest	10			0.356

Table 2: The table shows the calculated $Accuracy_z$ of the FVA in meters using FEMA/NSSDA guidelines (RMSEz x 1.9600) and the $Accuracy_z$ of the CVA in meters using NDEP/ASPRS guidelines (95th percentile) for Louisiana Region 1.

2.2 LiDAR Completeness Review

Dewberry received 1580 LiDAR tiles. The LiDAR was delivered in LAS format 1.2 that adheres to the ASPRS LAS 1.2 specifications with some notes, listed below. The Point Data Format 1 is used, with intensity values present. The LAS files are named appropriately according to the United States National Grid and have the correct extents (1500m x 1500m).

All spatial projection information was correct and is as follows:

- Projection: NAD 1983 UTM Zone 15N
    - Horizontal and Vertical Units: Meters
- Vertical Datum: NAVD88, Geoid09

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

- 1,882 tiles had scan angles greater than 20° and 1,214 tiles had combined scan angle ranks greater than 40°. As discussed in the qualitative LiDAR QA/QC section, several flight line ridges were identified in the LiDAR data.

The LiDAR data has been classified to contain the appropriate classes as required:

- Class 1 (Unclassified)
- Class 2 (Bare Earth)
- Class 7 (Low point/Noise)
- Class 9 (Water)
- Class 10 (Ignored Ground)

2.3 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. No issues were identified beyond the overlap issue described previously.

Each tile was queried to extract the number of LiDAR points. Woolpert Inc. collected the LiDAR at with a nominal point spacing of 2 pulses per square meter. The expected total number of points per tile should be approximately 4.5 million. The mean within the project area of each tile is approximately 1.57 million. The large discrepancy between the expected number of points per tile and the actual number of points per tile is due to the large areas of tidal water prevalent in almost every tile (Figure 3). Dewberry did not identify any issues with point density during the manual qualitative review of the LiDAR.

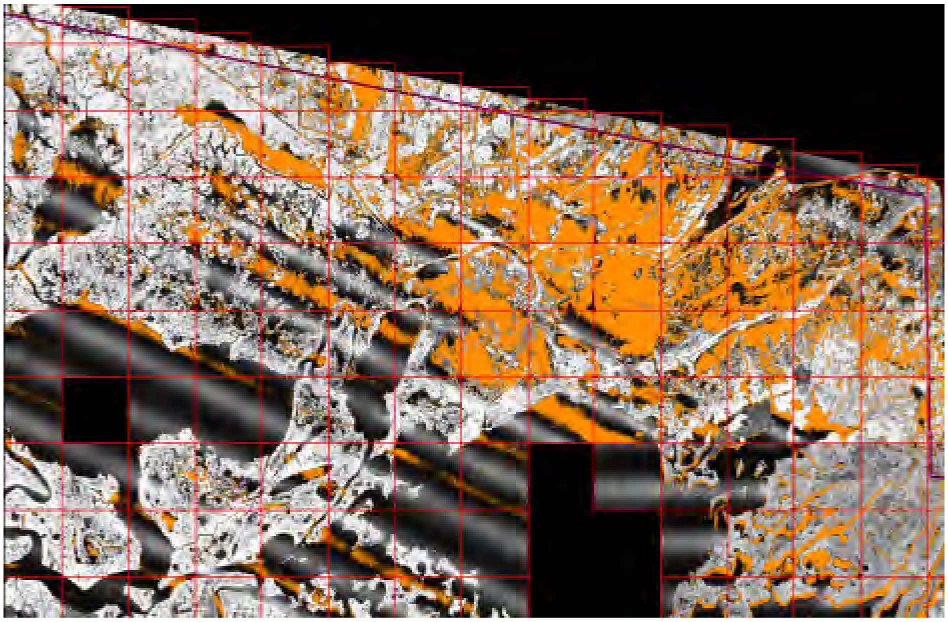

Figure 3 - Intensity images generated from full point cloud data. All areas that are orange indicate that there are no points in those areas because it is water. Large areas of water with no point returns will decrease the number of points per tile.

2.4 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%

Dewberry analysts performed a visual inspection of 100% of the bare earth data digital terrain model (DTM). 100% of the data was looked at the micro and macro levels. The DTMs 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.

In the qualitative review of the LiDAR, Dewberry identified numerous issues that need to be addressed by Woolpert before the data should be accepted. These include numerous misclassification issues and one data void. Of concern are several flight line ridges and areas where the ground model is not as well defined. Dewberry also identified several missing LAS tiles that should be delivered. All calls will be provided to the USGS and Woolpert in a GDB and shapefile format. The table below summarizes the calls (Table 3).

Table 3 - LiDAR Visual QA Calls

Issue	Number of Occurrences in 1st Delivery	Number of Occurrences Remaining in 2nd Delivery
Misclassifications	41	1
Data Voids	1	1
Loss of Definition	64	4
Missing Tiles	47	0
Flight Line Ridges	100 Calls – 17 Flight Lines	0
Total	253	6

2.4.1 Misclassification

Misclassification calls in this document imply that LiDAR points are unclassified in the delivered dataset when they should be classified to ground. In other words, this call indicates that points that are unclassified (Class 1) should be moved to the ground (Class 2). One specific type of misclassification call is aggressive classification. This occurs when too many ground points are removed from the ground resulting in a loss of definition to the surface. This predominantly occurs along ridge tops or where there are significant changes in slope. Two examples of these calls and their corrections in the second delivery can be found below from Figure 4 to Figure 7.

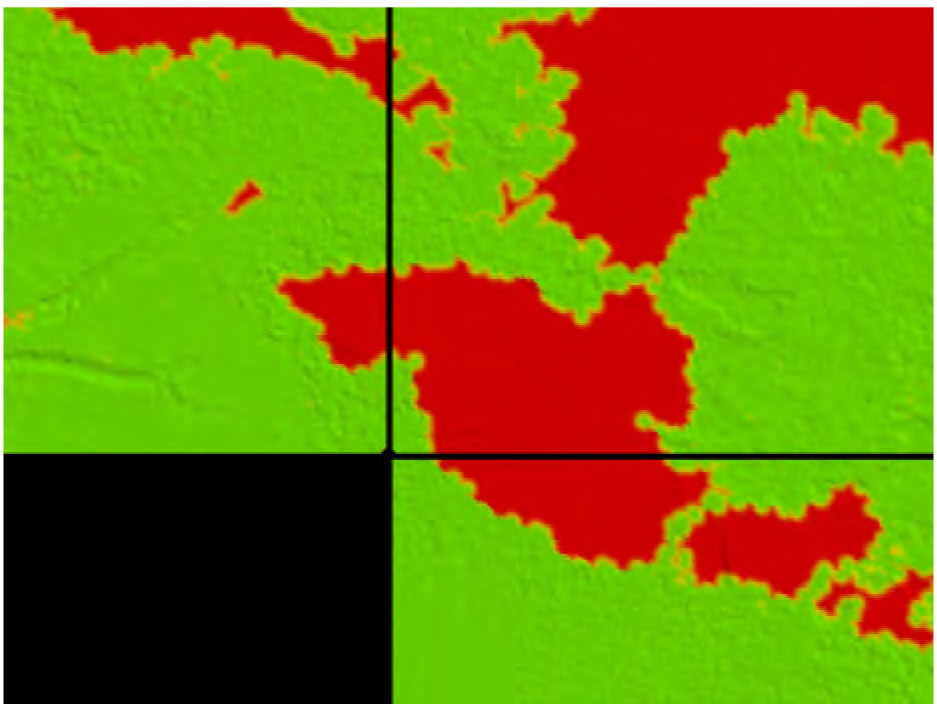

Figure 4 - Ground density model of Tiles 15RXN495685, 15RXN480685, and 15RXN495670 showing an area of ground (in red) that is currently unclassified (Class 1) and should be moved to ground (Class 2).

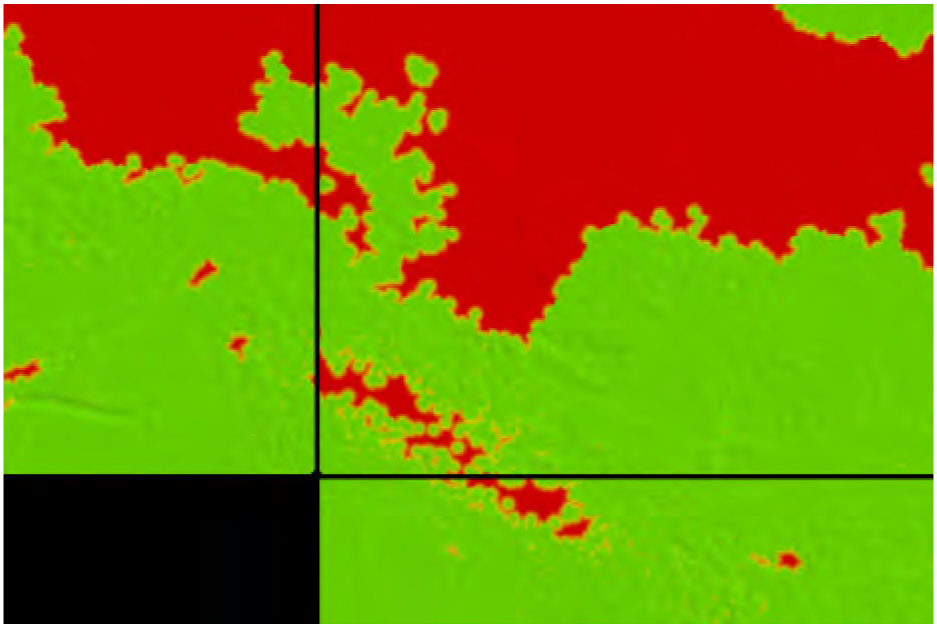

Figure 5 - Ground density model of Tiles 15RXN495685, 15RXN480685, and 15RXN495670 showing that the previously misclassified area has been corrected in the second delivery.

Figure 6 - Ground density model of Tile 15RXN615670 showing an area of ground (in red) that is currently unclassified (Class 1) and should be moved to ground (Class 2).

