KUCERA INTERNATIONAL INC.

GEOGRAPHIC INFORMATION PROFESSIONALS / PHOTOGRAMMETRISTS

2012 State of Kansas, DASC

Area FEMA01

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
- High Grass (**HG**) – High Grass, Weeds, Crops
- Urban (**UR**) – Urban, Hard Surface

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 FEMA01 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	26	10.0		6.9
HG	23			19.7
UR	25			10.8
Consolidated	74		15.5	

Table 2: Computed Vertical Accuracies per Method

The digital vertical data for the FEMA01 area meets all mandatory and target specifications as per the following vertical accuracy tests:

Compared with the 24.5cm FVA specification, FVA tested 10.0cm 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.

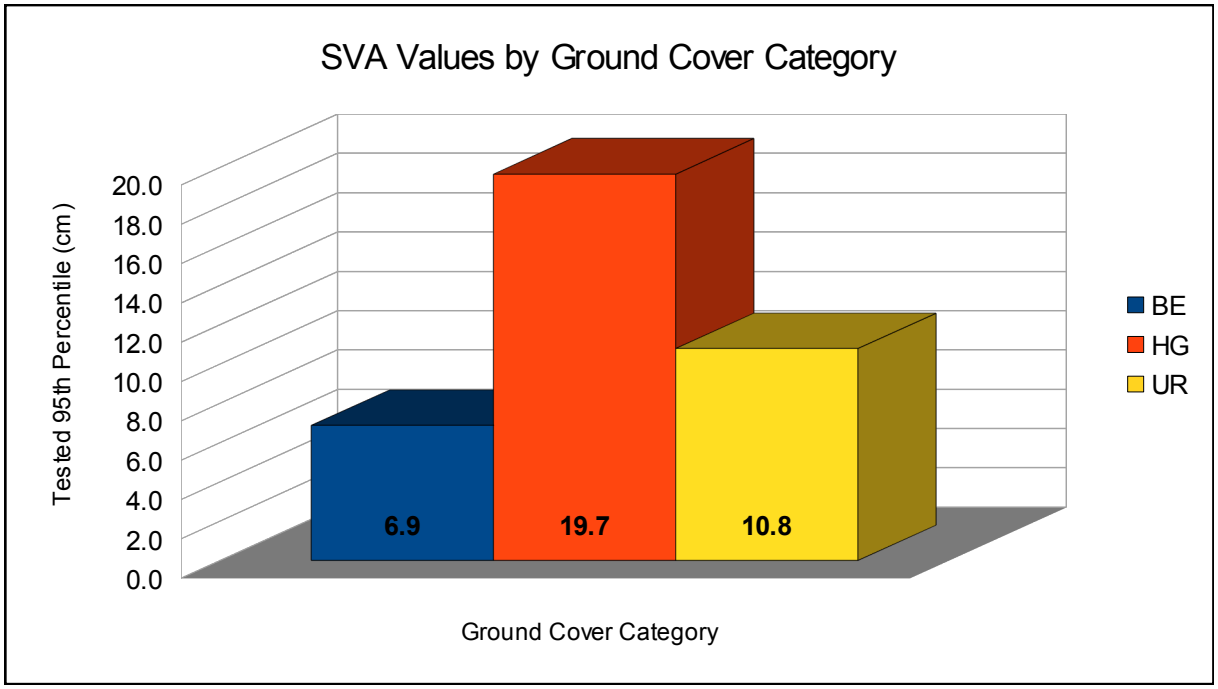
Compared with the 36.3cm CVA specification, CVA tested 15.5cm at the 95% confidence level on the BE, HG and UR ground cover categories combined, based on the 95th percentile. NDEP and ASPRS guidelines specify that vertical accuracy at the 95% confidence level equals the 95th percentile when random errors may not follow a normal distribution, as in vegetated or obstructed areas. Table 3 lists the outliers larger than the 95th percentile (15.5cm).

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 to be larger than 36.3cm. **None** exist in FEMA01 area.*
F1HG21	505846.932	4389893.778	15.8	
F1HG05	526402.500	4340432.552	19.3	
F1HG19	529651.694	4389543.079	19.7	
F1HG15	538441.050	4406910.872	23.8	

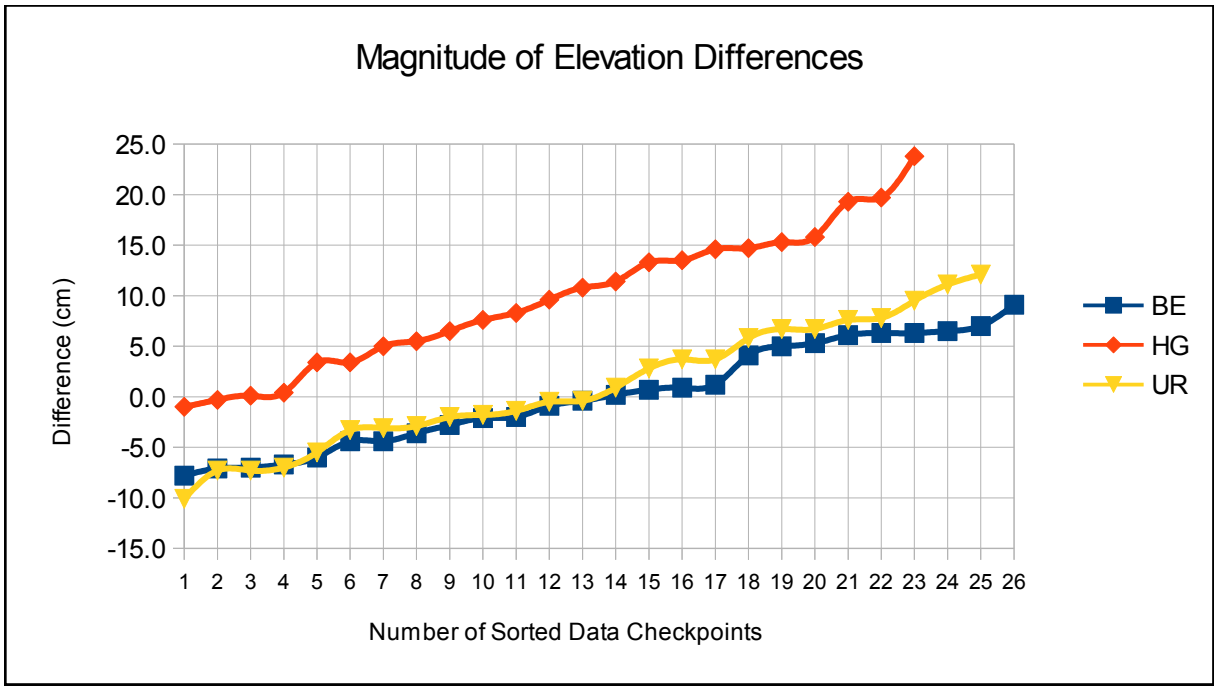
Table 3: Outliers Larger Than CVA 95th Percentile

Compared with the 36.3cm SVA target values, SVA tested 6.9cm at the 95% confidence level in BE; 19.7cm in HG and 10.8cm in the UR 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.



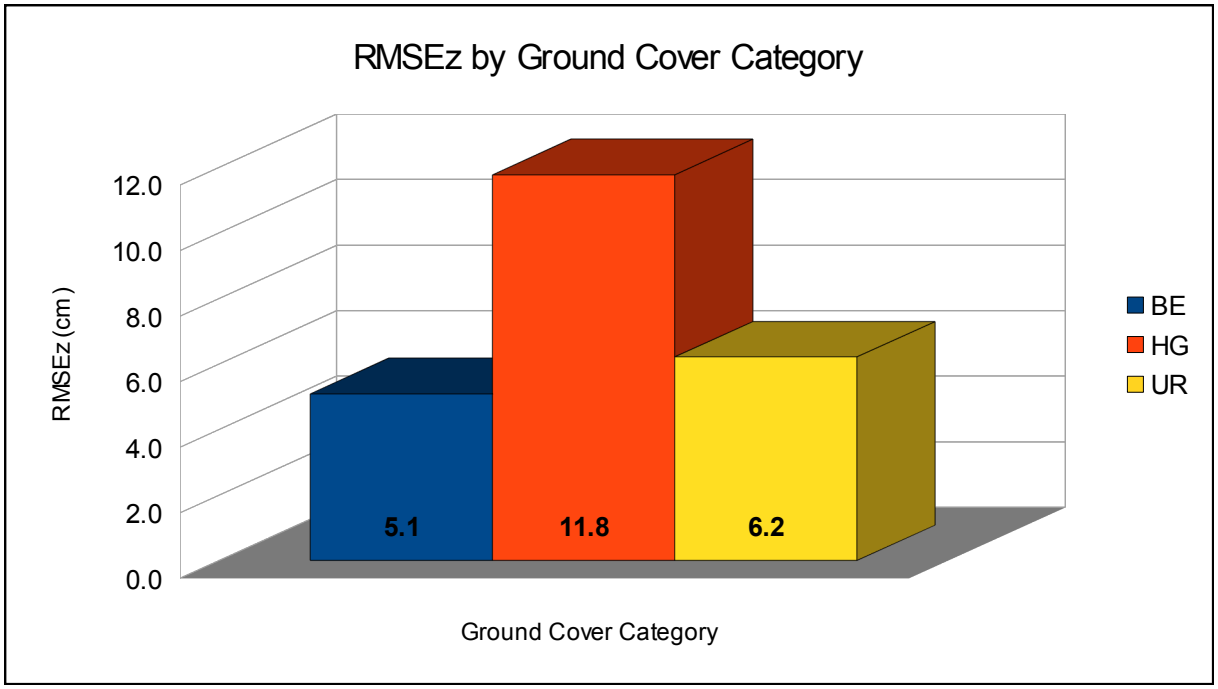
Drawing 1: SVA Values by Ground Cover Category



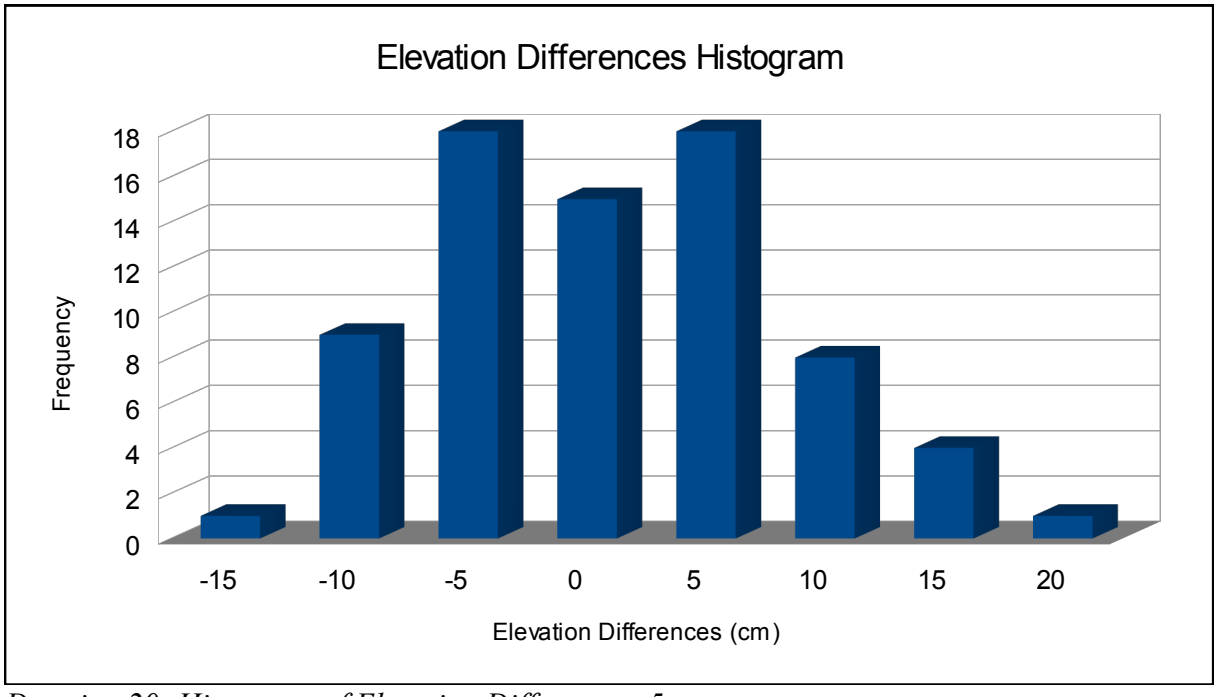
Drawing 2: Magnitude of Elevation Differences

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.



