Cecil County, MD
LIDAR Review – 2005

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9/28/2005

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Introduction

As part of the Spatial Systems Associates team, Dewberry's role is to assess the quality of the LIDAR as flown by Airborne 1 Corporation (A1) and post-processed by Computational Consulting Services LLC (CCS) in 2005. Dewberry's business model and reputation for LIDAR assessment is rooted in performing independent quality assurance and quality control (QA/QC). By maintaining independence, Dewberry is not influenced by external factors, thereby allowing unbiased reporting of the data as tested. All quantitative and qualitative assessments were performed in-house without any contact with the data collection or processing firms.

The LIDAR assessment contains both quantitative and qualitative reviews. The **quantitative** assessment utilizes ground truth surveys in which GPS and conventional measurements are compared to the LIDAR data, and the differences are computed. These differences represent the error which translates into the accuracy statements. The results are then reported based on FEMA Guidelines and Specifications for Flood Hazard Mapping Partners (Appendix A: Guidance for Aerial Mapping and Surveying), and by the testing guidelines of the National Digital Elevation Program (NDEP), using methods developed by Dewberry for both of these programs. **The LIDAR data for Cecil County meets and exceeds both guidelines**. These results will be detailed in this report.

The **qualitative** assessment utilizes an interpretive and statistical based methodology to assess the quality of the data for a bare-earth terrain model. 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 and **it satisfies major FEMA requirements and other applications requiring digital terrain model (DTM) equivalent to 2' contours.**

The project area and associated tile scheme for Cecil County, MD can be seen in Figure 1. Figure 2 illustrates a color coded DEM of the project area.

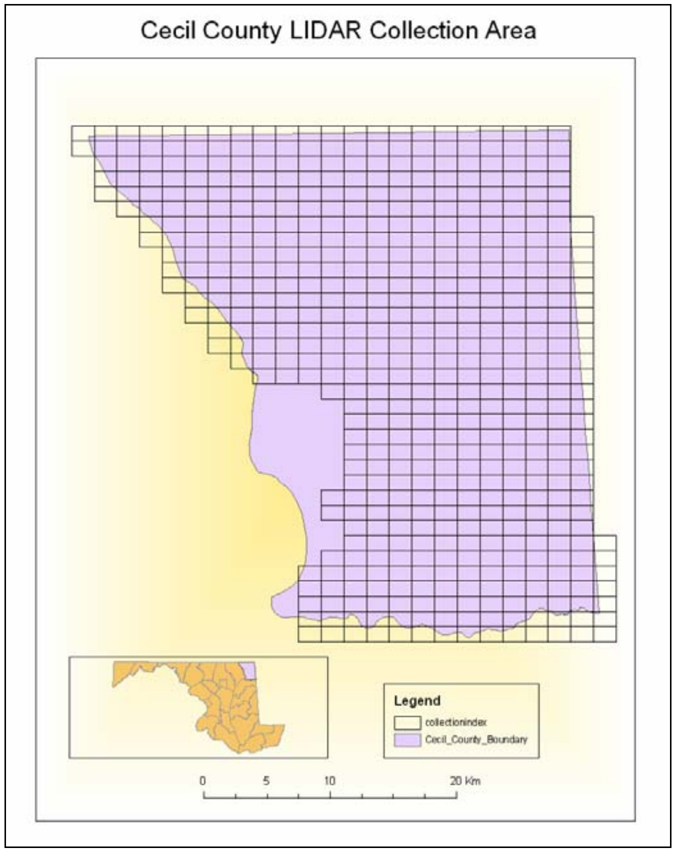

Figure 1 - Cecil County LIDAR collection area.

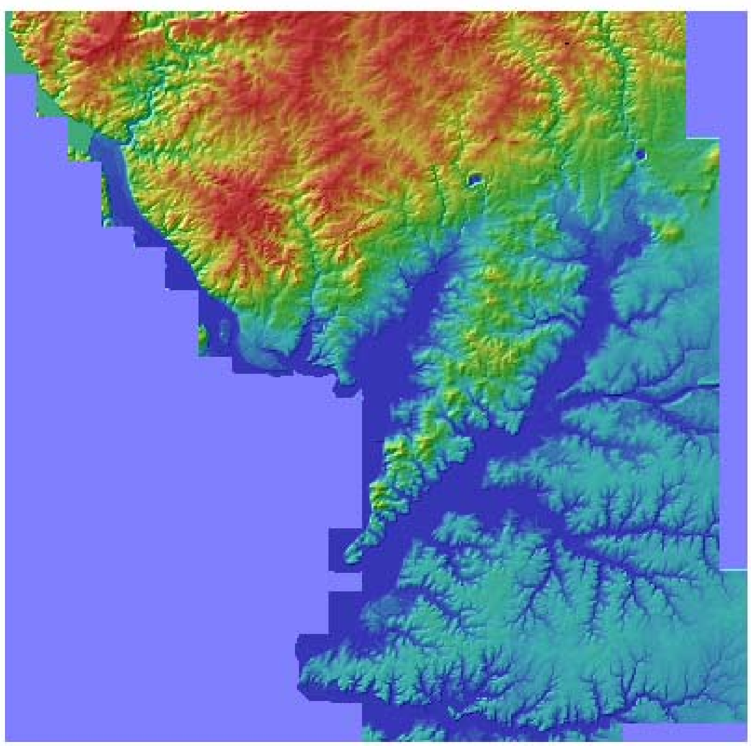

Figure 2 - Combined tingrid and hillshade of project area.

Fundamental Review of LIDAR Data

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

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

In order to assess whether or not the system obtained accurate elevation data, only open terrain areas were evaluated. The principle here is if the data were to be measured in open terrain, the pulse of energy emitted by the sensor would be detected as a strong peak in reflected light. Since the laser light would not be influenced by the filtering through vegetation (which would cause many return pulses), the mathematics could easily identify the "last peak pulse" return of the laser, thereby obtaining an accurate elevation difference (delta) between the sensor and the target. Using the geo-referenced position of the aircraft, coupled with the orientation of the sensor scanner and mirror angle, and the delta range measurement, an accurate elevation is computed. It should be noted that accurate elevation differences does not definitively conclude that the system performed to specification as the system could obtain excellent "relative position" accuracies but weak "absolute position" accuracies. Relative position accuracies are defined as delta heights between the aircraft and the target being measured, but the true positions could be in error. Therefore all the data within a dataset could have accurate delta elevations but be spatially offset. A scenario could exist whereby the relative accuracies are good, but the absolute positional accuracy of the aircraft is in error. This could be caused by factors such as inconsistent survey control values, blunders in antenna heights, systematic biases due to tropospheric modeling, geoid modeling, etc. However, the quantitative testing typically identifies "absolute" inaccuracies.

Using only the checkpoints in open terrain, the land cover "Dirt\Low Grass" had an RMSE of 0.101 m using all of the checkpoints without discarding any outliers. This is a very clear indication that the system performed to specification, especially regarding absolute positional accuracy. It should be noted that although the land cover category of "Urban/Pavement" could be considered open terrain, it is not open terrain since this includes sidewalks and roadways. This is due to the wavelength of the LIDAR system and the ability of asphalt to absorb the laser light, yielding slightly lower elevations. Also built-up areas that include structures can sometimes introduce multi-path which elongates the return path of the LIDAR pulse to the sensor when near building edges at ground level. This can lower the elevations slightly.

Since the data exhibited accurate results for open terrain areas, it is conceivable that the results would be similar to not only the surface model (first return), but also the terrain model (last return) as long as the LIDAR could penetrate the openings of vegetation and produce a strong enough return. It is at this stage that the vegetation removal process is employed, yielding a bare-earth terrain product. The process of removing artifacts which consists of vegetation and man-made structures is complicated due to the complexity of geographic phenomena. A balance must be struck between removing artifacts while maintaining the integrity of the bare-earth. For example, if too-aggressive editing is employed along a tree-lined stream embankment, the potential could be that the stream channel geometry is enlarged or the height of the top of stream bank is erroneously lowered (over-smoothed). This could yield improper results for hydraulic modeling for flood studies. Conversely, if artifacts are left behind, this too can cause errors in modeling especially if it indicates that these features would impede the flow of water. It is then imperative to answer the fundamental question number 2; "Did the vegetation removal process yield desirable results?"

