LiDAR Quality Assurance (QA) Report
Coastal New York LiDAR
NOAA Coastal Services Center

NOAA Contract: EA133C-11-CQ-0007

September 20, 2012

Submitted to:
NOAA Coastal Services Center

Prepared by:
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1 Executive Summary

Contract:	**Production Contractor:**	**Date Prepared:**	**Delivery #:**	**Dewberry Recommendation:**
Coastal New York LiDAR	Photo Science, Inc.	9/20/2012	Area 1, Delivery 2	Accept All Data for Priority Area 1 (Hudson River)

Data History:

- Area 1, Delivery 2

The following LiDAR quality assurance report documents Dewberry's second review of LiDAR data and derived products for the Priority Area 1 of the Coastal New York LiDAR Project by Photo Science, Inc. (PSI) for the NOAA Coastal Services Center. Priority Area 1 consists of approximately 481 square miles that amount to 755 LAS tiles (1500 meters x 1500 meters) and 237 hydro enforced DEMs (3000 meters x 3000 meters). Each tile contains LAS point cloud data classified according to the ASPRS classification scheme. The deliverables also include an ESRI Geodatabase containing hydrographic breaklines.

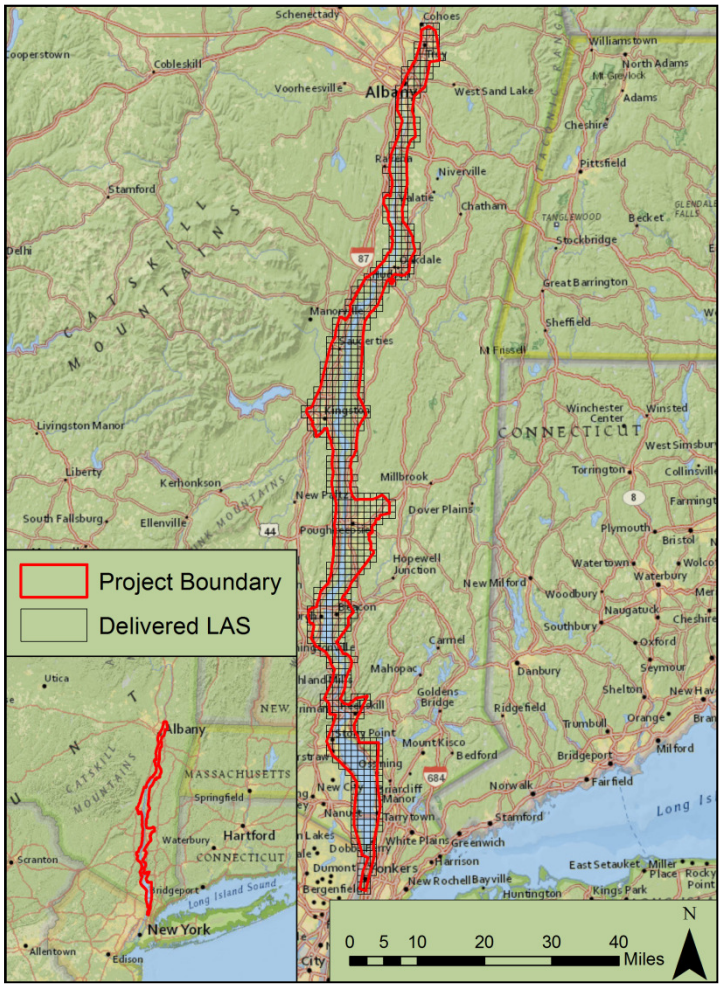

Figure 1 - Location of LAS tiles for Area 1.

The LiDAR data and derived products were processed through Dewberry's comprehensive quantitative/qualitative review. 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. As this is the second review of the data, only areas previously identified for corrections were reviewed.

The LiDAR data for the Coastal NY Priority Area 1 was thoroughly examined by Dewberry for completeness and conformity to project specifications. Vertical accuracy testing will be completed when all project data has been delivered. All qualitative issues, including misclassifications and artifacts, that were identified during the first review have been corrected by PSI.

The first breakline review resulted in a few edit calls for small breakline issues, such as incomplete capture of a breakline, topological issues, horizontal placement issues, and a few breakline segments that were floating above the surrounding terrain. All issues have been corrected or addressed by PSI.

During the first review, DEM edit calls included null pixels around the project boundary and a small amount of pixels existing beyond the project boundary. All issues have been corrected in the DEMs.

While metadata is a final delivery, it was not delivered as part of the first or second delivery of Priority Area 1 data. FGDC compliant metadata should be delivered for each deliverable, including LiDAR, breaklines, and DEMs.

1.1 Deliverables Summary for Priority Area 1

Deliverable	Applicable Acceptance Criteria	Dewberry Recommendation
All-Return LAS Point Cloud Data	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 35, 36, 37, 38, 39, 41, 42, 43, 47, 50	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
Breakline Geodatabase	35, 36, 37, 38, 39, 54, 55, 56, 57	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
Hydro-Enforced DEMs	35, 36, 37, 38, 39, 43, 44, 45, 48, 49	☑ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
LAS Metadata	46	☐ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
Breakline Metadata	58	☐ Accept ☐ Accept with Comments ☐ Return for Corrections ☐ Reject
DEM Metadata	46	☐ 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 11-14 of the Quality Plan.

Overview
The goal of the NOAA Coastal Services Center LiDAR Task Order is to provide high accuracy elevation datasets of multiple deliverable products including LiDAR, hydro enforced digital elevation models (DEMs), and 3D breaklines for areas of coastal New York including Long Island, eastern Westchester, and the tidal extent of the Hudson River. The data is intended for use in coastal management decision making, including applications such as detailed mapping of areas at risk of sea level rise and the remapping of Coastal Erosion Hazard Areas. The mission of the NOAA Coastal Services Center is to support the environmental, social, and economic well being of the coast by linking people, information, and technology. NOAA Coastal Services Center is working with the New York State Department of Environmental Conservation.

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

The total project area for LiDAR acquisition is ~950 square miles. This report documents the quality of the LiDAR deliverables for Priority Area 1, which consists of ~481 square miles.

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.

2.1 LiDAR Completeness Review

Dewberry received 755 LiDAR files. 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 appropriately according to the SOW and have correct extents (1500m x 1500m).

All spatial projection information was as follows:

- Horizontal Datum: NAD83 (NSRS 2007)
- Vertical Datum: NAVD88, processed with Geoid09
- Projection: UTM Zone 18N
- Horizontal and Vertical Units: Meters

All LAS files were updated to show the NSRS 2007 adjustment with the projection information, as required by the SOW.

Each record includes the following fields (among others):

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

- Classification
- GPSI time

Dewberry creates DeltaZ orthos from the LiDAR data with a 1 meter cell size to specifically analyze how well adjoining flight lines match. If the adjoining flight lines are within 5 cm, the overlapping or adjacent pixels are colored green. If the adjoining flight lines are between 5 cm and 10 cm of each other, the overlapping or adjacent pixels are colored yellow. If the adjoining flight lines are greater than 10 cm different from each other, the overlapping or adjacent pixels are colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. When there are large portions of overlapping flight lines that are not colored green, it is an indication that the flight lines do not match each other well, may not match the ground well, may have calibration issues, and may cause flight line ridges exceeding project specifications.

Dewberry created the DeltaZ orthos from the ground points so that we could examine the relative fit of overlapping flight lines. Some yellow and red pixels are expected due to terrain change greater than 10 cm that occurs in the same 1 meter pixel, such as on embankments, berms, and cliffs. Areas of flat, open terrain or bare earth, however, should not show large elevation discrepancies between adjacent flight lines. As the image below illustrates, all adjoining flight lines for Priority Area 1 matched within specifications.

