LiDAR Quality Assurance (QA) Final Report
Sub-project 1: Platte River Corridor
Nebraska/Kansas LiDAR
January 13, 2010

Submitted to:
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Executive Summary

<u>Reference</u>: U.S. Army Corps of Engineers Contract W912P9-08-D-0507

The following quality assurance report documents Dewberry's review of the Sub-project 1 (Platte River Channel) LiDAR and breakline data produced by Merrick & Company under subcontract to Optimal Geomatics for the U.S. Army Corps of Engineers. The project area consists of 265 tiles of LiDAR data in LAS format with 3-dimensional breaklines compiled to define the hydrological network. The LiDAR data was acquired in March of 2009. With cooperation from the Central Nebraska Public Power & Irrigation District, hydro power plant releases were stopped prior to and during the period of the Sub-project 1 flight mission to offer the lowest river flows possible in order to reveal as much in-channel area as possible. Each tile contains LAS 1.1 point cloud data classified into four ASPRS classes (class 1 = unclassified; class 2 = ground; class 7 = Low point/noise; class 9 = water). The data was reviewed quantitatively for statistical and accuracy errors, as well as qualitatively for classification and visual anomalies. Overall the LiDAR data was determined to be of good quality.

<u>Completeness</u>: According to the requirements of the contract, the LiDAR data was to contain point cloud data with multiple returns per pulse and with an intensity value recorded for each point. Dewberry verified that all 265 LAS tiles were of the proper size (each 2,000 m x 2,000 m) and contained multiple returns with intensity values recorded for each point. All the data was delivered in the correct file format and projected to the Universal Transverse Mercator coordinate system, Zone 14 North in meters with NAD83 datum. The vertical coordinate system is NAVD88 with elevation in meters. The breaklines were compiled from the LiDAR and delivered in ArcGIS geodatabase format with the correct projection. The location of the sub-project area in relation to the project boundary is illustrated in Figure 1.

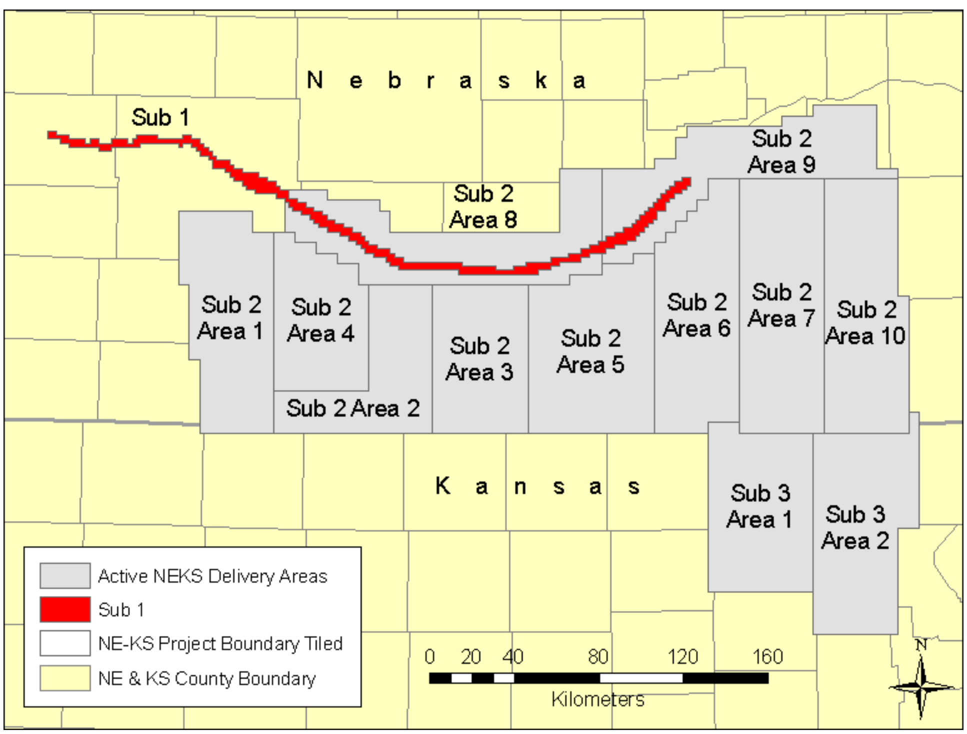


Figure 1: NE-KS project boundary with Sub-project 1 highlighted

Quantitative Analysis: Using checkpoints provided by USDA-NRCS-Nebraska, Dewberry tested the RMSE per FEMA/NSSDA and NDEP/ASPRS specifications. Please see section XX for details on the specific accuracy requirements for Sub-project 1. Checkpoints were provided in three land cover categories (open terrain, weeds/crops, and high grass). Table 1 shows the accuracy assessment scores in open terrain at the 95% confidence level using the FEMA/NSSDA methodology ($RMSE_Z$ x 1.9600), and Table 2 shows the accuracy assessment scores in each land cover category measured at the 95th percentile (NDEP/ASPRS methodology).

Table 1: Vertical accuracy assessment summary (FEMA/ASPRS methodology)

Criterion	Checkpoints Used	Accuracy Specification	Results Achieved
$RMSE_Z$	29	0.092 m	0.076 m
FVA (open terrain)	10	0.182 m	0.175 m

Table 2: Vertical accuracy assessment summary (NDEP/ASPRS methodology)

Criterion	Checkpoints Used	Accuracy Specification	Results Achieved
Consolidated	29	0.182 m	0.142 m
Fundamental (open terrain)	10	0.182 m	0.175 m
Supplemental (open terrain)	10	0.182 m	0.137 m
Supplemental (vegetation)	8	0.182 m	0.149 m
Supplemental (urban)	11	0.182 m	0.035 m

- **Tested 0.076 meters $RMSE_Z$ (FEMA/NSSDA methodology)**
- **Tested 0.175 meters fundamental vertical accuracy at 95% confidence level in Open Terrain (FEMA/NSSDA and NDEP/ASPRS methodologies)**
- **Tested 0.142 meters consolidated vertical accuracy at 95th percentile in all land cover categories (NDEP/ASPRS methodology)**
- **Tested 0.137 meters supplemental vertical accuracy at 95th percentile in Open Terrain category (NDEP/ASPRS methodology)**
- **Tested 0.149 meters supplemental vertical accuracy at 95th percentile in Vegetation category (NDEP/ASPRS methodology)**
- **Tested 0.035 meters supplemental vertical accuracy at 95th percentile in Urban category (NDEP/ASPRS methodology)**

Qualitative Analysis: Dewberry visually inspected 100% of the data. No remote-sensing data voids were found and the data is free of major systematic errors. The cleanliness of the bare earth model meets expectations; minor errors were found in less than 2% of the data, including artifacts left in the ground classification, noise in the flight line overlap areas, and small ridges in the flight lines. All of the remaining errors are minor and should not affect the usability of the data.

QA Report

1 Introduction

The following definitions are provided to distinguish between steps taken by Dewberry, as prime contractor, to provide Quality Assurance (QA) of the LiDAR data produced by Merrick, and steps taken by Merrick, as data producer, to perform Quality Control (QC) of the data that it provides to Dewberry. Collectively, this QA/QC process ensures that the LiDAR data delivered to USDA-NRCS-Nebraska and the Corps of Engineers are accurate, usable, and in conformance with the deliverables specified in the Scope of Work. These definitions are taken from the DEM Quality Assessment chapter of the 2nd edition of “Digital Elevation Model Technologies and Applications: The DEM Users Manual,” published by the American Society for Photogrammetry and Remote Sensing (ASPRS), 2007:

> **Quality Assurance (QA)** — Steps taken: (1) to ensure the end client receives the quality products it pays for, consistent with the Scope of Work, and/or (2) to ensure an organization’s Quality Program works effectively. Quality Programs include quality control procedures for specific products as well as overall Quality Plans that typically mandate an organization’s communication procedures, document and data control procedures, quality audit procedures, and training programs necessary for delivery of quality products and services.
>
> **Quality Control (QC)** — Steps taken by data producers to ensure delivery of products that satisfy standards, guidelines and specifications identified in the Scope of Work. These steps typically include production flow charts with built-in procedures to ensure quality at each step of the work flow, in-process quality reviews, and/or final quality inspections prior to delivery of products to a client.

Dewberry’s role is to provide overall project management as well as quality management that include QA of the data including a completeness validation of the LiDAR masspoints, vertical accuracy assessment and reporting, and a qualitative review of the derived bare earth surface.

First, the completeness verification is conducted at a project scale. It consists of a file inventory and a validation of conformity to format, projection, and georeference specifications. At this point Dewberry also ensures that the data adequately covers the project area. The LiDAR data review begins with the computation of general statistics over all fields per file, followed by an analysis of the results to identify anomalies, especially in the elevation fields and LAS class fields.

The quantitative analysis addresses the quality of the data based on absolute accuracy of a limited collection of discrete checkpoint survey measurements. Although only a small amount of points are actually tested through the quantitative assessment, there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to surrounding LiDAR measurements as acquisition conditions remain similar between points and from one flight line to the next.

To fully address the LiDAR data for overall accuracy and quality, a manual qualitative review for anomalies and artifacts is conducted on each tile. This includes creating pseudo-image products such as 3-dimensional models. The QA analyst uses multiple images and overlays to find potential errors in the data as well as areas where the data meets and exceeds expectations.

Three fundamental questions are addressed during Dewberry's QA process:

- Was the data complete?
- Did the LiDAR system perform to specifications?
- Did the ground classification process yield desirable results for the intended bare-earth terrain product?

Under the referenced task order, LiDAR data was acquired for 239 square miles in south central Nebraska (Sub-project 1). All quality assurance processes and results are given in the following sections.

2 Completeness of Deliverables

Dewberry reviews the inventory of the data delivered by validating the format, projection, and georeferencing. LAS files were delivered in tiles that adhere to the project boundary and the specified 2,000 m x 2,000 m tile schema. Each LAS file was verified to be projected according to the project specifications in the horizontal projection UTM 14 North (NAD83) and the vertical datum NAVD88, with horizontal and vertical units in meters.

