Dewberry
50th Anniversary

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Vertical Accuracy Assessment Report
2005 Lidar Bare-Earth Dataset for
Santa Rosa County, Florida

Date: July 21, 2006

References: A — NOAA Coastal Services Center Task Order T005, 23 Feb 2006, Santa Rosa County Lidar Validation
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

Background

NOAA Guidance: Reference A tasked Dewberry to validate the bare-earth lidar dataset of Santa Rosa, FL, both quantitatively (for accuracy) and qualitatively (for usability). This report addresses the vertical accuracy assessment only, 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.
- Vertical units (ellipsoid heights) are in meters above the GRS80 ellipsoid surface.

NSSDA Guidance: 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."

FEMA Guidance: 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 each 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 Santa Rosa 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 Photo Science Inc. (PSI) for the lidar data acquisition, Dewberry completed the GPS survey of 108 checkpoints in March of 2006 and submitted the QA/QC checkpoint survey data and photos to the Coastal Services Center on 4/7/2006.

Initial Issues: When the initial lidar dataset was received from NOAA for validation on 6/20/2006, the Class 2 surface (ground surface) appeared noisy, even on roads; furthermore, roads and open fields showed data in both Classes 1 (unclassified surface) and 2 (ground surface). Following a telecon with PSI, a corrected dataset was provided; the second dataset was much better, and Dewberry proceeded. Next, Dewberry noted that the elevations were orthometric heights rather than ellipsoid heights. Following several telecons and emails, it was decided that Dewberry would evaluate orthometric heights rather than ellipsoid heights. After converting its QA/QC checkpoint data from ellipsoid heights to orthometric heights, Dewberry immediately noted a systematic positive bias of about 20 cm between the lidar data and the field survey data. In attempting to determine the cause for such a bias, a telecon was conducted on 7/13/2006 with NOAA and PSI to discuss the issue; immediately thereafter, Dewberry detected a corrupted file when Geoid03 calculations (used to convert ellipsoid heights to orthometric heights) were repeated on a different computer. This removed over half of the 20 cm bias, leaving a positive bias of approximately 8 cm, typical for many elevation datasets. Dewberry then proceeded with its standard lidar accuracy assessment processes.

Assessment Procedures and Results: The lidar accuracy assessment for Santa Rosa County was performed in accordance with References D and E which assume that lidar errors in some land cover categories may not follow a normal error distribution. This assessment was 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 Santa Rosa County's five major land cover categories: (1) open terrain, (2) weeds and crops, (3) scrub and bushes, (4) forests, and (5) built-up 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 Santa Rosa 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	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 the optional determination of Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). 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 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 Santa Rosa 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 built-up areas in order to facilitate the analysis of the data based on each of these land cover categories that exist within Santa Rosa 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.

<u>QA/QC Steps</u>: 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 24 checkpoints in open terrain; 21 checkpoints in weeds and crops; 21 checkpoints in scrub; 21 checkpoints in forests; and 21 checkpoints in built up areas, for a total of 108 checkpoints.
2. Next, Dewberry interpolated the bare-earth lidar DTM (Class 2 points) to provide the z-value for each of the 108 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 Santa Rosa 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.

Santa Rosa County Checkpoints

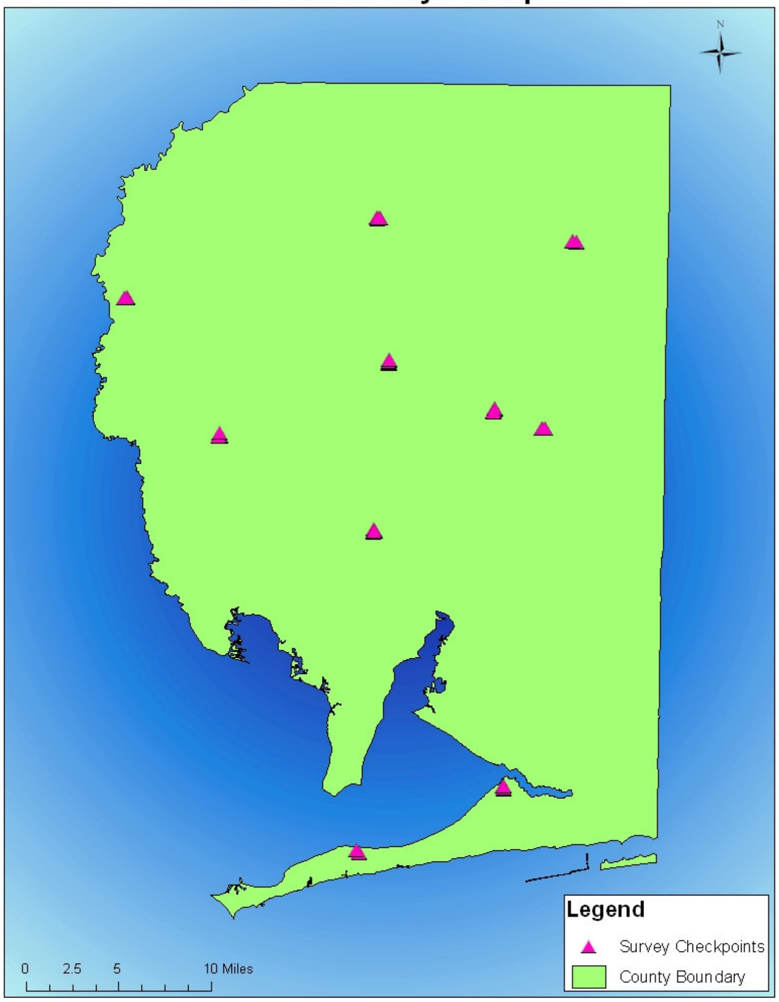


Figure 1 — Location of QA/QC Checkpoint Clusters

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 (95^{th} Percentile) Spec = 0.363 m	SVA — Supplemental Vertical Accuracy (95^{th} Percentile) Target = 0.363 m
Total Combined	108		0.37 m	
Open Terrain	24	0.22 m		0.19 m
Weeds/Crops	21			0.20 m
Scrub	21			0.40 m
Forest	21			0.38 m
Built Up	21			0.27 m

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

Even with the remaining positive bias shown by Figures 3 and 5 and Table 4 below, The $RMSE_z$ in open terrain was 11 cm, whereas the standard was 15 cm. Compared with the 29.4 cm specification, FVA tested 22.0 cm at the 95% confidence level in open terrain, based on $RMSE_z$ x 1.9600.

Compared with the 36.3 cm specification, CVA tested 37.0 cm at the 95% confidence level in open terrain, weeds and crops, scrub, forests, and built-up areas combined, based on the 95th Percentile. This slightly exceeds the standard. Table 3 lists the 5% outliers larger than the 95^{th} percentile (37.0 cm). If any one of these six elevation differences had been a few centimeters lower, this statistic would have passed. These few cm differences are within the range that Dewberry’s surveyed elevations could have been in error. Also, in dense vegetation, interpolation of z-values is performed on larger TIN triangles (due to filtering out of points in surrounding vegetation) where interpolations are routinely less accurate.

Table 3 — 5% Outliers Larger than 95^{th} Percentile

<table>
<tr><th>Land Cover Category</th><th>Elevation Diff. (m)</th><td rowspan="7">Six points had errors larger than the 37 cm 95th percentile error and 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. These differences are extremely minor</td></tr>
<tr><td>Forest</td><td>0.38</td></tr>
<tr><td>Forest</td><td>0.38</td></tr>
<tr><td>Forest</td><td>0.39</td></tr>
<tr><td>Scrub</td><td>0.40</td></tr>
<tr><td>Scrub</td><td>0.41</td></tr>
<tr><td>Weeds/Crop</td><td>0.53</td></tr>
</table>

Compared with the 36.3 cm SVA target values, SVA tested 19 cm at the 95% confidence level in open terrain; 20 cm in weeds and crops; 40 cm in scrub; 38 cm in forests; and 27 cm in built-up areas, based on the 95th Percentile. These values exceed their target values in scrub and forests; but this is typical.

Figure 2 illustrates the SVA by specific land cover category.

