CHAPTER 3

Applications and Accuracy Standards

3-1. Purpose. The purpose of this chapter is to align USACE mapping accuracy standards with the American Society for Photogrammetry and Remote Sensing (ASPRS) *Positional Accuracy Standards for Digital Geospatial Data* (ASPRS, 2014), and to identify potential user positional accuracy “needs” (not “wants”) for common USACE applications. Traditionally within USACE, aerial mapping data have been acquired and developed according to either *National Map Accuracy Standards* (NMAS, Bureau of the Budget, 1947) or ASPRS *Accuracy Standards for Large-Scale Maps* (ASPRS, 1990). Both of these standards pertain to graphic maps with a published scale and contour interval and are generally considered to be obsolete for modern mapping with digital cameras and LiDAR sensors.

a. Map Standards Evolution. With digital maps, where map scales and contour intervals can easily be altered by hitting a zoom button but without improving accuracy, new accuracy standards were devised. The *National Standard for Spatial Data Accuracy* (NSSDA), published by the Federal Geographic Data Committee (FGDC, 1998), ties accuracy to a defined value at ground scale, assuming all errors follow a normal error distribution; but the NSSDA does not specify threshold accuracy values as did the NMAS. *Guidelines for Digital Elevation Data*, published by the National Digital Elevation Program (NDEP, 2004), and the *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by ASPRS (ASPRS, 2004), both use the NSSDA guidelines as their basis, again without accuracy thresholds, but they also provide alternative methods for accuracy testing for LiDAR data where errors do not necessarily follow a normal error distribution, as in vegetated terrain. In 2010, the U.S. Geological Survey (USGS) published its draft *Lidar Guidelines and Base Specifications*, V.13, embraced by the Federal Emergency Management Agency (FEMA) Procedure Memorandum No. 61 – *Standards for Lidar and Other High Quality Digital Topography* (FEMA, 2010), but FEMA also established multiple vertical accuracy thresholds of lower accuracies than the USGS minimum thresholds. In 2012 USGS published its *Lidar Base Specification, Version 1.0* (Heidemann, 2012), and in 2014, USGS tightened these standards with Version 1.2 (Heidemann, 2014). In 2014, ASPRS also published its *Positional Accuracy Standards for Digital Geospatial Data* (ASPRS, 2014) which provided horizontal and vertical accuracy thresholds for digital orthophotos, photogrammetric mapping, and LiDAR, including new LiDAR standards for Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA). This chapter compares each of these accuracy standards, guidelines and/or specifications and summarizes procedures for testing and reporting according to these standards.

b. USACE Mapping Standards. Except for the addition of tables with English units, the USACE Accuracy Standards for Photogrammetry and LiDAR Mapping are identical to the *ASPRS Positional Accuracy Standards for Digital Geospatial Data* (ASPRS, 2014) and replace the obsolete *ASPRS Accuracy Standards for Large-Scale Maps* (ASPRS, 1990). Tables are also provided for comparing the various accuracy thresholds with specific USACE applications.

3-2. USACE Accuracy Standards for Photogrammetry and LiDAR Mapping. USACE has previously utilized the *ASPRS Accuracy Standards for Large-Scale Maps* (ASPRS, 1990), but ASPRS and USACE recognize that those standards are essentially obsolete because they pertain only to maps with published map scale and contour interval. Almost all mapping today is performed with digital cameras or LiDAR for which map scale and contour interval can be manipulated by clicking on a zoom button, but without any improvement in accuracy. Since ASPRS published its *Accuracy Standards for Large-Scale Maps* in 1990, the NSSDA (1998), NDEP (2004), and ASPRS (2004) standards and guidelines were developed for digital geospatial data, but without accuracy thresholds preferred by many. FEMA (2010) established vertical accuracy thresholds, unique to floodplain mapping, using all technologies; and USGS (Heidemann, 2012, and Heidemann, 2014) both established standard vertical accuracy thresholds for LiDAR data only. Until recently, little has been done to address accuracy standards for planimetric mapping and digital orthoimagery produced from digital metric cameras. To address this need, the *ASPRS Positional Accuracy Standards for Digital Geospatial Data* (ASPRS, 2014), at Appendix C, were developed and have been endorsed by USACE for this Engineering Manual. Aligned with ASPRS, 2014, the new USACE horizontal map accuracy standards for digital orthoimages, regardless of pixel size, include three standard levels: (1) for highest accuracy work, (2) for standard mapping and GIS work, and (3) for visualization and less accurate work. Whether digital geospatial data are orthophotos, planimetric data, or elevation data, the horizontal accuracy class is based on $RMSE_x$, $RMSE_y$ and/or $RMSE_r$ (Table 3-1) and the vertical accuracy class is based on $RMSE_z$ (Table 3-2). Although ASPRS tables are totally metric, English units are equally applicable. Expanded tables are also provided below.

Table 3-1 Horizontal Accuracy Standards for Digital Geospatial Data

Horizontal Accuracy Class	Absolute Accuracy			Relative Accuracy Measures
	$RMSE_x$ and $RMSE_y$ cm)	**$RMSE_r$ (cm)**	**Horizontal Accuracy at 95% Confidence Level (cm)**	**Orthoimagery Mosaic Seamline Mismatch (cm)**
X-cm	$\leq X$	$\leq 1.41*X$	$\leq 2.45*X$	$\leq 2*X$

