2010 Lidar

Accuracy Assessment and Quality Control Report For the Milwaukee, WI Project Area

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2. INTRODUCTION

Lidar-based elevation data may be used for hydraulic modeling and floodplain mapping if it meets specific quality assurance and quality control criteria (FEMA 2003). GroundPoint Technologies LLC (Groundpoint) performed an independent accuracy assessment and quality control review of the bare-earth randomly spaced Lidar data collected in Milwaukee, Wisconsin. The methodology was designed to meet FEMA guidelines and specifications for flood mapping (FEMA, 2003). This document presents the results of the accuracy assessment and quality review.

Lidar data for Milwaukee, WI was collected by Pictometry International Corp (Pictometry) in 5 missions from April 16-18, 2010. The data was collected at a nominal post spacing of 70 centimeters over an area covering approximately 245 square miles (see Figure 1).

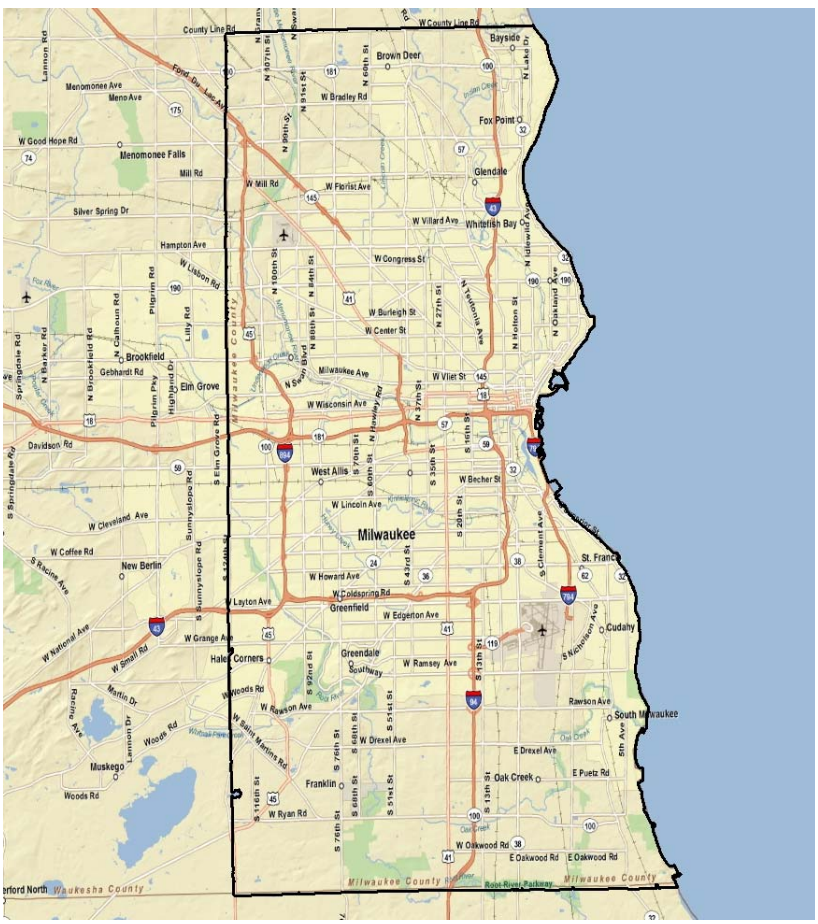

Figure 1 shows the boundary of the 2010 lidar Milwaukee, WI collection area.

Pictometry processed the raw point cloud data to ensure proper alignment of the data between flight lines. The data was then classified for “Ground” by using a series of automated filters in

Terra Solid software to remove above ground vegetation and buildings. Points in water and on bridges were manually removed from the Ground class. The data was then tiled and saved in the industry standard LAS 1.2 format. The data was delivered on an external hard drive to Groundpoint in classified LAS fomat in the summer of 2010.

A Lidar checkpoint ground survey was also contracted by Pictometry for the accuracy assessment of the data. The survey consisted of 100 checkpoints in five different land cover types. The elevation values of the checkpoints are compared to the lidar data elevation values. The elevation differences are used to calculate the root-mean-square error (RMSE) of the data. FEMA provides guidelines and specifications for assessing the accuracy of lidar data that will be used for flood hazard mapping for the 2-foot (flat terrain in the floodplain) and 4ft (hilly terrain) contour intervals (FEMA, 2003). The data meets FEMA specifications for two foot contour mapping if the RMSE is no greater than 18.5 centimeters (7.2834 inches) and the error residuals have a normal distribution. The Milwaukee, WI data was captured with a specification for meeting accuracy standards at a 1-foot contour interval. Therefore the updated FEMA guidelines of September 2010 will be used for the vertical accuracy assessment reference of this lidar data. The updated guidelines will not be used for the rest of the project since the guidelines were published after the rest of the QAQC work was completed. The updated guidelines refer to the National Digital Elevation Program guidelines from 2004 for determining the accuracy of lidar data. The NDEP guidelines state that lidar data collected for 1 ft contour mapping will meet fundamental accuracy specifications for open ground if the RMSE is no greater than 9.25 centimeters (3.642 inches) and the error residuals have a normal distributions. The guidelines also state that supplemental accuracy for other land cover types will be calculated at the 95th percentile. RMSE should not be used for land cover types other than open ground since these land cover types often do not display a normal error distribution. Because these guidelines came out when this project was nearing completion, both RMSE and 95th percentile will be calculated for the supplemental accuracy. The accuracy assessment methodology and results are reported in section 3 Accuracy Assessment. ***The fundamental accuracy assessment for the Milwaukee, WI lidar collection meets the RMSE specifications for 1 foot contour mapping in open ground.***

In addition to performing an accuracy assessment, Groundpoint visually inspected the Ground lidar points to assess the completeness and consistency of the dataset, which may not be captured during the accuracy assessment. The visual inspection of the data is reported in section 4 Quality Control Review. ***A few minor problems were discovered during the Quality Control Review. These problems were communicated to Pictometry and corrected.***

3. Accuracy Assessment

Groundpoint utilized a methodology for assessing the accuracy of the randomly spaced Lidar data that is compliant with FEMA and specifications and supplemented with NDEP specifications for the 1 ft contour interval.

