Charles and St. Mary's County
LIDAR Review – 2004

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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 and processed by Sanborn Mapping in 2004. 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.

As stated, the LIDAR assessment contains both quantitative and qualitative reviews. The quantitative assessment utilized ground truth surveys which are compared to the LIDAR data. 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 qualitative assessment utilizes interpretive and statistical methods based on the level of cleanliness for a bare-earth terrain model.

The project area for assessment encompassed the two counties of St Mary's and Charles located in the state of Maryland. Figure 1 illustrates the project area with the tiles scheme overlaid.

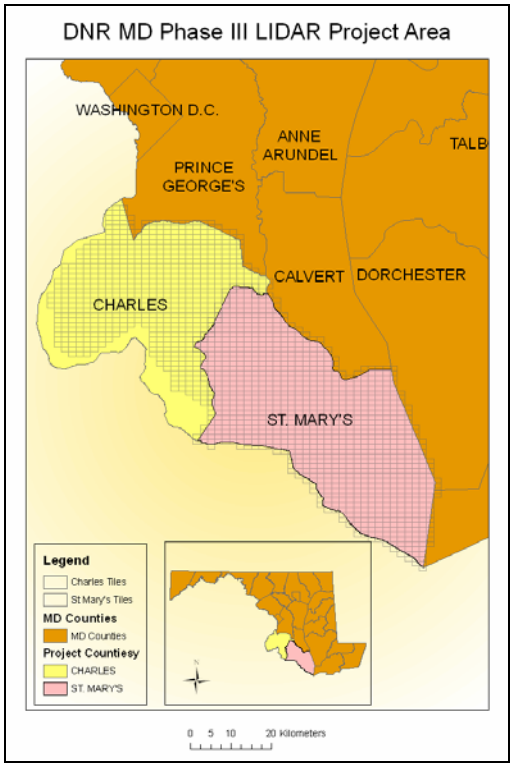

Figure 1 – Overview of Charles and St Mary's Counties MD

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 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 delta elevation between the sensor and the target. Using the geo-referenced position of the aircraft, coupled with that of the sensor data, an accurate elevation is obtained. It should be noted that any discrepancies of the elevation does not definitively conclude that the system did not perform to specification as the system could obtain excellent "relative position" accuracies but weak "absolute position" accuracies. Relative position accuracies are defined as true delta heights between the aircraft and the target being measured. 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 "Grass/Ground" had an RMSE of 9.7 cm 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 introduce some multi-path of the LIDAR near building edges, again lowering 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.

Quantitative Analysis – Checkpoint Survey

As outlined in the initial proposal, the vertical accuracy of the LIDAR data (ground-truthing) was to be performed by surveying checkpoints in strategic locations. 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 both counties were submitted for the LIDAR analysis by an independent surveyor. This represented 20 points for each land cover category 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 2 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.

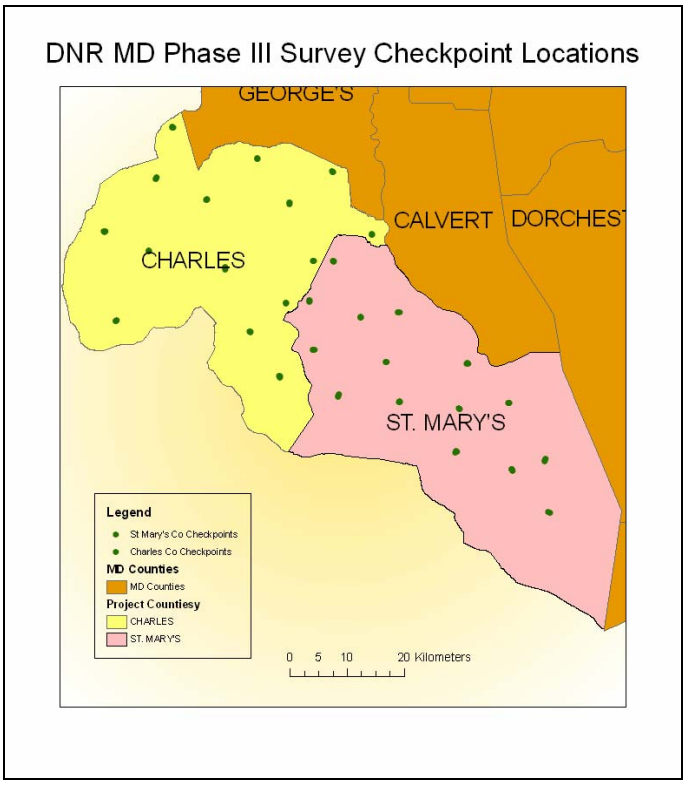

Figure 2 -Location of Survey Checkpoints. Due to the scale of the map, all points are not visible due to the clustering of points.

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. 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.

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 two horizontally closest LIDAR points, and analyzing their Z-values, assumptions can be derived about the validity of the interpolation process. For example, if a checkpoint’s two 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. This process also looks at the Z-values for the closest points and compares them to the LIDAR point to ensure a large delta difference does not exist.

Data Dictionary	
PID	Point ID number
Z	Surveyed elevation of PID
TINz	Computed TIN elevation of survey checkpoint
Dist1	Closest LIDAR point to checkpoint
Dist2	2nd Closest LIDAR point to checkpoint
Z1	Elevation of closest LIDAR point
Z2	Elevation of 2nd Closest LIDAR point
Avg_Z1-Z2	Average elevation of Z1 and Z2
Avg-Tinz	Computed average elevation minus TINz

