Dewberry Engineers Inc.
1000 North Ashley Drive, Suite 801
Tampa, FL 33602

813.225.1325
813.225.1385 fax
www.dewberry.com

IA_Eastern_2_2019 - Final Accuracy Report

Report Produced for U.S. Geological Survey

USGS Contract: G16PC00020

Task Order: 140G0219F0101

Report Date: June 6, 2022

SUBMITTED BY:
Dewberry
1000 North Ashley Drive Suite 801
Tampa, FL 33602
813.225.1325

SUBMITTED TO:
U.S. Geological Survey
tnm_help@usgs.gov

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1. EXECUTIVE SUMMARY

The following report documents the comprehensive final project accuracy results for The IA Eastern lidar project. Preliminary accuracy testing was verified for each WUID to ensure project-wide accuracy would meet specification.

The IA Eastern lidar project survey report includes all information regarding the survey checkpoints, please refer to that report for details on the survey.

For accuracy testing, Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Below is a description of the types of checkpoints utilized and the acceptable criteria for the IA Eastern lidar project accuracy requirements.

NVA (Non-vegetated Vertical Accuracy) is determined with checkpoints located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, 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 NVA 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 (RMSEz) of the checkpoints x 1.9600. For the IA Eastern lidar project, vertical accuracy must be 19.6 cm or less based on an RMSEz of 10 cm x 1.9600.

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The IA Eastern lidar project VVA standard is 30 cm based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid. The relevant testing criteria are summarized in Table 1.

Table 1. Acceptance Criteria

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm (based on $RMSE_z$ (10 cm) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	30 cm (based on combined 95th percentile)

1.1 Project Area

The IA Eastern lidar project encompasses approximately 14,724 square miles within the state of Iowa, covering twenty-four different counties. The figure below shows the twenty-four counties for the IA Eastern project and the checkpoints that were collected.