Table 3-2 Vertical Accuracy Standards for Digital Elevation Data

Vertical Accuracy Class	Absolute Accuracy			Relative Accuracy (where applicable)		
	RMSE$_z$ Non-Vegetated (cm)	NVA[1] at 95% Confidence Level (cm)	VVA[2] at 95th Percentile (cm)	Within-Swath Hard Surface Repeatability (Max Diff) (cm)	Swath-to-Swath Non-Vegetated Terrain (RMSD$_z$) (cm)	Swath-to-Swath Non-Vegetated Terrain (Max Diff) (cm)
X-cm	≤*X*	≤1.96**X*	≤3.00**X*	≤0.60**X*	≤0.80**X*	≤1.60**X*

a. USACE Horizontal Accuracy Standards for Orthoimagery. These standards do not associate product accuracy with the ground sample distance (GSD) of the source imagery. The relationship between the recommended RMSE$_x$ and RMSE$_y$ accuracy class and the orthoimagery pixel size varies depending on the imaging sensor characteristics and the specific mapping processes used. The appropriate horizontal accuracy class must be negotiated and agreed upon between the end user and the data provider, based on specific project needs and design criteria. This section provides some general guidance to assist in making that decision. Example tables are provided to show the following: (1) the general application of the horizontal accuracy standard and associated quality criteria in Table 3-1 as related to orthoimagery (see Table 3-3); (2) typical values associated with different levels of horizontal accuracy in metric units (see Table 3-4); and (3) typical values associated with different levels of horizontal accuracy in English units (see Table 3-5).

[1] Statistically, in non-vegetated terrain and elsewhere when elevation errors follow a normal distribution, 68.27% of errors are within one standard deviation (*s*) of the mean error, 95.45% of errors are within (2 * *s*) of the mean error, and 99.73% of errors are within (3 * *s*) of the mean error. The equation (1.9600 * *s*) is used to approximate the maximum error either side of the mean that applies to 95% of the values. Standard deviations do not account for systematic errors in the data set that remain in the mean error. Because the mean error rarely equals zero, this must be accounted for. Based on empirical results, if the mean error is small, the sample size sufficiently large and the data is normally distributed, 1.9600 * RMSE$_z$ is often used as a simplified approximation to compute the NVA at a 95% confidence level. ASPRS encourages standard deviation, mean error, skew, kurtosis and RMSE to all be computed in error analyses in order to more fully evaluate the magnitude and distribution of the estimated error.

[2] VVA standards do not apply to areas previously defined as low confidence areas and delineated with a low confidence polygon. If VVA accuracy is required for the full data set, supplemental field survey data may be required within low confidence areas where VVA accuracies cannot be achieved by the remote sensing method being used for the primary data set.

Table 3-3 Common Horizontal Accuracy Classes

Horizontal Accuracy Class $RMSE_x$ and $RMSE_y$ (cm)	$RMSE_r$ (cm)	Orthoimage Mosaic Seamline Maximum Mismatch (cm)	Horizontal Accuracy at the 95% Confidence Level (cm)
0.625	0.9	1.25	1.5
1.25	1.8	2.5	3.1
2.5	3.5	5	6.1
5	7.1	10	12.2
7.5	10.6	15	18.4
10	14.1	20	24.5
12.5	17.7	25	30.6
15	21.2	30	36.7
17.5	24.7	35	42.8
20	28.3	40	49.0
22.5	31.8	45	55.1
25	35.4	50	61.2
27.5	38.9	55	67.3
30	42.4	60	73.4
45	63.6	90	110.1
60	84.9	120	146.9
75	106.1	150	183.6
100	141.4	200	244.8
150	212.1	300	367.2
200	282.8	400	489.5
250	353.6	500	611.9
300	424.3	600	734.3
500	707.1	1,000	1,223.9
1,000	1,414.2	2,000	2,447.7

(1) Non-Standard Highest Accuracy. Given current sensor and processing technologies for large and medium format metric cameras, an orthoimagery accuracy of 1-pixel $RMSE_x$ and $RMSE_y$ is considered achievable, assuming proper project design and best practices implementation. This level of accuracy is more stringent by a factor of two than orthoimagery accuracies typically associated with the ASPRS 1990 Class 1 accuracies. Achieving the highest level of accuracy requires specialized consideration related to sensor type, ground control density, ground control accuracies and overall project design. In many cases, this results in higher cost. As such, the highest achievable accuracies may not be appropriate for all projects.

Many geospatial mapping projects require high resolution and high quality imagery, but do not require the highest level of positional accuracy. This is particularly true for update or similar projects where the intent is to upgrade the image resolution, but still leverage existing DTM and ground control data that may originally have been developed to a lower accuracy standard.

(2) Orthoimagery Accuracy Examples. Table 3-4 (metric units) and Table 3-5 (English units) provide general guidelines to determine the appropriate orthoimagery accuracy class for three different levels of geospatial accuracy. Values listed as “Highest accuracy” specify an $RMSE_x$ and $RMSE_y$ accuracy class of 1-pixel (or better) and are considered to reflect the highest tier accuracy for the specified resolution given current technologies; this accuracy class is appropriate when geospatial accuracies are of higher importance and when the higher accuracies are supported by sufficient sensor, ground control and DTM accuracies. Values listed as “Standard high accuracy” specify a 2-pixel $RMSE_x$ and $RMSE_y$ accuracy class; this accuracy is appropriate for a standard level of high quality and high accuracy geospatial mapping applications and is equivalent to ASPRS 1990 Class 1 accuracies of the past. This level accuracy is typical of a large majority of existing USACE projects designed to legacy standards. $RMSE_x$ and $RMSE_y$ accuracies of 3 or more pixels would be considered appropriate for “Lower accuracy - visualization” when higher accuracies are not needed. Users should be aware that the use of the symbol ≥ in Tables 3-4 and 3-5 is intended to infer that users can specify larger threshold values for $RMSE_x$ and $RMSE_y$. The symbol ≤ in these tables indicate that users can specify lower thresholds at such time as they may be supported by current or future technologies.
The orthoimagery pixel sizes and associated $RMSE_x$ and $RMSE_y$ accuracy classes presented in Tables 3-4 and 3-5 are largely based on experience with current sensor technologies and primarily apply to large and medium format metric cameras. These tables are only provided as a guideline for users during the transition period to the new standard. These associations may change in the future as mapping technologies continue to advance and evolve. The final choice of both image resolution and final product accuracy class depends on specific project needs and is the sole responsibility of the end user; this should be negotiated with the data provider and agreed upon in advance.

