Dewberry
8401 Arlington Boulevard
Fairfax, Virginia 22031-4666
703 849 0396
703 849 0182 fax
www.dewberry.com

FINAL REPORT

QA/QC Assessment of Escambia County, Florida Lidar Dataset Produced by 3001, Inc.

NOAA CSC Contract EA133C05CQ1048
Task Order No. T006

March 15, 2007

Table of Contents

References:

A — NOAA Coastal Services Center Task Order T006, 27 Mar 2006, Escambia County Florida Lidar

B — Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, "Geospatial Positioning Accuracy Standards," published by the Federal Geographic Data Committee (FGDC), 1998

C — Appendix A, *Guidance for Aerial Mapping and Surveying*, "Guidelines and Specifications for Flood Hazard Mapping Partners," published by the Federal Emergency Management Agency (FEMA), April 2003

D — *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 10, 2004

E — *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004

F – Dewberry's Vertical Accuracy Assessment Report, 2006 Lidar Bare-Earth Dataset for Escambia County, Florida, dated December 28, 2006

G – Dewberry's Qualitative Assessment Report, 2006 Lidar Bare-Earth Dataset for Escambia County, Florida, dated December 31, 2006

Vertical Accuracy Assessment of Reprocessed Lidar Data

Background

<u>NOAA Guidance</u>: Reference A tasked Dewberry to collect and deliver topographic elevation point data derived from multiple return light detection and ranging (lidar) measurements and to provide independent QA/QC including the survey of 100 checkpoints to be used for vertical testing of the bare-earth lidar dataset of Escambia County, FL, both quantitatively (for accuracy) and qualitatively (for usability). In the initial report, dated December 28, 2006 (Reference F), the lidar data did not meet NOAA's specifications and the data was rejected, to be reprocessed by 3001, Inc. This section of the Final Report addresses the vertical accuracy assessment of the reprocessed data, for which NOAA's major specifications are summarized as follows:

- Vertical accuracy: 15 cm $RMSE_z$ = 29.4 cm vertical accuracy at 95% confidence level, tested in flat, non-vegetated terrain only, employing NSSDA procedures in Reference B.
- Validation that the data also satisfies FEMA requirements in Reference C (18.5 cm $RMSE_z$ for all land cover categories combined).
- Vertical units (ellipsoid heights) are in meters above the GRS80 ellipsoid surface.

<u>NSSDA Guidance</u>: Section 3.2.2 of Reference B specifies: "A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications."

<u>FEMA Guidance</u>: Section A.8.6 of Reference C specifies the following lidar testing requirement for data to be used by the National Flood Insurance Program (NFIP): "For the NFIP, TINs (and DEMs derived therefrom) should normally have a maximum RMSE of 18.5 centimeters, equivalent to 2-foot contours, in flat terrain; and a maximum RMSE of 37 centimeters, equivalent to 4-foot contours, in rolling to hilly terrain. The Mapping Partner shall field verify the vertical accuracy of this TIN to ensure that the 18.5- or 37.0-centimeter RMSE requirement is satisfied for all major vegetation categories that predominate within the floodplain being studied … The assigned Mapping Partner shall separately evaluate and report on the TIN accuracy for the main categories of ground cover in the study area, including the following: [followed by explanations of seven potential categories]… Ground cover Categories 1 through 5 are fairly common everywhere … The assigned Mapping Partner shall select a minimum of 20 test points for <u>each</u> major vegetation category identified. Therefore, a minimum of 60 test points shall be selected for three (minimum) major land cover categories, 80 test points for four major categories, and so on."

NDEP and ASPRS Guidance: NDEP guidelines (Reference D) and ASPRS guidelines (Reference E) also recommend a minimum of 60 checkpoints, with up to 100 points preferred. (These guidelines are referenced because FEMA's next update to Appendix A will include these newer NDEP and ASPRS guidelines, now recognizing that vertical errors for lidar bare-earth datasets in vegetated terrain do not necessarily follow a normal error distribution as assumed by the NSSDA.)

NWFWMD Guidance: The North West Florida Water Management District (NWFWMD) accepted FEMA's five standard land cover categories as representative of the floodplains within Escambia County, with the goal of surveying 20 x 5 = 100 QA/QC checkpoints if sufficient checkpoints could be reasonably identified.

Vertical Accuracy Test Procedures

Ground Truth Surveys: Using the same GPS base stations as used by Land Air Mapping (now 3001) for the lidar data acquisition, Dewberry completed the GPS survey of 102 checkpoints in June of 2006 and submitted the QA/QC checkpoint survey data and photos to the Coastal Services Center on 6/30/2006.

The QA/QC checkpoint survey in Escambia County incorporated both GPS and conventional methods to ensure the desired accuracy was met. For logistical and spatial distribution reasons, the project area was further divided into a north and south zones. This allowed us to use NGS control as base stations so that each of our test areas was based on the same control points used by the lidar vendor, 3001. Because our goal was to establish checkpoints that were approximately three times more accurate than the lidar, our target $RMSE_z$ was approximately 5 cm and this dictated our survey approach. As with any survey of this nature, many factors play a role such as cost, accessibility, and limitations of the survey equipment as well as achievable accuracy. Therefore a balance was created in establishing checkpoints using a combination of GPS Fast Static, Real Time Kinematic (RTK) and conventional survey techniques.

The approach that was used is termed the "cluster" survey. This process establishes a series of secondary base stations dispersed throughout the project area which are then used as the basis in which RTK measurement (cluster points) and conventional measurements are derived. Since there is no adequate existing NGS control throughout the County it was imperative that these secondary base stations be established. The location of the secondary base stations are based on many factors such as; location within the county in relationship to other base station locations, land cover type, and proximity to existing NGS control. The process of establishing these secondary base stations were identified using existing aerial photographs from Google Earth. First, an ideal open area was identified that would support a GPS base station with no obstructions, secondly it needed to be within 15 miles of a NGS control monument to maintain the desired accuracy, and thirdly it had to be central within the range of RTK to be able to measure the different land cover types as required; therefore the area also had to have many land cover types near by. After these three criteria were met, fast static surveys were established from the existing NGS control to the secondary base stations. For most areas, a total of three GPS units were used simultaneously, two on NGS control and the third on the secondary base station. This allowed for a minimum of two vectors into each secondary base. Due to logistical constraints, some areas were performed similarly except that only two GPS units were used at a time. However each secondary base had two vectors but one vector was measured one day from an NGS control point and a second vector was measured the next day from a second NGS control point.

By utilizing multiple station observations the accuracy was assessed with a least squares adjustment and the results indicated no outliers were apparent. For this survey no repeat observations were required. After each secondary base station was established it was used as the base station for all RTK measurements. The advantage of RTK is the ability to resolve phase ambiguities and achieve centimeter level accuracy with less than 1 minute of observations (at times only a few seconds is required). For the RTK measurements a few factors dictated where they were established. In choosing suitable locations, not only is the correct land cover type important but also the location in relationship to the flight lines. For example, if a line is flown in an east/west direction, two points along the same axis do not truly give a unique check on the data (other than land cover type). Our process involved ensuring we could cover as many different flight lines as possible. Again if the lines were flown east/west our checkpoints were collected in a north/south pattern. Again this allows us to cover more flight lines. For each suitable site, an RTK measurement was taken and a picture taken and documented. Additionally, inter-visible pairs were established to allow the use of conventional equipment to measure points within the forest where GPS would not be suitable. The two points allowed for the instrument setup as well as a back sight. Although there are two points typically in the land cover type grass, these are not considered two check points as they do not meet the required spacing between checkpoints. However they are used as an internal verification of the lidar. Again to ensure data integrity, some points were measured twice with the RTK, usually a few days later. If any measurement exceeded our 5 cm criteria it was rejected and a new observation was performed until a comparison of less than 5 cm existed.

The process of verifying our survey is done through a series of checks and balances utilizing multiple measurements, ties into existing control and through least squares adjustments. However the definitive check is how well the lidar fits to the checkpoints. It is understood that the survey is to verify the lidar but the lidar can also be used to verify the survey. If a good comparison is obtained, which was the case for this survey, we can conclude that both the survey and the lidar meet specification.

Initial Issues: The initial proposal submitted by Dewberry included the firm Land Air Mapping for the acquisition and post processing of the lidar data for this project, including delivery of digital data and metadata to Dewberry for QA/QC by September 30, 2006. Issues included the following:

- July 5, 2006, notified by the Land Air PM that some of the flight lines needed to be reflown, but deliveries would still be completed to Dewberry by September 30, 2006.
- September 27, 2006, notified by the Land Air PM that data did not pass Land Air’s internal QA/QC, requesting extension until October 15, 2006 for reprocessing and delivery.
- October 8, 2006, notified by the Land Air PM that there were unspecified delays, requesting extension until October 30, 2006 for delivery.
- October 30, 2006, notified by the (former) Land Air PM that he was no longer an employee because Land Air had been acquired by 3001, Inc. and all responsibilities for lidar projects had been assumed by 3001, with no role for the prior Land Air lidar staff in the new organization.
- During the months of November and December, 3001’s new PM indicated complexities in understanding the raw data, control points used, etc. from Land Air. Actual datasets were delivered to Dewberry in project areas, between December 8, 2006 and December 21, 2006.

As is typical of new management, the transition from one company to the newer one was not without problems. Many facets of this project were affected from the acquisition to initial processing to final post processing. Each internal deliverable was affected and subsequently delayed the Quality Assurance testing and analysis.

Assessment Procedures and Results: The initial (December, 2006) and subsequent (March, 2007) lidar accuracy assessments for Escambia County were performed by Dewberry in accordance with References D and E which assume that lidar errors in some land cover categories may not follow a normal error distribution. These assessments were also performed in accordance with References B and C which assume that lidar bare-earth datasets errors do follow a normal error distribution. Comparisons between the two methods help determine the degree to which *systematic errors* may exist in Escambia County’s five major land cover categories: (1) open terrain, (2) weeds and crops, (3) scrub and bushes, (4) forests, and (5) urban areas. When a lidar bare-earth dataset passes testing by both methods, compared with criteria specified in Reference A, the dataset clearly passes all vertical accuracy testing criteria for a digital terrain model (DTM) suitable for NOAA and FEMA requirements.