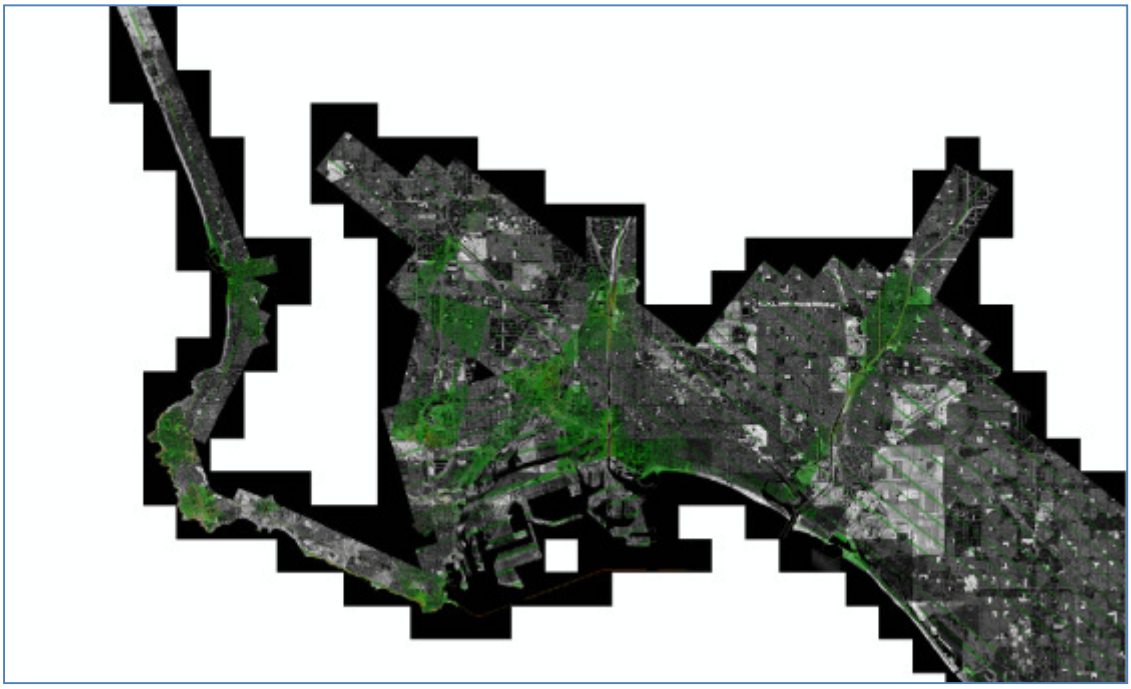

Figure 2 - DeltaZ Orthos for Priority Area 1 show adjoining flight lines match very well.

All tiles met the project requirement to have 20% overlap on adjoining swaths.

The LiDAR data has been classified to contain the appropriate classes as settled upon by PSI and NOAA:

- Class 1 (Unclassified)
- Class 2 (Bare Earth)
- Class 7 (Low point/Noise)
- Class 9 (Non tidal water)
- Class 10 (Breakline Proximity)
- Class 17 (Default Overlap Points)

- Class 18 (Ground Overlap Points)
- Class 25 (Water Overlap Points)
- Class 30 (Tidal Bare Water Overlap)

In addition, 747 tiles had points in class 11. Class 11 is generally used as withheld and is assumed to be used as such for this project.

2.2 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. With a nominal point spacing of 1.0 meters, the expected total number of points per tile should be approximately 2.3 million. Utilizing the full point cloud the mean in PSI's Priority Area 1 is approximately 5 million points per tile, which equates to a nominal point spacing of 2.2 points per square meter.

2.3 LiDAR Qualitative Review

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

- The point density is homogenous and sufficient to meet the user's needs;
- The ground points have been correctly classified (no man-made structures or vegetation remains, no gaps except over water bodies);
- The ground surface model exhibits a correct definition (no aggressive classification, no over-smoothing, no inconsistency in the post-processing);
- No obvious anomalies due to sensor malfunction or systematic processing artifacts are present (data voids, spikes, divots, ridges between flight lines or tiles, cornrows, etc);
- Residual artifacts <5%

Dewberry analysts performed a visual inspection of 100% of the bare earth data digital terrain model (DTM). 100% of the Priority Area 1 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 equal to the cell size of the final DEM deliverables. 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. The table below shows a breakdown of the calls made during the first review of Priority Area 1 Data.

Table 1 - Breakdown of the edit calls made for the first delivery of Priority Area 1 LiDAR

Issue	Number of Occurrences
Aggressive Misclassification	42
Artifacts	8
Total	**50**

All issues have been corrected in the second delivery of data. There are no qualitative issues remaining in the dataset. Examples of the original issues along with corrections are shown below.

2.3.1 Aggressive Misclassification

Aggressive misclassification calls in this document imply that LiDAR points are unclassified in the delivered dataset when they should be classified to ground. This call indicates areas where some class 1 points could be reclassified to class 2, ground, to improve detail in the surface model and to more correctly model surface features. There were 42 instances of aggressive misclassification identified in the first delivery of Priority Area 1. All instances of aggressive misclassification have been corrected. Examples of aggressive misclassification calls made in Priority Area 1, along with the corrections, can be found below.

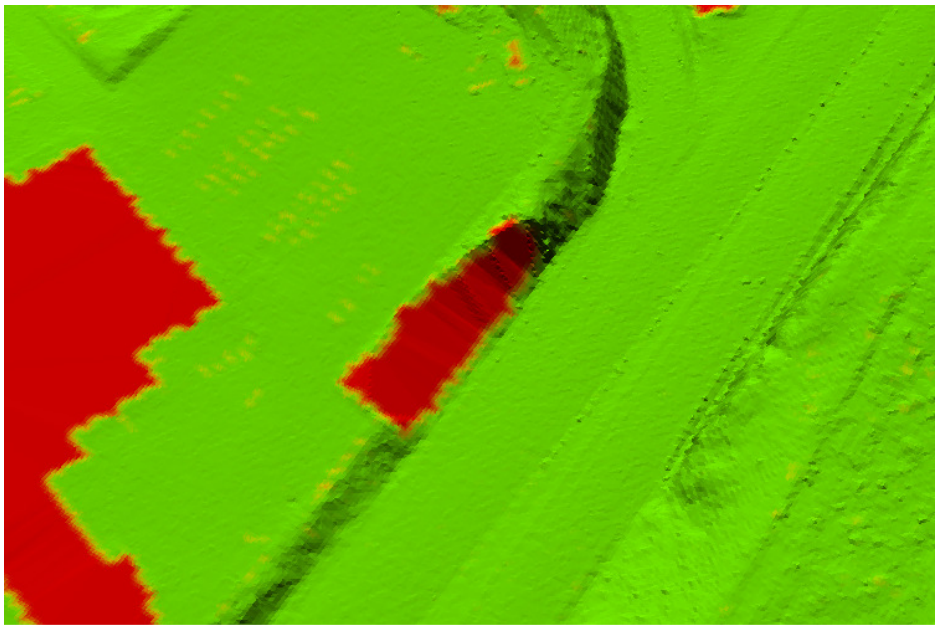

Figure 3 - Tile 18TWL805960 from the first delivery. Ground density model shows a hillside where ground points that have been removed from the ground model are colored red. Buildings and hydrographic features are expected to appear red, but red along embankments identify areas of possible aggressive misclassification.

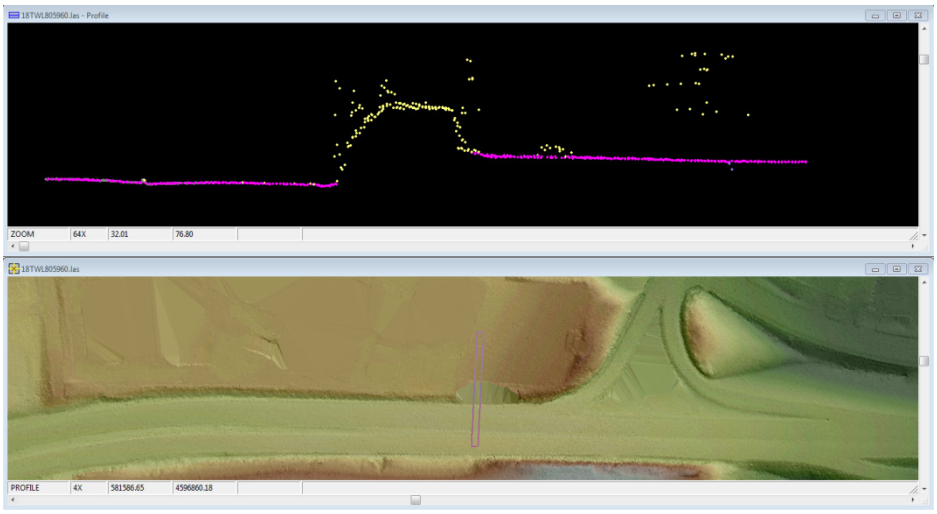

Figure 4 - 18TWL805960 from the first delivery. Profile view of LAS cloud colored by classification is shown on top while bare-earth TIN colored by elevation is shown on bottom. This image shows that there are legitimate class 1 (yellow) points that could be reclassified to class 2 (purple), in order to improve the definition of the bare-earth surface.