Table 3-4 Digital Orthoimagery Accuracy Examples for Current Metric Large and Medium Format Cameras (Metric Units)

Common Orthoimagery Pixel Sizes[3]	Recommended Horizontal Accuracy Class $RMSE_x$ & $RMSE_y$ (cm)	Orthoimage $RMSE_x$ & $RMSE_y$ in terms of pixels	Recommended use
1.25 cm	≤1.25	≤1-pixel	Highest accuracy
	2.5	2-pixels	Standard high accuracy
	≥3.75	≥3-pixels	Lower accuracy - visualization
2.5 cm	≤2.5	≤1-pixel	Highest accuracy
	5	2-pixels	Standard high accuracy
	≥7.5	≥3-pixels	Lower accuracy - visualization
5 cm	≤5	≤1-pixel	Highest accuracy
	10	2-pixels	Standard high accuracy
	≥15	≥3-pixels	Lower accuracy - visualization
7.5 cm	≤7.5	≤1-pixel	Highest accuracy
	15	2-pixels	Standard high accuracy
	≥22.5	≥3-pixels	Lower accuracy - visualization
15 cm	≤15	≤1-pixel	Highest accuracy
	30	2-pixels	Standard high accuracy
	≥45	≥3-pixels	Lower accuracy - visualization
30 cm	≤30	≤1-pixel	Highest accuracy
	60	2-pixels	Standard high accuracy
	≥90	≥3-pixels	Lower accuracy - visualization
60 cm	≤60	≤1-pixel	Highest accuracy
	120	2-pixels	Standard high accuracy
	≥180	≥3-pixels	Lower accuracy - visualization
1 meter	≤100	≤1-pixel	Highest accuracy
	200	2-pixels	Standard high accuracy
	≥300	≥3-pixels	Lower accuracy - visualization
2 meter	≤200	≤1-pixel	Highest accuracy
	400	2-pixels	Standard high accuracy
	≥600	≥3-pixels	Lower accuracy - visualization

[3] It should be noted that in Tables 3-4 and 3-5, it is the pixel size of the final digital orthoimagery that is used to associate the horizontal accuracy class, not the Ground Sample Distance (GSD) of the raw image. When producing digital orthoimagery, the GSD as acquired by the sensor (and as computed at mean average terrain) should not be more than 95% of the final orthoimage pixel size. In extremely steep terrain, additional consideration may need to be given to the variation of the GSD across low lying areas in order to ensure that the variation in GSD across the entire image does not significantly exceed the target pixel size. In all cases, the orthoimage mosaic seamline maximum mismatch is 2 x the value for RMSEx and RMSEy, and horizontal accuracy at the 95% confidence level is 2.4477 x the value for RMSEx and RMSEy.

Table 3-5 Digital Orthoimagery Accuracy Examples for Current Metric Large and Medium Format Cameras (English Units)

Common Orthoimagery Pixel Sizes[4]	Recommended Horizontal Accuracy Class $RMSE_x$ & $RMSE_y$ (inch)	Orthoimage $RMSE_x$ & $RMSE_y$ in terms of pixels	Recommended use
1 inch	≤1	≤1-pixel	Highest accuracy
	2	2-pixels	Standard high accuracy
	≥3	≥3-pixels	Lower accuracy - visualization
2 inch	≤2	≤1-pixel	Highest accuracy
	4	2-pixels	Standard high accuracy
	≥6	≥3-pixels	Lower accuracy - visualization
3 inch	≤3	≤1-pixel	Highest accuracy
	6	2-pixels	Standard high accuracy
	≥9	≥3-pixels	Lower accuracy - visualization
4 inch	≤4	≤1-pixel	Highest accuracy
	8	2-pixels	Standard high accuracy
	≥12	≥3-pixels	Lower accuracy - visualization
6 inch	≤6	≤1-pixel	Highest accuracy
	12	2-pixels	Standard high accuracy
	≥18	≥3-pixels	Lower accuracy - visualization
9 inch	≤9	≤1-pixel	Highest accuracy
	18	2-pixels	Standard high accuracy
	≥27	≥3-pixels	Lower accuracy - visualization
12 inch	≤12	≤1-pixel	Highest accuracy
	24	2-pixels	Standard high accuracy
	≥36	≥3-pixels	Lower accuracy - visualization
24 inch	≤24	≤1-pixel	Highest accuracy
	48	2-pixels	Standard high accuracy
	≥72	≥3-pixels	Lower accuracy - visualization
36 inch	≤36	≤1-pixel	Highest accuracy
	72	2-pixels	Standard high accuracy
	≥108	≥3-pixels	Lower accuracy - visualization

[4] It should be noted that in Tables 3-4 and 3-5, it is the pixel size of the final digital orthoimagery that is used to associate the horizontal accuracy class, not the Ground Sample Distance (GSD) of the raw image. When producing digital orthoimagery, the GSD as acquired by the sensor (and as computed at mean average terrain) should not be more than 95% of the final orthoimage pixel size. In extremely steep terrain, additional consideration may need to be given to the variation of the GSD across low lying areas in order to ensure that the variation in GSD across the entire image does not significantly exceed the target pixel size. In all cases, the orthoimage mosaic seamline maximum mismatch is 2 x the value for RMSEx and RMSEy, and horizontal accuracy at the 95% confidence level is 2.4477 x the value for RMSEx and RMSEy.

b. USACE Horizontal Accuracy Standards for Planimetric Data. Table 3-6 (metric units) and Table 3-7 (English units) present 10 common horizontal accuracy classes for digital planimetric data, approximate GSD of source imagery for high accuracy planimetric data, and equivalent map scales per legacy National Map Accuracy Standards (NMAS) and ASPRS 1990 accuracy standards. In these tables, the values for the approximate GSD of source imagery only apply to imagery derived from common large and medium format metric cameras. The range of the approximate GSD of source imagery is only provided as a recommendation, based on the current state of sensor technologies and mapping practices. Different ranges may be considered in the future depending on future advances of such technologies and mapping practices.