Both these questions can be answered using a combination of quantitative and qualitative review processes.

Verification Process

The delivery of LIDAR data to Dewberry consisted of 514 tiles out of the 533 for the project area. All the following statistics are therefore based on the 514 tiles. None of the missing tiles impacted addressing the quantitative or qualitative review process. Within this delivery, two tiles were outside the project area but again were included in the statistics.

During the analysis process, the data is first reviewed in its native format as text files. This review involves looking at the size of the file, the number of records (NOR) each file contains, and the minimum and maximum values within each file. The average NOR for all tiles is computed and then compared to each file to identify any large discrepancies. If a tile has a significantly lower number of records this does not necessarily conclude there is an error as the dataset may be over a large water body. However if a large number of tiles have low values, then action is warranted to investigate. For this project area no anomalies with the number of records were detected. Figure 3 illustrates the tile scheme classified by the number of records (number of LIDAR points) for each tile. Additionally, the minimum and maximum values were reviewed and no anomalies were found, however the minimum elevation is zero meters and this value appears in many tiles. Since this is a coastal community, it is easily conceivable that some NAVD88 elevations may be lower than zero meters. The processing of this data appears to assign a value of zero to anything less than zero meters. Table 1 illustrates the total number of LIDAR points (NOR) and the minimum and maximum elevations. The full table for the NOR can be found in Appendix A.

Number of Records, Minimum and Maximum Elevations.		
NOR	Min (m)	Max (m)
680362574	0.00	163.15

Table 1 -Number of LIDAR points with the minimum and maximum elevation values.

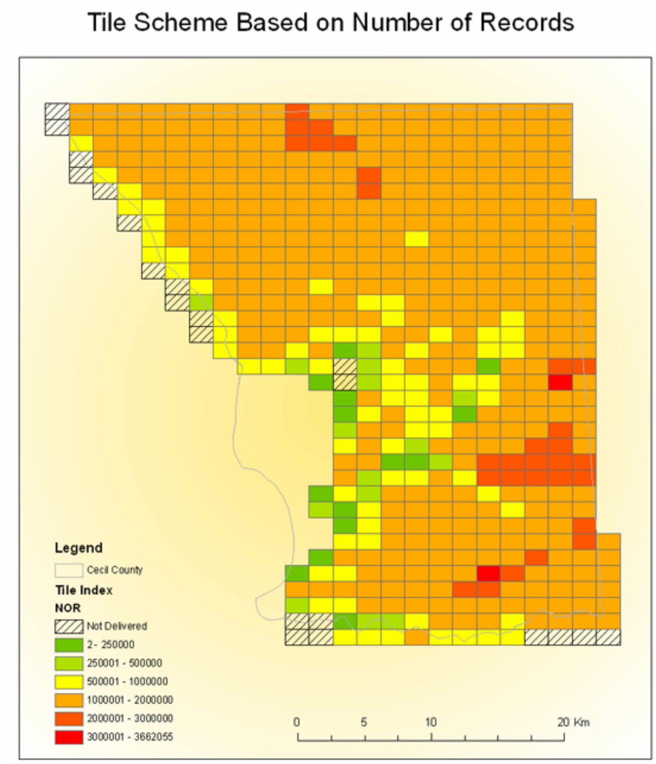

Figure 3 - Color coded map illustrating the number of records for each tile.

Quantitative Analysis – Checkpoint Survey

The vertical accuracy of the LIDAR data was performed by surveying checkpoints in strategic locations by the Spatial Systems Associates team's survey company. These checkpoint surveys were to follow the locational criteria as set forth by the FEMA Guidelines and Specifications for Flood Hazard Mapping Partners (Section A.6.4 of Appendix A: Guidance for Aerial Mapping and Surveying), and by the testing guidelines of the National Digital Elevation Program (NDEP), using methods developed by Dewberry for both these programs. The first part of this process is to base the number of checkpoints on the number of major land cover categories representative of the area being mapped. The example given was that if 5 categories represented the major land cover categories, then a minimum of 20 checkpoints would be measured for each of these land cover categories, for a total of 100 checkpoints.

A total of 100 checkpoints for Cecil County were submitted for the LIDAR analysis by the surveyor. This represented 20 points for each land cover category, rather than 20 total checkpoints as defined by paragraph 3.2.2 of the National Standard for Spatial Data Accuracy which states: "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.[4] When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications." Footnote 4 refers the reader to Section 3 of Appendix 3-C which states: "Due to the diversity of user requirements for digital geospatial data and maps, it is not realistic to include statements in this standard that specify the spatial distribution of check points. Data and/or map producers must determine check point locations. This section provides guidelines for distributing the check point locations. Check points may be distributed more densely in the vicinity of important features and more sparsely in areas that are of little or no interest. When data exist for only a portion of the dataset, confine test points to that area. When the distribution of error is likely to be nonrandom, it may be desirable to locate check points to correspond to the error distribution." However, the NSSDA does not address the size of the project area which could mean a few acres to thousands of square miles. Even though the data has been tested as per specification, further review may be warranted by intended users to verify that the data will meet their needs.

Figure 4 illustrates the geographic location of the checkpoints relative to the project area. It should be noted that the checkpoints encompass a large area and are in strategic geographic locations spread out to verify as much of the data as possible. Since the flight lines consisted of smaller flight line blocks of the project area, the location of the checkpoints help verify the data from different flights.

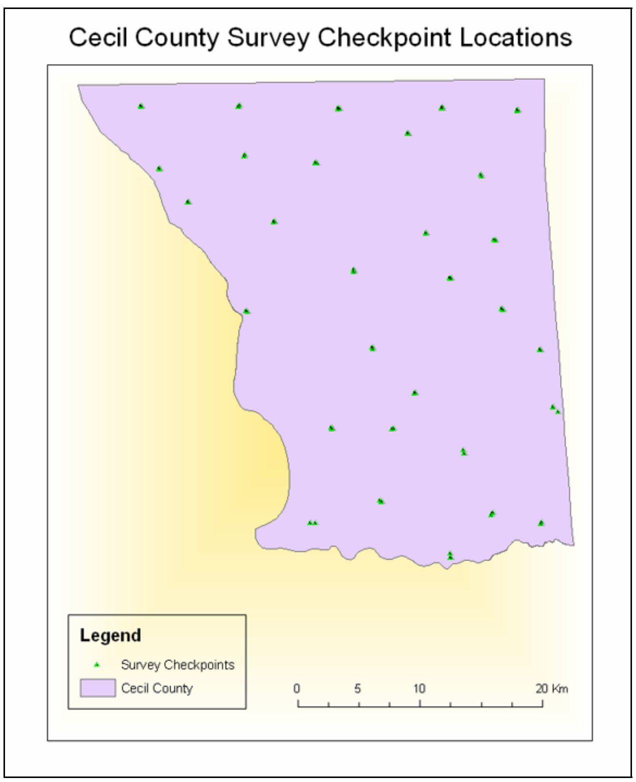

Figure 4 - Location of survey checkpoints. Due to the scale of the map, not all points are visible as some are clustered.