Table 1 – Data Dictionary

Surveyor Checkpoints – Delta Elevations & Distance to Closest LIDAR Point									
PID	**Z**	**TINz**	**Z_Delta**	**Dist1**	**Dist2**	**Z1**	**Z2**	**Avg_Z1-Z2**	**Avg-TINZ**
101	1.402	1.420	0.018	0.680	0.720	1.380	1.430	1.405	-0.015
102	1.685	1.500	-0.185	0.280	0.830	1.500	1.490	1.495	-0.005
103	1.652	1.520	-0.132	0.450	0.790	1.560	1.410	1.485	-0.035
104	4.952	4.930	-0.022	0.460	0.500	4.940	4.910	4.925	-0.005
105	5.559	5.620	0.061	0.620	0.660	5.620	5.600	5.610	-0.010
106	5.555	5.750	0.195	0.700	0.740	5.740	5.770	5.755	0.005
107	5.537	5.620	0.083	1.470	1.920	5.580	5.640	5.610	-0.010
108	7.878	8.130	0.252	0.340	0.440	8.140	8.160	8.150	0.020
109	8.557	8.670	0.113	0.130	0.830	8.680	8.670	8.675	0.005
110	7.964	8.170	0.206	0.200	1.050	8.170	8.200	8.185	0.015
111	2.153	2.340	0.187	0.170	0.580	2.340	2.330	2.335	-0.005
112	1.633	1.790	0.157	0.190	0.850	1.800	1.800	1.800	0.010
113	2.136	2.370	0.234	0.130	0.800	2.370	2.330	2.350	-0.020
114	29.133	29.060	-0.073	0.150	0.530	29.060	29.050	29.055	-0.005
115	29.625	29.580	-0.045	0.270	0.950	29.580	29.620	29.600	0.020
116	29.262	29.120	-0.142	0.450	0.590	29.090	29.120	29.105	-0.015
117	34.696	34.800	0.104	0.300	0.310	34.860	34.750	34.805	0.005
118	33.583	33.610	0.027	0.310	0.410	33.620	33.610	33.615	0.005
119	34.496	34.730	0.234	0.680	0.990	34.780	34.710	34.745	0.015
120	35.209	35.320	0.111	0.390	0.720	35.310	35.320	35.315	-0.005
121	33.716	33.820	0.104	0.380	0.690	33.810	33.820	33.815	-0.005
122	33.235	33.390	0.155	0.190	0.590	33.380	33.420	33.400	0.010
123	32.499	32.640	0.141	0.380	0.890	32.640	32.580	32.610	-0.030
124	9.947	9.990	0.043	0.260	0.730	9.980	9.990	9.985	-0.005
125	8.896	8.930	0.034	0.430	0.610	8.940	8.970	8.955	0.025
126	7.505	7.600	0.095	0.640	0.880	7.580	7.600	7.590	-0.010
127	7.581	7.640	0.059	0.560	0.560	7.630	7.630	7.630	-0.010
128	27.931	28.020	0.089	0.160	0.470	28.020	27.990	28.005	-0.015
129	25.978	26.000	0.022	0.400	0.850	25.990	26.020	26.005	0.005

Surveyor Checkpoints – Delta Elevations & Distance to Closest LIDAR Point									
PID	Z	TINz	Z_Delta	Dist1	Dist2	Z1	Z2	Avg_Z1-Z2	Avg-TINZ
130	29.693	29.750	0.057	0.330	0.880	29.750	29.770	29.760	0.010
131	4.927	4.840	-0.087	0.520	0.550	4.820	4.840	4.830	-0.010
132	5.018	4.940	-0.078	0.340	0.600	4.920	4.950	4.935	-0.005
133	4.817	4.930	0.113	0.640	0.650	4.930	4.930	4.930	0.000
134	7.319	7.320	0.001	0.250	0.580	7.320	7.310	7.315	-0.005
135	11.682	11.740	0.058	0.220	0.230	11.740	11.740	11.740	0.000
136	7.345	7.340	-0.005	0.060	0.550	7.330	7.420	7.375	0.035
137	39.588	39.580	-0.008	0.160	0.750	39.580	39.590	39.585	0.005
138	41.610	41.520	-0.090	0.320	0.620	41.490	41.540	41.515	-0.005
139	39.240	39.310	0.070	0.270	0.980	39.310	39.290	39.300	-0.010
140	39.164	39.150	-0.014	0.230	0.780	39.150	39.230	39.190	0.040
141	41.766	41.740	-0.026	0.700	0.750	41.740	41.730	41.735	-0.005
142	44.382	44.440	0.058	0.520	0.630	44.410	44.440	44.425	-0.015
143	47.058	47.120	0.062	0.470	0.630	47.090	47.130	47.110	-0.010
144	51.894	51.900	0.006	0.770	1.020	51.930	51.910	51.920	0.020
145	52.641	52.630	-0.011	0.320	0.770	52.640	52.640	52.640	0.010
146	51.956	52.010	0.054	0.610	0.970	52.030	51.980	52.005	-0.005
147	46.710	46.710	0.000	0.810	0.910	46.740	46.700	46.720	0.010
148	47.887	47.910	0.023	0.450	0.670	47.920	47.880	47.900	-0.010
149	48.669	48.650	-0.019	0.660	0.880	48.620	48.670	48.645	-0.005
150	46.971	47.050	0.079	0.520	0.550	47.090	46.990	47.040	-0.010
151	57.320	57.389	0.069	0.694	1.035	57.360	57.440	57.400	0.011
152	57.920	58.006	0.086	0.584	0.665	57.980	58.060	58.020	0.014
153	56.445	56.712	0.267	0.969	1.067	56.750	56.620	56.685	-0.027
154	36.286	36.311	0.025	0.270	0.702	36.290	36.310	36.300	-0.011
155	36.295	36.242	-0.053	0.420	0.784	36.260	36.210	36.235	-0.007
156	37.958	38.019	0.061	0.590	0.783	37.970	38.080	38.025	0.006
157	48.694	48.710	0.016	0.284	0.391	48.710	48.710	48.710	0.000
158	48.560	48.519	-0.041	0.523	0.663	48.550	48.480	48.515	-0.004
159	49.919	50.098	0.179	1.073	1.250	49.960	50.270	50.115	0.017
160	47.498	47.622	0.124	0.478	0.680	47.620	47.570	47.595	-0.026
161	57.600	57.714	0.114	0.353	0.980	57.740	57.780	57.760	0.046
162	57.985	58.032	0.047	0.468	0.699	58.040	58.060	58.050	0.018
163	56.806	56.977	0.171	0.301	0.720	57.020	56.910	56.965	-0.012
164	59.543	59.466	-0.077	0.516	0.700	59.440	59.500	59.470	0.004
165	59.011	59.067	0.056	0.302	0.565	59.070	59.060	59.065	-0.002
166	58.831	59.015	0.184	0.598	0.690	59.000	59.030	59.015	0.000
167	58.557	58.648	0.091	0.211	0.936	58.660	58.690	58.675	0.027
168	37.369	37.409	0.040	0.259	1.144	37.390	37.490	37.440	0.031
169	37.303	37.382	0.079	0.261	0.711	37.370	37.420	37.395	0.013
170	36.430	36.530	0.100	0.329	0.853	36.510	36.560	36.535	0.005
171	65.545	65.549	0.004	0.796	0.865	65.560	65.540	65.550	0.001
172	63.563	63.612	0.049	0.271	0.896	63.610	63.620	63.615	0.003
173	63.636	63.643	0.007	0.711	1.064	63.610	63.710	63.660	0.017
174	58.041	58.014	-0.027	0.740	0.897	58.010	58.020	58.015	0.001
175	56.707	56.791	0.084	0.584	0.740	56.800	56.790	56.795	0.004

