LiDAR Quality Assurance (QA) Report
California LiDAR and Imagery QA
NOAA Coastal Services Center

NOAA Contract: EA133C-11-CQ-0007

March 20, 2012

Submitted to:
NOAA Coastal Services Center

Prepared by:
Dewberry

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1 Executive Summary

Contract: California LiDAR and Imagery Project	**Production Contractor:** Fugro EarthData, Inc.	**Date Prepared:** 3/20/2012	**Delivery #:** Full Delivery	**Dewberry Recommendation:** Accept
Data History: ❑ Area 1, Delivery 5 – Accepted 02/29/2012. ❑ Area 2, Delivery 3 – Accepted 02/29/2012. ❑ Area 3, Delivery 3 – Accepted 12/02/2011. ❑ Area 4, Delivery 5 – Accepted 03/16/2012.				

The following LiDAR quality assurance report documents Dewberry's review of LiDAR data and derived products of the California LiDAR and Imagery Project by Fugro EarthData, Inc (FEDI) for the NOAA Coastal Services Center. The project area consists of approximately 2,337 square miles that amount to 4.335 LAS tiles (1500 meters x 1500 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 Project Area.

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.

The LiDAR data for was thoroughly examined by Dewberry for completeness and conformity to project specifications. Vertical accuracy testing shows that the fundamental and consolidated vertical accuracies meet project specifications. There were some qualitative issues, including misclassifications, artifacts, and voids that was addressed by FEDI.

The breakline review resulted in a few edit calls for small breakline issues, such as a few missing features, incomplete capture of a breakline, and horizontal placement issues. The elevations of the breaklines were compared against the elevations of the LiDAR data. A few areas were identified where breakline elevations should be modified to better represent the project area. All of these issues were corrected by FEDI.

While metadata is a final delivery, it was not delivered as part of the deliverables. FGDC compliant metadata should be delivered for each deliverable, including LiDAR, breaklines, and DEMs (when they are created).

1.1 Deliverables Summary for Fugro EarthData All Areas

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.

1.2 Report Approval

Approved by: ______________________ Date: 3/20/2012
(sign & stamp)

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

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), Ortho Imagery and 3D breaklines for areas of coastal California. This data will be used to support coastal management decision making and coastal management applications such as sea level rise. 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 California State Coastal Conservancy Ocean Protection Council.

Dewberry’s role is to provide Quality Assurance (QA) of the LiDAR data and supplemental deliverables provided by Fugro EarthData, Inc (FEDI) 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 orthoimagery is being reviewed as a separate deliverable and a separate quality assurance report will be created to document those results.

The total project area for LiDAR acquisition is ~2172 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 Quantitative Review

One of the first steps in assessing the quality of the LiDAR is a vertical accuracy analysis of the ground models in comparison to surveyed checkpoints. An independent survey was conducted by McGee Surveying Consulting. This survey yielded 216 checkpoints within the Project Area in four different land cover types: Open Terrain, Marsh, Vegetation, and Urban.

Vertical Accuracy Checkpoints

Figure 2 - Survey Checkpoint map.

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 95^{th} 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 95^{th} 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.

Because the statement of work specifies that bare earth points located in marsh areas must meet a RMSE value of 15 cm, the supplemental vertical accuracy for marsh land cover was computed with both the FEMA/NSSDA and NDEP/ASPRS methodologies.

Dewberry found no errors in this section of the review.

Table 1 outlines the calculated RMSEz and associated statistics while Table 2 outlines vertical accuracy and the statistics of the associated errors as computed by the different methods.

100 % of Totals	$RMSE_Z$ (m) Open Terrain Spec=0.09 m Marsh Spec=0.15 m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.093	0.048	0.031	1.819	0.080	216	-0.228	0.493
Open Terrain	0.048	0.018	0.017	-1.144	0.045	130	-0.228	0.134
Grass/Weeds/Crops	0.173	0.133	0.095	1.225	0.112	43	-0.041	0.493
Marsh	0.117	0.103	0.089	1.023	0.057	20	0.027	0.247
Urban	0.036	0.012	0.017	-0.081	0.035	23	-0.066	0.088

Table 1: The table shows the calculated RMSEz values as well as associated statistics of the errors

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_Z$ x 1.9600) Spec=0.18m	CVA — Consolidated Vertical Accuracy (95^{th} Percentile) Spec=0.36m	SVA — Supplemental Vertical Accuracy (95^{th} Percentile) Marsh Spec=0.29m All others target=0.36m	SVA — Supplemental Vertical Accuracy (RMSEz x 1.9600) Marsh Spec=0.29m
Consolidated	216		0.221		
Open Terrain	130	0.094		0.087	
Grass/Weeds/Crops	43			0.325	
Marsh	20			0.197	0.229
Urban	23			0.065	

Table 2: The table shows the calculated $Accuracy_z$ of the FVA using FEMA/NSSDA guidelines (RMSEz x 1.9600) and the $Accuracy_z$ of the CVA using NDEP/ASPRS guidelines (95^{th} percentile). Marsh SVA is calculated with both methodologies and all other SVA is calculated using NDEP/ASPRS guidelines (95^{th} percentile).

2.2 LiDAR Completeness Review

Dewberry received 4,335 LiDAR files which cover the entire project area without gaps. 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 correct and is as follows:

- Vertical Datum: NAVD88, processed with Geoid09
- Projection: NAD83 (NSRS 2007), UTM Zone 10\11N

- Horizontal and Vertical Units: Meters

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 noted that several tile have total scan angles exceeding the project specifications of a total field of view of 40°. Data used in the ground surface that exceeds the 40° specification could potentially be skewed and not match the ground or surrounding flight lines very well.

Dewberry creates 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 9 cm of each other vertically, the overlapping or adjacent pixels are colored green. If the adjoining flight lines are between 9 cm and 18 cm of each other, the overlapping or adjacent pixels are colored yellow. If the adjoining flight lines have a vertical offset of or exceeding 18 cm, the overlapping or adjacent pixels are colored red. Large portions of flight lines that are not colored green can be an indication that the flight lines do not match each other well, may not match the ground well, and may cause flight line ridges exceeding project specifications.