The relevant criteria are summarized in Table 1. Criteria in yellow refer to NOAA-specific requirements in Reference A ($RMSE_z$ = 15-cm in open terrain only), whereas criteria in green refer to FEMA requirements in Reference C, but expressed in terminology used by the NDEP and ASPRS in references D and E.

Table 1 — DTM Acceptance Criteria for Escambia County

Quantitative Criteria	Measure of Acceptability
$RMSE_z$ = NSSDA vertical accuracy statistic at 68% confidence level	15 cm in open terrain only
$Accuracy_z$ = NSSDA vertical accuracy statistic at the 95% confidence level = $RMSE_z$ x 1.9600	29.4 cm (15 cm $RMSE_z$ x 1.9600) in open terrain only
Fundamental Vertical Accuracy (FVA) in open terrain only = 95% confidence level	36.3 cm (18.5 cm $RMSE_z$ x 1.9600) for open terrain only
Supplemental Vertical Accuracy (SVA) in individual land cover categories = 95% confidence level	36.3 cm (based on 95th percentile per category; this is a target value only, not mandatory)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined = 95% confidence level	36.3 (based on combined 95th percentile)

Vertical Accuracy Testing in Accordance with NDEP and ASPRS Procedures

References D and E specify the mandatory determination of Fundamental Vertical Accuracy (FVA) and Consolidated Vertical Accuracy (CVA), and the optional determination of Supplemental Vertical Accuracy (SVA). FVA determines how well the lidar sensor performed in category (1), open terrain, where errors are random and normally distributed; whereas SVA determines how well the lidar pulse penetrated the vegetation as well as how well the vegetation classification algorithms worked in land cover categories (2), (3) and (4) where lidar elevations are often higher than surveyed elevations, and category (5) where lidar elevations are often lower.

FVA is determined with check points located only in land cover category (1), open terrain (grass, dirt, sand, and/or rocks), where there is a very high probability that the lidar sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The FVA determines how well the calibrated lidar sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600, as specified in Reference B. For Escambia County, for which floodplains are essentially flat, FEMA would require the FVA to be 36.5 cm at the 95% confidence level (based on an $RMSE_z$ of 18.5 cm, equivalent to 2 ft contours), whereas NOAA has a stricter standard, i.e., $Accuracy_z$ of 29.4 cm at the 95% confidence level (based on an $RMSE_z$ of 15 cm) in open terrain, somewhat better than 2 ft contours. In open terrain, $Accuracy_z$ and FVA refer to the very same calculations, based on $RMSE_z$.

CVA is determined with all checkpoints in all land cover categories combined where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all land cover categories combined. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA is determined separately for each individual land cover category, again recognizing that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution, and where discrepancies can be used to identify the nature of systematic errors by land cover category. For each land cover category, the SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each individual land cover category. SVA statistics are calculated individually for open terrain, weeds and crops, scrub, forests, and urban areas in order to facilitate the analysis of the data based on each of these land cover categories that exist within Escambia County. The SVA criteria in Table 1 are target values only and are not mandatory; it is common for some SVA criteria to fail individual target values, yet satisfy FEMA's mandatory CVA criterion.

QA/QC Steps: The primary QA/QC steps used by Dewberry were as follows:

1. Dewberry surveyed "ground truth" QA/QC vertical checkpoints in accordance with guidance in references B, C, D and E. Figure 1 shows the location of "cluster areas" where Dewberry attempted to survey two QA/QC checkpoints in each of the five land cover categories. Some cluster areas did not include all land cover categories. The final totals were 20 checkpoints in open terrain; 21 checkpoints in weeds and crops; 20 checkpoints in scrub; 20 checkpoints in forests; and 21 checkpoints in built up areas, for a total of 102 checkpoints.
2. Next, Dewberry interpolated the bare-earth lidar DTM (Class 2 points) to provide the z-value for each of the 102 checkpoints.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the lidar data and the ground truth survey checkpoints and computed the FVA, CVA and SVA values using procedures in References D and E.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by NDEP and ASPRS guidelines. Also, the overall descriptive statistics of each dataset were computed to assess any trends or anomalies. The following tables, graphs and figures illustrate the data quality.

Figure 1 shows the location of the QA/QC checkpoint clusters within Escambia County, symbolized to reflect the five land cover categories used. However, most of the symbols for the different land cover categories overlay each other and are not individually visible at this scale.

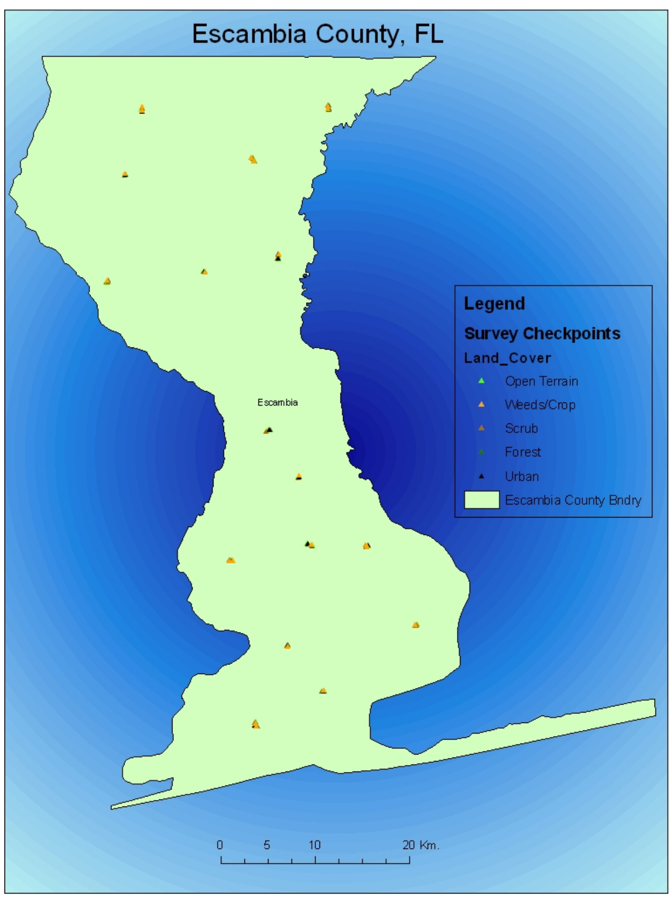


Figure 1 — Location of QA/QC Checkpoint Clusters

Table 2 summarizes the vertical accuracy by fundamental, consolidated and supplemental methods:

Table 2 — FVA, CVA and SVA Vertical Accuracy at 95% Confidence Level

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec = 0.294 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec = 0.363 m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target = 0.363 m
Total Combined	102		0.382 m	
Open Terrain	20	0.139 m		0.126 m
Weeds/Crops	21			0.318 m
Scrub	20			0.347 m
Forest	20			0.494 m
Urban	21			0.168 m

Fundamental and Consolidated Vertical Accuracy at 95% confidence level, using NDEP/ASPRS methodology:

The $RMSE_z$ values are shown in Table 4 below. The $RMSE_z$ in open terrain was 7 cm, whereas the standard was 15 cm. Based on $RMSE_z$ x 1.9600, the FVA tested 13.9 cm at the 95% confidence level in open terrain which is well within the 29.4 cm specification.

There are two methods to compute the consolidated vertical accuracy at the 95% confidence level:

- The method used by the NSSDA and FEMA computes $Accuracy_z$ as the consolidated $RMSE_z$ x 1.9600 = 17 cm x 1.9600 = 33.3 cm which passes the 36.3 cm standard. Therefore the data passes all FEMA accuracy testing guidelines.
- The method used by the NDEP and ASPRS computes CVA as the consolidated 95^{th} percentile = 38.2 cm which would not quite pass a 36.3 cm standard. The CVA value slightly exceeds the standard by 2 cm due to outliers located in forested terrain.

Table 3 lists all outliers greater that the required 36.3 cm. Typically, 5% of the points exceed the standard based on lidar errors in vegetation that do not follow a normal distribution for errors. Although 8% of the points exceed the standard in this case, the data are still marginally acceptable as the remainder of the points were well within the specifications as evidenced by the overall statistics outlined in Table 4. Most of the outliers are located in heavily vegetated areas where interpolated z-values are less accurate due to the reduced number of (and wider spacing between) bare-earth points.

Table 3 — Outliers Larger than the CVA Standard

Land Cover Category	Elevation Diff. (m)	
Forest*	-0.90	Eight points had errors larger than the CVA standard (36.3 cm) which permits up to 5% of the checkpoints, normally 5 of 100, to be larger than 36.3 cm.
Forest	-0.47	
Built Up	-0.42	
Scrub	-0.37	
Forest	0.38	
Forest	0.40	
Forest	0.42	
Weeds/Crop	0.57	

*This point was removed from the statistics due to potential survey error.

Compared with the 36.3 cm SVA target values, SVA tested 12.6 cm at the 95% confidence level in open terrain; 31.8 cm in weeds and crops; 34.7 cm in scrub; 49.4 cm in forests; and 16.8 cm in built-up areas, based on the 95th percentile. Forest was the only category in which SVA values exceeded the target values although this is typical.

Figure 2 illustrates the SVA by specific land cover category.