Surveyor Checkpoints – Delta Elevations & Distance to Closest LIDAR Point									
PID	Z	TINz	Z_Delta	Dist1	Dist2	Z1	Z2	Avg_Z1-Z2	Avg-TINZ
176	57.746	57.852	0.106	0.519	0.947	57.860	57.850	57.855	0.003
177	7.006	7.435	0.429	0.636	0.931	7.420	7.430	7.425	-0.010
178	3.339	3.730	0.391	0.486	0.962	3.710	3.770	3.740	0.010
179	7.156	7.518	0.362	0.803	1.220	7.540	7.370	7.455	-0.063
180	7.176	7.389	0.213	1.070	1.579	7.350	7.450	7.400	0.011
181	24.320	24.334	0.014	0.390	0.484	24.330	24.340	24.335	0.001
182	23.795	23.859	0.064	0.506	0.824	23.890	23.820	23.855	-0.003
183	23.942	24.018	0.076	0.965	1.096	24.020	24.040	24.030	0.013
184	31.747	31.849	0.102	0.735	0.902	31.840	31.820	31.830	-0.019
185	32.339	32.446	0.107	0.145	0.828	32.440	32.450	32.445	-0.001
186	31.576	31.658	0.082	1.136	1.176	31.570	31.620	31.595	-0.063
187	7.614	7.811	0.197	0.492	0.738	7.820	7.800	7.810	-0.001
188	8.790	8.900	0.110	0.075	0.962	8.900	8.930	8.915	0.015
189	8.819	8.937	0.118	0.531	0.759	8.900	9.000	8.950	0.013
190	7.738	7.860	0.122	0.748	1.700	7.880	7.730	7.805	-0.055
191	44.865	44.872	0.007	0.843	1.058	44.850	44.870	44.860	-0.012
192	39.938	39.961	0.023	0.418	0.643	39.950	40.000	39.975	0.014
193	40.045	39.952	-0.093	0.318	0.974	39.950	39.900	39.925	-0.027
194	5.260	5.154	-0.106	0.292	1.004	5.150	5.140	5.145	-0.009
195	4.733	4.740	0.007	0.346	0.487	4.740	4.740	4.740	0.000
196	5.130	5.109	-0.021	0.387	0.600	5.070	5.170	5.120	0.011
197	5.789	5.963	0.174	0.284	0.767	5.950	5.970	5.960	-0.003
198	38.502	38.551	0.049	0.115	0.803	38.550	38.600	38.575	0.024
199	38.084	38.063	-0.021	0.279	0.903	38.080	38.060	38.070	0.007
200	38.772	38.914	0.142	0.915	1.122	38.770	38.800	38.785	-0.129

Table 2 - St Mary's and Charles county statistics illustrating the horizontally closest LIDAR points to the actual ground truth surveys. Additional comparisons are made by comparing the survey elevations with that of the average of the closet points.

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. The following graphs and tables outline the vertical accuracy and the statistics of the associated errors.

Table 3 summarizes the RMSE using:

- 100% of the checkpoints (method used by FEMA when errors are assumed to follow a normal distribution)
- 95% of the checkpoints ("95% clean" methodology used in Phase I of the North Carolina Floodplain Mapping Program -- NCFMP -- where errors are still assumed to follow a normal distribution but where 5% of the errors are assumed to fall in "uncleaned" areas)
- Checkpoints categorized by land cover type based on 100% of points

RMSE by Land Cover				
%	**RMSE (m)**	**# of Points**	**Land Class**	**RMSE Criteria (cm)**
100	**0.125**	100	**All**	18.5 (FEMA methodology)
95	**0.098**	**95**	**All**	**18.5 (NCFMP Phase 1 methodology)**
20	**0.097**	20	**Grass/Ground**	
20	**0.158**	20	**High Grass/Crops**	
20	**0.142**	20	**Brush/Low Trees**	
20	**0.142**	20	**Forest**	
20	**0.059**	20	**Urban/Pavement**	

Table 3 – RMSE of LIDAR based on QA/QC survey checkpoints.

Table 3 clearly shows that 100 percent of the combined checkpoints fall within the desired and targeted RMSE of 18.5 cm, thereby satisfying FEMA requirements for the equivalency of 2 foot contours. It can also be seen that all land cover categories by themselves are within the targeted RMSE value which indicates strong data. Utilizing the North Carolina approach, 5% of the largest errors are removed in order to account for uncleaned areas and gross blunders. Statistically, the data in Table 4 not only improves overall, but also improves in the vegetated categories

RMSE by Land Cover Base on the Best 95% of the Checkpoints				
%	**RMSE (cm)**	**# of Points**	**Land Class**	**RMSE Criteria (cm)**
100	**0.125**	100	**All**	18.5 (FEMA methodology)
95	**0.098**	**95**	**All**	**18.5 (NCFMP Phase 1 methodology)**
19	**0.081**	19	**Grass/Ground**	Based on best 95% of the checkpoints
18	**0.095**	18	**High Grass/Crops**	Based on best 95% of the checkpoints
20	**0.135**	20	**Brush/Low Trees**	Based on best 95% of the checkpoints
17	**0.104**	17	**Forest**	Based on best 95% of the checkpoints
20	**0.059**	20	**Urban/Pavement**	Based on best 95% of the checkpoints

Table 4 - RMSE of LIDAR based on the best 95% of QA/QC survey checkpoints.

Figure 3 and Figure 4 graphically illustrate the RMSE by land cover category and the delta difference between the LIDAR compared to that of the survey QA/QC checkpoints.

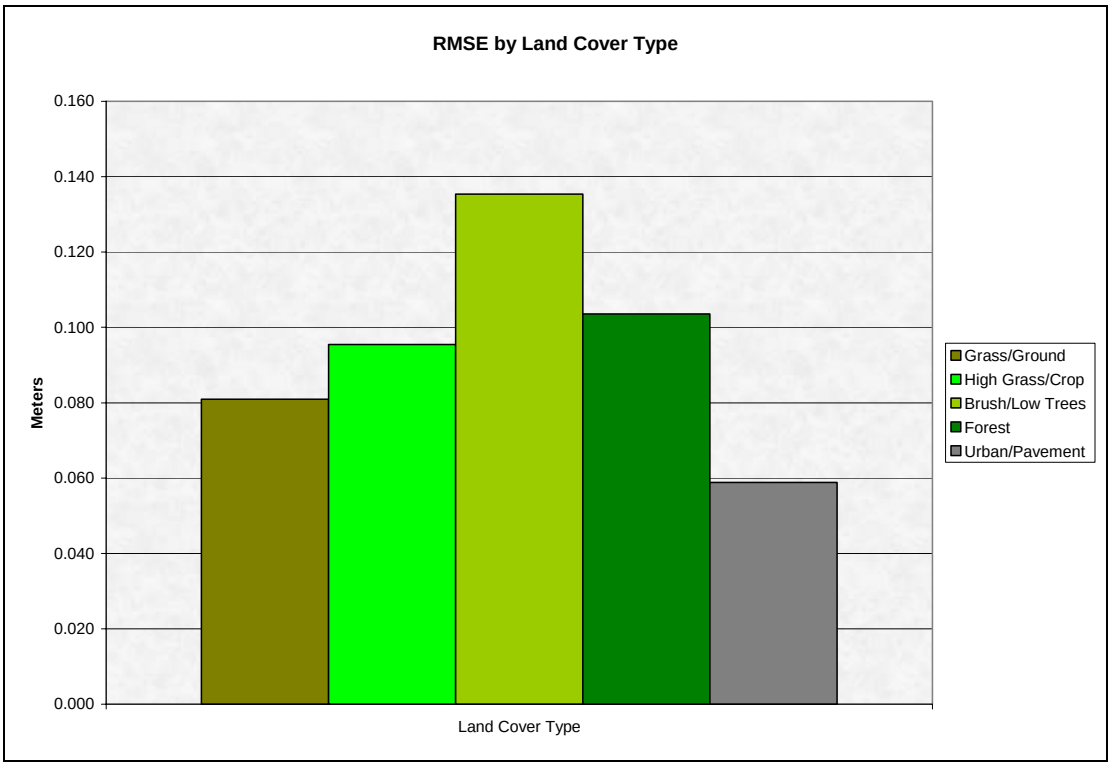

Figure 3 – RMSE by specific land cover types.