Dewberry created the DeltaZ orthos using only ground points in order to examine the relative fit of overlapping flight lines. Some yellow and red pixels are expected due to terrain change greater than 9 cm that occurs in the same 1 meter pixel, such as on embankments, berms, and cliffs. In large areas of high relief, significant portions of the flight line may appear red or yellow. For California Area 2, several such areas were detected. These areas were examined further to determine if changes in terrain or actual flight line offsets were causing the coloration. In addition, flight line ridges exceeding project specifications of 9.80 cm vertical accuracy were identified and marked during the visual LiDAR QA process. It was also discovered that some areas of flight line offsets were due to temporal changes between flights rather than line calibration issues. Dewberry found seven areas of flight line offsets which exceed project specifications. Please see the LiDAR Qualitative review section of this report for more information of flight line offsets and ridges.

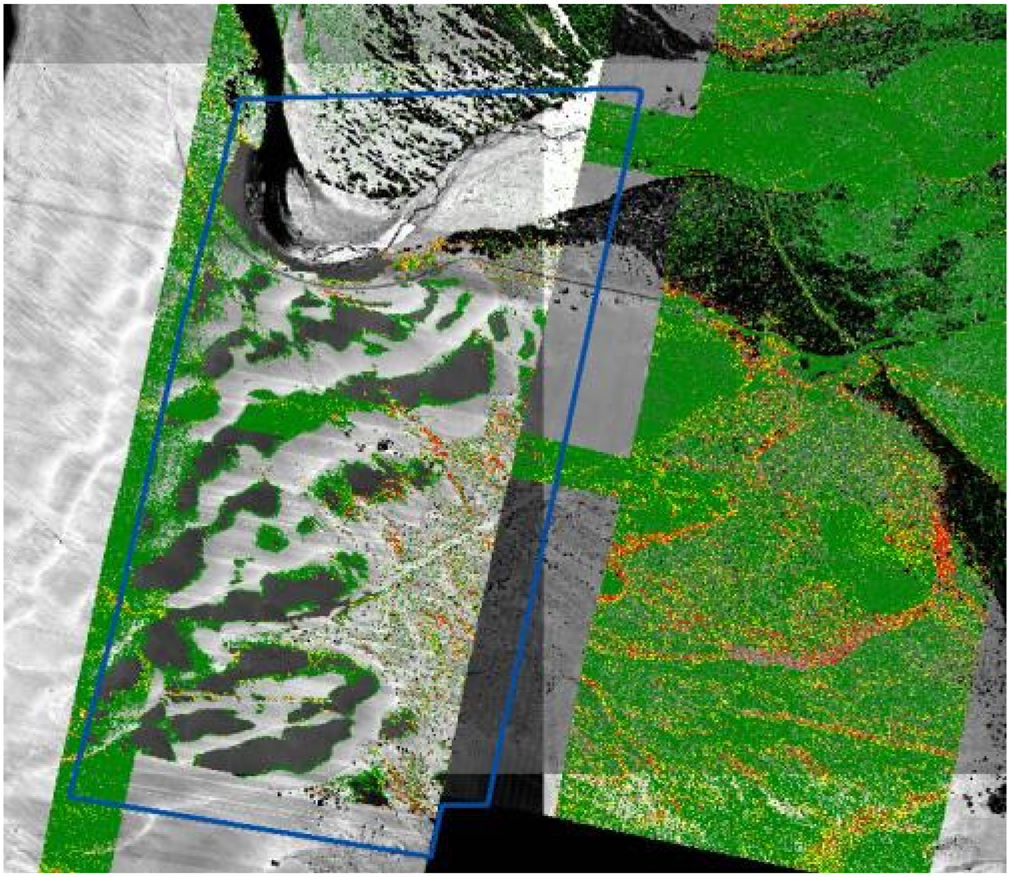

Figure 3 - The amount and placement of red and yellow pixels in the delta z ortho image above indicates the possibility of flight line offsets. Further analysis showed that two flight line ridges exist within the area outlined in blue. The remaining red areas are a product of the terrain, not an offset.

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 required:

- Class 1 (Unclassified)
- Class 2 (Bare Earth)
- Class 7 (Low point/Noise)
- Class 9 (Water)
- Class 12 (Overlap)

All points are classified into one of the aforementioned classes. There are no points existing in extraneous classes. Dewberry notes that Class 10 (mudflats) might be delivered in subsequent LAS tiles.

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. With a nominal point spacing of 1.0 meters, the expected total number of points per tile should be approximately 2.3 million. Using the full point cloud, the mean in FEDI's Project Area is approximately 4.4 million points per tile, which equates to an average nominal point spacing of 2 points per square meter.

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 reviewed 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. The table below shows a breakdown of the calls made in the review.

Table 3 - Breakdown of the edit calls made for the LiDAR

	Artifact	Misclassification	Flight Line Ridge	Sensor Anomaly	Voids	Water Classification	Total
Area 1	175	291	0	0	1	847	1314
Area 2	48	210	1	2	1	0	262
Area 3	93	136	0	0	13	4	246
Area 4	60	105	9	4	0	0	178
Total	**376**	**742**	**10**	**6**	**15**	**851**	**2000**

2.4.1 Artifacts

Artifacts are features that are left in the ground model that should be removed. Artifacts identified in the dataset include bridges, vegetation, porches and other structures, and divots or low points. Of all the edit calls in the first delivery Dewberry believes that FEDI has addressed all of these issues. Examples of the calls can be found below and a GDB that contains the locations of all edit calls accompanies this report.