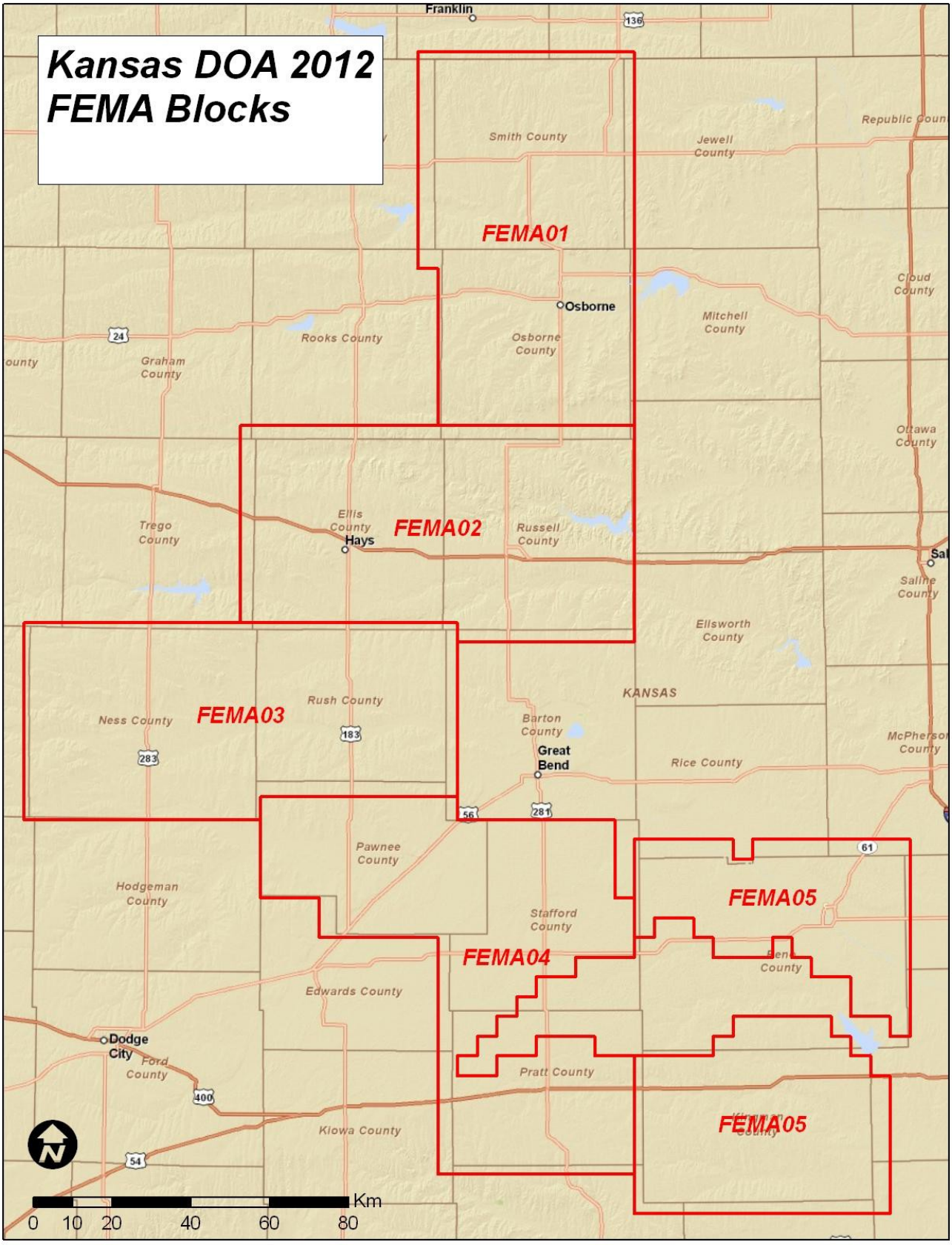
Drawing 19: RMSEz Values by Ground Cover Category

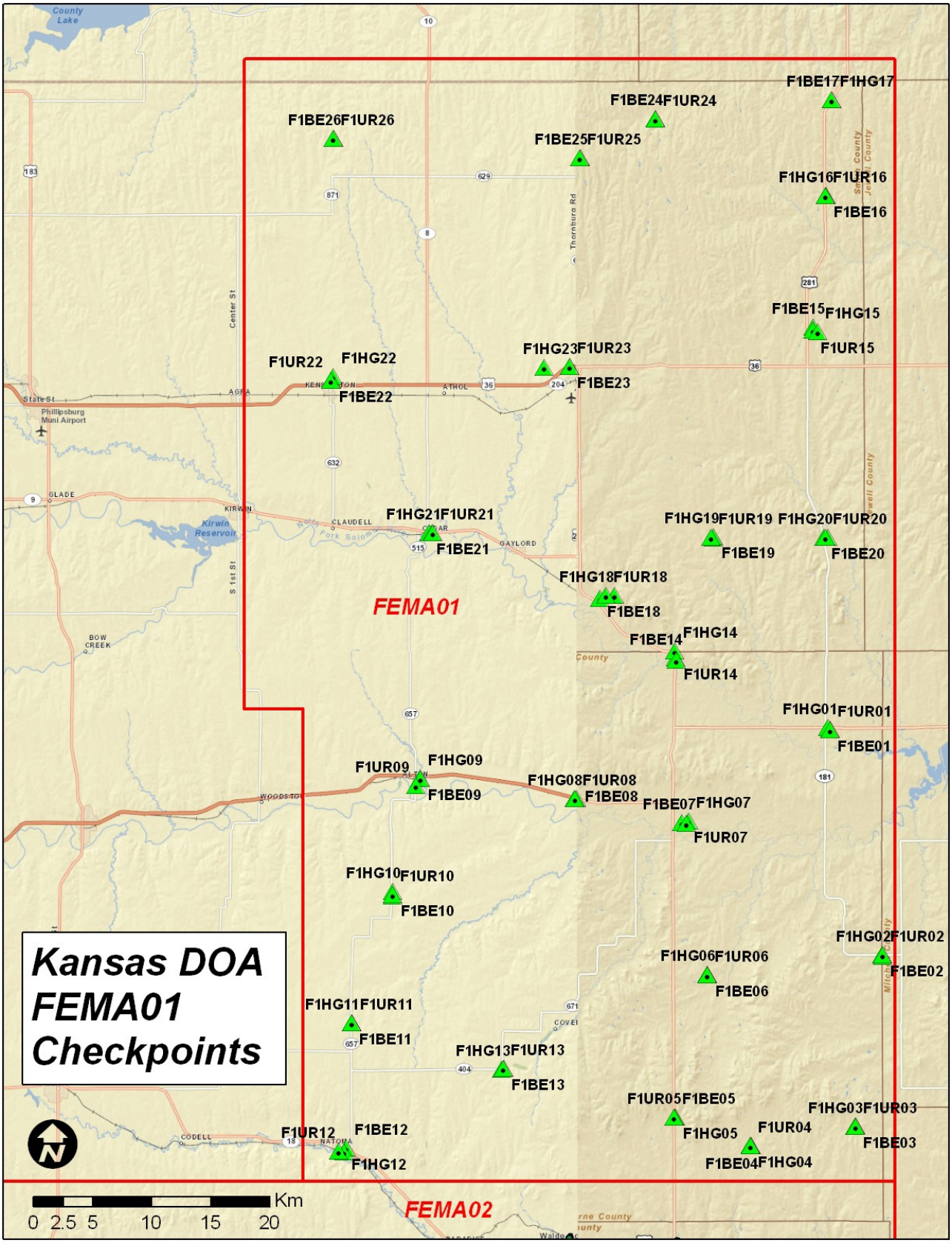


Drawing 20: Histogram of Elevation Differences, 5cm range

Land Cover Category	# of Points	RMSEz (cm)	Mean (cm)	Median (cm)	Std Dev (cm)	Min (cm)	Max (cm)	Skew
BE	26	5.1	0.1	-0.1	5.2	-7.8	9.1	0.069
HG	23	11.8	9.6	9.6	7.0	-1.0	23.8	0.167
UR	25	6.2	1.0	-0.4	6.3	-10.1	12.1	0.088
Consolidated	74	8.1	3.4	3.4	7.4	-10.1	23.8	0.453

Table 20: Overall Descriptive Statistics by Ground Cover Category


Kansas DOA 2012
FEMA Blocks
Franklin
136
Smith County
Jewell County
Republic Coun
FEMA01
Osborne
Cloud County
Mitchell County
24
Rooks County
Osborne County
ounty
Graham County
Ottawa County
Ellis County
Hays
FEMA02
Russell County
Trego County
Saline County
Ellsworth County
KANSAS
Rush County
FEMA03
Ness County
183
283
Barton County
Great Bend
McPherson County
Rice County
56
281
61
Pawnee County
Hodgeman County
FEMA05
Stafford County
FEMA04
Edwards County
Dodge City
Ford County
400
Pratt County
Kiowa County
54
FEMA05
Km
0 10 20 40 60 80


F1BE17F1HG17
F1BE24F1UR24
F1BE26F1UR26
F1BE25F1UR25
F1HG16F1UR16
F1BE16
F1BE15F1HG15
F1UR15
F1HG23F1UR23
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F1HG22
F1BE23
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F1HG21F1UR21
F1BE21
F1HG19F1UR19
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F1BE01
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F1HG13F1UR13
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F1HG05
F1UR04
F1BE03
F1BE04F1HG04
F1UR12
F1BE12
F1HG12
FEMA02
Kansas DOA
FEMA01
Checkpoints
Km
0 2.5 5 10 15 20

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.

2012 State of Kansas, DASC

Area FEMA02

Vertical Accuracy Assessment Report

Background

The National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS) 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
- High Grass (**HG**) – High Grass, Weeds, Crops
- Urban (**UR**) – Urban, Hard Surface

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) 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 FEMA02 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 4: 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	22	13.4		13.9
HG	22			29.3
UR	22			10.5
Consolidated	66		22.7	

Table 5: Computed Vertical Accuracies per Method

The digital vertical data for the FEMA02 area meets all mandatory and target specifications as per the following vertical accuracy tests:

Compared with the 24.5cm FVA specification, FVA tested 13.4cm 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.