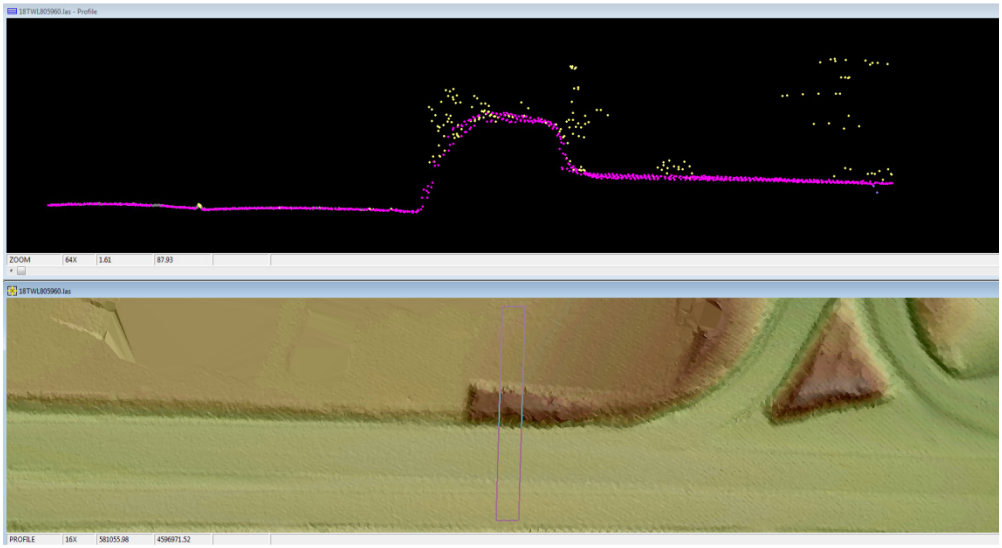

Figure 5 - 18TWL805960 from the second delivery. Profile view of LAS cloud colored by classification is shown on top while bare-earth TIN colored by elevation is shown on bottom. Class 1 (yellow) points have been correctly reclassified to class 2 (purple).

2.3.2 Artifacts

Artifacts are features that are left in the ground model that should be removed. There were 8 artifacts identified in the first delivery of Priority Area 1 and included vegetation and structures. All instances of identified artifacts have been removed in order to improve the bare-earth surface model. Examples of the artifact calls made in Priority Area 1, along with corrections, can be found below.

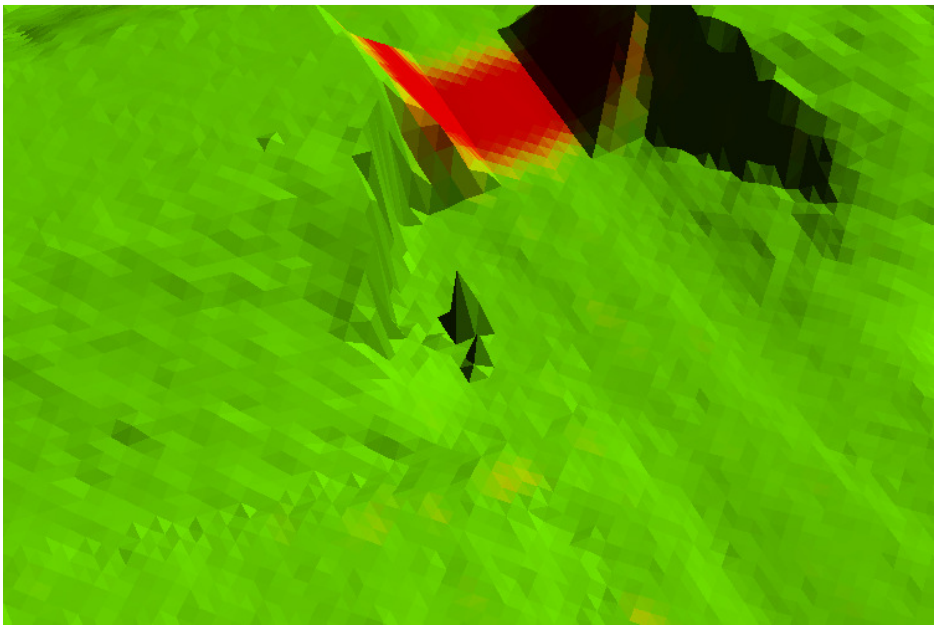

Figure 6 - Tile 18TWM985770 from the first delivery. Ground density model showing vegetation artifacts that were left in the ground model appear as spikes in the surface.

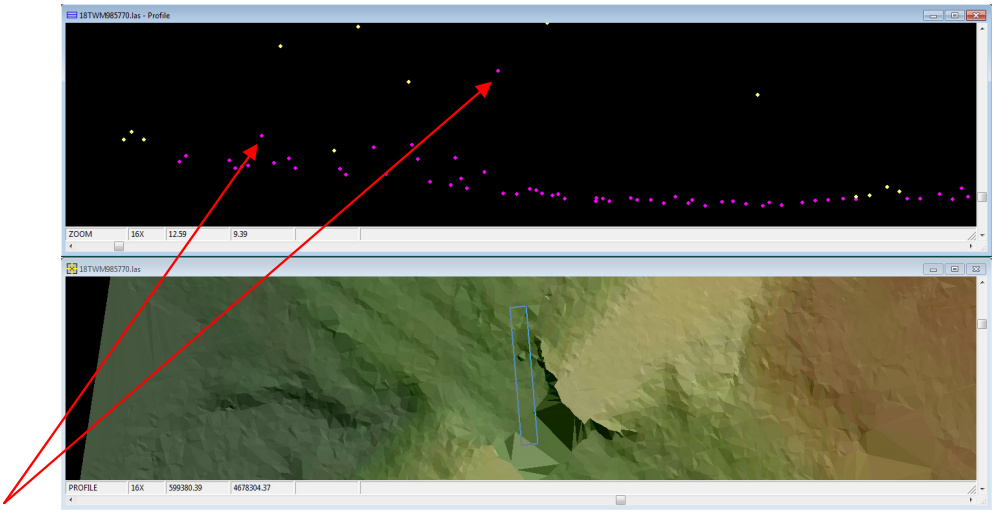

Figure 7 - Tile 18TWM985770 from the first delivery. Profile view of the LAS cloud colored by classification is shown on top while bare-earth TIN colored by elevation is shown on bottom. High ground points (purple), up to 3 meters above the true ground surface, should be reclassified to unclassified (class 1).

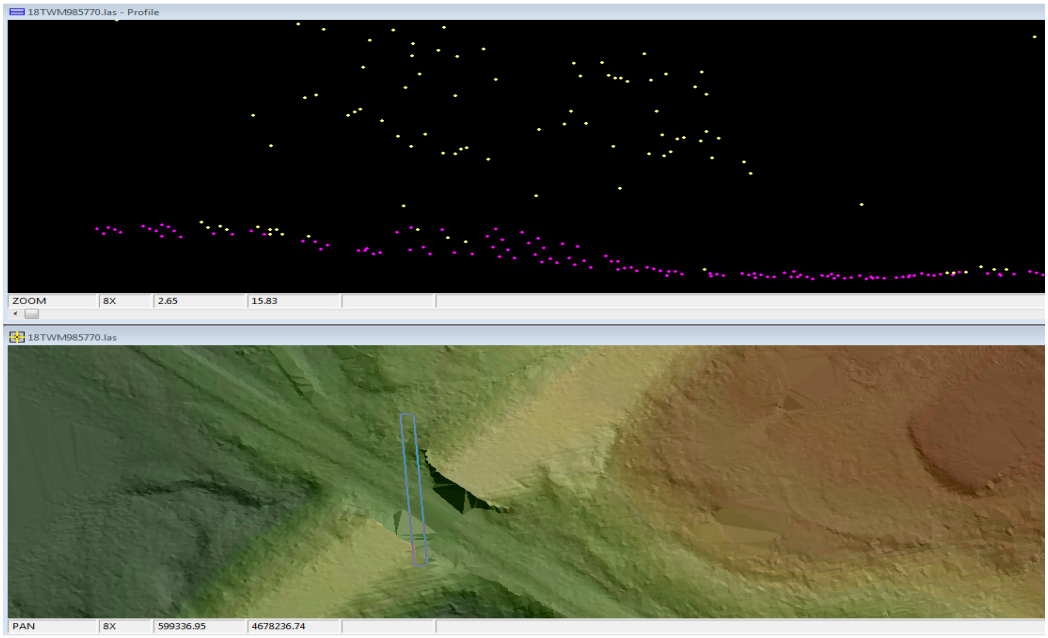

Figure 8 - Tile 18TWM985770 from the second delivery. Profile view of the LAS cloud colored by classification is shown on top while bare-earth TIN colored by elevation is shown on bottom. High ground points were correctly reclassified to unclassified (class 1).