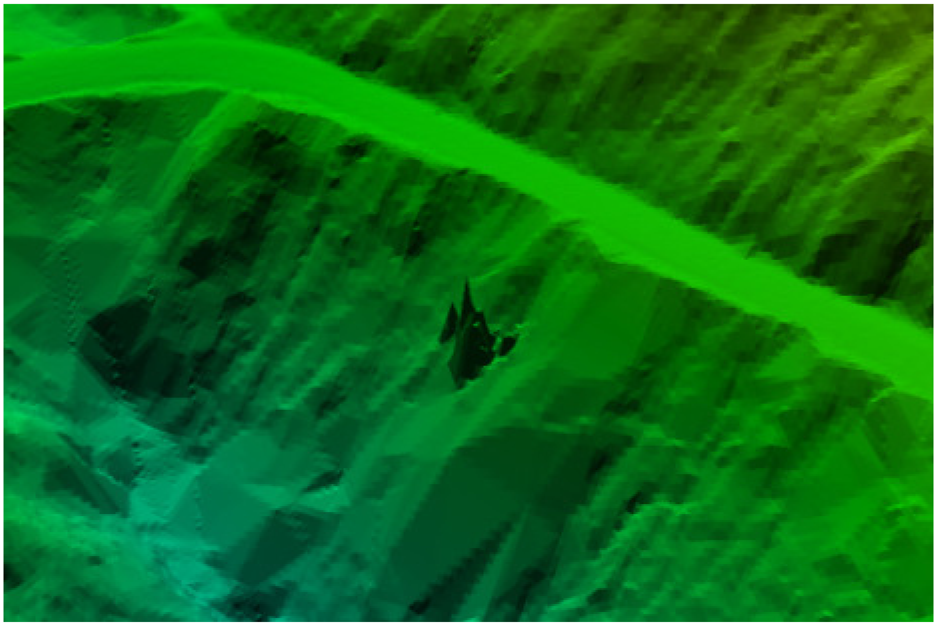

Figure 4 – Tile c6135_40065. Bare earth elevation model showing a vegetation artifact. The artifact is approximately 7 m in height and should be removed from the ground model.

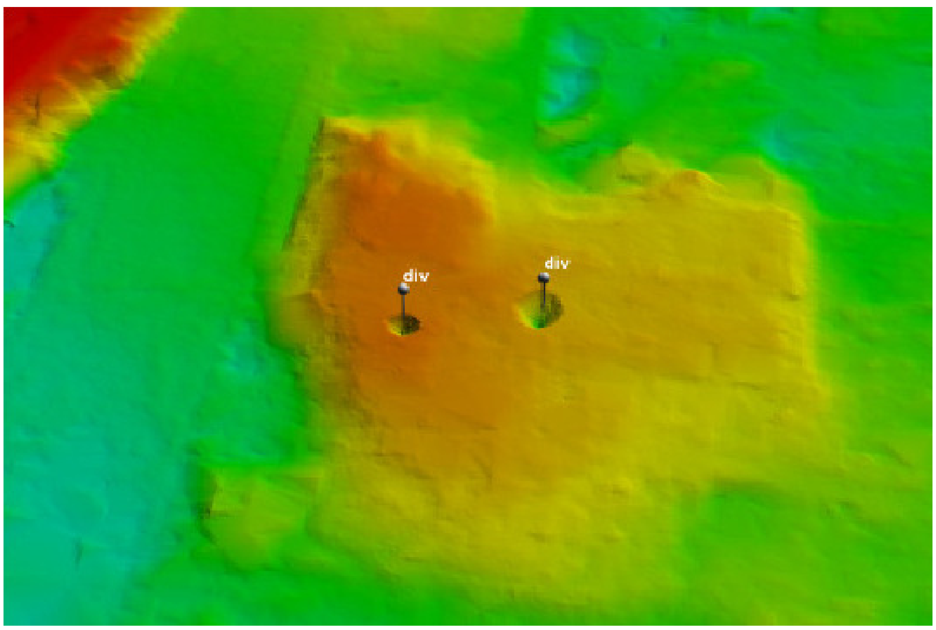

Figure 5 - Tile C4005_45225. Ground density model colored by elevation. The image shows divots that are impacting the ground model.

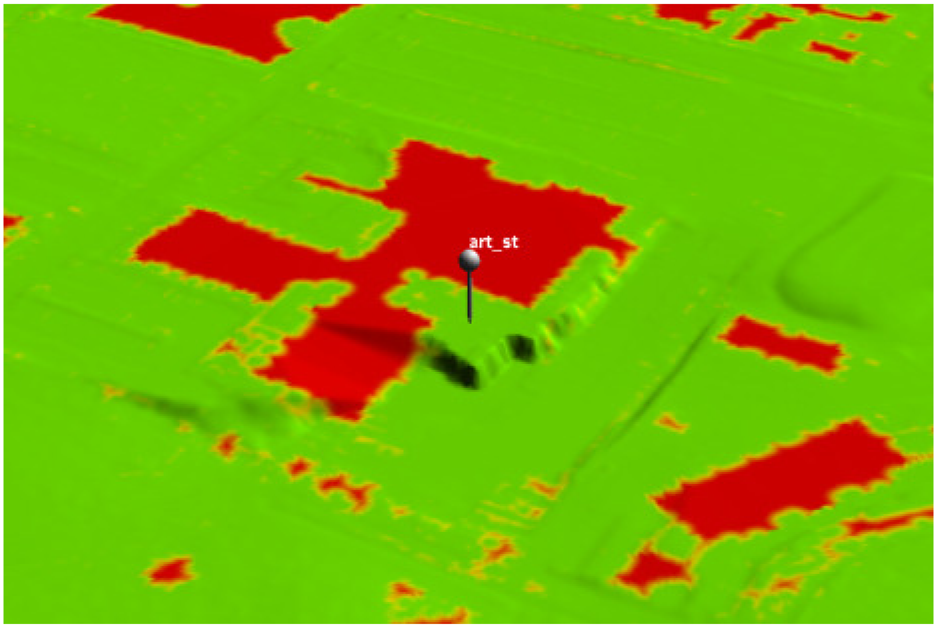

Figure 6 - Tile C4080_37290, first delivery. Ground density model. The image shows part of structure that has not been removed from the ground model.