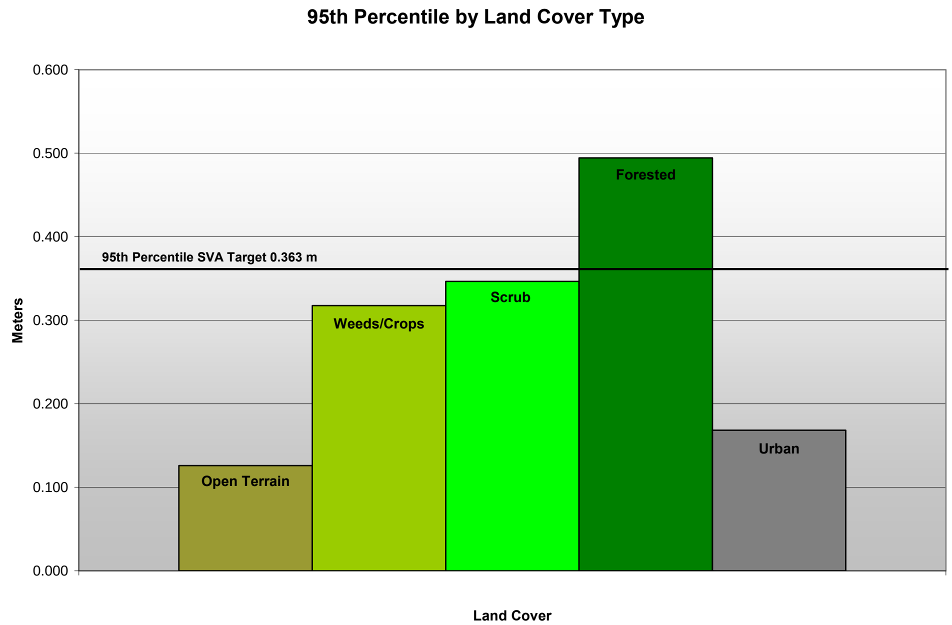


Figure 2 — Graph of SVA Values by Land Cover

Figure 3 illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data by specific land cover category and sorted from lowest to highest. This graph shows that most of the data follows a fairly normal distribution while highlighting the few outliers that exceed the target values.

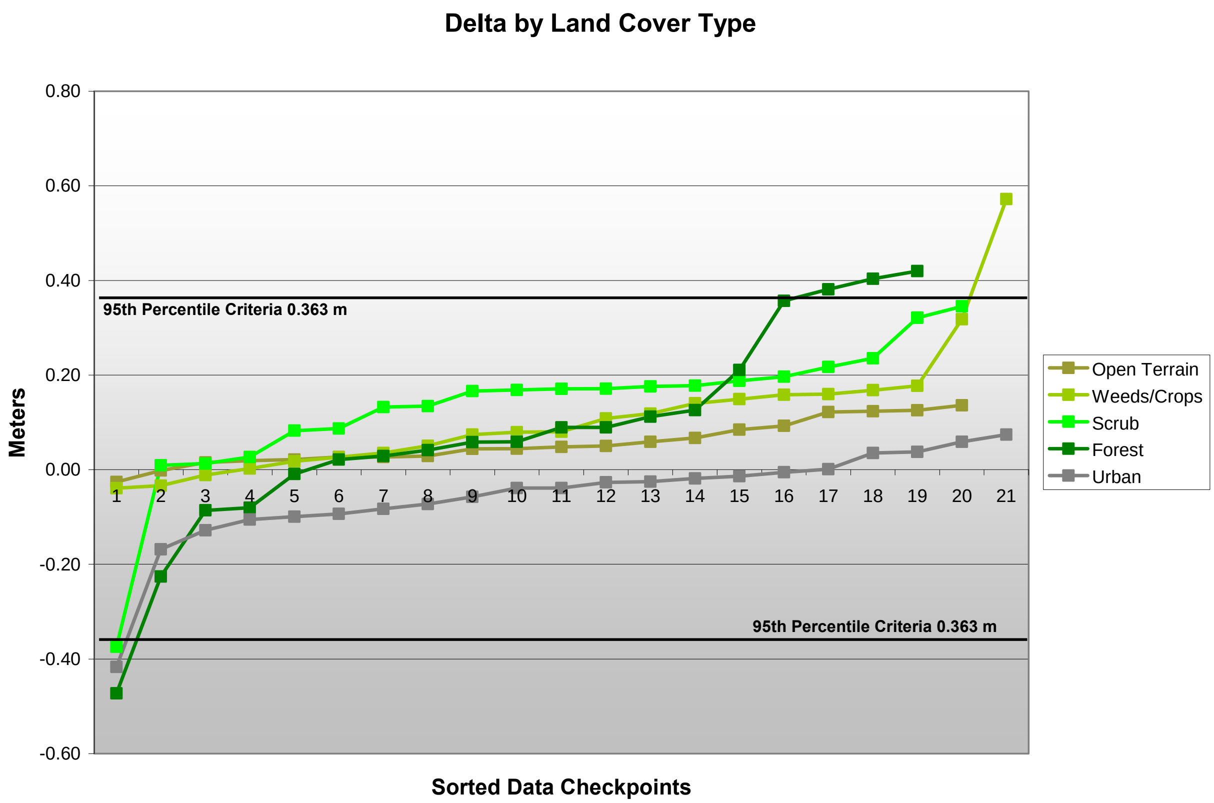


Figure 3 — Magnitude of Elevation Discrepancies, Sorted from Largest Negative to Largest Positive

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

The NSSDA and FEMA guidelines were both published before it was recognized that lidar errors do not always follow a normal error distribution. Future changes to these FGDC and FEMA documents are expected to follow the lead of the NDEP and ASPRS. Nevertheless, to comply with FEMA's current guidelines in Reference C, $RMSE_z$ statistics were computed in all five land cover categories, individually and combined, as well as other statistics that FEMA recommends to help identify any unusual characteristics in the lidar data. These statistics are summarized in Figures 4 and 5 and Table 4 below, consistent with Section A.8.6.3 of Reference C. Table 4 also shows that an apparent positive systematic bias (approximately 5 cm) still remains in all land cover categories, other than urban, but this bias is greatly decreased from the larger bias that existed prior to 3001's adjustment of the elevations to fit their validation surveys completed in February, 2007. This remaining bias is now in the range that Dewberry considers "normal."

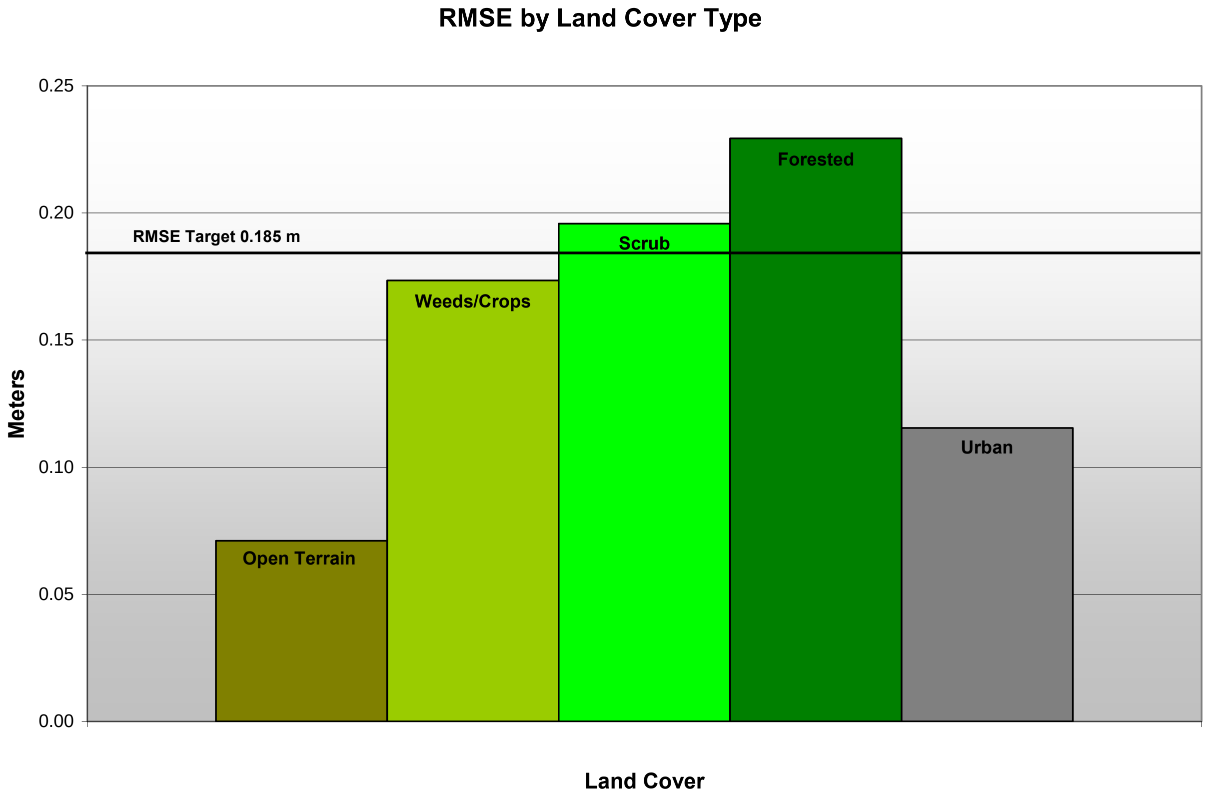


Figure 4 — $RMSE_z$ statistics by Land Cover Category

Table 4 — Overall Descriptive Statistics by Land Cover Category and Consolidated

Land Cover Category	$RMSE_z$ (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.17	0.06	0.05	-0.20	0.15	101	-0.47	0.57
Open Terrain	0.07	0.06	0.05	0.38	0.05	20	-0.03	0.14
Weeds/Crop	0.17	0.11	0.08	2.09	0.14	21	-0.04	0.57
Scrub	0.20	0.13	0.17	-2.08	0.15	20	-0.37	0.35
Forest	0.23	0.08	0.06	-0.48	0.22	19	-0.47	0.42
Urban	0.12	-0.06	-0.04	-2.15	0.10	21	-0.42	0.07

Fundamental and Consolidated Vertical Accuracy at 95% confidence level, using NSSDA/FEMA methodology:

Using NSSDA and FEMA guidelines, vertical accuracy at the 95% confidence level (called $Accuracy_z$) is computed by the formula $RMSE_z$ x 1.9600.