Table 3-6 Horizontal Accuracy/Quality Examples for High Accuracy Digital Planimetric Data (Metric Units)

ASPRS 2014				Equivalent to map scale in		Equivalent to map scale in NMAS
Horizontal Accuracy Class $RMSE_x$ & $RMSE_y$ (cm)	$RMSE_r$ (cm)	Horizontal Accuracy at the 95% Confidence Level (cm)	Approximate GSD of Source Imagery (cm)	ASPRS 1990 Class 1	ASPRS 1990 Class 2	
2.5	3.5	6.1	1.25 to 2.5	1:100	1:50	1:63
5	7.1	12.2	2.5 to 5	1:200	1:100	1:127
7.5	10.6	18.4	3.75 to 7.5	1:300	1:150	1:190
10	14.1	24.5	5 to 10	1:400	1:200	1:253
15	21.2	36.7	7.5 to 15	1:600	1:300	1:380
20	28.3	49.0	10 to 20	1:800	1:400	1:507
30	42.4	73.4	15 to 30	1:1,200	1:600	1:760
60	84.9	146.9	30 to 60	1:2,400	1:1,200	1:1,521
100	141.4	244.8	50 to 100	1:4,000	1:2,000	1:2,535
200	282.8	489.5	100 to 200	1:8,000	1:4000	1:5,069

Table 3-7 Horizontal Accuracy/Quality Examples for High Accuracy Digital Planimetric Data (English Units)

ASPRS 2014				Equivalent to map scale in		
Horizontal Accuracy Class $RMSE_x$ & $RMSE_y$ (inch)	$RMSE_r$ (inch)	Horizontal Accuracy at the 95% Confidence Level (inch)	Approximate GSD of Source Imagery (inch)	ASPRS 1990 Class 1	ASPRS 1990 Class 2	Equivalent to map scale in NMAS
1	1.4	2.4	0.5 to 1.0	1:100	1:50	1:63
2	2.8	4.9	1 to 2	1:200	1:100	1:127
3	4.2	7.3	1.5 to 3	1:300	1:150	1:190
4	5.7	9.8	2 to 4	1:400	1:200	1:253
6	8.5	14.7	3 to 6	1:600	1:300	1:380
9	12.7	22.0	4.5 to 9	1:900	1:450	1:570
12	17.0	29.4	6 to 12	1:1,200	1:600	1:760
24	33.9	58.7	12 to 24	1:2,400	1:1,200	1:1,521
36	50.9	88.1	18 to 36	1:3,600	1:1,800	1:2,280
60	84.9	146.9	30 to 60	1:6,000	1:3,000	1:3,800

c. USACE Vertical Accuracy Standards for Digital Elevation Data. The USACE Vertical Accuracy Standards are identical to Vertical Data Classes from the *ASPRS Positional Accuracy Standards for Digital Geospatial Data* (ASPRS, 2014) at Appendix C which defines Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) at the 95% confidence level and 95th percentile, respectively. High-density, irregularly-spaced elevation mass points in Digital Terrain Models (DTMs) are routinely produced from LiDAR point clouds. Uniformly-gridded (raster) Digital Elevation Models (DEMs) are either interpolated from LiDAR mass points or compiled from stereo imagery. Breaklines can be produced from either photogrammetry or lidargrammetry (explained in Chapter 6). Users should not assume that accuracy statistics will be the same whether testing a LiDAR point cloud, a LiDAR DTM with mass points and breaklines, or a raster DEM interpolated from the DTM; but the same accuracy standards may be applicable to each, depending upon which deliverable is to be tested.
Table 3-8 (metric units) and Table 3-9 (English units) provide vertical accuracy examples and other quality criteria for ten common vertical accuracy classes; the "appropriate contour interval" is equivalent to ASPRS 1990 Class 1 contours where the contour interval is three times $RMSE_z$. Table 3-10 (metric units) and Table 3-11 (English units) provide the same vertical accuracy classes with the recommended lidar Nominal Point Density (NPD) and Nominal Point Spacing (NPS) suitable for each of them. Contours other than "appropriate" for the tested $RMSE_z$ can be mapped or displayed so long as the distinction is clearly presented in the metadata.

(1) Accuracy Testing in Vegetated and Non-Vegetated Terrain. Tables 3-8 and 3-9 list ten vertical accuracy classes for elevation data compiled from LiDAR, stereo photogrammetry or IFSAR, with different accuracy values for NVA and VVA. The last two columns of these tables are relevant to LiDAR only, but the remaining columns are relevant to LiDAR, photogrammetry and IFSAR. There is no mathematical link between LiDAR point density and LiDAR vertical accuracy although denser data tends to be more accurate because more points penetrate through vegetation to the ground, requiring less need for interpolation.