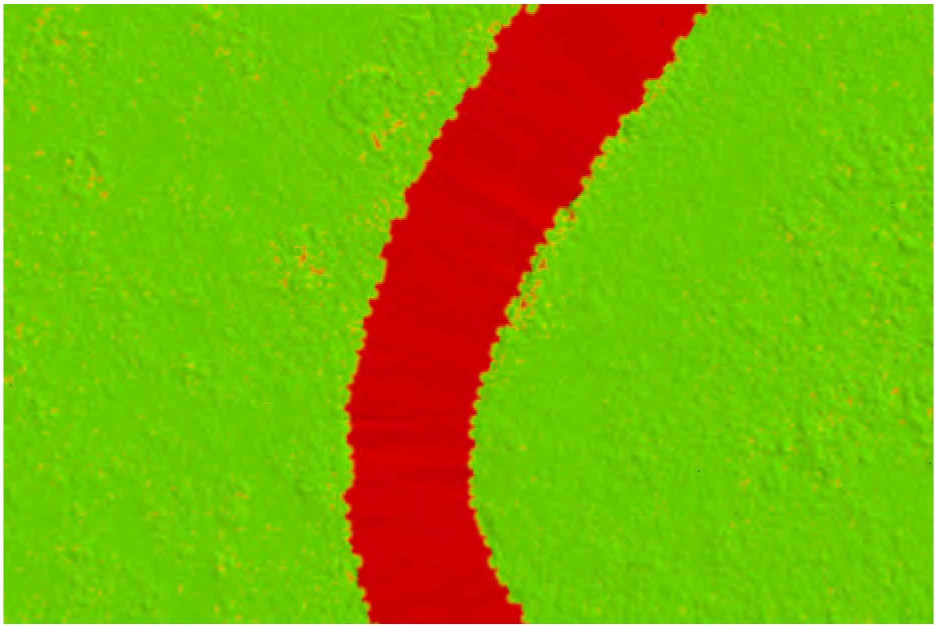

Figure 7 - Ground density model of Tile 15RXN615670 showing that the misclassification has been corrected in the second delivery.

2.4.2 Data Voids

One Data void was identified in tile 15RYN650295. The void occurs in areas where the intensity values are very dark (Figure 8 to Figure 11). Because no points were collected in the void areas, they may be difficult and costly to fully correct, however users should be made aware of any data voids left in the final products. Woolpert responded to this issue and stated that “there is no available lidar coverage in this area due to excessive cloud cover.” Dewberry notes this here for the end-client.

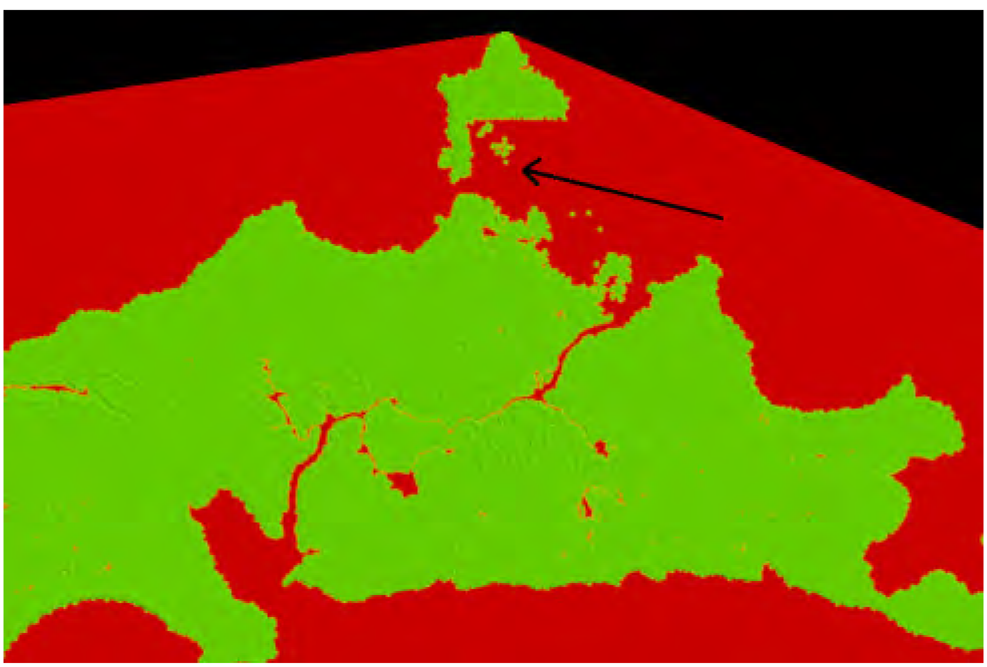

Figure 8 – A LiDAR ground density model showing low point density areas in red. The majority of red in the tile is water and not an error however the linear geometry of the void shown by the arrow implies that the void is legitimate. Tile 15RYN650295.

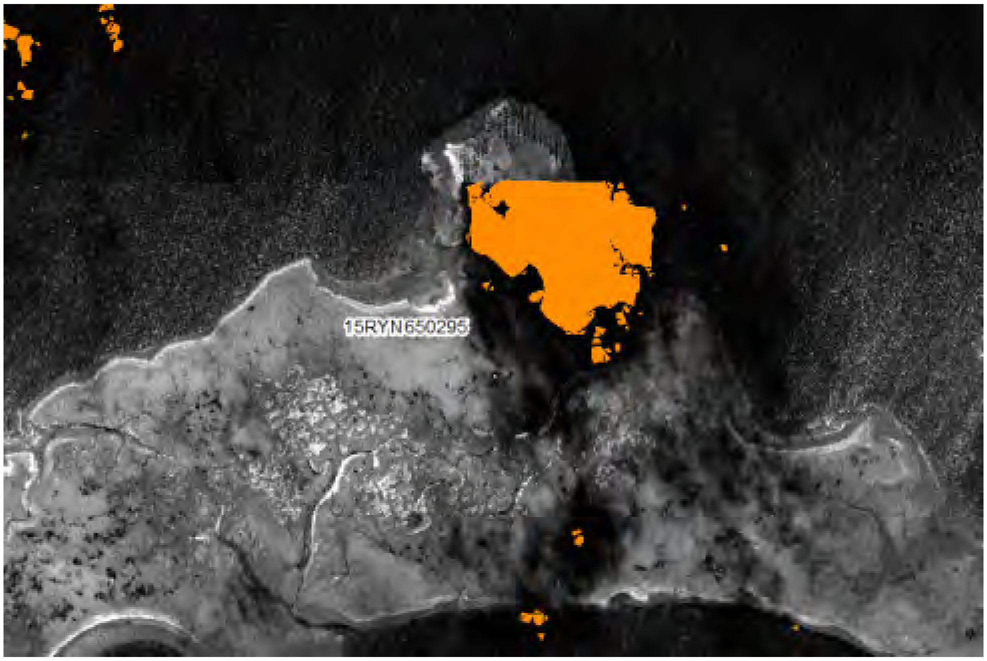

Figure 9 – LiDAR intensity image of the same ground feature shown in Figure 13. Voids areas were no points were collected are colored orange. The large void here intrudes on the geography in an unnatural way. The void measure approximately 5.3 acres.

Figure 10 – Aerial photograph of the ground feature shows confirms the area identified in the previous two figures is a legitimate data void.

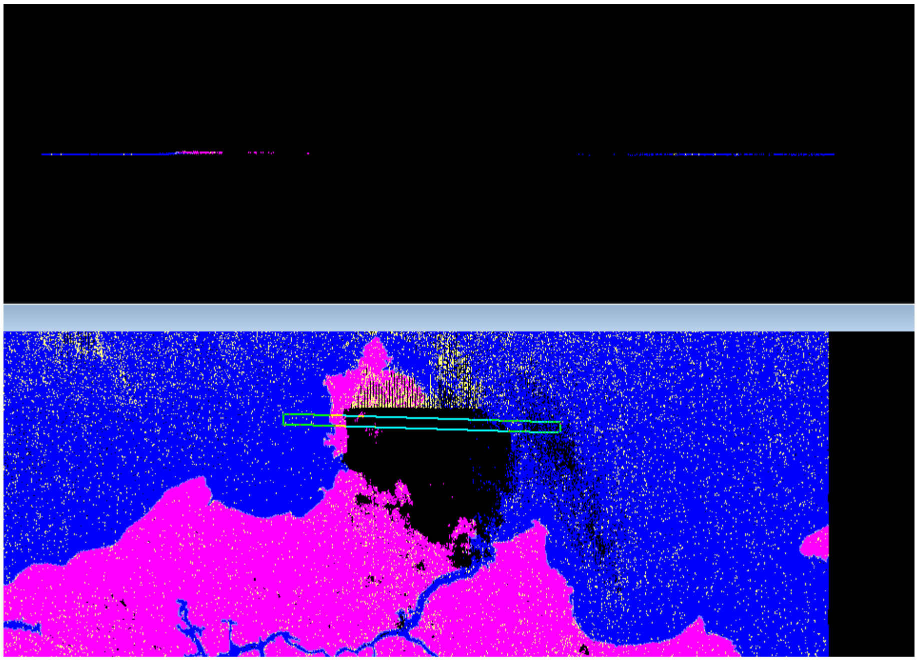

Figure 11 – LAS profile of tile 15RYN65029 colored by classification (where ground is shown in pink, water in blue and unclassified point in yellow.) No LiDAR points were collected in the void area.

2.4.3 Loss of Definition

Areas in the dataset were identified where a loss of ground definition occurs. This sometime occurs across tile edges, but also seems to happen at the transition of flight line overlaps. The loss of definition to the ground does affect the ground model and Woolpert should address these areas to make a more consistent ground model. The images below use tiles 15RXN930400 and 15RXN930385 as examples. Tile 15RXN930400 has a well-defined ground and 32% of the points in the tile are classified to ground. Tile 15RXN930385 has a poorly-defined ground and only 12% if the points in the tile are classified to ground. Woolpert addressed 60 of the 64 edit calls that Dewberry made for this issue.

