KUCERA INTERNATIONAL INC.

GEOGRAPHIC INFORMATION PROFESSIONALS / PHOTOGRAMMETRISTS

State of Kansas, DOA

Area FEMA07

Vertical Accuracy Assessment Report

Background

The National Digital Elevation Program (NDEP)[1] and the American Society for Photogrammetry and Remote Sensing (ASPRS)[2] define guidelines for testing and reporting the accuracy of digital geospatial data. The ASPRS guidelines are directly referenced to the assessment of LiDAR digital data. The NDEP specifies the mandatory determination of Fundamental Vertical Accuracy (FVA) and the optional determination of Supplemental Vertical Accuracy (SVA) and/or Consolidated Vertical Accuracy (CVA). The standards call for a minimum of three ground cover categories and recommend the survey of a minimum of 20 checkpoints per ground cover category, setting the minimum total checkpoint count at 60 for the study area. Because of the rural nature of the project area, three hybrid major ground categories were agreed upon as representative of the project area. They are:

- Bare Earth (**BE**) – Bare Earth, Low Grass, Hard Surfaces
- Brush (**BR**) – Brush Lands, Low Trees
- High Grass (**HG**) – High Grass, Weeds, Crops

FVA is determined with check points located only in open terrain (grass, dirt, sand, rocks and/or hard surfaces) where there is a high probability that the LiDAR sensor will have detected the bare-earth ground surface and where errors are expected to follow a normal error distribution. 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 National Standard for Spatial Data Accuracy (NSSDA)[3] guidelines.

CVA is determined with all checkpoints in all land 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, recognizing that the LiDAR sensor and post-processing may not have mapped the bare-earth ground surface, and that errors may not follow a normal error distribution. For each land cover category, the SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in that particular land cover category.

Kucera International's vertical accuracy assessment for the FEMA07 area was carried out in accordance with the methods noted above. The following summarizes the steps involved in the assessment:

- Ground survey personnel collected and processed GPS data for each of the ground cover checkpoints. These points were distributed throughout ground cover categories within the project area limits.
- 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 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.
- The results were analyzed by Kucera to assess the quality of the data. Various accuracy parameters as

defined by 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.

Table 1 summarizes the criteria used to evaluate the vertical data:

Criteria	*Acceptable Value*
Fundamental Vertical Accuracy (FVA) in open terrain only = 95% confidence level	24.5cm ($RMSE_Z$ x 1.9600) for open terrain only
Supplemental Vertical Accuracy (SVA) in individual ground cover categories = 95% confidence level	36.3cm (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	36.3cm (based on combined 95th percentile)

Table 1: Vertical Accuracy Acceptance Criteria

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

Ground Cover Category	*# of Points*	*FVA Fundamental Vertical Accuracy Spec = 24.5 cm*	*CVA Consolidated Vertical Accuracy Spec = 36.6 cm*	*SVA Supplemental Vertical Accuracy Spec = 36.3 cm*
BE	21	12.0		10.9
HG	21			26.7
BR	20			21.8
Consolidated	62		21.7	

Table 2: Computed Vertical Accuracies per Method

The digital vertical data for the FEMA07 area meets all mandatory and target specifications as per the following vertical accuracy tests:

Compared with the 24.5cm FVA specification, FVA tested 12.0cm at the 95% confidence level on the BE 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 state that this method is valid only when random errors follow a normal error distribution, as in the BE category.

