VERTICAL ACCURACY ASSESSMENT REPORT

FOR

STATE OF ILLINOIS
DEPARTMENT OF TRANSPORTATION

HENRY COUNTY
ILLINOIS

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AERO-METRIC PROJECT NO. 1-090718

PHOTOGRAMMETRY & GEOSPATIAL DATA SOLUTIONS

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State of Illinios
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Vertical Accuracy Assessment Report

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Background

The National Standard for Spatial Data Accuracy (NSSDA)[1] defines guidelines for testing and reporting the accuracy of digital geospatial data. The NSSDA makes the assumption that all errors follow a normal error distribution where Root-Mean-Square-Error (RMSE) procedures apply. The Federal Emergency Management Agency (FEMA)[2] guidelines implement the NSSDA standards and recommend the survey of a minimum of 20 checkpoints per ground cover category representative of the area being tested. A minimum of three categories (60 checkpoints) is required. The National Digital Elevation Program (NDEP)[3] and the American Society for Photogrammetry and Remote Sensing (ASPRS)[4] provide an alternative method for reporting the vertical accuracy whereby errors in vegetation categories are not assumed to follow a normal error distribution. The ASPRS guidelines are directly referenced to the assessment of LiDAR digital data. A minimum of 60 checkpoints is again recommended, with up to 100 points preferred. For the Henry County project, five major ground cover categories were defined by Aero-Metric as representative of the project area (hard surface, short grass, tall grass, brush, and woods). A total of 863 checkpoints were collected over the entire project area including building and profile points.

Aero-Metric's vertical accuracy assessment for the Henry County project was carried out in accordance with the two methods mentioned above. The first method (defined by NSSDA and FEMA) assumes all errors follow a normal error distribution and the newer second method (defined by NDEP and ASPRS) assumes that errors in some land cover categories may not follow a normal error distribution. Comparing the two methods helps determine the amount of systematic errors that may exist in the five ground cover categories: hard surface, short grass, tall grass, brush, and woods. The following table summarizes the criteria used to evaluate the vertical data. Criteria highlighted in yellow refer to the NSSDA and FEMA guidelines and those highlighted in orange refer to the NDEP and ASPRS guidelines.

Table 1 -- DTM Acceptance Criteria

Criteria	*Acceptable Value*
$RMSE_z$= NSSDA vertical accuracy statistic at 68% confidence level (1.0 x $RMSE_z$)	0.60 ft for all ground cover categories combined
$Accuracy_z$= NSSDA vertical accuracy statistic at the 95% confidence level (1.96 x $RMSE_z$)	1.19 ft ($RMSE_z$ x 1.9600) for all ground cover categories combined
Fundamental Vertical Accuracy (FVA) in open terrain only = 95% confidence level	1.19 ft ($RMSE_z$ x 1.9600) for open terrain only
Supplemental Vertical Accuracy (SVA) in individual ground cover categories = 95% confidence level	1.19 ft (based on 95th percentile per category; this is a target value only, not mandatory)
Consolidated Vertical Accuracy (CVA) in all ground cover categories combined = 95% confidence level	1.19 ft (based on combined 95th percentile)

Aero-Metric tested the digital vertical data using the following steps:

1. ILDOT ground survey personnel collected and processed GPS data for each of the ground cover checkpoints. These points were distributed throughout ground cover category areas within the project limits.
2. The checkpoints were compared to the digital vertical data using the TerraSolid, LTD program TerraScan. The program creates a TIN surface from the digital vertical data and computes vertical differences between the surface and the surveyed checkpoints. An output file records the vertical differences and associated statistics.
3. The results were analyzed by Aero-Metric to assess the quality of the data. Various accuracy parameters as defined by the NDEP and ASPRS guidelines were used in the review process. Also, the overall descriptive statistics of each dataset were computed to assess any tendencies or inconsistencies. The following tables, graphs, and figures illustrate the data quality.

Using the NDEP and ASPRS Guidelines for Vertical Accuracy Testing

The required Fundamental Vertical Accuracy (FVA) and the optional Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA) are specified by the NDEP and ASPRS guidelines. FVA determines how well the digital data was collected in open terrain type ground cover where all errors are presumed to be random. The SVA determines how well the digital data represents the actual ground in each of the ground cover categories, tested separately. The CVA determines the overall accuracy of all the ground categories combined as one test.

FVA for this project is calculated using only the checkpoints in the *Hard Surface* ground cover category. The digital data in this category is most likely to represent the actual ground surface and the random errors will follow a normal error distribution. The FVA shows how well the Photogrammetric process used to produce the digital vertical data represents the actual ground. 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 Appendix 3-A of the NSSDA guidelines. As shown in Table 1, the FVA for this project (2 ft contours) is 1.19 ft.

