KUCERA INTERNATIONAL INC.

GEOGRAPHIC INFORMATION PROFESSIONALS / PHOTOGRAMMETRISTS

State of Kansas, DOA

Area FEMA12

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 FEMA12 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	14.7		13.9
HG	20			34.8
BR	21			26.6
Consolidated	62		31.0	

Table 2: Computed Vertical Accuracies per Method

The digital vertical data for the FEMA12 area meets all mandatory and target specifications as per the following vertical accuracy tests:

Compared with the 24.5cm FVA specification, FVA tested 14.7cm 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.

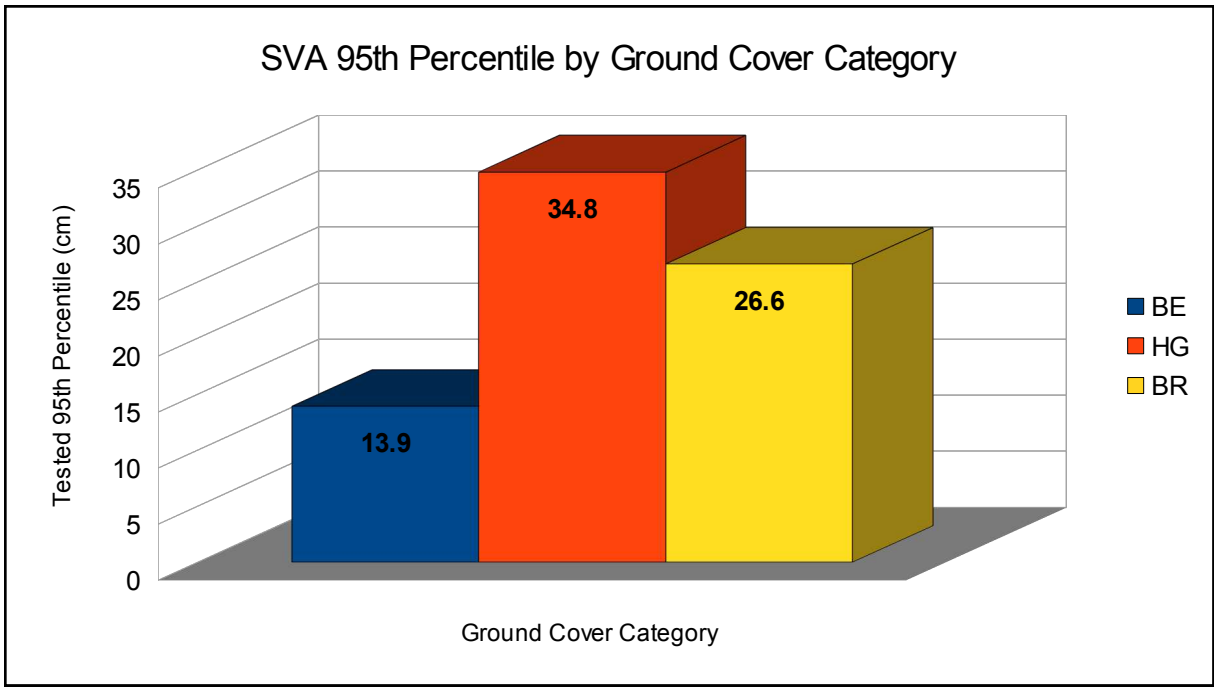
Compared with the 36.3cm CVA specification, CVA tested 31.0cm at the 95% confidence level on the BE, BR and HG ground cover categories combined, based on the 95th percentile. NDEP and ASPRS guidelines specify that vertical accuracy at the 95% confidence level equals the 95th percentile when random errors may not follow a normal distribution, as in vegetated or obstructed areas. Table 3 lists the 5% outliers larger than the 95th percentile (31.0cm).

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.*
HG12	531654.192	4255685.865	**37.7**	
HG15	530567.270	4276673.613	34.6	
HG04	516466.451	4248201.218	31.8	
HG14	520029.189	4276795.842	31.1	