$Accuracy_z$ in open terrain = 7 cm x 1.9600 = 13.7 cm, satisfying the 29.4 cm standard.

$Accuracy_z$ in consolidated categories = 17 cm x 1.9600 = 33.3 cm, satisfying the 36.3 cm standard.

Figure 5 illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -47 cm and a high of +57 cm, the error histogram shows that the majority of the discrepancies approximate a normal distribution, with a slightly positive bias.

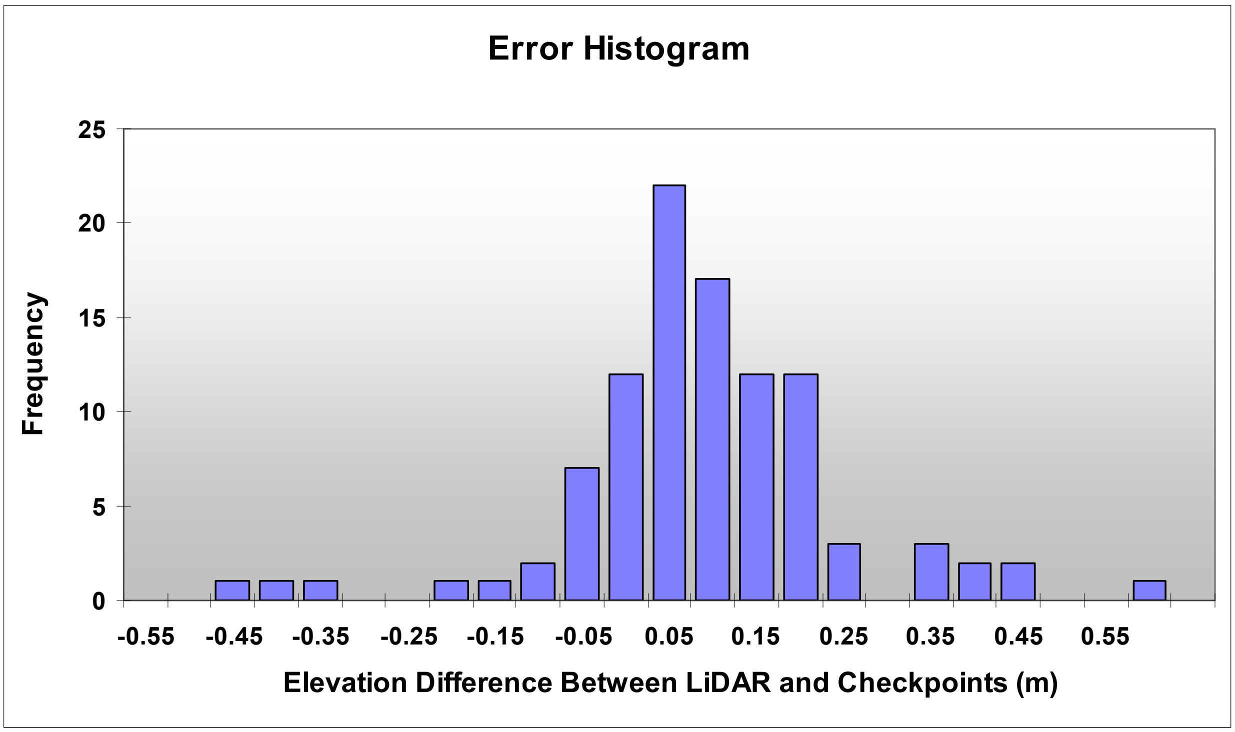
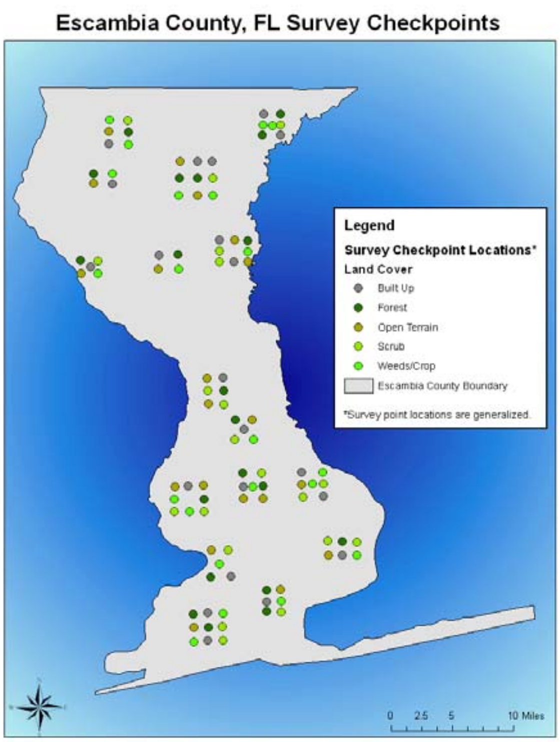


Figure 5 — Histogram of Elevation Discrepancies within 0.10 m Bands

Figure 6 (left) displays the approximate location of survey checkpoints by land cover category, and Figure 6 (right) displays the same map with size of errors found in the accuracy analysis. The symbols for cluster points were moved slightly so they do not overlay each other. The larger errors are red and orange, and the smaller errors are yellow and green. The one point shown in red is the point that the undersigned decided to delete from the dataset because of a *potential* survey error for which we did not want to blame the lidar data for the discrepancy.



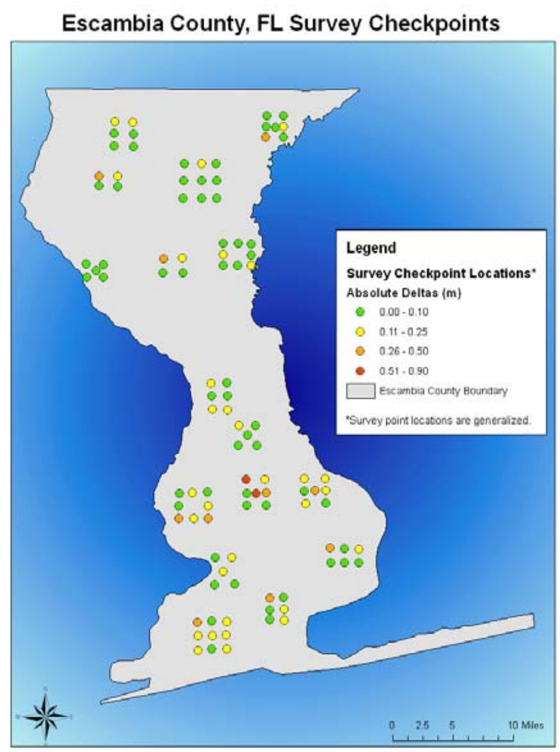


Figure 6. The left image shows the approximate location of QC checkpoints color-coded by land cover category. The right image shows the approximate size of the errors at each checkpoint location.

Vertical Accuracy Conclusions

Based on the vertical accuracy testing conducted by Dewberry, the undersigned certifies that the lidar dataset for Escambia County, Florida satisfies the criteria established by Reference A:

- Countywide lidar dataset tested 13.7 cm vertical accuracy at 95% confidence level in open terrain, based on open terrain $RMSE_z$ (7 cm) x 1.9600.
- Countywide lidar dataset tested 33.3 cm vertical accuracy at 95% confidence level in all land cover categories combined, based on consolidated $RMSE_z$ (17 cm) x 1.9600.

Qualitative Assessment of Reprocessed Lidar Data

NOAA Guidance

Reference A tasked Dewberry to validate the bare-earth lidar dataset of Escambia County, FL, both quantitatively (for accuracy) and qualitatively (for usability). The initial quantitative and qualitative assessments of the data revealed errors in the post-processing of the data as well as some anomalies in the relative accuracy. Dewberry concluded from these evaluations that the data did not meet the required specifications and should be re-processed. Section 2 of this Final Report addresses the qualitative aspect of the re-processed data.

Qualitative Assessment Techniques

Dewberry's qualitative assessment utilizes an interpretive and statistical based methodology to assess the quality of the data for a bare-earth digital terrain model (DTM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model. In the initial assessment it was determined that although the data was considered good overall there were a few issues that needed to be addressed in order to be utilized efficiently. The most critical problems that were found were the presence of cornrows, flightline offsets, and noise.

For the original qualitative assessment Dewberry reviewed approximately 80% of the data on a macro level and 30% on a micro level. This entailed looking at each tile individually and examining it for any gross anomalies. If the tile had any questionable findings it was then reviewed at a micro level. For this assessment only tiles that had been flagged for errors in the previous evaluation were reviewed in order to determine if the re-processing was effective. These tiles are illustrated in Figure 7.