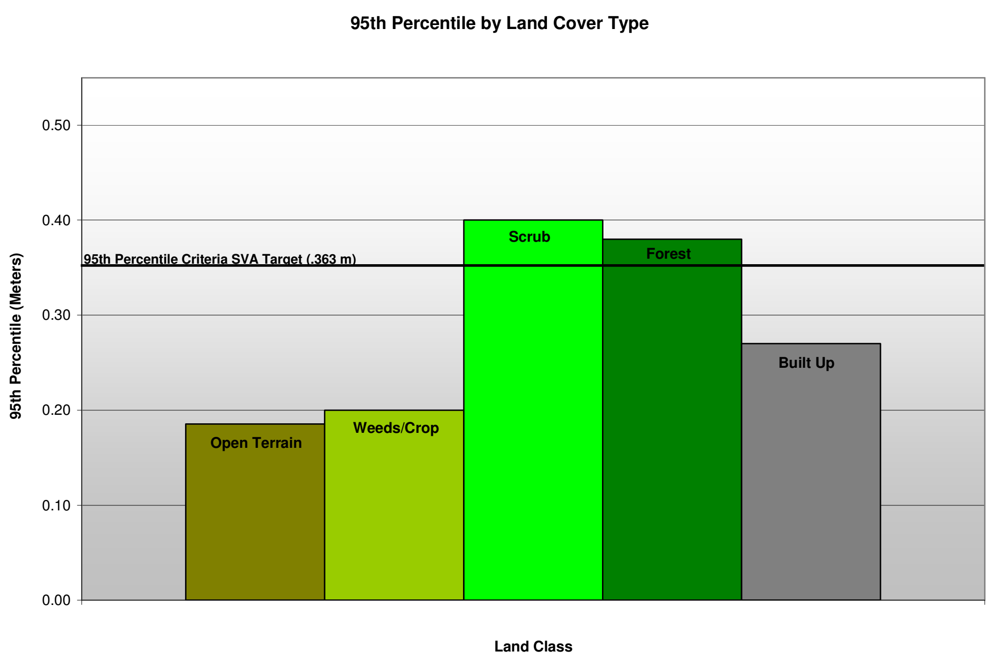


Figure 2 — Graph of SVA Values by Land Cover

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 shows a bias of about +8 cm in open terrain and vegetated categories. In open terrain, instead of having elevation errors that vary between -15 cm and +31 cm, if the elevation errors followed a normal error distribution exactly, the mean would be zero, and the elevation errors would vary between -23 cm and +23 cm. But this never happens! Most lidar datasets evaluated by Dewberry have displayed a systematic bias of this magnitude or greater. Because the dataset passed its important FVA criterion, we cannot justify the additional costs necessary to isolate the cause of a remaining 8 cm bias.

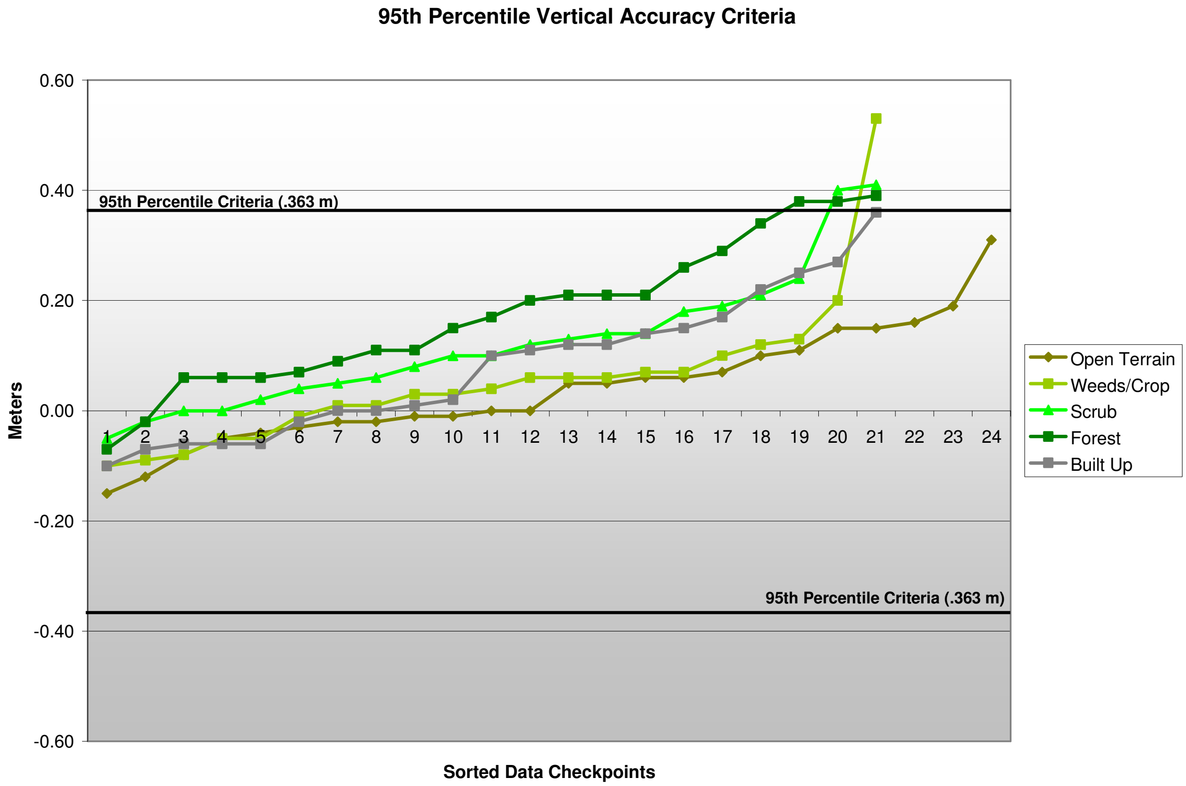


Figure 3 — Magnitude of Elevation Discrepancies, Sorted from Largest Negative to Largest Positive

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 the mean and median values are skewed on the high side of a normal error distribution.

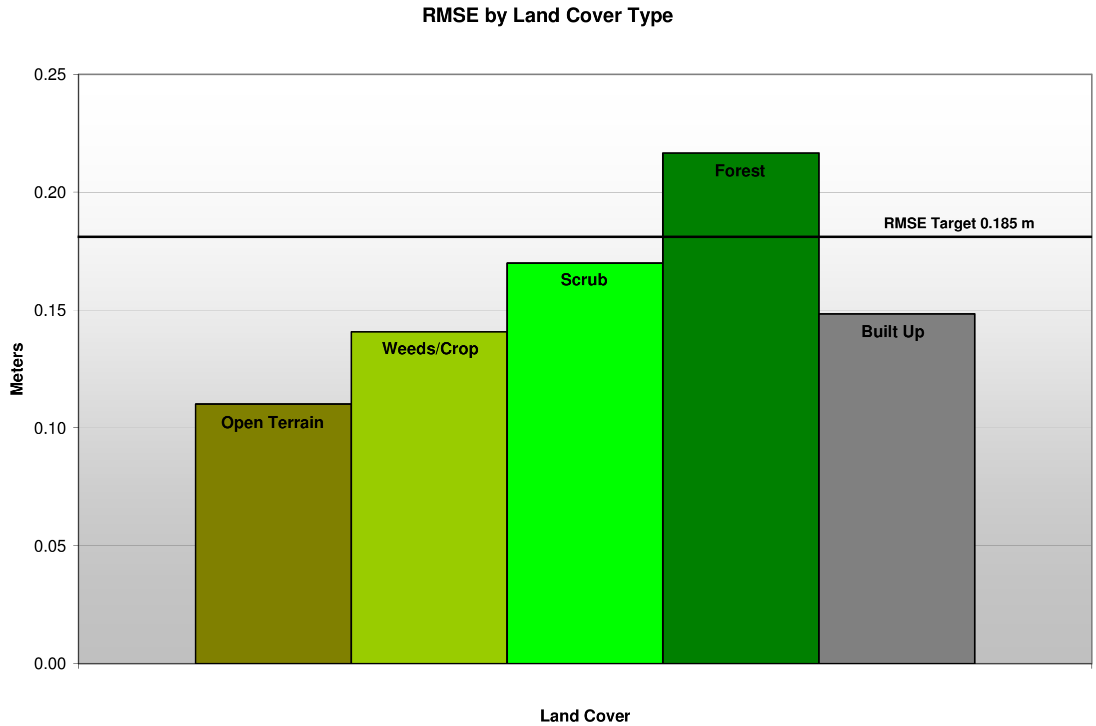


Figure 4 — $RMSE_z$ statistics by Land Cover Category

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	0.16	0.09	0.07	0.84	0.13	108	-0.15	0.53
Open Terrain	0.11	0.04	0.03	0.57	0.11	24	-0.15	0.31
Weeds/Crops	0.14	0.05	0.04	2.34	0.13	21	-0.10	0.53
Scrub	0.17	0.12	0.10	1.07	0.12	21	-0.05	0.41
Forest	0.22	0.17	0.17	0.14	0.13	21	-0.07	0.39
Built Up	0.15	0.08	0.10	0.48	0.13	21	-0.10	0.36

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

Although the NSSDA and FEMA guidelines predated FVA and CVA terminology, 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 = 11 cm x 1.9600 = 21.6 cm, satisfying the 29.4 cm FVA standard.

$Accuracy_z$ in consolidated categories = 16 cm x 1.9600 = 31.4 cm, satisfying the 36.3 cm CVA 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 -15 cm and a high of +53 cm, the histogram shows that the majority of the discrepancies are skewed on the positive side of what would be a "bell curve," with mean of zero, if the data were truly normally distributed. Again, this histogram is typical of all lidar datasets evaluated by Dewberry for hundreds of counties nationwide, because discrepancies in vegetation are typically positive.