3.1 Lidar Checkpoint Ground Survey Data

A Lidar checkpoint ground survey was provided by Pictometry.
The surveyor collected a total of 100 points in the following cover types:

1. Bare-earth (e.g., plowed fields, lawns, golf courses), 21 Checkpoints
2. High Grass, Weeds, and Crops (e.g., overgrown fields and hay) 22 Checkpoints
3. Brush lands and low trees (e.g., scrubby low trees and bushes), 16 Checkpoints
4. Forested (e.g., hay fields, corn fields, wheat fields), 21 Checkpoints
5. Urban areas (e.g., high, dense manmade structures), 20 Checkpoints

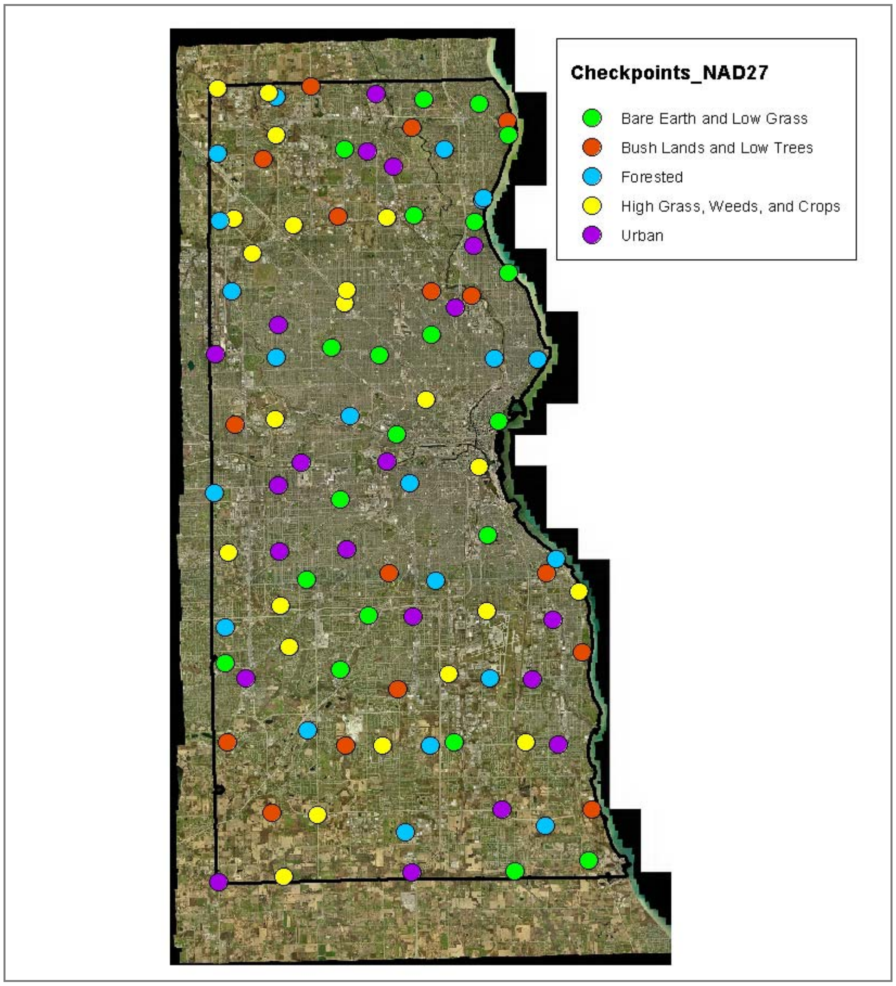

Figure 2 shows the distribution of surveyed checkpoints by landcover class.

FEMA recommends 20 survey points per class. The brush lands and low trees class only has 16 checkpoints but all other classes have 20 or more checkpoints. Statistics were still caluculated for the brush class, but it should be noted that the sample size does not meet FEMA guidelines. Digital photos and field sketches are also required for each checkpoint and the surrounding area to verify land cover and other conditions. All of the points include field sketches and photos taken in 4 directions from the surveyed checkpoint.

The Lidar Checkpoint Survey Data for the collection area is available in Appendix A. The Northing and Easting (Y and X) points are in NAD27, State Plane Coordinate zone Wisconson South, feet, and the elevation (Z) is in NAVD 88, Geoid 2003, feet. The coordinate system of the survey points corresponds to the coordinate system of the lidar data.

3.2 Lidar Data

The Lidar data was delivered by Pictometry via an external hard drive. There are 319 Lidar tiles, all in LAS format. The LAS files contain all points classified as either "Unclassified", "Ground", "Overlap", and "Low Point". The data was delivered in NAD27, State Plane Wisconsin South horizontal coordinate reference system and NAVD88 vertical datum adjusted to GEOID '03 (all units in feet).

3.3 Checkpoint Survey/Lidar Data Post-Processing

The checkpoint survey data was delivered in excel format. The excel file was converted to a shapefile and brought into an ESRI ArcMap project along with the Lidar collection area index. The checkpoints were well distributed throughout the region (See Figure 3 below). Groundpoint used LP360 software, a plugin for ArcGIS, to perform the accuracy assessment.