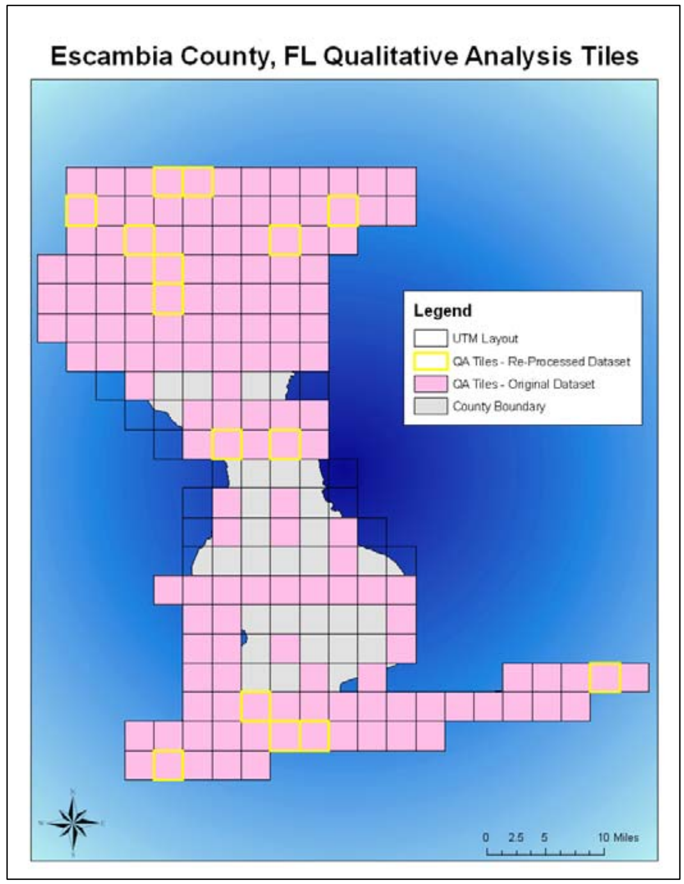


Figure 7: Location of QA tile review

Qualitative Assessment Conclusions

The first issue that was addressed was the presence of cornrows. This phenomenon is believed to be caused by a problem in the lidar sensor. During turbulent flight conditions the sensor may lose sync causing the rotations of the mirror to be at two different flight elevations. This produces a furrow effect resembling crops in a field. The cornrows that were observed in the initial dataset produced furrows that were from approximately 5 cm to 50 cm off from each other. The re-processing techniques were successful in smoothing these ridges and the cornrows are no longer visible in the bare-earth product (see Figures 8 through 10).

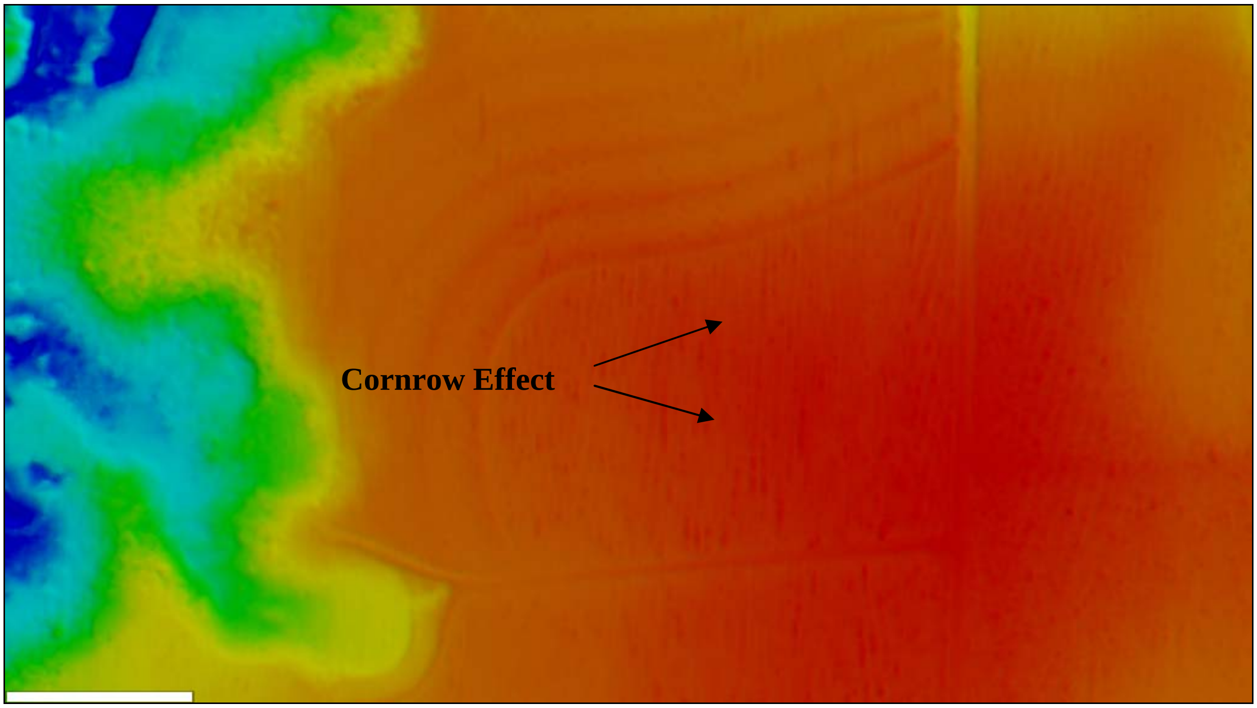


Figure 8: Cornrows visible in the first delivery of the lidar data.

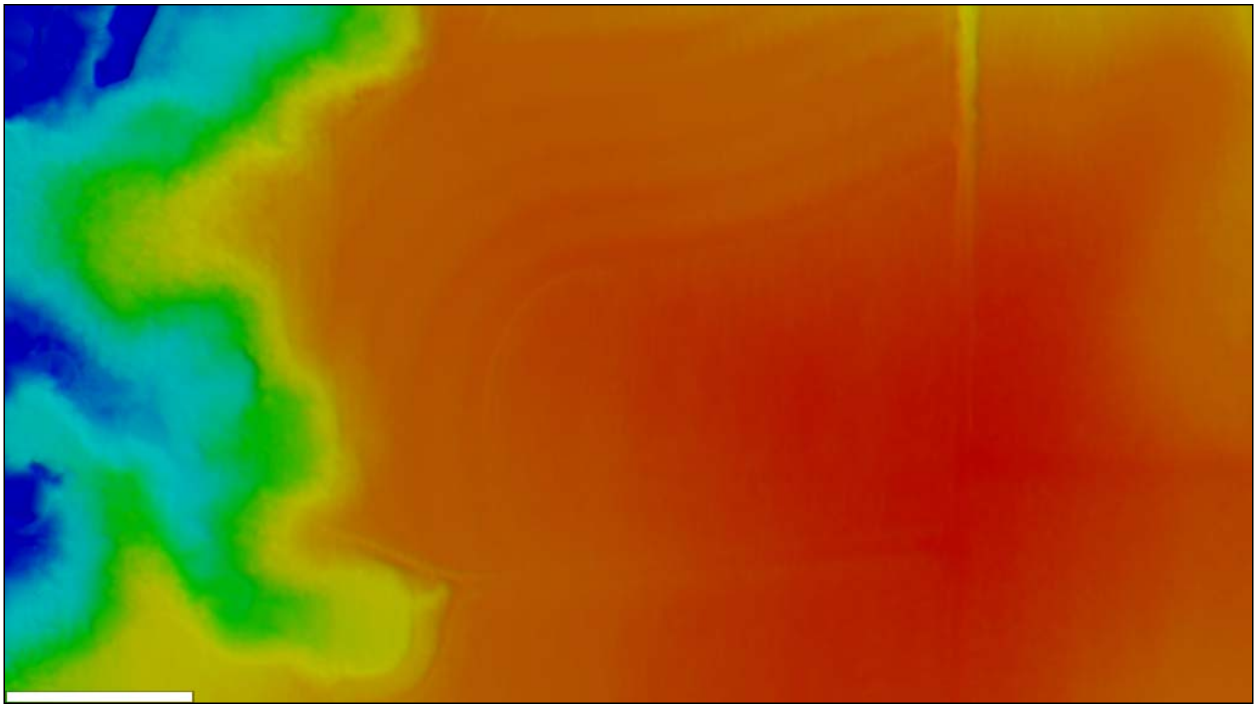


Figure 9: Ridges have been smoothed out during re-processing and cornrows are no longer visible.

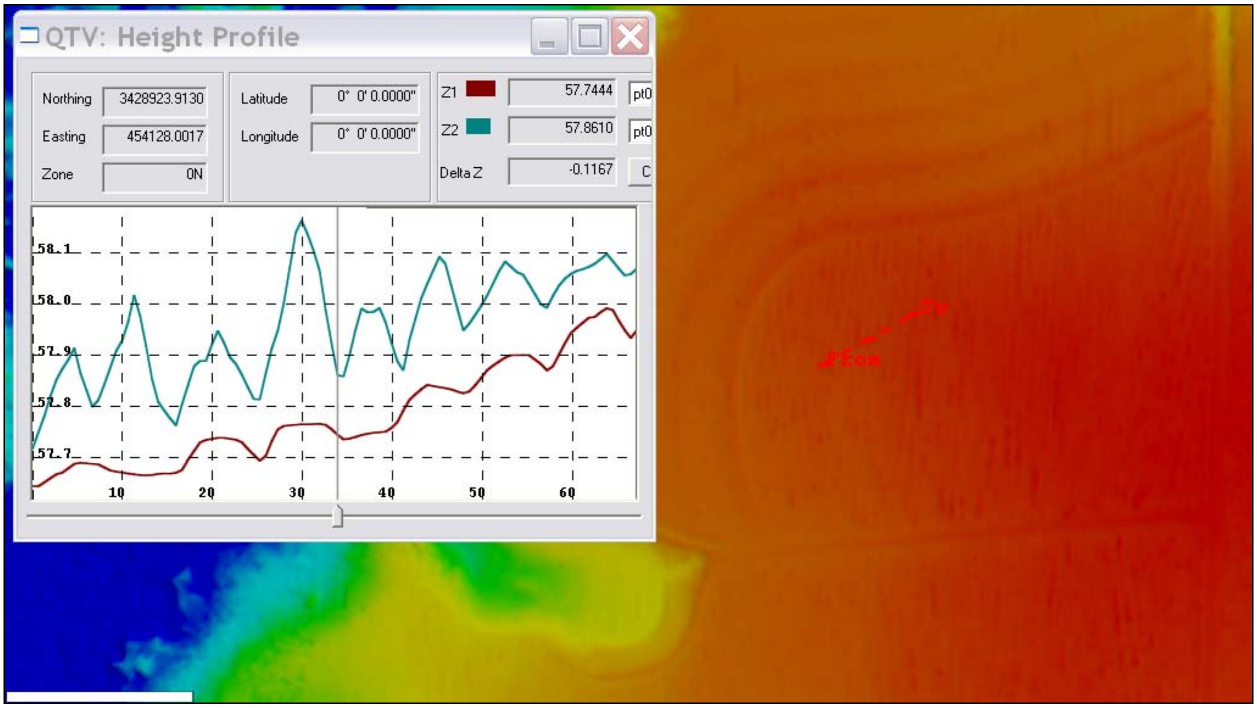


Figure 10: Cross-section drawn across cornrows. The blue line represents the data before it was reprocessed; the red line represents the data after re-processing. Although the ridges are still there they are negligible and will not negatively affect the accuracy.