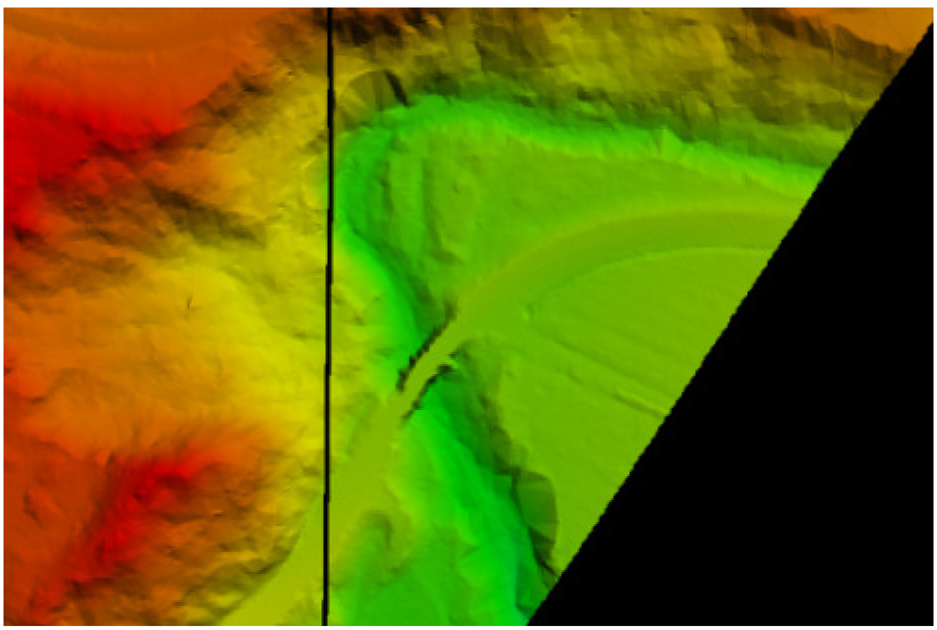

Figure 7 - Tile c2730_38070. Bare earth elevation model showing a bridge artifact left classified to ground. The bridge should be removed.

2.4.2 Misclassification

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 that points that are unclassified (Class 1) or water (Class 9) 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. Another type of misclassification occurs when an entire feature has been incorrectly classified. Dewberry believes that FEDI has addressed all of these issues. An example of a misclassification call and its corrections can be found below and a GDB that contains the locations of all edit calls accompanies this report.

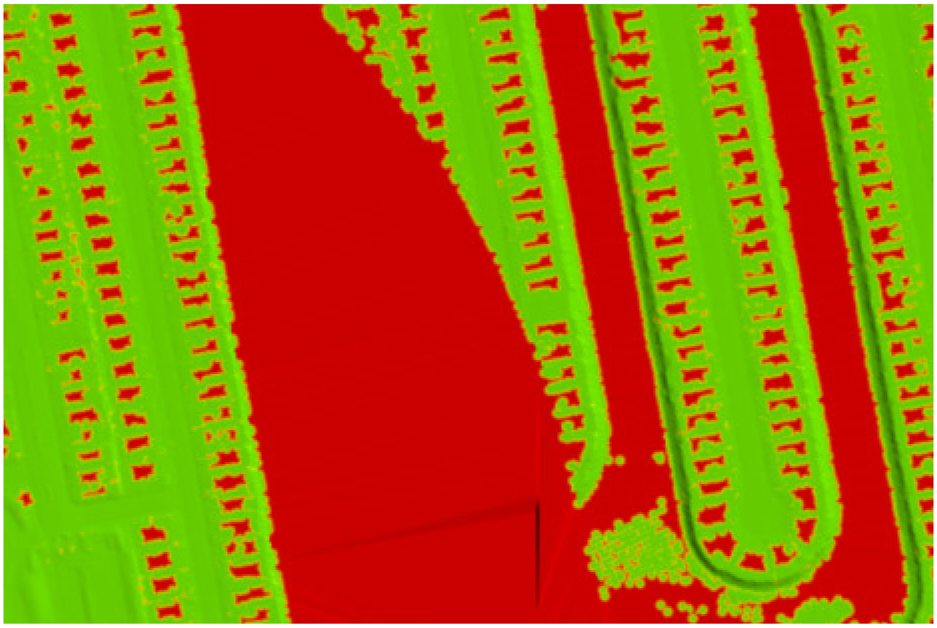

Figure 8 - Tile C2910_37920, first delivery. Ground density mode shows a large amount of ground points that have been removed from the ground model.

2.4.3 Flight Line Ridges and Temporal Changes

Flight line ridges occur when one flight line is vertically offset from an adjoining flight line. In one instance, flight line ridges found during the review were caused by temporal changes between flight times. Actual changes in ground conditions caused sporadic ridges of up to 2 or more meters in the ground models of some tiles. This occurred in along sandy beaches or riverbeds which are subject to frequent temporal changes. It was recommended that in those cases, the most recent depiction of the ground be used, which may necessitate the use of points previously classified as overlap.

LiDAR by nature can only depict the ground surface at the time of collection. This means there is no easy fix for areas where cohesive data does not exist. Dewberry's original recommendation to the data provider was to correct large flight line ridges by using only points from the most recent flight line present in the area. For the second delivery LiDAR, the majority of flight line ridges were corrected or minimized in this way, however in some cases temporal flight line ridges that are over project specifications remain. Often the data provider was able to correct the ridge originally identified, however the correction created a second ridge nearby.

The temporal flight line ridges in the dataset cannot be fully eliminated because each flight line does not fully cover the area on its own. Because of this, Dewberry does not feel that further corrections from the LiDAR provider would be appreciably beneficial. The figures below show several examples of the flight line ridges and their corrections. Figure 9 shows a ridge that was identified in the original delivery. The GDB accompanying this report contains a shapefile identifying flight line ridges detected in the first delivery and is attributed with comments from the data provider indicating whether issues existed in correcting the ridge. Additionally, Dewberry has included 6 new temporal flight line ridge calls which resulted from correcting the original ridges. These calls are added as a reference for the user.