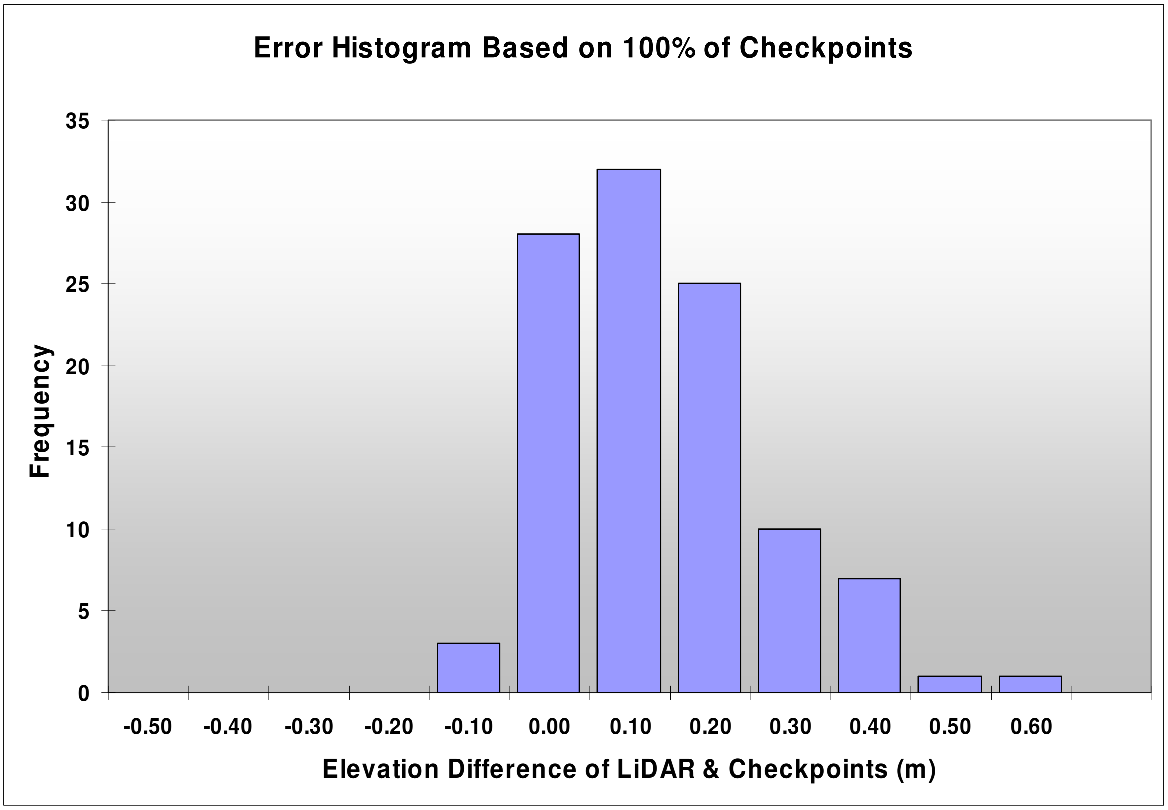


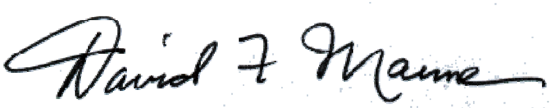
Figure 5 — Histogram of Elevation Discrepancies within 0.10 m Bands

Conclusions

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

- **Based on NSSDA, FEMA, NDEP and ASPRS methodology: Tested 21.6 cm vertical accuracy at 95% confidence level in open terrain.**

- **Based on NSSDA and FEMA methodology: Tested 31.4 cm vertical accuracy at 95% confidence level in all land cover categories combined.**



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Qualitative Assessment Report
2006 Lidar Bare-Earth Dataset for
Santa Rosa County, Florida

Date: August 14, 2006

References: A — NOAA Coastal Services Center Task Order T005, 23 Feb 2006, Santa Rosa County Lidar Validation
B — Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, "Geospatial Positioning Accuracy Standards," published by the Federal Geographic Data Committee (FGDC), 1998
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E — *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004

NOAA Guidance

Reference A tasked Dewberry to validate the bare-earth lidar dataset of Santa Rosa County, FL, both quantitatively (for accuracy) and qualitatively (for usability). This report addresses the qualitative aspect as the quantitative assessment was previously addressed in the report dated July 21, 2006, as summarized below.

Quantitative Assessment.

The findings of the quantitative assessment were favorable; the data met all acceptance criteria as found in Table 1, and the major accuracy reporting statistics were as follows:

- **Based on NSSDA, FEMA, NDEP and ASPRS methodology: Tested 21.6 cm vertical accuracy at 95% confidence level in open terrain (29.4 cm criteria).**
- **Based on NSSDA and FEMA methodology: Tested 31.4 cm vertical accuracy at 95% confidence level in all land cover categories combined (36.3 cm criteria).**

Table 1 — DTM Acceptance Criteria for Santa Rosa 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	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 95^{th} 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 95^{th} percentile)

Qualitative Assessment

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 removed to produce a bare-earth model. No major issues were found with this data both quantitatively and qualitatively, and it should satisfy most users of the data.

Overview

Within this review of the lidar data, two fundamental questions were addressed:

- Did the lidar system perform to specifications?
- Did the vegetation removal process yield desirable results for the intended bare-earth terrain product?

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data is typically accepted. Now with the proliferation of lidar, new issues arise due to the vast amount of data. Unlike photogrammetry where point spacing can be eight meters or more, lidar point spacing for this project is two meters or less. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for elevation technologies, and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the data set is statistically bound to have some errors both in the measurement process and in the vegetation removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and that of the interpolated value within the three closest lidar points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the lidar data is actually tested. However 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 the next contiguous lidar measurement. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DTM.

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the vegetation removal process was performed correctly. To reiterate the quantitative approach, if the lidar operated correctly in open terrain areas, then it most likely operated correctly in the vegetated areas. This does not mean that the bare-earth was measured, but that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the lidar pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, Dewberry employs a visualization process. This includes creating pseudo image products such as hillshades and 3-dimensional models. By creating multiple images and using overlay techniques, not only can potential errors be found, but we can also find where the data meets and exceeds expectations. This report will present representative examples where the lidar and post processing had issues but for the most part the data is of excellent quality.

Dewberry reviewed approximately 20% of the tiles in detail. Our effort concentrated on the coastlines to ensure homogenous data in these critical areas, but tiles were also selected dispersed throughout the county. The tiles were selected based on a semi-random approach to ensure a good distribution but tiles were also selected by land cover type and edge matching with adjacent tiles. Figure 1 illustrates the tiles that were reviewed.

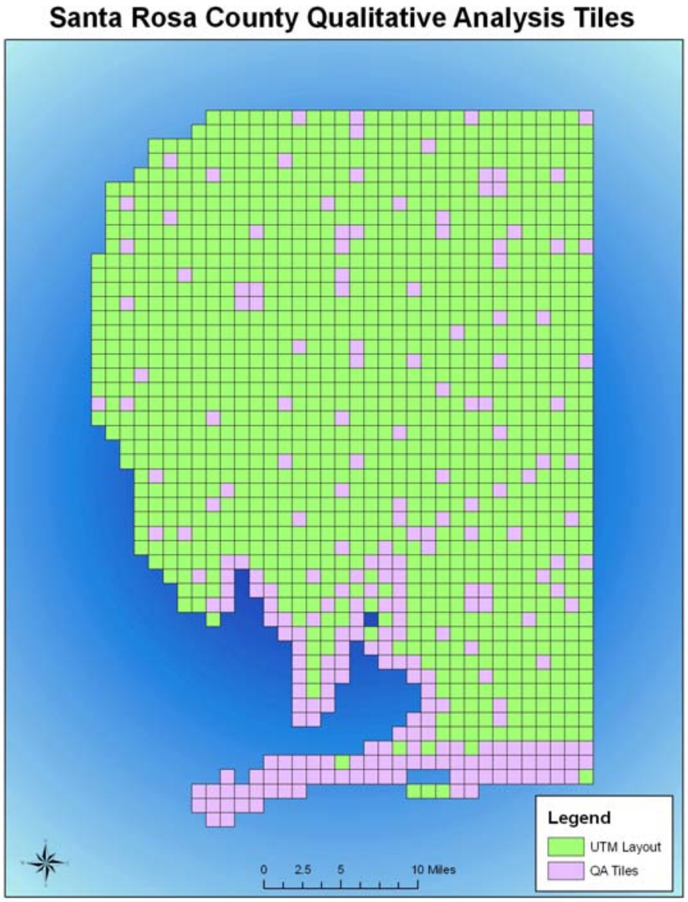


Figure 1 - Location of QA/QC tile review

The process of identifying issues utilized two different software packages; ESRI and QT Modeler. Each package has a strength that the other does not possess. For this analysis, both packages were used but most of the examples are illustrated with QT Modeler for ease of clarification. To reiterate, the data for the most part is exceptionally good. It exhibits excellent accuracy and vegetation classification, providing a good bare-earth data product.

The lidar data contained sporadic issues such as artifacts or small anomalies which is typical of any lidar dataset. However one issue that is scattered throughout is a term we call "edge match" issues. Edge match issues are caused by defining a seam line between adjacent areas and removing points from both of the overlapping scans. This in effect joins one scan to the next with no overlapping areas. This methodology can reduce the noise level in the overlap area. In most cases the data is of excellent quality and the adjacent data matches quite well, but there are areas where it does not match to the same high level of accuracy. Figure 2 illustrates a DEM comprised of "edge match" issues where it is easily apparent to see one surface is higher than the other along the seam line. Figure 3 illustrates the mass points color coded by elevation, again the height offset is easily identified. Figure 4 illustrates a cross section perpendicular to the seam line. In this example the offset is close to 35 cm but typically the offset errors are approximately 20 cm.