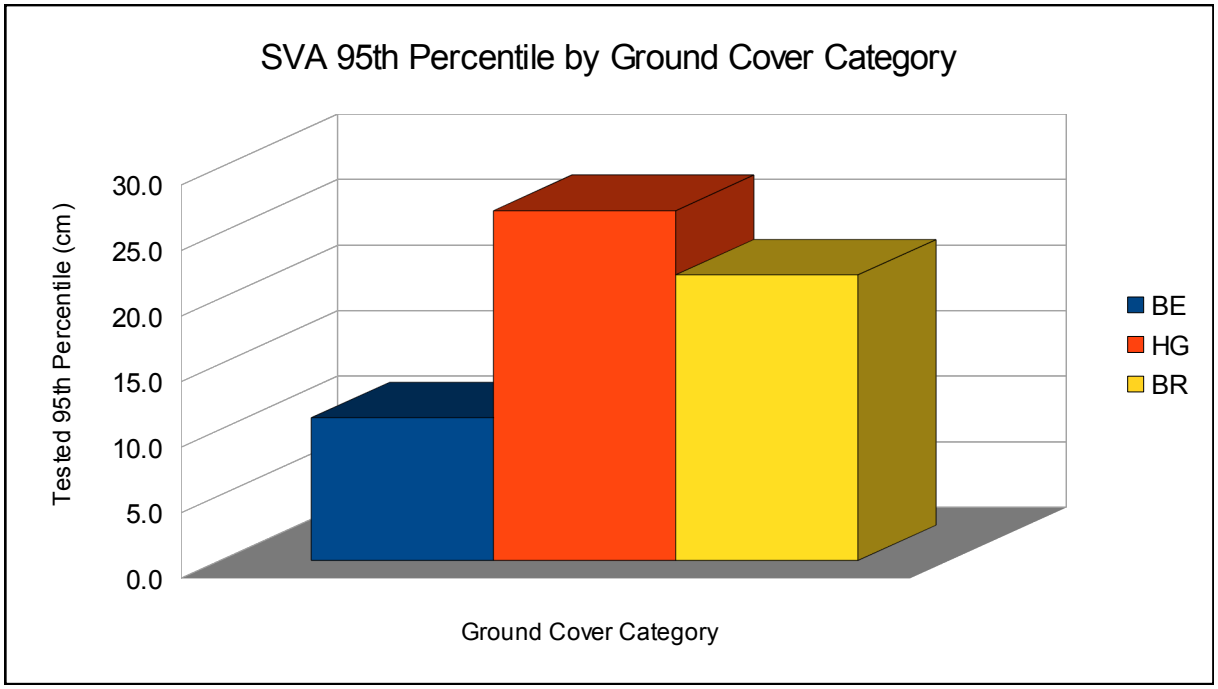
Compared with the 36.3cm CVA specification, CVA tested 21.7cm at the 95% confidence level on the BE, BR and HG ground cover categories combined, based on the 95th percentile. NDEP and ASPRS guidelines specify that vertical accuracy at the 95% confidence level equals the 95th percentile when random errors may not follow a normal distribution, as in vegetated or obstructed areas. Table 3 lists the 5% outliers larger than the 95th percentile (21.7cm).

PT ID	*X UTM 14N (m)*	*Y UTM 14N (m)*	*Elev. Diff (cm)*	*The errors in **bold** are larger than the CVA standard (36.3cm) which permits up to 5% of the checkpoints, 3 of 60, to be larger than 36.3cm.*
BR17	615434.796	4269492.859	**45.5**	
HG07	596700.859	4281368.340	33.3	
HG15	626463.100	4267970.651	26.7	
BR14	636899.029	4274268.404	24.5	

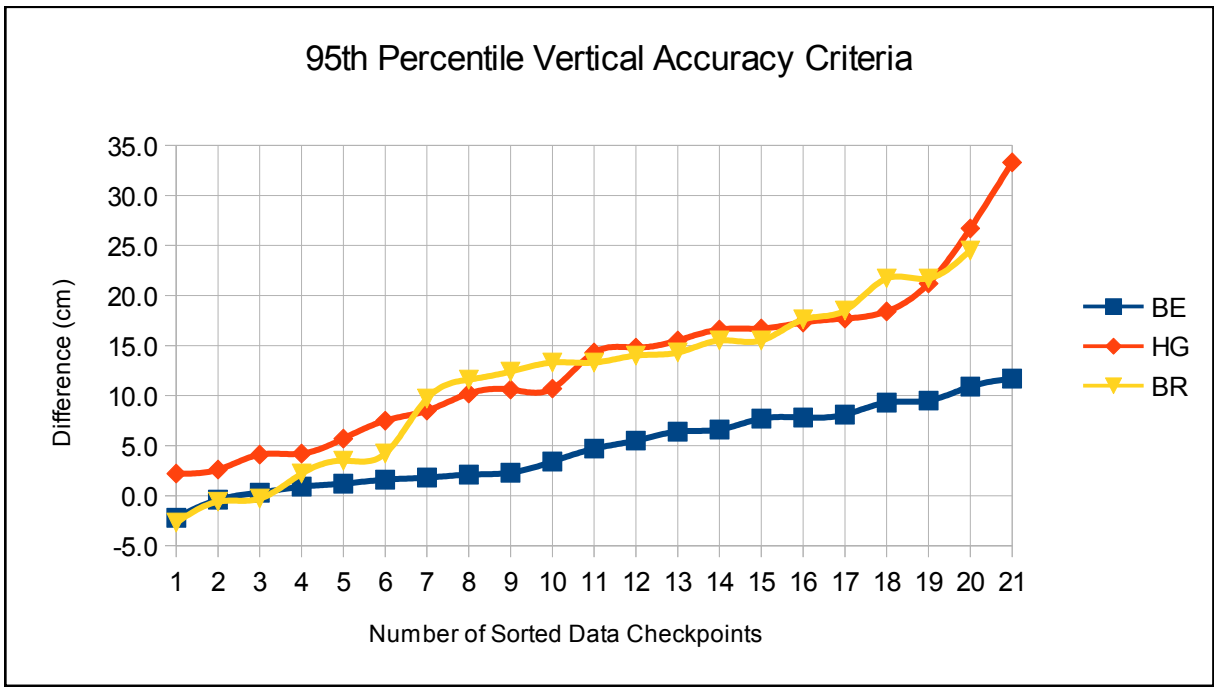
Table 3: 5% Outliers Larger Than CVA 95th Percentile