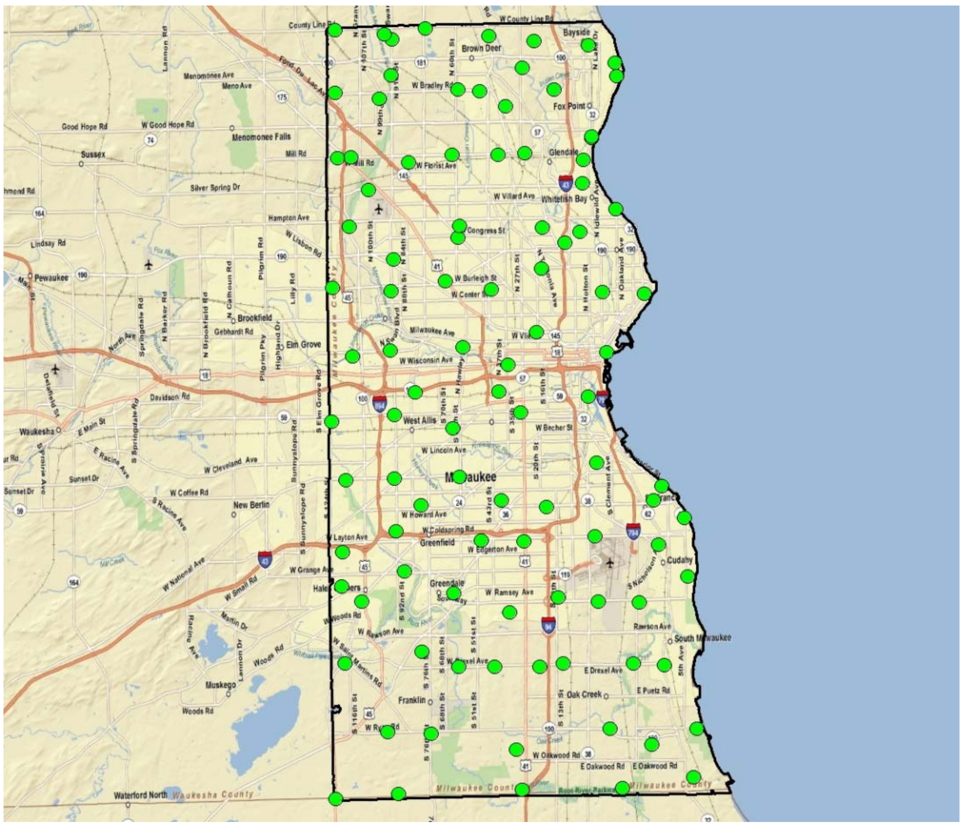

Figure 3 shows the distribution of all lidar points in the Milwaukee, WI collection area.

3.4 Randomly Spaced Lidar Accuracy Assessment Methodology

In order to compare the elevation values of the checkpoints to the Lidar data a TIN surface was created from the Lidar points and a point shapefile was created from the XYZ values of the table of checkpoints. A TIN is a 3D surface that preserves the precision of the Lidar data points while simultaneously modeling the values between the points. Figure 4 shows an example of the TIN created for performing the accuracy assessment from the check point survey.

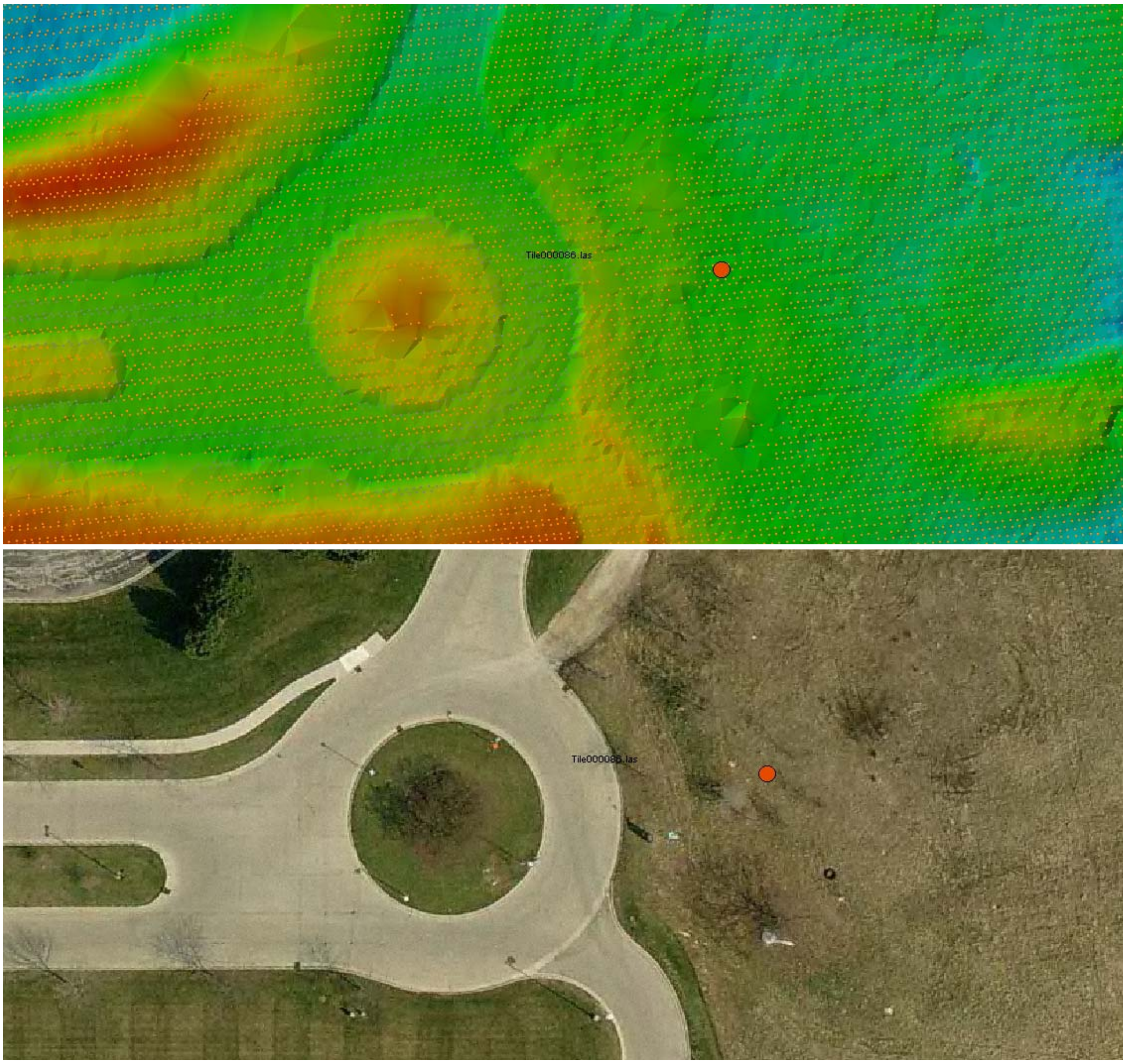

Figure 4 shows a checkpoint in the Brush land cover type displayed with a TIN created from the lidar ground points in the top image. The TIN colors indicate elevation range. The bottom image shows the same checkpoint displayed with orthoimagery provided by Milwaukee.