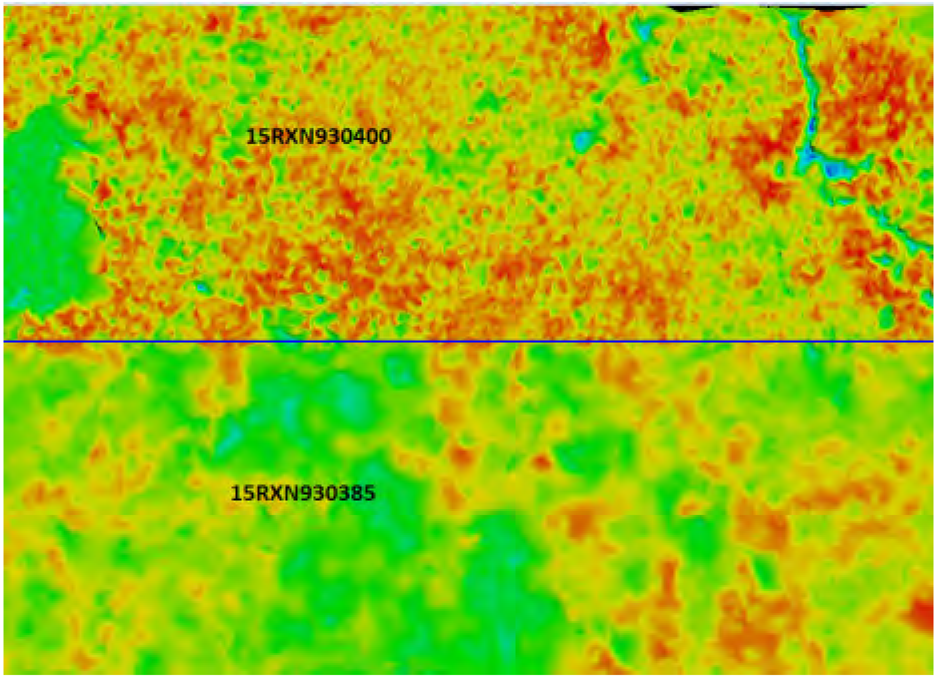

Figure 12 - Difference in ground model definition between the two tiles. The upper tile is well-defined compared to the tile below.

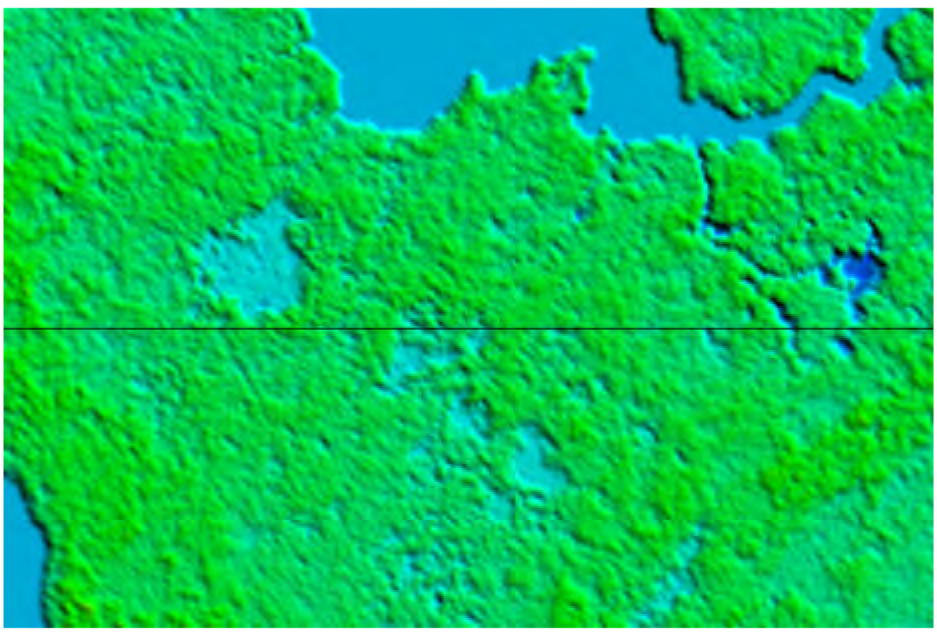

Figure 13 – Tiles 15RXN930400 and 15RXN930385, second delivery. Ground points have been added to the ground model which improves the overall quality of the ground model.

2.4.4 Missing Tiles

The data delivered to Dewberry appears to be missing 47 tiles. Dewberry assumes all these tiles were not delivered because they contain no ground (i.e. are entirely water). Woolpert sent these tiles in the second delivery and Dewberry confirms that these tiles do not contain ground that is misclassified.

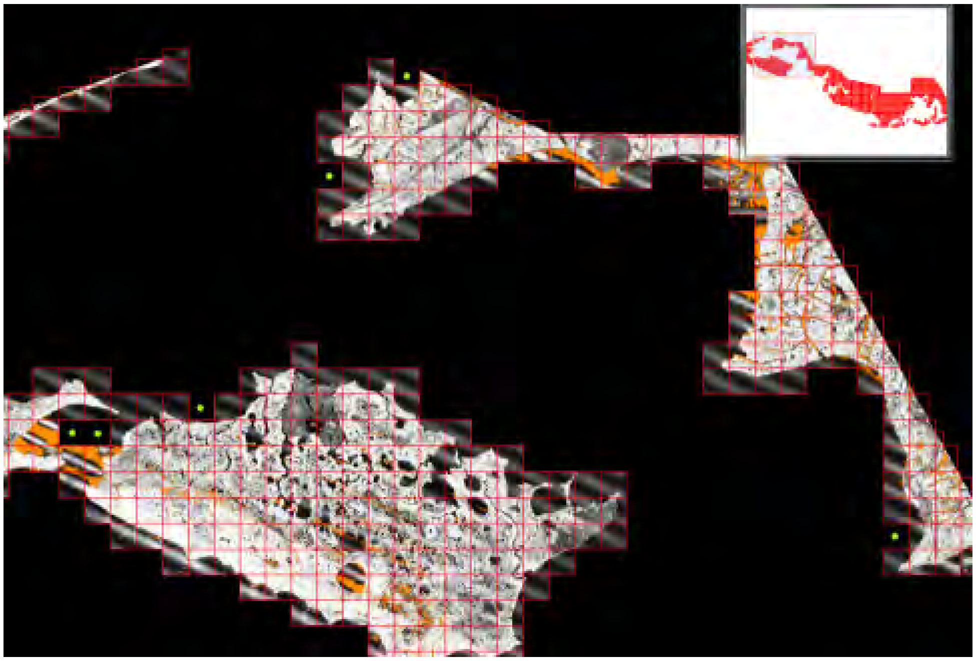

Figure 14 – Green dots show tiles that Dewberry recommends Woolpert deliver to ensure there is no ground.

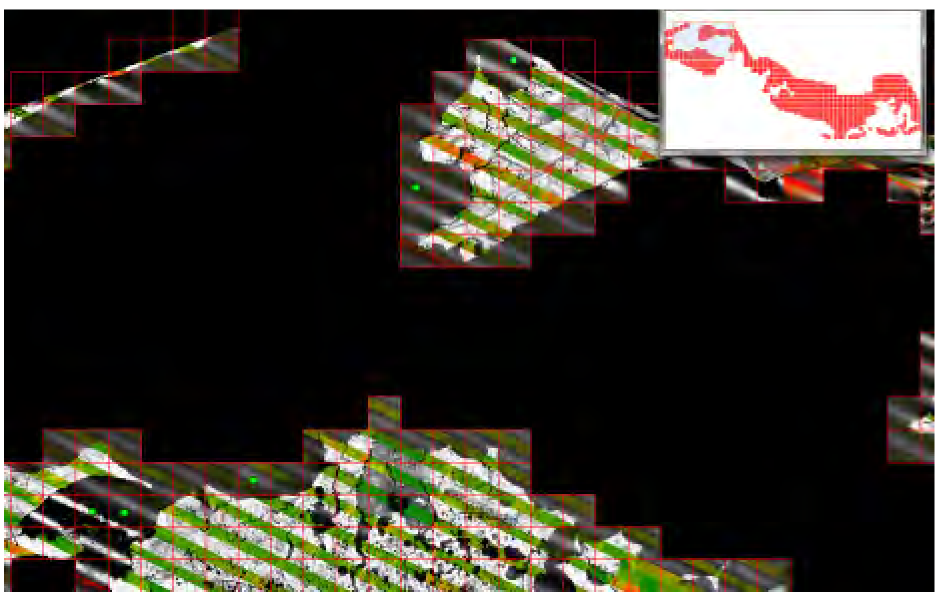

Figure 15 – The image above confirms that the missing tiles were delivered in the second delivery.

2.4.5 Flight Line Ridges

In the first delivery, several flight line ridges were identified in the Louisiana Region 1 LiDAR dataset. The ridges are caused by a vertical mismatch between two adjacent flight lines. Elevation differences along adjoining flight lines range from 10 cm up to 50 cm. Dewberry identified 100 distinct areas where a flight line ridge occurs, but after reviewing the DeltaZs, Dewberry recommended that 17 flight lines be reviewed by Woolpert for calibration issues. Woolpert addressed the majority of these issues in the second delivery. While some instances of flight line ridges occur in the dataset, Dewberry believes that the remaining issues are nugatory, and that the dataset as a whole meets project specifications. Examples of the flight line that was corrected can be found below.