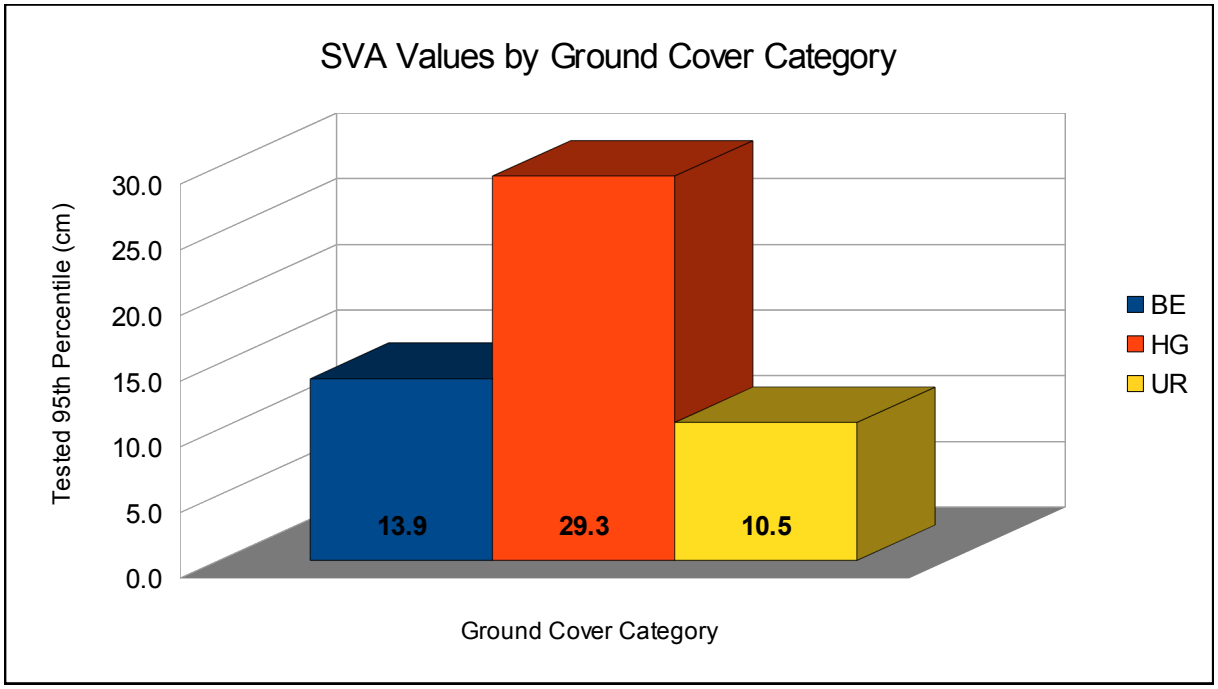
Compared with the 36.3cm CVA specification, CVA tested 22.7cm at the 95% confidence level on the BE, HG and UR ground cover categories combined, based on the 95th percentile. NDEP and ASPRS guidelines specify that vertical accuracy at the 95% confidence level equals the 95th percentile when random errors may not follow a normal distribution, as in vegetated or obstructed areas. Table 3 lists the outliers larger than the 95th percentile (22.7cm).

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 to be larger than 36.3cm. **None** exist in FEMA02 area.*
F2HG23	533895.889	4300353.039	23.6	
F2HG21	513320.456	4284108.876	24.7	
F2HG22	516629.789	4303224.545	29.5	
F2HG08	473543.539	4328307.185	31.4	

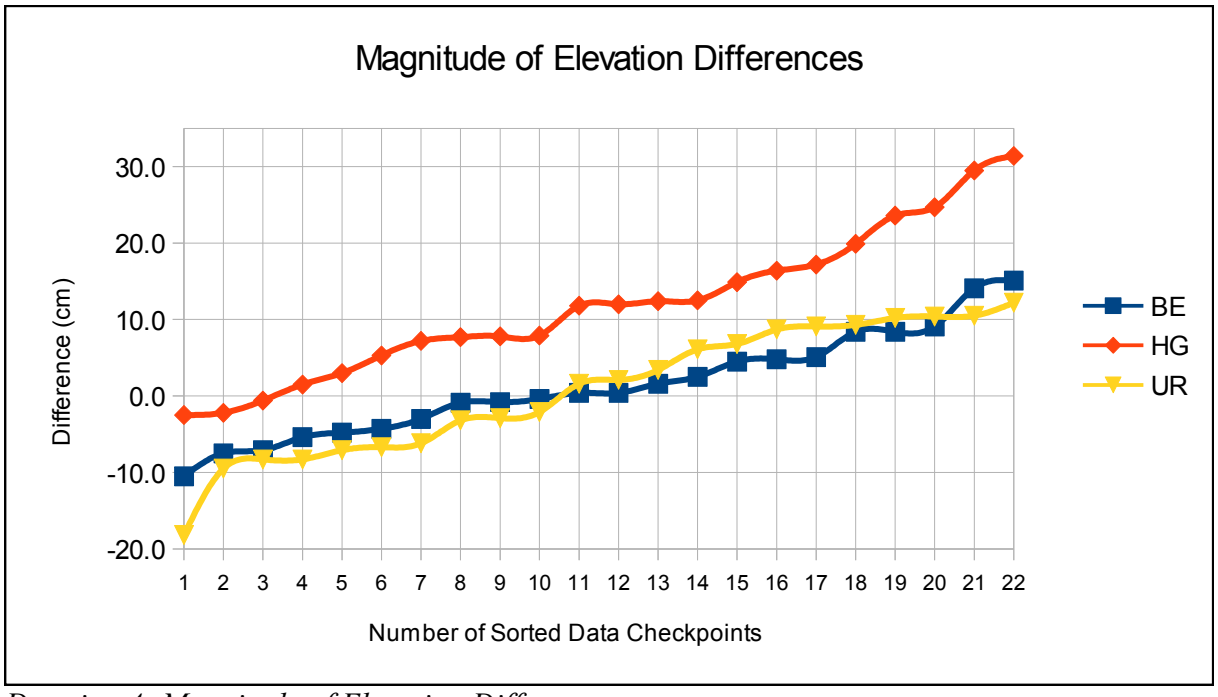
Table 6: Outliers Larger Than CVA 95th Percentile

Compared with the 36.3cm SVA target values, SVA tested 13.9cm at the 95% confidence level in BE; 29.3cm in HG and 10.5cm in the UR 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.



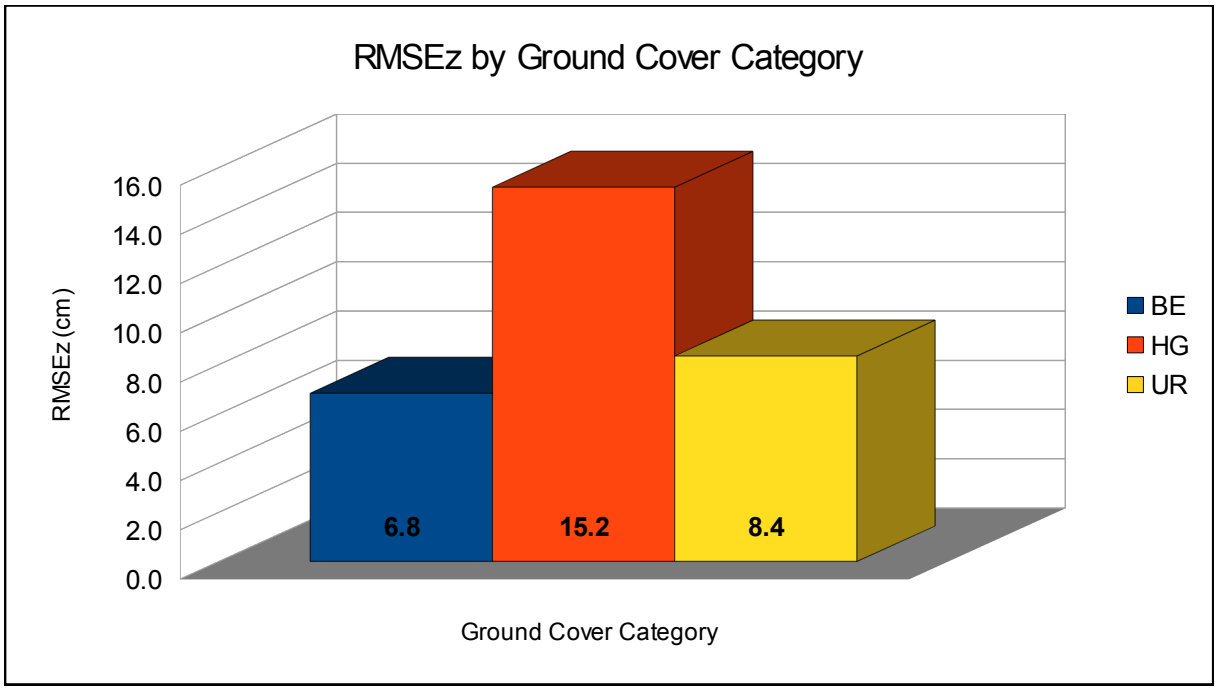
Drawing 3: SVA Values by Ground Cover Category



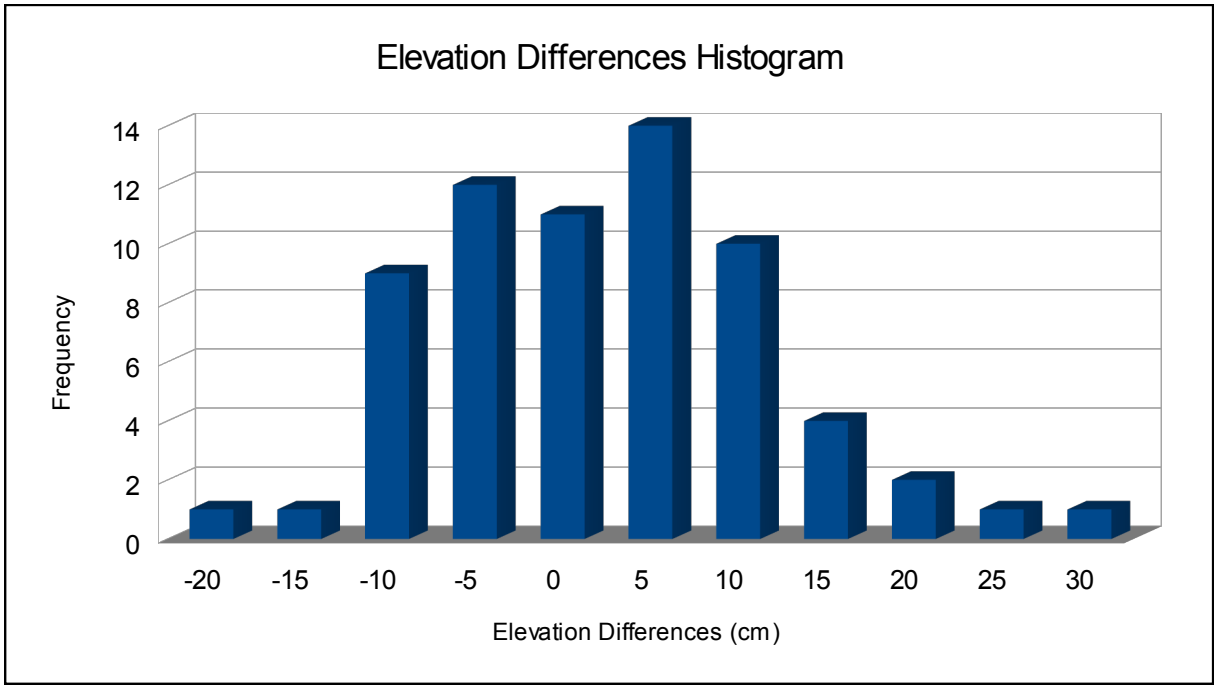
Drawing 4: Magnitude of Elevation Differences

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

The NSSDA and FEMA 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.