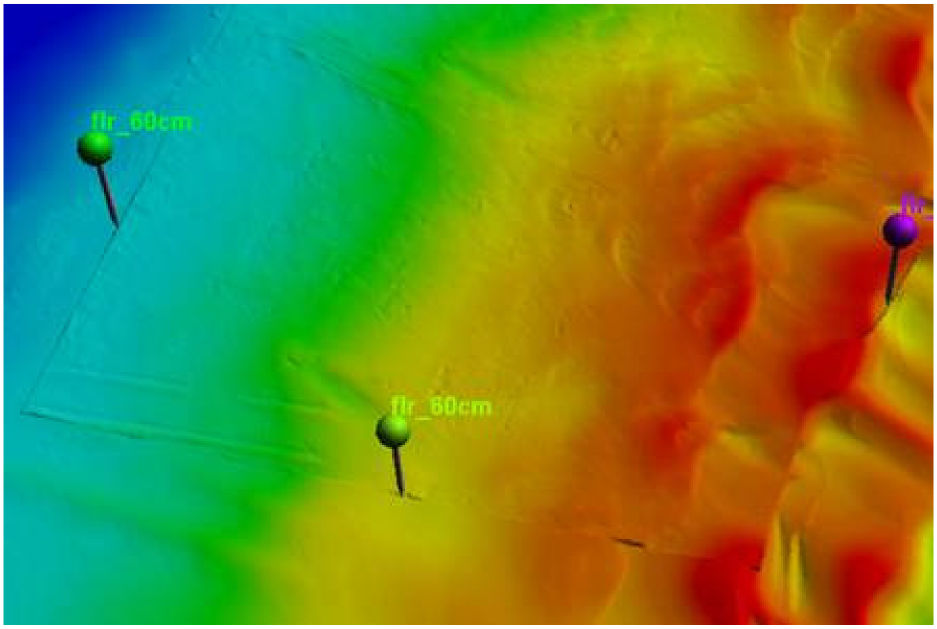

Figure 9 – Tile c7155_38820, first delivery. Ground elevation model. Changes in ground conditions between have created the unnaturally raised portion of ground seen above. Three ridges measure approximately 60 cm each.

2.4.4 Sensor Anomaly

During the review Dewberry identified a few areas where reflective paint from an airport runway caused a sensory anomaly leading to an inaccurate portrayal of the ground model. These points should be moved from ground (class 2) to unclassified (class 1). These areas were corrected by FEDI in the subsequent deliveries of the dataset. An example is shown below and a GDB that contains the location of the edit calls accompanies this report.

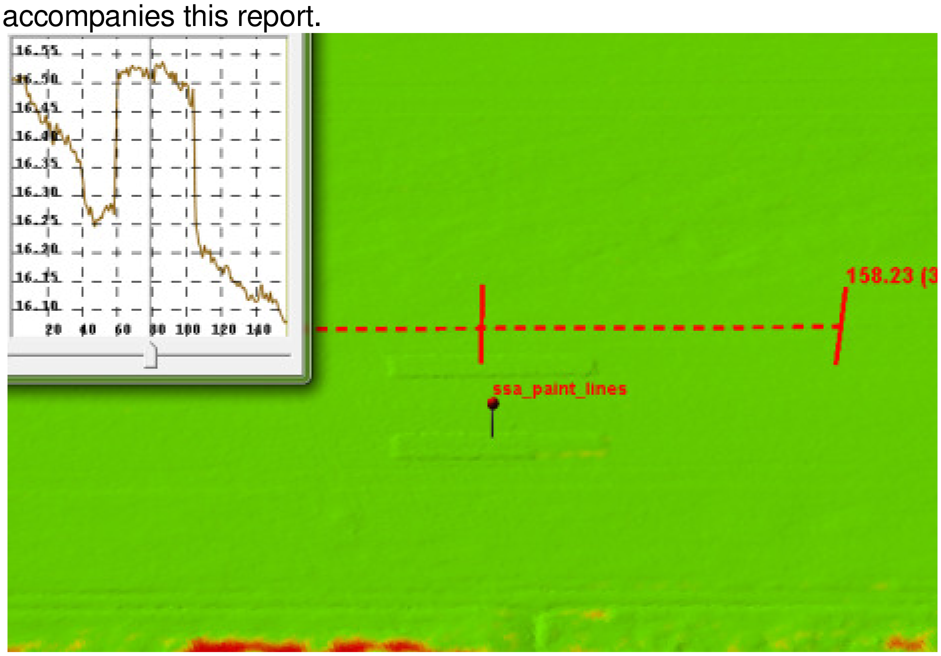

Figure 10 - Tile 3960_46245, first delivery. Ground density model. The image shows a large spike in elevation over the surface of the painted runway.

2.4.5 Voids

Voids will exist in the bare earth surface models where points have been legitimately removed due to structures or other cultural features and over water where there may not be any LiDAR returns. Other voids, such as coverage gaps, should not exist in the dataset. The coastal California project area is the combination of several different datasets, but continuous data should exist from the 10 meter contour line inland all the way to the coast. As part of the deliverables FEDI provided a document that reported a known data void in the dataset. There was also one other void in this dataset that was not caught by FEDI but was addressed in subsequent deliveries. An example is shown below and a GDB that contains the location of the void edit call accompanies this report.

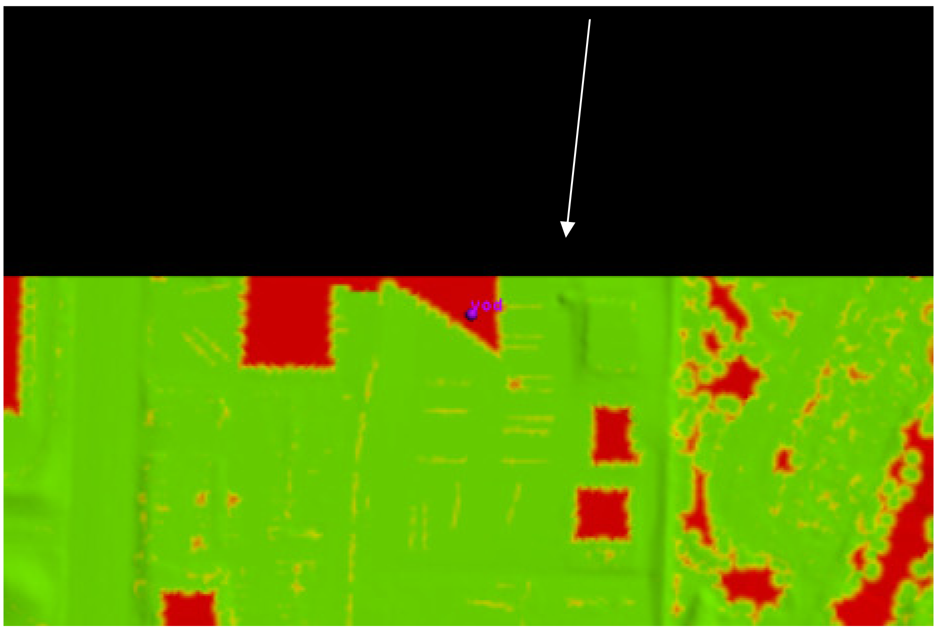

Figure 11 - Tile C2985_37785, first delivery. Ground density model that there is a geometric area without ground points that is not due to water.