The second issue that was discovered during the initial assessment was offsets between flightlines. Although this phenomenon could not explicitly be explained for this dataset, Dewberry believes that the elevation differences between flightlines were caused by a possible mis-calibrated sensor or were a result of post-processing error. These offsets were mostly found in the coastal tiles along the southern edge of the county although there were a few instances where elevation differences were found inland. Most of the elevation differences were minimal (5 cm – 10 cm) and would not have any adverse effects on modeling. However, some offsets that were found along the coast were large (40 cm) and required attention.

The re-processing techniques were effective in relieving some of the offset issues although they were not aggressive enough to totally resolve the offsets found along the southern coast. Figures 11 and 12 illustrate an offset that was resolved during the smoothing process. Figures 13 through 15 display the worst case example where the offset is still approximately 20 cm, the level where offsets are considered to be marginally acceptable. Other offsets are of this magnitude or smaller along the coastal area where this issue was most prominent.

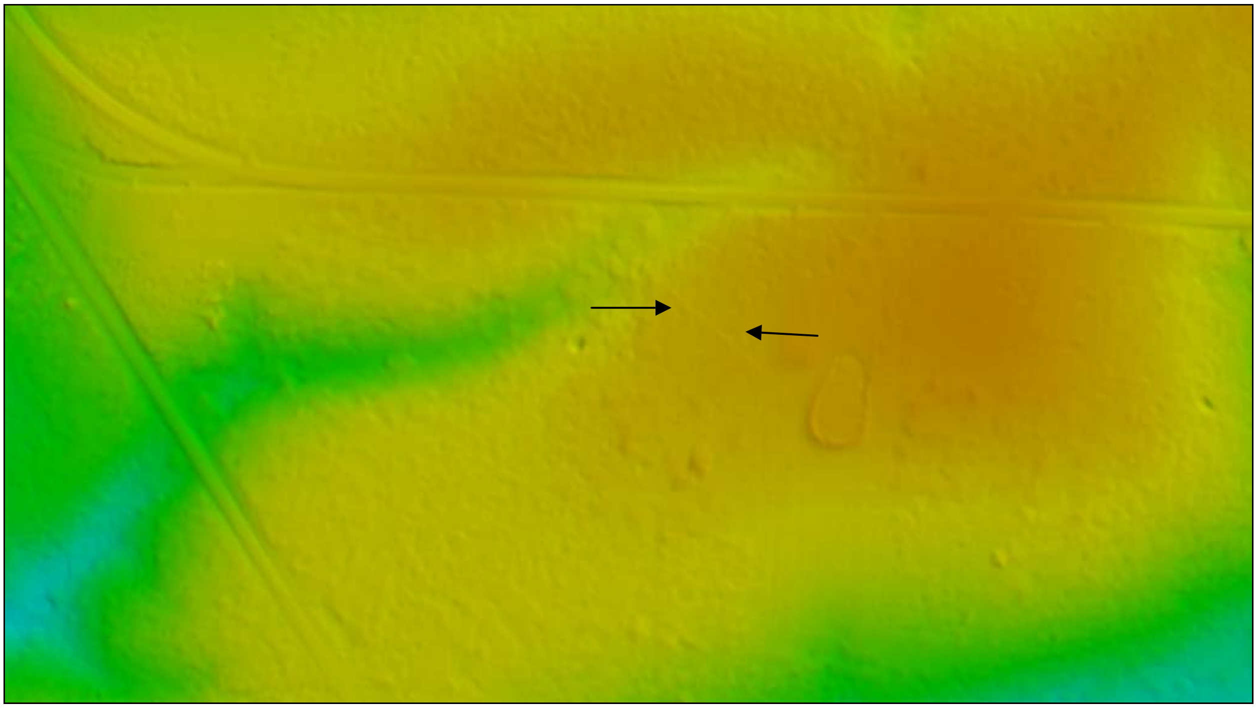


Figure 11: Vertical offset found in the initial delivery.

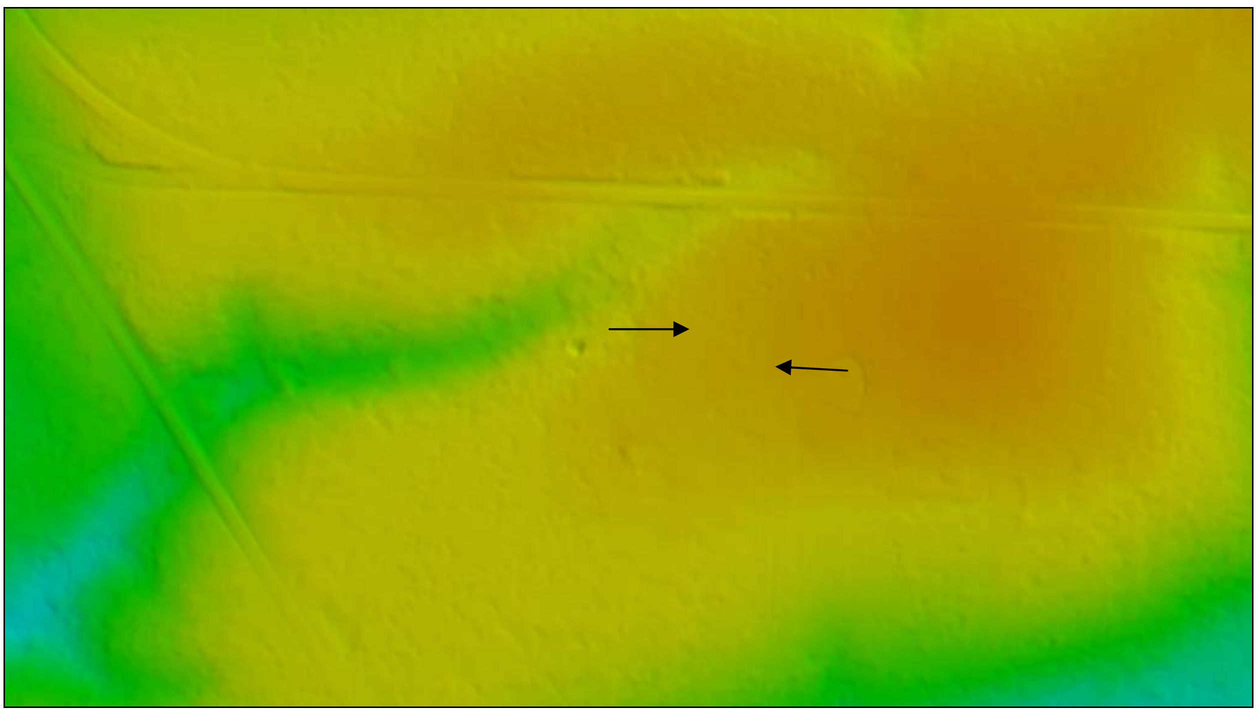


Figure 12: Offset was smoothed during re-processing and is no longer visible.

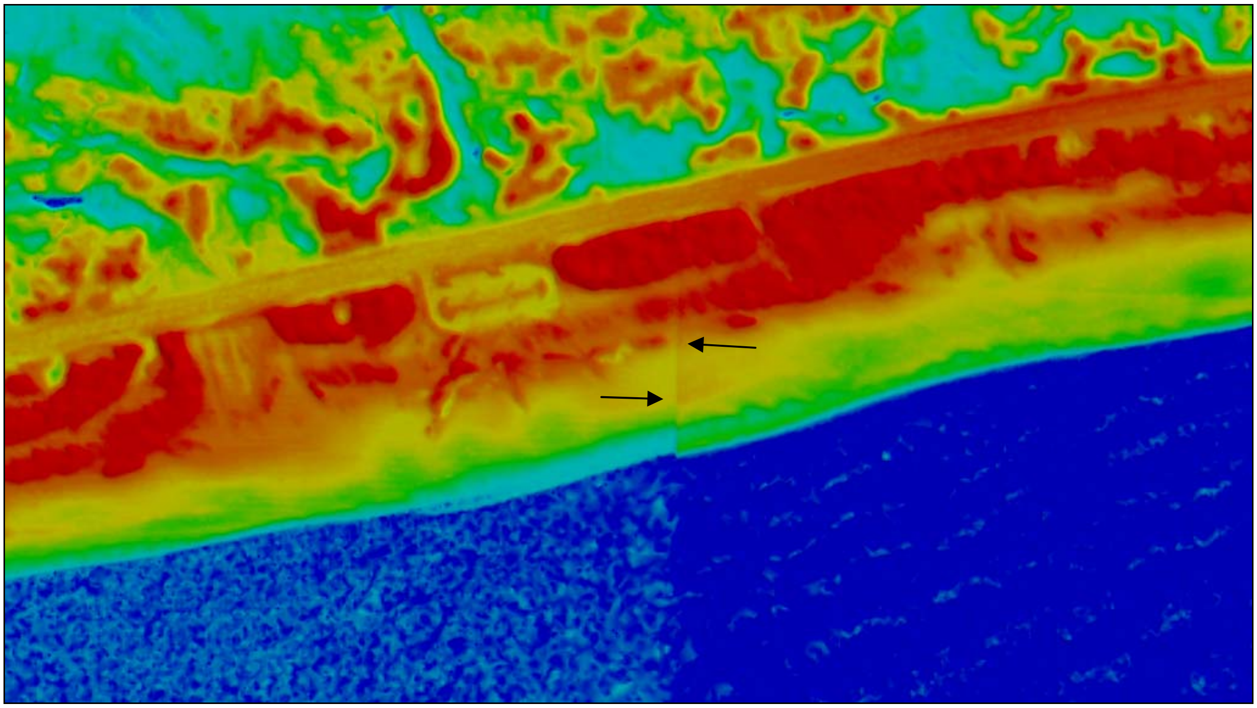


Figure 13: Elevation offset, original dataset.

