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NY FEMA R2 CENTRAL 2018 D19- Final Accuracy Report

Report Produced for U.S. Geological Survey

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1. EXECUTIVE SUMMARY

The following report documents the comprehensive final project accuracy results for The NY FEMA R2 Central 2018 D19 lidar project. Preliminary accuracy testing was verified for each WUID to ensure project-wide accuracy would meet specification.

The NY FEMA R2 Central 2018 D19 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 NY FEMA R2 Central 2018 D19 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 NY FEMA R2 Central 2018 D19 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 NY FEMA R2 Central 2018 D19 lidar project VVA standard is 29.4 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	29.4 cm (based on combined 95th percentile)

1.1 Project Area

The NY FEMA R2 Central 2018 D19 lidar project encompasses approximately 15,742 square miles within the state of New York. The figure below shows the defined project area (DPA) in Albers Equal Area - NAD 83 (2011) coordinate system and the checkpoints that were collected.

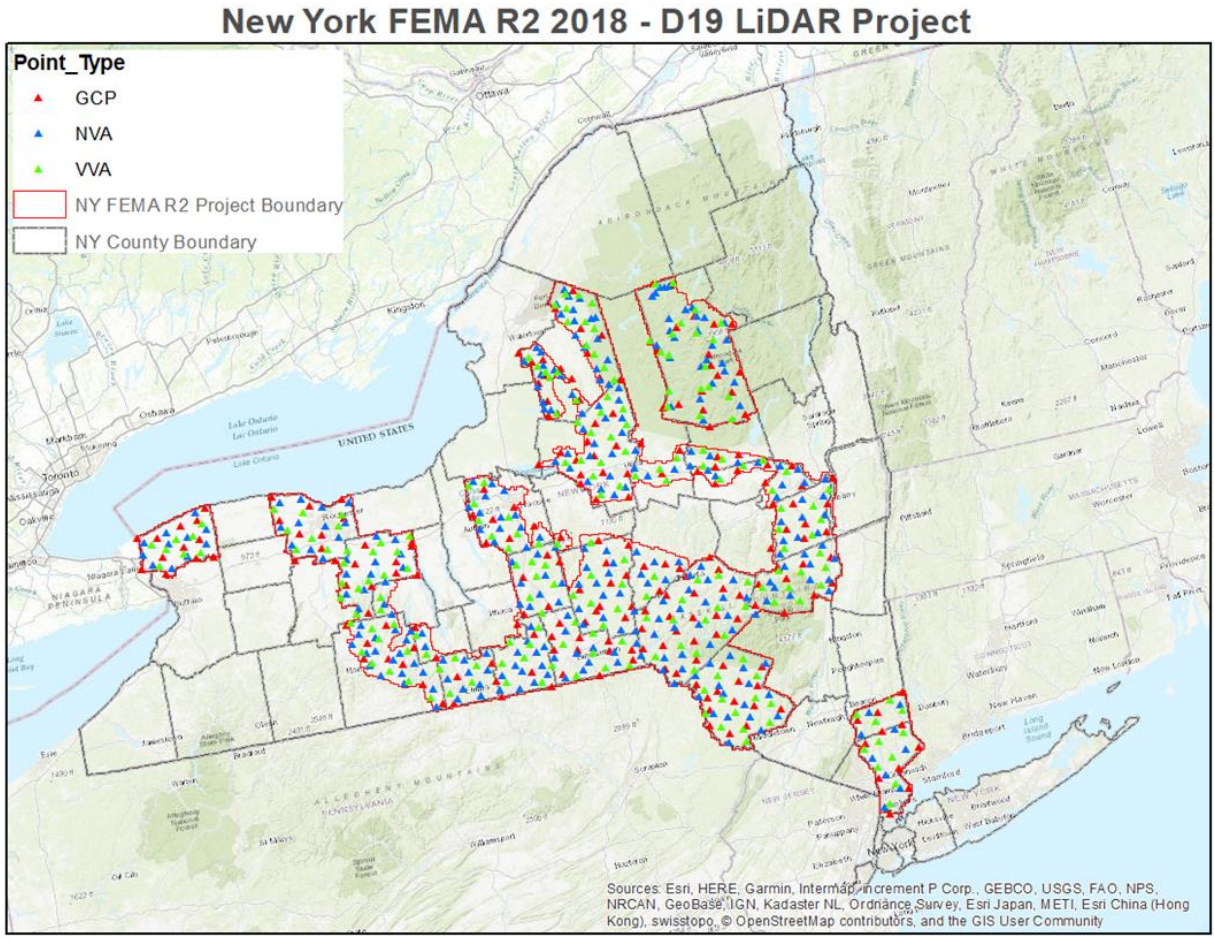

Figure 1. NY FEMA R2 - Project area map and checkpoints in Albers Equal Area CRS

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:	Geoid12B
Coordinate System:	Albers Equal Area
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 1. 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 ($RMSE_z$ x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Non-Vegetated Terrain	300	0.063	0.124	0.019	0.019	0.677	0.060	-0.158	0.351	3.464

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 2. Tested NVA and VVA

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	300	11.8	
VVA	209		16.1

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 $RMSE_z$ =6 cm, equating to +/- 11.8 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 16.1 cm at the 95th percentile.