2.4.6 Water Classification Issues

Water classification calls in this document imply that LiDAR points dealing with water were initially classified incorrectly in the delivered dataset. This call indicates that points that are ground (Class 2) should be moved to water (Class 9). All instances of this issue were addressed in subsequent deliveries of the dataset. An example of water classification calls made can be found below and a GDB that contains the locations of all edit calls accompanies this report.

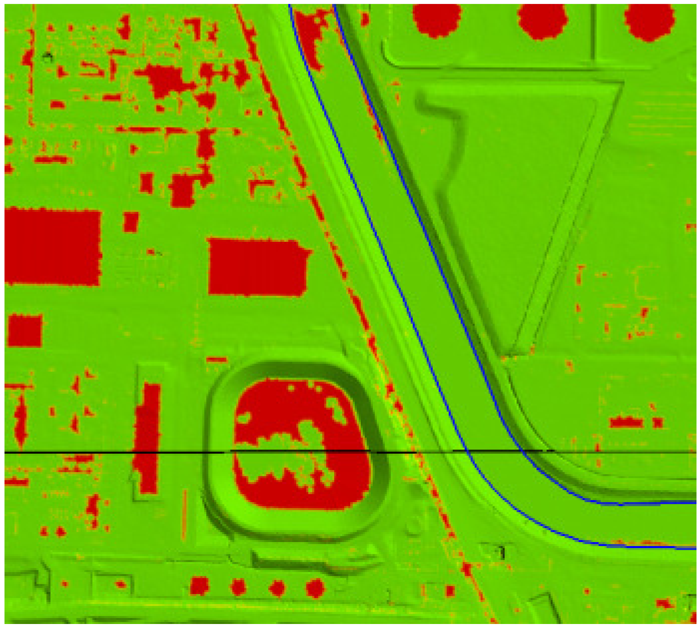

Figure 12 - Tile C3840_37425. Ground density model. The blue lines are the river breaklines and the area in between should be classified as water. This image shows that this is not the case and that the points are incorrectly classified as ground (class 2).

2.5 LiDAR Recommendation

Dewberry recommends that NOAA accept the LiDAR.

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.

All hydrographic features were delivered in GeoDatabases. Per NOAA specifications, a separate 3D breakline file was delivered for Tidal Waters, Streams and Rivers, and Pond and Lakes.

The delivered GeoDatabases were correctly defined with proper spatial projection shown below:

- Horizontal Datum: NAD83 (NSRS 2007)
- Vertical Datum: NAVD88
- Projection: UTM Zone 10\11N
- 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 shapefile did not contain classes for any features, including those outlined in the data dictionary.

The shapefile was 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. As seen in the table below, Dewberry confirms that FEDI corrected all edit calls in the second delivery of the dataset.

	Missing Features	Incomplete Capture	Horizontal Placement	Total
Area 1	3	1	20	24
Area 2	5	0	5	10
Area 3	4	0	1	5
Area 4	2	4	13	19
Total	**14**	**5**	**39**	**57**

3.3.1 Missing Features

Issues were found where breaklines were not collected for pond and island features that meet collection criteria. All missing features identified by Dewberry have been captured by FEDI. Examples are shown below and all edit calls are provided in the GDB that accompanies this report.

Figure 13 - Tiles C64045_40815 and C6045_40800. Full point cloud shows a water body larger than 2 acres that has not been captured

Figure 14 - Tile C4350_37020. Full point cloud intensity shows an “island” in the tidal water. This feature should be collected in the breaklines.

3.3.2 Incomplete Collection of Breaklines

Edit calls were placed for incomplete collection of breaklines when the current breaklines did not fully capture the entire water feature. Incomplete collection of breaklines is called when more than a slight or small adjustment to horizontal placement of the breaklines is necessary. Dewberry believes that FEDI has extended all necessary breaklines.

Figure 15 - *Tile C2925_37860. River here is just at 100 ft wide and should be extended as necessary.*

3.3.3 Horizontal Placement

While the horizontal accuracy of the breaklines must only be within two times the nominal point spacing of the project, breaklines that are burned into the bank or cause bare earth ground points to be incorrectly classified as water should still be corrected. Areas were identified where the current hydrographic breakline do not correctly represent the land water interface. All of these issues have been addressed by FEDI in subsequent deliveries of the dataset. Examples are shown below and all edit calls are located in the GDB that accompanies this report.

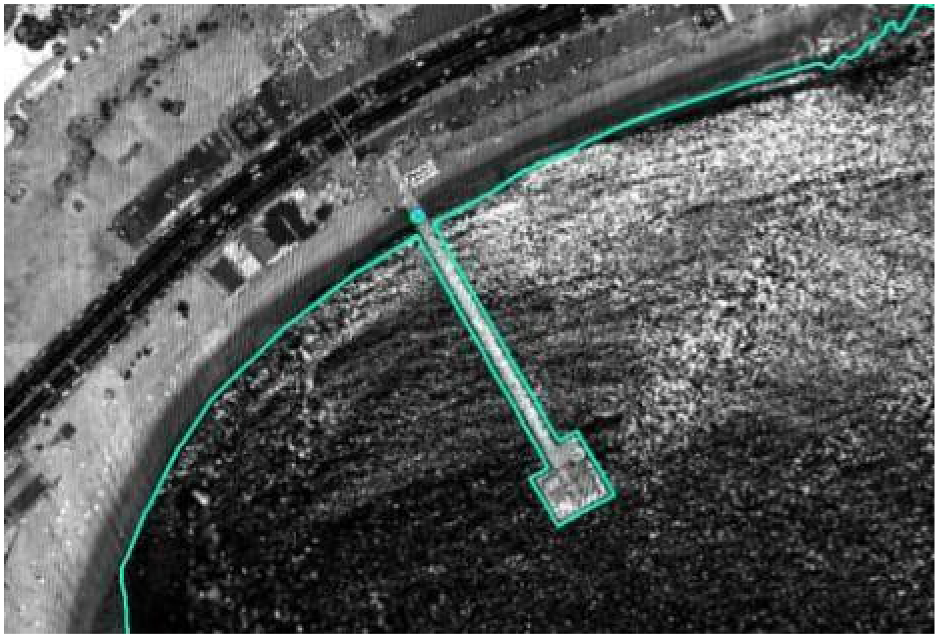

Figure 16 - Tile C3450_37665. Tidal Water breaklines, shown here in teal, are overlaid on the full point cloud intensity imagery. The hydrographic bank line should be adjusted to follow coastline under pier.