LP360 software tools and Microsoft Excel were used to implement a randomly spaced Lidar accuracy assessment. LP360 was used to compute spot elevations from the TIN surface at the location of each survey point. The results were exported to a text file and brought into Microsoft Excel for the statistical analysis.

3.5 Overall Statistics for the Randomly Spaced Lidar Data

For floodplain mapping, NDEP specifies the vertical accuracy of the data must have a root-mean-square error (RMSE) no greater than 9.25 centimeters (3.641 inches or 0.303 feet) for normally distributed data. This is equivalent to 1-foot contour interval mapping. RMSE is the square root of the average of the squared elevation differences between data set elevation values and checkpoint elevation values for identical points.

$$\text{RMSE} = \sqrt{\sum \frac{(\text{Lidar}_z - \text{Checkpoint}_z)^2}{n}}$$

The data is checked for a normal distribution by using a frequency histogram and measures of kurtosis and skew. Kurtosis describes the curve of the distribution; whether it is more flat or peaked than normal. The skew gives an indication of whether there are systematic errors or biases in the data, which would make the curve lopsided. Data with a normal distribution has a bell shape on the frequency histogam with a zero mean, zero kurtosis, and zero skew. Lidar data rarely meets these three criteria exactly for a normal distribution; therefore FEMA specifies limits for Kurtosis and Skew.

The collection area data does meet FEMA specifications for a normal distribution (See Figure 5). The mean elevation difference is -0.187 ft (-5.70 cm) meaning the lidar data elevation values are on average below true ground elevation values. The standard deviation is 0.186 ft therefore 95% of the elevation differences should fall between –0.559ft and 0.186 ft (-17.038 cm and 5.66 cm).

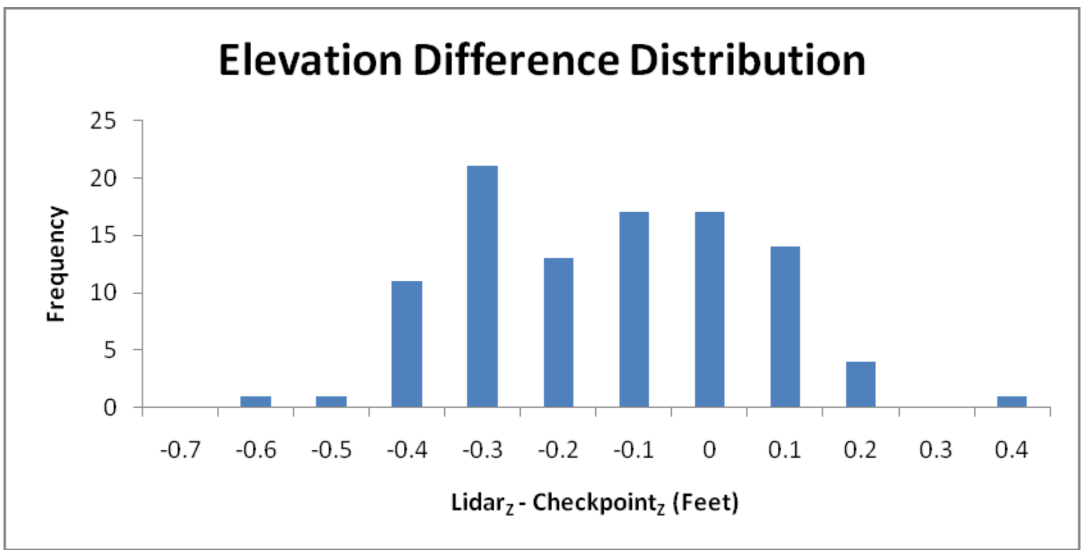

Figure 5 is a histogram showing the distribution of error residuals. A "normal" shaped histogram would be bell shaped and centered on zero. This histogram is not bell shaped, but within the limits of the FEMA specification for normally distributed lidar data.

The shape of the curve is flatter than normal with a Kurtosis of -0.395. The error distribution is skewed slightly to the right with a Skew of 0.025. FEMA recommends any skew value exceeding the absolute value of 0.5 be investigated to determine whether there is a valid reason why the errors do not have a normal distribution since the RMSE calculation is only valid on data with a normal distribution. This data meets the FEMA criteria for a normal distribution

The set of elevation residual differences (between survey and Lidar elevations) for 100 survey points was processed and the results of the statistical analysis are shown in table 2. The survey checkpoints are considered to be “true ground”. When the resulting error residual is positive the lidar data is above true ground. When the resulting error residual is negative then the lidar data is below true ground. Using all land cover types, the average elevation difference is negative with an overall average of -0.187 ft (-5.70 cm). Table 1 contains the Z value of all the points by landcover type, the checkpoint Z value and the error residual ($Lidar_Z$ – $Checkpoint_Z$).

Table 1. Error Residuals between Checkpoint Z value and Lidar Z value.