CVA is calculated with all the checkpoints in all the ground cover categories combined. There is a possibility that the digital vertical data may yield errors that do not follow a normal distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all ground cover categories combined. The CVA produces a listing of the 5% outliers that are larger than the 95th percentile and that may not follow the normal error distribution.

SVA is computed for each ground cover category separately. There again is a possibility that the digital vertical data may yield errors that do not follow a normal error distribution. Systematic errors per ground cover category are identified. For each category, the SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each individual ground cover category. The individual SVA statistics are used to analyze the data based on each of the ground cover categories.

Table 2 summarizes the vertical accuracy by Fundamental, Consolidated, and Supplemental methods:

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

Ground Cover Category	*# of Points*	*FVA Fundamental Vertical accuracy Spec = 1.19 ft*	*CVA Consolidated Vertical accuracy Spec = 1.19 ft*	*SVA Supplemental Vertical accuracy Spec = 1.19 ft*
Total Combined	863		0.91	
Hard Surface	41			0.65
Short Grass	166	0.56		0.62
Tall Grass	175			1.04
Brush	26			1.21
Woods	34			1.19

The digital vertical data for the Henry County project meets all mandatory and target specifications as per the following vertical accuracy tests:

Compared with the 1.19 ft FVA specification, FVA tested 0.46 ft at the 95% confidence level on the hard surfaces ground cover category, based on $RMSE_z$ x 1.9600. The NSSDA specifies that vertical accuracy at the 95% confidence level equals $RMSE_z$ x 1.9600; the NDEP and ASPRS stat that this method is valid only when random errors follow a normal error distribution, as in the hard surface category.

Compared with the 1.19 ft CVA specification, CVA tested 0.91 ft at the 95% confidence level on the hard surfaces, short grass, tall grass, brush, and woods ground cover categories combined, based on the 95^{th} Percentile. NDEP and ASPRS guidelines specify that vertical accuracy at the 95% confidence level equals the 95^{th} percentile when random errors may not follow a normal error distribution, as in vegetated or obstructed areas. Table 3 lists the 5% outliers larger than the 95^{th} percentile (0.91ft).

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

Ground Cover Category	***Elev. Diff (ft)***
Hard Surface	1.58
Tall Grass	1.05
Tall Grass	1.05
Tall Grass	1.21
Tall Grass	1.08
Tall Grass	1.28
Tall Grass	1.23
Tall Grass	0.99
Tall Grass	0.93
Tall Grass	0.99
Tall Grass	1.01
Tall Grass	0.94
Tall Grass	1.02
Tall Grass	1.57
Tall Grass	0.98
Tall Grass	1.20
Tall Grass	1.01
Tall Grass	1.02
Tall Grass	1.17
Tall Grass	1.48
Brush	1.06
Brush	1.02
Brush	1.70
Brush	1.26
Brush	1.01
Woods	0.96
Woods	1.04
Woods	1.12
Woods	1.31
Woods	1.42
Profile	1.25
Profile	0.92
Profile	0.91
Profile	1.36

Twenty-two of the errors were larger than the CVA standard (1.19ft) which permits up to 5% of the checkpoints, 43 out of 863, to be larger than 1.19 ft.

Profile	1.83	
Profile	1.08	
Profile	2.22	
Profile	1.62	
Profile	1.92	
Profile	1.29	
Profile	1.77	
Profile	1.28	
Profile	2.15	
Profile	1.11	

Compared with the 1.19 ft SVA target values, SVA tested 0.65 ft at the 95% confidence level on hard surfaces; 0.62 ft in short grass; 1.04 ft in tall grass; 1.21 ft in brush; and 1.19 ft in woods ground cover categories, based on the 95th Percentile. Only the Brush and Woods categories exceed the target value (1.19 ft). This is probably due to the leafy conditions. It is harder for the LiDAR pulses to reach the ground and also harder for the surveyor using GPS to measure the ground in leafy conditions.

Figure 1 illustrates the SVA by specific ground cover category. Figure 2 illustrates the magnitude of the differences between the checkpoints and the digital vertical data by specific ground cover category and sorted from lowest to highest. Twenty-two of the checkpoints are beyond the 1.19 ft criteria shown in figure 2. This exceeds the 95% requirement, where up to 5% of the checkpoints could be outside the 1.19 ft criteria.