2.1 LiDAR Inventory

Dewberry received 265 LiDAR files covering Sub-project 1. They are in the correct format and projection:

- LAS version: 1.1
- Point data format: 1
- Projection set in the header:
    - NAD_1983_UTM_Zone_14N;
    - Horizontal unit: meters;
    - NAVD88 – Geoid03;
    - Vertical unit: 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
    - Class 1 – unclassified
    - Class 2 – ground
    - Class 7 – low point/noise, overlap
    - Class 9 – water
- GPS time (this is expressed in second of the week; note that the date of collection will be given in the metadata file because the date contained in the header is the file creation date according to the LAS standard).

2.2 Breakline Inventory

Dewberry received one ArcGIS file geodatabase containing breaklines for Sub-project 1. The geodatabase contains the following feature classes:

- Hydro_Lines (with feature types: Single Line Hydro and Dual Line Hydro)

- Hydro_Connectors
- Islands
- Waterbodies

3 LiDAR Quantitative Assessment

Dewberry utilizes several tools to evaluate each LAS tile for completeness, conformity to project specifications, and geospatial accuracy. An automated script is used to validate the header of each tile against the project specifications, as illustrated in section 3.1.1.

3.1 Statistical 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 statistically review 100% of the data at a macro level to identify any gross outliers. The statistical analysis consists of first extracting the header information and then reading the actual records and computing the number of points, minimum, maximum, and mean elevation for each class. Minimum and maximum for other relevant variables are also evaluated.

Each tile was queried to extract the number of LiDAR points. With a nominal point spacing of 0.7 meters, the number of points per tile should be approximately 8 million. The mean in Sub-project 1 is approximately 7.9 million, which is as expected. All tiles are within the anticipated size range except for those on the edge of the project boundary (Figure 2).

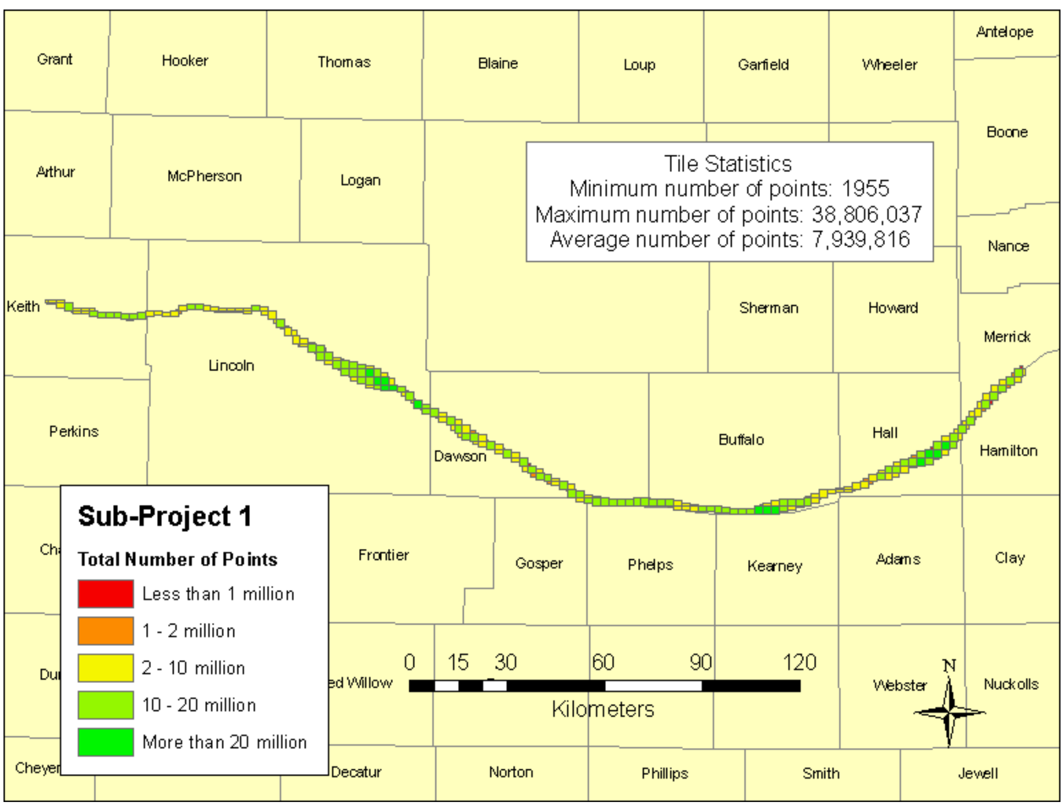


Figure 2: Number of points per tile.

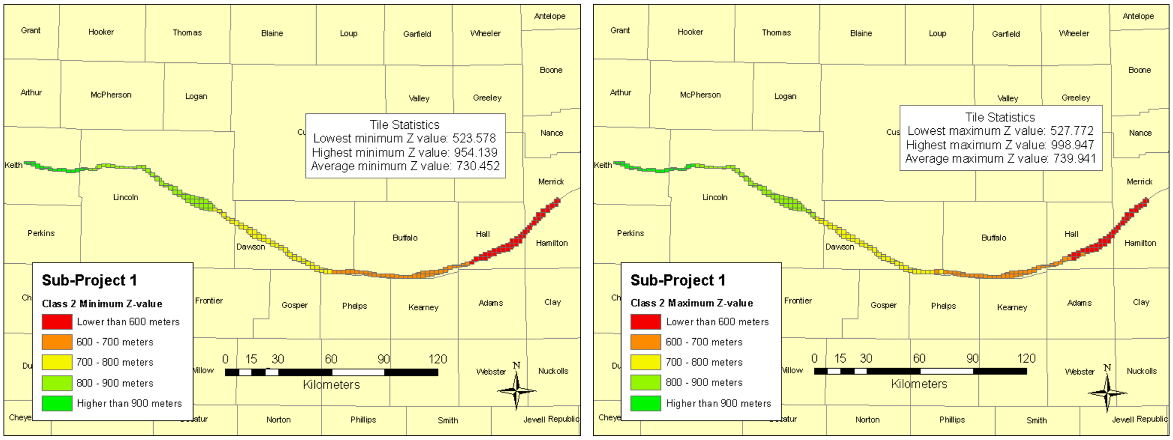


Figure 3: Minimum and maximum elevation by tile for ground points (class 2)

3.1.1 ASPRS Classification Scheme

According to the contract requirements, the LiDAR data were to be delivered in LAS format with each point classified according to a five-class ASPRS scheme:

- Class 1 – Unclassified
- Class 2 – Ground
- Class 7 – Low point and noise
- Class 9 – Water
- Class 12 – Overlap

The Area 1 dataset was delivered with four classes (1, 2, 7 and 9) with class 7 combined to include low points, noise and overlap. Merrick utilizes overlap points in the ground classification to increase the clarity, but if they begin to cause over-densification in the ground (evidenced by noise), those points are classified into class 7.

3.1.2 Pulse Return Analysis

According to the contract requirements, the LiDAR data was to be collected using a sensor with the ability to collect multiple echoes per laser pulse, with a minimum of first, last and one intermediate return. The sensors used for this project met that requirement, returning data with up to four total returns per pulse.

3.2 Vertical Accuracy Assessment

Typically for this type of data collection, a ground truth survey is conducted following the *FEMA Guidelines and Specifications for Flood Hazard Mapping Partners Appendix A: Guidance for Aerial Mapping and Surveying* which is based on the NSSDA specifications. This methodology utilizes a minimum of 20 points for each of the predominant land cover types (i.e. open terrain, vegetation, urban, etc.) for a minimum of three land cover classes.

The FEMA guidelines are established for data to have a vertical accuracy equivalent to 2-foot contours, where $RMSE_Z$ is equal to 18.5 cm (0.185 m) and vertical accuracy at the 95% confidence level is equal to 36.3 cm (0.363 m). The accuracy requirement for Sub-project 1 is more stringent to meet accuracy requirements for 1-foot contours. Therefore the $RMSE_Z$ must equal 9.2 cm and the vertical accuracy at the 96% confidence level must equal 18.2 cm (0.182 m)

Dewberry uses photographs of each checkpoint to classify it as accurately as possible, but in some cases the land cover has changed between the time of LiDAR collection and the time of the checkpoint survey or documentation. Some checkpoints are located on farmland and are classified as vegetation, but because the LiDAR was collected in winter, there was little or no vegetation surrounding the checkpoint at the time of collection. This means that the checkpoint may be closer to open terrain than weeds/crops. Since there were several months between the time of collection and the time that the checkpoints were photographed, the vegetation on the land has changed.

The Nebraska Partners elected to use pre-existing survey points for LiDAR accuracy testing. 53 checkpoints were made available by USDA-NRCS-Nebraska for assessment by Dewberry. Of these 53 points, 29 were used in the final assessment after it was determined that 24 points were not suitable for analysis. Checkpoints are deemed unsuitable for analysis when they are determined to be located on a surface that is not ground, such as a bridge, culvert or other man-made feature. Checkpoints may also be invalidated if they are located on terrain with an incline greater than 20 degrees, or if the ground has been disturbed between the time of checkpoint measurement and the LiDAR collection, such as burial or relocation of the point due to land development. The photo in Figure 4 shows a checkpoint surveyed on a footbridge, a feature that is removed from the surface model when conducting the accuracy assessment.

Figure 4: Checkpoint BM-14-8-15C located on a bridge

Figure 5 shows the point distribution across the Platte River Channel. The checkpoints are well distributed overall, though the distribution within each land cover category is not a wide as desired. The urban checkpoints are concentrated in the western half of the dataset, while the vegetation checkpoints are concentrated in the eastern half. The accuracy scores were good for all land cover categories, regardless of their spatial distribution, indicating high accuracy throughout the dataset.