Checkpoint	$Checkpoint_Z$	$Lidar_Z$	LidarZ - $Checkpoint_Z$	Checkpoint	$Checkpoint_Z$	$Lidar_Z$	LidarZ - $Checkpoint_Z$
BareEarth	675.215	675.585	-0.37	Brush	709.93	710.094	-0.164
BareEarth	702.828	703.162	-0.334	Brush	721.193	721.357	-0.164
BareEarth	797.271	797.664	-0.393	Brush	649.371	649.657	-0.286
BareEarth	718.773	719.074	-0.301	Brush	644.932	645.392	-0.46
BareEarth	721.531	721.751	-0.22	Brush	704.144	704.466	-0.322
BareEarth	765.984	766.171	-0.187	Brush	651.937	651.951	-0.014
BareEarth	784.056	784.358	-0.302	Brush	733.484	733.761	-0.277
BareEarth	615.434	615.9	-0.466	Brush	679.358	679.668	-0.31
BareEarth	689.414	689.529	-0.115	Brush	684.631	684.922	-0.291
BareEarth	683.564	683.536	0.028	Forested	740.62	740.672	-0.052
BareEarth	587.729	588.039	-0.31	Forested	670.209	670.677	-0.468
BareEarth	701.29	701.661	-0.371	Forested	767.24	767.424	-0.184
BareEarth	703.863	704.07	-0.207	Forested	715.013	714.94	0.073
BareEarth	756.369	756.425	-0.056	Forested	732.72	732.909	-0.189
BareEarth	656.87	657.189	-0.319	Forested	826.284	826.432	-0.148
BareEarth	691.083	691.451	-0.368	Forested	657.703	657.676	0.027
BareEarth	654.598	654.691	-0.093	Forested	627.682	627.947	-0.265
BareEarth	692.402	692.417	-0.015	Forested	758.203	758.315	-0.112
BareEarth	685.571	685.897	-0.326	Forested	659.512	659.412	0.1
BareEarth	662.188	662.634	-0.446	Forested	700.039	700.023	0.016
BareEarth	689.82	689.679	0.141	Forested	717.446	717.518	-0.072
Tall Grass	761.793	761.952	-0.159	Forested	670.641	670.514	0.127
Tall Grass	728.027	728.11	-0.083	Forested	675.04	675.014	0.026
Tall Grass	740.997	741.573	-0.576	Forested	708.64	708.999	-0.359
Tall Grass	732.702	733.118	-0.416	Forested	706.116	706.367	-0.251
Tall Grass	691.788	692.123	-0.335	Forested	705.677	705.65	0.027
Tall Grass	735.508	735.979	-0.471	Forested	757.5	757.569	-0.069
Tall Grass	651.684	652.137	-0.453	Forested	659.464	659.902	-0.438

Checkpoint	$Checkpoint_Z$	$Lidar_Z$	LidarZ - $Checkpoint_Z$	Checkpoint	$Checkpoint_Z$	$Lidar_Z$	LidarZ - $Checkpoint_Z$
Tall Grass	669.936	670.34	-0.404	Forested	743.911	743.994	-0.083
Tall Grass	754.133	754.356	-0.223	Forested	779.074	779.231	-0.157
Tall Grass	730.938	731.253	-0.315	Urban	822.094	822.075	0.019
Tall Grass	598.696	599.074	-0.378	Urban	679.874	679.816	0.058
Tall Grass	757.803	757.859	-0.056	Urban	668.126	668.144	-0.018
Tall Grass	680.426	680.562	-0.136	Urban	775.918	775.604	0.314
Tall Grass	671.328	671.598	-0.27	Urban	679.433	679.404	0.029
Tall Grass	716.745	716.771	-0.026	Urban	717.497	717.63	-0.133
Tall Grass	662.567	662.537	0.03	Urban	700.447	700.612	-0.165
Tall Grass	694.783	695.192	-0.409	Urban	741.839	741.921	-0.082
Tall Grass	737.726	738.024	-0.298	Urban	819.13	819.05	0.08
Tall Grass	782.428	782.627	-0.199	Urban	732.768	732.781	-0.013
Tall Grass	750.235	750.3	-0.065	Urban	765.041	764.896	0.145
Tall Grass	753.887	754.206	-0.319	Urban	708.497	708.47	0.027
Tall Grass	769.169	769.506	-0.337	Urban	597.307	597.358	-0.051
Brush	682.248	682.573	-0.325	Urban	767.922	768.043	-0.121
Brush	779.181	779.449	-0.268	Urban	746.625	746.616	0.009
Brush	785.572	785.873	-0.301	Urban	668.133	668.36	-0.227
Brush	689.231	689.397	-0.166	Urban	648.253	648.604	-0.351
Brush	759.016	759.277	-0.261	Urban	700.725	700.836	-0.111
Brush	687.211	687.689	-0.478	Urban	689.828	689.693	0.135
Brush	642.325	643.008	-0.683	Urban	654.22	654.308	-0.088

It is common for a Lidar dataset to have larger error residuals in areas with heavy brush or tall grass since the Lidar pulses often do not penetrate all the way to the ground, thus making it very difficult to define a ground surface in the point classification process. This is a limitation of Lidar data and caution should be used when using the Lidar data in these areas.

A summary of the residual error statistics between the survey data and the random Lidar surface at each survey point's horizontal coordinates is shown in Table 3. The mean difference between survey points and Lidar data is -0.187 ft, the negative value indicating that on average the Lidar data is slightly below the earth's surface as defined by the survey points.

Table 2. Summary Error Residual Statistics (Lidar Surface - Checkpoint Data)

Statistic measures - Overall			
Value	**Measure**	**App A ref.**	**Notes**
100	Number of points		Number of points used in analysis
-0.187	Mean (ft)	N/A	Average elevation difference for all checkpoints. Overall Lidar values are below checkpoint values .
-0.186	Median (ft)	N/A	Elevation difference for checkpoint in the middle of all checkpoint differences
0.314	Max (ft)		Maximum elevation difference between checkpoints and Lidar derived elevations
-0.683	Min (ft)		Minimum elevation difference between checkpoints and Lidar derived elevations
0.263	RMSE (ft)	A.8.6.1	Measure of how widely lidar values are dispersed from the checkpoint data of higher accuracy. Meets FEMA specifications for 2' contour mapping.
0.186	Standard Deviation (ft)	A.8.6.3	Measure of how widely error values are dispersed from average.
< -0.746 > 0.372	3-sigma level (ft)	A.8.6.3	Statistical outliers (elev diff > 3-sigma), or the Mean – 3 * Standar Deviation and the Mean + 3 * Standard Deviation.
-0.395	Kurtosis	A.8.6.3	Flatter than normal.
0.025	Skewness	A.8.6.3	Skewed to the right of normal, this value is within the FEMA threshold of +/-0.5.
0.035	Variance (ft^2)	N/A	Variance of elevation differences for all checkpoints

The individual RMSE of all cover types except Brush also meets the 0.303 ft (9.25cm) RMSE specification. The Forested and Urban cover types have the lowest RMSE values of 0.202 ft (6.150 cm) and 0.144 ft (4.384 cm) respectively. Areas in the Brush cover type have the highest RMSE of 0.332 ft (10.130 cm) indicating less accurate surface definition in this cover type. It is common for the Brush cover type to exceed RMSE specifications because the lidar returns often do not get recorded from the actual ground surface beneath the brush. This can happen either because the brush is too dense for the lidar to penetrate to the ground or because the brush is too low to the ground. When the brush is too low to the ground then there isn't enough time between the returns of a lidar pulse for both of the returns to get recorded by the sensor. This is referred to as vertical discrimination of the lidar sensor. The amount of vertical discrimination varies from sensor to sensor. A typical sensor has a vertical discrimination of 2-3 meters. This means that if the 1st return of a lidar pulse reflects off an object then the 2nd return must be at least 2-3 meters away from the 1st pulse. If there are any objects within the 2-3 meter distance then their reflections will not be recorded by the sensor. Therefore if the brush is within 2-3 meters of the ground then the return from the ground will not get recorded by the sensor.