Just as important as the geographic location of the checkpoint, the "locale" also plays a significant role. Since the comparison of the checkpoints cannot be in exactly the same locations as the LIDAR points (if the checkpoints are measured without any prior knowledge of the LIDAR point locations), interpolation methods must be incorporated and accounted for. Therefore, the comparison is truly between the checkpoints and the terrain model, i.e., the Triangular Irregular Network (TIN) of the bare-earth terrain model. Care must be taken to assess the slope of the checkpoint locations since the checkpoints are verifying the LIDAR. Checkpoints located on a high slope could falsely accuse the LIDAR data of being inaccurate when caused by allowable horizontal displacemnent. The outline for the Independent Surveyor was to establish checkpoints on as level terrain as possible within a 5 meter radius. The secondary criteria was that the slope be less than 20% (preferably less than 10%) and at least 5 meters away from any breaklines, as specified in sections A.6.4, Appendix A to FEMA's Guidelines and Specifications; this same criteria for selection and location of checkpoints has been adopted by the National Digital Elevation Program (NDEP) which has submitted its recommendations to the Federal Geographic Data Committee (FGDC) for adoption in the next revision to the National Standard for Spatial Data Accuracy (NSSDA). If the LIDAR indicates a high slope, but there is confidence that the checkpoint is on fairly level ground, this could indicate an error within the LIDAR. The minimum and maximum slope is between 0.4 and 18.3%. It should be recognized that this slope calculation is based on a raster approach which looks at the neighboring 8 cells to define the slope. Since the guidelines for defining checkpoints locations is to have slope less than 20%, the raster approach is valid based on a 3 meter cell size. However to verify some of the higher slope values, the slope was also calculated for the specific TIN triangle face for each checkpoint and compared to the Tin Grid slope. For the highest slope of 18.3%, the TIN slope was 16.1% indicating that the error was most likely caused by the variance in the LIDAR and the land cover type of low trees and brush. The full table can be found in Appendix B.

In addition to verifying the slope, a routine was performed to ensure that LIDAR points were geographically close to the actual survey checkpoints. By reviewing the three nearest LIDAR pints to each checkpoint, the interpolation process is known to be more accurate when the LIDAR pints are close to the checkpoints. For example, if a checkpoint’s three closest LIDAR points are 5 -10 meters away, we may not have as much confidence in the interpolated TIN value as we would if the two closest points are less than 2 meters. For the100 TIN triangles that included the 100 checkpoints, the nearest LIDAR points (Dist1) varied between 0.04 and 2.20 meters; the second nearest LIDAR points (Dist2) varied between 0.21 and 2.80 meters; and the farthest LIDAR pints (Dist3) varies between 0.38 and 3.40 meters. This is excellent, demonstrating the high density of the LIDAR dataset

Vertical Accuracy Assessment Using RMSE Methodology

The first method of testing vertical accuracy is to use the Root Mean Square Error (RMSE) approach which is valid when errors follow a normal distribution. This methodology measures the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The vertical accuracy assessment compares the measured survey checkpoint elevations with those of the Triangulated Irregular Network (TIN) as generated from the LIDAR. The survey checkpoint's X/Y location is overlaid on the TIN and the interpolated Z value is recorded. This interpolated Z value is then compared to the survey checkpoint Z value and this difference represents the amount of error between the measurements. In previous DNR MD LIDAR QA/QC reports we had reported the North Carolina Flood Plain Mapping - Phase 1 methodology where 5% of the largest errors are removed in order to account for uncleaned areas and gross blunders. Since this approach does not use 100% of the checkpoint data, our experience has shown that it is not a valid approach to reporting accuracy. Additionally this method is no longer employed by North Carolina.

Table 2 summarizes the RMSE using:

- 100% of the checkpoints (method used by FEMA when errors are assumed to follow a normal distribution)
- Checkpoints categorized by land cover type based on 100% of points

RMSE by Land Cover				
%	**RMSE (m)**	**# of Points**	**Land Class**	**RMSE Criteria (m)**
100	0.121	100	**Consolidated**	0.185 (FEMA methodology)
20	0.101	20	**Dirt/Low Grass**	
20	0.092	20	**Crop/High Grass**	
20	0.177	20	**Low Trees/Brush**	
20	0.133	20	**Fully Forested**	
20	0.075	20	**Urban**	

Table 2 – RMSE of LIDAR based on QA/QC survey checkpoints.

Table 2 illustrates that all of the combined checkpoints easily meet the RMSE criteria of 0.185 m and the data has excellent vertical accuracy.

Figure 5 & Figure 6 graphically illustrate the RMSE by land cover category and the elevation differences (delta) between the LIDAR compared to that of the survey QA/QC checkpoints.

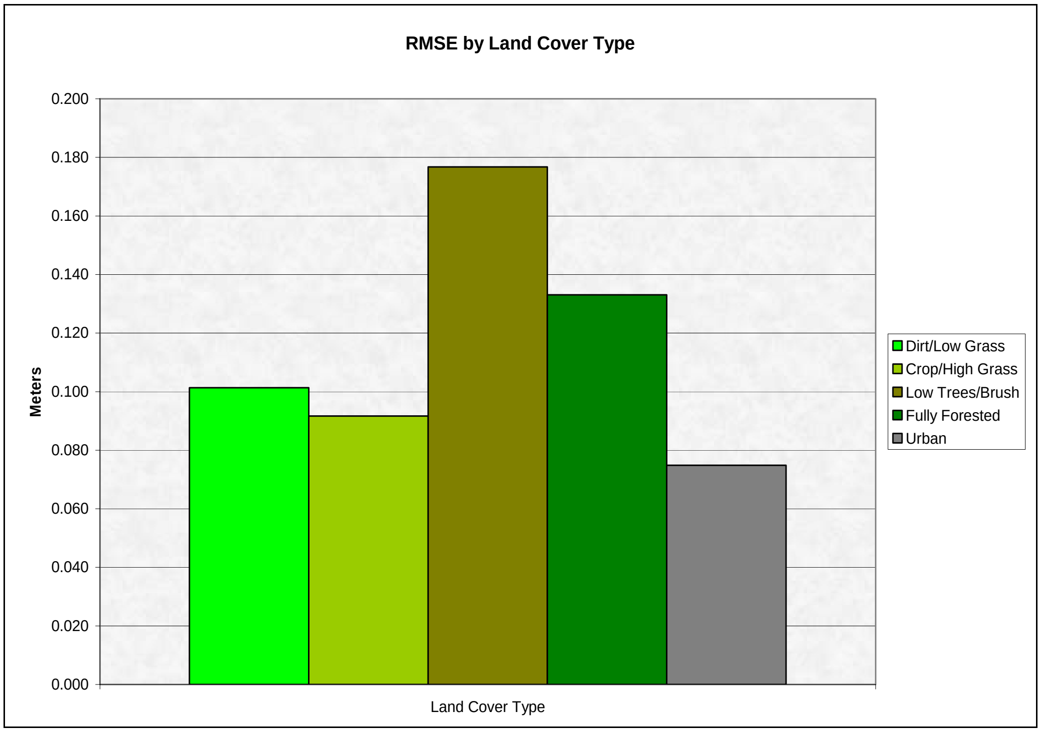

Figure 5 – RMSE by specific land cover type.

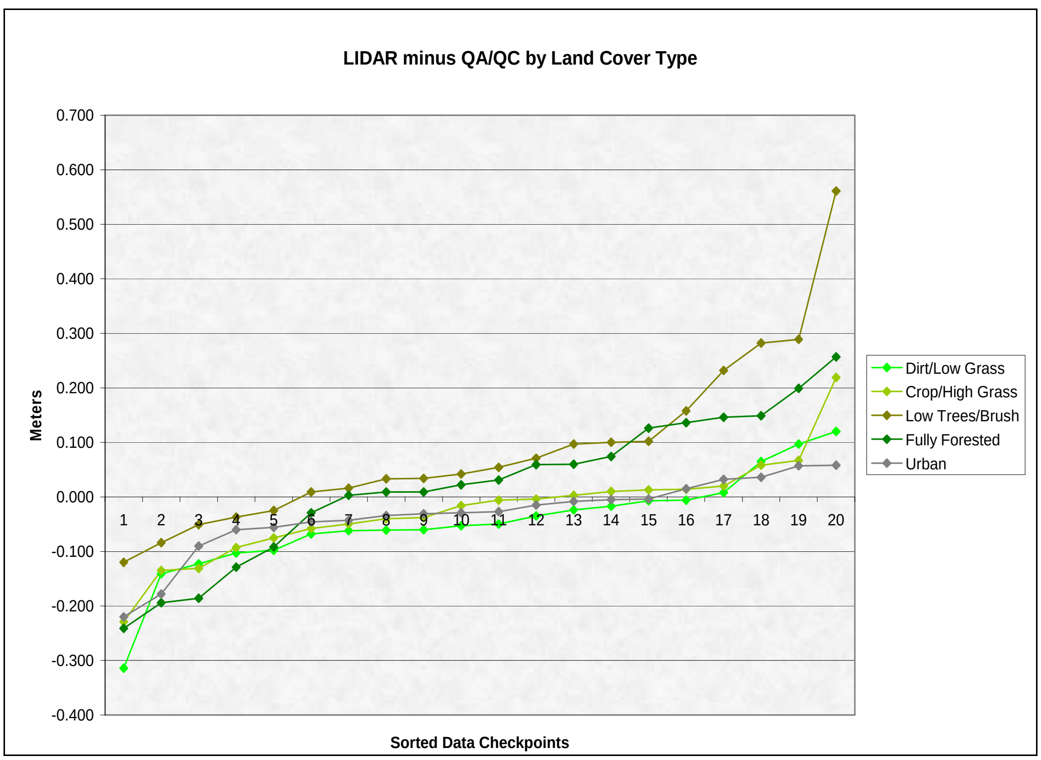

Figure 6 – Illustrates the magnitude of differences between the checkpoints and LIDAR data by specific land cover type.