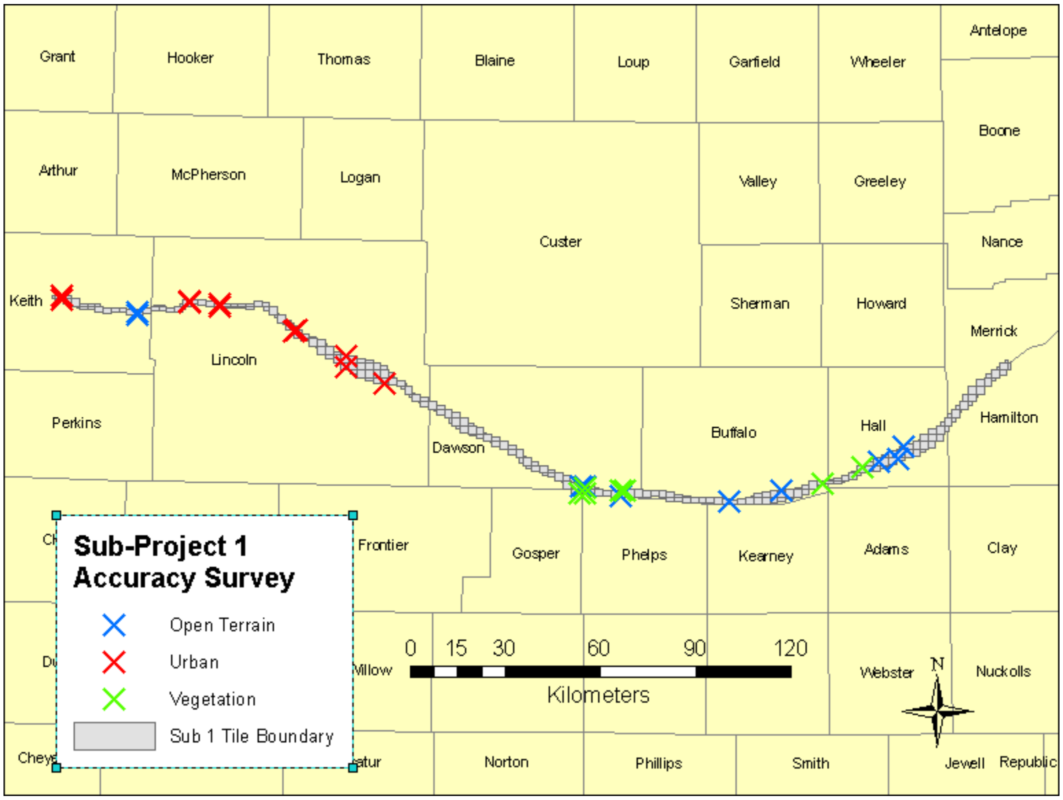


Figure 5: Sub-project 1 survey checkpoints provided by USDA-NRCS-Nebraska

3.2.1 Methodology

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 $RMSE_Z$ value. The $RMSE_Z$ 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 ($RMSE_Z$ 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 ($RMSE_Z$ x 1.9600) in open terrain where there is no reason for LiDAR errors to depart from a normal error distribution.

The following tables and graphs outline the vertical accuracy and the statistics of the associated errors as computed by the different methods. Table 3 shows the results of the Sub-project 1 dataset calculated with the FEMA/NSSDA methodology; vertical accuracy at the 95% confidence level equals the $RMSE_Z$ x 1.9600. By this method, the fundamental vertical accuracy equals the $RMSE_Z$ (0.089 m x 1.9600), or 0.175 m (17.5 cm). This means that 95% of the surveyed points have an absolute delta Z of less than or equal to 0.175 m.

Table 3: Final statistics for Sub-project 1 using FEMA/NSSDA processes.

100 % of Totals	$RMSE_Z$ (m) Spec=0.092 m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.076	0.046	0.022	0.440	0.061	29	-0.042	0.152
Open Terrain	0.089	0.068	0.079	-0.302	0.061	10	-0.021	0.140
Vegetation	0.101	0.087	0.093	-0.376	0.056	8	0.007	0.152
Urban	0.021	-0.003	0.001	-0.532	0.021	11	-0.042	0.026

Table 4 shows the results of the Sub-project 1 dataset calculated with the NDEP/ASPRS process. The Consolidated Vertical Accuracy (CVA) at the 95th percentile is 0.142 m, which is within the accuracy requirement. The supplemental vertical accuracy, where each land cover type is tested independently, is within specifications for all land cover types.

Table 4: Final statistics for Sub-project 1 using NDEP/ASPRS processes.

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_Z$ x 1.9600) Spec=0.182 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.182 m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.182 m
Consolidated	29		0.142	
Open Terrain	10	0.175		0.137
Vegetation	8			0.149
Urban	11			0.035

Figure 6 illustrates the distribution of the elevation differences between the LiDAR data and the surveyed checkpoints. The slight majority of delta Z values are above zero which indicates a slightly positive error distribution.

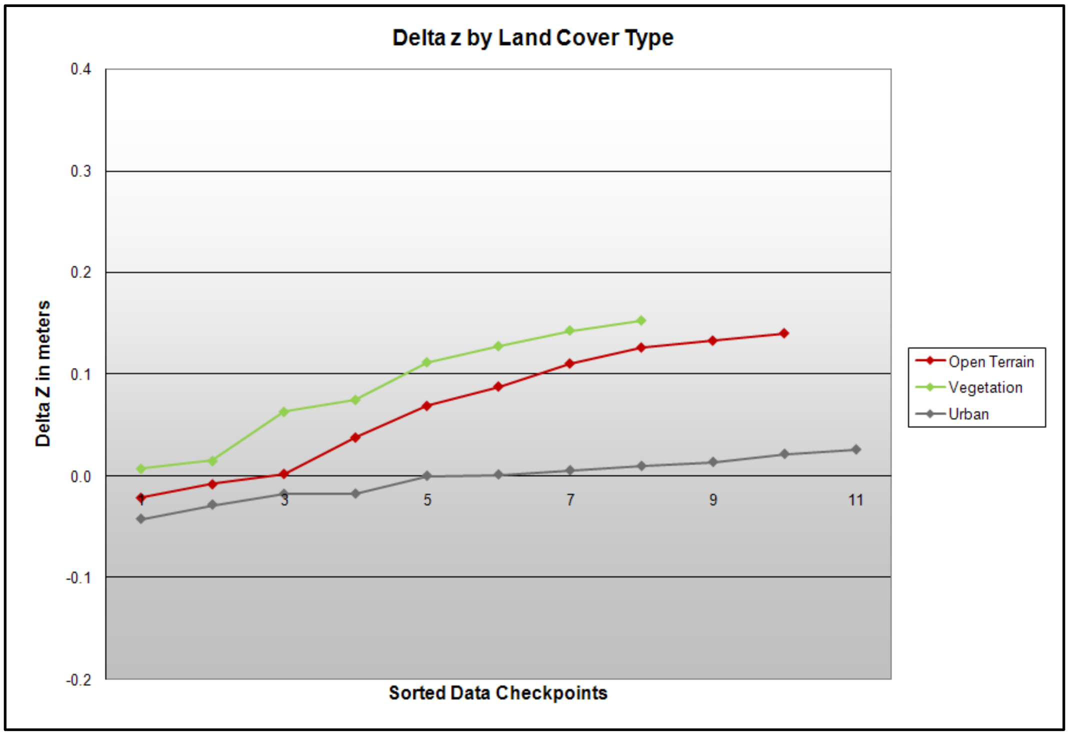


Figure 6: Checkpoint distribution sorted by error value (delta Z)

Given the good results throughout the dataset, Dewberry is confident that the data meets the accuracy requirements. Compared with the 0.182 m specification for vertical accuracy at the 95% confidence level, equivalent to 1-foot contours, the dataset passes by all methods of accuracy assessment.

4 LiDAR Qualitative Analysis

4.1 Protocol

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, large spikes/divots, ridges between flight lines/tiles, cornrows, etc);
- 90% of artifacts classified, 95% of outliers, 95% of the vegetation, 98% of the buildings.

Dewberry analysts, experienced in evaluating LiDAR data, performed a visual inspection of 100% of the bare earth data using digital elevation models (DEMs). The DEMs are built by first creating a fishnet grid of the LiDAR masspoints with a grid distance of 2x the full point cloud resolution. Next, a triangulated irregular network (TIN) is built based on this gridded DEM and displayed as a 3D surface. A shaded relief effect (hillshade) was applied which enhances 3D rendering. The software used for visualization allows the user to navigate, zoom and rotate models, as well as display density and elevation information with an adaptive color coding in order to better identify anomalies.

One of the variables established when creating the models is the threshold for missing data. For each individual triangle, the point density information is stored; if it meets the threshold, the corresponding surface will be displayed in green, if not it will be displayed in red (Figure 7).

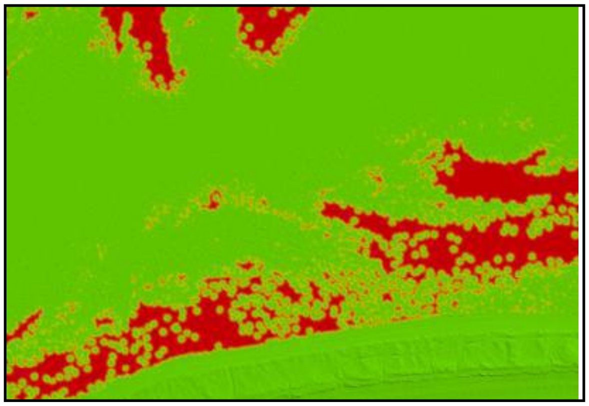


Figure 7: Stock example of low point density (red areas)

Please note that if this density model is created with ground points only, low density areas are expected where buildings, water, and/or heavy vegetation were classified out of the ground. Dewberry did not identify any areas of poor LiDAR penetration at the extent illustrated by the sample figure above. The LiDAR was collected to meet the 0.7 m nominal point spacing and therefore maintained sufficient density throughout the sub-project area.

The section below discusses some of the minor anomalies that Dewberry discovered while reviewing the data. These issues are included to make the end-user aware of the unique characteristics of the data; overall the LiDAR is accurate and free of collection and processing errors.

4.2 Quality Report

Dewberry's qualitative review consists of a micro-level review of 100% of the tiles. There is no automated toolset more effective than the manual inspection by a GIS analyst to find errors in automated processing of LiDAR data. Dewberry analysts inspected the data for processing anomalies, classification errors, and artifacts remaining in the ground classification. The following issues represent small anomalies in the data that generally do not create problems when conducting geographic and hydrographic analysis, but the user should be aware of their existence.