Table 3. Summary of Error Residual Statistics for All the Checkpoints and for the Checkpoints Classified by Land Cover Type.

Cover Type	RMSE (ft)	RMSE (cm)	Average Elevation Difference (ft)	Standard Deviation (ft)	Maximum Elevation Difference Value (ft)	Minimum Elevation Difference Value (ft)	Number of Checkpoints Used in Analysis
All 5 Cover Types	0.263	8.023	-0.187	0.186	0.314	-0.683	100
Subtypes:							
BareEarth	0.289	8.799	-0.240	0.165	0.141	-0.466	21
High Grass	0.312	9.512	-0.268	0.164	0.030	-0.576	22
Brush	0.332	10.130	-0.298	0.152	-0.014	-0.683	16
Forested	0.202	6.150	-0.117	0.169	0.127	-0.468	21
Urban	0.144	4.384	-0.027	0.145	0.314	-0.351	20

FEMA sent out a memorandum in late September 2010 that updated the methodology for calculating the vertical accuracy of all land cover classes that are not open ground. Most non-ground land cover types do not have a normal error distribution, which is a requirement when calculating RMSE. The accuracy in non-ground cover types is referred to as supplemental vertical accuracy (SVA) and is calculated using the 95th percentile method as defined in the NDEP guidelines of 2004. The 95th percentile indicates that 95 percent of the errors in the dataset will have absolute values of equal or lesser value and 5 percent of the errors will be of larger value. FEMA lists the target SVA for 1-foot contour mapping as 0.60 ft. FEMA also states that one SVA category can test higher and another lower than the target SVA value so long as the overall consolidated vertical accuracy (CVA) for all land cover types meets the target. This SVA was calculated as an additional accuracy measurement for the Milwaukee, WI lidar dataset. Table 4 presents the results of this calculation. The bare earth cover type was calculated as well so that a comparison could be made for the relative amount of error in each cover type.

Table 4 Supplemental Vertical Accuracy of all land cover types.

Cover Type	95th Percentile (ft)
All 5 Cover Types (CVA)	0.475
Bare Earth	0.456
High Grass	0.521
Brush	0.606
Forested	0.453
Urban	0.333

3.6 ACCURACY ASSESSMENT SUMMARY

The Milwaukee, WI lidar data meets the FEMA specifications for a normal distribution. The overall RMSE of 0.263 ft (8.023 cm) also meets the requirement to be less than 9.25 cm, which is based on the National Digital Elevation Program guidelines for 1-foot contour mapping. Individually, all of the ground cover categories, except Brush, meet the target 95th percentile value of 0.60 ft. The brush category is barely over the target at 0.606 ft.

4. QUALITY CONTROL REVIEW

The methodology Groundpoint presents here for reviewing the Lidar quality control implements the FEMA and FGDC guidelines (FEMA, 2003 and FGDC, 1998). Groundpoint coordinated with Milwaukee and Pictometry to obtain all available information.

4.1 Deliverables Review

4.1.1 Verify Pre-Flight Deliverables

Pictometry provided pre-flight deliverables including a map showing the collection area with planned flight lines, the collection plan, and information about times of high PDOP for the GPS equipment.

4.1.2 Verify Post-Flight Deliverables

Pictometry provided a metadata file for the collection that has information about the ellipsoid model and data processing procedures for processing the lidar data. Pictometry also provided information about the LIDAR system data report, the daily flight report, and ground control report. Pictometry did not provide a system calibration report.

4.1.3 Verify Mission Documentation

4.1.3.1 Calibration Report

There is no information about system calibration during acquisition. Groundpoint's accuracy assessment indicates that there do not appear to be any apparent system calibration issues impacting the quality of the final data products, and that the final data products are within FEMA standards for use in Floodplain Mapping.

4.1.3.2 PDOP

Pictometry provided PDOP information and charts for each mission.

4.1.3.3 Base Station

Pictometry provided base station and distance to base station information for each day.

4.1.3.4 Mission Report

There is no specific mission report, but most of the information was provided within the Daily Flight Logs and other documentation.

4.1.3.5 Flight Lines

Pictometry provided a shapefile of flightlines (see Figure 6).

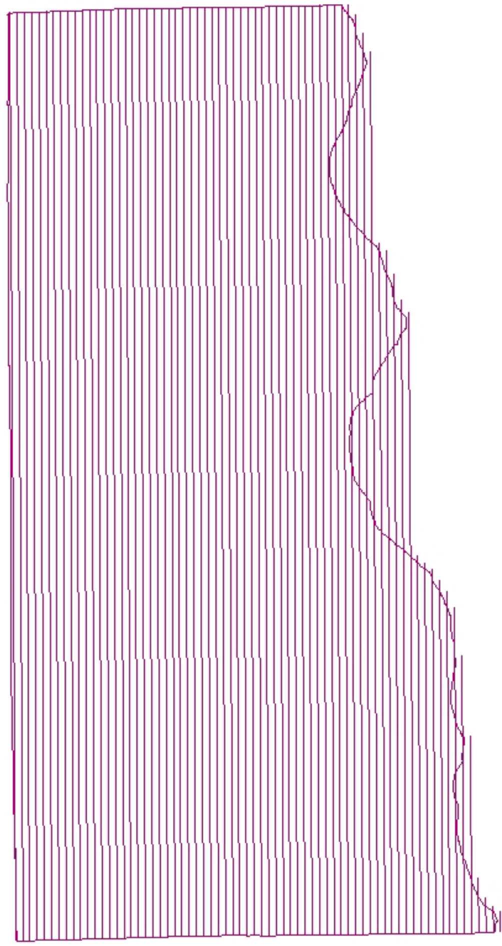

Figure 6 shows the flightlines for the collection area.