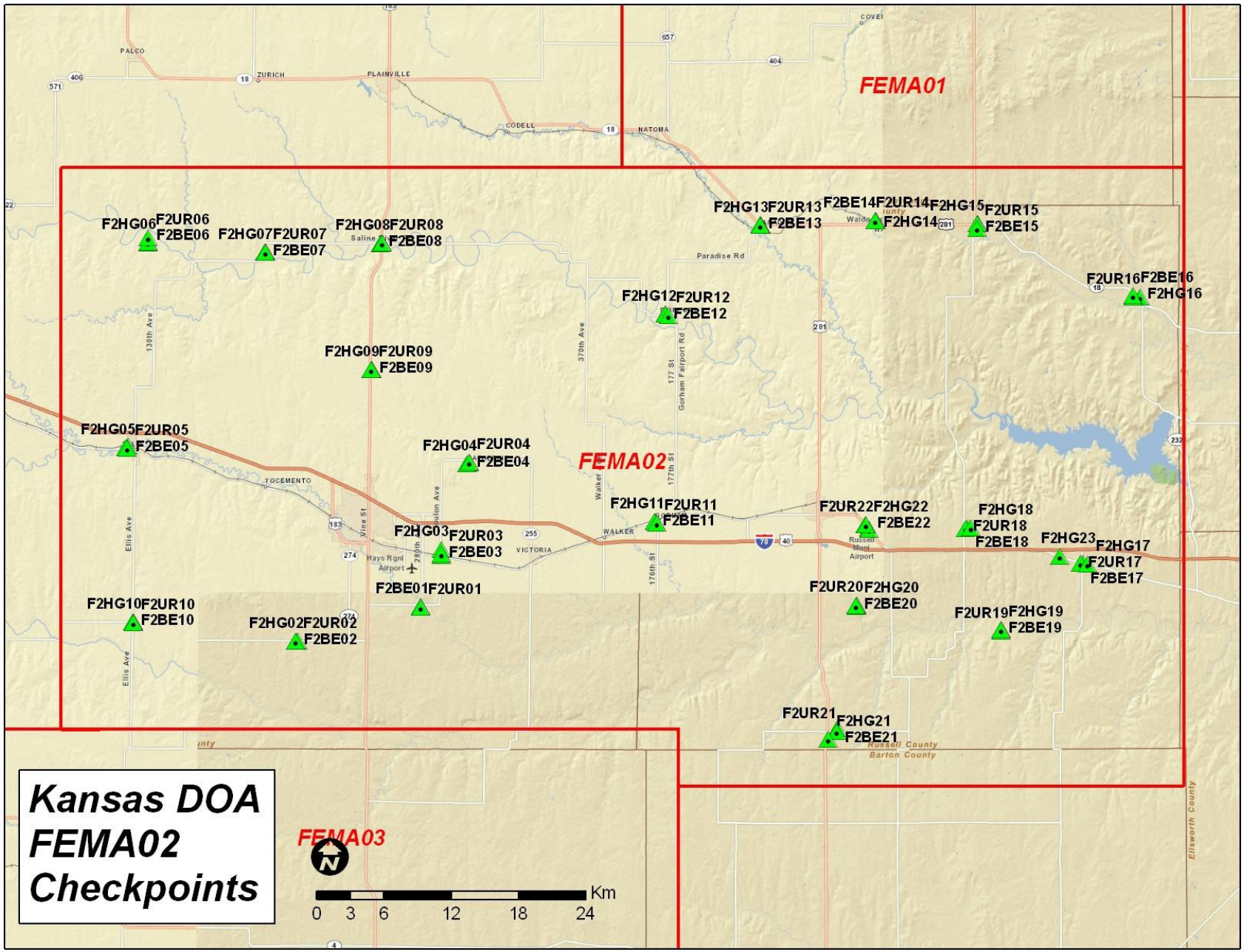
Drawing 5: RMSEz Values by Ground Cover Category



Drawing 6: Histogram of Elevation Differences, 5cm range

Land Cover Category	# of Points	RMSEz (cm)	Mean (cm)	Median (cm)	Std Dev (cm)	Min (cm)	Max (cm)	Skew
BE	22	6.8	1.4	0.4	6.9	-10.5	15.1	0.353
HG	22	15.2	11.9	11.9	9.7	-2.5	31.4	0.417
UR	22	8.4	0.8	1.9	8.5	-18.2	12.2	-0.404
Consolidated	66	10.8	4.7	4.7	9.8	-18.2	31.4	0.444

Table 7: Overall Descriptive Statistics by Ground Cover Category


FEMA01
FEMA02
FEMA03
F2HG06 F2UR06 F2BE06
F2HG07 F2UR07 F2BE07
F2HG08 F2UR08 F2BE08
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F2HG23
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F2HG03 F2UR03 F2BE03
F2HG04 F2UR04 F2BE04
F2HG05 F2UR05 F2BE05
F2BE01 F2UR01
Kansas DOA
FEMA02
Checkpoints
Km
0 3 6 12 18 24

2012 State of Kansas, DASC

Area FEMA03

Vertical Accuracy Assessment Report

Background

The National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS) 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:

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- Urban (**UR**) – Urban, Hard Surface

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) 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 FEMA03 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.
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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 8: 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	23	11.4		8.7
HG	23			19.5
UR	23			7.9
Consolidated	69		17.6	

Table 9: Computed Vertical Accuracies per Method

The digital vertical data for the FEMA03 area meets all mandatory and target specifications as per the following vertical accuracy tests:

Compared with the 24.5cm FVA specification, FVA tested 11.4cm 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.

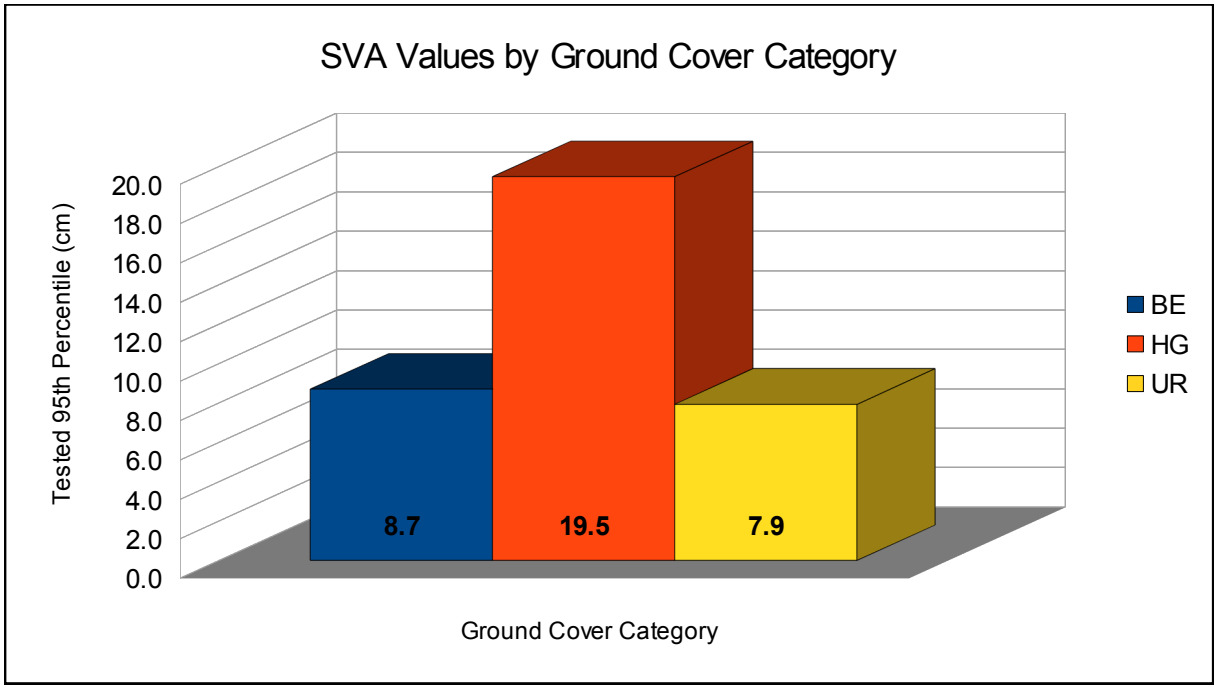
Compared with the 36.3cm CVA specification, CVA tested 17.6cm at the 95% confidence level on the BE, HG and UR ground cover categories combined, based on the 95th percentile. NDEP and ASPRS guidelines specify that vertical accuracy at the 95% confidence level equals the 95th percentile when random errors may not follow a normal distribution, as in vegetated or obstructed areas. Table 3 lists the outliers larger than the 95th percentile (17.6cm).

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 to be larger than 36.3cm. **None** exist in FEMA03 area.*
F3HG02	432648.460	4238342.494	18.4	
F3HG20	494686.356	4265358.805	19.3	
F3HG15	461667.749	4258398.414	19.5	
F3HG13	473759.022	4264611.530	22.6	

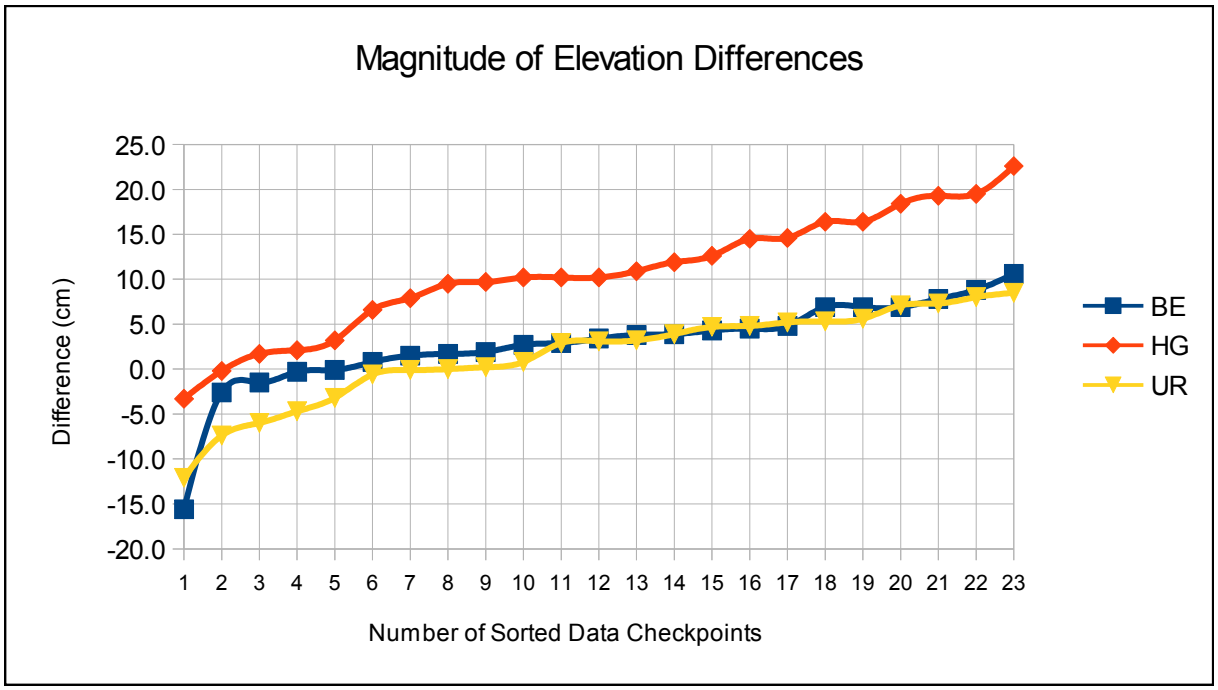
Table 10: Outliers Larger Than CVA 95th Percentile

Compared with the 36.3cm SVA target values, SVA tested 8.7cm at the 95% confidence level in BE; 19.5cm in HG and 7.9cm in the UR 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.