4.2.1 Artifacts

While reviewing the dataset, several buildings were found classified as ground. There is a 2% allowance for building artifacts; therefore these errors do not need to be reprocessed. Figure 8 shows the building remaining in the ground classification. The image on the left shows the full point cloud colored by intensity and the model on the right shows the ground classification colored by elevation. The profile graph shows the full point cloud in red and ground in blue. Please refer to Appendix A for screenshot thumbnails.

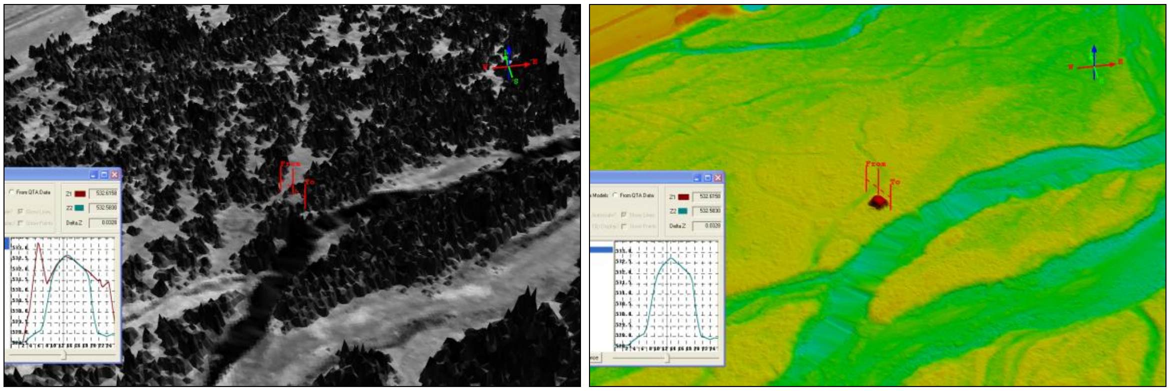


Figure 8: tile 14T NL 7504-2 with a building in the ground classification

Dewberry also identified one case of vegetation remaining in the ground classification. There is a 5% allowance for vegetation in the project area so this error does not need to be reprocessed. Figure 9 shows the full point cloud colored by intensity on the left and the ground classification colored by elevation on the right. The profile graph shows the height of the artifact in the ground model.

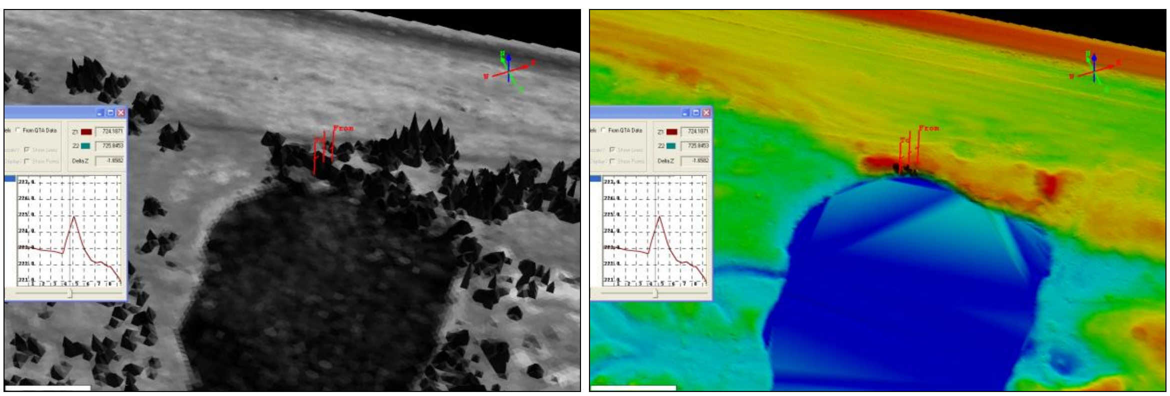


Figure 9: tile 14T ML 4005-1 with vegetation in the ground classification

4.2.2 Ridges

Dewberry identified two ridges in the LAS data. The first, in tile 14T LL 1060-4, does not seem to be caused by collection anomalies such as flight line mismatch, point bunching or spreading, etc. The second, in tile 14T NL 5015-1, follows a flight line seam and probably the result of the slight elevation error along the edge of the collection swath. The ridges are relatively small in height and should not present any major issues with quality or accuracy. In Figure 10 the image on the left shows a ridge in the ground classification that is approximately 6cm high and the image on the right shows a ridge that is approximately 14cm high. Please refer to Appendix A for screenshot thumbnails.

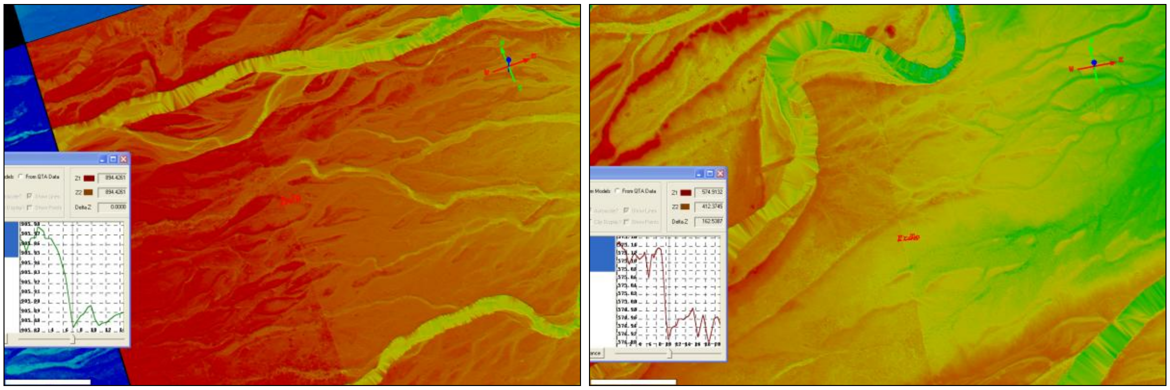


Figure 10: tile 14T LL 1060-4 (left) and tile 14T NL 5015-1 showing small ridges

4.2.3 Flight Line Overlap Noise

Noise due to small elevation differences between flight lines is a minor error found throughout the dataset. In areas where two or more flight lines overlap, the ground model appears more rough (noisy) as illustrated in Figure 11. All the noisy areas had elevation differences between flight lines of less than 10cm, which is relatively minor and should not affect the usability of the data. Please refer to Appendix A for screenshot thumbnails.

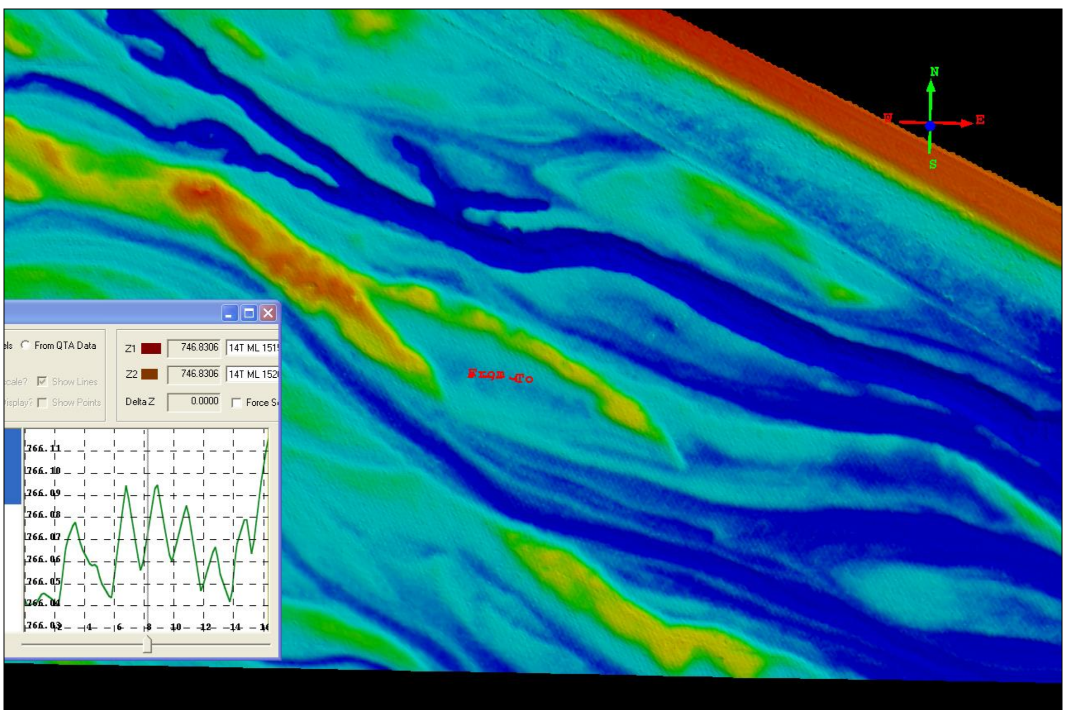


Figure 11: tile 14T ML 1025-3 with noise in the flight line overlap area

5 Breakline Quantitative Analysis

3-dimensional breaklines were compiled for the Platte River Channel to define the hydrological network for enhanced LiDAR analysis and to assist in building DEMs and GeoTerrains. It is important that the breaklines are horizontally and vertically accurate compared to the LiDAR; additionally the breaklines must maintain monotonicity, meaning the vertices must consistently decrease and not fluctuate in elevation. These accurate and monotonic breaklines are referred to as *hydro-enforced* breaklines. Dewberry conducts a quantitative assessment of the vertical accuracy of the breaklines to determine how close the breaklines are to the ground surface. This is done in conjunction with a test for monotonicity to get an objective assessment of the breakline accuracy and usability.

5.1 Issues with Hydro-Enforcement

There is an inherent inaccuracy when trying to hydro-enforce breaklines with elevations derived from LiDAR ground points along the water's edge. LiDAR points cannot always be found at the exact land/water interface, and points farther away from the edge of the bank will often have a higher elevation. Since the elevation of the breakline is determined by the closest LiDAR point to the breakline vertex, and sometimes the closest point is higher up the bank (and therefore has a higher elevation), this causes an error in monotonicity.