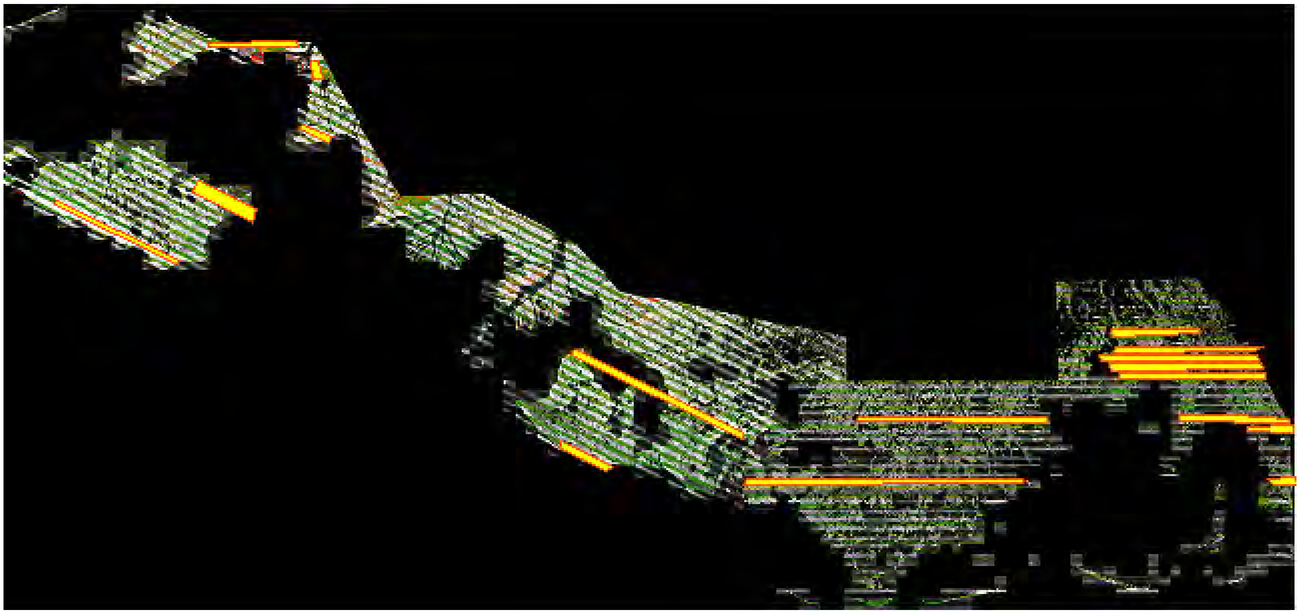

Figure 16 - Project wide area showing the 17 flight lines (highlighted in yellow), in the first delivery, that were addressed by Woolpert.

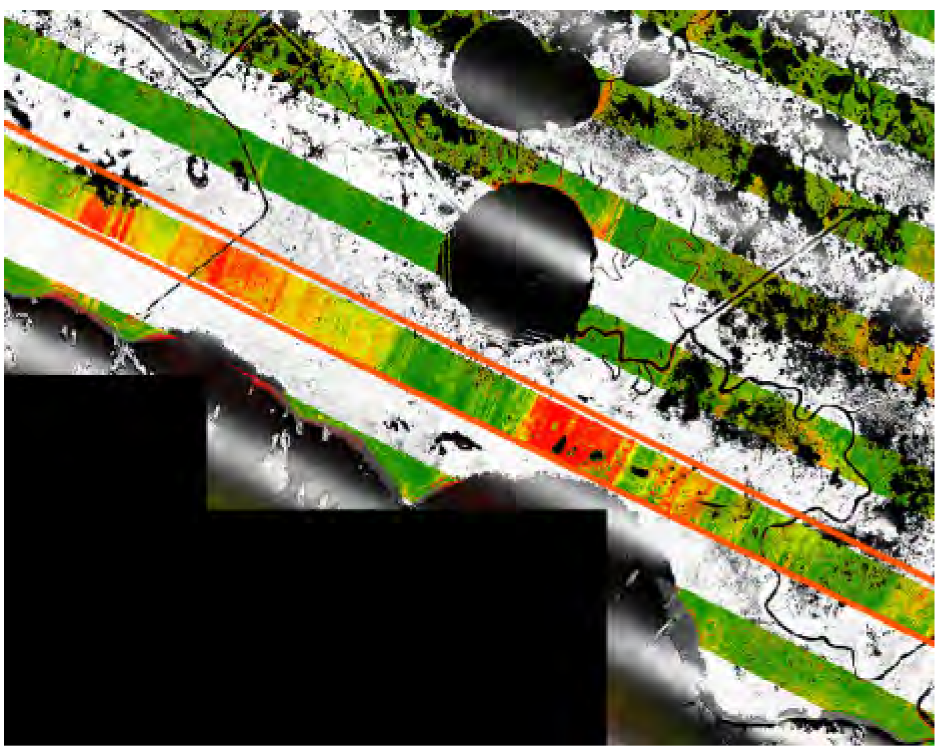

Figure 17 - DeltaZ image from project area, first delivery. Red and yellow areas represent places where the flight line overlap difference is greater than 10cm and is therefore out of project specifications.

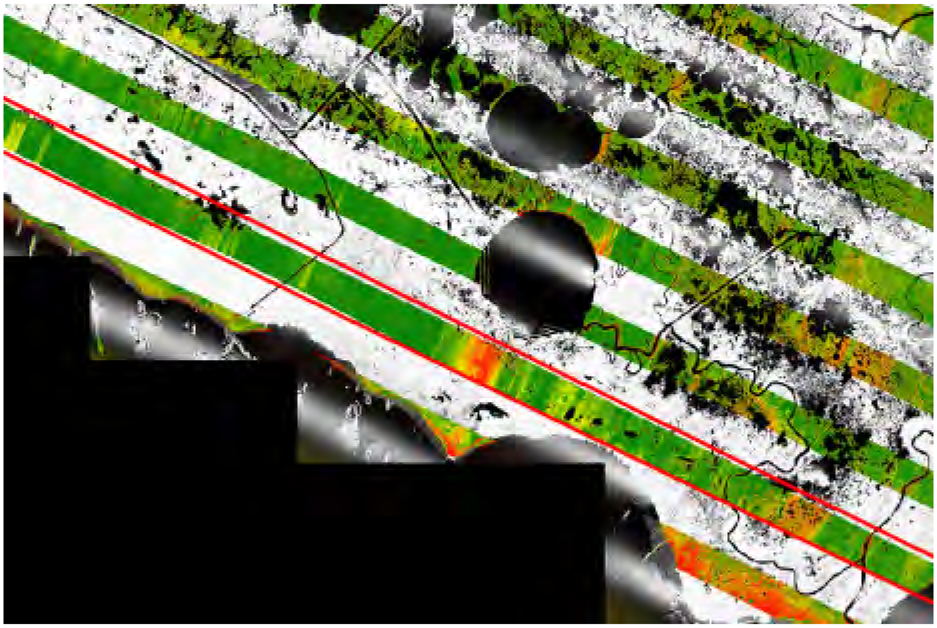

Figure 18 - DeltaZ image from project area, second delivery. Woolpert greatly reduced the flight line overlap in the dataset in the second delivery.

2.5 LiDAR Recommendation

In the second delivery Woolpert addressed the majority of the issued raised by Dewberry in first review of the dataset. Dewberry believes that the remaining misclassification issues do not significantly affect the overall quality of the dataset. Woolpert has acknowledged the one data void and because it is not prevalent, Dewberry recommends that the USGS accept this one issue.

3 Breakline Analysis

A qualitative/quantitative review was completed on the breaklines. The comprehensive qualitative review consisted of a visual review of the breaklines for completeness in compilation and horizontal placement as well as proper feature coding. This visual analysis was followed by several automated tests for hydro-enforcement and topology using ESRI PLTS tools and proprietary tools developed by Dewberry. The breakline review followed the Breakline QA/QC Checklist provided in the Quality Plan. Overall the breaklines are of good quality and Dewberry recommends the USGS accept the data.

3.1 Breakline Data Overview

The Woolpert breakline data was delivered as 13 shapefiles containing the following features:

1. Islands – Split into 6 shapefiles due to the large size of the data
2. Ponds and Lakes
3. Tidal Waters – Split into 6 shapefiles due to the large size of the data.

This complies with project specifications.

The data is correctly projected horizontally and vertically:

- Horizontal Projection*: NAD_1983_UTM_Zone_15N*
- Vertical Datum: NAVD88, Geoid09
- Horizontal and Vertical Units: Meters and Meters

Lastly, all feature classes were verified to contain z-elevation values as specified by the data dictionary.

3.2 Breakline Completeness and Qualitative Review

The breakline completeness review includes ensuring all feature classes necessary are present, compiled accurately and has the correct extents. All feature classes were reviewed against intensity imagery Dewberry creates for its QC process. A review was performed on 100% of the data in an ESRI environment to validate data collection consistency and to validate all necessary features were collected.

3.2.1 Breakline Overview

Dewberry understands that these breaklines were compiled using automated methods. Woolpert and the USGS agreed that an elevation of zero (0) meters could be used to help delineate the placement of breaklines. Dewberry only called breakline issues on features that were above an elevation of zero meters. Furthermore, due to the marshy land cover and frequent temporal changes to the land/water boundaries inherent to this portion of Louisiana, the USGS has determined that standard breakline specifications can be relaxed. Project specifications requiring any island over half an acre, any water body over 2 acres, and any stream or river over 100 feet wide to be collected were therefore used as a reference point, but were not strictly enforced in all circumstances. The same principle applies to portions of ground captured as land or portions of land captured as ground found within a single feature. Dewberry called only those errors large enough to have significant impact on the DEMs and other products for this project.

During the completeness review, the quality of the collected breaklines is assessed. This includes validating the horizontal placement of breaklines as well as verifying the coding and attribution of breaklines. 71 issues were identified in the visual check. Examples of the types of issues found in the breakline visual QA can be found below. The table below summarizes the calls (Table 4):

Table 4: Breakline visual QA calls

Issue	Number of Occurrences in 1st Delivery	Number of Occurrences Remaining in 2nd Delivery	Number of Occurrences Remaining in 3rd Delivery
Island not captured	3	0	0
Water captured as ground due to intensity issue	48	10	0
Ground captured as water	14	7	0
Water body greater than 2 acres not captured	6	0	0
Total	71	17	0

3.2.2 Island not captured

One large island was not captured as ground by the island breaklines. The island is approximately 250 acres. Woolpert corrected this issue in the second delivery. An example of the issue and its correction can be seen below in Figure 19 and Figure 20. No further issues remain with this call in the second delivery.