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 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.

In the review Dewberry identified vertices in seventy-five (75) breakline features that dig into the terrain surface. These vertices have a direct impact on the DEM. Figure 17 show several vertices in the pond bank digging by up to 2.6 meters, shown in red. Upon review of full point cloud intensity image and ortho image, it was determined that there is some degree of tree overhang in this area but not to the degree shown here. Dewberry confirms that FEDI has adjusted the all the breaklines so that they no longer dig into the surrounding terrain.

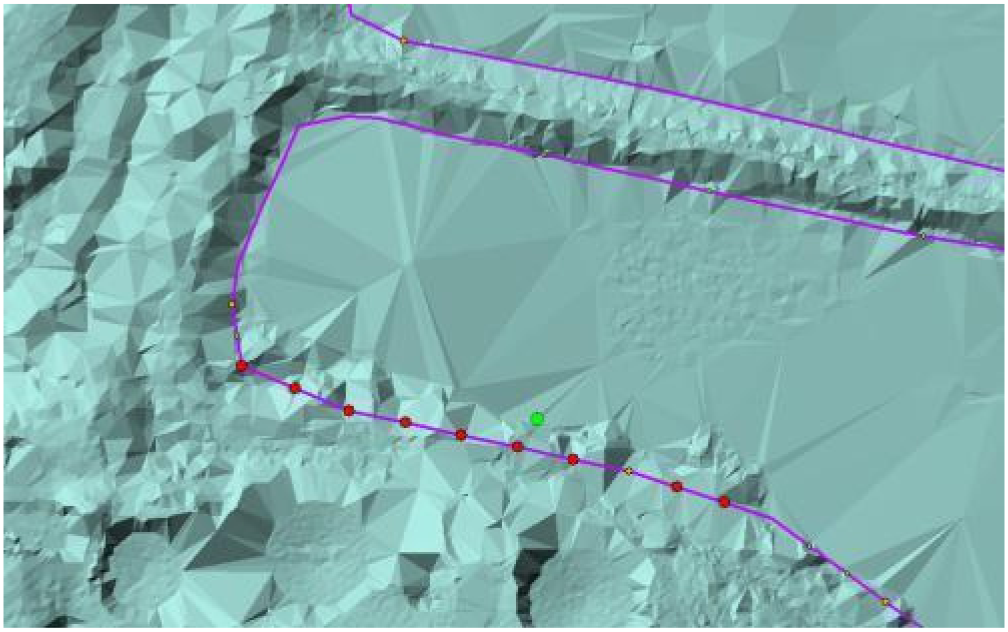

*Figure 17 - T*ile C4620_36765. *Pond, in purple, shown overlaid first with a GeoTerrain built from ground points in the LAS.*

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 with these checks are listed below:

- Unnecessary Polygon Boundary: 32 issues
- Geometry on Geometry: 2 Issues
- Connectivity Error: 40 Issues
- Monotonicity Error: 2 Issues

Dewberry can confirm that FEDI has corrected all of the topology issues associated with the breaklines.

3.6 Breakline Recommendation

Dewberry recommends that NOAA accept the breaklines delivered by FEDI. Dewberry believes that FEDI has addressed all issues that were raised during the QA/QC process.

4 Hydro-enforced Digital Elevation Model Analysis

Dewberry received 1,430 hydro-enforced bare earth DEMs as part of the project deliverables. The specifications for the project require the DEMs to be in a raster grid format with 1 meter cell size, tiled in 3,000 m by 3,000 m tile grids and projected to UTM Zone 10/11N meters. DEMs are to be free of artifacts, gaps, and artificial smoothing.

4.1 Quantitative 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 meter cell size, are in 3,000 m by 3,000 m tiles, and are projected to the correct coordinate system.

4.2 Qualitative Review

Dewberry performed a visual analysis in Global Mapper. This software overlays a colored DEM on top of a hillshade which aids in the identification of errors and anomalies. The table below illustrates the types of calls that were made during the DEM review. All issues were addressed by FEDI in the final delivery of the dataset.

	DEM Edge Areas	Water Issues	Artifacts / Classification Issues	Total
Area 1	114	27	18	159
Area 2	10	5	38	53
Area 3	0	0	0	0
Area 4	4	20	6	30
Total	**128**	**52**	**62**	**242**

4.2.1 DEM Edge Issues

During the DEM review Dewberry noticed several areas where the DEM extended pass the valid LiDAR boundary provided by FEDI. In these areas the DEM would tin across which reduces the quality of the ground model. FEDI has removed all of these instances from the DEM.

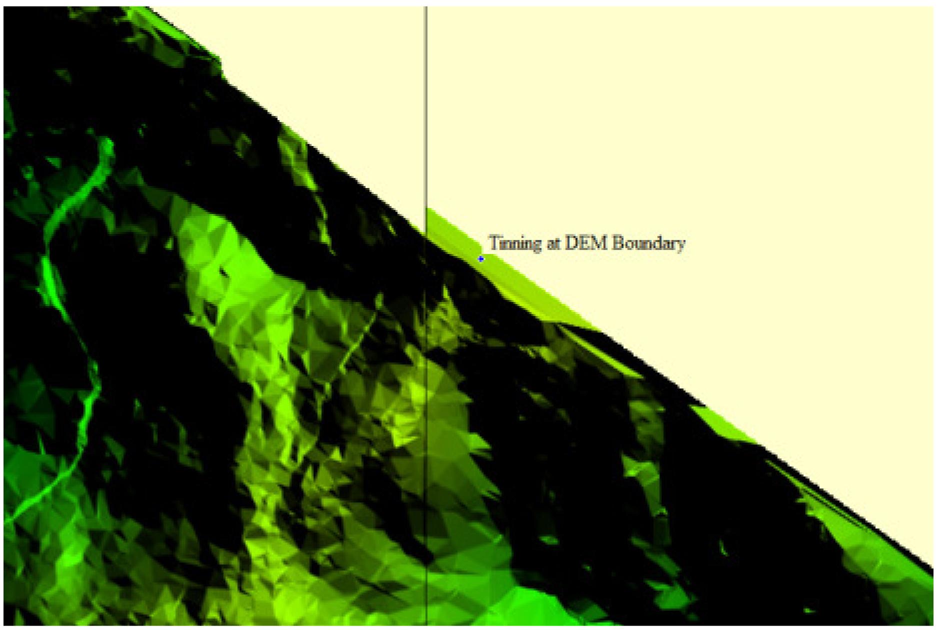

Figure 18 - DEM tile c4260_44100. The DEM was not properly clipped and was tinning across the area.