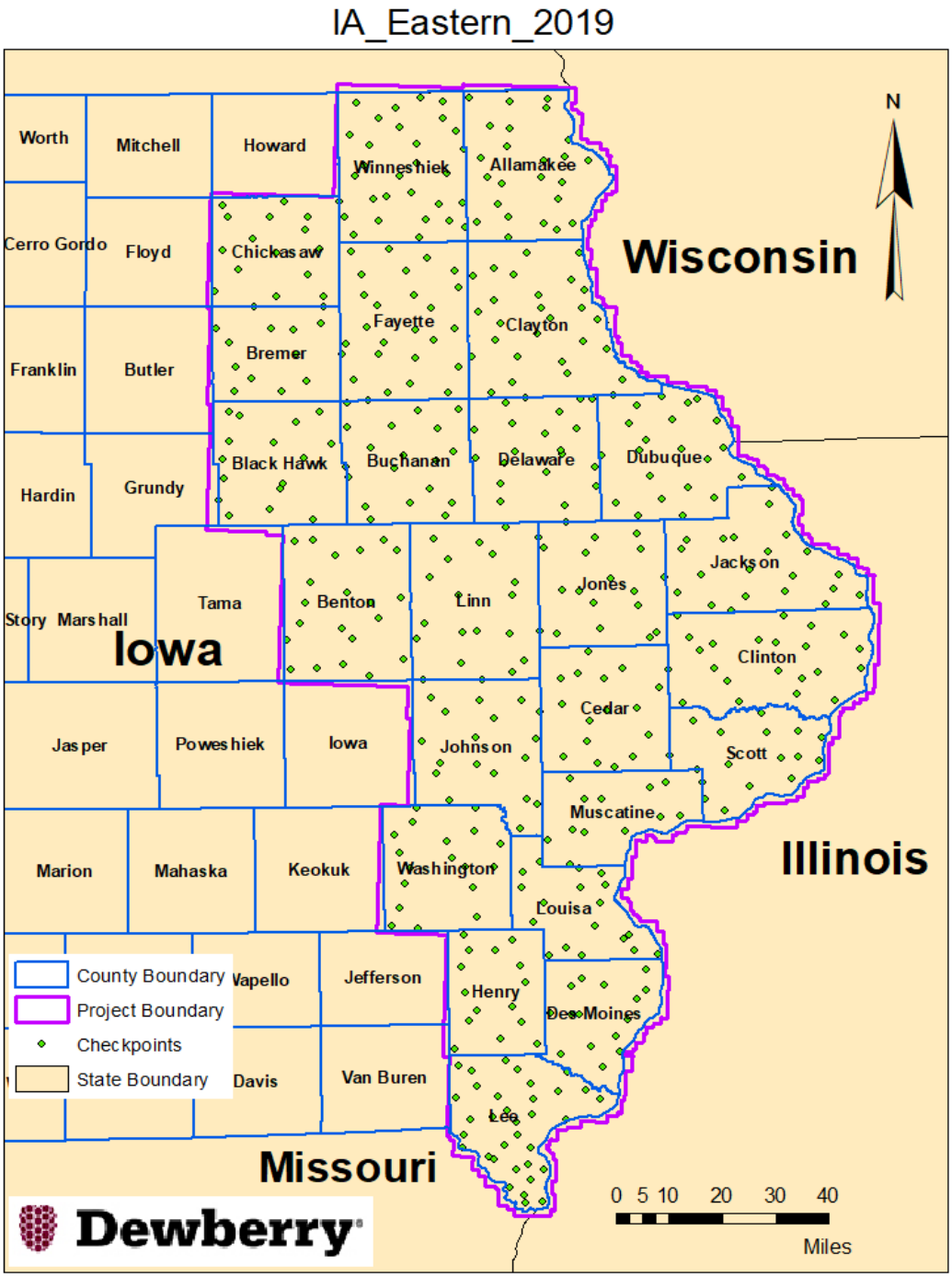

Figure 1. Project map with counties outlined and checkpoints in each county displayed.

1.2 Coordinate Reference System

Data produced for the project are delivered in the following spatial reference system:

Horizontal Datum:	North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011)
Vertical Datum:	North American Vertical Datum of 1988 (NAVD88)
Geoid Model:	Geoid18
Coordinate System:	UTM Zone: 15N
Horizontal Units:	Meters
Vertical Units:	Meters

2. LIDAR POSITIONAL ACCURACY

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to 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 and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy.

2.1 Final Swath Vertical Accuracy Assessment

Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the non-vegetated (open terrain and urban) independent survey checkpoints. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy. The table below summarizes the swath project accuracy specification, the amount of NVA points tested, and the final tested swath accuracy results.

Table 2. NVA at 95% Confidence Level for Raw Swaths

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.10 m	NVA –Non-vegetated Vertical Accuracy	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis

			($RMSE_z$ x 1.9600) Spec=0.196 m							
Non-Vegetated Terrain	275	0.041	0.079	0.001	0.001	0.214	0.041	-0.152	0.139	0.732

One checkpoint (NVA-262) was removed from the raw swath vertical accuracy testing due to its location underneath a power line. Only non-vegetated terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation, structures, and other above ground features from the ground classification. While NVA-262 is located in open terrain, the overhead power lines are modeled by the lidar point cloud. These high points caused erroneous high values during the swath vertical accuracy testing, so this point was removed from the final calculations. Once the data underwent the classification process, the power lines were removed from the final ground classification and this point could be used in the final vertical accuracy testing for the fully classified lidar data. Table 3, below, provides the coordinates for this checkpoint and the vertical accuracy results from the raw swath data. Table 4, below, provides the usable vertical accuracy results of this checkpoint from the fully classified lidar. The differences in the tables show how above ground features can cause erroneous vertical accuracy results in the raw swath data. Figure 2, below, shows a 3D model of the lidar point cloud and the location of the checkpoint beneath a power line.