(2) LiDAR Relative Accuracy Swath-to-Swath. Performed prior to LiDAR point classification, relative accuracy swath-to-swath (rightmost column in Tables 3-8 and 3-9) is normally tested by preparing elevation difference maps (called *Δz orthos* or *DZ orthos*) produced by subtracting (single-return) elevations from one swath from (single-return) elevations from each overlapping swath and displaying the absolute value of elevation differences in colored elevation bands. Single-returns are most likely ground points in open, non-vegetated terrain (ASPRS LAS Class 2). For the 5-cm Vertical Accuracy Class in Table 3-8, for example, the maximum difference is 8 cm. A DZ ortho might display all elevation differences (absolute values) of 4-cm or less in green, all absolute differences between 4-cm and 8-cm in amber, and all absolute differences greater than 8-cm in red. There should be no red, but if there is some red, the DZ ortho would highlight problem areas for reprocessing of data, with airborne GPS data being the primary cause for failure. DZ orthos can also be used to determine at what scan angle, less-accurate points from high scan angles should be classified as LAS Class 12 (overlap points) rather than LAS Class 2 (ground points).

(3) LiDAR NPD and NPS. In Tables 3-10 and 3-11, NPD and NPS are geometrically inverse methods to measure the pulse density or spacing of a LiDAR collection. NPD is a ratio of the number of points to the area in which they are contained, and is typically expressed as pulses per square meter (ppsm or pts/m^2). NPS is a linear measure of the typical distance between points and is most often expressed in meters. Although either expression can be used for any dataset, NPD is usually used for LiDAR collections with NPS <1, and NPS is used for those with NPS ≥1. Both measures are based on all 1st (or last)-return LiDAR point data as these return types each reflect the number of pulses. Conversion between NPD and NPS is accomplished using the formulas: $NPS = 1/\sqrt{NPD}$, and $NPD = 1/NPS^2$. Although typical point densities are listed in these tables for specified vertical accuracies, users can select higher or lower point densities to best fit project requirements and complexity of surfaces to be modeled. For example, the National Enhanced Elevation Assessment (NEEA) specified Quality Level 1 (QL1) LiDAR as having the same vertical accuracy as QL2 LiDAR, but with higher point density of 8 pts/m^2.

Table 3-8 Vertical Accuracy/Quality Examples for Digital Elevation Data (Metric Units)

Vertical Accuracy Class	Absolute Accuracy (cm)				Relative Accuracy Max Diff (cm) (where applicable)	
	$RMSE_z$ Non-Vegetated	NVA at 95% Confidence Level	VVA at 95th Percentile	Appropriate Contour Interval	Within-Swath Hard Surface Repeatability	Swath-to-Swath Non-Veg Terrain
1-cm	1	2	3	3	0.6	1.6
2.5-cm	2.5	4.9	7.5	7.5	1.5	4
5-cm	5	9.8	15	15	3	8
10-cm	10	19.6	30	30	6	16
15-cm	15	29.4	45	45	9	24
20-cm	20	39.2	60	60	12	32
33.3-cm	33.3	65.3	100	100	20	53.3
66.7-cm	66.7	130.7	200	200	40	106.7
100-cm	100	196.0	300	300	60	160
333.3-cm	333.3	653.3	1,000	1,000	200	533.3

Table 3-9 Vertical Accuracy/Quality Examples for Digital Elevation Data (English Units)

Vertical Accuracy Class	Absolute Accuracy (inch)				Relative Accuracy Max Diff (inch) (where applicable)	
	$RMSE_z$ Non-Vegetated	NVA at 95% Confidence Level	VVA at 95th Percentile	Appropriate Contour Interval	Within-Swath Hard Surface Repeatability	Swath-to-Swath Non-Veg Terrain
1-inch	1	2	3	3	0.6	1.6
2-inch	2	3.9	6	6	1.2	3.2
3-inch	3	5.9	9	9	1.8	4.8
4-inch	4	7.8	12	12	2.4	6.4
6-inch	6	11.8	18	18	3.6	9.6
9-inch	9	17.6	27	27	5.4	14.4
12-inch	12	23.5	36	36	7.2	19.2
24-inch	24	47.0	72	72	14.4	38.4
36-inch	36	70.6	108	108	21.6	57.6
60-inch	60	117.6	180	180	36.0	96.0

Table 3-10 Examples for Vertical Accuracy and Recommended Lidar Point Density (Metric Units)

Vertical Accuracy Class	Absolute Accuracy		Recommended Minimum NPD (pts/m^2)	Recommended Maximum NPS (m)
	$RMSE_z$ Non-Vegetated (cm)	NVA at 95% Confidence Level (cm)		
1-cm	1	2.0	≥20	≤0.22
2.5-cm	2.5	4.9	16	0.25
5-cm	5	9.8	8	0.35
10-cm	10	19.6	2	0.71
15-cm	15	29.4	1	1.0
20-cm	20	39.2	0.5	1.4
33.3-cm	33.3	65.3	0.25	2.0
66.7-cm	66.7	130.7	0.1	3.2
100-cm	100	196.0	0.05	4.5
333.3-cm	333.3	653.3	0.01	10.0

Table 3-11 Examples for Vertical Accuracy and Recommended Lidar Point Density (English Units)

Vertical Accuracy Class	Absolute Accuracy		Recommended Minimum NPD (pts/m^2)	Recommended Maximum NPS (m)
	$RMSE_z$ Non-Vegetated (inch)	NVA at 95% Confidence Level (inch)		
1-inch	1	2.0	≥16	≤0.25
2-inch	2	3.9	8	0.35
3-inch	3	5.9	4	0.50
4-inch	4	7.8	2	0.71
6-inch	6	11.8	1	1.00
9-inch	9	17.6	0.5	1.41
12-inch	12	23.5	0.25	2.00
24-inch	24	47.0	0.1	3.16
36-inch	36	70.6	0.05	4.47
60-inch	60	117.6	0.025	6.33

d. USACE Accuracy Testing/Reporting. Table 3-12 summarizes the recommended number of check points, based on project areas up to 2,500 km^2 (approximately 965 mi^2), for horizontal accuracy testing of orthoimagery and planimetrics, and for vertical and horizontal accuracy testing of elevation datasets. For horizontal testing of areas >2500 km^2, users should determine the number of additional horizontal check points, if any, based on criteria such as resolution of imagery and extent of urbanization. For vertical testing of areas >2500 km^2, add 5 additional vertical check points for each additional 500 km^2 area. Each additional set of 5 vertical check points would include 3 check points for NVA testing and 2 for VVA testing. The recommended number and distribution of NVA and VVA check points may vary depending on the importance of different land cover categories and user requirements.