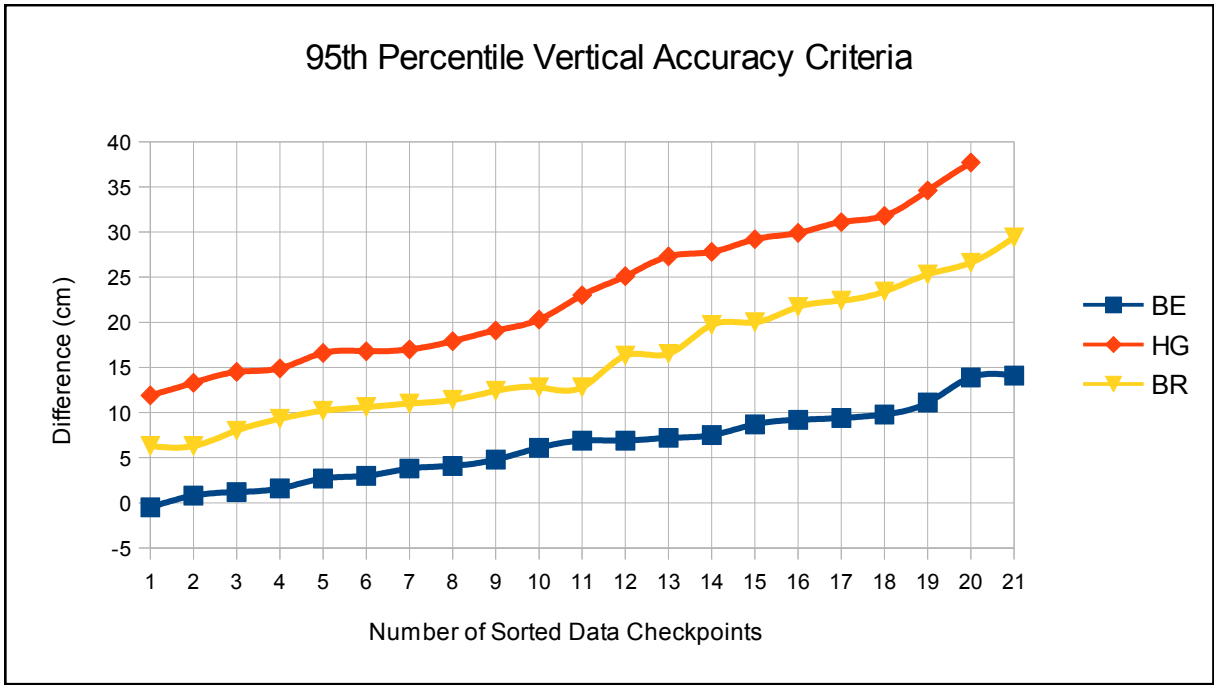
Table 3: 5% Outliers Larger Than CVA 95th Percentile

Compared with the 36.3cm SVA target values, SVA tested 13.9cm at the 95% confidence level in BE; 34.8cm in HG and 26.6cm 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.



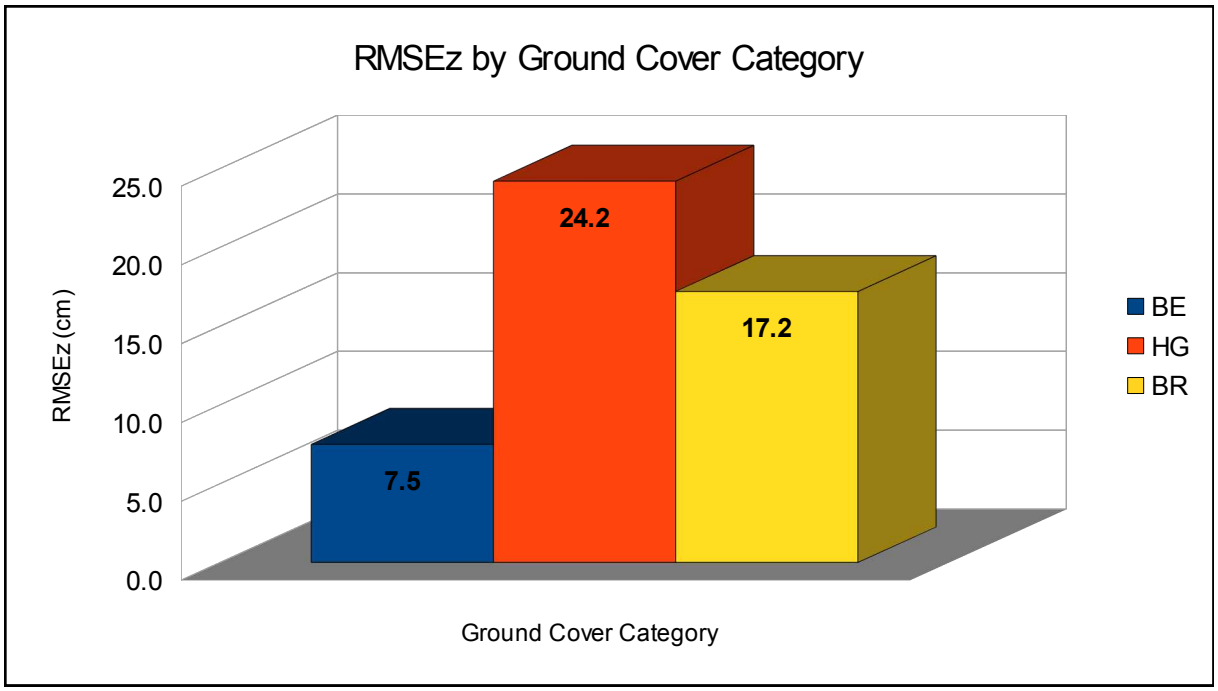
Drawing 1: Graph of SVA Values by Ground Cover Category