Table 3 summarizes the descriptive statistics referenced in the FEMA guidelines. The RMSE and mean values are excellent with slightly high skew values. The skew represents the asymmetry of distribution around the mean. Since the mean is acceptable and all data easily meets specifications, the skew is not an issue.

Overall Descriptive Statistics								
Land Class	RMSE (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.121	0.001	-0.006	1.04	0.122	100	-0.314	0.561
Dirt/Low Grass	0.101	-0.047	-0.052	-0.85	0.092	20	-0.314	0.120
Crop/High Grass	0.092	-0.024	-0.011	0.31	0.091	20	-0.229	0.219
Low Trees/Brush	0.177	0.088	0.048	1.55	0.157	20	-0.120	0.561
Fully Forested	0.133	0.020	0.027	-0.37	0.135	20	-0.241	0.257
Urban	0.075	-0.032	-0.028	-1.36	0.069	20	-0.220	0.058

Table 3 - Overall descriptive statistics.

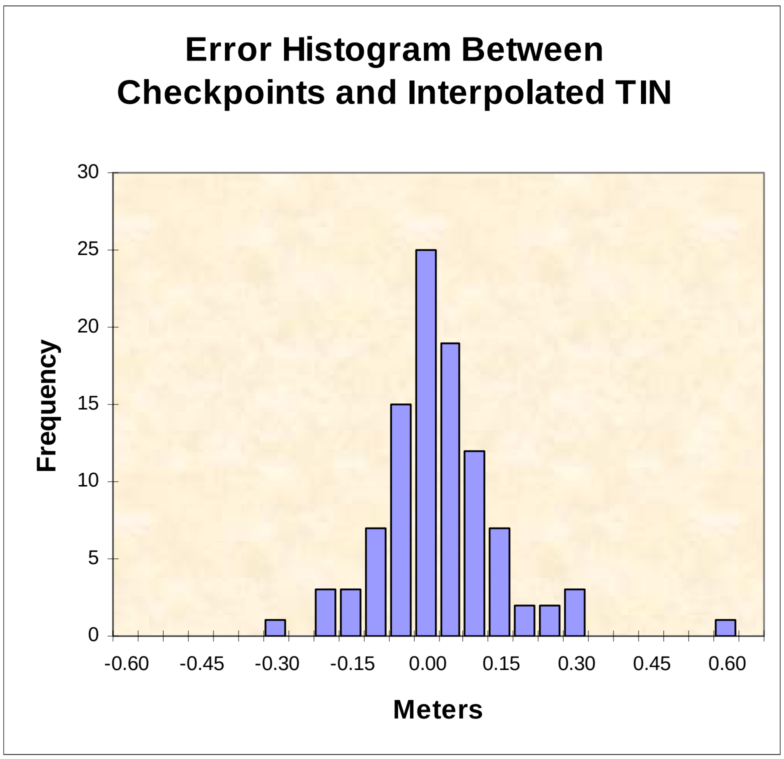

Figure 7 - Error Histogram of all the data checkpoints.

Vertical Accuracy Assessment using NDEP Methodology

The Fundamental Vertical Accuracy (FVA) at the 95% confidence level equals 1.9600 times the RMSE in open terrain only; in open terrain, there is no valid excuse why errors should not follow a normal error distribution, for which RMSE methodology is appropriate. Supplemental Vertical Accuracy (SVA) at the 95% confidence level utilizes the 95th percentile error individually for each of the other land cover categories, which may have valid reasons (e.g., problems with vegetation removal) why errors do not follow a normal distribution. Similarly, the Consolidated Vertical Accuracy (CVA) at the 95% confidence level utilizes the 95th percentile error for all land cover categories combined. This NDEP methodology is used on all 100% of the checkpoints and not just on the best 95% of those checkpoints.

The target objective for this project was to achieve bare-earth elevation data with an accuracy equivalent to 2 ft contours, which equates to an RMSE of 0.185 m when errors follow a normal distribution. With these criteria, the Fundamental Vertical Accuracy of 0.363 m must be met. Furthermore, it is desired that the Consolidated Vertical Accuracy and each of the Supplemental Vertical Accuracies also meet the 0363 m criteria to ensure that elevations are also accurate in vegetated areas. As summarized in Table 4 this data:

- Satisfies the NDEP's mandatory Fundamental Vertical Accuracy criteria for 2 ft contours in open terrain e.g. dirt/low grass.
- Satisfies the NDEP's optional Consolidated Vertical Accuracy criteria for 2 ft contours for all land cover categories combined.
- Satisfies the NDEP's optional Supplemental Vertical Accuracy for 2 ft contours for crop/high grass, low trees/brush, fully forest and urban/pavement.

Vertical Accuracy at 95% Confidence Level Based on NDEP Methodology for 2 ft contours				
Land Cover	**# of Points**	**Fundamental Vertical Accuracy (mandatory) 0.36 (m) standard**	**Consolidated Vertical Accuracy (optional) 0.36 (m) standard**	**Supplemental Vertical Accuracy (optional) 0.36 (m) standard**
Consolidated	100		0.242	
Dirt/Low Grass	20	0.199		
Crop/High Grass	20			0.220
Low Trees/Brush	20			0.303
Fully Forested	20			0.242
Urban	20			0.180

Table 4 - Vertical Accuracy per NDEP Methodology

As outlined in Table 4, the data satisfies the mandatory FVA criteria, the optional CVA and SVA for all land cover categories. Table 5 lists the five outliers which are greater than the CVA's 95th percentile value of 0.242 meters. Although these values are listed as outliers, only one is greater than 0.363 meters.

Checkpoint Outliers		
Pt Name	**Land Class**	**Elev. Diff (ft)**
628	Dirt/Low Grass	-0.314
606	Fully Forested	0.257
623	Low Trees/Brush	0.282
677	Low Trees/Brush	0.289
691	Low Trees/Brush	0.561

Table 5 - Points with elevation difference outside 95th percentile

Quantitative Conclusion

The checkpoint survey was well done. The points are spatially spread out throughout the county and cover many different LIDAR flight lines. They also appear to satisfy all criteria for establishing checkpoints. The comparisons of the checkpoint survey to that of the LIDAR exhibits excellent results, and by utilizing the multiple testing methods it is clear that the data exceeds all mandatory criteria. The data also exhibits strong results for the NDEP's optional SVA criteria. This data conforms to the equivalency of two foot contours and should satisfy most users who require this accuracy.

Qualitative Analysis

Overview

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 stated, 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 constitutes 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 digital terrain model (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 utilizing existing imagery (if available), creating pseudo image products such as hillshades and 3-dimensional modeling, and statistical spatial analysis. 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 performed exceptionally well, as well as examples where improvements are recommended.

Qualitative Assessment

Based on the samples tested by Dewberry, it is our professional judgment that this data can easily meet the desired accuracy for not only 2 ft contours, but also for cleanliness suitable for most applications. No major issues were encountered but a few minor issues were identified. Overall the data was consistent and no one area was weaker than any other. While assessing this dataset, one of our focuses was to review the data on a macro level and not to identify all micro level issues (although many similar tiles have the same micro issues). It is assumed that data collected on a volume of this scale may have unidentified errors at the local level in specific locations and may need modification to fit application needs. For example, transportation groups may need all the bridge deck elevations whereas the hydrologist would prefer that the bridges be removed. Overall this data will meet the needs of the general users of elevation data.