Compared with the 36.3cm SVA target values, SVA tested 10.9cm at the 95% confidence level in BE; 26.7cm in HG and 21.8cm in the BR land cover categories, based on the 95th percentile. These tested values all come in under the target value.

Drawing 1 illustrates the SVA by specific ground cover category. Drawing 2 illustrates the magnitude of differences between the checkpoints and LiDAR data by specific land cover category and sorted from lowest to highest.



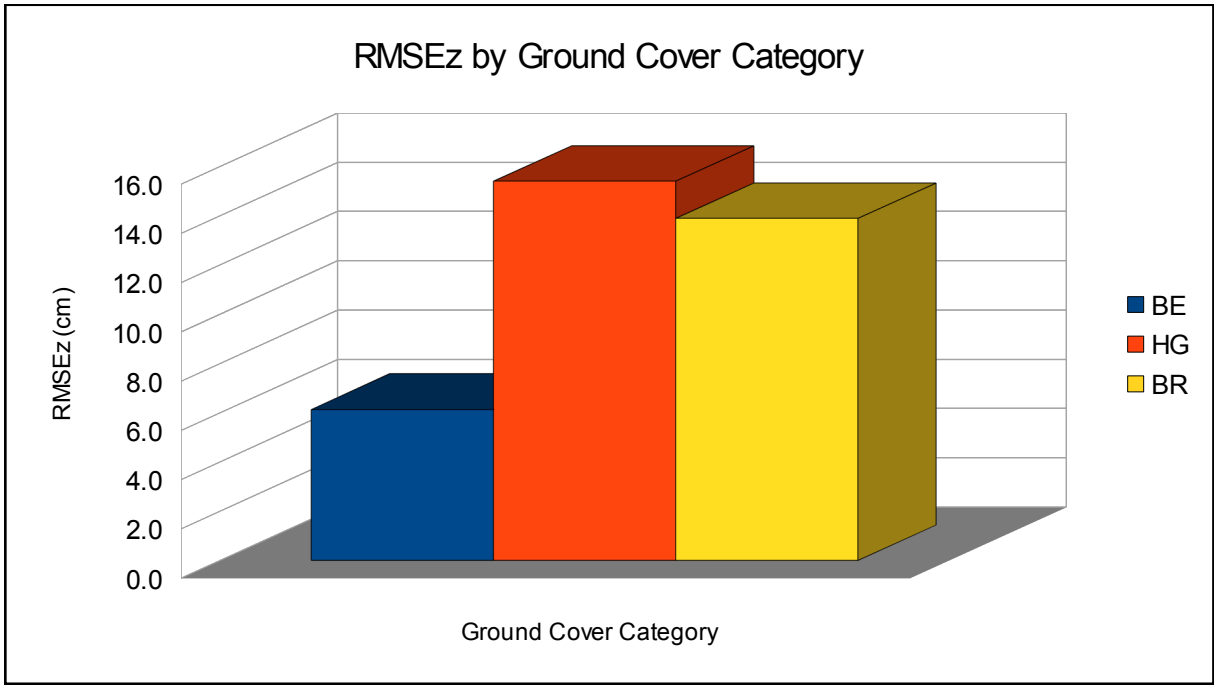
Drawing 1: Graph of SVA Values by Ground Cover Category