Table 3. Checkpoint removed from raw swath vertical accuracy testing

Point ID	NAD83(2011) UTM Zone 15N		NAVD88 (Geoid 18)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
NVA-262	617804.892	4796570.155	385.242	389.399	4.157	4.157

Table 4. Final tested vertical accuracy for NVA-262 post ground classification

Point ID	NAD83(2011) UTM Zone 15N		NAVD88 (Geoid 18)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
NVA-262	617804.892	4796570.155	385.242	385.270	0.028	0.028

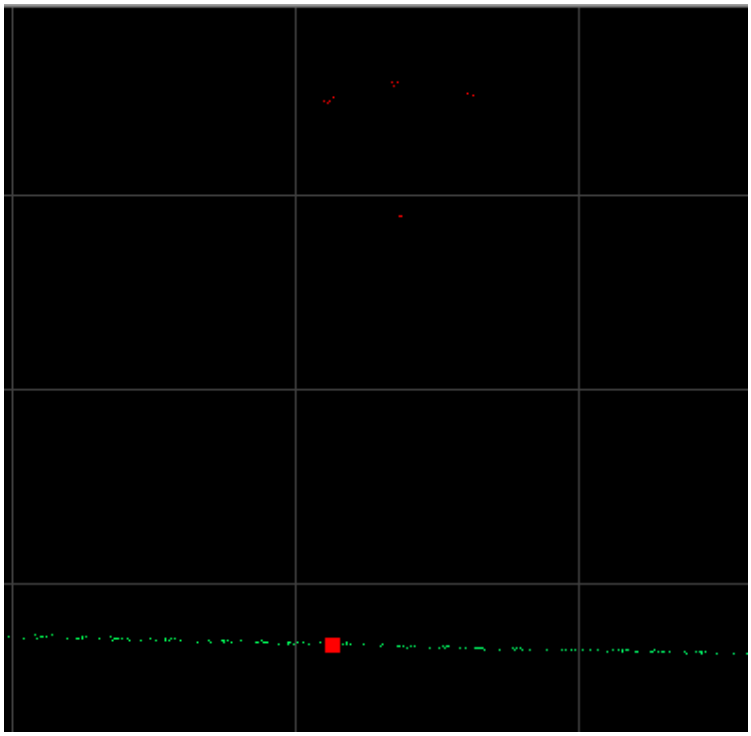

Figure 2. Open Terrain checkpoint 262, shown as the large red marker, is located underneath power line features. This point was removed from raw swath vertical accuracy testing because above ground features, including power lines, have not been separated from the ground classification yet.

2.2 Vertical Accuracy Results

The table below summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified lidar LAS files.

Table 5. Tested NVA and VVA

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=0.294 m
NVA	276	0.078	
VVA	200		0.153

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =4 cm, equating to +/- 7.8 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 15.3 cm at the 95th percentile.

Table 6 lists the 5% outliers that are larger than the VVA 95th percentile.

Table 6. 5% Outliers

Point ID	NAD83(2011) UTM Zone 15N		NAVD88 (Geoid 18)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
114	598300.697	4647736.329	247.693	247.900	0.207	0.207
115	616478.769	4650195.518	234.064	234.270	0.206	0.206
126	654997.279	4635825.362	252.694	252.870	0.176	0.176
129	618063.438	4635248.558	216.172	216.330	0.158	0.158
130	600249.903	4635163.716	235.197	235.350	0.153	0.153
134	621532.051	4623159.892	249.172	249.350	0.178	0.178
135	635475.377	4625455.801	255.647	255.810	0.163	0.163
136	650484.830	4622640.705	245.423	245.590	0.167	0.167
150	604123.475	4606285.619	208.067	208.220	0.153	0.153
185	658414.523	4524964.522	204.090	204.350	0.260	0.260
187	641778.534	4519302.318	214.196	214.350	0.154	0.154

Table 7 provides overall descriptive statistics.

Table 7. Overall Descriptive Statistics

100 % of Totals	# of Points	RMSEz (m) NVA	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)

		Spec=0.1 m							
NVA	276	0.040	-0.001	-0.003	0.237	0.040	0.752	-0.152	0.140
VVA	200	N/A	0.044	0.038	0.455	0.060	0.761	-0.146	0.260

2.3 Final Horizontal Accuracy Results

Dewberry tests the horizontal accuracy of lidar datasets when checkpoints are photo-identifiable in the intensity imagery. Photo-identifiable checkpoints in intensity imagery typically include checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90-degree corners of different reflectivity, e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints, as defined in the intensity imagery, are compared to surveyed XY coordinates for each photo-identifiable checkpoint. These differences are used to compute the tested horizontal accuracy of the lidar. As not all projects contain photo-identifiable checkpoints, the horizontal accuracy of the lidar cannot always be tested.