4.2.2 Water Issues

Water artifacts occur when the surrounding water in the breakline is at a constant elevation except for an unnatural spike. All of these instances were removed from the DEMs by FEDI in subsequent deliveries.

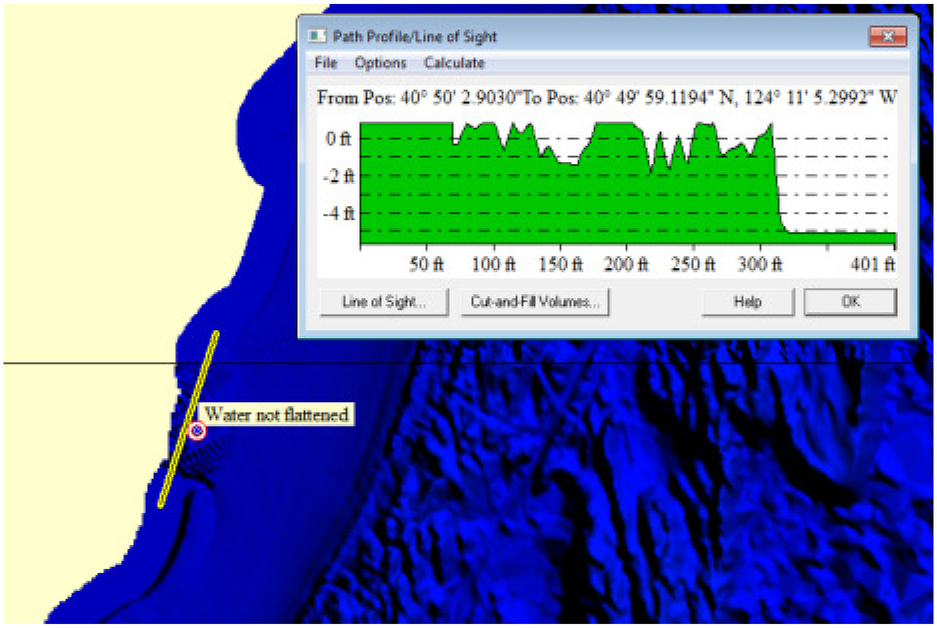

Figure 19 - DEM tile C3990_45180. The image above shows that the water was not flattened in this area.

4.2.3 Classification Issues

Classification issues are usually associated with the LiDAR and the processing and creation of the DEMs. An example is shown below and all issues involving classification have been corrected by FEDI.

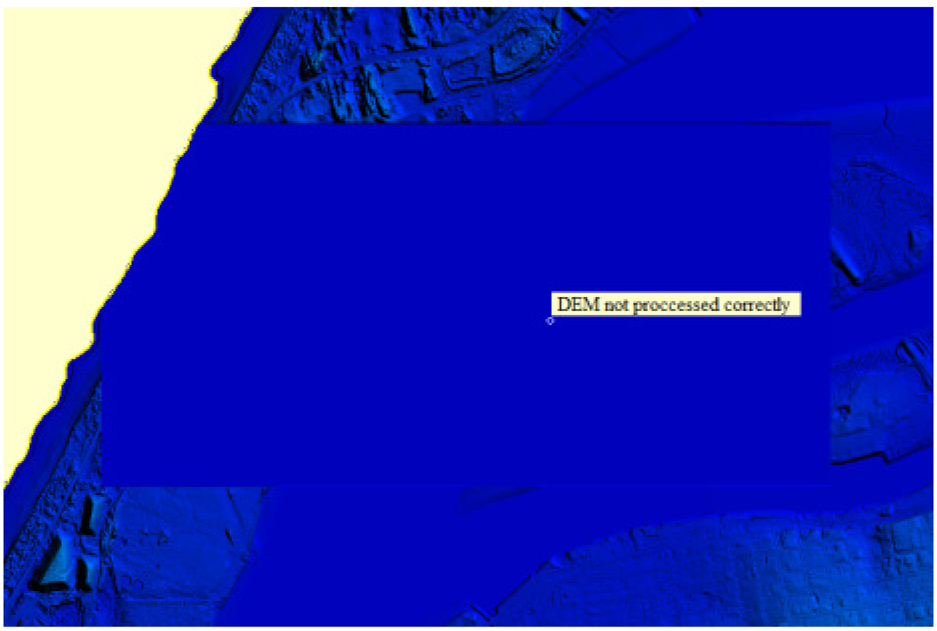

Figure 20 - DEM tile C3990_45180. The DEM was missing LiDAR data from tiles C3990_45180 and C4005_45180.

4.3 DEM Recommendation

It is Dewberry's recommendation that the DEMs for be accepted.

5 Metadata

Metadata was not delivered with the 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 were not included. 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 that contains all the LiDAR and breakline edit 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. Issue - A more detailed explanation of the identified issue
3. CallType - States whether the issue should be addressed or if it is for reference.
4. FEDI_Rvw - A field that FEDI will fill out after they address each issue
5. Dwb_Rvw - Populated with Dewberry's response to the correction by FEDI

Also included in this GDB is a polygon feature class that contains the locations of the classification issues along the project boundary.

7 Recommendation Summary

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

- Dewberry recommends that NOAA accept the LiDAR.
- Dewberry recommends that NOAA accept the breaklines.
- Dewberry recommends that NOAA accept the DEMs.