2.4 LiDAR Recommendation

Dewberry recommends the LiDAR for Priority Area 1 (Hudson River) are accepted. All identified qualitative issues have been addressed by PSI and the LiDAR has been updated to show the NSRS 2007 adjustment in the projection information.

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. 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.

3.1 Breakline Data Overview

The breakline qualitative review starts with an overview. First, the ESRI geodatabase is reviewed in ArcCatalog for correct spatial projection and data organization.

The delivered geodatabase contained the correct feature classes, shown below:

- PONDS_AND_LAKES
- STREAMS_AND_RIVERS
- TidalWaters

The delivered geodatabase has been updated to reflect the NSRS 2007 adjustment. The coordinate system of the delivered breaklines is defined below:

- Horizontal Datum: NAD83 (NSRS 2007)
- Vertical Datum: NAVD88
- Projection: UTM Zone 18N
- Horizontal and Vertical Units: Meters

3.2 Breakline Completeness Review

The breakline completeness review includes ensuring all necessary features are present and have the correct extents.

The breaklines 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.

3.3 Breakline Qualitative Review

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. A breakdown of the edit calls made during the first review of Priority Area 1 data can be seen in the table below.

Table 2 - Breakdown of the edit calls made for the first delivery of Priority Area 1 Breaklines

Issue	Number of Occurrences
Breakline Should Be Removed	6
Horizontal Placement Issues	12
Total	**18**

All issues have been corrected or appropriately addressed in the second delivery of data. There were a few edit calls requesting the expansion of tidal water breaklines. PSI did not make any changes in these areas. Dewberry agrees with this course of action as upon further review, these calls are placed in areas of "wet" ground, but not water. The breaklines model the correct extent of the tidal waters as is with no further changes required. There are no qualitative issues remaining in the dataset. Examples of the original issues along with corrections are shown below.

3.3.1 Breakline Should Be Removed

Five (5) issues were identified in the first delivery where a breakline captures ground and not water. In these instances the breaklines were smaller than the required 2 acre capture rule for ponds and lakes. One (1) issue was identified in the first delivery for a pond breakline that was collected within a larger tidal water breakline. In all instances PSI has corrected the breaklines and the corresponding DEMs and LAS files. Examples of the edit calls and corrections are shown below.

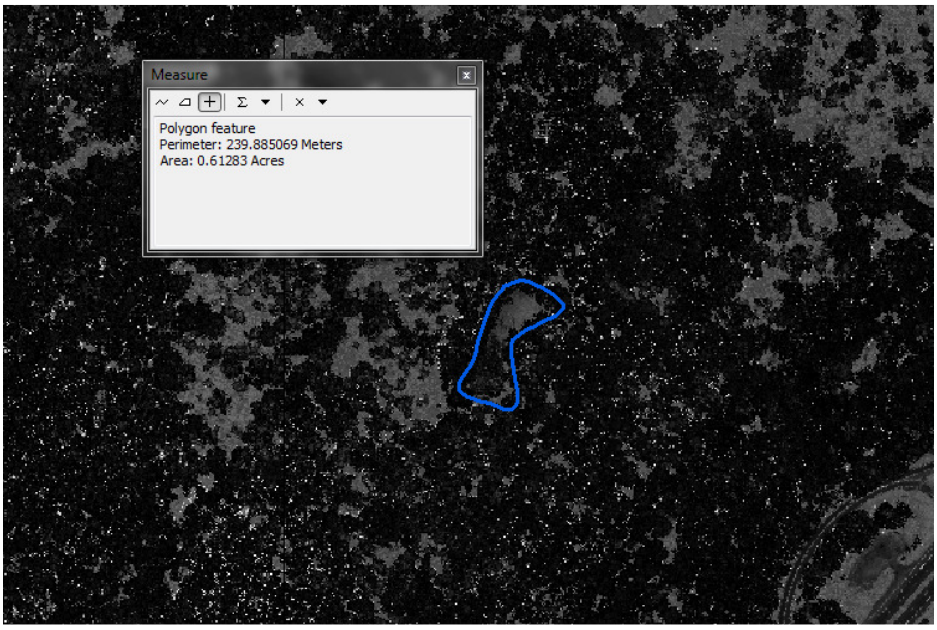

Figure 9 - Tile 18TWL805885 from the first delivery. Full point cloud intensity image shows a pond and lake breakline (blue) 0.6 acres in size that appears to capture mostly ground. This feature should be removed from the breaklines.

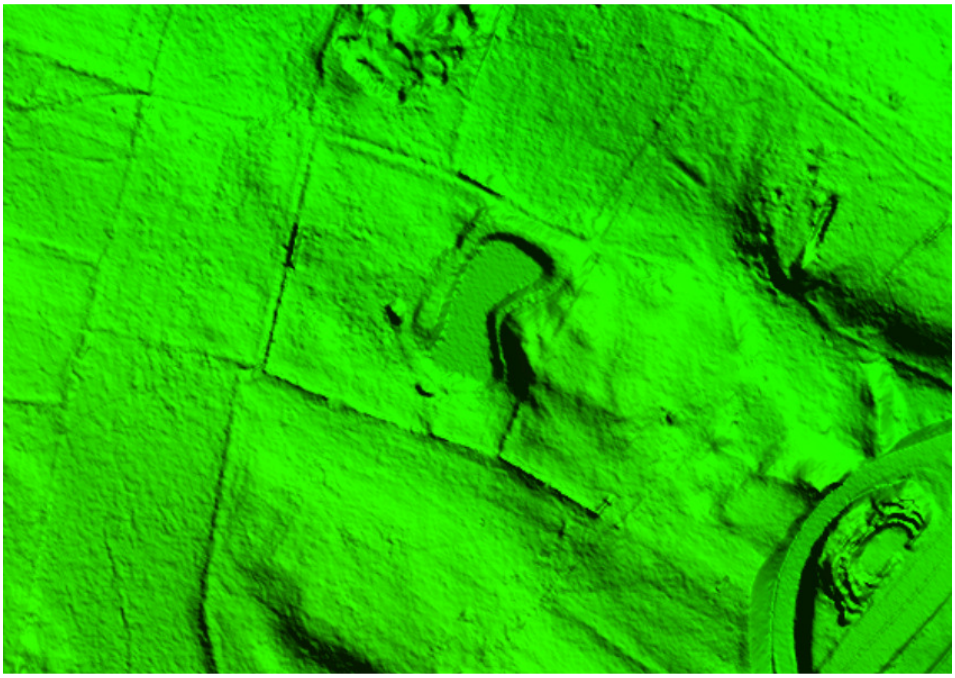

Figure 10 – DEM Tile 18TWL790870 from the second delivery. DEM image shows the pond and lake breakline has been removed and is no longer used to flatten the DEM.