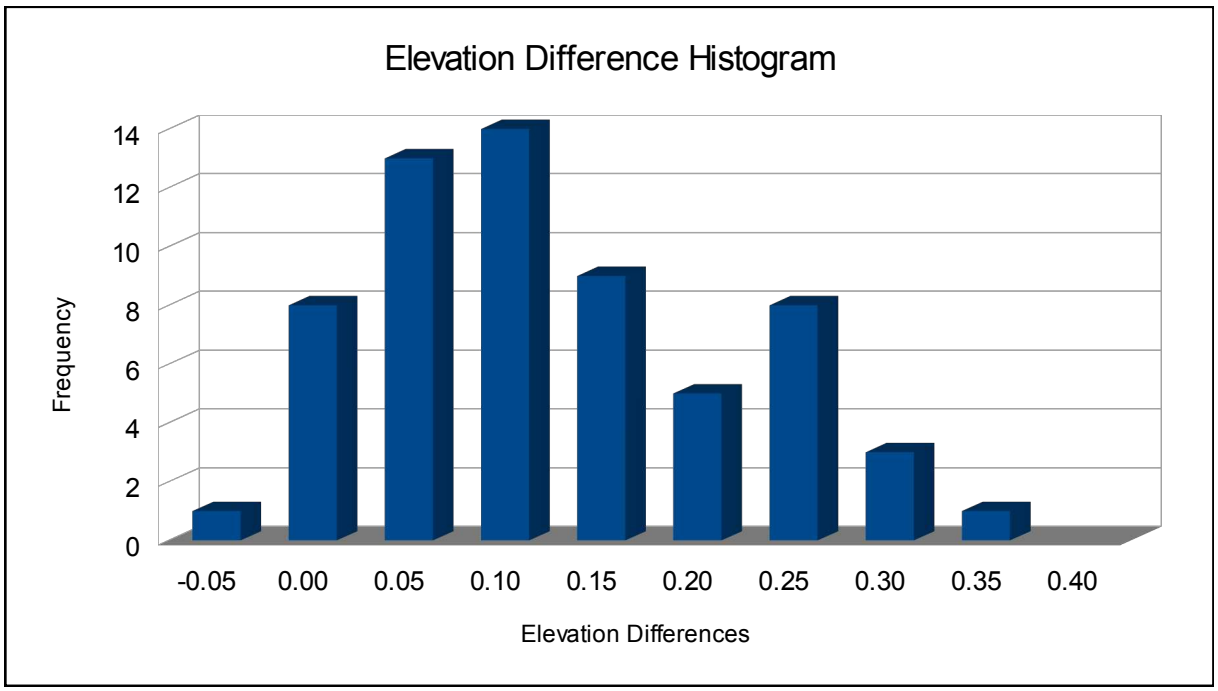
Drawing 2: Magnitude of Elevation Differences

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.