The data tiles were sampled in strategic locations to aid in identifying potential problems. Tiles were also chosen in a pseudo random pattern, that is; to ensure each row and column of tiles had sample selections with no set pattern. This allowed Dewberry to test a multitude of data flown on different days. Additionally, tiles were chosen to include areas of dense forest, swamps with mixed vegetation, agricultural, and urban terrain. Some tiles will illustrate duplicate issues. This is meant as a means to identify that these particular issues occur in more than one tile.

The process of identifying issues utilized two different software packages; ESRI and Terramodel. 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 ESRI for ease of clarification. To reiterate, the data for the most part is exceptionally good. It exhibits excellent accuracy and vegetation removal, providing a good bare-earth data product.

The three types of minor issues that were found are;

1. Inconsistent bridge editing
2. Elevations that are set to zero
3. Sporadic artifacts

1. Inconsistent Bridge Editing

As mentioned previously, the need for having bridges maintained or removed from the data is based on the need and application of the data. Hydrologists may want them removed, transportation engineers may want them to stay and hydraulic engineers may want the bridge abutments to stay, but the deck removed. However this data has bridges that are in, or out, or have portions of the bridge deck removed. Figure 8 and Figure 9 illustrate this issue. In the northeast quadrant two bridges have been removed. However bridges in the southwest and southeast only partially are removed. Figure 10 illustrates a 3-D view of a bridge with the same issue. There are many examples of inconsistent bridge editing throughout this project.

Figure 8 - TIN Grid and Hillshade illustrating inconsistent bridge editing (BJ138b61).

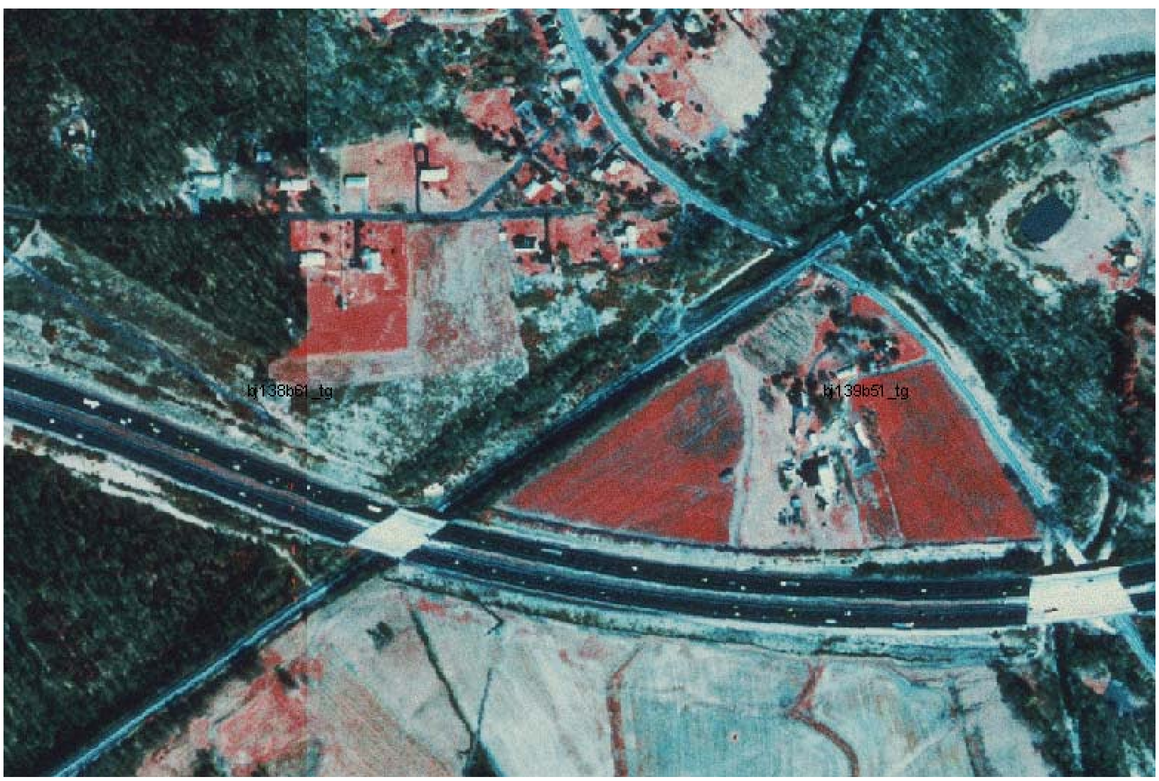

Figure 9 - Aerial color-infrared photograph of area illustrating bridge locations (BJ138b61).

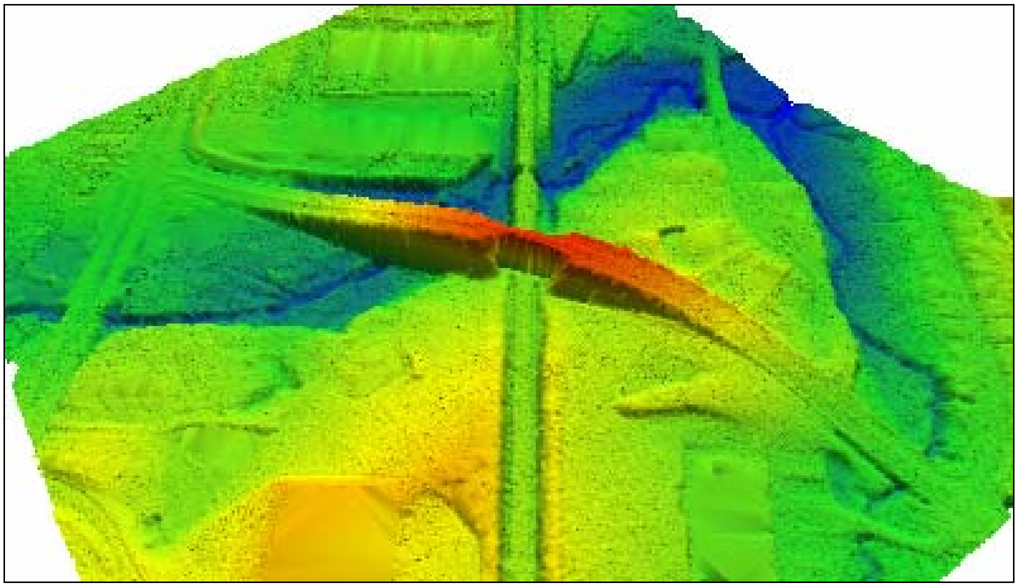
Figure 10 - 3-D view of bridge editing issue.

2. Elevations That Are Set To Zero

As mentioned in the verification process, many tiles have a minimum elevation of zero meters. Since this is a coastal community, it is conceivable that some elevations can be less than the zero meters in NAVD88. Figure 11 illustrates a quarry where the floor elevation is exactly zero meters. We believe that this quarry, as well as other areas, could be less than zero.

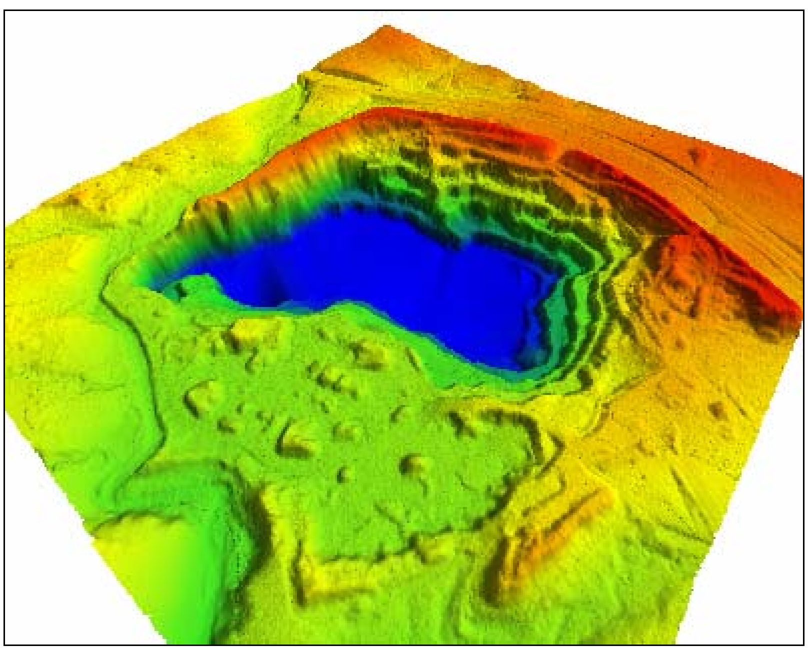
Figure 11 - Quarry with a minimum elevation of 0.00 meters.