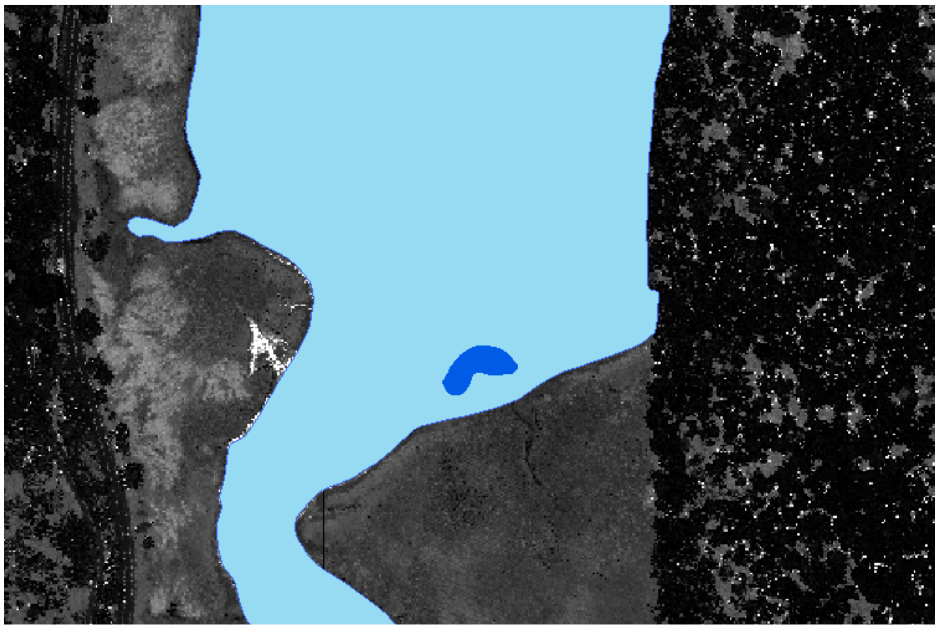

Figure 11 - Tile 18TWL850720 from the first delivery. Full point cloud intensity image shows a pond and lake breakline (dark blue) has been captured within a larger tidal water breakline (light blue). This feature should be removed from the breakline dataset.

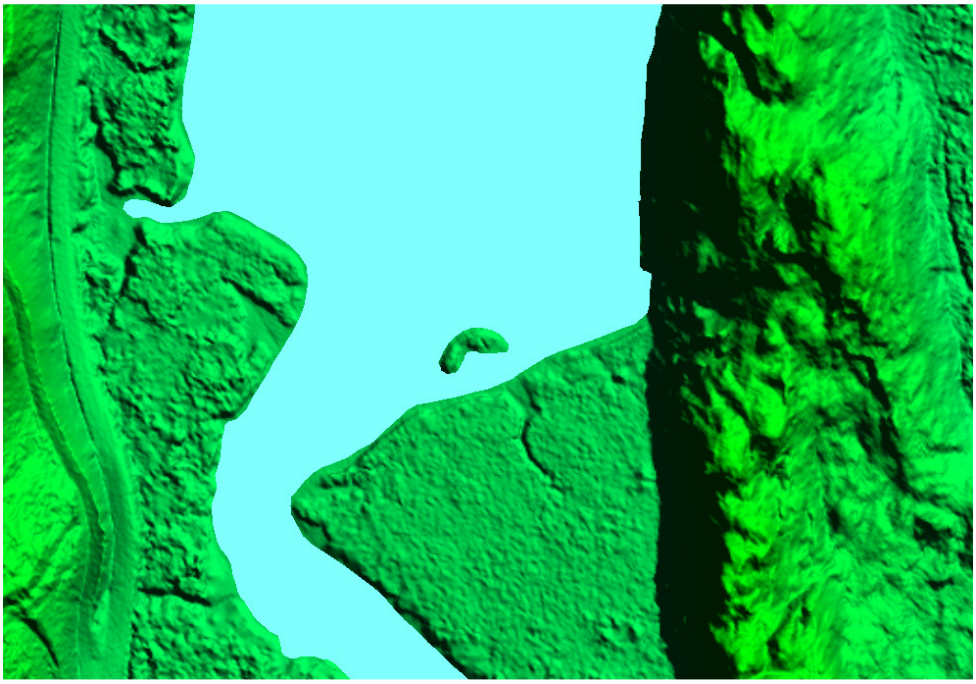

Figure 12 – DEM Tile 18TWL850780 from the second delivery. DEM image shows pond and lake breakline has been removed from tidal water breakline (light blue) and now correctly represents an island in the dataset.

3.3.2 Horizontal Placement

Ten (10) areas were identified in the first area where the current hydrographic breaklines do not capture all of the water in the immediate area. In the second delivery, these breaklines were either extended to fully capture the hydrographic feature or addressed with comments reflecting that extending the current

breakline would only capture “wet” ground and not actual water. One (1) issue in the first delivery occurred on a stream breakline that captured ground within the breakline. This breakline was adjusted to contain only water in the second delivery. One (1) edit call was placed in the first delivery on an island within a stream breakline that is larger than 1 acre. This island was excluded from the hydrographic breakline in the second delivery so that it is not flattened but models the ground in the final DEM deliverables. Examples of edit calls as corrections are shown below.

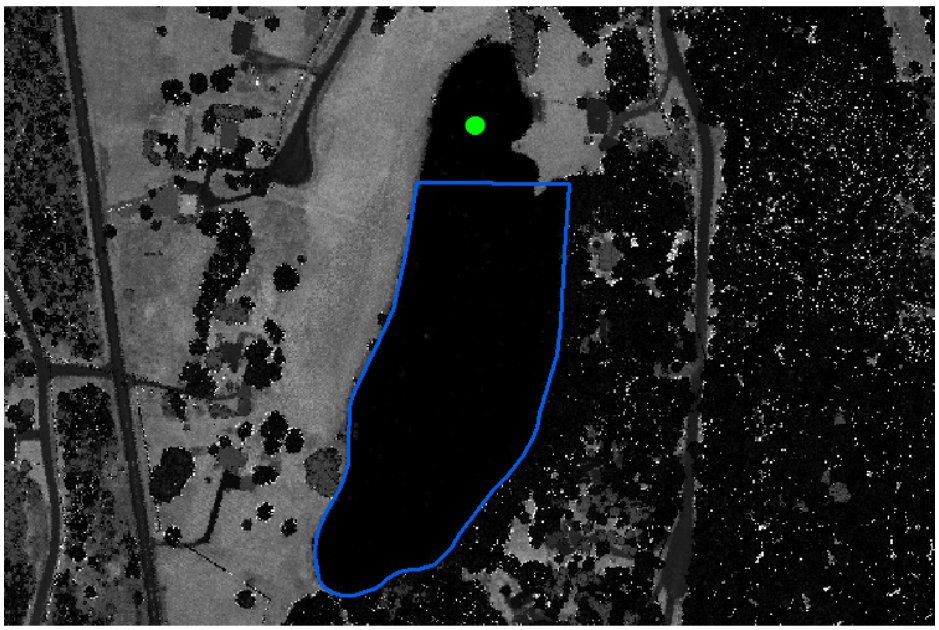

Figure 13 - Tile 18TWM910635 from the first delivery. Pond breakline (blue) is overlaid on the full point cloud intensity imagery. The breakline should be adjusted to capture all of the water in the area.

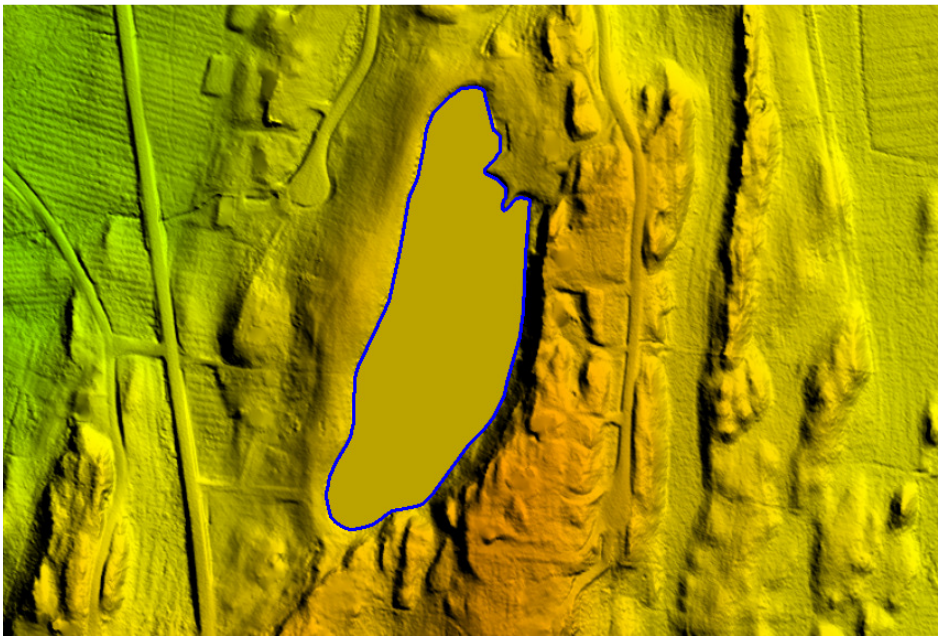

Figure 14 – DEM Tile 18TWM910620 from the second delivery. Breakline has been extended to fully capture water and has been hydro-enforced in the corresponding DEM.