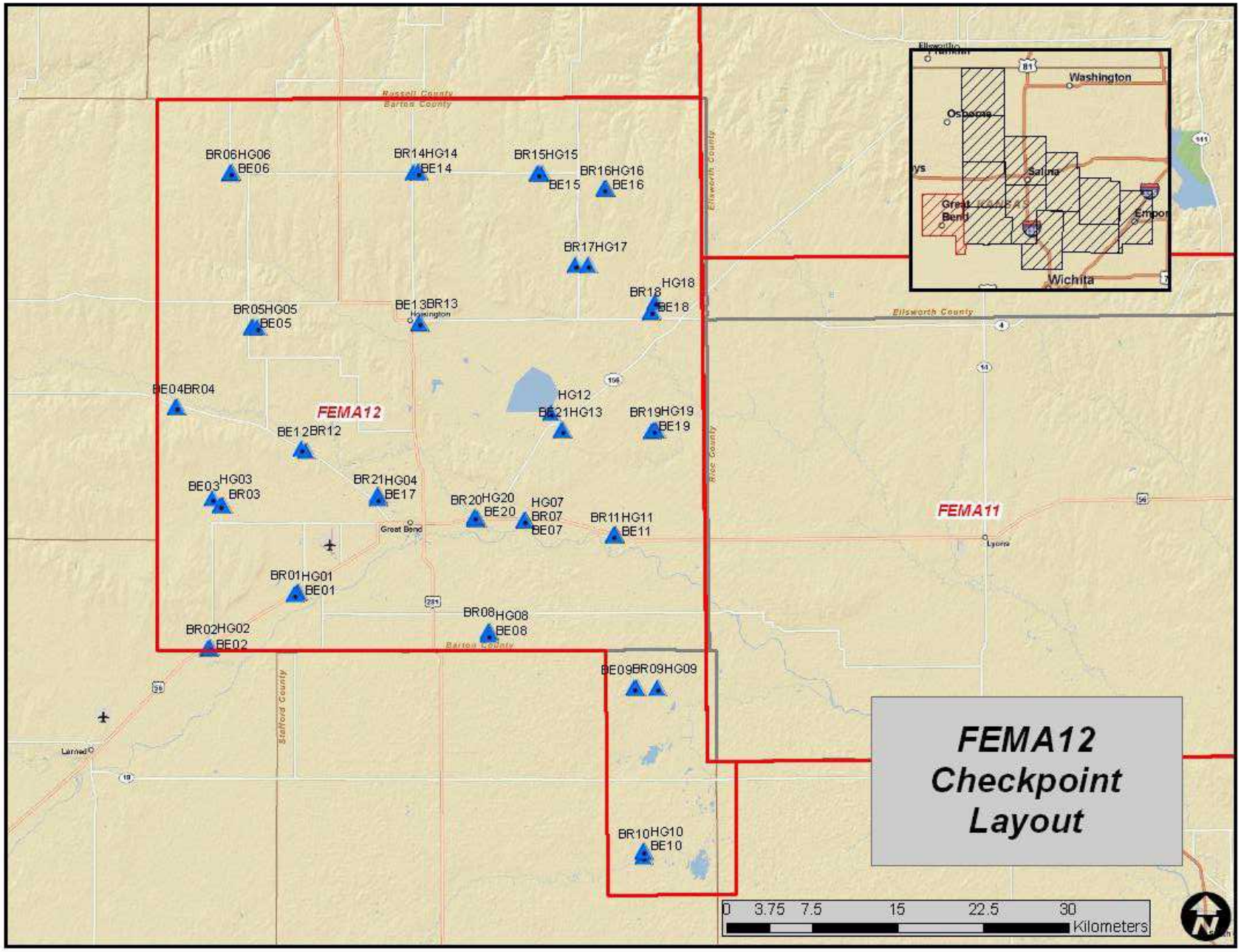
Drawing 3: RMSEz Values by Ground Cover Category



Drawing 4: Elevation Difference Histogram, 5cm range

Land Cover Category	# of Points	RMSEz (cm)	Mean (cm)	Median (cm)	Std Dev (cm)	Min (cm)	Max (cm)	Skew
BE	21	7.5	6.3	6.9	4.1	-0.5	14.1	0.241
HG	20	24.2	23.0	21.7	7.8	11.9	37.7	0.300
BR	21	17.2	15.8	12.8	7.0	6.3	29.4	0.413
Consolidated	62	17.6	14.9	13.1	9.4	-0.5	37.7	0.496

Table 4: Overall Descriptive Statistics by Ground Cover Category


Russell County
Barton County
Ellsworth County
Rice County
Stafford County
Washington
Osborne
Salina
Great Bend
Wichita
Hoisington
Great Bend
Lyons
Larned
BR06HG06
BE06
BR14HG14
BE14
BR15HG15
BE15
BR16HG16
BE16
BR17HG17
BR18HG18
BE18
BR05HG05
BE05
BE13BR13
BE04BR04
FEMA12
HG12
BE21HG13
BR19HG19
BE19
BE12BR12
BE03HG03
BR03
BR21HG04
BE17
BR20HG20
BE20
HG07
BR07
BE07
BR11HG11
BE11
FEMA11
BR01HG01
BE01
BR08HG08
BE08
BR02HG02
BE02
BE09BR09HG09
BR10HG10
BE10
FEMA12
Checkpoint
Layout
0 3.75 7.5 15 22.5 30
Kilometers

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.