Table 3-12 Recommended Number of Check Points Based on Area

Project Area (Square Kilometers)	Horizontal Accuracy Testing of Orthoimagery and Planimetrics	Vertical and Horizontal Accuracy Testing of Elevation Data sets		
	Total Number of Static 2D/3D Check Points (clearly-defined points)	Number of Static 3D Check Points in NVA[5]	Number of Static 3D Check Points in VVA	Total Number of Static 3D Check Points
≤500	20	20	5	25
501-750	25	20	10	30
751-1000	30	25	15	40
1001-1250	35	30	20	50
1251-1500	40	35	25	60
1501-1750	45	40	30	70
1751-2000	50	45	35	80
2001-2250	55	50	40	90
2251-2500	60	55	45	100

(1) Horizontal Accuracy Testing/Reporting. The USACE performs horizontal accuracy testing and reporting of either digital orthophotos or planimetric data in accordance with the NSSDA described in section 3-3.c(3) and the *ASPRS Positional Accuracy Standards for Digital Geospatial Data* described in section 3-3.i(1). Horizontal accuracy is tested by comparing the planimetric coordinates of well-defined points in the dataset with coordinates of the same points from an independent source of higher accuracy. A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For testing the horizontal accuracy of digital orthophotos, these well-

[5] Although vertical check points are normally not well defined, where feasible, the horizontal accuracy of lidar data sets should be tested by surveying approximately half of all NVA check points at the ends of paint stripes or other point features that are visible and can be measured on lidar intensity returns.

defined points must also be clearly photo-identifiable on the image, and it is highly desirable that well-defined point features have 90° corners oriented in a north-south and east-west direction so as to minimize the effects of saw-toothed pixelization that occurs when edges are at a 45° angle, for example. The check points that will be used for accuracy testing must be collected separately from the data to be tested and must not be used as control or as any part of the production procedures. A minimum of 20 check points shall normally be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications. Check points may be distributed more densely in the vicinity of important features and more sparsely in areas that are of little or no interest. For a dataset covering a rectangular area that is believed to have uniform positional accuracy, check points may be distributed so that points are spaced at intervals of at least 10 percent of the diagonal distance across the dataset *and* at least 20 percent of the points are located in each quadrant of the dataset. For small project areas, fewer than 20 check points may be used if the survey cost for the check points exceeds 20% of the cost of the dataset being tested. Compute $RMSE_x$ and $RMSE_y$ separately; then $RMSE_r$ = the square root of ($RMSE_x^2 + RMSE_y^2$) and $Accuracy_r = RMSE_r * 1.7308$. Report horizontal accuracy as:

Tested __ (meters, feet) horizontal accuracy at the 95% confidence level

(a) Example of Horizontal Accuracy Testing Spreadsheet. Table 3-13 is an example of a spreadsheet used to compute the horizontal accuracy statistics for digital orthophotos with 3-inch pixels to determine if they satisfy (ASPRS, 2014) standard high accuracy (see Table 3-5). The terms in Table 3-13 are defined as follows:

x and y = horizontal coordinates in Easting and Northing, respectively, of clearly defined points that are photo-identifiable on the orthoimagery and also surveyed relative to Continuously Operating Reference Stations (CORS) for independent QA/QC check points

Δx = discrepancy in Easting = x coordinate on orthophoto minus x coordinate of check point

Δy = discrepancy in Northing = y coordinate on orthophoto minus y coordinate of check point

Δx^2 and Δy^2 = discrepancies squared

MSE = the mean of the sum of the discrepancies squared

$RMSE_x$, $RMSE_y$, $RMSE_r$ = root mean square error in x, y and radially (both x and y)

$Accuracy_r$ = horizontal accuracy at the 95% confidence level per NSSDA procedures

Table 3-13. Spreadsheet for Horizontal Accuracy Testing of 3" Standard High Accuracy Orthophotos