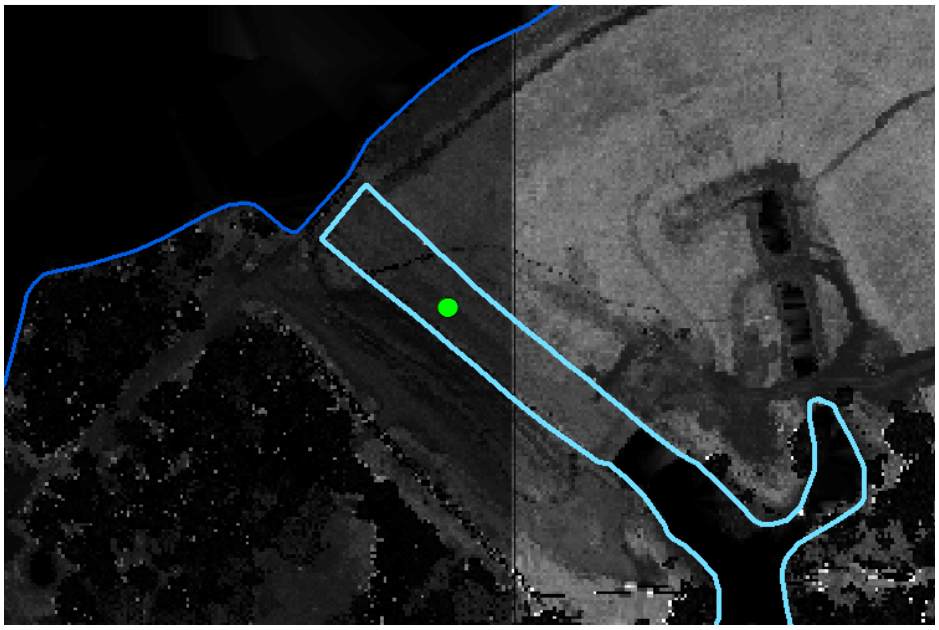

Figure 15 - Tiles 18TWM970815 and 18TWM985815 from the first delivery. Stream breakline (light blue) is overlaid on the full point cloud intensity imagery. The hydrographic stream line should be adjusted to better represent the land/water interface and to exclude ground from the breakline capture.

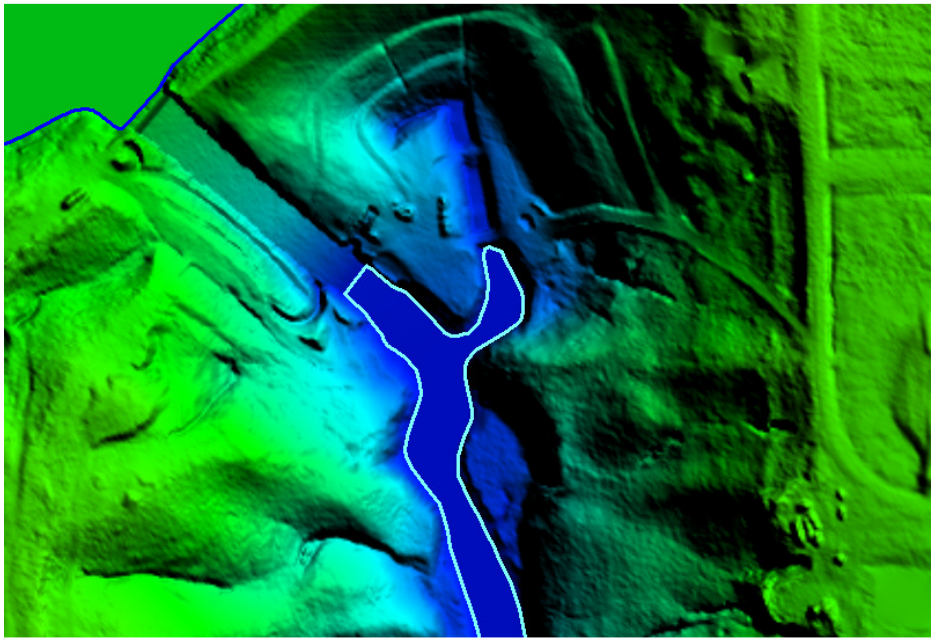

Figure 16 – DEM Tile 18TWM970800 from the second delivery. Breakline has been adjusted to exclude ground from capture and corresponding DEM has been updated to reflect those changes.

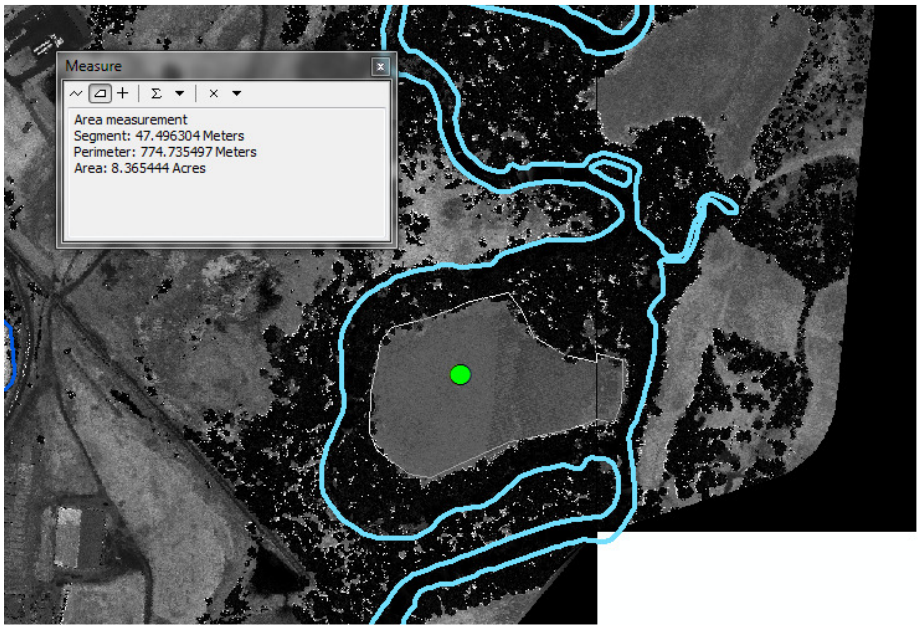

Figure 17 - Tile 18TXM015770 from the first delivery. Stream breaklines (light blue) are overlaid on the full point cloud intensity imagery. This 8 acre island should be removed from the stream breakline and can be represented with a "hole".