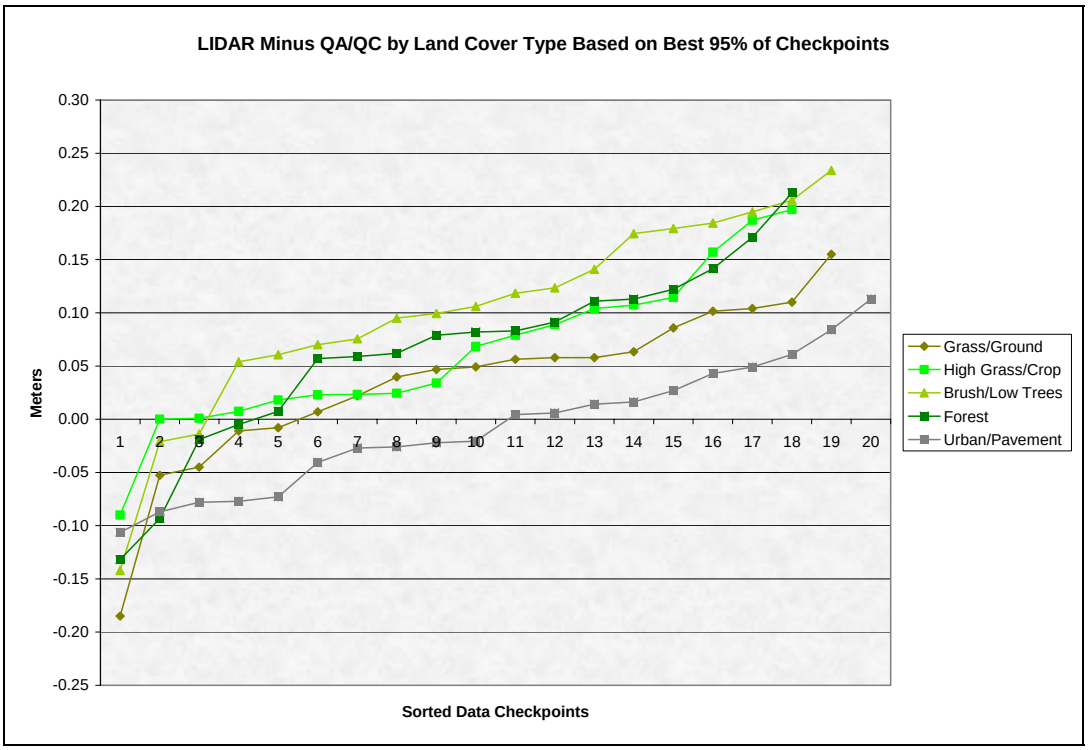

Figure 4 – Illustrates the magnitude of differences between the checkpoints and LIDAR data by specific land cover type and sorted from lowest to highest.

Table 5 summarizes the descriptive statistics referenced in the FEMA guidelines and the NCFMP reporting methodology.

Overall Descriptive Statistics								
	RMSE (m)	**Mean (m)**	**Median (m)**	**Skew**	**Std Dev (m)**	**# of Points**	**Min (m)**	**Max (m)**
100% Pts	**0.125**	0.067	0.060	0.692	0.106	100	-0.185	0.429
95% Pts	**0.098**	0.050	0.057	-0.230	0.085	94	-0.185	0.234
Grass/Ground	**0.081**	0.034	0.049	-1.299	0.075	19	-0.185	0.155
High Grass/Crops	**0.095**	0.064	0.051	0.128	0.073	18	-0.090	0.197
Brush/Low Trees	**0.135**	0.090	0.103	-0.962	0.103	20	-0.142	0.234
Forest	**0.104**	0.075	0.082	-0.427	0.074	17	-0.093	0.213
Urban/Pavement	**0.059**	-0.007	-0.008	0.169	0.060	20	-0.106	0.113
	Shaded cells based on the best 95% of checkpoints							

Table 5– Overall descriptive statistics.

Figure 5 and Figure 6 illustrates the histogram of the associated delta errors between the interpolated LIDAR TIN and the survey checkpoint. It is interesting to note that the errors do not follow a normal distribution. Even when the 5% largest errors are removed, the errors still do not follow a normal distribution. With this scenario where some errors do not follow a normal distribution, invalidates the RMSE methodology, the NDEP recommends that alternative criteria be used to determine the Fundamental Vertical Accuracy (mandatory) and Supplemental and Consolidated Vertical Accuracies (optional).

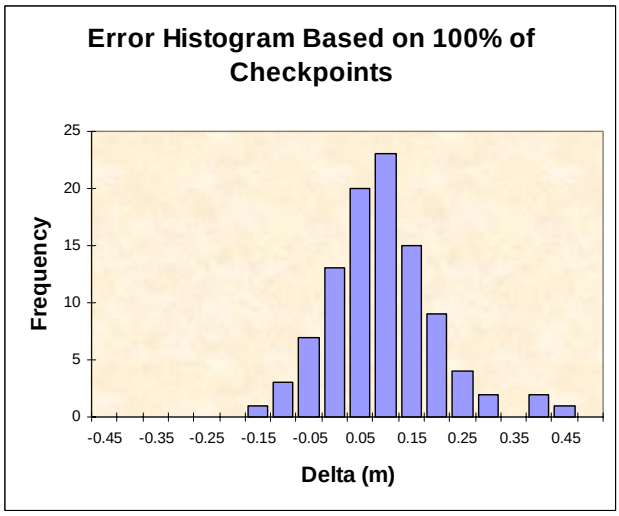

Figure 5 -- Error Histogram of all checkpoints (100%).