3" Pixels	QA/QC Check Point State Plane Coordinates		Orthophoto State Plane Coordinates at QA/QC Check Points		Orthophoto minus Check Point		Discrepancies Squared	
Point	Easting (x)	Northing (y)	Easting (x)	Northing (y)	Δx	Δy	Δx^2	Δy^2
Number	Feet	Feet	Feet	Feet	Feet	Feet	$Feet^2$	$Feet^2$
1	6,455,367.23	1,815,494.12	6,455,366.79	1,815,494.31	-0.44	0.19	0.1936	0.0361
2	6,463,928.43	1,740,487.99	6,463,928.56	1,740,487.73	0.13	-0.26	0.0169	0.0676
3	6,478,942.94	1,757,945.80	6,478,942.87	1,757,945.75	-0.07	-0.05	0.0049	0.0025
4	6,420,656.79	1,815,293.31	6,420,656.61	1,815,293.37	-0.18	0.06	0.0324	0.0036
5	6,500,864.57	1,758,833.24	6,500,864.91	1,758,833.30	0.34	0.06	0.1156	0.0036
6	6,502,026.54	1,779,378.91	6,502,026.46	1,779,378.86	-0.08	-0.05	0.0064	0.0025
7	6,527,762.07	1,731,210.40	6,527,761.78	1,731,210.55	-0.29	0.15	0.0841	0.0225
8	6,539,890.05	1,755,842.11	6,539,890.08	1,755,842.69	0.03	0.58	0.0009	0.3364
9	6,568,022.06	1,800,468.17	6,568,021.76	1,800,468.33	-0.30	0.16	0.0900	0.0256
10	6,601,277.62	1,803,163.22	6,601,277.55	1,803,163.49	-0.07	0.27	0.0049	0.0729
11	6,435,447.02	1,737,489.68	6,435,447.05	1,737,489.21	0.03	-0.47	0.0009	0.2209
12	6,445,012.85	1,757,524.80	6,445,013.08	1,757,524.85	0.23	0.05	0.0529	0.0025
13	6,536,017.65	1,791,341.52	6,536,017.36	1,791,341.99	-0.29	0.47	0.0841	0.2209
14	6,491,082.08	1,825,513.30	6,491,081.90	1,825,513.46	-0.18	0.16	0.0324	0.0256
15	6,354,325.53	2,120,133.88	6,354,325.14	2,120,133.51	-0.39	-0.37	0.1521	0.1369
16	6,458,453.07	2,120,765.53	6,458,454.09	2,120,765.27	1.02	-0.26	1.0404	0.0676
17	6,432,704.31	1,797,681.41	6,432,704.18	1,797,681.57	-0.13	0.16	0.0169	0.0256
18	6,661,469.34	2,121,876.55	6,661,469.58	2,121,876.87	0.24	0.32	0.0576	0.1024
19	6,464,182.87	2,087,807.68	6,464,182.68	2,087,807.47	-0.19	-0.21	0.0361	0.0441
20	6,516,739.03	2,105,251.01	6,516,739.37	2,105,251.38	0.34	0.37	0.1156	0.1369
						Sums	2.1387	1.5567
		3" Orthophoto Standard High Accuracy				MSE	0.1069	0.0778
		$RMSE_{xy}$ standard = 6.0 in (0.500 ft)			$RMSE_{xy}$ (ft)		0.3270	0.2790
		$RMSE_r$ standard = 8.5 in (0.707 ft)			$RMSE_r$ (ft)		0.4298	
		$Accuracy_r$ standard = 14.7 in (1.224 ft)			$Accuracy_r$ (ft)		0.7440	

(b) Explanation of Example Horizontal Accuracy Test Data. The numbers in violet at the bottom of Table 3-13 list the $RMSE_{xy}$, $RMSE_r$ and $Accuracy_r$ (horizontal accuracy at 95% confidence levels) standards for standard high accuracy orthophotos with 3-inch pixels (see Table 3-5). The numbers in orange are the horizontal State Plane coordinates of 20 surveyed QA/QC check points. The numbers in blue are the horizontal State Plane coordinates of these photo-identifiable check points as measured on the digital orthophotos. The numbers in pink show the discrepancies between the orthophoto coordinates and the check point coordinates, and the numbers in yellow show those discrepancies squared. Beneath the yellow columns are the sums of the 20 squared discrepancies in x and y coordinates and the mean square errors (MSE) in x and y coordinates, i.e., the MSE in R<u>MSE</u> prior to taking the square root. The numbers in green show the final $RMSE_x$ and $RMSE_y$ values as well as the $RMSE_r = \sqrt{RMSEx^2 + RMSEy^2}$. Lastly, also in green, the horizontal accuracy at the 95% confidence level ($Accuracy_r$ per the NSSDA) is computed as 1.7308 * $RMSE_r$. For this example project, because all of the values highlighted in green are better than the standard high accuracy thresholds for those values (shown in violet), this project passes the required standard. The horizontal accuracy of these digital orthophotos should thus be reported in the metadata as follows:

Tested 0.744 feet horizontal accuracy at the 95% confidence level

(2) <u>Vertical Accuracy Testing/Reporting</u>. Because of minimal additional effort to do so, the USACE performs vertical accuracy testing and reporting of LiDAR point clouds, DTMs and/or DEMs from LiDAR, IFSAR or photogrammetry consistent with both common methodologies: (1) to compute Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) consistent with the ASPRS, 2014 *Positional Accuracy Standards for Digital Geospatial Data*; and (2) to compute Fundamental Vertical Accuracy (FVA), Consolidated Vertical Accuracy (CVA) and Supplemental Vertical Accuracies (SVA) consistent with USGS and FEMA procedures explained in Section 3-3 d (2) below. The spreadsheet for vertical accuracy testing of digital elevation data initially looks similar to that in Table 3-13, with three exceptions: (1) there are no double columns for x and y coordinates, Δx, Δy, Δx^2 and Δy^2 values, but only single columns for z coordinates, Δz and Δz^2 values; (2) rather than testing 20 horizontal check points, elevation data are tested with (normally not photo-identifiable) check points in each of the major land cover categories being tested, i.e., a total of 100 vertical check point when five land cover categories are tested for an area of 965 square miles, for example; and (3) an additional column is added for the absolute values of the Δz values for computing CVA, SVA, and VVA values which are based on the 95th percentile statistics that require absolute values. Pass/fail parameters should include NVA and VVA when ASPRS, 2014 vertical accuracy classes are specified, and/or pass/fail parameters should include FVA and CVA when USGS or FEMA specifications are used. Either one or the other approach should be specified in the Scope of Work, but there are benefits to documenting all forms of vertical accuracy statistics in the metadata as will be demonstrated in the example below.