3. Sporadic Artifacts

Figure 12 and Figure 13 illustrates show one of several buildings that remain after the post processing to remove building and vegetation.

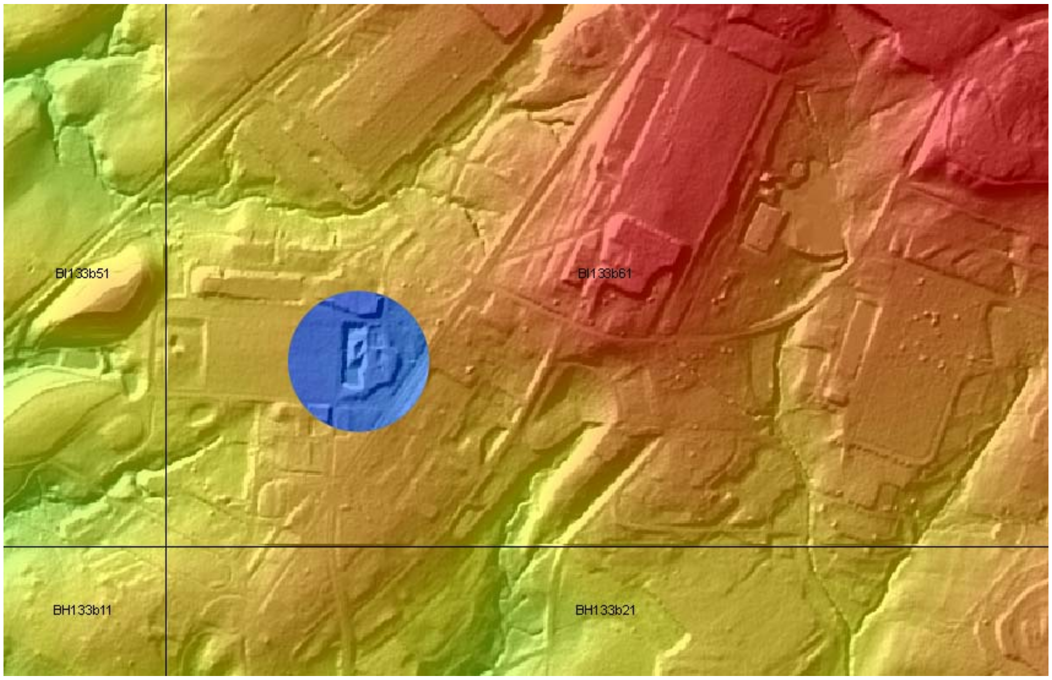

Figure 12 - Potential artifact highlighted within the circle.

Figure 13 - Potential artifact highlighted within the circle

Figure 14 illustrates a rest stop along the highway that may have a large artifact consisting of vegetation beside the structure. The profile illustrates a change in elevation of over 4 meters.

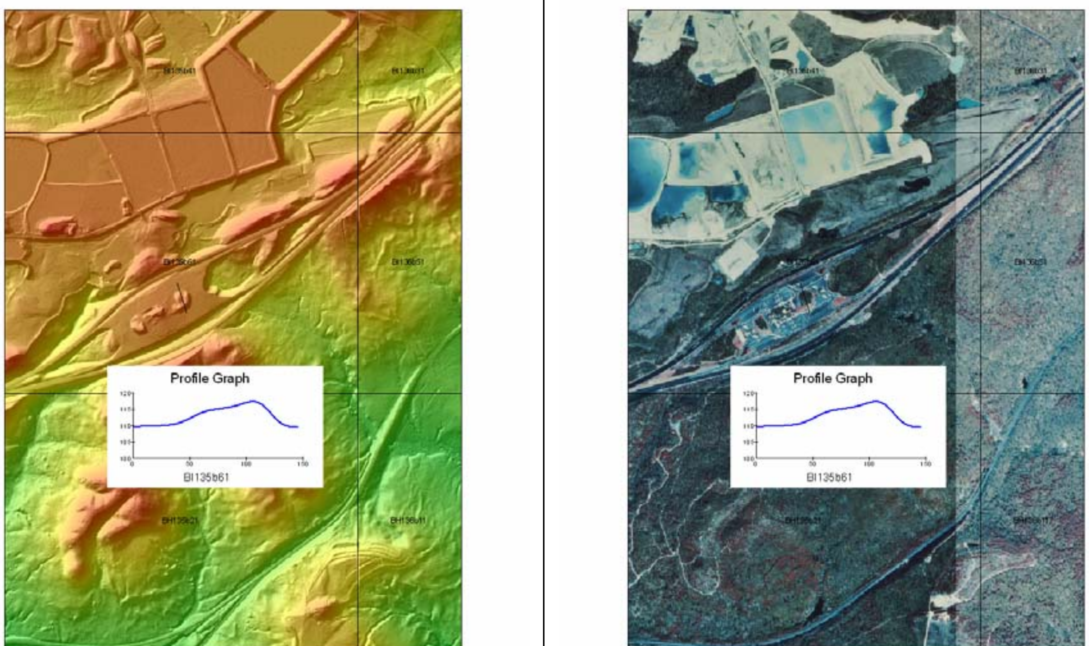

Figure 14 - Potential artifact with associated profile for both the Tin GRID/Hillshade and a CIR photograph.

Figure 15 and Figure 16 illustrate potential artifacts within the clover leaf circles.

Figure 15 - Potential artifact in clover leaf.

Figure 16 - Potential artifact in clover leaf.

Figure 17 to Figure 19 illustrate "noisy data." Noisy data is data within specification but showing a high variance in the elevations relative to each other. This particular area consists of flight lines that are flown perpendicular to each other. On the left side of Figure 18, the flight line was flown north-south whereas the right side of the image has lines north-south and east-west. The difference between these two datasets are approximately 0.15 meters.

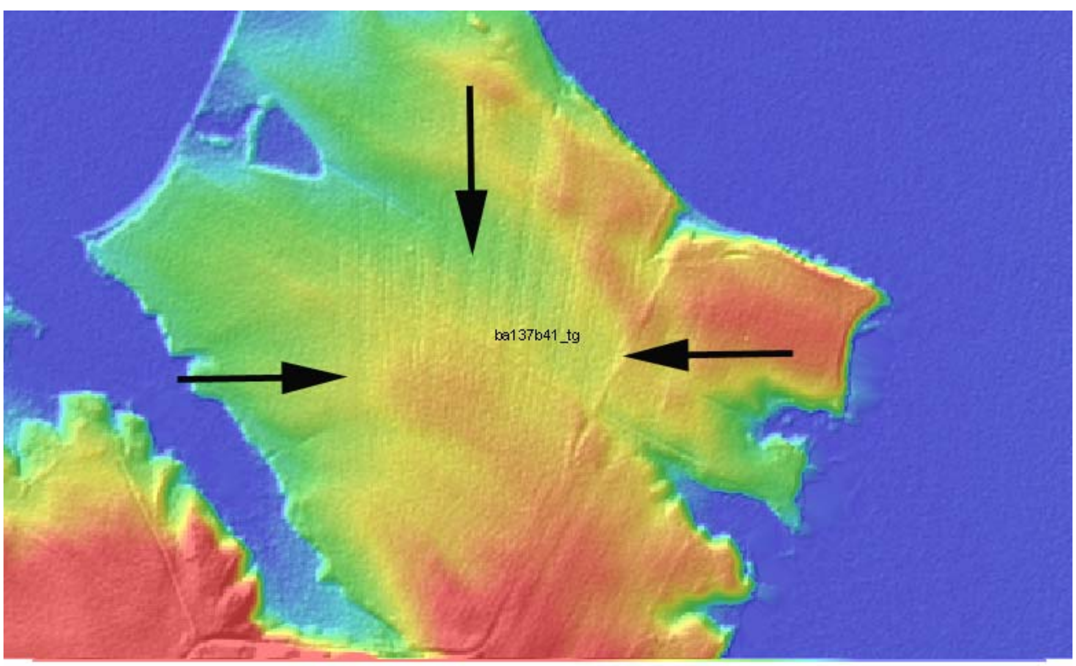

Figure 17 – Tin Grid/Hillshade with "noise" within the arrow area.