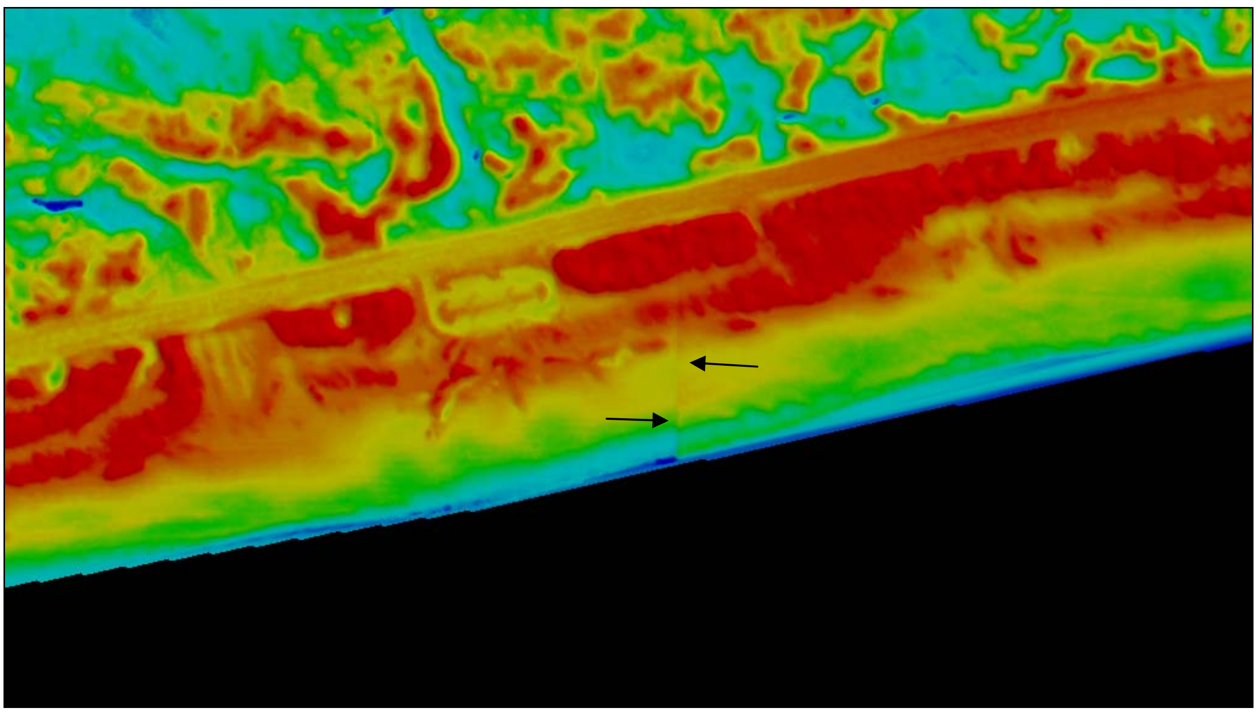


Figure 14: Elevation offset, after re-processing. The re-processing improved but did not eliminate this offset.

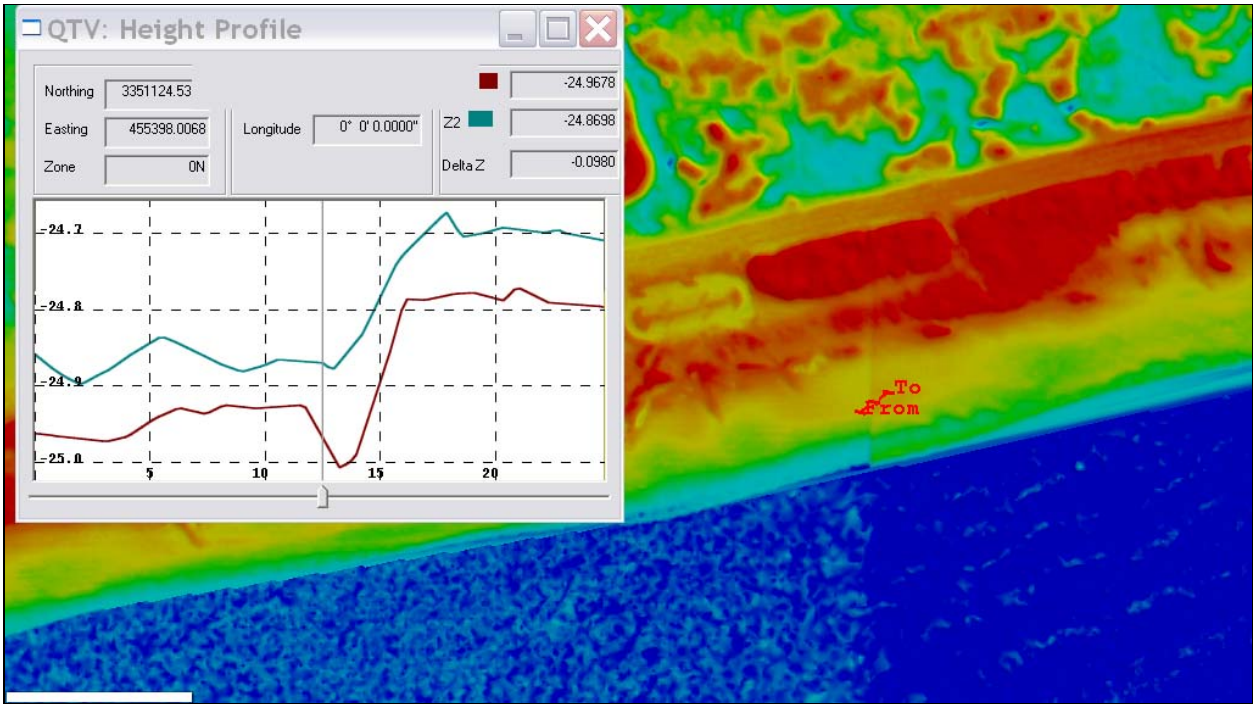


Figure 15: Cross-section of offset at worst case location. The blue line represents the original data before it was smoothed; the red line represents the re-processed data. The offset measures approximately 20 cm which was found along numerous coastal tiles. This is the level where offsets are considered to be marginally acceptable.

The final issue that was addressed was the level of cleanliness in the data. The original product was determined to be good data and met the generalized guideline to be generally clean of artifacts. There were a few instances however where the classification techniques were unsuccessful and the resulting data was noisy. The techniques carried out in the re-processing were successful in reducing this noise and the resulting dataset proves to be good, clean data. Figures 16 through 19 exemplify this change.

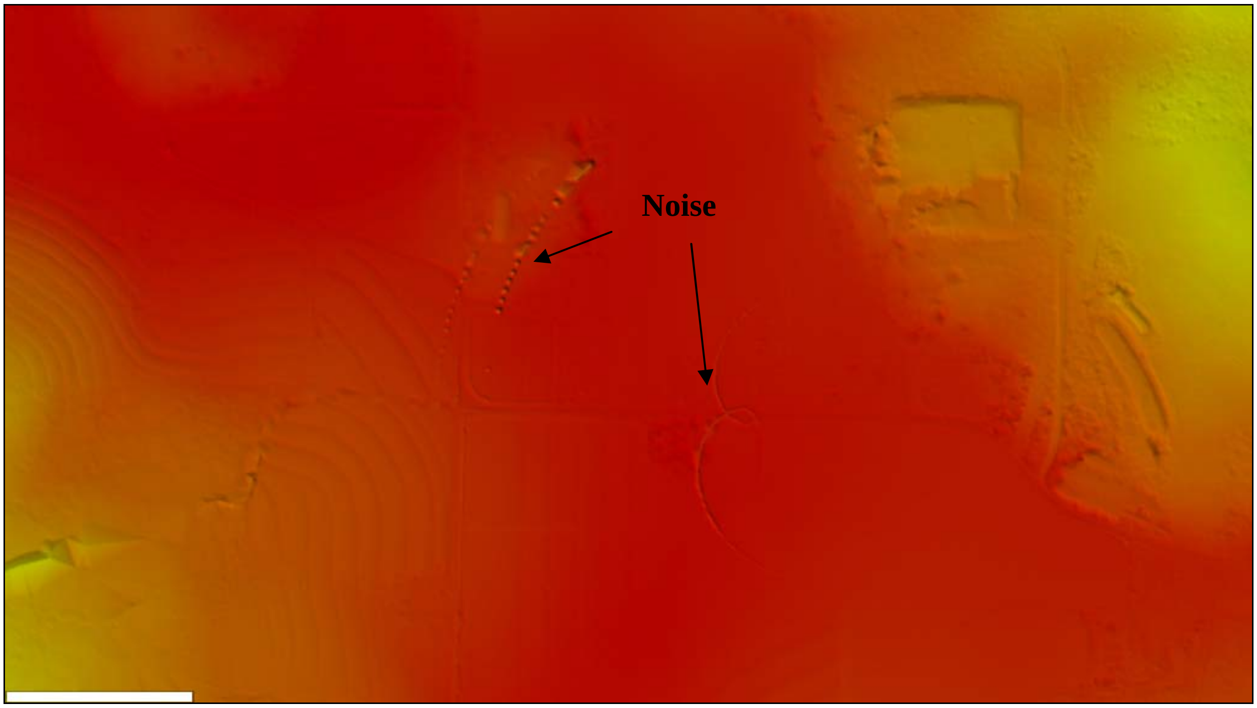


Figure 16: Anomalies in initial delivery.