When an error like this occurs, the LiDAR provider will assign the elevation from the previous vertex to each subsequent vertex until it reaches a vertex that has suitable ground points around it, thereby maintaining monotonicity. Unfortunately, this causes a different type of error, where the breaklines will "float" above the LiDAR or "burn" into the LiDAR. The following images show how the breaklines affect the creation of a terrain. Figure 12 shows a terrain created with LiDAR ground points only. Note the profile graph on the top right; the LiDAR points on either side of the stream channel have different elevations so the channel is not smooth.

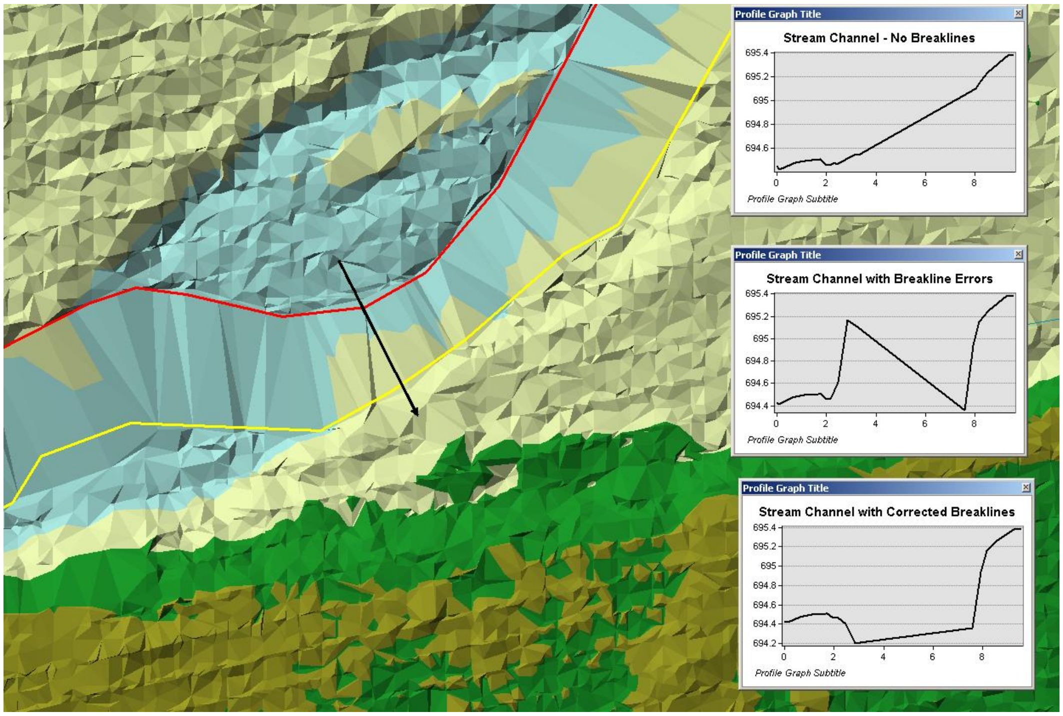


Figure 12: Terrain created without breaklines

Figure 13 shows a terrain created with the LiDAR ground points and the breaklines. Note how the channel geometry changed due to the influence of the breakline vertex elevations. In the profile graph (middle right), the breakline on the northern bank (left side of the graph) has elevations that are much higher than the LiDAR. This causes the edge of the stream to be almost a meter higher than the surrounding land, which is unsuitable for hydro modeling. On the southern bank (right side of the profile graph), the breakline elevations are slightly lower than the surrounding LiDAR, causing a trench-like effect. This error is still not desirable, but will cause less of a problem than the “floating” breakline.

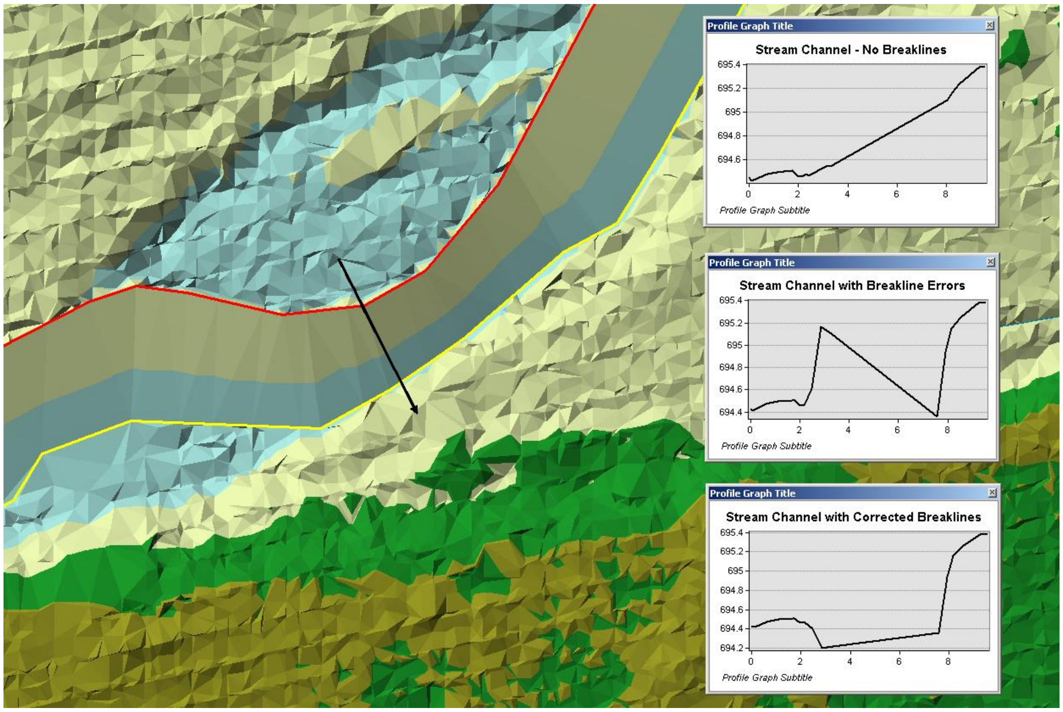


Figure 13: Terrain created with breaklines (with elevation errors)

The final example in Figure 14 shows a terrain created with the breaklines after Merrick corrected several of the most pronounced vertex elevation errors. The profile graph shows a well defined stream channel where the breakline is the lowest point on each side of the stream. While there still are small elevation differences between the LiDAR and the breaklines, this provides the best model of the land surface for hydro modeling.

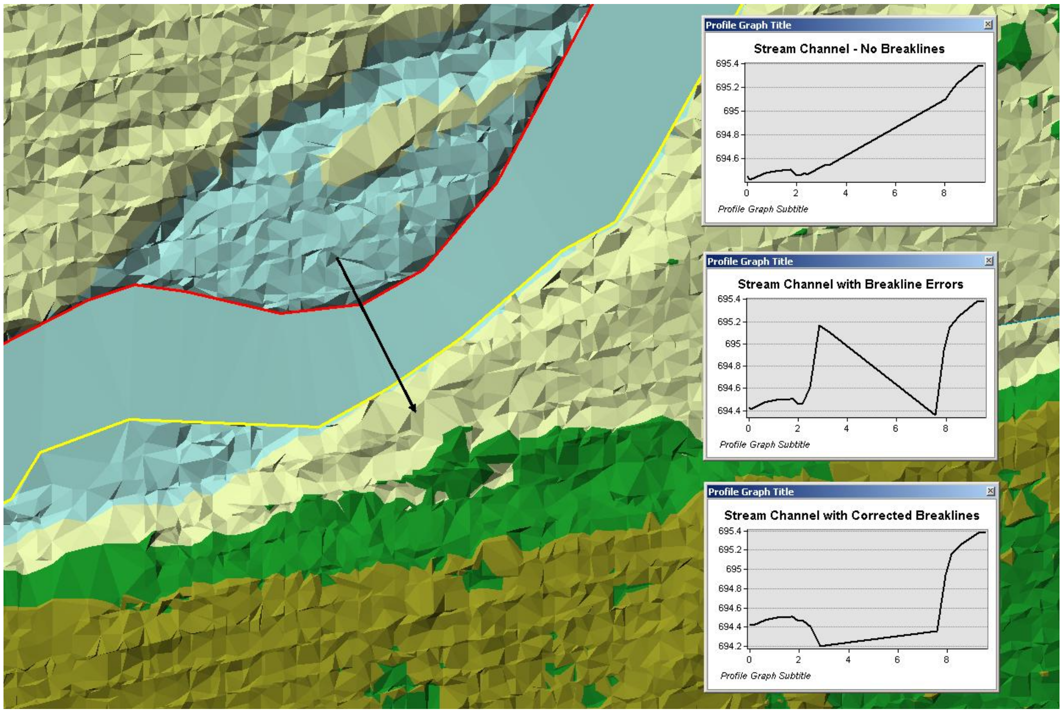


Figure 14: Terrain created with corrected breaklines

5.2 Vertical Accuracy Assessment

In order to test the relative accuracy of the breaklines compared to the LiDAR, Dewberry conducts a vertical accuracy assessment using a similar methodology to the one outlined in section 3.2.1.

5.2.1 Methodology

Instead of using survey points as a benchmark by which to measure the elevation of the ground, Dewberry analysts used a sample of the breakline vertices as “checkpoints” to measure the difference in the LiDAR, though the LiDAR is assumed to be vertically accurate, so the elevation difference is a measure of the error in the breakline elevation. For this assessment, every seventh point (approximately 14%) was tested against the ground points.

Dewberry requires the vertical accuracy of the LiDAR to be within 18.2 cm (see Table 2), the breaklines are interpolated from the LiDAR, and so a higher threshold is expected. Additionally, since the positive delta Z errors, where the breakline “floats” above the LiDAR, will have a more detrimental impact on the quality of the data, Dewberry calculated the $RMSE_z$ for all points and then interpolated the total vertical accuracy as well as the vertical accuracy of positive delta Z errors only.