Table 3 lists the 5% outliers that are larger than the VVA 95th percentile.

Table 3. 5% Outliers

Point ID	NAD83(2011) Albers Equal Area		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA-004	1396499.251	2375547.105	117.187	117.368	0.181	0.181
VVA-125	1765150.815	2353293.201	568.913	569.100	0.188	0.188
VVA-136	1760975.921	2403843.000	431.256	431.040	-0.216	0.216
VVA-139	1742723.694	2419127.238	196.544	196.790	0.246	0.246
VVA-157	1669184.564	2445558.172	402.717	402.950	0.233	0.233
VVA-173	1624678.378	2520026.157	234.455	234.720	0.265	0.265
VVA-175	1625267.537	2452567.853	404.935	405.150	0.215	0.215
VVA-190	1695481.849	2488352.054	566.691	566.982	0.291	0.291
VVA-191	1723977.203	2498391.735	544.792	545.436	0.644	0.644
VVA-192	1718792.923	2481743.188	532.287	532.588	0.301	0.301
VVA-193	1696124.236	2466589.951	532.786	532.540	-0.246	0.246

Table 4 provides overall descriptive statistics.

Table 4. 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	300	0.060	0.013	0.014	0.155	0.059	1.132	-0.165	0.262

VVA	209	N/A	0.037	0.030	1.255	0.094	7.967	-0.246	0.644

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

Forty 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 5. Tested horizontal accuracy at the 95% confidence level

# of Points	$RMSE_x$ (Target=41 cm)	$RMSE_y$ (Target=41 cm)	$RMSE_r$ (Target=58 cm)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=100 cm
40	28.1	26.3	38.5	66.6

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. Forty (40) 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 = 28.1 cm and RMSEy = 26.3 cm which equates to +/- 66.6 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 6 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Table 6. DEM tested NVA and VVA

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy	VVA — Vegetated Vertical Accuracy

		(RMSE$_z$ x 1.9600) Spec=19.6 cm	(95th Percentile) Spec=29.4 cm
NVA	300	11.5	
VVA	209		19.7

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$_z$ =5.9 cm, equating to +/- 11.5 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 19.7 cm at the 95th percentile.

Table 7 lists the 5% outliers that are larger than the VVA 95th percentile.

Table 7. 5% Outliers

Point ID	NAD83(2011) Albers Equal Area		NAVD88 (Geoid 12B)		Delta Z	Abs Delta Z
	Easting X (m)	Northing Y (m)	Survey Z (m)	DEM Z (m)		
VVA-045	1545858.356	2273856.095	463.186	463.386	0.200	0.200
VVA-063	1613934.906	2370115.256	468.765	468.962	0.197	0.197
VVA-136	1760975.921	2403843.000	431.256	430.994	-0.262	0.262
VVA-139	1742723.694	2419127.238	196.544	196.749	0.205	0.205
VVA-157	1669184.564	2445558.172	402.717	402.943	0.226	0.226
VVA-166	1644330.944	2494932.823	338.550	338.747	0.197	0.197
VVA-173	1624678.378	2520026.157	234.455	234.799	0.344	0.344
VVA-175	1625267.537	2452567.853	404.935	405.189	0.254	0.254
VVA-190	1695481.849	2488352.054	566.691	566.979	0.288	0.288
VVA-191	1723977.203	2498391.735	544.792	545.426	0.634	0.634

VVA-192	1718792.923	2481743.188	532.287	532.549	0.262	0.262
VVA-193	1696124.236	2466589.951	532.786	532.508	-0.278	0.278

Table 8 provides overall descriptive statistics.

Table 8. 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	300	0.59	0.11	0.01	0.135	0.058	0.821	-0.169	0.236
VVA	209	N/A	0.041	0.036	0.959	0.097	6.768	-0.278	0.634

4. FINAL ACCURACY SUMMARY

Based on the accuracy testing conducted by Dewberry, the lidar and DEM dataset for the NY FEMA R2 Central 2018 D19 lidar project satisfies the project's pre-defined accuracy criteria as described throughout this report.