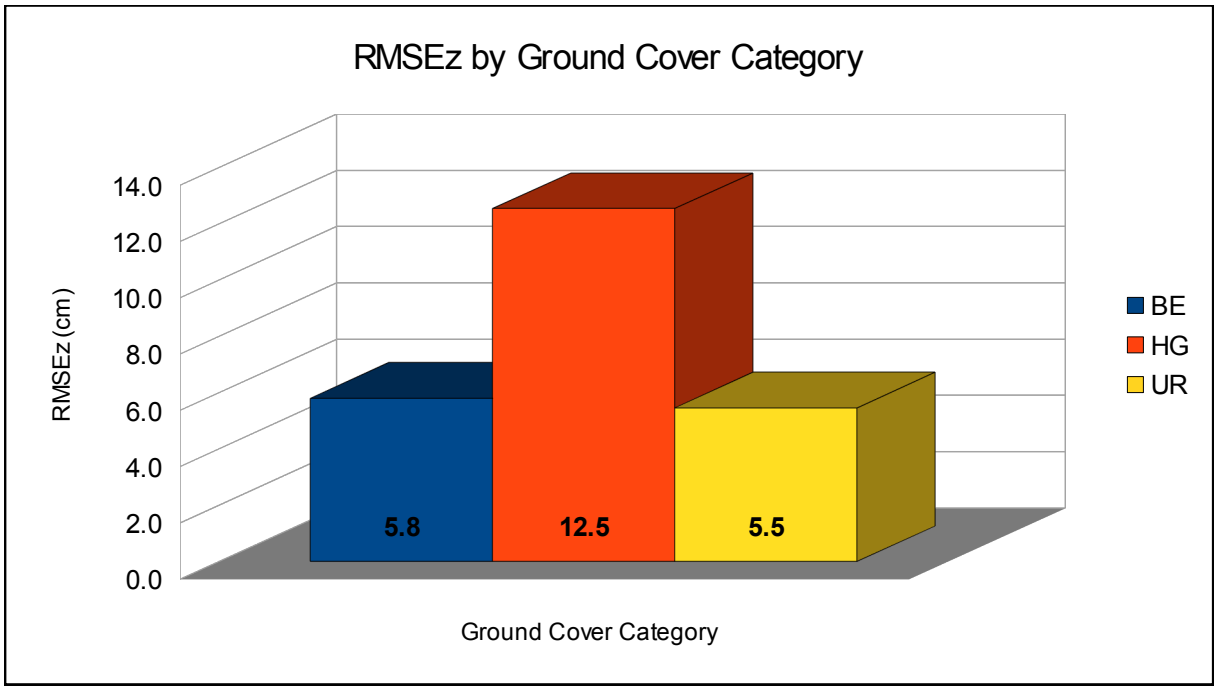
Drawing 7: SVA Values by Ground Cover Category



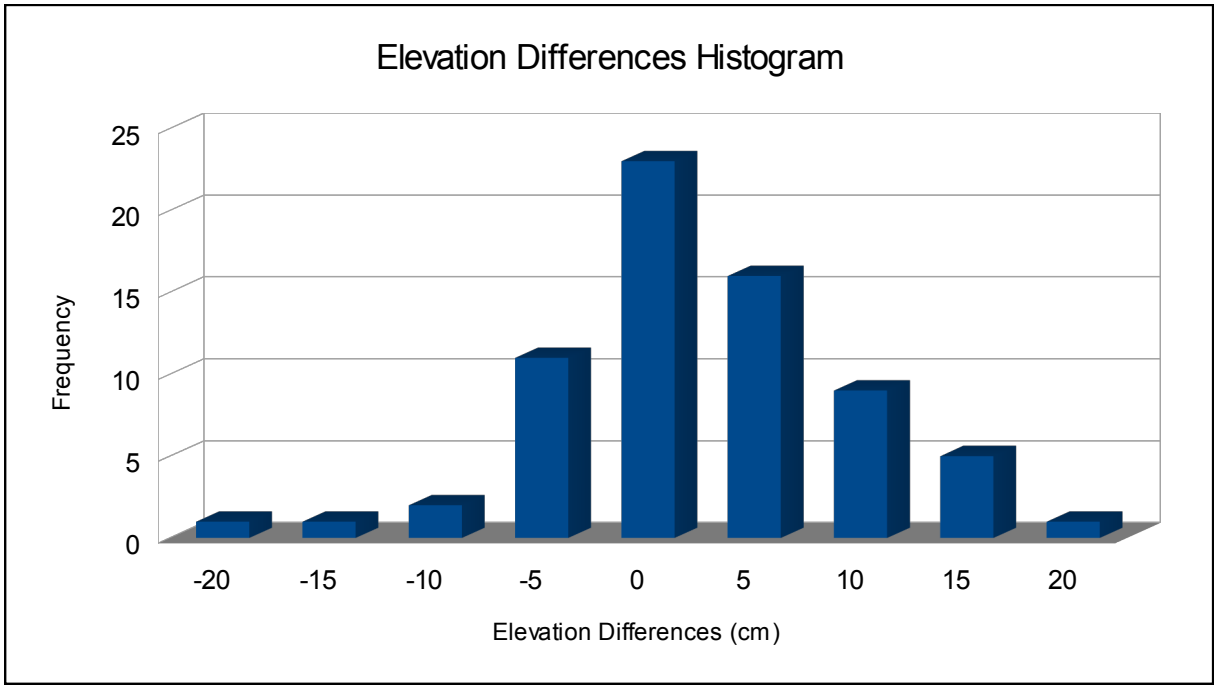
Drawing 8: Magnitude of Elevation Differences

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

The NSSDA and FEMA 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.



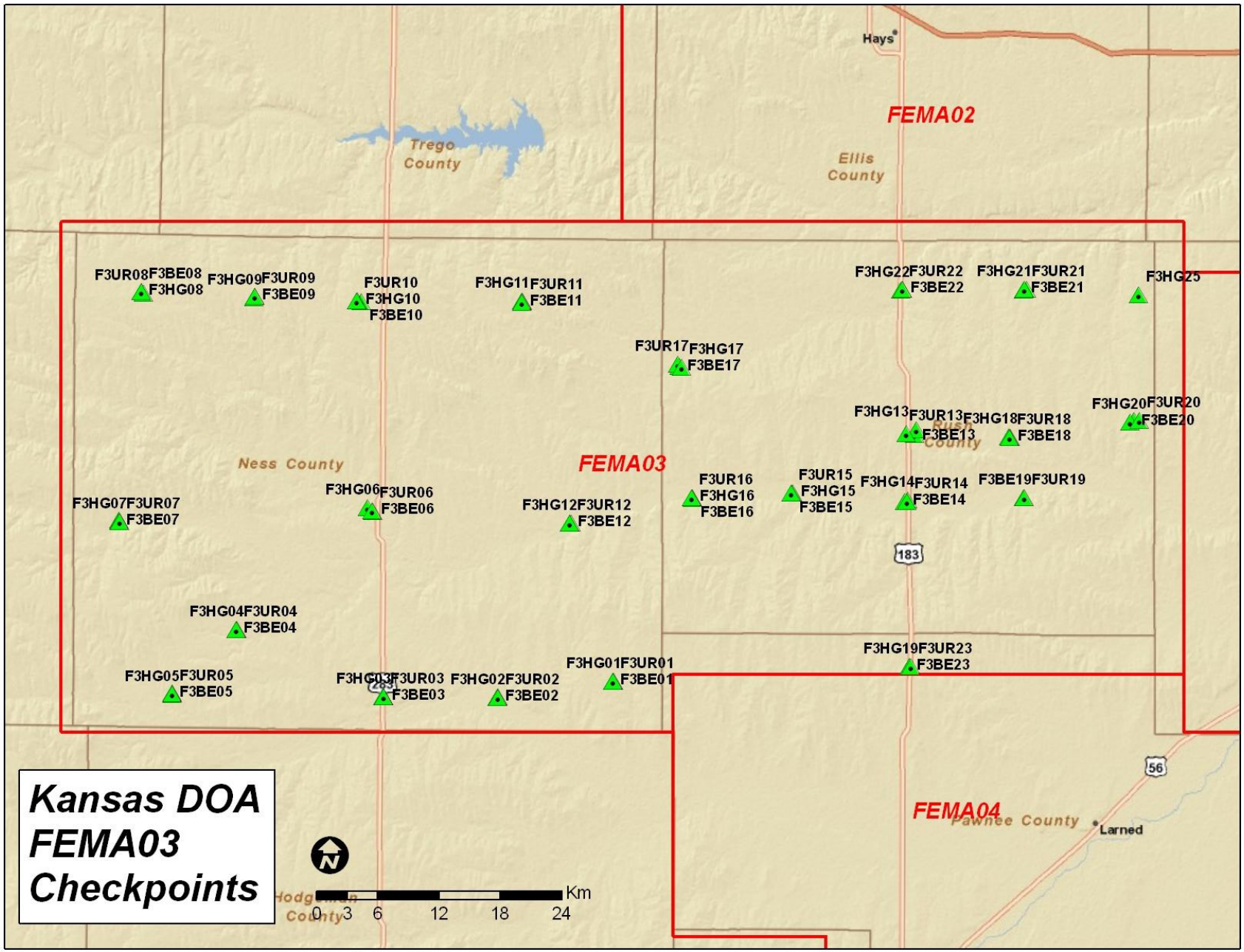
Drawing 9: RMSEz Values by Ground Cover Category



Drawing 10: Histogram of Elevation Differences, 5cm range

Land Cover Category	# of Points	RMSEz (cm)	Mean (cm)	Median (cm)	Std Dev (cm)	Min (cm)	Max (cm)	Skew
BE	23	5.8	2.8	3.4	5.2	-15.6	10.6	-1.928
HG	23	12.5	10.6	10.2	6.8	-3.3	22.6	-0.292
UR	23	5.5	1.6	3.1	5.3	-12.1	8.5	-0.951
Consolidated	69	8.6	5.0	4.5	7.0	-15.6	22.6	-0.027

Table 11: Overall Descriptive Statistics by Ground Cover Category


Kansas DOA
FEMA03
Checkpoints
FEMA02
FEMA03
FEMA04
Hays
Trego County
Ellis County
Ness County
Rush County
Pawnee County
Larned
Hodgeman County
183
56
F3UR08 F3BE08 F3HG08
F3HG09 F3UR09 F3BE09
F3UR10 F3HG10 F3BE10
F3HG11 F3UR11 F3BE11
F3HG22 F3UR22 F3BE22
F3HG21 F3UR21 F3BE21
F3HG25
F3UR17 F3HG17 F3BE17
F3HG13 F3UR13 F3BE13
F3HG18 F3UR18 F3BE18
F3HG20 F3UR20 F3BE20
F3HG07 F3UR07 F3BE07
F3HG06 F3UR06 F3BE06
F3HG12 F3UR12 F3BE12
F3UR16 F3HG16 F3BE16
F3UR15 F3HG15 F3BE15
F3HG14 F3UR14 F3BE14
F3BE19 F3UR19
F3HG04 F3UR04 F3BE04
F3HG19 F3UR23 F3BE23
F3HG05 F3UR05 F3BE05
F3HG03 F3UR03 F3BE03
F3HG02 F3UR02 F3BE02
F3HG01 F3UR01 F3BE01
N
0 3 6 12 18 24 Km

2012 State of Kansas, DOA

Area FEMA04

Vertical Accuracy Assessment Report

Background

The National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS) 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
- High Grass (**HG**) – High Grass, Weeds, Crops
- Urban (**UR**) – Urban, Hard Surface

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) 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 FEMA04 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 12: 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	33	11.1		11.1
HG	32			22.8
UR	33			5.4
Consolidated	98		19.7	

Table 13: Computed Vertical Accuracies per Method

The digital vertical data for the FEMA04 area meets all mandatory and target specifications as per the following vertical accuracy tests:

Compared with the 24.5cm FVA specification, FVA tested 11.1cm 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.