5.2.2 Quality Report

The breakline vertex samples were tested by feature class (Waterbodies, Double Hydrolines, and Single Hydrolines) against the LiDAR. Table 5 shows the RMSE values at the 95% confidence level (following the FEMA/NSSDA methodology) and the 95th percentile (following the NDEP/ASPRS methodology).

Table 5: Initial Vertical Accuracy Results

Breakline Feature Class	# of Points	$RMSE_Z$ x 1.960	Vertical Accuracy @ 95th Percentile
Waterbodies	821	0.180 m	0.200 m
Single Hydrolines	13,823	0.496 m	0.504 m
Double Hydrolines	72,225	0.758 m	0.737 m

Since it the positive elevation errors in the double and single hydrolines are the biggest concern, Dewberry altered the test to focus on the delta Z of the “floating” breaklines. The revised assessment gives a better idea of the vertical accuracy of the breaklines with positive elevation errors, or “floating” breaklines, which would have a greater impact on DEM and terrain generation. Table 6 shows the vertical accuracy computations on the positive elevation errors only.

Table 6: Vertical Accuracy Results, Positive delta Z only

Breakline Feature Class	# of Points	$RMSE_Z$ x 1.960	Vertical Accuracy @ 95th Percentile
Double Hydroline	3,666	0.156 m	0.143 m
Single Hydroline	1,462	0.135 m	0.137 m

Even though the total vertical accuracy is not within the expected threshold, the level of error for the breaklines that would have the most effect on the usability of the generated DEM or terrain is within desired levels.

6 Breakline Qualitative Analysis

6.1 Protocol

In addition to testing the breaklines for relative accuracy and monotonicity, Dewberry conducts a visual review of the data by overlaying the breaklines and images made from the LiDAR intensity values. This allows Dewberry to check for completeness, proper feature coding, and horizontal positioning. The breaklines were specifically checked to meet the following acceptance criteria:

- All tributaries greater than 100 meters, streams and canals greater than 8 ft will be collected as double line features;
- Islands greater than 5 meters in any direction;
- Hydro connectors to ensure connectivity within culverts;
- Waterbodies are collected for closed lakes and ponds greater than 0.25 acres and streams greater than 10 meters in width;
- Breaklines will be topologically correct, contain no duplicate points, contain no under/overshoots, and lines will intersect polygons precisely.

6.2 Quality Report

Dewberry conducted a visual review of 100% of the data. The breaklines were found to have no major errors in completeness, horizontal positioning, feature coding, etc. All collection specifications were met and the data is of good quality for hydro modeling.

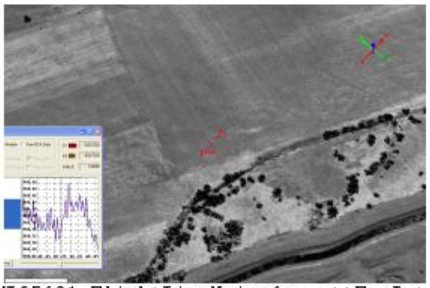
7 Conclusion

Dewberry has completed an extensive quantitative and qualitative assessment of the LiDAR and breaklines for Sub-project 1, the Platte River Channel. Overall the data is of good quality and meets the minimum specifications for absolute and relative accuracy. The Nebraska Partners provided a sufficient number of checkpoints to conduct a vertical accuracy assessment and the LiDAR data passed in all three land cover categories. The qualitative review did not find any major anomalies in the data; several small issues have been identified and described in this report, but there are no issues that require reprocessing.

The breakline dataset has also been tested absolute and relative accuracy and deemed to be of good quality. While there are some issues with the relative accuracy compared to the LiDAR, the dataset is the best compromise between contract specifications for monotonicity and vertical accuracy. In Dewberry’s qualitative assessment, no collection or feature coding issues were identified. This dataset will be useful for building DEMs and GeoTerrains.

Aside from the minor issues identified in the LiDAR and breakline quality reports, Dewberry issues acceptance for this data with no further corrections necessary. Any additional editing to these datasets will not result in significant improvements. The LiDAR and breakline data are of good quality and will be useful for geographic and hydrographic modeling.

8 Appendix A – Minor Issue Images



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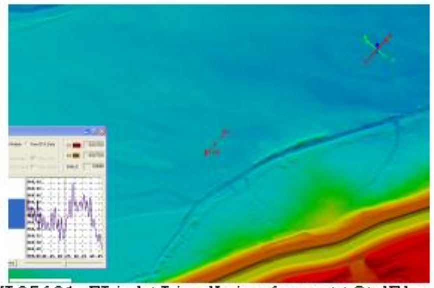

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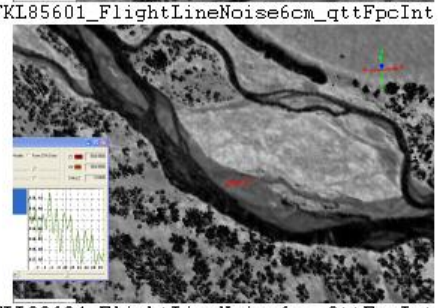

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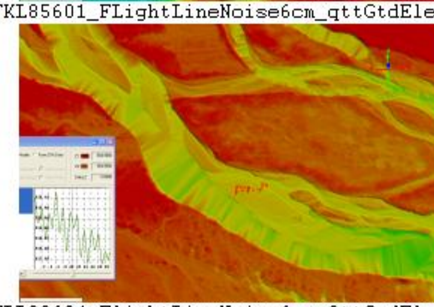

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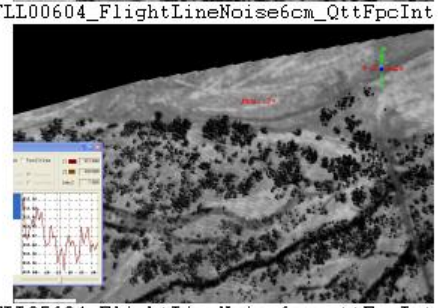

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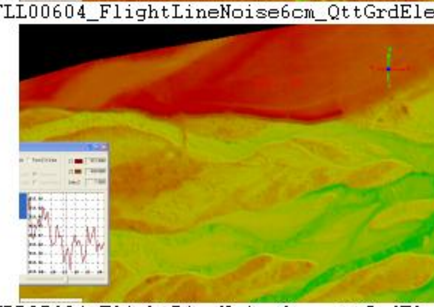

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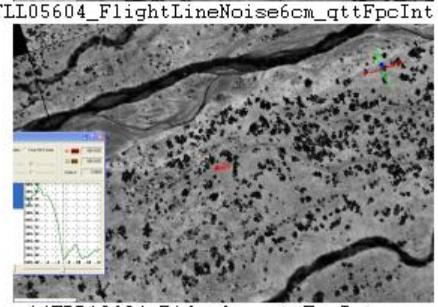

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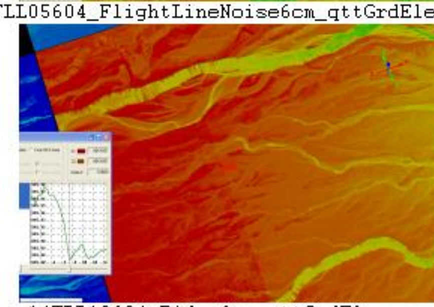

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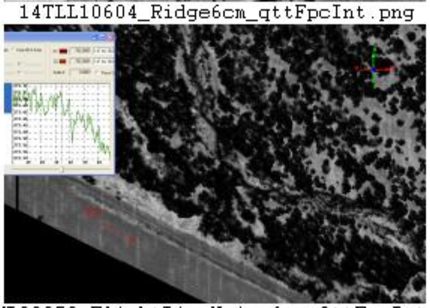

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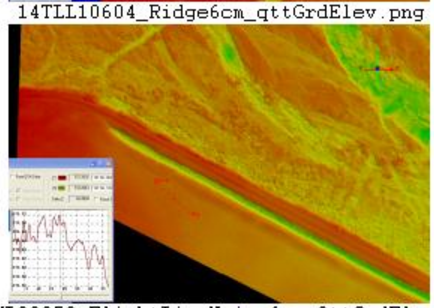