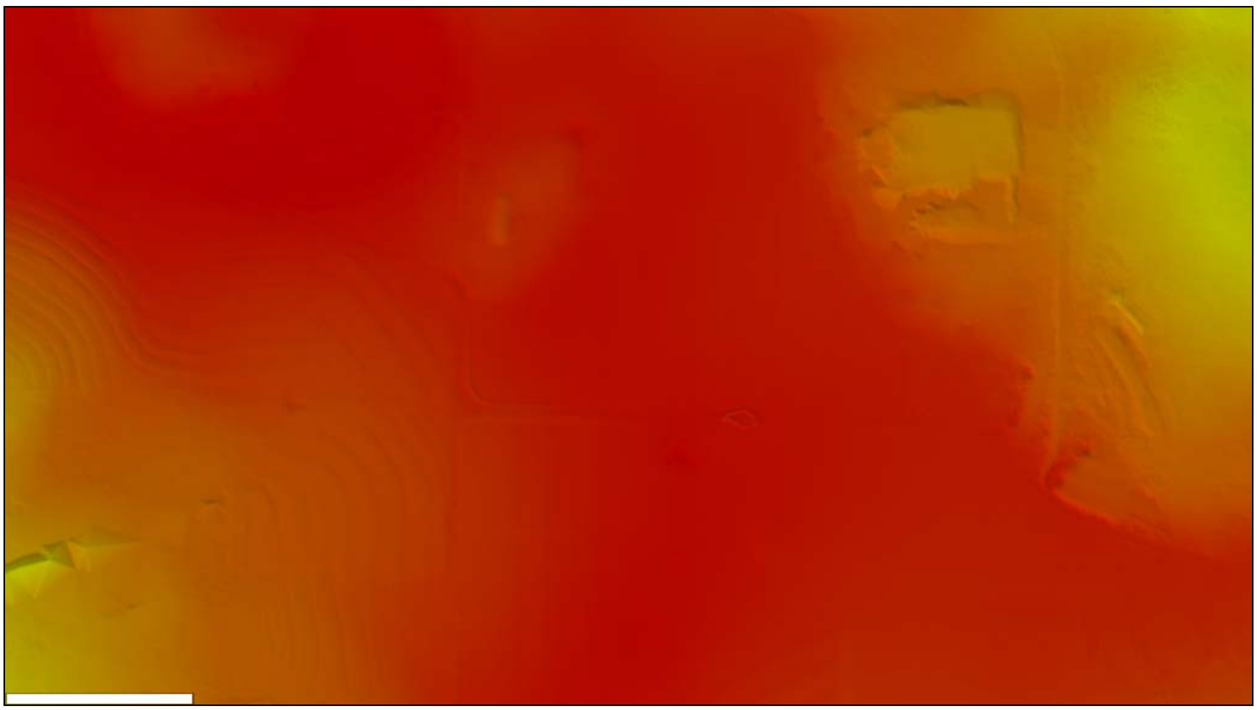


Figure 17: Anomalies have been smoothed out during re-processing.

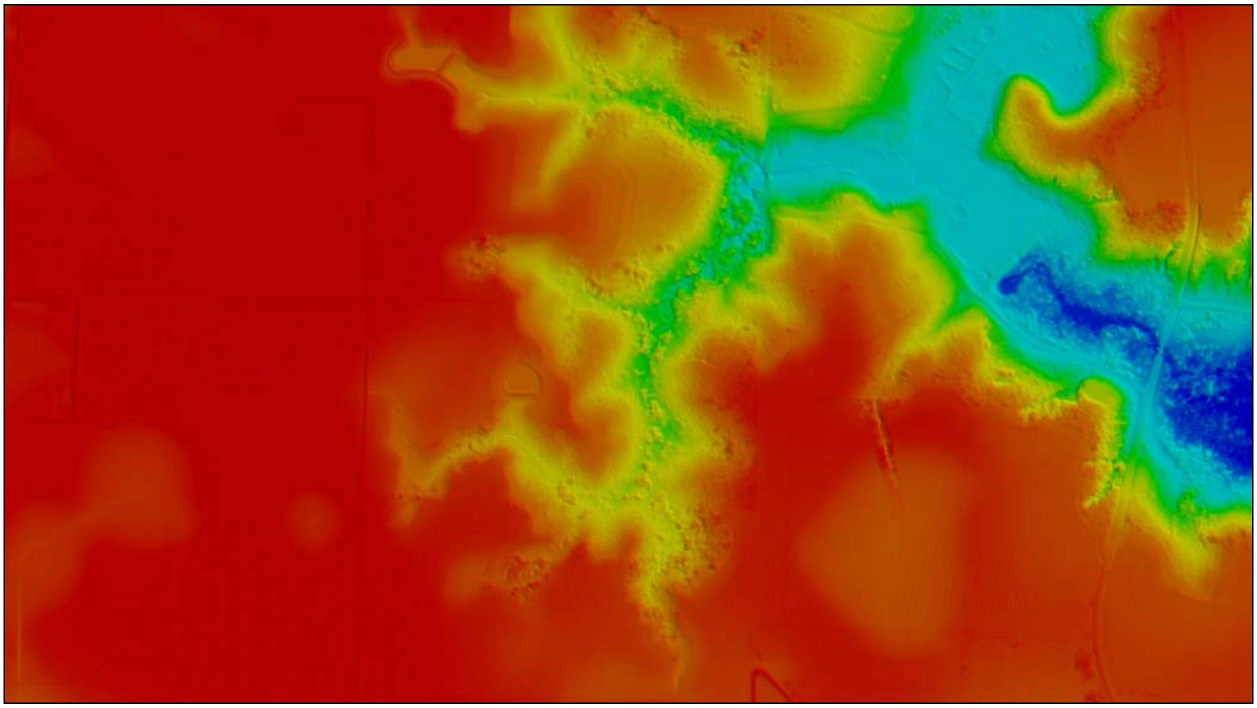


Figure 18: Original stream bed is noisy due to unsuccessful vegetation removal.

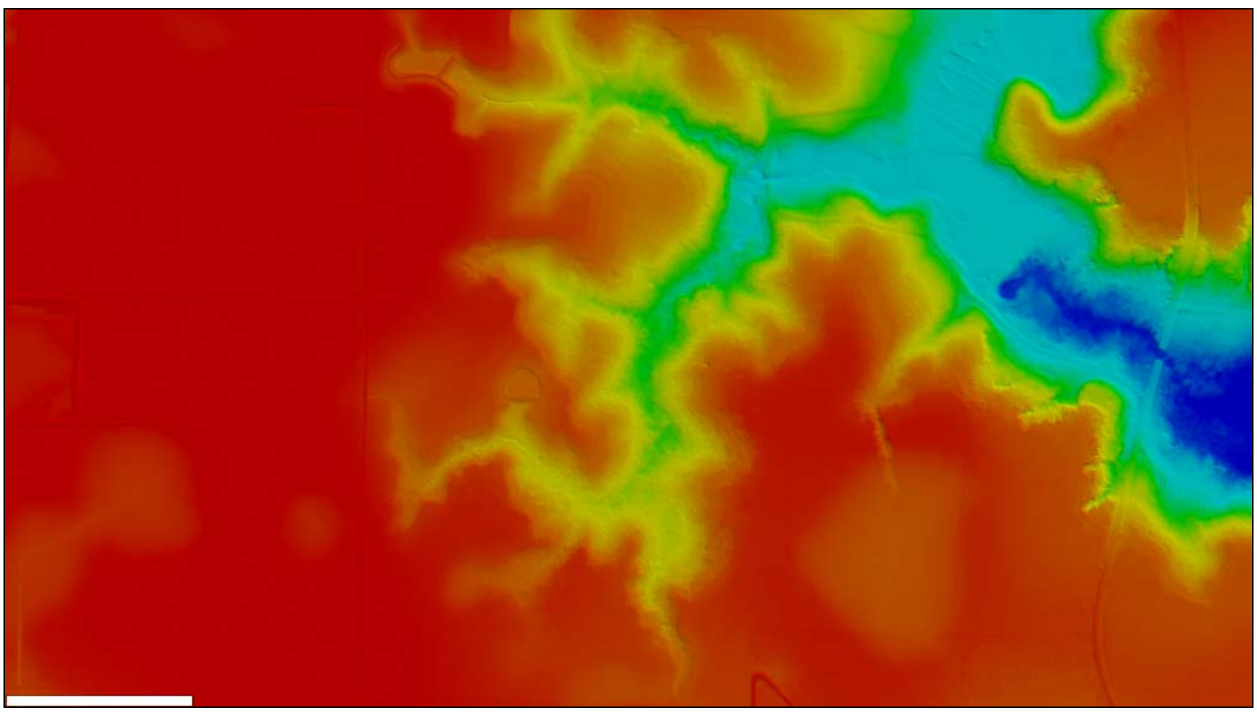


Figure 19: Re-processing significantly reduced vegetation within stream bed.

Metadata

Dewberry reviewed the metadata provided by 3001, Inc. and made numerous changes, including addition of the vertical datum, horizontal and vertical accuracy statements, acquisition dates, and organizational information. Whereas the metadata are acceptable and satisfy FGDC requirements, Dewberry recommends that NOAA perform a final edit on such information as points of contact for distribution and duplication of the data for which NOAA, or possibly the North West Florida Water Management District, should have the "final word."

Overall Conclusions

The re-processing techniques implemented by 3001, Inc. proved to be successful in improving the overall relative accuracy of the lidar data. Quantitatively, the reprocessed lidar data passes the vertical accuracy criteria. Qualitatively, the reprocessed lidar data passes also. Although some of the vertical offsets are approximately 20 cm, the lidar industry has no standard acceptance criteria for such offsets, and 20 cm offsets are commonly considered to be marginally acceptable. Although there were a few areas where there are still recognizable elevation differences between flightlines, these offsets are not significant and do not render the data unusable.

The metadata also are acceptable and satisfy FGDC requirements; however, we recommend a final edit by NOAA, especially as pertains to points of contact for distribution and duplication of the data.

David F. Maune, Ph.D., PS, GS, CP
QA/QC Manager