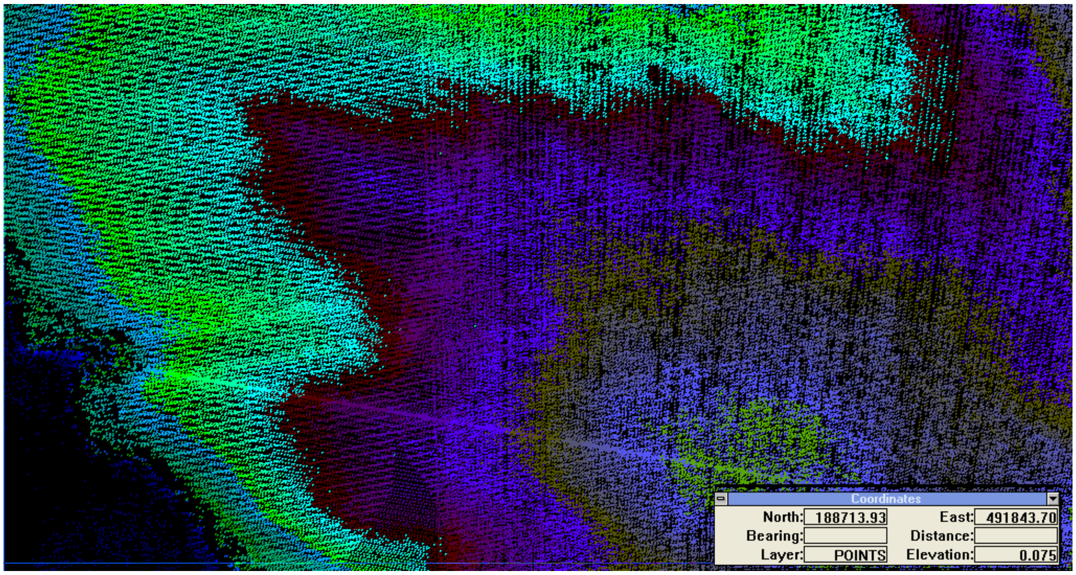

Figure 18 – Scan lines, note the right side of the image has flight lines that are flown perpendicular to each other.

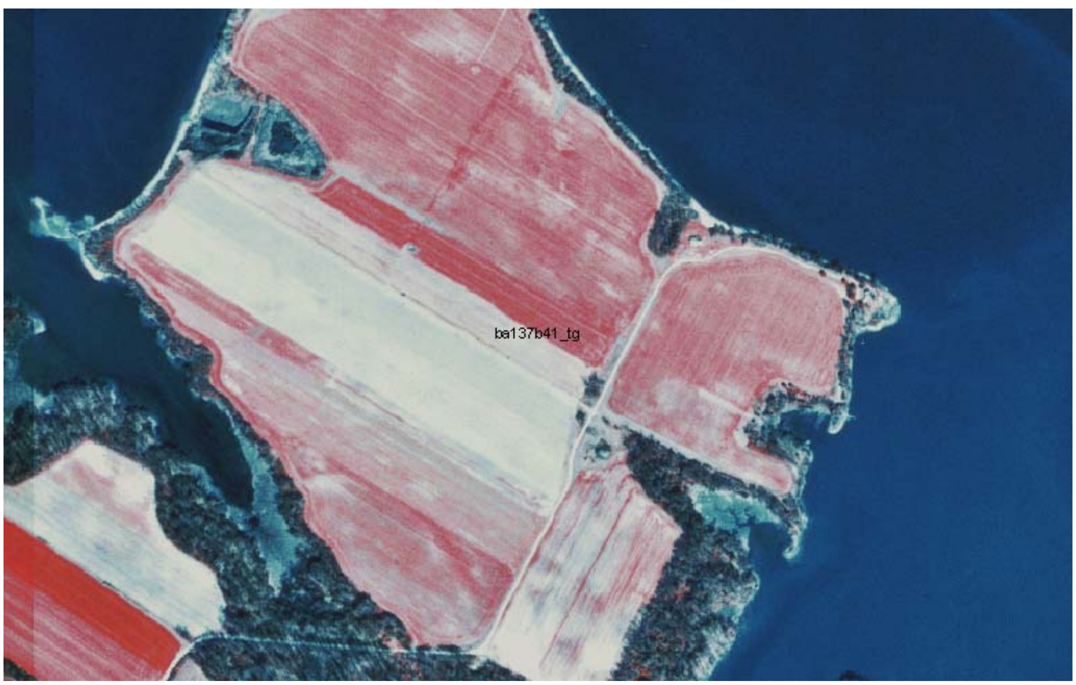

Figure 19 – CIR photo of area with noisy data.

Figure 20 illustrates what appears to be an artifact nearly five meters tall based on the shape and elevation. However by using the intensity imagery, the feature in question is clearly identifiable and its texture is similar to the surrounding area.