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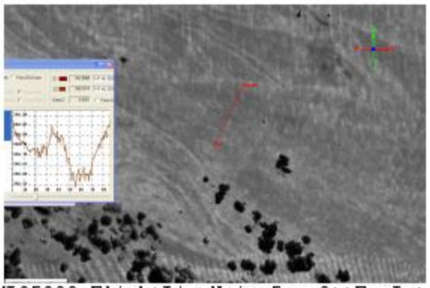
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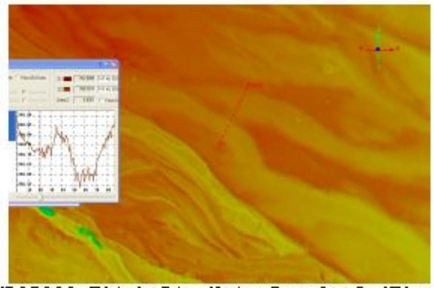
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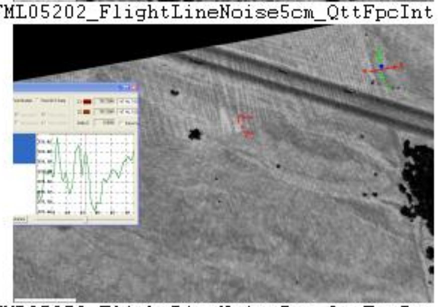
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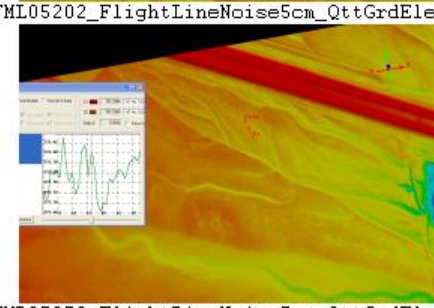
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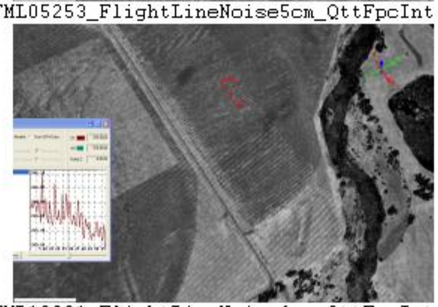
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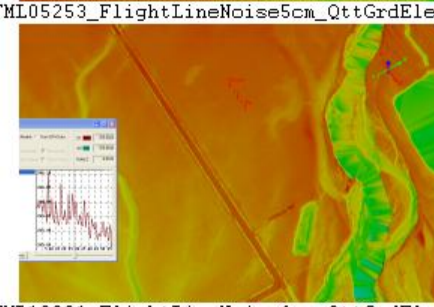
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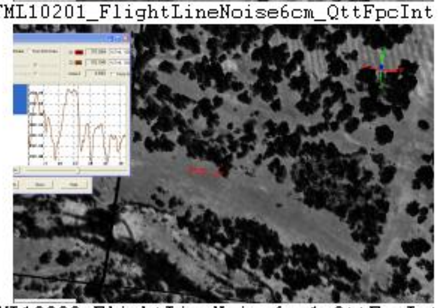
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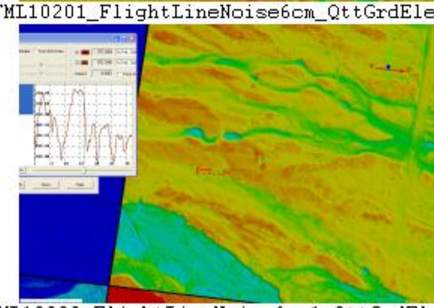
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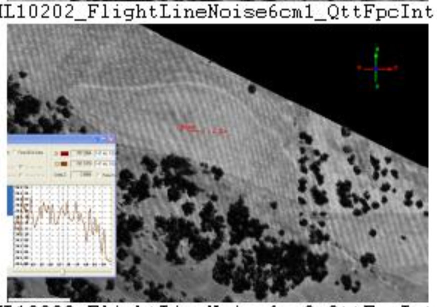
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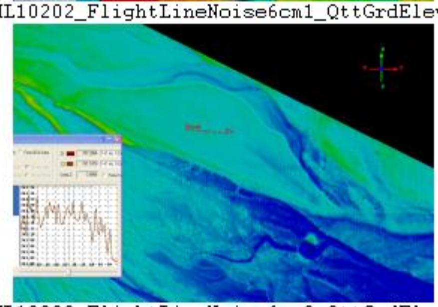
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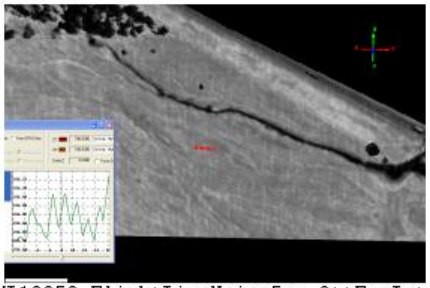
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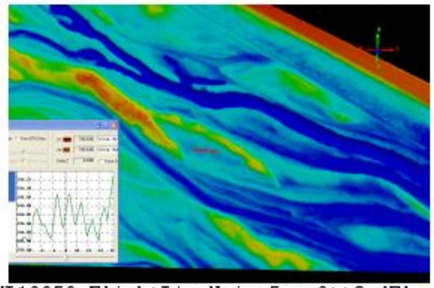
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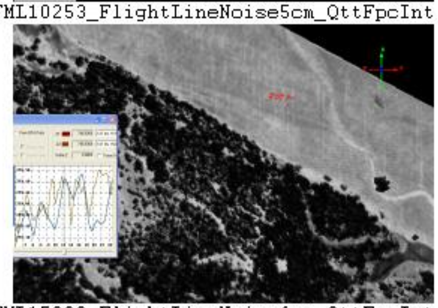
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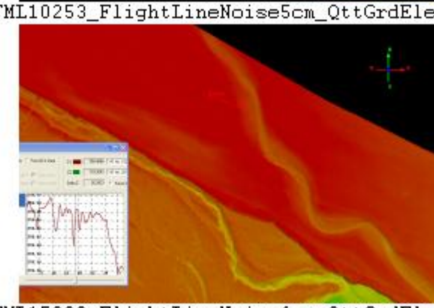
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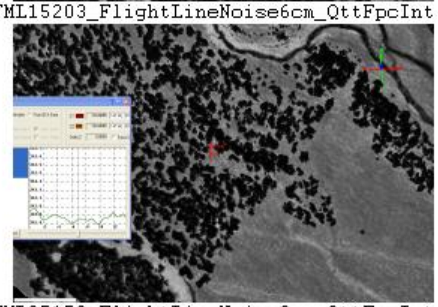
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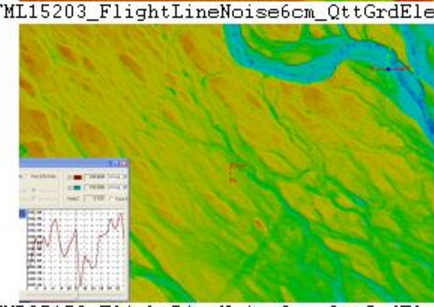
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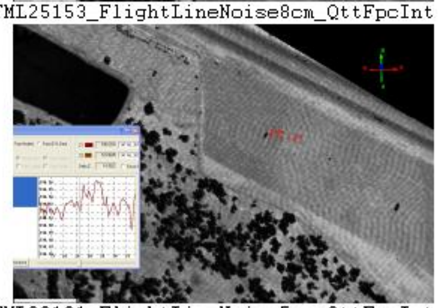
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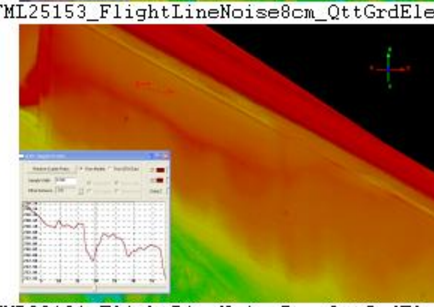
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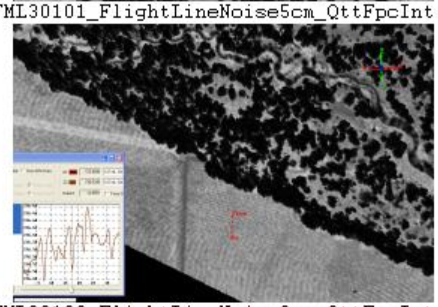
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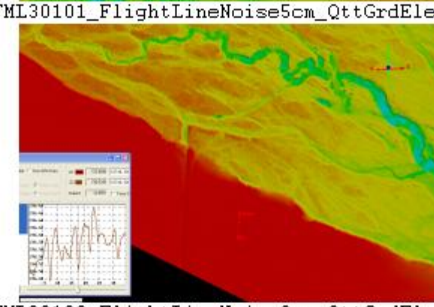
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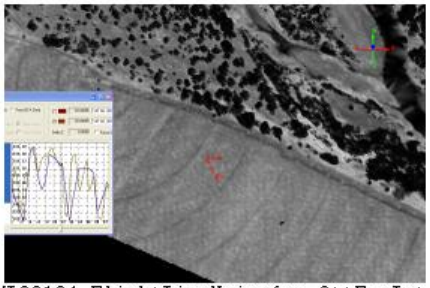

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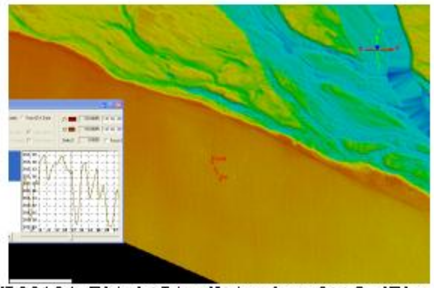

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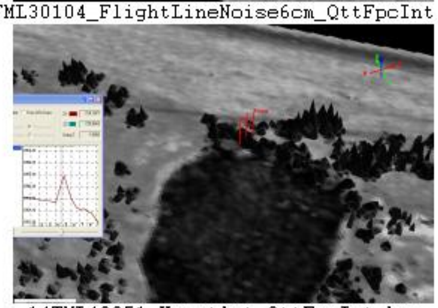

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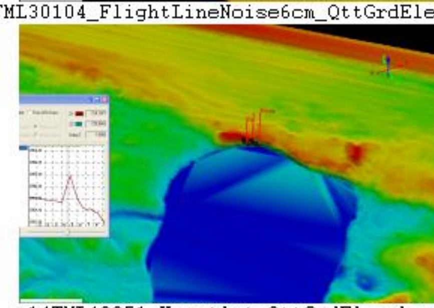

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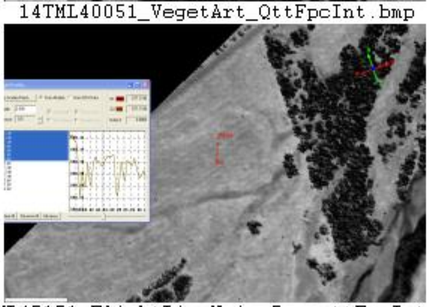

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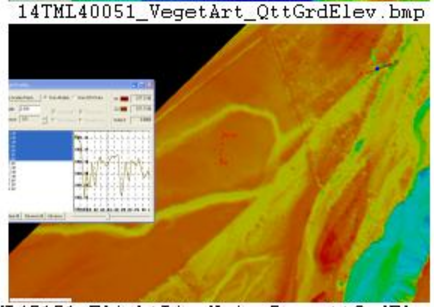

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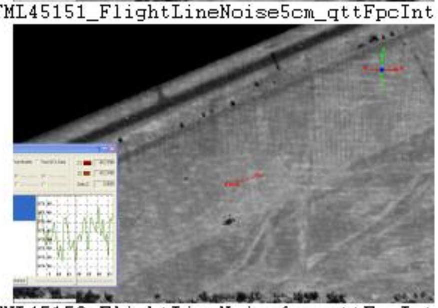