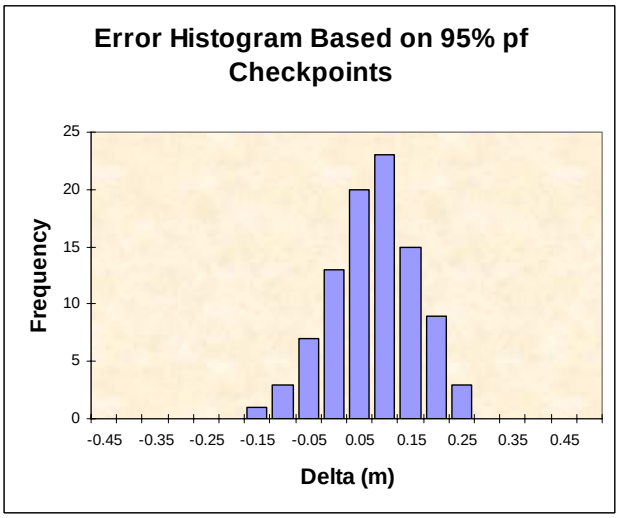

Figure 6 -- Error Histogram of the best 95% of data checkpoints.

Figure 5 and Figure 6 illustrate that the errors do not follow a normal distribution even when the top 5% of outliers are removed. It also illustrates that the LIDAR data compared to survey checkpoints tends to have a slight shift, which could be in the range of 0 – 10cm. This shift could be systematic or it could be purely random since the data does not follow a normal distribution.

Vertical Accuracy Assessment using NDEP Methodology

The Fundamental Vertical Accuracy 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 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 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 18.5 cm when errors follow a normal distribution. With this criteria, the Fundamental Vertical Accuracy of 36.3 cm must be met. Furthermore, it is desired that the Consolidated Vertical Accuracy and each of the Supplemental Vertical Accuracies also meet the 36.3 cm criteria to ensure that elevations are also accurate in vegetated areas. As summarized in Table 6, this data:

- Satisfies the NDEP's mandatory Fundamental Vertical Accuracy criteria for 2 ft contours.
- Satisfies the NDEP's optional Consolidated Vertical Accuracy criteria for 2 ft contours.
- Satisfies the NDEP's optional Supplemental Vertical Accuracy for 2 ft contours in all but one category (High Grass/Crop) for vegetated areas.

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) 0.363 (m) standard**
Total Combined	**100**		**0.235**	
Grass/Ground	20	0.190		
High Grass/Crop	20			0.393
Brush/Low Trees	20			0.234
Forest	20			0.272
Urban/Pavement	20			0.107

Table 6 - Vertical Accuracy per NDEP Methodology

As outlined above, the data exceeds all criteria except for the optional supplemental vertical accuracy for the land cover High Grass/Crop. This value slightly exceeds the criterion but this is partly due to two outliers, 0.39, and 0.43 m. All other 18 checkpoints are less than 0.20 m.

Survey Conclusion

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 criteria except in High Grass/Crop that slightly exceeds desired value. Since the data is typically tested on the whole dataset with all land cover categories, the higher values of the High Grass/Crop are averaged with the lower values from the other land cover categories. No remote sensing technology other than LIDAR, can achieve this accuracy especially in vegetated areas. Easily stated 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.

Phase II 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. However there are issues that need to be addressed to maintain the full integrity of the data. Through this analysis, it became apparent that no major sensor malfunctions were detected but quality control on submitted data was an issue as well as the post processing of the LIDAR data. This is partly addressed in the section “Verification Process” and will be outlined in this current section. It is Dewberry's intent to identify "issues" with the data so that further data collection and post processing can be improved for the governing parties responsible for LIDAR data collection. This analysis will also address the quality of the data for additional verification purposes.

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. However there are two main issues with this data that should be addressed; the first being “divots” and the second being “scan line issues”. Since these two types of issue are scattered throughout the data set, one example of each type of issue is examined. Additionally the Appendix will illustrate on a tile be tile basis both questionable issues and where we feel the LIDAR is particularly good in spite of difficult scenarios. Many of the same issues will be repeated throughout this section and should be used as verification of the review process. The many examples can also illustrate that although there may be one error (divot) the remainder of the tile can have excellent data.

Divot Issues

The divot issue can be broken down into two categories based on elevation; 1-2 meters and 5 meters or greater in depth. The divots, big or small, tend to be in urban areas and with our experience we have not encountered this before. It must be noted that there could be plausible explanations for some of the occurrences. For definition purposes we shall define divots as small scooped areas of terrain which do not look as if they belong based on the surrounding area.

Small divots are readily apparent in many tiles with a large suburban environment. Figure 7 and Figure 8 illustrates an example of small divots with their associated cross sections. These values range from 0.5 meters to 2 meters. Upon working with Spatial Systems and Sanborn, an

explanation was sought to find the cause of these divots. Sanborn was able to prove that some of the smaller divots were elevations on an external stairways leading to basements. However, Dewberry is not convinced that this is the cause for all instances as there are too many. Our experience has shown us that not all houses have external stairways leading to the basement of houses. However we will reserve judgment as we are not able to ground truth this issue. Figure 9 illustrates a small to large divot. Although the surrounding terrain elevations are 61 -62 meters, points near skylights on the roof have elevations between 53 – 57 meters and were not removed during bare-earth processing. Again there could be a suitable explanation, for example the house may have been under construction prior to the image and the LIDAR depicts the terrain at that point in time. Again Dewberry's stand is that this phenomenon happens too many times and even around houses that appear to have been there for years.

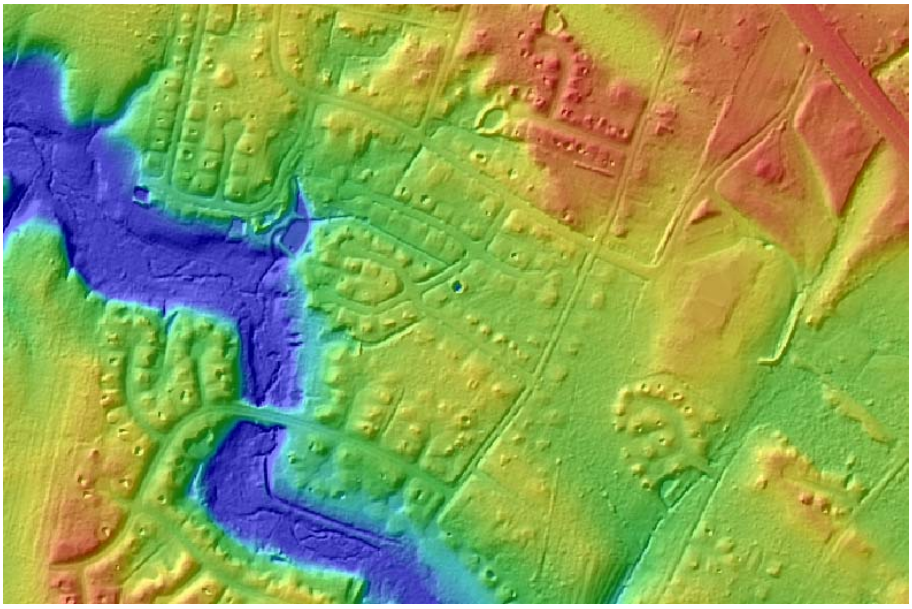

Figure 7 – Tile AD1132 illustrating both small and one large divot. Notice the blue divot in the center of the image that exhibits the elevation equal to that of the stream area.