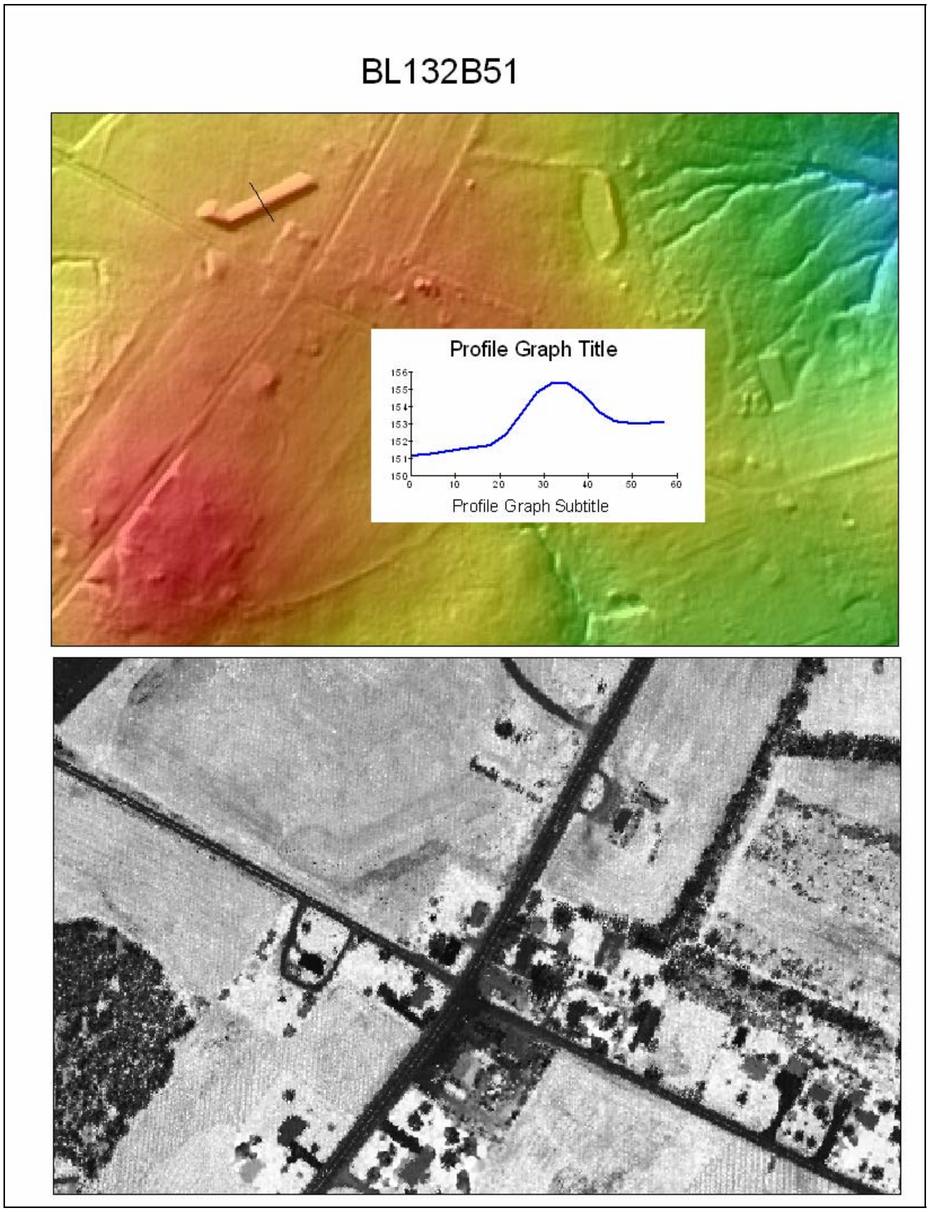

Figure 20 - Legitimate feature illustrated by Tin Grid/Hillshade and intensity image.

Figure 21 and Figure 22 illustrate what appears to be noisy data; however the photo shows the smoothness is from a plowed field and the roughness is an area within a forest. These are shown as to not misconstrue noisier terrain values with errors in the LIDAR because they may be legitimate features.

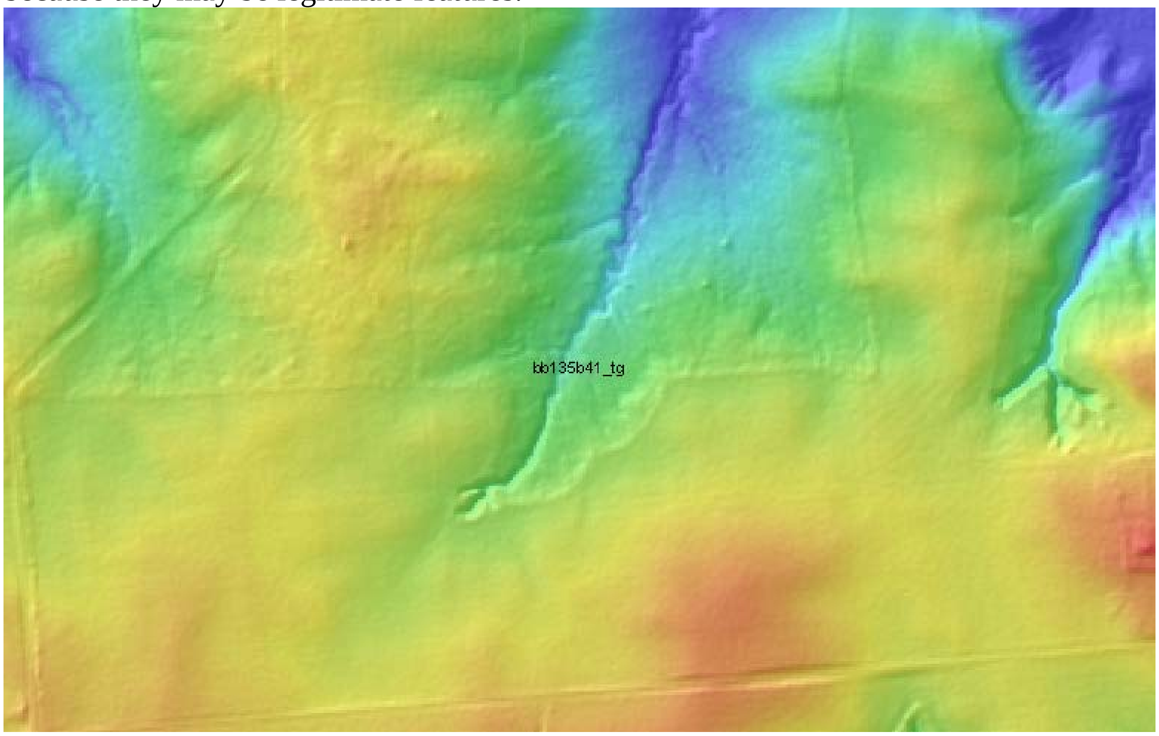

Figure 21 – Plowed Field and forest floor from LIDAR

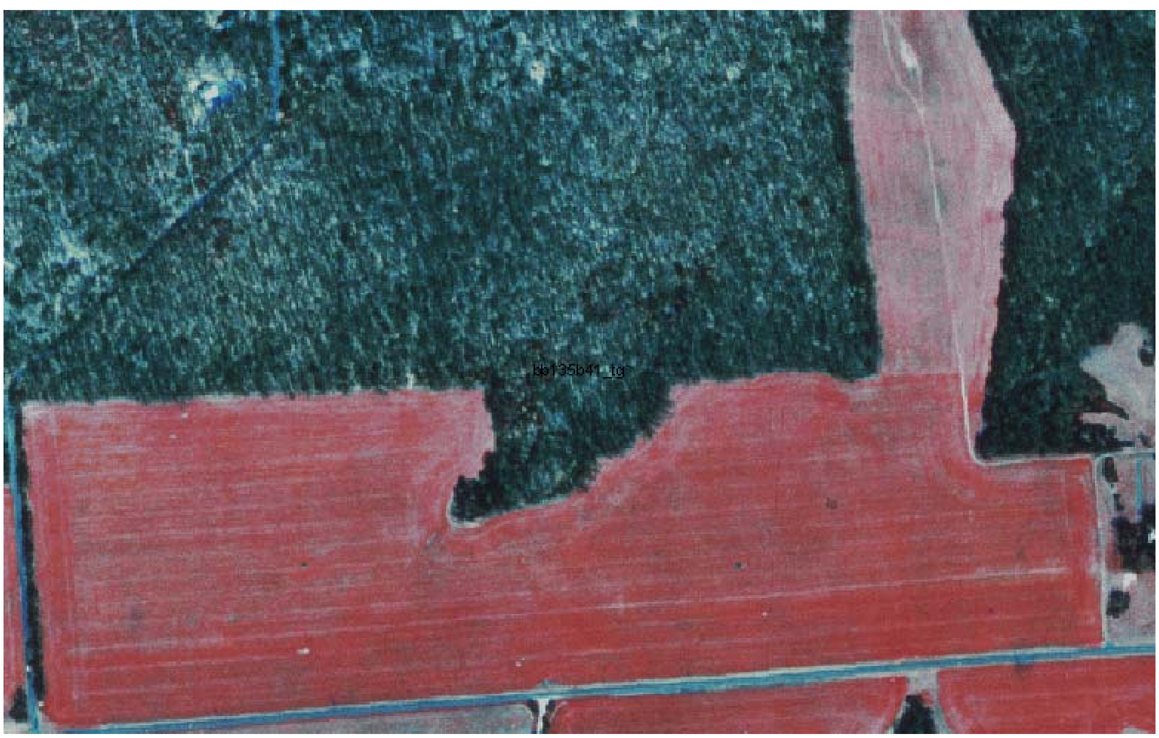

Figure 22 – Plowed field and forest from CIR imagery.

Qualitative Conclusion

The data for this county exhibits excellent characteristics for cleanliness for a bare-earth terrain product. The issues outlined above tend to be very minor and do not hamper the general use of this product. Our recommendation is only directed towards the bridge editing and the elevations set to a zero value.

Conclusion

From a quantitative perspective, the absolute accuracy of the bare-earth elevation data easily satisfies accuracy standards for digital elevation data equivalent to 2’ contours.

From a qualitative perspective, the data are clean without being too clean (over-smoothed), with only a few manmade structures that were not removed during the bare-earth processing. Bridge editing for hydro-enforcement should be performed in a consistent manner. Furthermore Dewberry recommends that the zero elevations be reviewed to determine elevations that should be legitimately below zero relative to NAVD88 vertical datum.