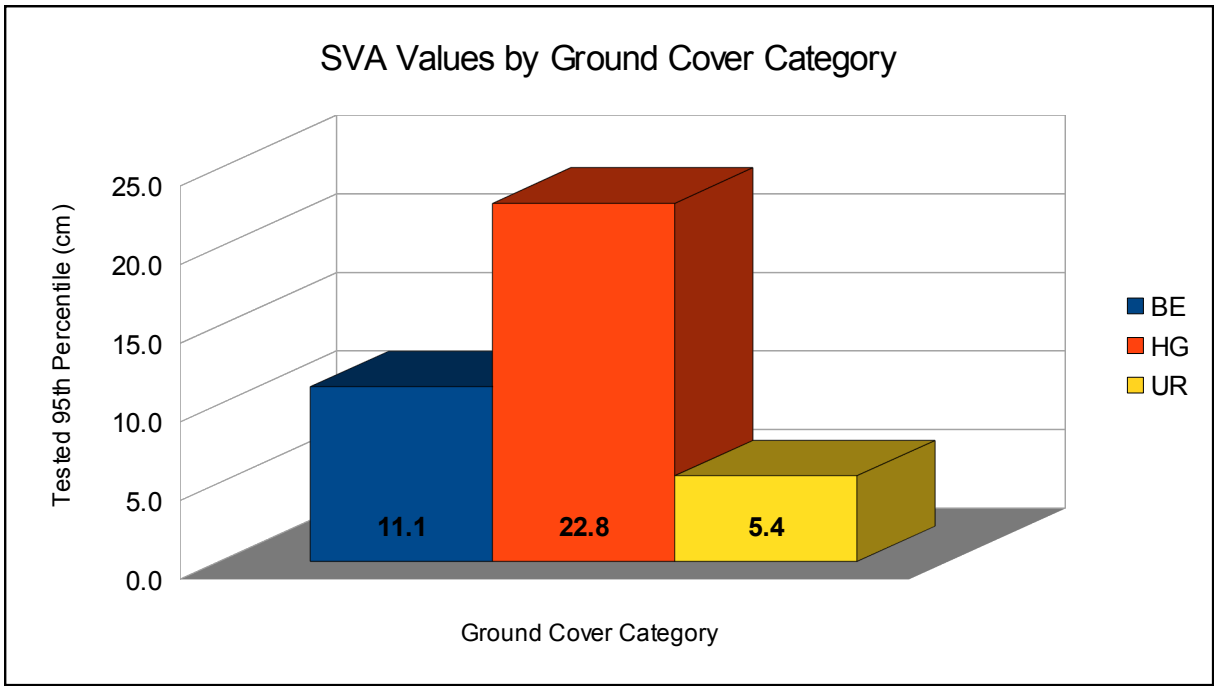
Compared with the 36.3cm CVA specification, CVA tested 19.7cm at the 95% confidence level on the BE, HG and UR ground cover categories combined, based on the 95th percentile. NDEP and ASPRS guidelines specify that vertical accuracy at the 95% confidence level equals the 95th percentile when random errors may not follow a normal distribution, as in vegetated or obstructed areas. Table 3 lists the outliers larger than the 95th percentile (19.7cm).

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 to be larger than 36.3cm. **None** exist in FEMA04 area.*
F4HG04	514062.482	4205808.459	20.7	
F4HG23	539262.494	4150391.922	20.8	
F4HG03	502344.031	4212269.984	22.5	
F4HG12	452129.415	4238276.594	23.1	
F4HG21	502843.094	4202497.039	29.2	

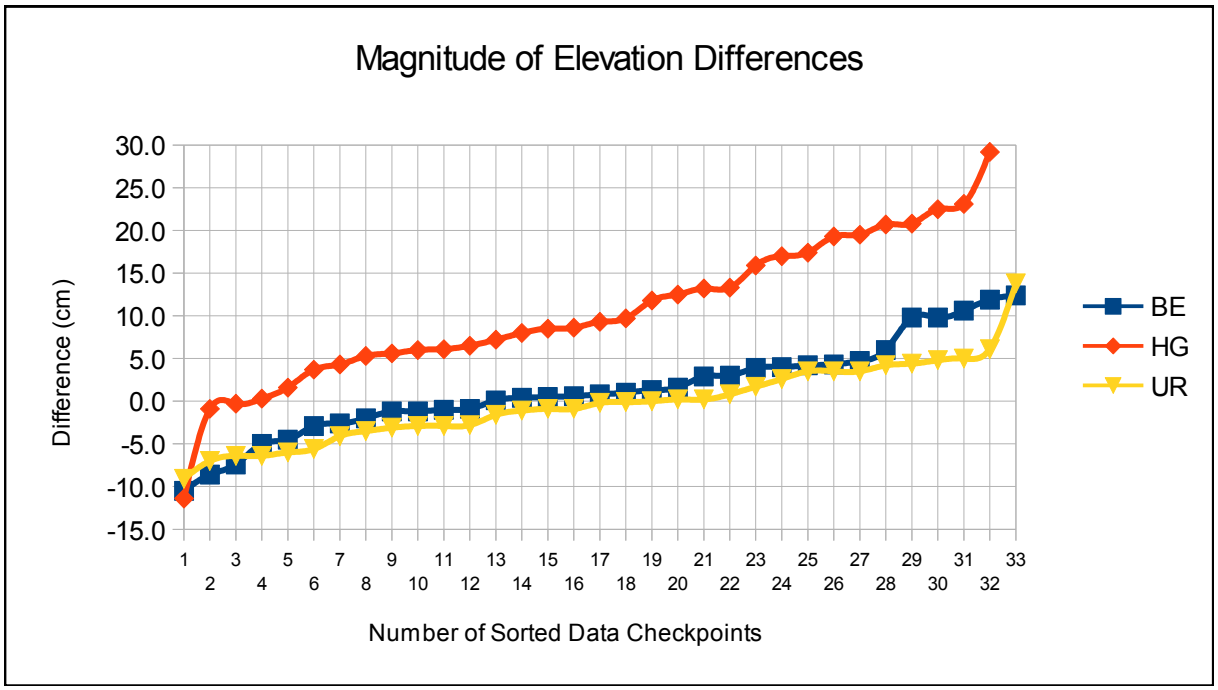
Table 14: Outliers Larger Than CVA 95th Percentile

Compared with the 36.3cm SVA target values, SVA tested 11.1cm at the 95% confidence level in BE; 22.8cm in HG and 5.4cm in the UR 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.



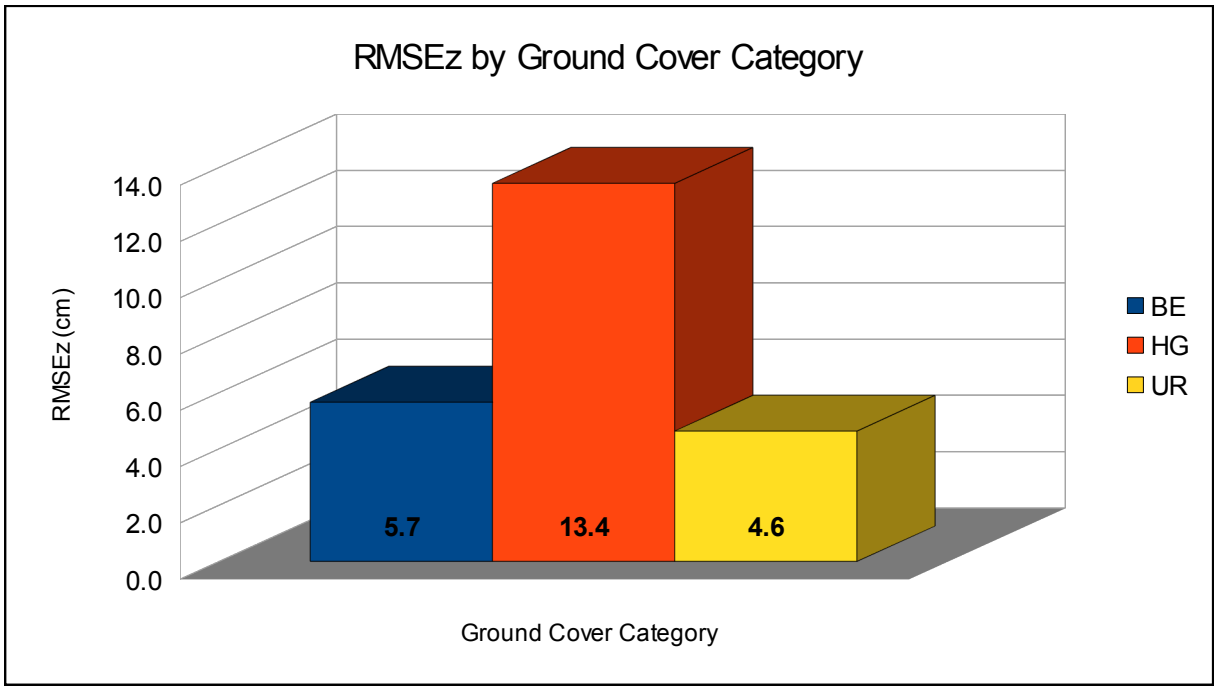
Drawing 11: SVA Values by Ground Cover Category



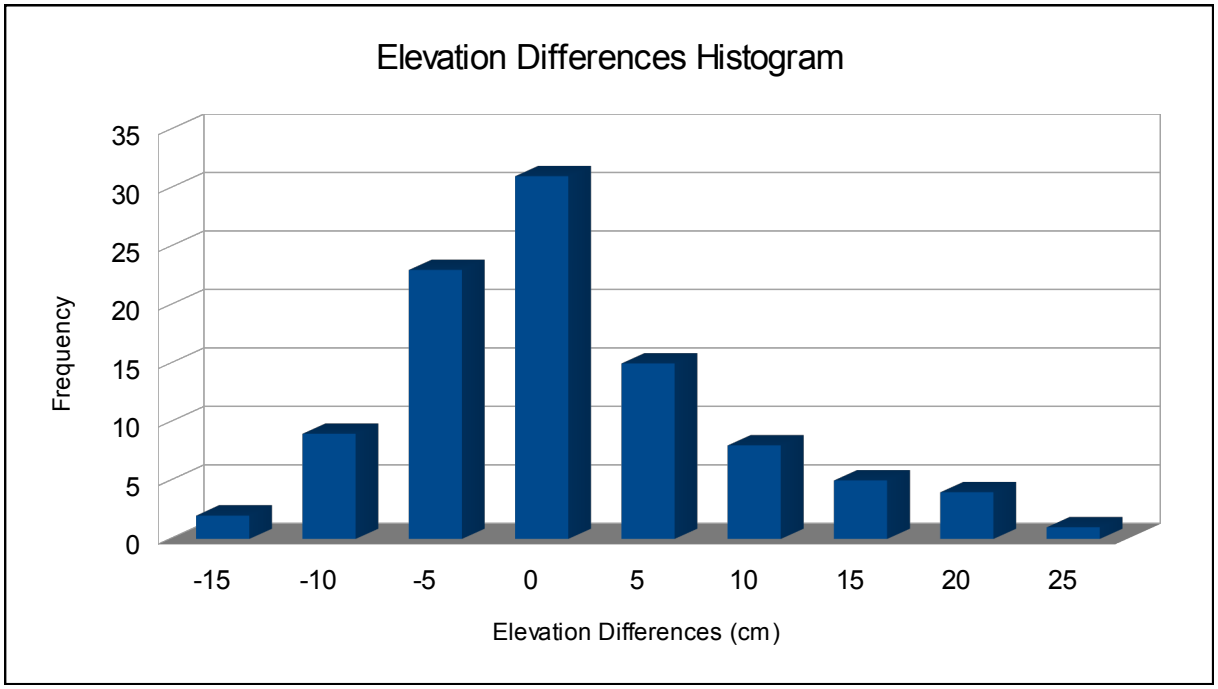
Drawing 12: Magnitude of Elevation Differences

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

The NSSDA and FEMA 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.