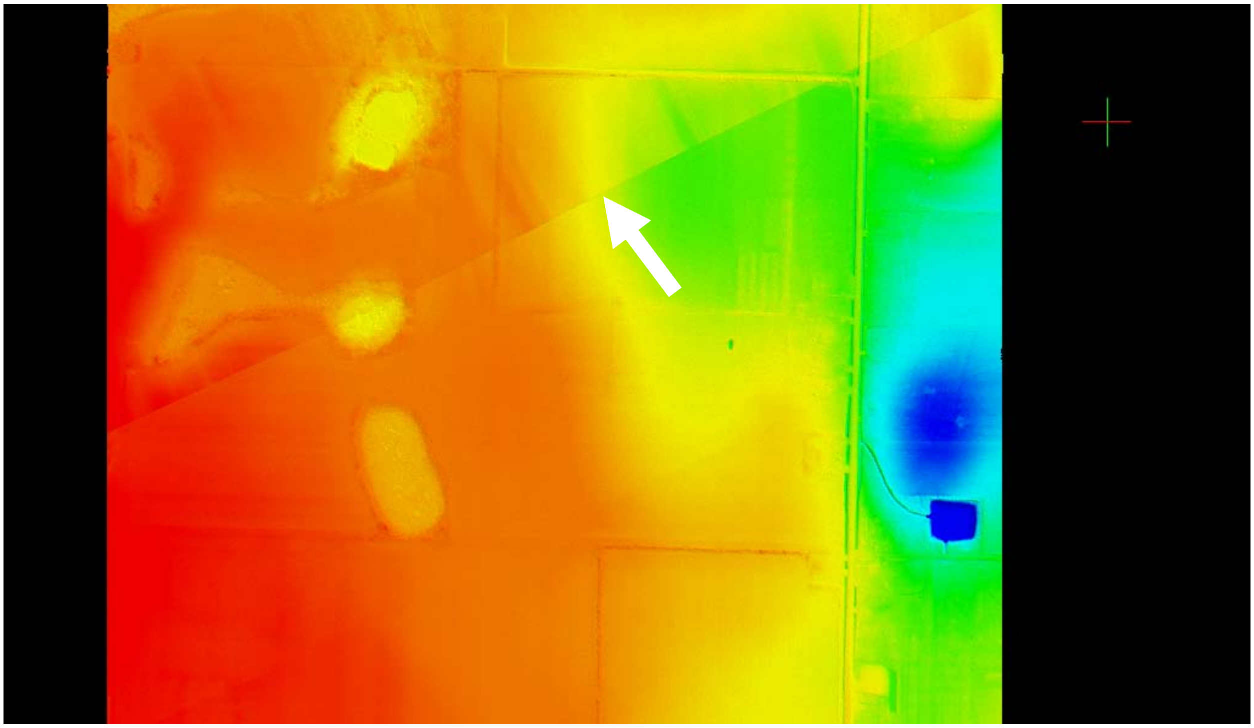


Figure 2 – DEM (Tile 0555) color coded by elevation illustrating the height offset of the edge match issue.

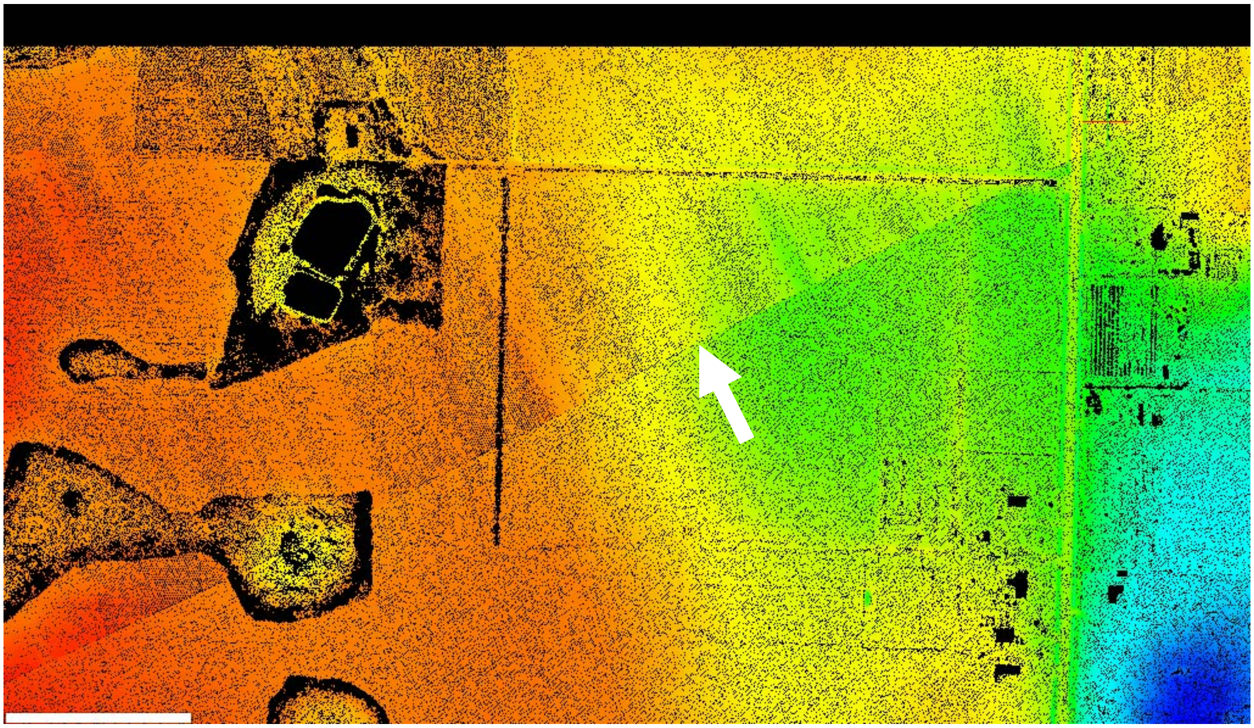


Figure 3 – DTM (Tile 0555 bare-earth mass points) color coded by elevation illustrating the height offset of the edge match issue.

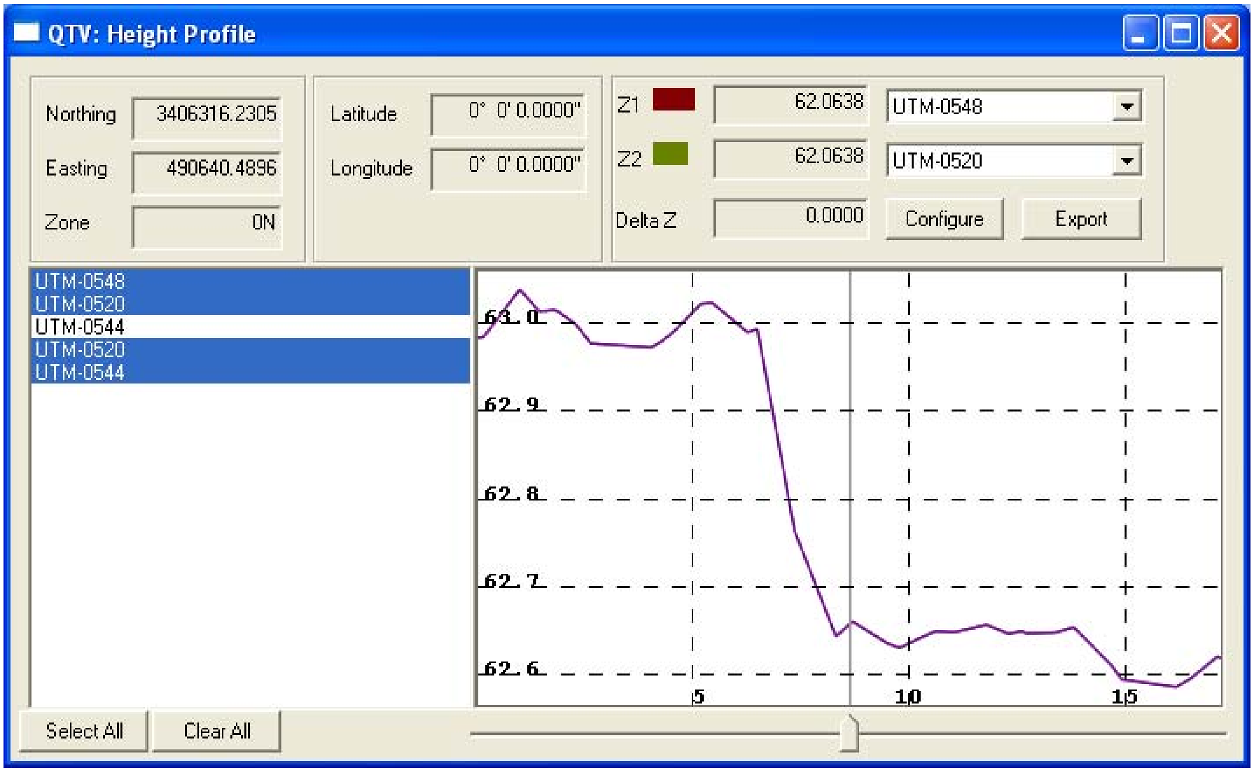


Figure 4 - Cross section of Tile 0544 perpendicular the seam line illustrating the edge match issue. The difference between adjacent areas is 35 cm.

This edge matching issue can be identified many times throughout this dataset (see Appendix A). This does not indicate that data is of poor quality or that the data does not meet specification because the checkpoint survey validated the accuracy, however further investigation is warranted.