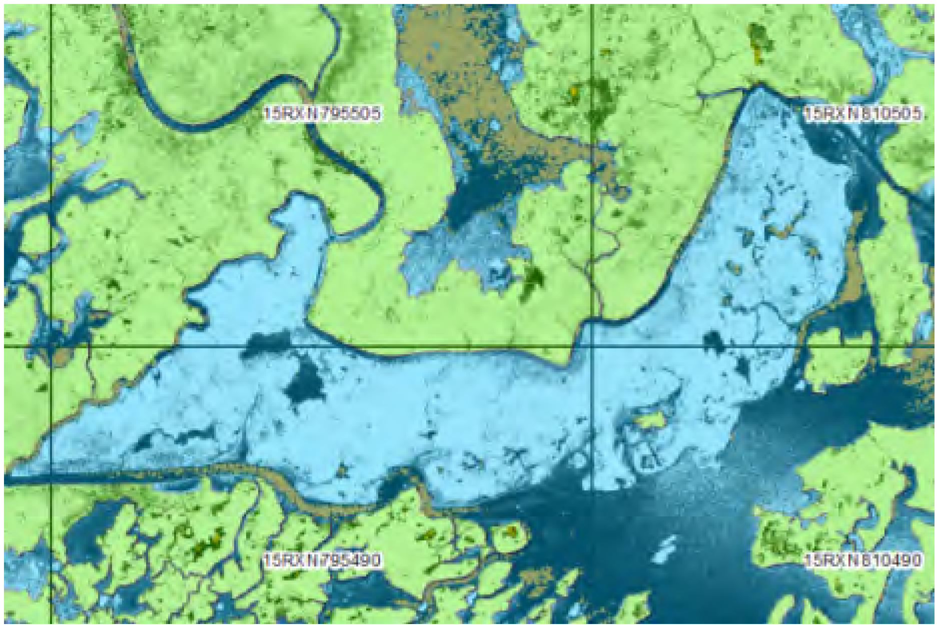

Figure 19 - Island breaklines are colored transparent green, Tidal water breaklines are transparent blue. The LiDAR intensity image is visible underneath the breaklines. A large land mass measuring approximately 250 square acres was not captured by the island breaklines. The island exists above the zero-elevation contour line.

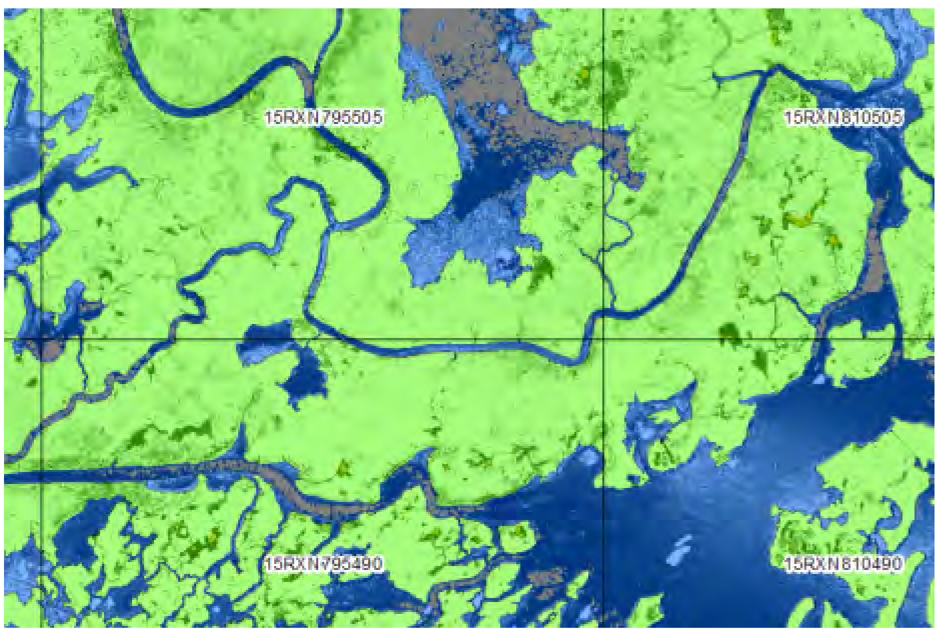

Figure 20 - Island breaklines are colored transparent green, Tidal water breaklines are transparent blue. The LiDAR intensity image is visible underneath the breaklines. The large land mass has now been correctly added to the island breaklines dataset.

3.2.3 Water captured as ground due to intensity issue

Several areas were identified where a very high LiDAR intensity return off water resulted in irregular portions of the water being mistakenly captured and classified as ground. These areas were also identified during the qualitative LiDAR quality review. 48 such areas were identified in the first delivery of the dataset, 10 remained in the second delivery, and none remained in the third delivery.

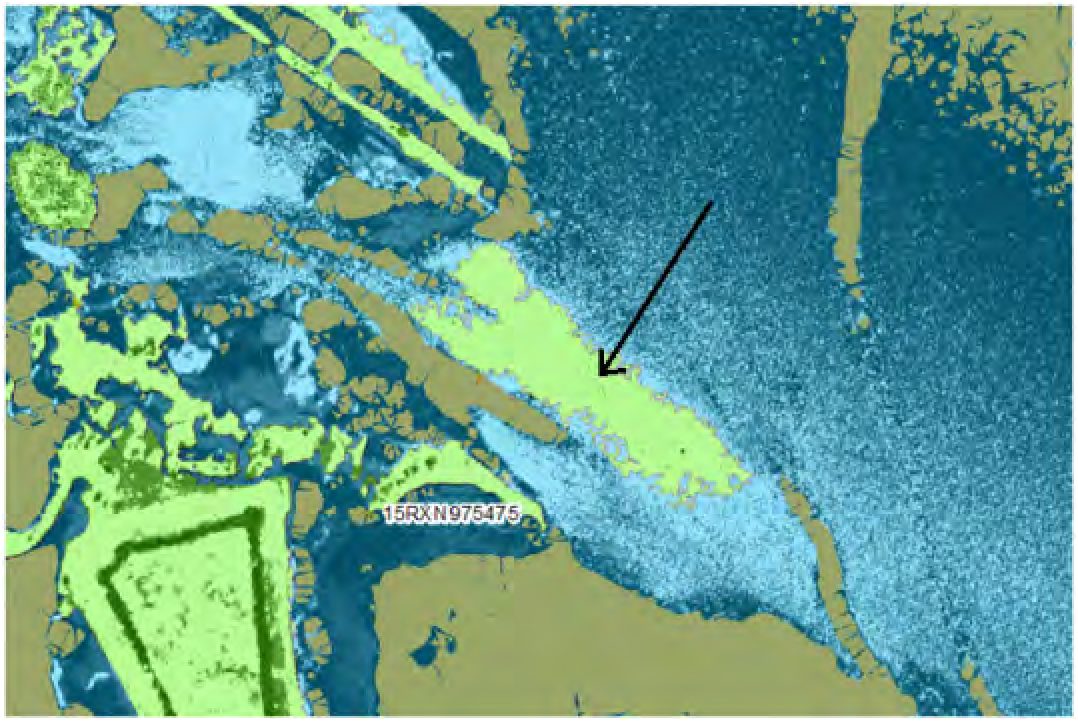

Figure 21 – Island breaklines are colored transparent green, Tidal water breaklines are transparent blue. The LiDAR intensity image is visible underneath the breaklines. Voids in the intensity image which represent water display in tan. A large portion of water has been mistakenly captured within an island breakline.

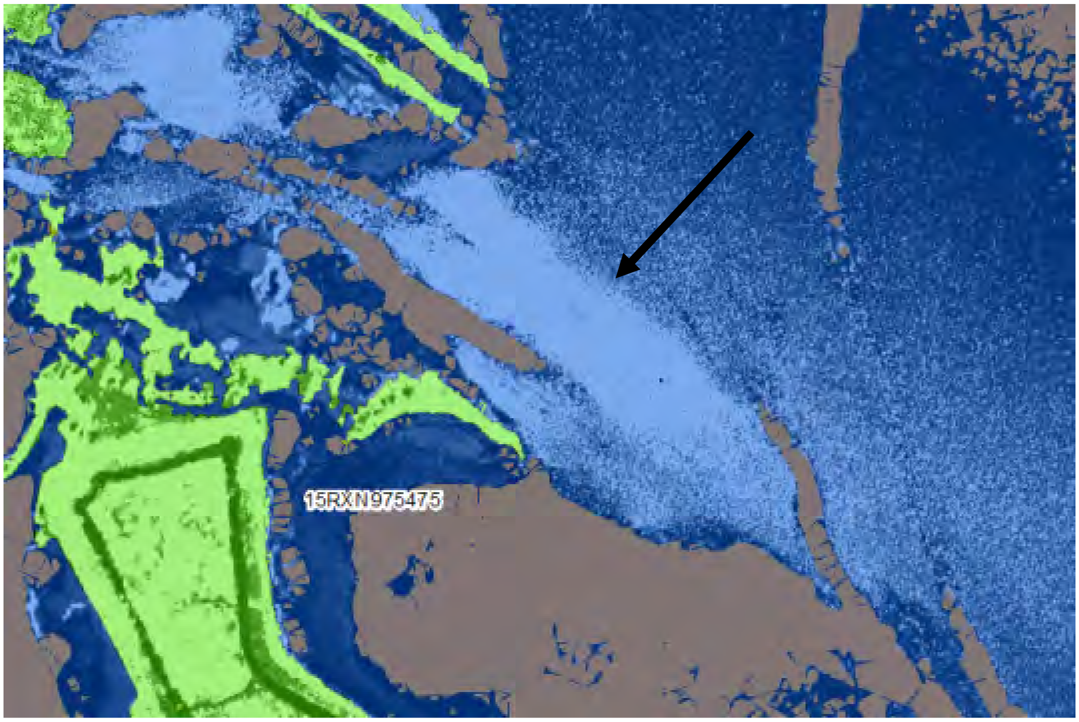

Figure 22 - Island breaklines are colored transparent green, Tidal water breaklines are transparent blue. The LiDAR intensity image is visible underneath the breaklines. Voids in the intensity image which represent water display in tan. The tidal water breaklines has been correctly adjusted to remove the issue.