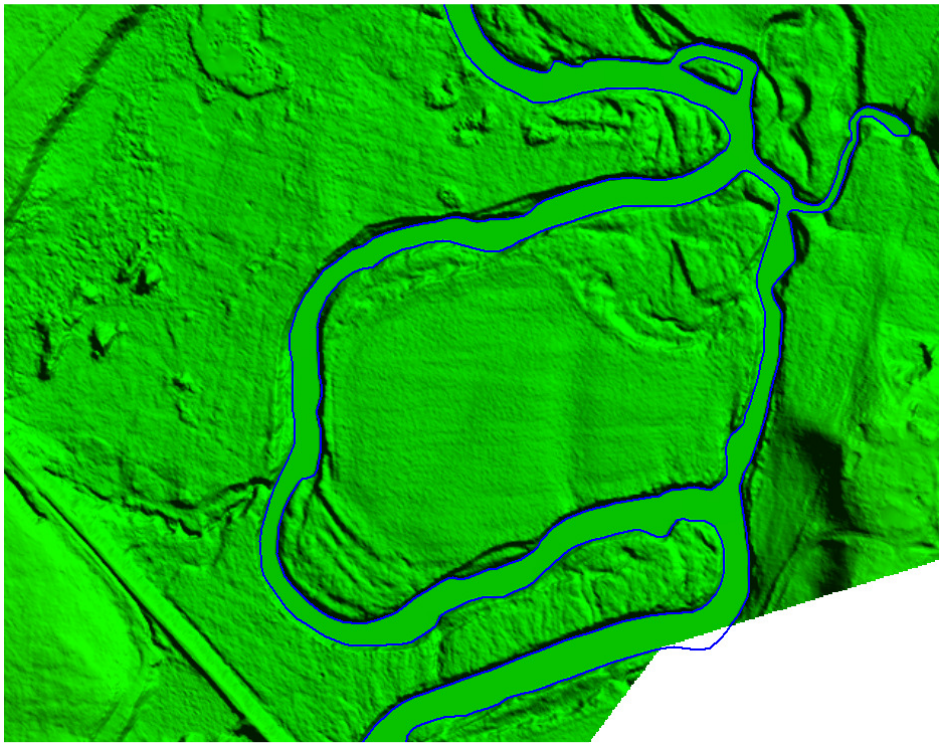

Figure 18 – DEM Tile 18TXM000770 from the second delivery. Island has been removed from stream breakline (blue) and corresponding DEM has been updated to show the island in the ground model.

3.4 Breakline Quantitative Review

The Quantitative Vertical Analysis compares the breakline vertices against the bare-earth LiDAR data. Dewberry begins this process by converting all breakline vertices to points. At the same time an ESRI

GeoTerrain is created from the LiDAR using only the ground points. The LiDAR elevation, extracted from the terrain, is recorded for every breakline vertex. An analysis of the differences in elevation between the breakline vertices and LiDAR is conducted to determine the vertical accuracy of the breakline collection.

During the first review, five (5) features were discovered that float above the terrain surface. These vertices had a direct impact on the DEM. All floating water features were addressed in the second delivery. Examples of edit calls, along with corrections, are shown in the examples below.

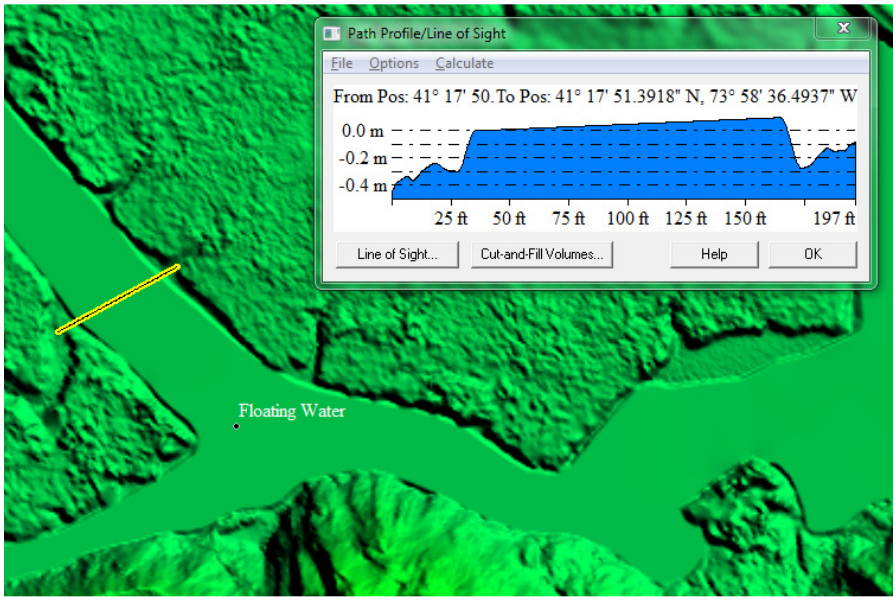

Figure 19 - DEM tile 18TWL850720 from the first delivery. The river breakline at this location is floating 0.3 meters above the ground and should be lowered accordingly.

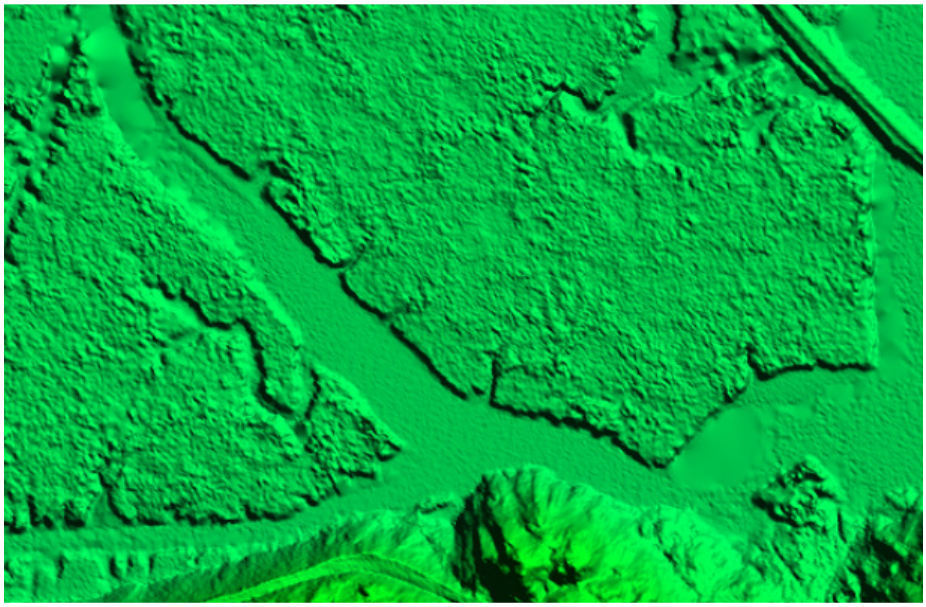

Figure 20 - DEM tile 18TWL850720 from the second delivery. This feature is actually a tidal feature and should not be enforced in the DEM. This feature has been correctly removed from the DEM and is no longer floating above surrounding ground.

3.5 Topology

One of the requirements of hydrographic 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." The issues identified during the first review with these checks are listed below:

- Adjacent Vertex Elevation Change: 3 issues with Ponds and Lakes features
- Unnecessary Polygon Boundaries: 1 issue with Ponds and Lakes features
- Feature on Feature: 1 issue with the Streams and Rivers feature
- Different Z at Intersection: 4 issues where overlapping vertices between pond/lake and stream/river features do not have matching Z-values

All topology issues have been corrected in the second delivery of Priority Area 1 data.

3.6 Breakline Recommendation

Dewberry recommends accepting the breaklines for Priority Area 1 (Hudson River). Topologic errors, horizontal placement issues, and floating breaklines have all been corrected. The breaklines now show the NSRS 2007 adjustment in their projection information.

4 Hydro-enforced Digital Elevation Model Analysis

Dewberry received 237 hydro-enforced bare earth DEMs as part of the deliverables for Priority Area 1. The specifications for the project require the DEMs to be 1 foot cell size, tiled in 3,000 meters by 3,000 meters tiles and projected to NAD83 (NSRS 2007) UTM Zone 18 , Meters. DEMs are to be free of artifacts, gaps, and artificial smoothing.

4.1 Qualitative Review

Dewberry ran a proprietary tool on all of the delivered DEMs to check their size and completeness. All the DEMs were correctly formatted with a 1 foot cell size and were in 3,000 m by 3,000 m tiles. The DEMs in the first delivery were not projected to include the NSRS 2007 adjustment. All DEMs have been updated in the second delivery to include the NSRS 2007 adjustment in their projection information.

The following figure illustrates the extent of the DEMs for Priority Area 1.