Other minor issues are artifacts within the data. Artifacts are described as "potential" artifacts as some physical phenomena emulates vegetation and without ground truth the assessments are speculative. Overall the level of cleanliness for this product is very good and easily meets the generalized guideline for lidar to be 95% clean of artifacts. At times though the classification process can be in error and minor issues are presented. Figure 5 illustrates potential artifacts. Figure 6 and Figure 7 illustrate overlap data that does not fit well compared to adjacent points. The typical relative accuracy from one point to the adjacent point is approximately 5 – 7 cm along a hard surface but in this scenario, it exceeds this value. In this example two scan lines have been merged, but they do not fit well together where one is lower than the other. For the most part the majority of the lower data has been classified as non-ground and therefore is not present in this data, but there are some points that have been classified as bare-earth (and they should be) but they have accuracy issues. The result of these lower points appears as elongated divots in the roadway.

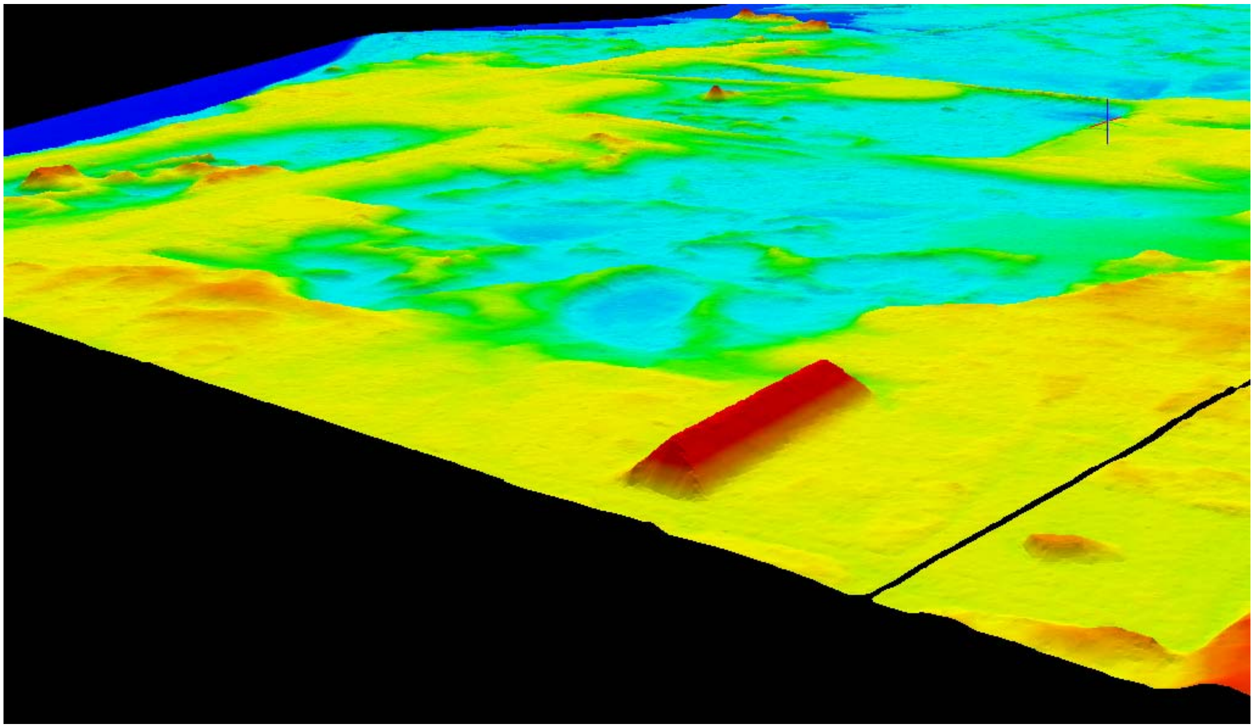


Figure 5 - Potential artifacts highlighted in red (vertical exaggeration is 2X).

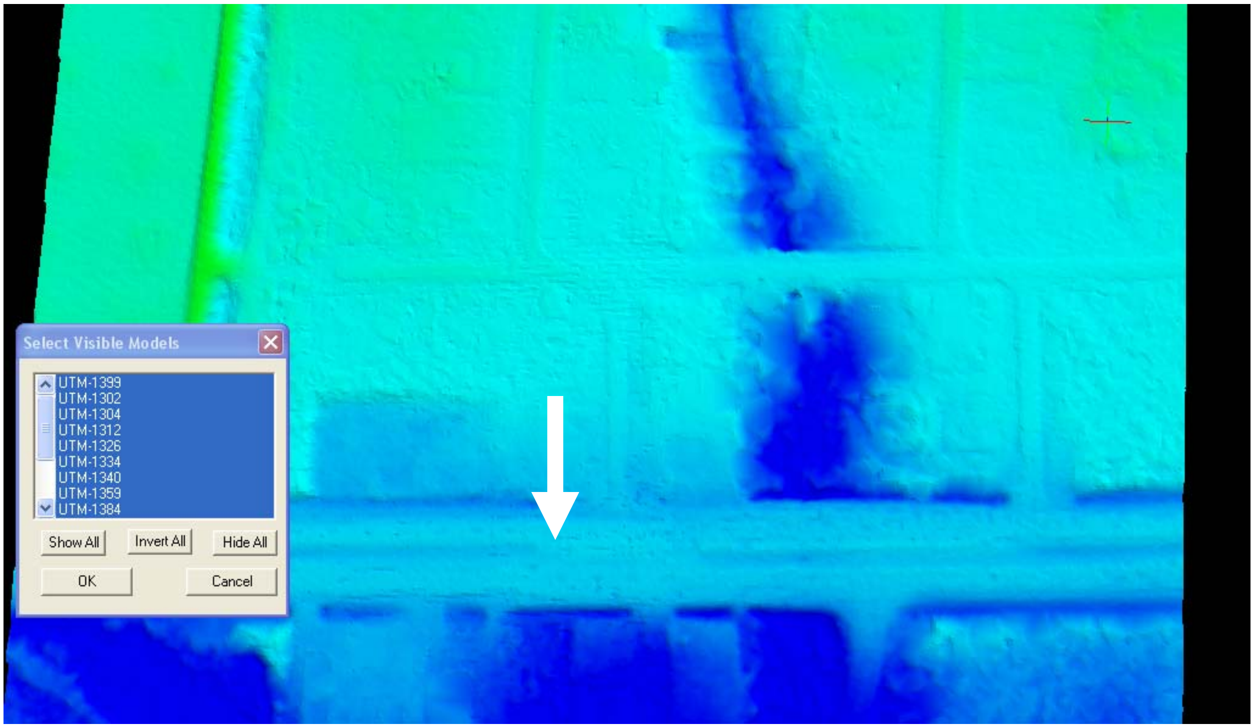


Figure 6 – DEM of points along a road where two scan lines have been merged. Since points from one of the scan line do not match well (they are lower) it causes the DEM to appear to have elongated divots in the surface. Typically these are less than 20 cm deep.

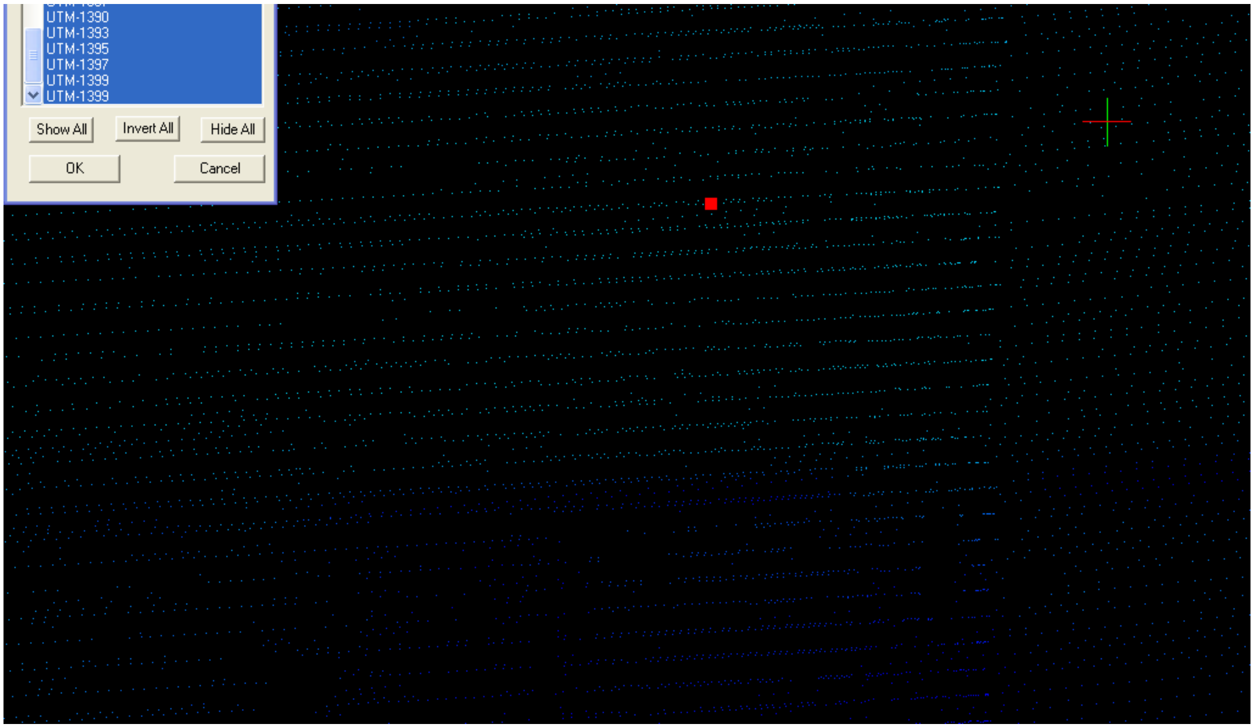
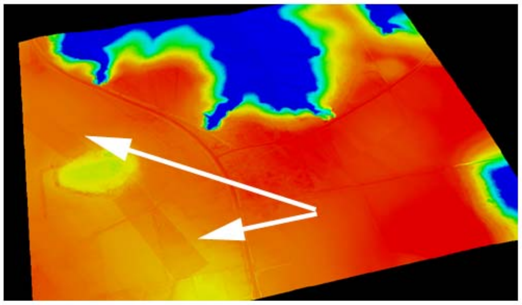


Figure 7 - Scan pattern from two different flight lines. The edge of the flight line can be seen on the right hand side of the zig-zag scan pattern. The area around the red marker illustrates that a second scan pattern from another flight line has been integrated but the elevations do not match the other scan line.