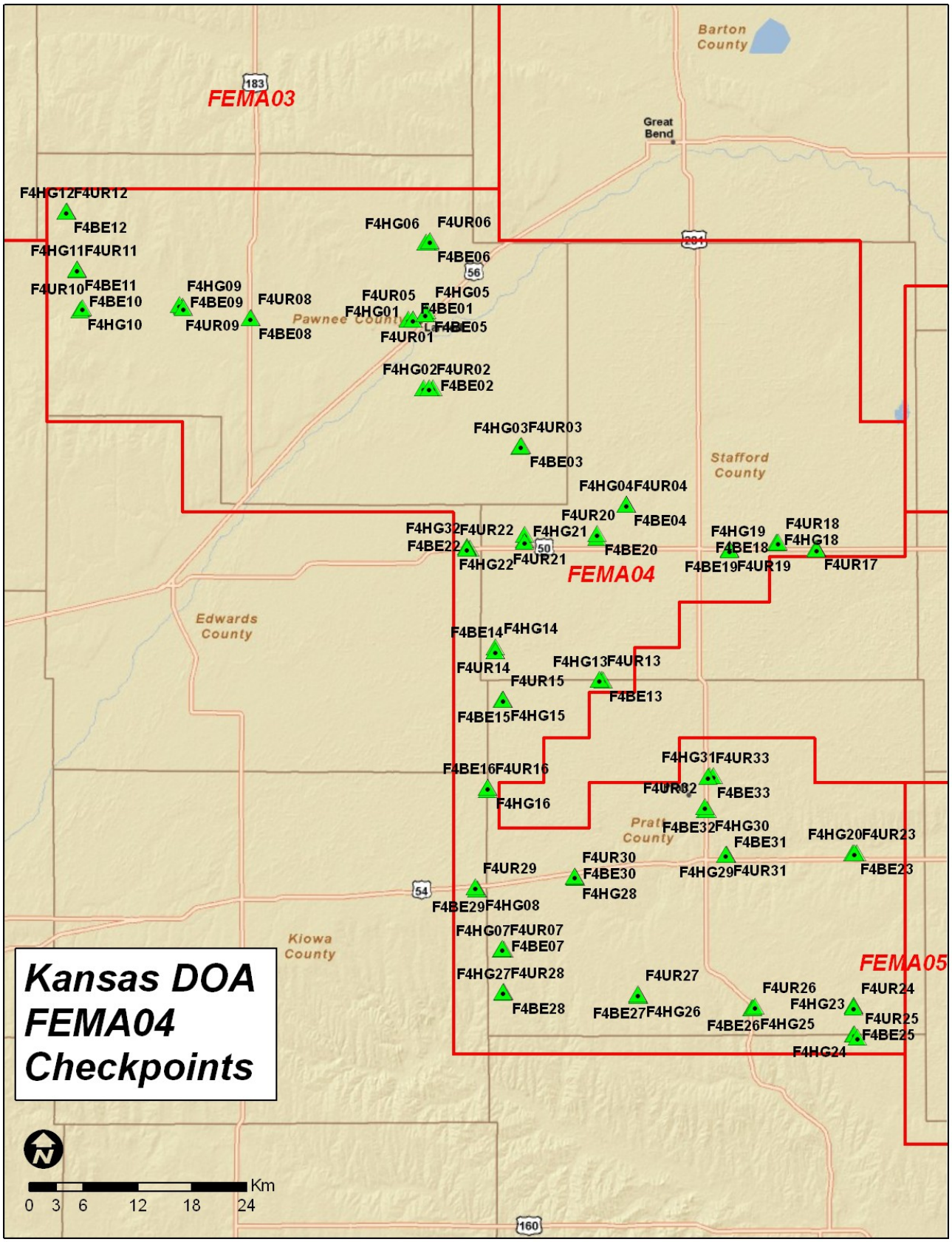
Drawing 13: RMSEz Values by Ground Cover Category



Drawing 14: Histogram of Elevation Differences, 5cm range

Land Cover Category	# of Points	RMSEz (cm)	Mean (cm)	Median (cm)	Std Dev (cm)	Min (cm)	Max (cm)	Skew
BE	33	5.7	1.4	0.8	5.6	-10.5	12.4	0.117
HG	32	13.4	10.4	9.0	8.6	-11.4	29.2	-0.061
UR	33	4.6	-0.3	-0.2	4.7	-9.1	13.8	0.378
Consolidated	98	8.8	3.8	2.8	8.0	-11.4	29.2	0.795

Table 15: Overall Descriptive Statistics by Ground Cover Category


Kansas DOA
FEMA04
Checkpoints
FEMA03
FEMA04
FEMA05
Barton County
Great Bend
Pawnee County
Stafford County
Edwards County
Kiowa County
Pratt County
F4HG12F4UR12
F4BE12
F4HG11F4UR11
F4UR10F4BE11
F4BE10
F4HG10
F4HG09
F4BE09
F4UR09
F4UR08
F4BE08
F4HG06
F4UR06
F4BE06
F4UR05
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F4HG05
F4BE01
F4BE05
F4HG02F4UR02
F4BE02
F4HG03F4UR03
F4BE03
F4HG04F4UR04
F4UR20
F4BE04
F4HG32F4UR22
F4BE22
F4HG22
F4HG21
F4UR21
F4BE20
F4HG19
F4BE18
F4BE19F4UR19
F4UR18
F4HG18
F4UR17
F4BE14F4HG14
F4UR14
F4HG13F4UR13
F4UR15
F4BE13
F4BE15F4HG15
F4BE16F4UR16
F4HG16
F4HG31F4UR33
F4UR32
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F4HG20F4UR23
F4BE23
F4UR30
F4BE30
F4HG28
F4UR29
F4BE29F4HG08
F4HG07F4UR07
F4BE07
F4HG27F4UR28
F4BE28
F4UR27
F4BE27F4HG26
F4UR26
F4BE26F4HG25
F4HG23
F4UR24
F4UR25
F4BE25
F4HG24
0 3 6 12 18 24
Km

2012 State of Kansas, DASC

Area FEMA05

Vertical Accuracy Assessment Report

Background

The National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS) 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
- High Grass (**HG**) – High Grass, Weeds, Crops
- Urban (**UR**) – Urban, Hard Surface

There were 7 Brush (BR) checkpoints mistakenly collected in the FEMA05 area. These points were included in the HG category in addition to the 21 HG checkpoints.

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) 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 FEMA05 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 16: 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	20	12.4		8.2
HG	28			15.9
UR	24			4.6
Consolidated	72		13.8	

Table 17: Computed Vertical Accuracies per Method

The digital vertical data for the FEMA05 area meets all mandatory and target specifications as per the following vertical accuracy tests:

Compared with the 24.5cm FVA specification, FVA tested 12.4cm 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.

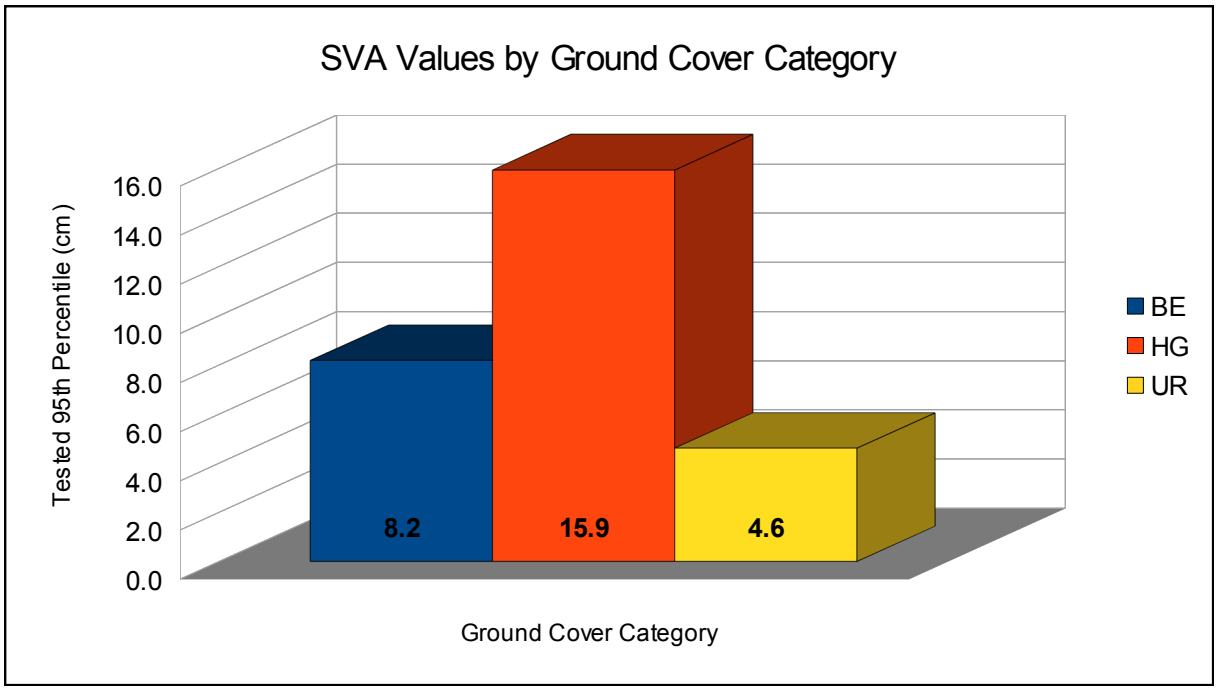
Compared with the 36.3cm CVA specification, CVA tested 13.8cm at the 95% confidence level on the BE, HG and UR ground cover categories combined, based on the 95th percentile. NDEP and ASPRS guidelines specify that vertical accuracy at the 95% confidence level equals the 95th percentile when random errors may not follow a normal distribution, as in vegetated or obstructed areas. Table 3 lists the outliers larger than the 95th percentile (13.8cm).

PT ID	*X UTM 14N (m)*	*Y UTM 14N (m)*	*Elev. Diff (cm)*	
F5HG20	551154.431	4143883.506	14.6	*The errors in **bold** are larger than the CVA standard (36.3cm) which permits up to 5% of the checkpoints to be larger than 36.3cm. **None** exist in FEMA05 area.*
F5HG02	607856.289	4222618.042	15.8	
F5HG18	574040.608	4144283.917	16.0	
F5BE08	554999.038	4212344.772	17.8	
F5UR02	592399.309	4211989.963	18.0	
F5BR07	569809.982	4202552.680	20.0	

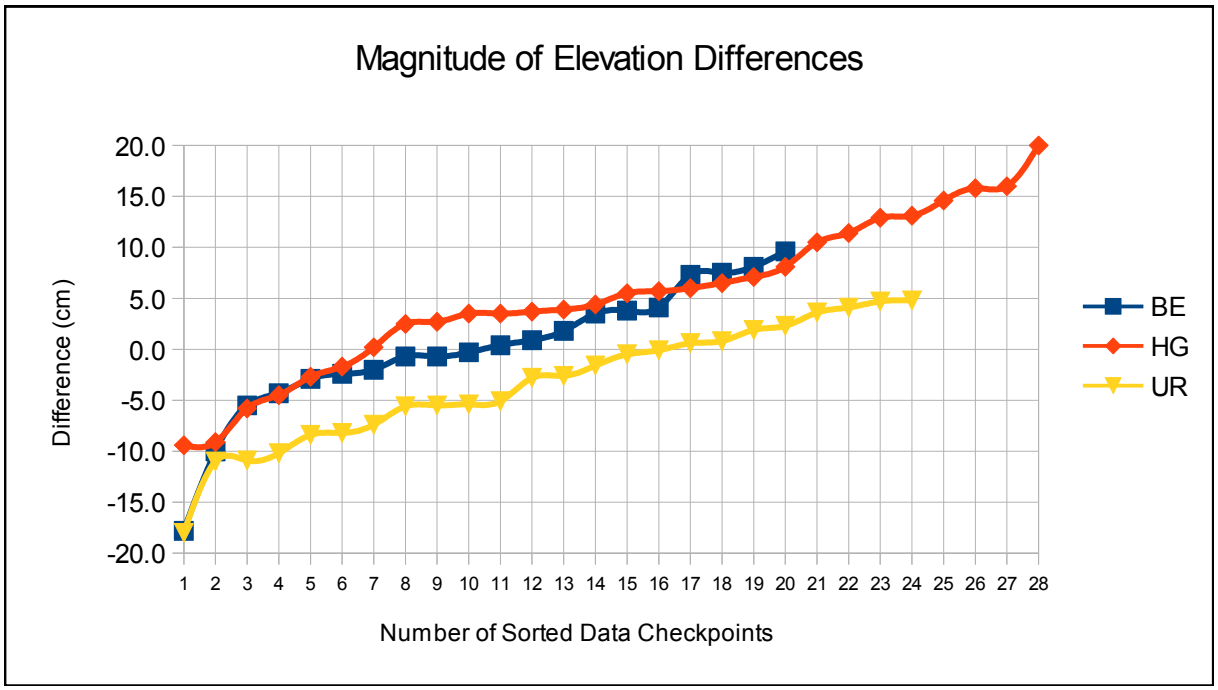
Table 18: Outliers Larger Than CVA 95th Percentile

Compared with the 36.3cm SVA target values, SVA tested 8.2cm at the 95% confidence level in BE; 15.9cm in HG and 4.6cm in the UR 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.