Drawing 2: Magnitude of Elevation Differences

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

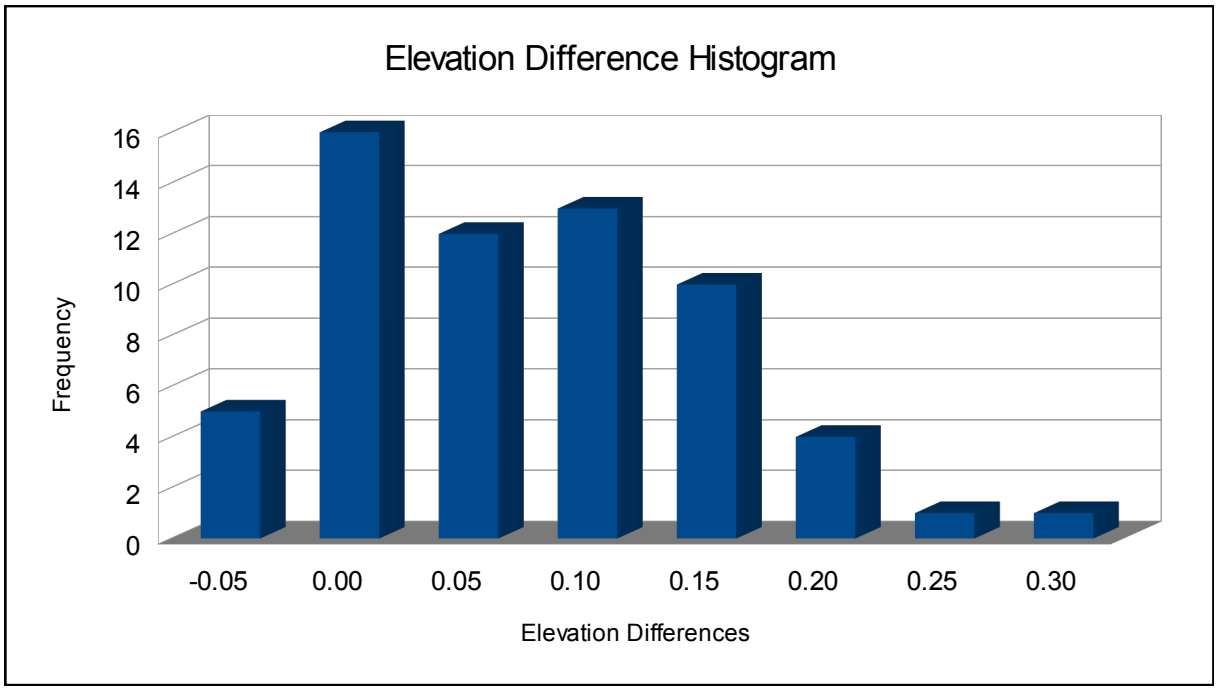
The NSSDA and FEMA[4] guidelines were both published before it was recognized that digital data errors do not always follow a normal error distribution. Future changes to these guidelines are expected to follow those of the NDEP and ASPRS. The following tables and drawings document $RMSE_z$, the statistical array and an elevation difference histogram.