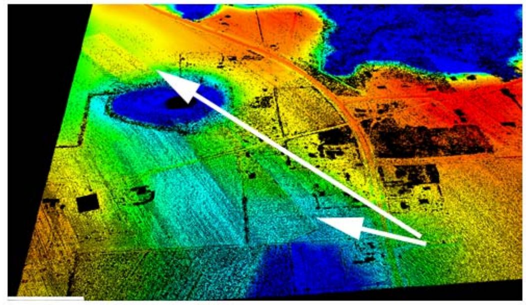
Conclusion

Overall the data is of high quality. The processing performed exceptionally well given the low relief and highly vegetated areas. There are some minor issues and these potentially can be reviewed to improve the dataset, but they are not a detriment to a usable data product that will easily conform to 2 foot contours. Additional examples are illustrated in Appendix A.

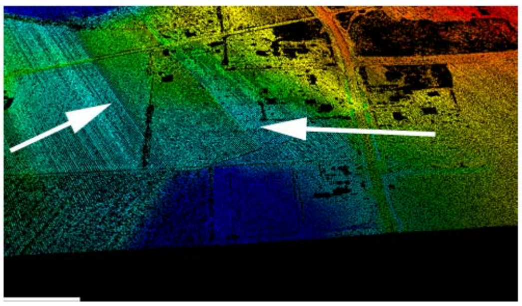
Appendix A – Potential Issues identified during the QA review.