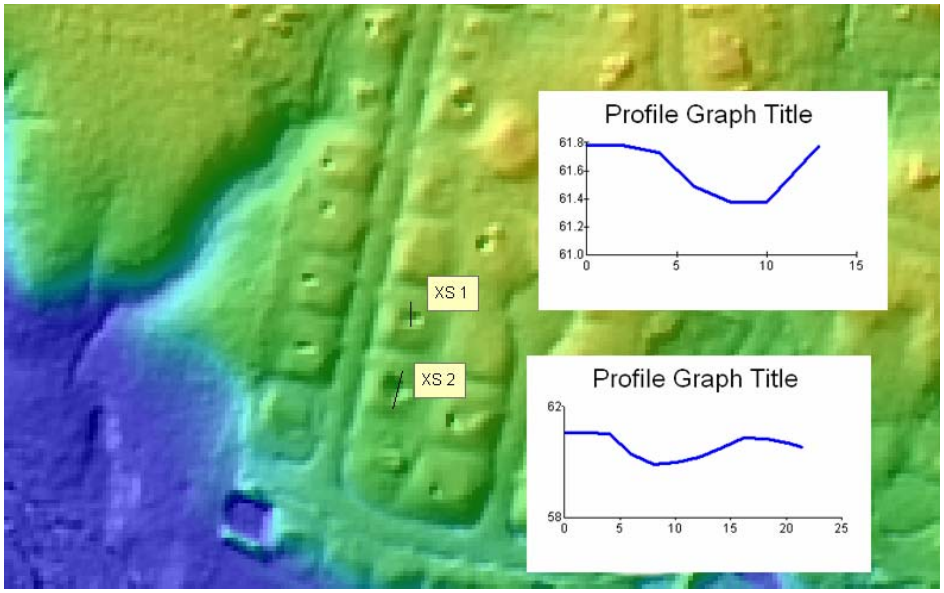

Figure 8 – Example of small divots (Tile AD1132) with their associated cross sections.

Figure 9 – Example of small to large divot at location of house.

Large divots are similar in nature to the smaller divots but do not have plausible explanations at this time. In many cases these larger divots are unnaturally deep and sometimes deeper than the surrounding water levels. This issue may be worth exploring further. Similarly to the smaller divots there may only be one or two points out of 1 million that are incorrect within the tile. Statistically this is not an issue, however those that want to portray the data may get a different picture as can be seen in Figure 10. Part of the process we use at Dewberry is to color code the images from blue to red and by reviewing the associated histogram. If the color does not appear to go from one extreme (blue) to another (red) then we can usually identify that certain elevations are skewing the results (see Figure 11). Figure 12 illustrates a large divot that exceeds

the surrounding elevations with it's associated cross section. To reiterate there are many instances of this issue through the counties.

Many examples will be found within the two counties depicting both small and large divots. For each of these issues they do not statistically influence the accuracy of the data. For example, if the smaller divots are external basement stairwells, then the elevations are legitimate such as the areas under or near a bridge. For floodplain modeling they actually depict where water could drain so this is not an issue. However, the large divots have not been explained. Dewberry's opinion is that the large divots are easily fixed by using the same methodology of looking for minimum and maximum points. This will not find all the tiles but it will find a great majority of them. Dewberry sees this issue as a minor one and could easily be remedied if needed.

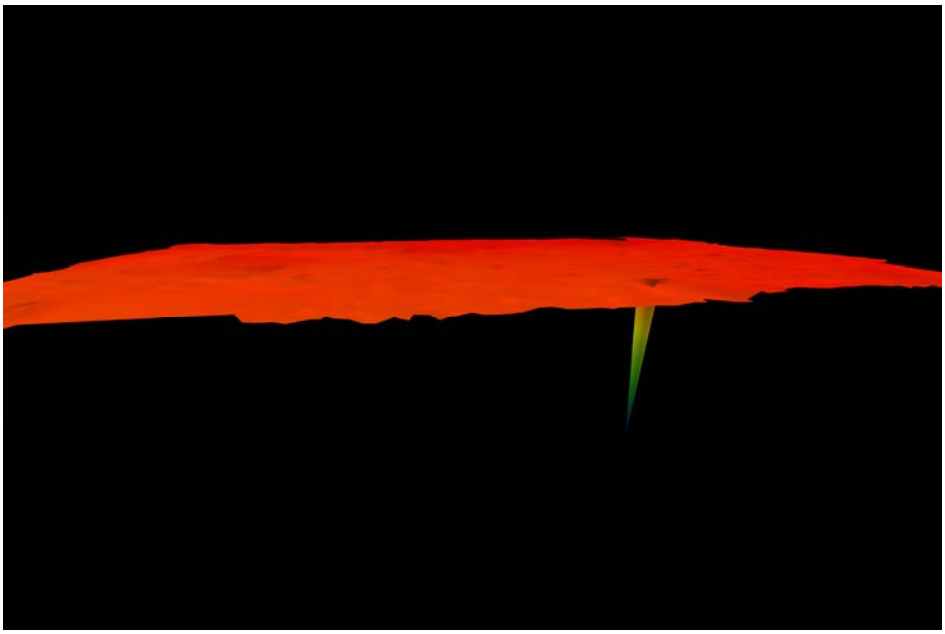

Figure 10 – 3D view of large divot. This LIDAR point is 35 meters deeper than the surrounding points.