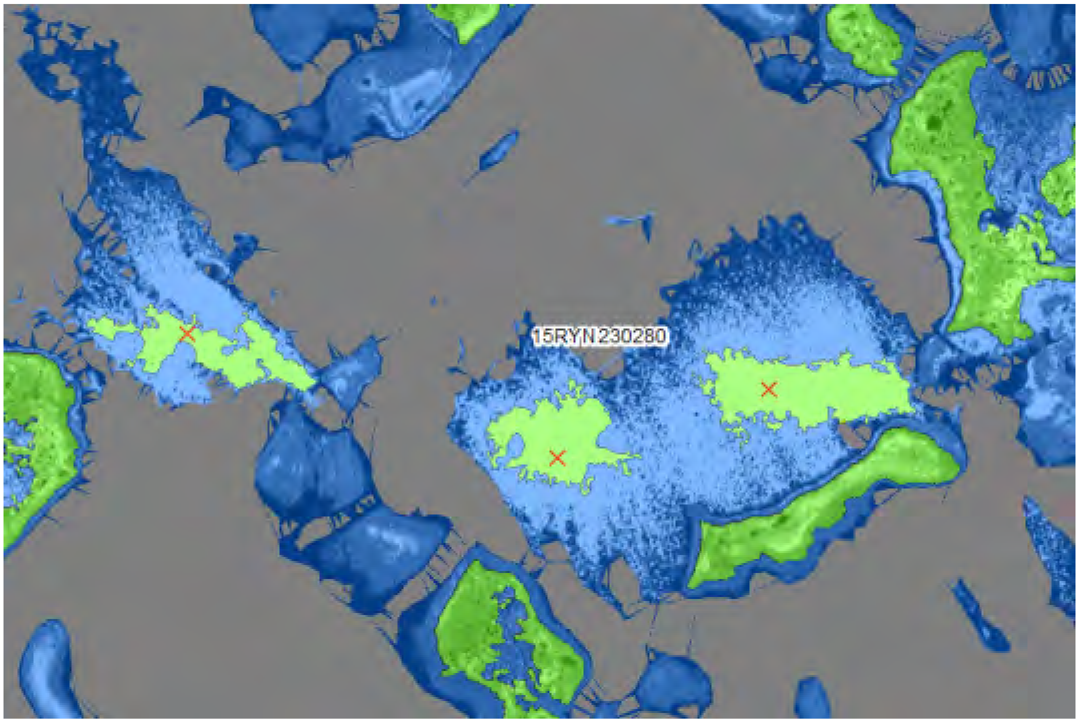

Figure 23 - Island breaklines are colored transparent green, Tidal water breaklines are transparent blue. The LiDAR intensity image is visible underneath the breaklines. Voids in the intensity image which represent water display in tan. The image above shows areas where the issue is still prevalent.

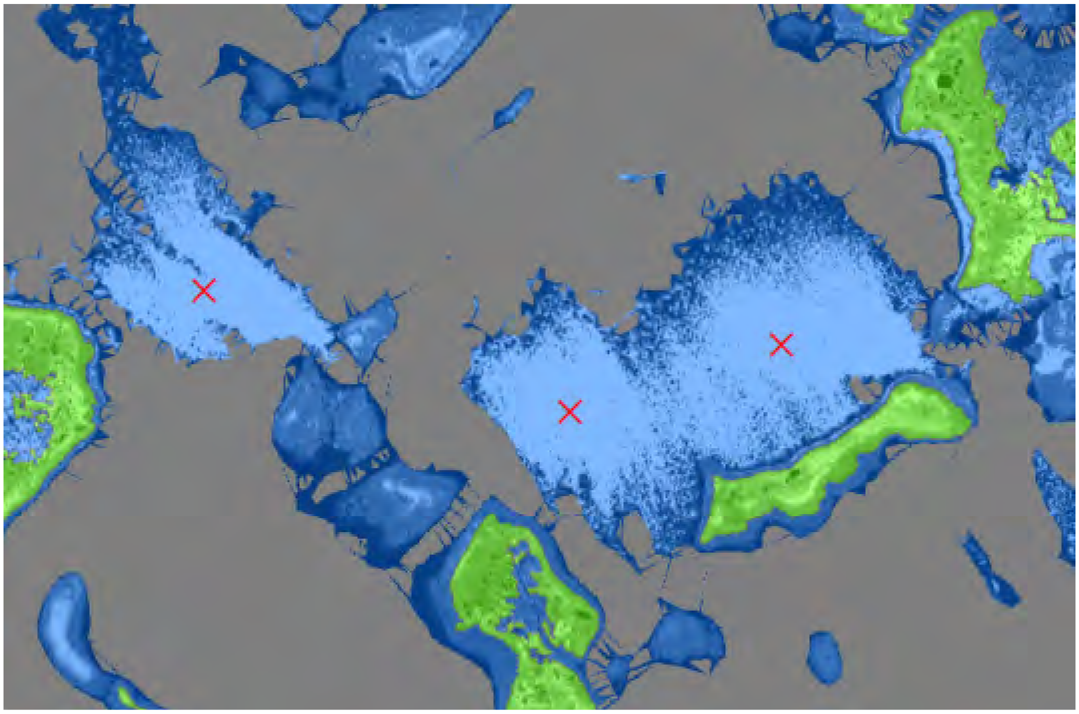

Figure 24 - Island breaklines are colored transparent green, Tidal water breaklines are transparent blue. The LiDAR intensity image is visible underneath the breaklines. Voids in the intensity image which represent water display in tan. The image above shows that the appropriate corrections were made in the third delivery.

3.2.4 Ground classified as water

In addition to the missed islands, 14 issues were identified in the first delivery, where a significant amount of ground had been classified as water. Of these 14 issues, none remain in the third delivery.

Figure 25- Tile 15RYN11265, first delivery. Island breaklines are colored transparent green, Tidal water breaklines are transparent blue. The LiDAR intensity image is visible underneath the breaklines. The image above shows ground that was captured as part of the tidal water breaklines.

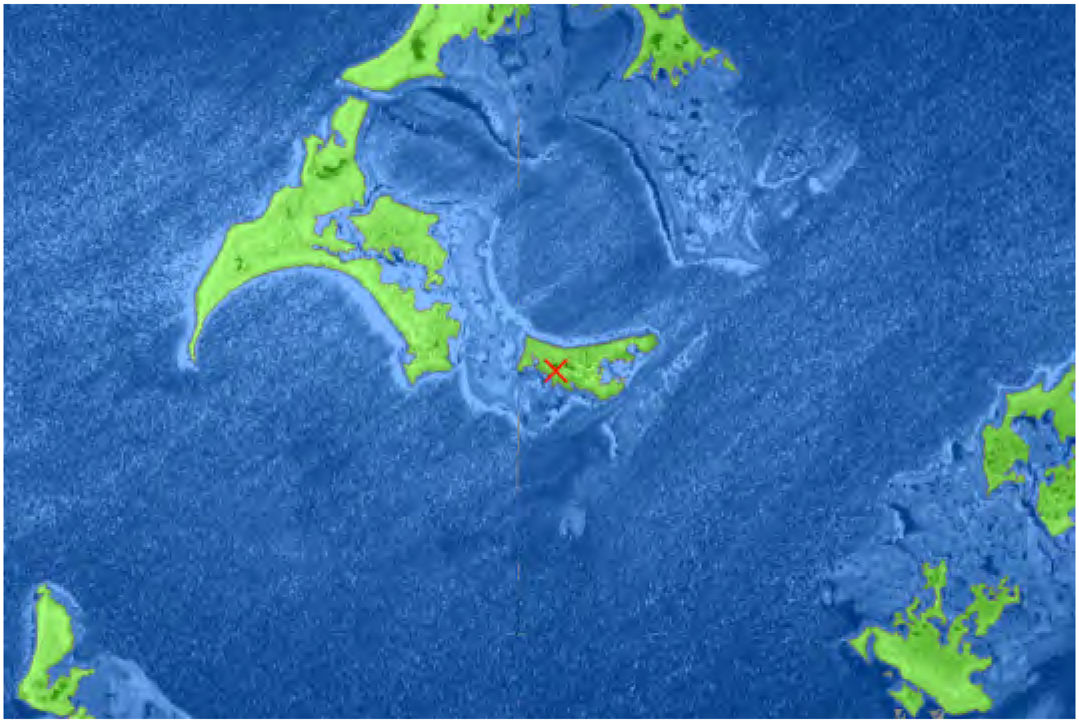

Figure 26- Figure 27- Tile 15RYN11265, third delivery. Island breaklines are colored transparent green, Tidal water breaklines are transparent blue. The LiDAR intensity image is visible underneath the breaklines. The image above shows that the ground was appropriately changed to the island breakline feature class.

3.2.5 Water body greater than 2 acres not captured

Dewberry identified six water bodies that are greater than 2 acres but are not captured by the breaklines. Dewberry can confirm that Woolpert has addressed all of these issues in the second delivery.