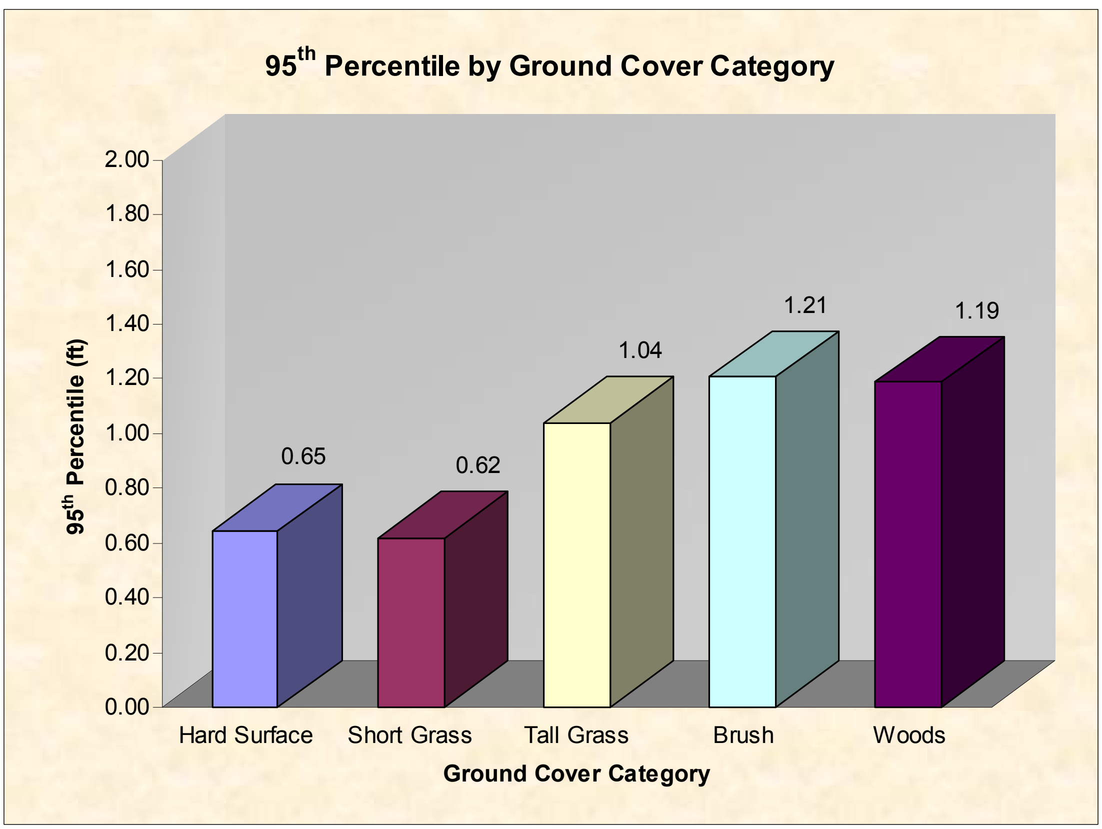

Figure 1 -- Graph of SVA Values by Ground Cover Category

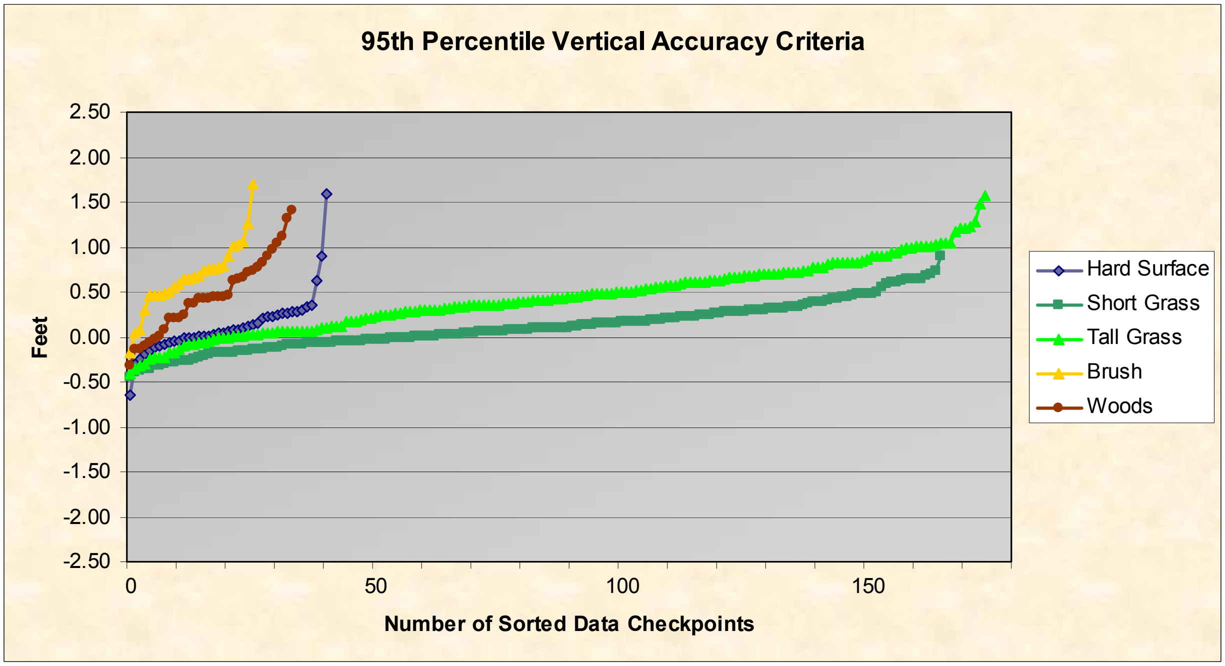

Figure 2 – Magnitude of Elevation Discrepancies, Sorted from Largest Negative to Largest Positive

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

The NSSDA and FEMA guidelines were both published before it was recognized that digital data errors do not always follow a normal error distribution. Future changes to these guidelines are expected to follow those of the NDEP and ASPRS. In order to comply with FEMA's current requirements, $RMSE_z$ and other statistics were computed in all five ground cover categories, individually and combined. These statistics are shown in Figures 3 and 4 and Table 4 below.

Figure 3 shows the RMSEz values as calculated for each ground cover category separately.

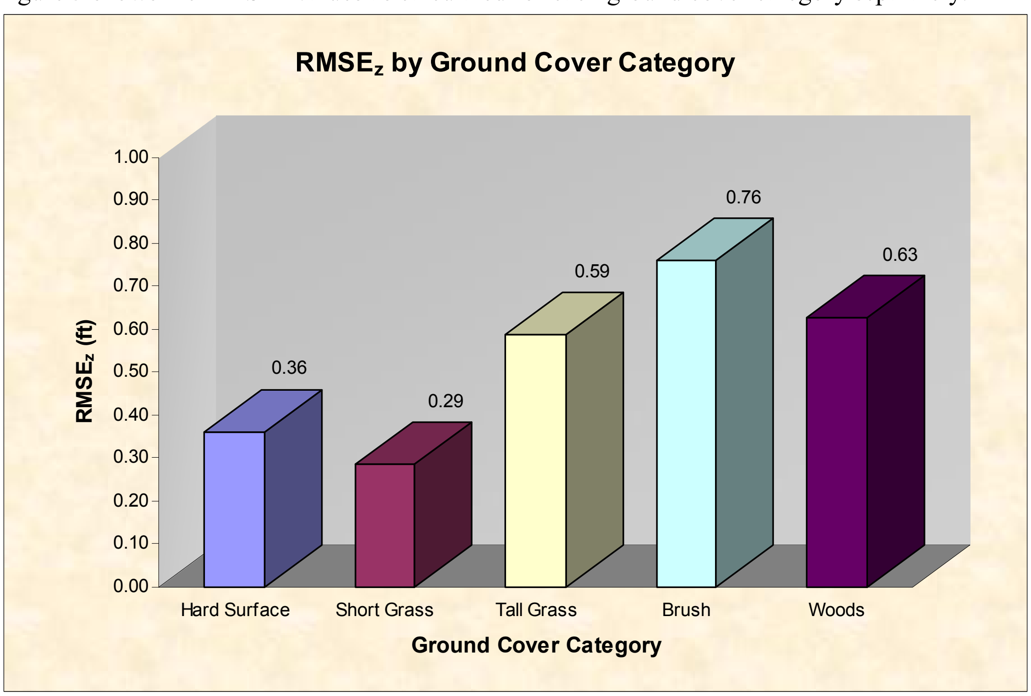

Figure 3 – $RMSE_z$ statistics by Ground Cover Category

Table 4 – Overall Descriptive Statistics by Ground Cover Category

Land Cover Category	***RMSEz (ft)***	***Mean (ft)***	***Median (ft)***	***Skew***	***Std Dev (ft)***	***# of Points***	***Min (ft)***	***Max (ft)***
Consolidated	0.46	0.27	0.22	1.06	0.38	863	-0.65	2.22
Hard Surface	0.36	0.12	0.06	2.02	0.34	41	-0.65	1.59
Short Grass	0.29	0.12	0.09	0.38	0.26	166	-0.44	0.89
Tall Grass	0.59	0.44	0.43	0.20	0.38	175	-0.40	1.57
Brush	0.76	0.66	0.66	0.33	0.39	26	-0.17	1.70
Woods	0.63	0.46	0.44	0.31	0.43	34	-0.31	1.42

Figure 4 shows a histogram of the elevation differences between the field surveyed checkpoints and the TIN surface computed from the digital vertical data. The histogram shows the number of occurrences (frequency) along the vertical axis that fell within the 0.20 ft ranges shown along the horizontal axis.