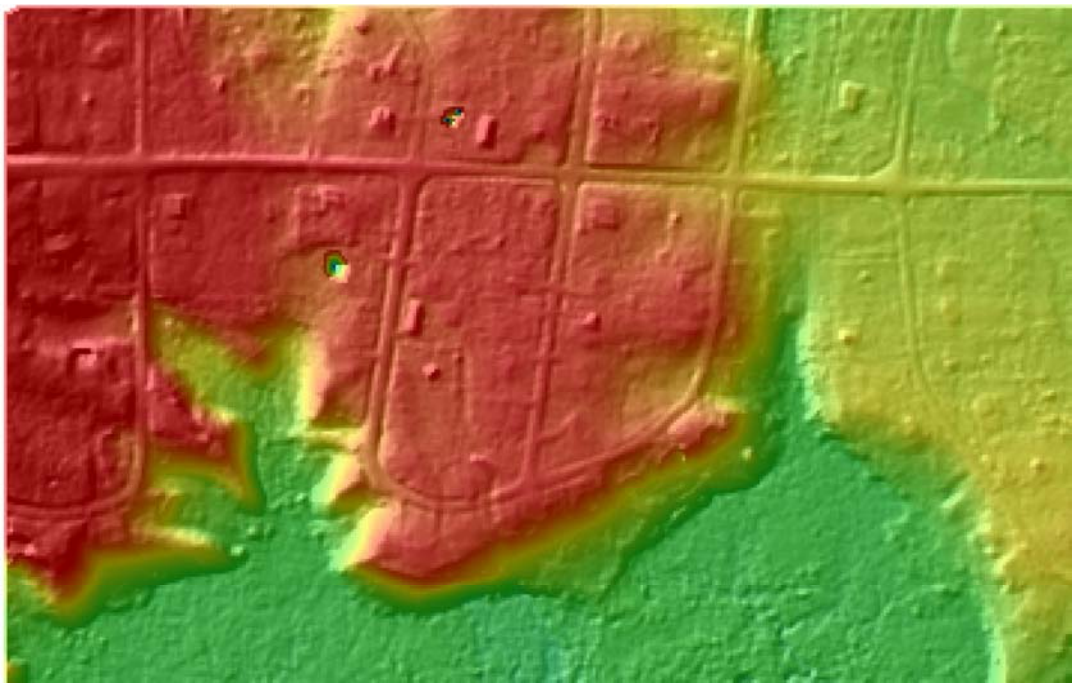

Figure 11 – Color coded image, blue to red. The water area at the bottom of the image should be blue but the larger divots depict elevations that are deeper than the water surface elevation.

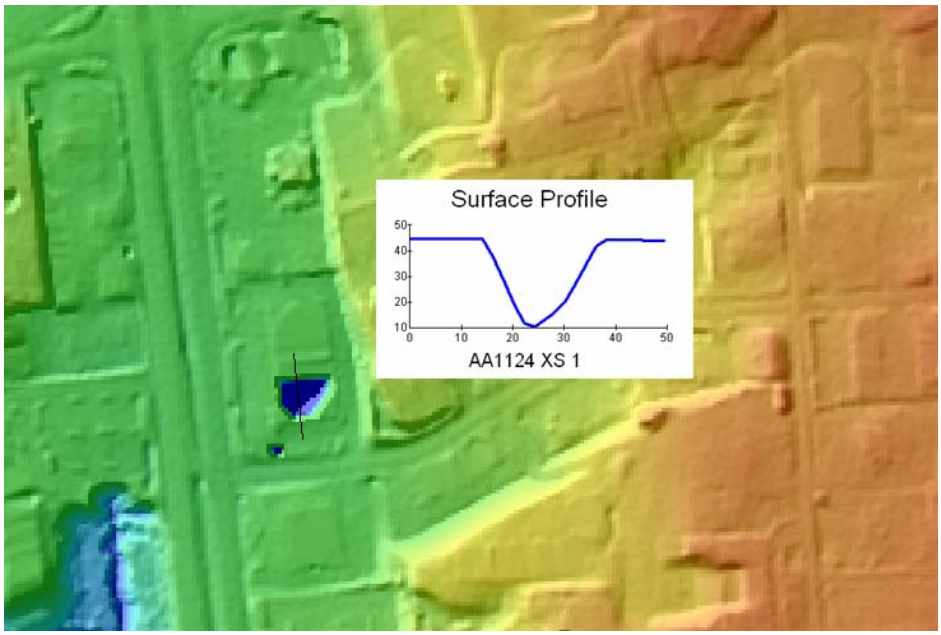

Figure 12 – Cross section view of large divot, illustrating a depression of 35 meters.

Scan Line Issues

The scan line issue is best described as an edge matching problem with elevations between flight lines. Ironically no checkpoints were located in these areas so the RMSE calculation was not compromised. However this clearly illustrates the value of measuring quantitative as well as assessing the qualitative aspect of the data. This data does meet the accuracy as required by the RMSE criteria but the integrity of the data in the scan line issue areas needs to be addressed.

When a flight line is flown, the next one generally is flown parallel to it with a percentage of overlap. This ensures that all areas are covered by the LIDAR scan especially since it is difficult to fly the aircraft is a perfectly straight line. The overlapping portion of the flight lines also allows the surface being measured to have the LIDAR light scan from a slightly different angle which can translate to better coverage in dense vegetation. The apparent issue within these two counties is that the adjacent flight line is either higher or lower (depending how you look at it) by as much as 30 centimeters. Figure 13 illustrates a LIDAR subset color coded by elevation. A gap exists running east to west in the center of the image. This is partly attributed to the vegetation removal process which removes adjacent points that appear to be artifacts because of the elevation change. In this case, the difference between the two flight lines is over 30 cm as can be seen by the profile in Figure 14. Figure 15 illustrates a 3D view of the same scan line with vertical exaggeration to highlight the issues.

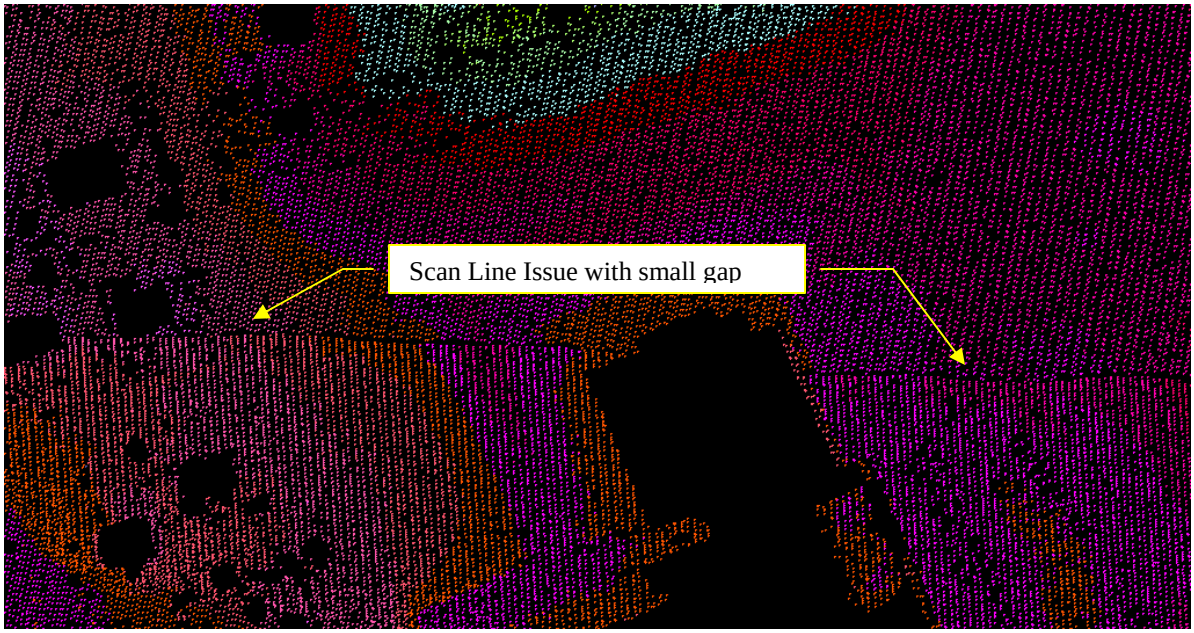

Figure 13 - AA1124: scan line issue. Note gap between the two flight lines in center of image.