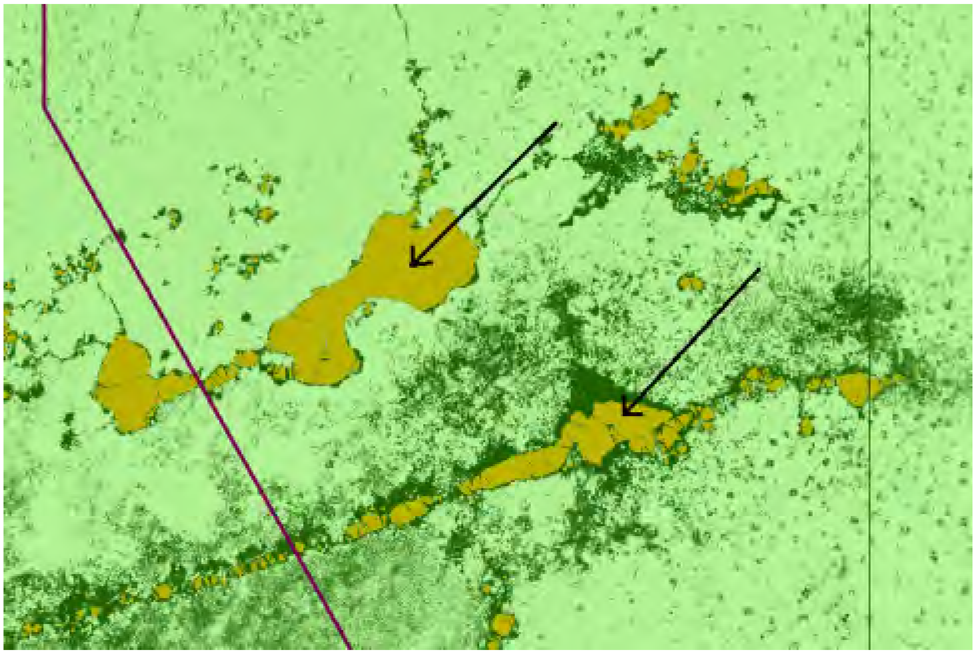

Figure 28 – Island breaklines in transparent green over LiDAR intensity image. The two identified water bodies were not captured as water. They measure over six acres each. The purple line denotes the Louisiana project boundary.

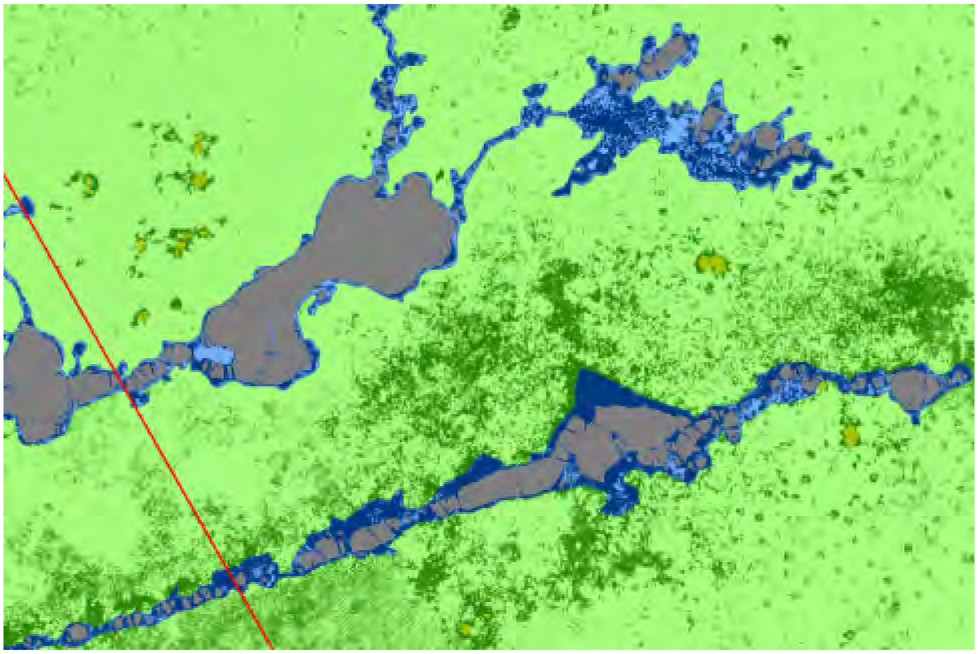

Figure 29 - Island breaklines in transparent green and tidal water breaklines over LiDAR intensity image. The two identified water bodies have been correctly captured in the second delivery. The red line denotes the Louisiana project boundary.

3.3 Breakline Quantitative Review

The Quantitative Vertical Analysis compares the island, streams, water bodies, and tidal waters 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.

Several vertices were discovered that float above the terrain surface. In the first delivery Dewberry reviewed and identified 19 water features that significantly float above or dig below the water. Of these 19 issues Dewberry identified 11 that were not corrected in the second delivery of the breaklines. These features have a direct impact on the DEM. These issues may be caused by the predetermined “0” elevation for water body features. The land around these breaklines is lower than 0 meters causing raised water bodies in the area.

Dewberry discussed this issue with the USGS and because of the method used to collect breaklines it was determined that these floating areas would be acceptable in this delivery. The images below are provided to make the end-user aware of the issue.

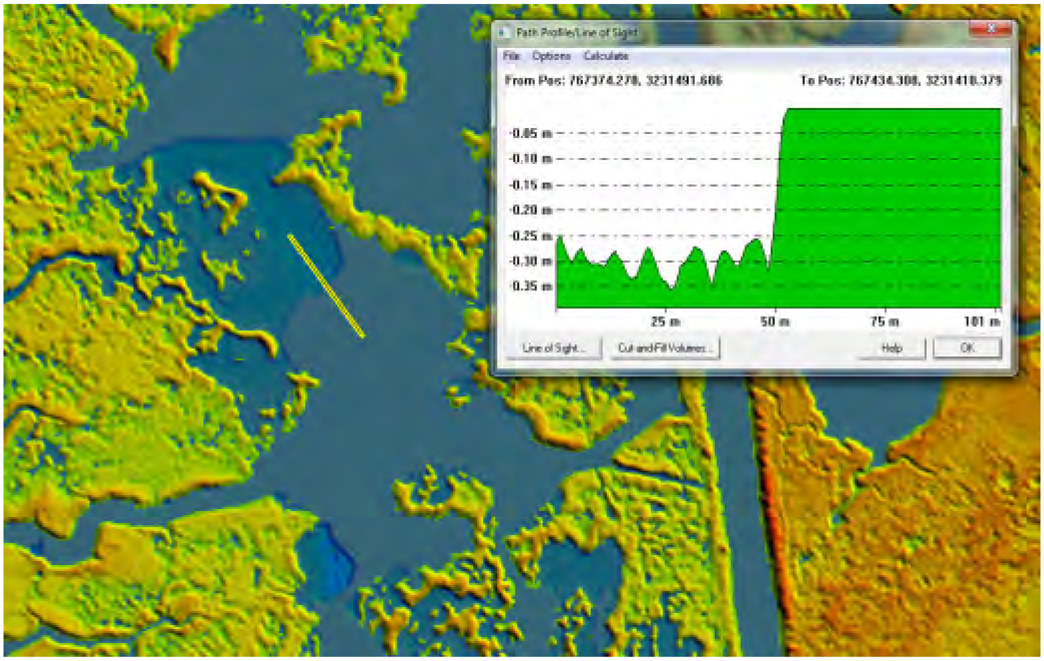

Figure 30 - An area of tidal waters which float 30 cm above the surrounding terrain. Tile 15RYN665310, first delivery.

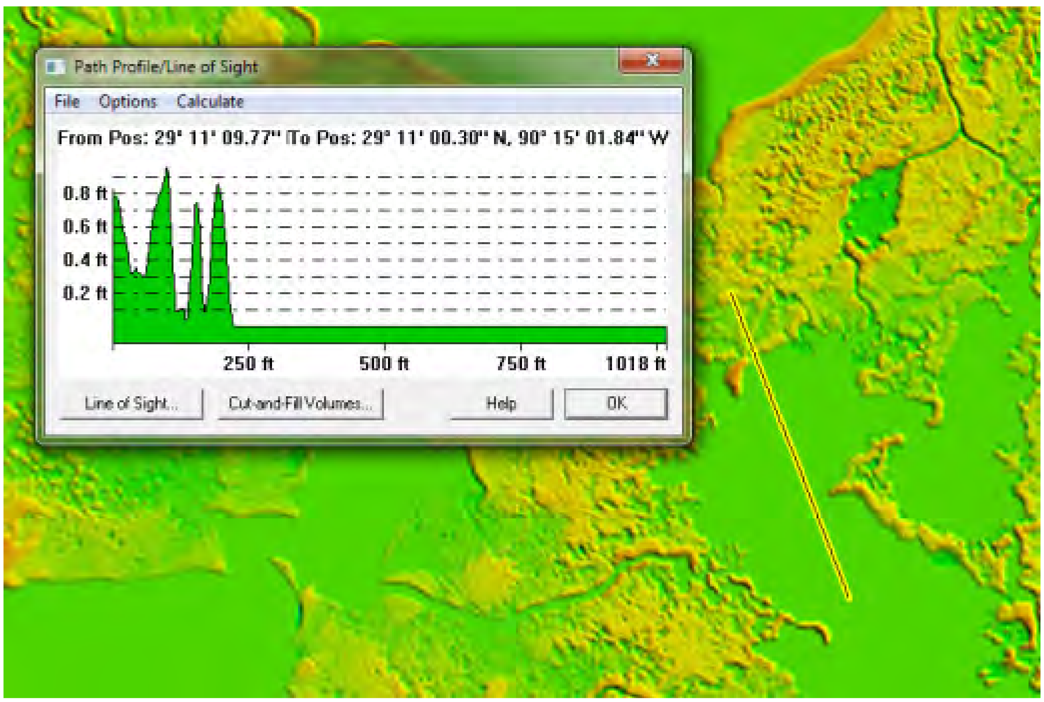

Figure 31 – Tile 15RYN665310, second delivery. This instance of floating water has been corrected.