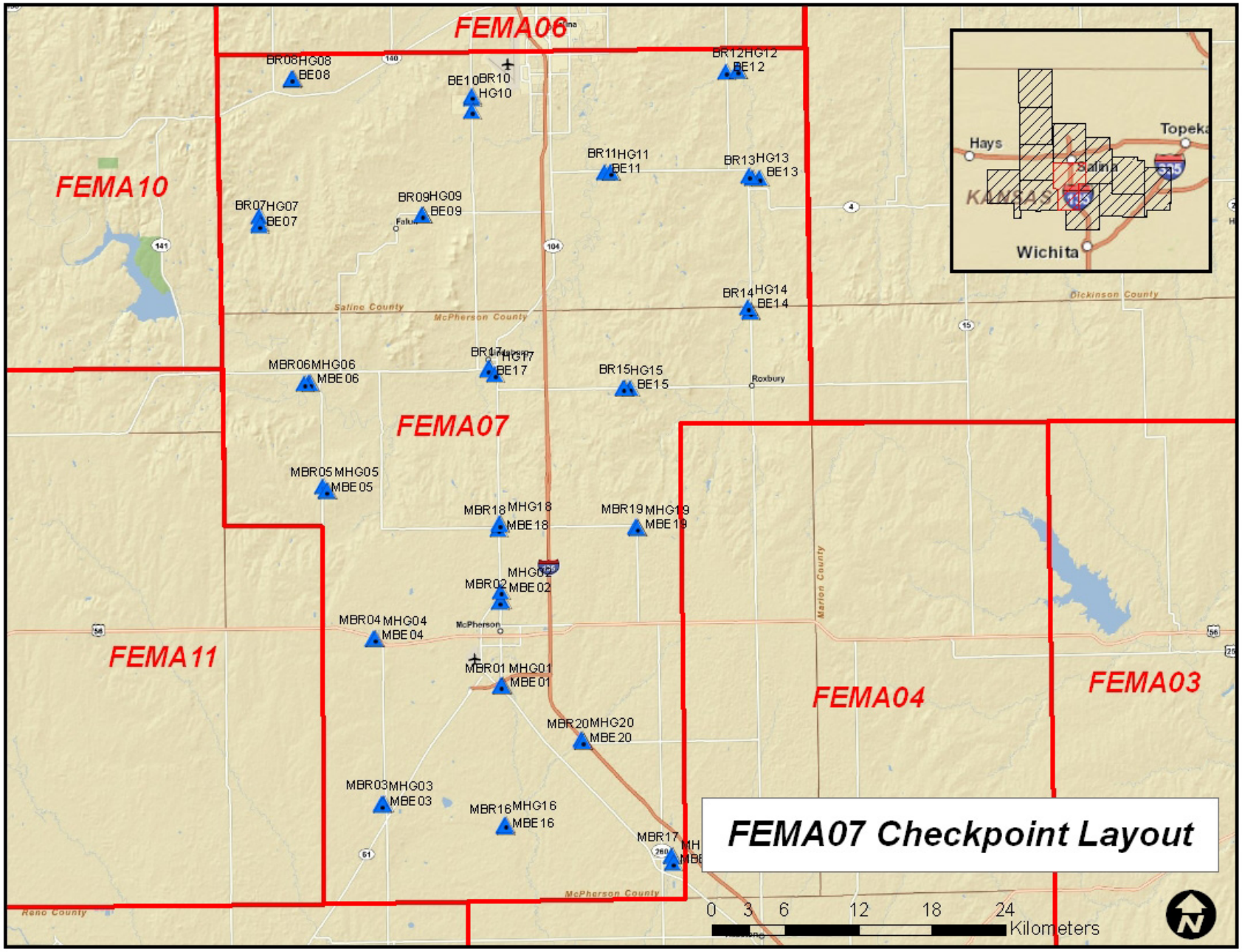
Drawing 3: RMSEz Values by Ground Cover Category

Land Cover Category	# of Points	RMSEz (cm)	Mean (cm)	Median (cm)	Std Dev (cm)	Min (cm)	Max (cm)	Skew
BE	21	6.1	4.7	4.7	4.0	-2.2	11.7	0.123
HG	21	15.4	13.3	14.3	8.0	2.2	33.3	0.696
BR	20	13.9	11.5	13.3	8.0	-2.7	24.5	-0.334
Consolidated	62	12.5	9.8	9.4	7.7	-2.7	33.3	0.599

Table 4: Overall Descriptive Statistics by Ground Cover Category



Drawing 4: Elevation Difference Histogram, 5cm range


FEMA06
FEMA10
FEMA07
FEMA11
FEMA04
FEMA03
BR08HG08
BE08
BE10BR10
HG10
BR12HG12
BE12
BR11HG11
BE11
BR13HG13
BE13
BR07HG07
BE07
BR09HG09
BE09
BR14HG14
BE14
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MBR01MHG01
MBE01
MBR20MHG20
MBE20
MBR03MHG03
MBE03
MBR16MHG16
MBE16
MBR17
Hays
Topeka
Salina
KANSAS
Wichita
Saline County
McPherson County
Dickinson County
Marion County
McPherson County
Reno County
Roxbury
McPherson
0 3 6 12 18 24
Kilometers
FEMA07 Checkpoint Layout

1 *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 2004
2 *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 2004
3 Part 3: *National Standards for Spatial Data Accuracy (NSSDA)*, "Geospatial Positioning Accuracy Standards," published by the Federal Geographic Data Committee (FGDC), 1998
4 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.