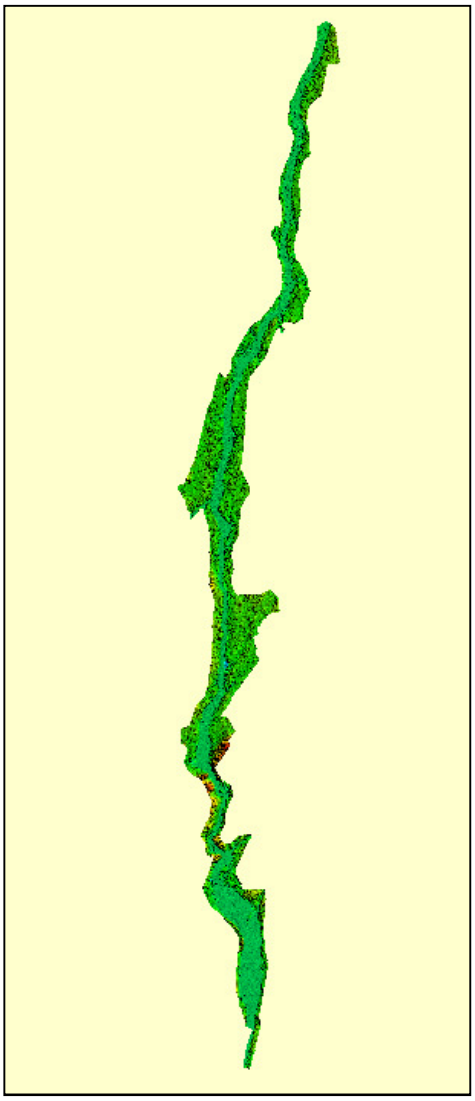

Figure 21 - DEMs for Priority Area 1

4.2 Qualitative Review

Dewberry performed a visual analysis. The DEMs were reviewed in Global Mapper. This software allows the viewer to see the DEMs as if in 3D. This helps with the identification of errors and anomalies. The DEM is required to be free of artifacts, gaps, and artificial smoothing. The table below summarizes the DEM edit calls made during the first delivery review.

Table 3 - Breakdown of the edit calls made for the first delivery of Priority Area 1 DEMs

Issue	Number of Occurrences
Data Void	4
Extent Issues	5
Total	**9**

All issues have been corrected in the second delivery of data. There are no qualitative issues remaining in the dataset. Examples of the original issues along with corrections are shown below.

4.2.1 Data Void

Four (4) edit calls were identified in the first delivery where the DEM did not extend to the project boundary. All instances of voids have been corrected in the second delivery. Examples of the void edit calls, along with corrections, are shown below.

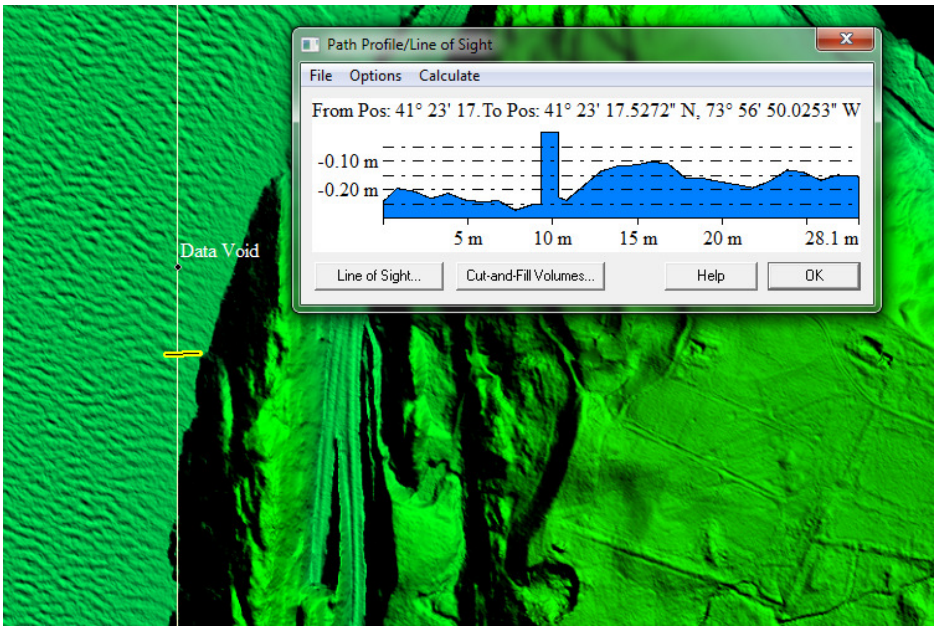

Figure 22 - DEM Tiles 18TWL850810 and 18TWL880810 from the first delivery. There is a vertical strip of null pixels that is represented by a 0 elevation in global mapper.

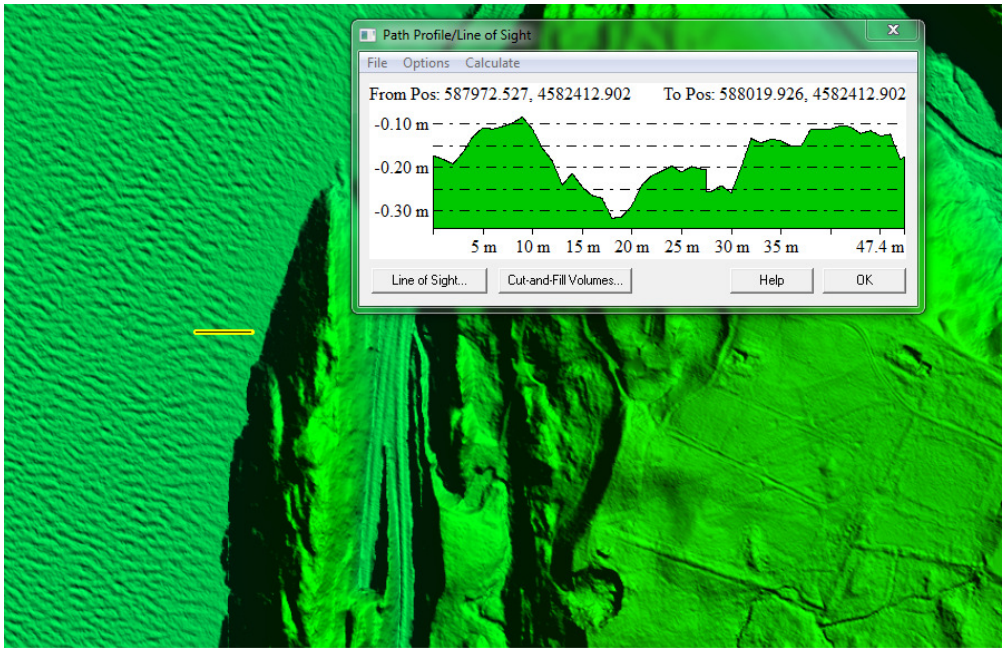

Figure 23 - DEM Tiles 18TWL850810 and 18TWL880810 from the second delivery. Data voids have been corrected.

4.3 DEM Recommendation

Dewberry recommends that the DEMs for Priority Area 1 (Hudson River) are accepted. Null pixels and pixels extending beyond the project boundary have all been corrected. The DEMs have been corrected to include the NSRS 2007 adjustment in the spatial projection information.

5 Metadata

Metadata was not delivered with the Priority Area 1 deliverables. Project level metadata is required for all data products including, LAS, breaklines, and DEMs. FGDC compliant metadata should be created with sufficient content to detail the full product lineage, including flight dates and times, datum information, re-projections, re-sampling algorithms, processing steps, field records, and any other pertinent information.

Flight lines, as flown, should be delivered in ESRI GDB format and should include start and stop dates and times for each flight line. Lastly, the control points used to control the LiDAR flight missions should be delivered in ASCII format.

These deliverables have not been included in any NY Coastal dataset that has been delivered so far. These deliverables do not need to be delivery area specific, but could be delivered once for the entire project area.

6 GDB

Along with this report, Dewberry is providing a GDB named “PriorityArea01_D2_QAQC_09202012” that contains all the LiDAR, breakline, and DEM edit calls from the first review, PSI’s comments to each edit call, and Dewberry’s comments for the review of those corrections. While all issues have been corrected, the GDB is redelivered with this report as a record that all edit calls have been addressed by PSI and reviewed by Dewberry.

7 Recommendation Summary

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

7.1 LiDAR:

1. There are no remaining LiDAR issues to be addressed.

7.2 Breaklines:

1. There are no remaining Breakline issues to be addressed.

7.3 DEMs:

1. There are no remaining DEM issues to be addressed.

7.4 Metadata:

1. FGDC compliant metadata in XML format should be delivered for each deliverable product, including LiDAR, breaklines, and DEMs.
2. An ESRI shapefile or GDB showing flight lines, as flown, should be delivered for the project area.
3. An ASCII file of the control points used to control the LiDAR flight missions should be delivered for the project area.