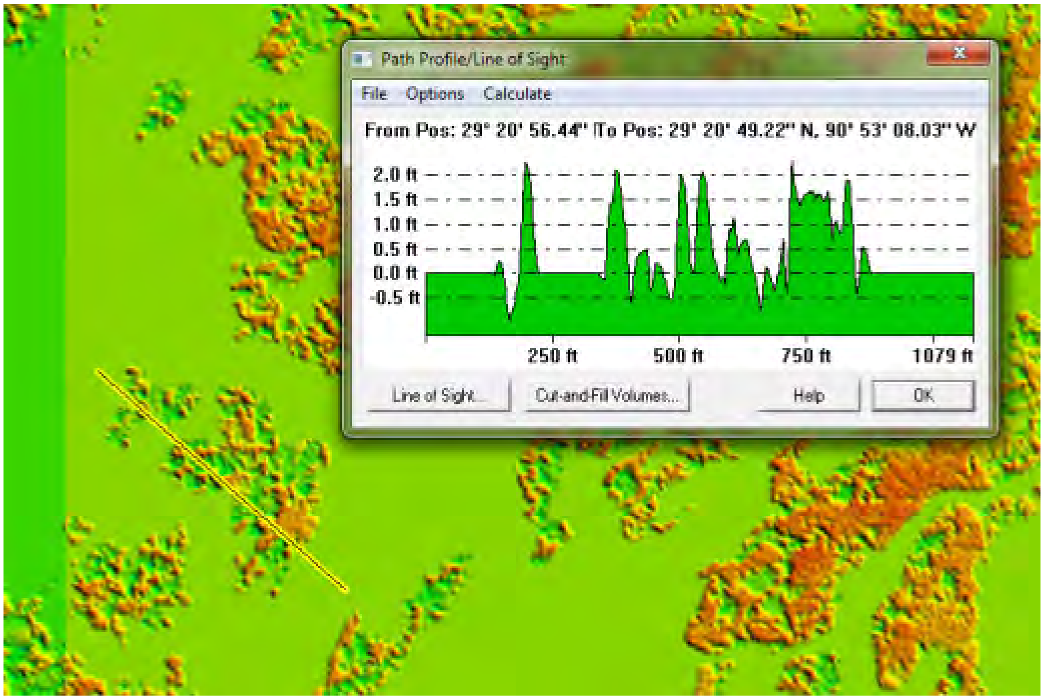

Figure 32 – Tile RYN050475, second delivery. The above image shows an example of the remaining floating water in the DEM. Dewberry recommends that no further fixes are required in these areas.

3.4 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."

Due to the number of vertices contained with the tidal waters and islands shapefiles, Dewberry could not perform certain tests with the data as delivered. Dewberry performed a simplification process that removes vertices and allows <10cm shift in the delineation of the breaklines. Only tests where the data was compared to itself were performed using this modified data. Tests that compared one feature type to another were performed using the full data. Additionally, because streams and rivers were not digitized as separate line features and because all elevations for all tidal waters were set to zero, the standard tool used to check monotonicity was not applicable. Instead, a 100% visual QA was done on DEMs looking specifically for water features that were not flat at one elevation. Two water artifacts were identified, and are included in the breakline DEM errors shaplefile (Figure 33). No other issues were found. No issues were found during the automated breakline checks.

3.5 Breakline Recommendation

Dewberry recommends that the USGS accept the breaklines for this project as delivered by Woolpert.

4 Hydro-enforced Digital Elevation Model Analysis

Dewberry received hydro-enforced bare earth DEMs as part of the deliverables for the project area. The DEMs are in ESRI ArcGRID format and are 1500 meters by 1500 meters and are at a 2 meter resolution. The naming convention follows the same parameters as the LAS naming, but cuts off the "15" in front of the tile name (e.g. 15RBT085925 → rbt085925). This issue was resolved in the second delivery.

4.1 Qualitative Review

Dewberry used a proprietary tool to validate the resolution and spatial projection on all DEMs. All DEMs have the correction resolution of 2 meters. All projection information was correct and is as follows:

- Projection: NAD 1983 UTM Zone 15N
- Horizontal and Vertical Units: Meters

Dewberry performed a visual analysis on each tile. Each tile was viewed in Global Mapper. Global Mapper colors the DEMs by elevation and creates an artificial Hillshade. This helps errors or anomalies to be identified. The aforementioned issues with the breaklines and LiDAR classification are visible in the DEMs. In addition to those issues, some water issues were also identified. No issues remain in the 3rd delivery. The table below summarizes the calls (
Table 5).

Table 5 - DEM calls

Issue	Number of Occurrences in 1st Delivery	Number of Occurrences Remaining in 2nd Delivery	Number of Occurrences Remaining in 3rd Delivery
Water Artifact	2	2	0
Total	2	2	0

4.1.1 Water Issues in DEMs

These issues are likely related to the breaklines and the classification to water step, but they are clearly identified in the DEMs and therefore mentioned here. Dewberry identified several areas of water that are in the ground. These areas affect the quality of the ground and should be addressed by Woolpert. Both water artifacts were corrected by Woolpert in the third delivery of the data.

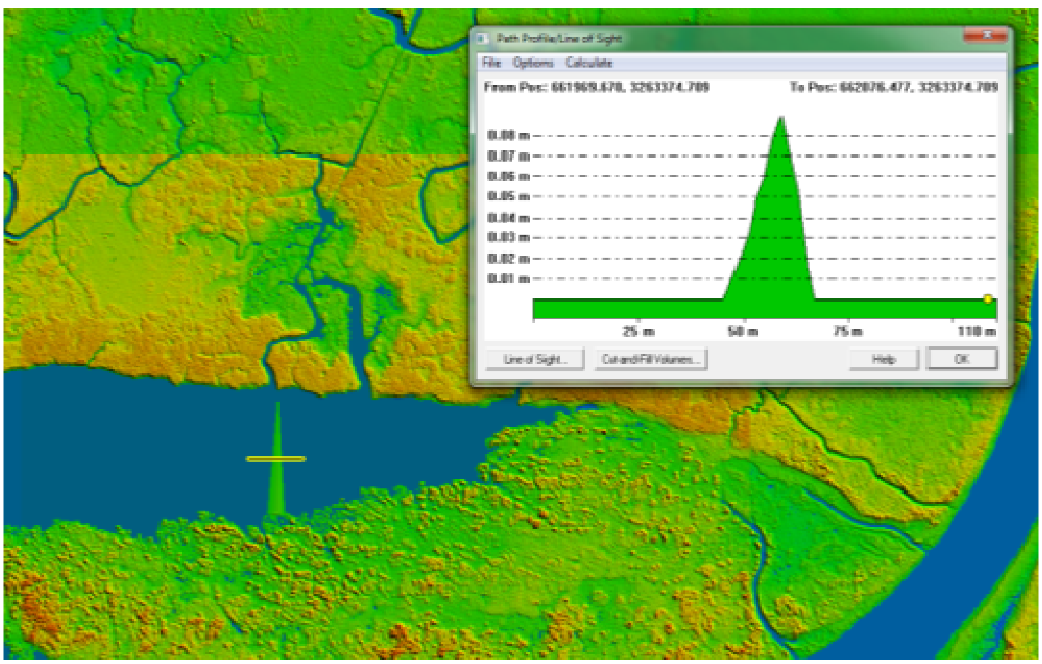

Figure 33- A water artifact identified during the visual DEM review. A total of two such artifacts were identified. Tile 15RXN615625.

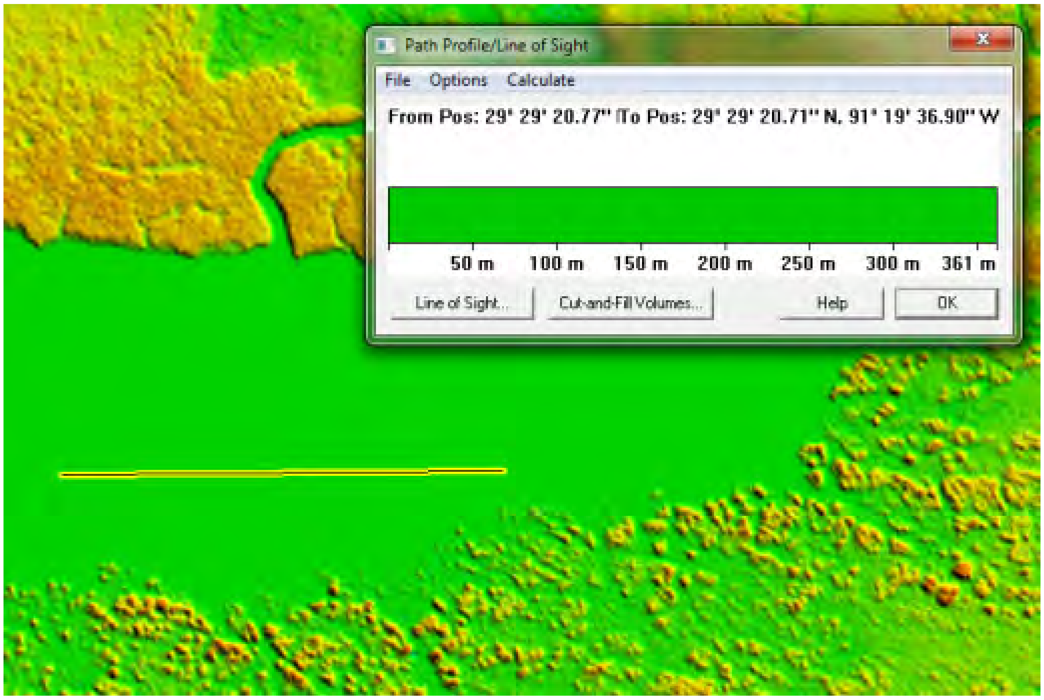

Figure 34- The water artifact identified during the visual DEM review has been corrected in the third delivery. Tile 15RXN615625.

4.2 DEM Recommendation

Dewberry recommends that the USGS accept the DEMs delivered by Woolpert.

5 Metadata

Project level metadata were delivered for the DEMs, breaklines, bare-earth LAS, raw LAS, QC Points, and the tile layout. No errors were found using the USGS MP Tool in ArcGIS. The metadata were found to be sufficient in detail and Dewberry recommends that the USGS accept this deliverable.

6 GDB

Dewberry will provide to the USGS and Woolpert a GDB that contains all the LiDAR and breakline calls. Each deliverable will contain a separate feature class with at least the following fields:

1. MainCall – A brief, generalized description of the call
2. Software – the software and test used to identify the issue
3. Description – A more detailed explanation of the identified issue
4. CallType – States whether the issue should be addressed or if it is for reference.
5. DewberryReview – Comments on the issue after the second delivery

7 Recommendation Summary

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

LiDAR Calls

- Dewberry recommends that the USGS accept the LiDAR.

Breakline Calls

- Dewberry recommends that the USGS accept the breaklines.

DEM Calls

- Dewberry recommends that the USGS accept the DEMs.

Metadata Calls

- Dewberry recommends that the USGS accept the metadata.