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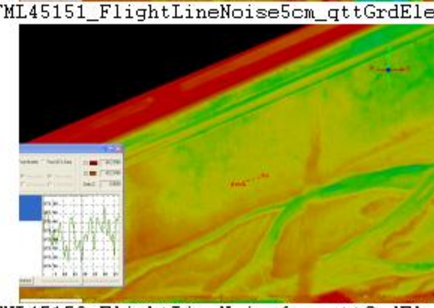

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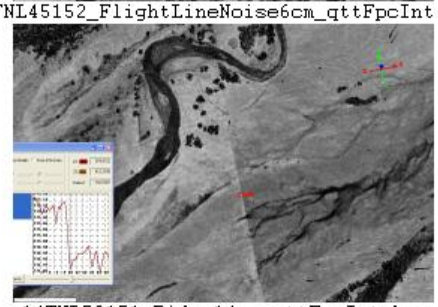

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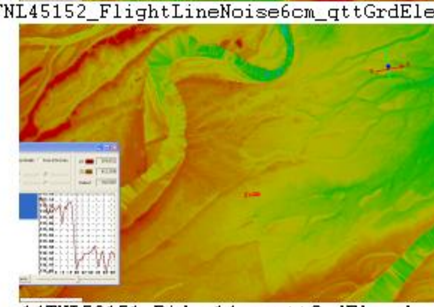

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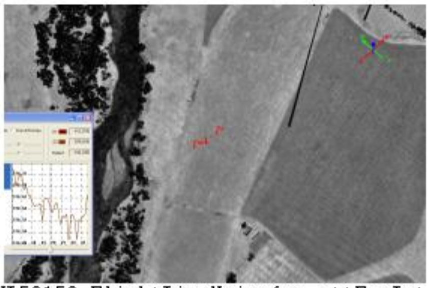
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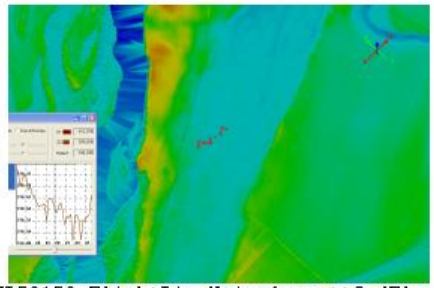
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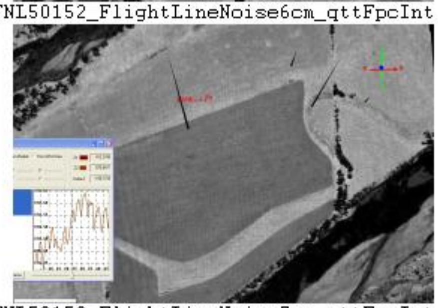
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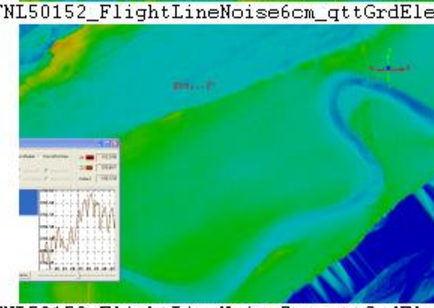
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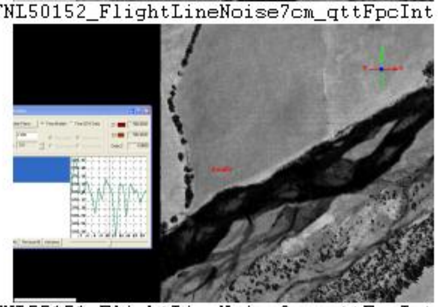
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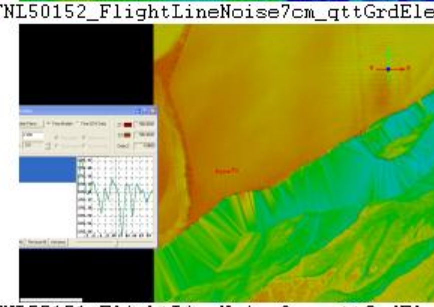
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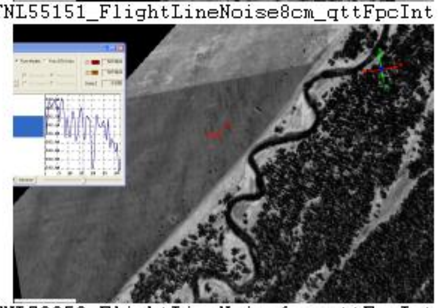
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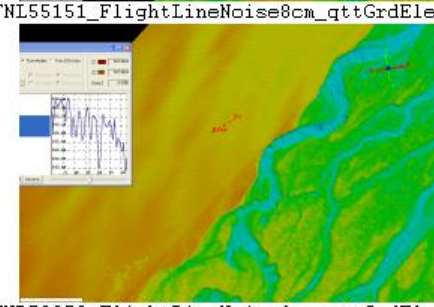
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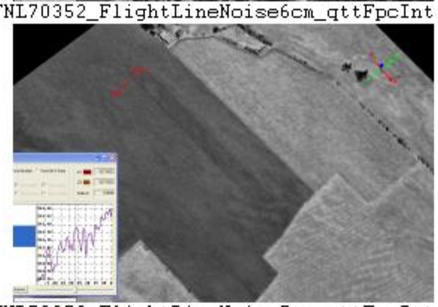
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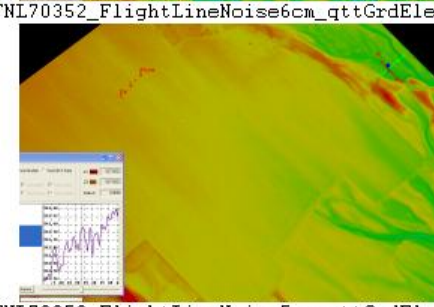
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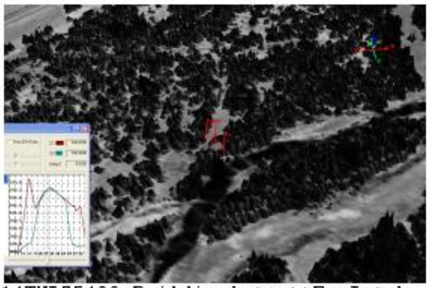

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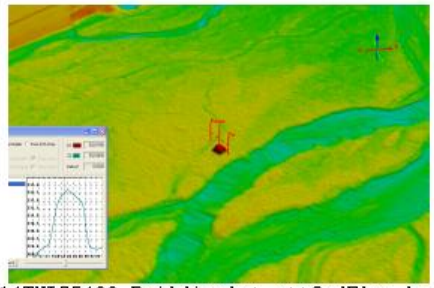

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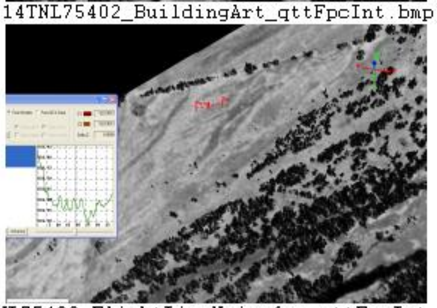

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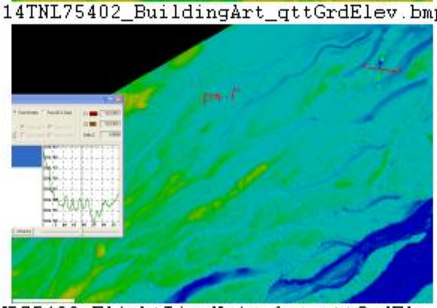

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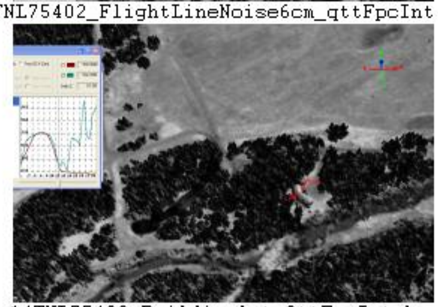

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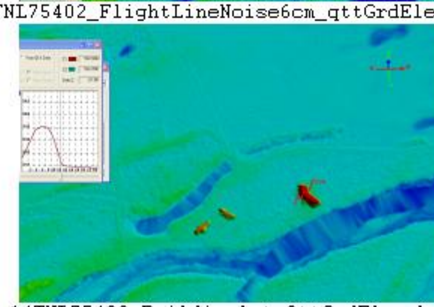

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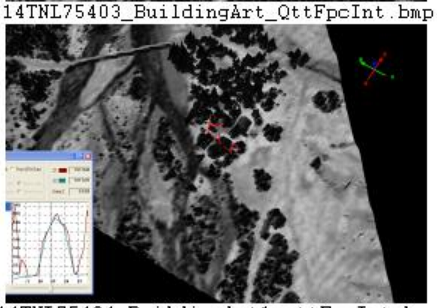

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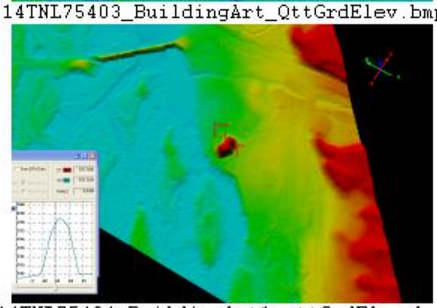

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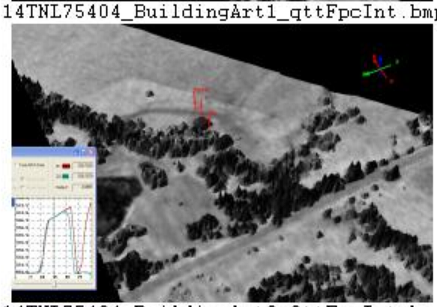

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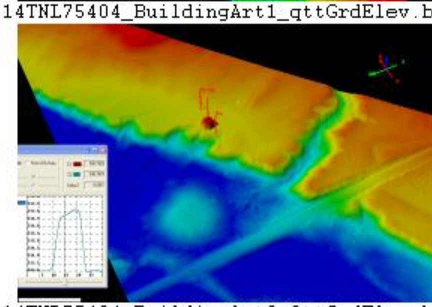

14TNL75404_BuildingArt2_QttGrdElev.bmp