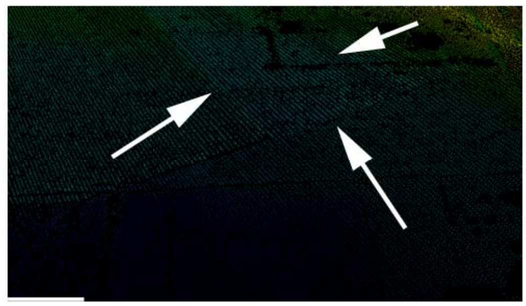
0011 sm raised pts.bmp



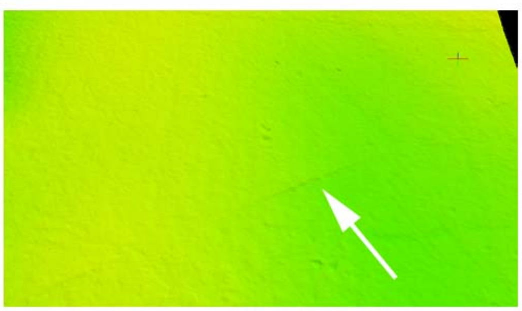
0011 zoom1 raised pts.bmp



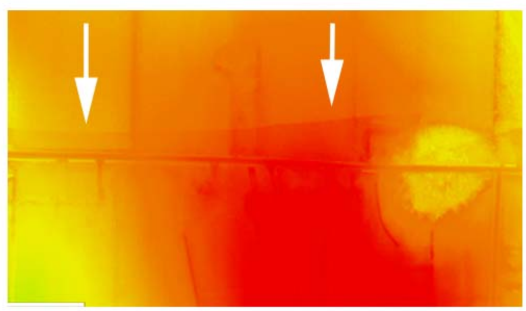
0011 zoom2 raised pts.bmp



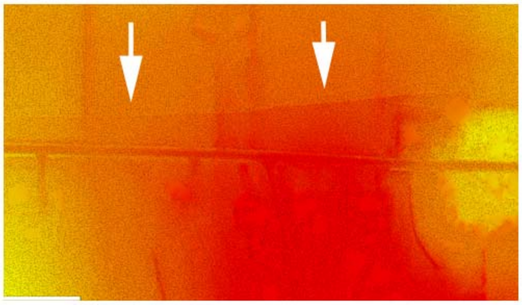
0011 zoomed raised pts.bmp



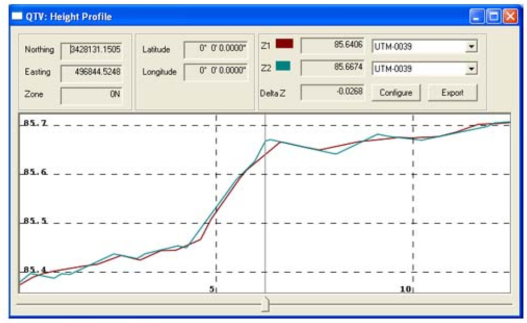
00280 edge offset qtt.bmp



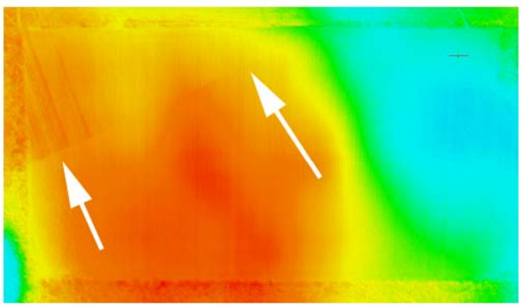
0039 line offset qtt.bmp



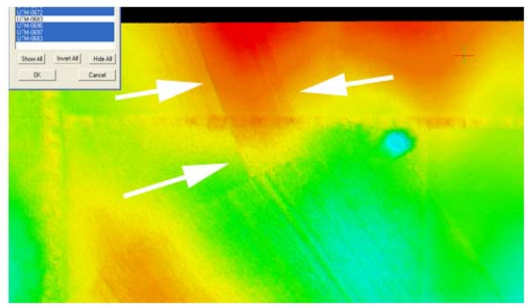
0039 line offset qtt-qtc.bmp



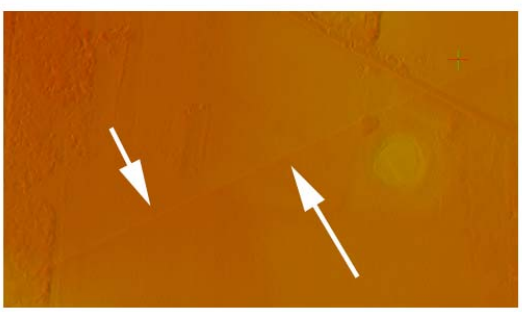
0039 xs.bmp



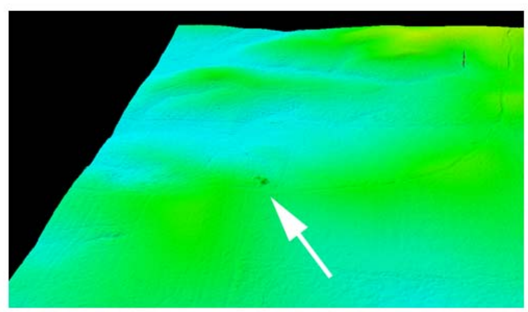
00683 edge offsets qtt.bmp



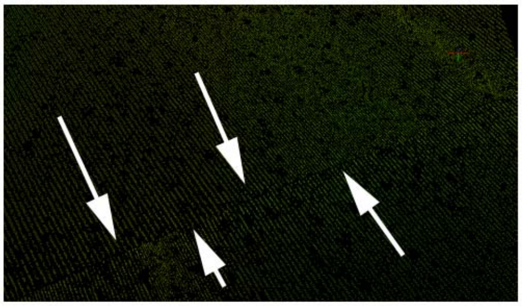
00683b edge offsets pts.bmp



00702 edge offset 15 qtt.bmp

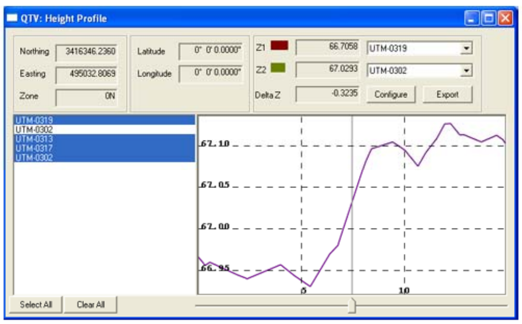


0241 artifact vx2.bmp

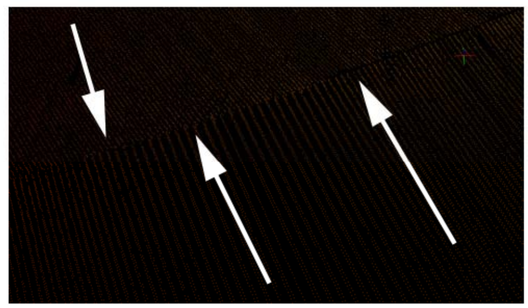


0280 edge offset qtc.bmp

0302 line offsets minimal qtt.bmp

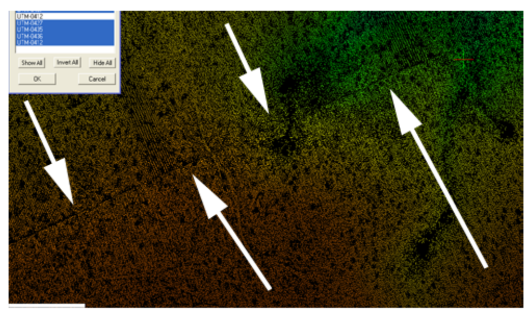


0302 line offsets minimal xs.bmp

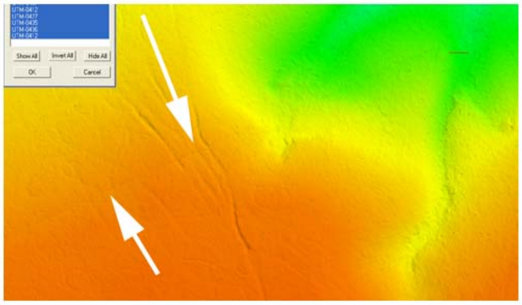


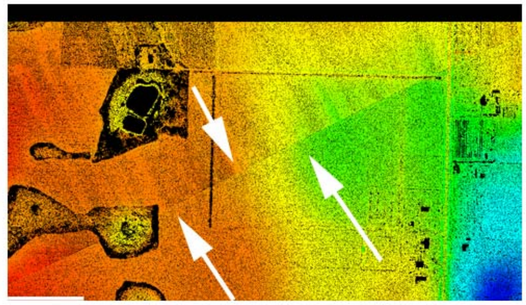
0319 edge offset 15cm pts.bmp

0319 edge offset 15cm qtt.bmp



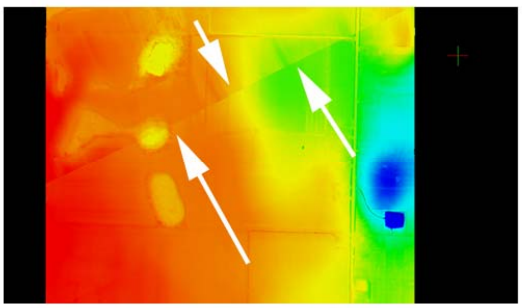
0412 edge scan offset - 15cm pts.bmp

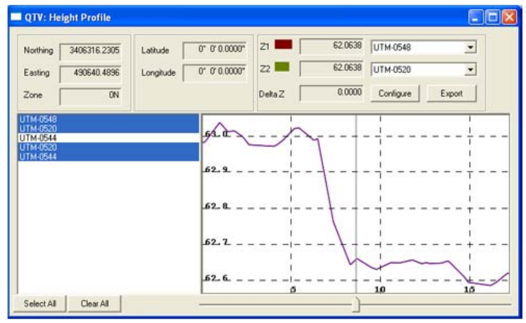




0412 edge scan offset - 15cm qtts.bmp

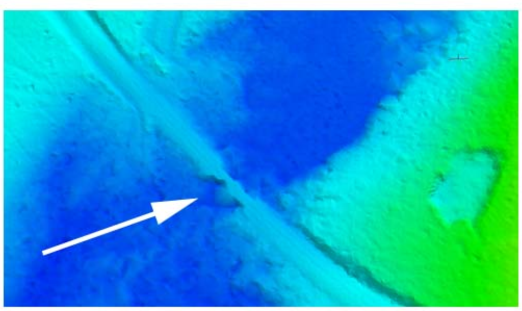
0544_scan edge offset 30 pts.bmp

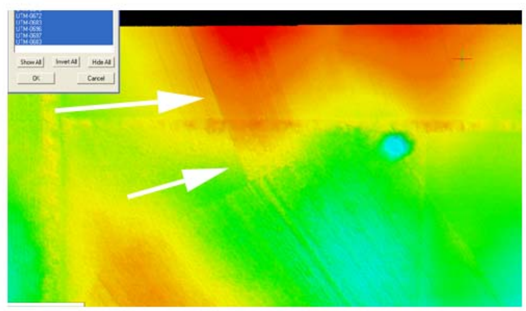




0544_scan edge offset 30 qtt.bmp

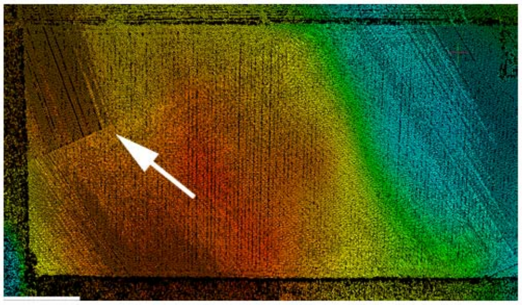
0544_scan edge offset xs.bmp



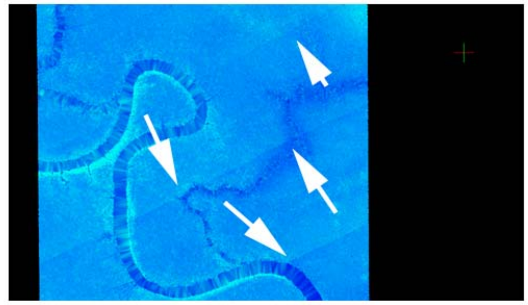


0593 INCONSISTENT BRIDGE EDITING.bmp

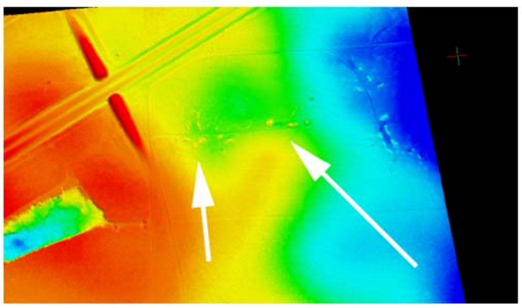
0683 bedge offsets qtt.bmp