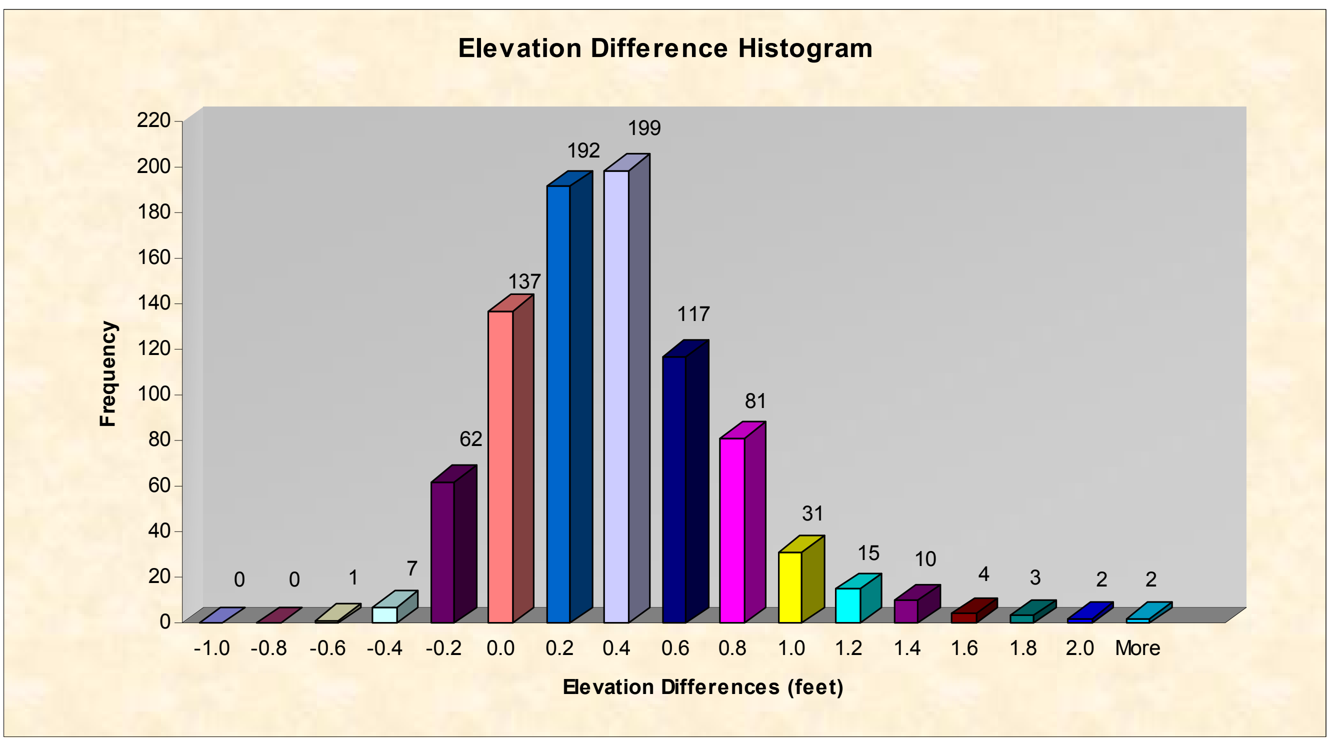

Figure 4 – Histogram of Elevation Discrepancies within 0.2 ft bands

Summary and Conclusions

The vertical accuracy testing methods derived from the NSSDA/FEMA and NDEP/ASPRS guidelines, when applied to the Henry County project, verify that the digital vertical data provided by AERO-METRIC is well suited for the production of 2 ft contours.

Per NSSDA/FEMA guidelines: $RMSE_z$ x 1.9600 = 95% confidence level
0.46 x 1.9600 = 0.90 ft

Per NDEP/ASPRS guidelines: 95^{th} percentile (CVA) = 95% confidence level
= 0.91 ft

Both of the 95% confidence level test results exceed the required 1.19 ft accuracy level to support the generation of 2 ft contours.

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

[2] 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

[3] *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 2004

[4] *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 2004