4.2 General Data Review

Pictometry delivered the Lidar data in LAS format to in the summer of 2010. Groundpoint performed the QAQC on the ground points of the data set. Groundpoint used UNC's LASTools, QCoherent's LP360, and ESRI's ArcGIS software for all data processing.

4.2.1 Total Number of Points

The collection area consists of 319 tiles. UNC's Las2las tool, Command Line tools, and ESRI's 3D analyst tools were used to extract the point count and other information from each las tile. There are 781,464,149 ground points in the collection area out of 2,368,063,475 total points.

Number of Points

2,368,063,475 All points
781,464,149 Ground points

4.2.2 Collection Area

The collection area consists of 319 tiles that total 245 mi^2. The following figure shows the lidar tiles in the collection area.

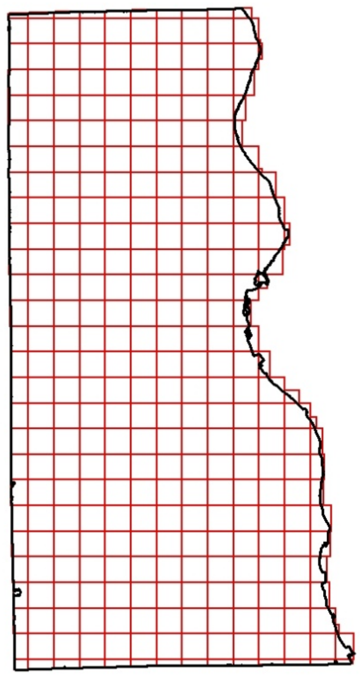

Figure 7 shows the 319 lidar tiles and the boundary of groundpoints in the collection area.

4.2.2.1 Datum

Groundpoint confirmed the consistency of the geographic projection system (NAD 1927 State Plane Wisconsin South Zone) while developing the terrain and subsequently derived raster DEM, and hillshade layers.

4.2.2.2 Round-Off Check

Groundpoint checked 20 random tiles. All tiles have two decimal places for X, Y, and Z coordinate values.

4.2.2.3 Edge Consistency

A visual review of the hillshade layer confirmed that elevations were consistent across file edges. Profile tools were also used to randomly check consistency across file edges.

4.2.2.4 Mosaic/Hillshade

Groundpoint created a terrain for the collection area from a composite of the multipoints corresponding to the full set of LAS tiles. The terrain was used as the basis for creating a 5 ft DEM raster, which was itself used to create a hillshade (Figure 8). The hillshade was generated using an illumination angle of 45 degrees facing in a 315 degree cardinal direction (southeast), and allowed for visual assessment of edge consistency, completeness in the dataset, and artifacts

Figure 8 shows an example of the Hillshade displayed at 1:4000 scale. The hillshade was used to confirm edge consistency and to look for artifacts and systematic errors in the data. The area within the red circle shows proper removal of ground points from an overpass.

4.2.3 Complete Coverage

The data collected in the Milwaukee, WI area is complete. There are no gaps between flight lines or large data voids.

4.2.3.1 Metadata Complete

Pictometry provided metadata for this lidar collection.

4.3 Technical Data Review

4.3.1 Range of Elevations

The minimum and maximum elevation locations were extracted from the las tiles. The minimum elevation of 475.31 ft is located in a quarry in tile 258. The maximum elevation of 994.80 ft is located in the southwest corner of the collection area in what appears to be a landfill in tiles 310, 324, and 325.

Elevation Range
Min: 475.31 ft
Max: 994.80 ft

4.3.2 Bare Earth Point Density and Post Spacing

As discussed above, the 319 tiles in Madison County contained a total of 781,464,149 ground points (out of 2,368,063,475 total points), and covered an area of 245 mi^2. This equates to an average of 0.114 ground points per ft^2, and taking the square root of the reciprocal yields an average ground post spacing of 2.956 ft.

Point Spacing
Point Density = 0.114 ground points per ft^2
Bare Earth Post Spacing = 2.956 ft

4.3.3 Void Areas

FEMA defines data voids as areas that are not within two times the required DEM posting of data points, which equates to 10m for the 2-foot contour interval accuracy standard. Data voids are acceptable over bodies of water or where points have been removed over man-made structures. Data voids are not acceptable with Lidar system malfunction or flight error. Data voids need to be flagged in areas where Lidar points have been removed due to dense vegetation. If the data voids in areas of dense vegetation are less than 1 acre then the voids may usually be filled by interpolation. If the data voids are greater than 1 acre then cross sections must be cut to fill the void areas.

To create the void areas, the multipoints for the merged tiles were converted to rasters using ESRI's "Feature to Raster" tool with an output cell size of 32 ft (10 m). The rasters were reclassified so that raster cells with data values were reclassified to "NoData" and raster cells that did not have any values were reclassified to "1". The rasters were mosaicked together and converted to polygon. The result represented data void areas 10 m x 10 m or larger as polygons.

This void feature class was layered over the orthoimagery provided by Milwaukee from so it could be determined what was on the ground in each area (e.g., water, buildings, vegetation), and therefore whether the void was acceptable (e.g., water and buildings) or not (e.g., vegetation). This information was recorded for each void area in the Landcover field in the attribute table.

A total of 145,287 data voids were identified. There are 1,524 data voids that are larger than one acre. All of the voids larger than one acre are due to water, wetland, building, or bridge removal. There were 10 voids that were flagged for being in bare earth areas that were corrected by Pictometry.

4.3.4 Artifacts

Visual inspection of the Lidar data was done using a hillshade derived from a countywide, 5 foot resolution DEM of the Lidar ground points as well as a TIN generated on the fly using LP360 software. The hillshade was initially inspected at 1:5000 scale. Any anomalies (artifacts) in the data were investigated using the orthoimagery provided by Milwaukee and/or "bird's eye" oblique imagery from www.bing.com\maps , and the original all points lidar data. Artifacts were flagged if the change in elevation from the surrounding ground elevation was greater than +/- 3 feet.