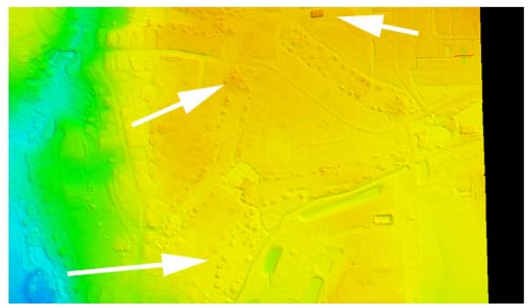
0683 edge offsets pts.bmp



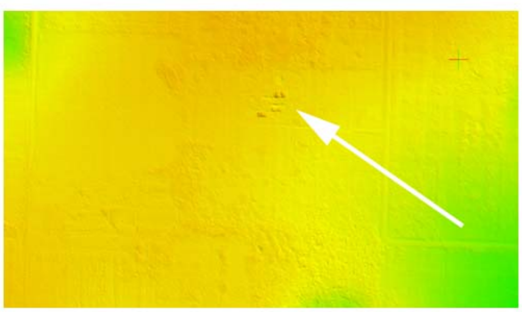
0867 scan line edge minimal.bmp



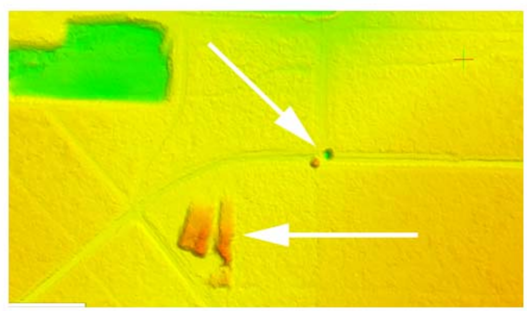
0897 artifacts qtt.bmp



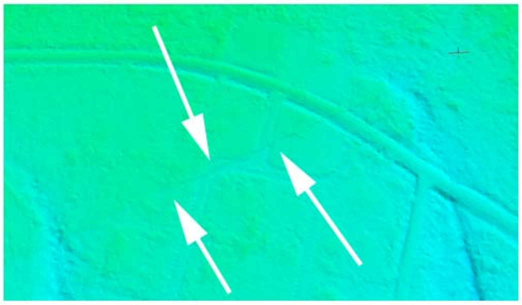
0909 artifacts qtt.bmp



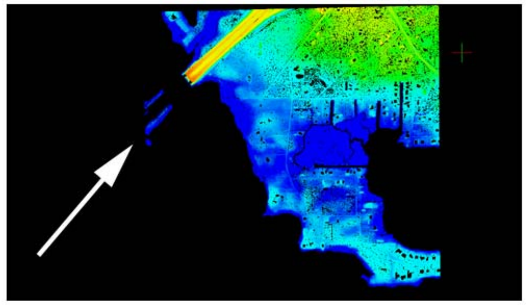
0988 artifacts.bmp



0988 artifacts hole.bmp

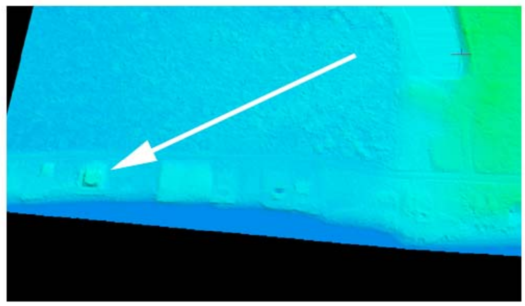


1038 edge issue over road 35 cm.bmp

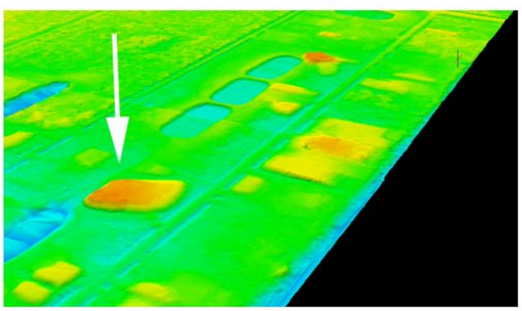


1048 pts in water.bmp

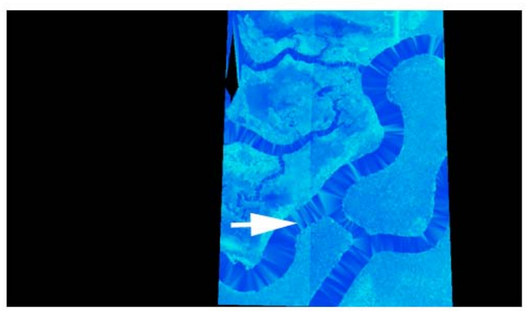
1065 edge issue 20 qtt.bmp



1068 artifact 2.5m.bmp

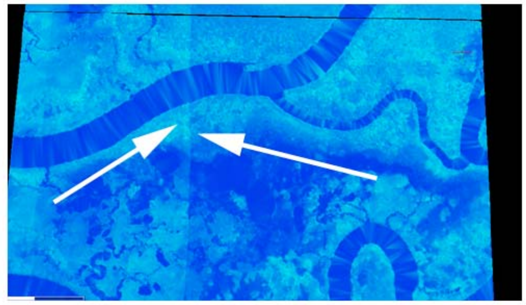


1079 artifacts.bmp

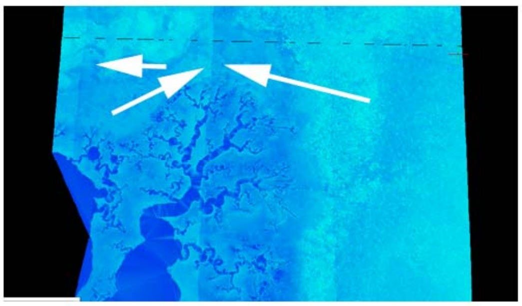


1108 edge issue.bmp

1128 incosistent bridge edit.bmp

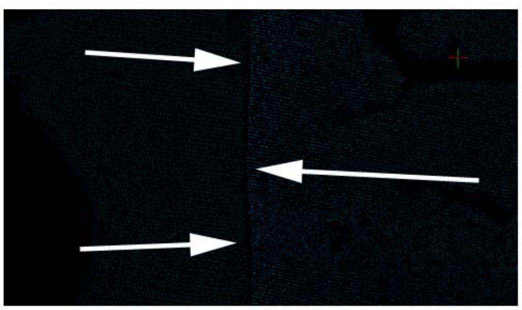


1137 edge issue.bmp

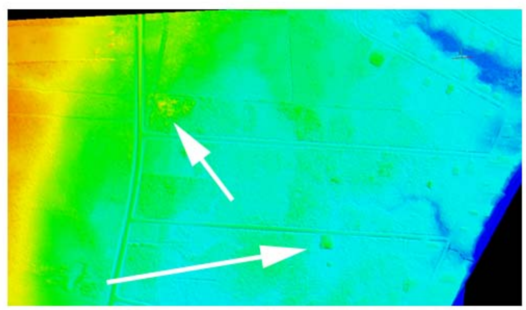


1164 edge issue.bmp

1164 edge issue 2.bmp



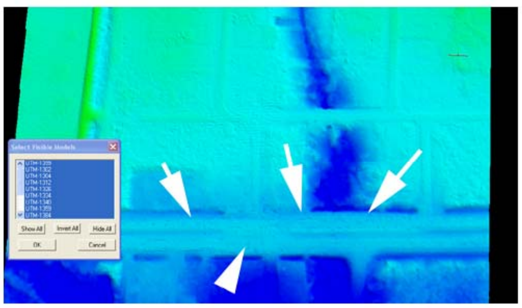
1164 edge issue pts.bmp



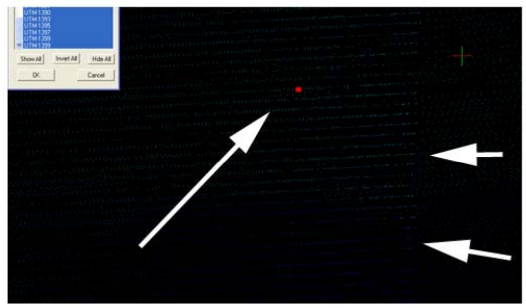
1185 artifacts.bmp

1302 edge issue 20cm or less.bmp

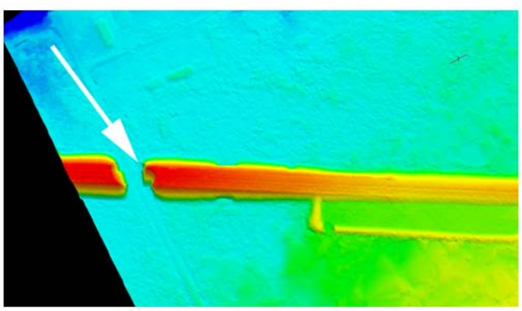
1387 artifact.bmp



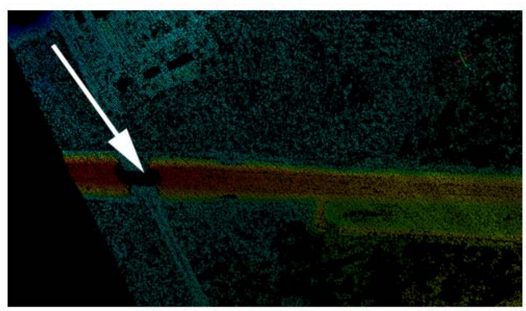
1399 elongated divots along road.bmp



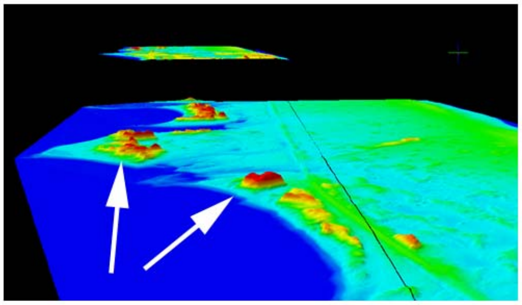
1399 elongated divots scan pattern.bmp



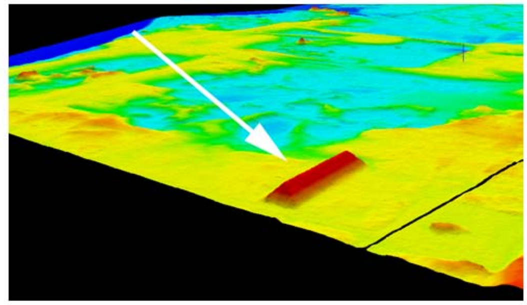
1411 bridge editing.bmp



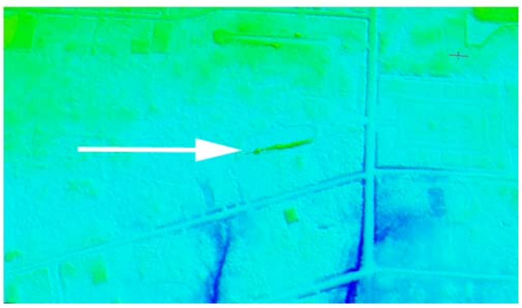
1411 bridge editing pts.bmp



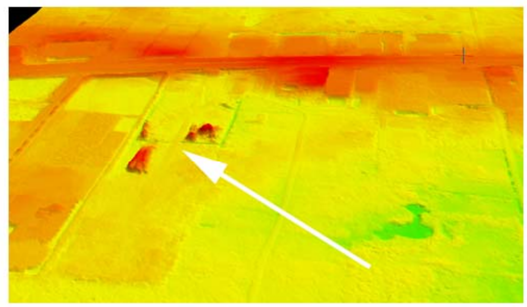
1426 artifacts maybe ok vx2.bmp



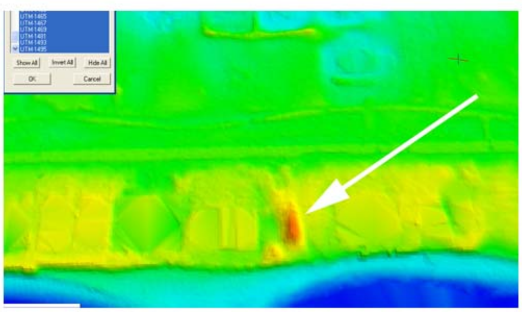
1428 what is it artifact.bmp



1439 artifacts.bmp



1439 artifacts 2.bmp



1452 artifact.bmp