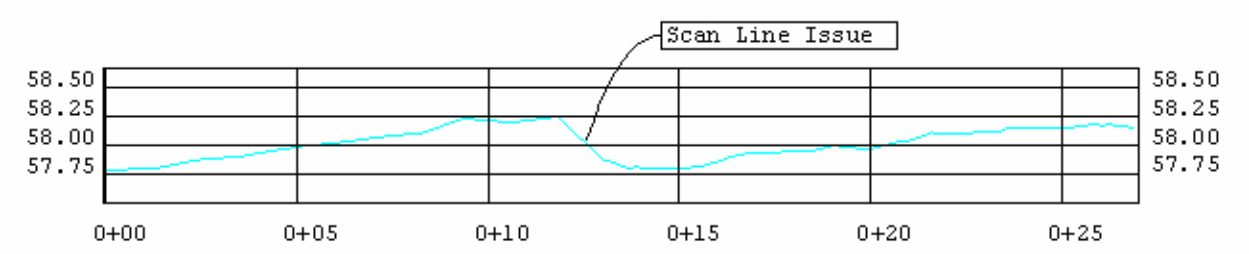

Figure 14 - AA1124 profile of scan line issue illustrating the mismatch between scan lines.

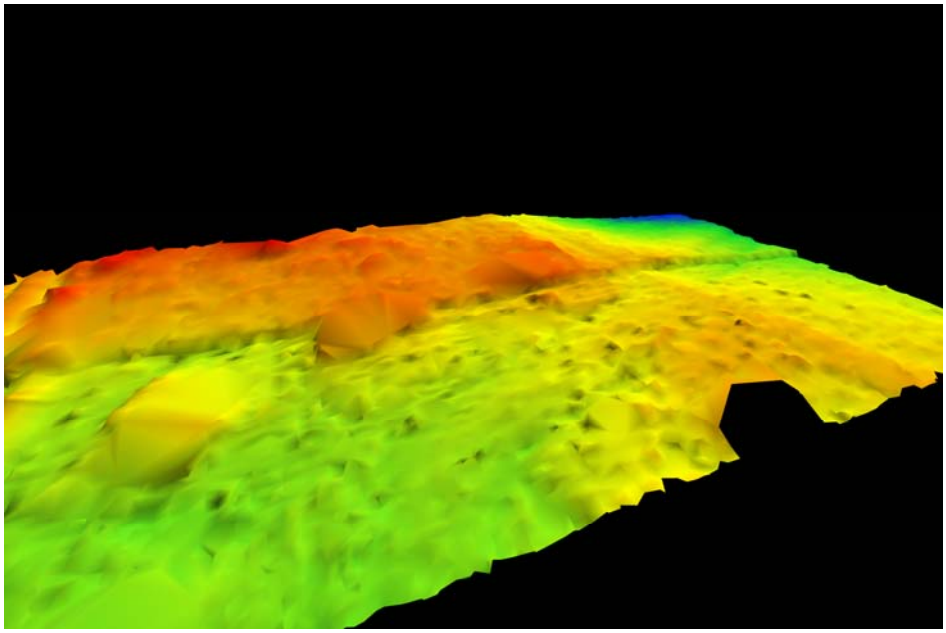

Figure 15 – 3D view with vertical exaggeration of scan line issue for tile AA1124.

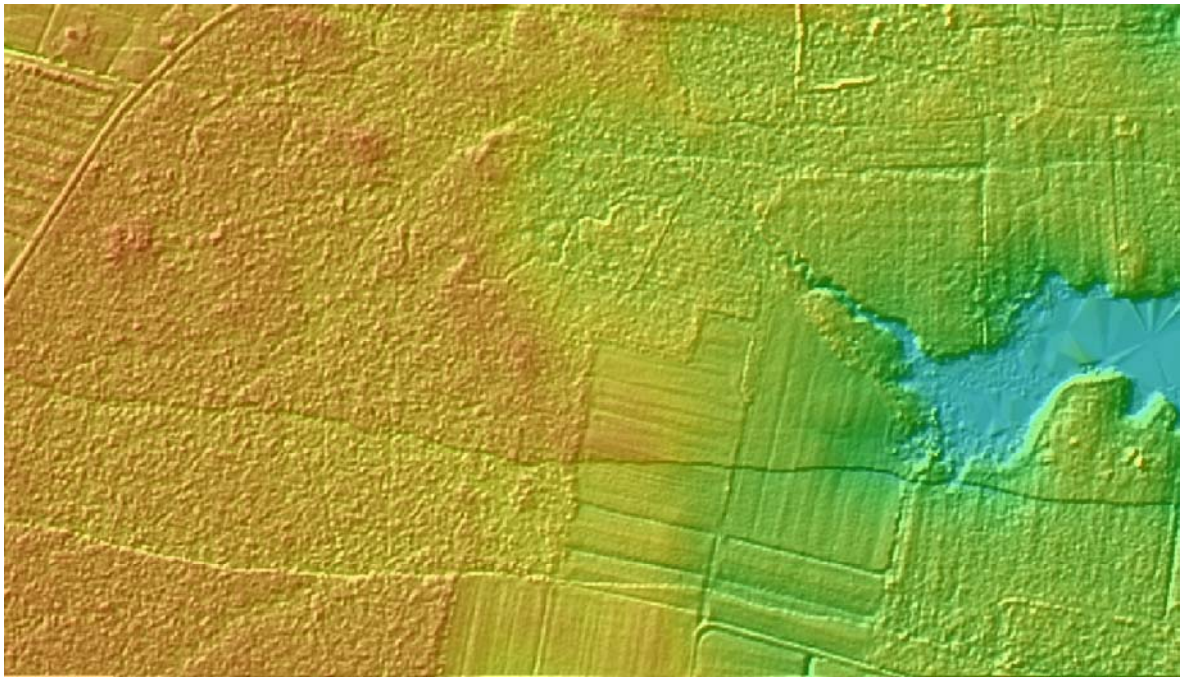

Figure 16 - Scan line issue in lower portion of image (right to left). Notice the data is lower within the strip.

Conclusion

Dewberry's analysis of the data concludes that it meets the equivalency of 2 foot contours and is of high quality for cleanliness except for the issues as listed above. We feel it is necessary to delete the erroneous low elevations and to address the scan line issues so that it matches the excellent quality of the remaining data. Of the hundreds of tiles that were analyzed, this data exhibits excellent quality for many applications and should serve most users for the best available data. Appendix A illustrates issues with the dataset based on a tile by tile basis.

As the independent QA/QC team member, the role of being independent and part of team may appear to be a juxtaposition of terms. However, Dewberry was truly independent without any collaboration other than clarification on some issues with the LIDAR provider (Sanborn). Overall, we evaluate this dataset to be excellent.