2.4 Horizontal Accuracy Test Procedures

Horizontal accuracy testing requires well-defined checkpoints that can be identified in the dataset. Elevation datasets, including lidar datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. However, the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) recommends at least half of the NVA vertical checkpoints should be located at the ends of paint stripes or other point features visible on the lidar intensity image, allowing them to double as horizontal checkpoints.

Dewberry reviews all NVA checkpoints to determine which, if any, of these checkpoints are located on photo-identifiable features in the intensity imagery. This subset of checkpoints are then used for horizontal accuracy testing.

The primary QA/QC horizontal accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.
2. Next, Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the lidar intensity imagery and the ground truth survey checkpoints.
4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

2.5 Horizontal Accuracy Results

Thirty-nine checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset.

Using NSSDA methodology (endorsed by the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)), horizontal accuracy at the 95% confidence level (called ACCURACYr) is computed by the formula RMSEr * 1.7308 or RMSExy * 2.448.

No horizontal accuracy requirements or thresholds were provided for this project. However, lidar datasets are generally calibrated by methods designed to ensure a horizontal accuracy of 1 meter or less at the 95% confidence level.

Table 8. Tested horizontal accuracy at the 95% confidence level

# of Points	$RMSE_x$ (Target=0.409 m)	$RMSE_y$ (Target=0.409 m)	$RMSE_r$ (Target=0.578 m)	$ACCURACY_r$ ($RMSE_r$ x 1.7308 Target=1 m)
39	0.201	0.183	0.272	0.471

This dataset was tested to meet ASPRS Actual Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1 meter at a 95% confidence level. Thirty-nine (39) checkpoints were used for horizontal accuracy testing. This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1 meter at a 95% confidence level. Actual positional accuracy of this dataset was found to be RMSEx = 20.1 cm and RMSEy = 18.3 cm which equates to +/- 47.1 cm at 95% confidence level.

3. DEM POSITIONAL ACCURACY

The same checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations.

Table 9 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Table 9. DEM tested NVA and VVA

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=0.294 m
NVA	276	0.087	
VVA	200		0.176

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =4.5 cm, equating to +/- 8.7 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 17.6 cm at the 95th percentile.

Table 10 lists the 5% outliers that are larger than the VVA 95th percentile.

Table 10. 5% Outliers

Point ID	NAD83(2011) UTM Zone 15N		NAVD88 (Geoid 18)	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
114	598300.697	4647736.329	247.693	247.893	0.200	0.200
115	616478.769	4650195.518	234.064	234.253	0.189	0.189
126	654997.279	4635825.362	252.694	252.884	0.190	0.190
129	618063.438	4635248.558	216.172	216.350	0.178	0.178
134	621532.051	4623159.892	249.172	249.354	0.182	0.182
183	645177.527	4531517.794	200.180	200.364	0.184	0.184
185	658414.523	4524964.522	204.038	204.363	0.325	0.325
187	641778.534	4519302.318	214.146	214.372	0.226	0.226
189	611033.491	4515688.764	212.183	212.359	0.176	0.176

191	632618.304	4510328.527	223.774	223.976	0.202	0.202
193	653693.078	4505382.959	161.246	161.439	0.193	0.193

Table 11 provides overall descriptive statistics.

Table 11. Overall Descriptive Statistics

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	276	0.045	0.003	0.000	0.292	0.044	0.860	-0.162	0.149
VVA	200	N/A	0.054	0.044	0.655	0.065	1.099	-0.135	0.325

4. FINAL ACCURACY SUMMARY

Based on the accuracy testing conducted by Dewberry, the lidar and DEM dataset for the IA Eastern lidar project satisfies the project's pre-defined accuracy criteria as described throughout this report.