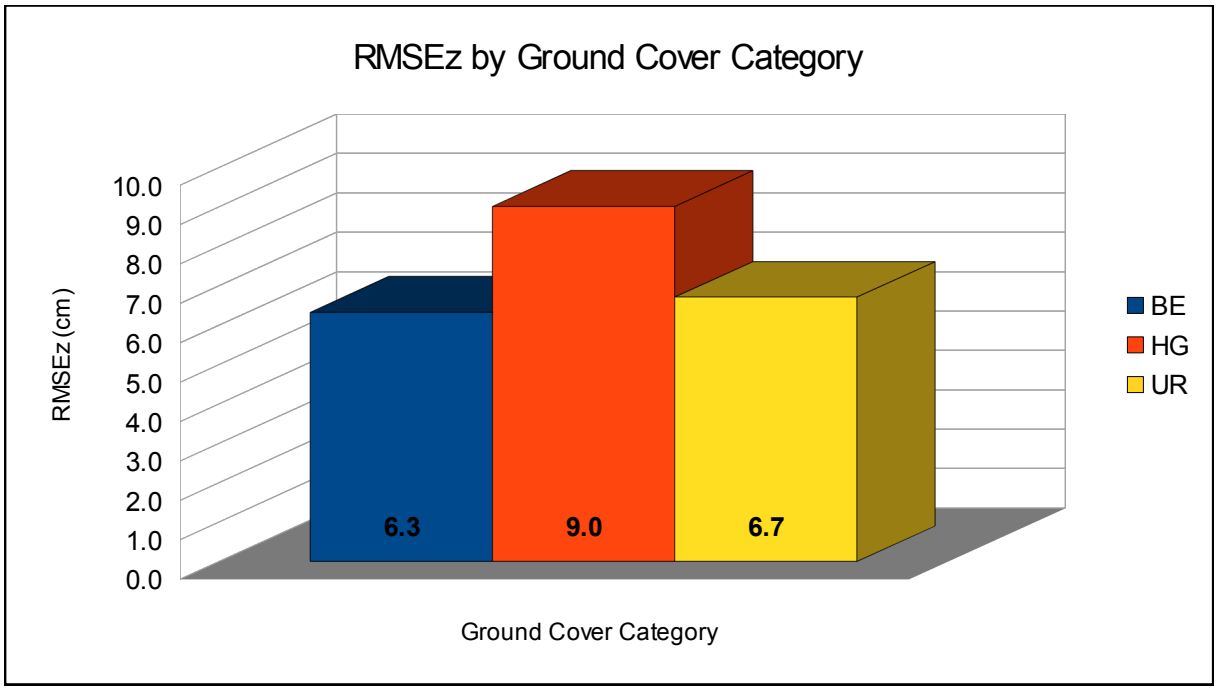
Drawing 15: SVA Values by Ground Cover Category



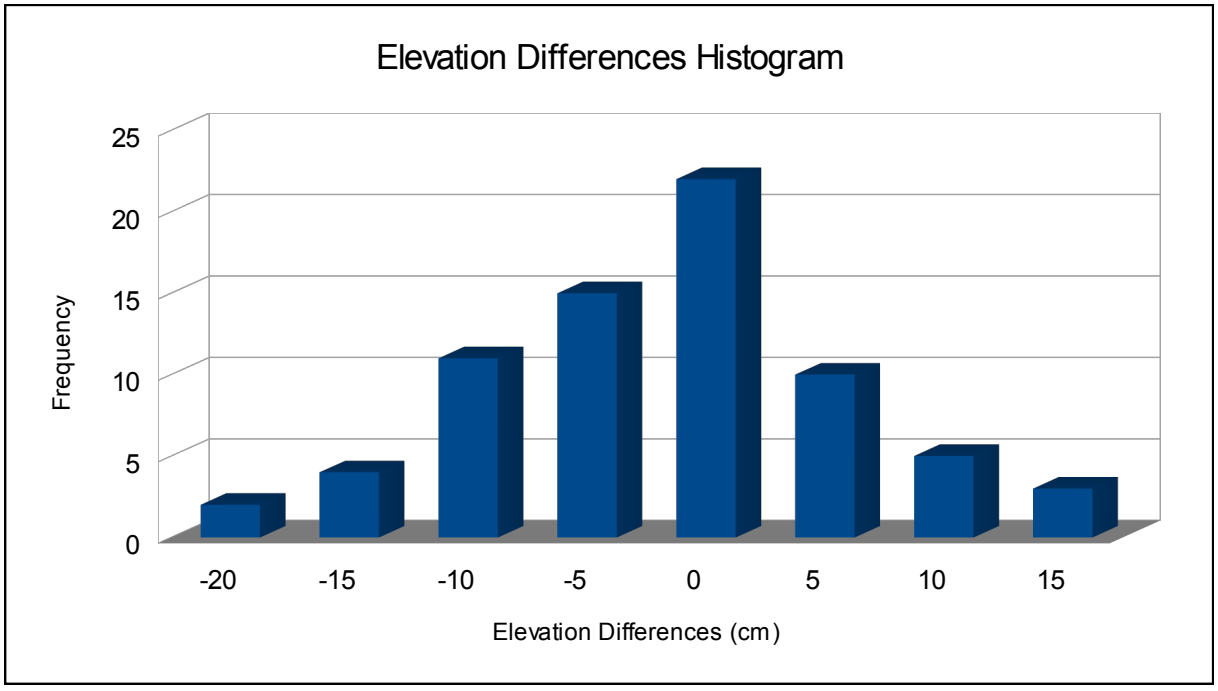
Drawing 16: Magnitude of Elevation Differences

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

The NSSDA and FEMA 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.



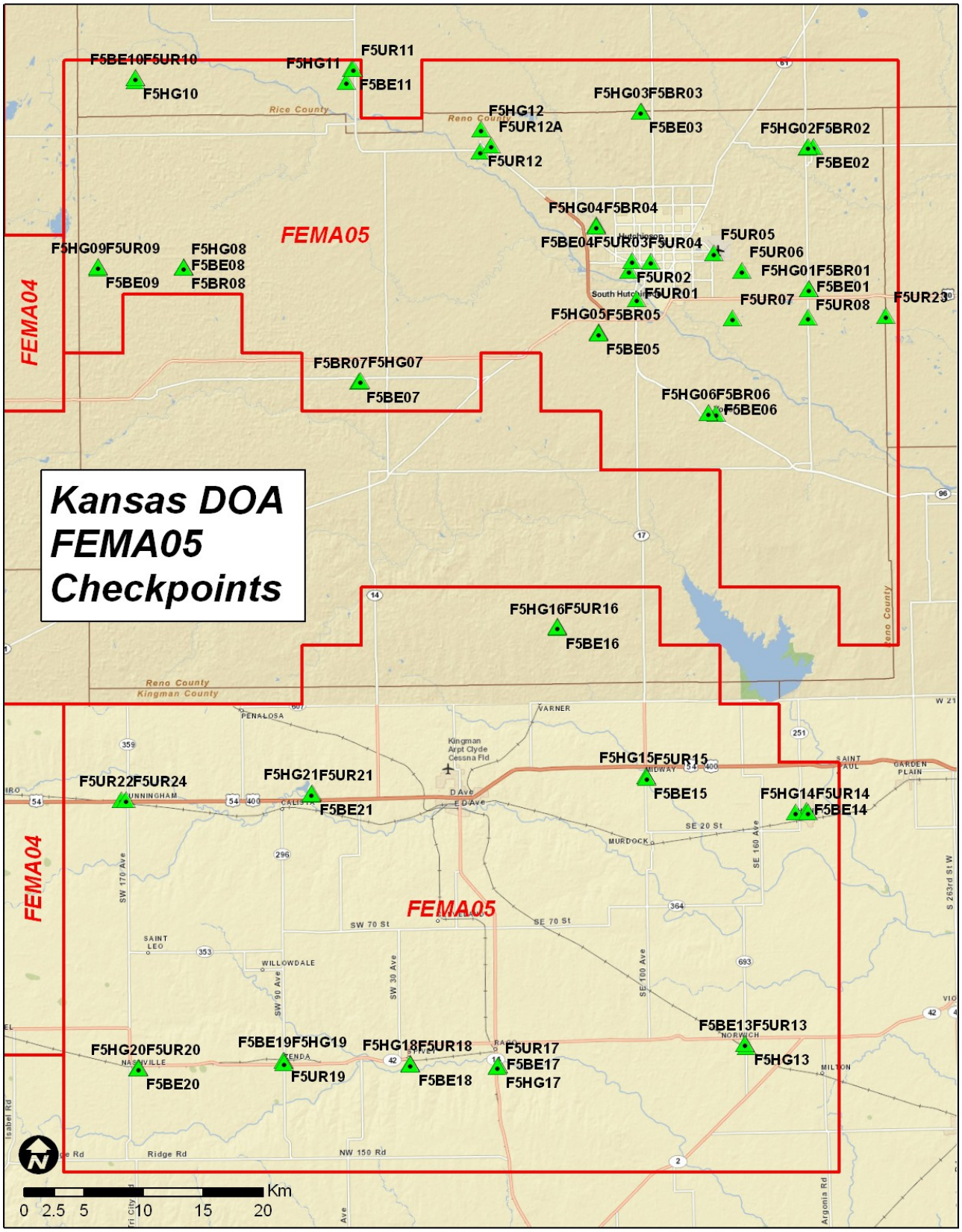
Drawing 17: RMSEz Values by Ground Cover Category



Drawing 18: Histogram of Elevation Differences, 5cm range

Land Cover Category	# of Points	RMSEz (cm)	Mean (cm)	Median (cm)	Std Dev (cm)	Min (cm)	Max (cm)	Skew
BE	20	6.3	0.0	0.1	6.5	-17.8	9.6	-0.981
HG	28	9.0	5.2	5.0	7.5	-9.4	20.0	-0.111
UR	24	6.7	-3.4	-2.7	5.9	-18.0	4.8	-0.533
Consolidated	72	7.6	0.9	0.9	7.6	-18.0	20.0	-0.020

Table 19: Overall Descriptive Statistics by Ground Cover Category


Kansas DOA
FEMA05
Checkpoints
FEMA04
FEMA05
FEMA04
FEMA05
F5BE10F5UR10
F5HG10
F5HG11
F5UR11
F5BE11
F5HG12
F5UR12A
F5UR12
F5HG03F5BR03
F5BE03
F5HG02F5BR02
F5BE02
F5HG04F5BR04
F5BE04F5UR03F5UR04
F5UR05
F5UR06
F5HG01F5BR01
F5BE01
F5UR07
F5UR08
F5UR23
F5UR02
F5UR01
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F5BE05
F5HG09F5UR09
F5BE09
F5HG08
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F5BE15
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F5HG13
F5HG20F5UR20
F5BE20
F5BE19F5HG19
F5UR19
F5HG18F5UR18
F5BE18
F5UR17
F5BE17
F5HG17
Reno County
Kingman County
Rice County
Reno County
PENALOSA
VARNER
Kingman Arpt Clyde Cessna Fld
CUNNINGHAM
CALISTA
D Ave
E D Ave
MIDWAY
SAINT PAUL
GARDEN PLAIN
MURDOCK
SE 20 St
SE 160 Ave
SW 170 Ave
SW 70 St
SE 70 St
SAINT LEO
WILLOWDALE
SW 90 Ave
SW 30 Ave
SE 100 Ave
NORWICH
MILTON
NASHVILLE
ZENDA
Ridge Rd
NW 150 Rd
Isabel Rd
Argonia Rd
S 263rd St W
Km
0 2.5 5 10 15 20