There is no category of artifacts that stands out as signifying a problem with the dataset. No systematic artifacts were found. There were originally 179 artifacts flagged throughout the collection area. The artifacts ranged from misclassification of ground points on culverts (culverts were treated as bridges and all points removed), some bridges were not removed from the ground points when they should have been removed, some building points were left in the ground data, there were a few divots (low points) in the data ranging from 5ft – 20ft deep, and there were many low points from swimming pools. Pictometry corrected all of these artifacts in the individual lidar las tiles.

5. Summary

The lidar data for the Milwaukee, WI collection area meets all the FEMA specifications for floodplain mapping. The data passes the accuracy assessment test for RMSE and a normal distribution. The final dataset passes all quality control specifications and the dataset has adequate documentation from the collection vendor.

6. References

Bellamo, Doug A., Memorandum for Regional Risk Analysis Branch Chiefs, Procedure Memorandum No. 61 – Standards for Lidar and Other High Quality Digital Topagraphy, September, 2010.

Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy, Federal Geographic Data Committee (FGDC), 1998, from http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3.

Guidelines for Digital Elevation Data Version 1.0, National Digitial Elevation Program (NDEP), 2004, from http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf

Map Modernization Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying, Federal Emergency Management Agency (FEMA), April 2003, from http://www.fema.gov/plan/prevent/fhm/dl_cgs.shtm

Appendix A

The Lidar Checkpoint Survey Data

Point #	Land cover type	Northing	Easting	Elevation
100	5	313336.238	2517720.063	822.094
101	2	314135.486	2528139.022	761.793
102	5	314849.722	2548602.411	679.874
103	1	315046.146	2565181.824	675.215
104	1	316822.537	2576903.284	702.828
105	3	324876.382	2577481.749	682.248
106	5	324870.292	2563130.423	668.126
107	4	321391.016	2547557.300	740.620
108	2	324047.820	2533517.702	728.027
109	3	324396.729	2526251.783	779.181
110	4	322319.610	2569989.677	670.209
118	1	348433.326	2518752.284	797.271
119	5	345898.998	2522050.614	775.918
120	2	350955.343	2529045.699	740.997
121	3	335694.214	2519233.063	785.572
122	4	337675.844	2531978.432	767.240
123	3	335118.563	2538006.473	689.231
124	2	335140.920	2544029.915	732.702
125	4	335184.555	2551532.628	715.013
126	1	335768.805	2555400.310	718.773
127	2	335685.537	2566952.760	691.788
128	5	335361.014	2572046.379	679.433
129	1	347303.471	2537180.180	721.531
130	3	344140.221	2546458.527	759.016
131	2	346616.335	2554567.719	735.508
132	4	345905.887	2561143.036	732.720
133	5	345789.110	2567901.480	717.497
134	3	350090.874	2575923.818	687.211
135	2	359809.434	2575378.913	651.684
136	5	355400.541	2571173.095	700.447
137	2	356775.437	2560688.082	669.936
138	5	355847.517	2548798.703	741.839

139	1	356107.504	2541792.469	765.984
140	2	357601.192	2527741.686	754.133
141	4	354160.584	2518819.268	826.284
142	1	361800.215	2531871.420	784.056
143	4	361618.294	2552535.684	657.703
144	3	362734.798	2570242.364	642.325
145	2	366022.703	2519354.623	730.938
146	5	366262.106	2527437.264	819.130
147	5	366574.656	2538223.092	732.768
148	1	368897.450	2560842.718	615.434
149	4	365050.311	2571671.746	627.682
150	3	362714.448	2545066.232	709.930
151	4	375699.392	2516987.799	758.203
152	4	377155.545	2548255.976	659.512
153	2	379819.720	2559499.266	598.696
154	1	374620.461	2537153.756	689.414
155	5	376807.178	2527349.040	765.041
156	5	380480.803	2530905.384	708.497
157	5	380739.902	2544696.742	597.307
158	4	387953.756	2538782.976	700.039
159	2	387396.348	2526775.996	757.803
160	3	386520.565	2520451.501	721.193
161	2	390575.339	2550993.247	680.426
162	4	397307.580	2526904.834	717.446
163	5	397807.395	2517161.459	767.922
164	1	385063.975	2546198.386	683.564
165	1	387176.218	2562505.247	587.729
170	4	396931.442	2568737.082	670.641
171	4	397158.345	2561838.000	675.040
172	1	397618.214	2543397.076	701.290
173	1	400991.697	2551731.513	703.863
174	1	398958.924	2535859.050	756.369
175	5	402609.767	2527282.851	746.625
176	5	405255.908	2555676.824	668.133
177	2	406090.648	2537895.751	671.328
178	4	407989.730	2519887.034	708.640
179	2	414006.454	2523155.038	716.745
180	2	408085.792	2538172.757	662.567
181	3	407865.319	2551844.913	649.371
182	3	407175.819	2558167.412	644.932
183	1	410800.007	2564049.035	656.870

189	4	422588.821	2560015.400	706.116
190	4	422907.393	2560103.330	705.677
191	5	415162.626	2558596.500	648.253
192	1	419035.252	2558752.128	691.083
193	1	420066.038	2549006.011	654.598
194	2	419792.082	2544616.217	694.783
195	3	419907.654	2536933.233	704.144
196	2	418600.775	2529806.075	737.726
197	2	419497.967	2520270.590	782.428
198	4	419287.348	2517998.953	757.500
199	4	430613.093	2553885.037	659.464
200	3	434219.129	2548616.919	651.937
201	5	427814.721	2545793.966	700.725
202	5	430334.012	2541534.458	689.828
203	1	430584.433	2537984.572	692.402
204	2	432969.523	2526923.117	750.235
205	3	429067.995	2524874.211	733.484
206	4	430057.393	2517550.938	743.911
207	3	435103.733	2563884.982	679.358
208	1	432877.039	2564166.941	685.571
209	1	438033.365	2559474.853	662.188
210	1	438682.236	2550585.239	689.820
211	5	439545.221	2543013.115	654.220
212	3	440768.513	2532524.281	684.631
213	4	438942.931	2527051.496	779.074
214	2	439721.139	2525690.659	753.887
215	2	440426.271	2517526.447	769.169