(a) <u>Example of Vertical Accuracy Testing Statistics</u>. The actual elevation dataset tested in this section was produced by Dewberry to the *USGS Lidar Base Specification Version 1.0* (Heidemann, 2012) requiring FVA of 24.5-cm ($RMSE_z$ of 12.5-cm in open terrain); CVA of 36.3-cm, and SVA target values of 36.3-cm in each of five land cover categories. Figure 3-1 plus Tables 3-14 and 3-15 refer to this elevation dataset with 100 vertical check points, 20 each in five major land cover categories: (1) open terrain (dirt, sand, rock, short grass); (2) urban terrain (concrete and asphalt surfaces); (3) weeds and crops; (4) brush lands; and (5) fully forested. Figure 3-1 shows the error histogram resulting from these 100 check points; this histogram shows an outlier of 49-cm in weeds and crops and a larger outlier of 70-cm in the fully forested land cover category. The remaining 98 elevation error values appear to approximate a normal error distribution with a mean error close to zero. Table 3-14 lists all the traditional accuracy statistics for this example dataset. Per NDEP guidelines, and to comply with USGS V1.0 specifications (Heidemann, 2012), Table 3-15 computes the FVA, SVA and CVA statistics for elevation datasets where errors do not all follow a normal distribution, as in this example, and compares 95th percentile statistics with Accuracy_z, the NSSDA's method for estimating vertical accuracy at the 95% confidence level based on $\text{RMSE}_z * 1.9600$ (when assuming errors follow a normal distribution). Table 3-16 consolidates these same statistics from Table 3-14 to compute NVA and VVA values to comply with ASPRS, 2014 standards.

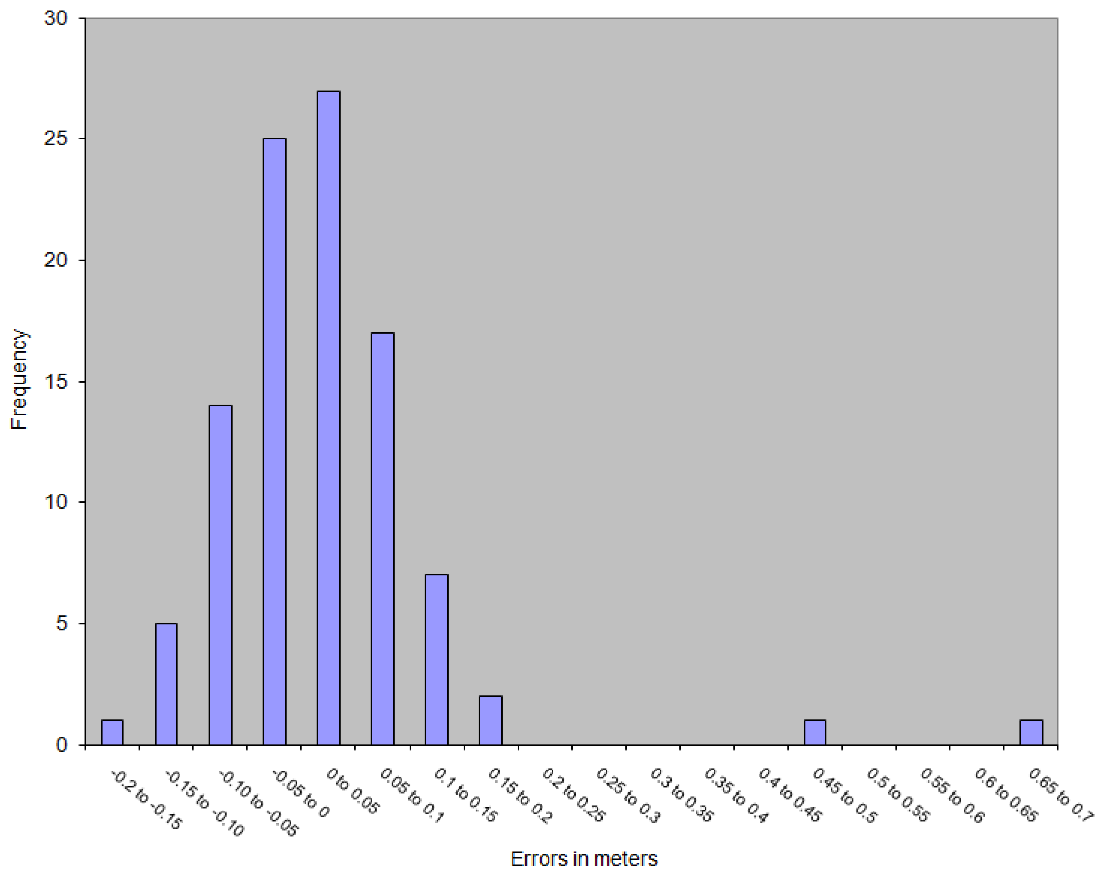

Figure 3-1. Error histogram of the example elevation dataset, showing two outliers in vegetated areas.

Table 3-14. Traditional Accuracy Statistics for the Example Elevation Dataset

Land Cover Category	# of Check Points	Min. (m)	Max. (m)	Mean (m)	Mean Absolute (m)	Median (m)	Skew	Kurtosis	Std Dev (m)	$RMSE_z$ (m)
Open Terrain	20	-0.10	0.08	-0.02	0.04	0.00	-0.19	-0.64	0.05	0.05
Urban Terrain	20	-0.15	0.11	0.01	0.06	0.02	-0.84	0.22	0.07	0.07
Weeds & Crops	20	-0.13	0.49	0.02	0.08	-0.01	2.68	9.43	0.13	0.13
Brush Lands	20	-0.10	0.17	0.04	0.06	0.04	-0.18	-0.31	0.07	0.08
Fully Forested	20	-0.13	0.70	0.03	0.10	0.00	3.08	11.46	0.18	0.17
Consoli-dated	100	-0.15	0.70	0.02	0.07	0.01	3.18	17.12	0.11	0.11

Table 3-15. Comparison of NSSDA and NDEP Accuracy Statistics with USGS V1.0 Requirements

Land Cover Category	NSSDA's $Accuracy_z$ at 95% confidence level based on $RMSE_z$ x 1.96	NDEP's FVA, plus SVAs and CVA based on the 95th Percentile	NDEP/USGS Accuracy Term	USGS Lidar Base Specification V1.0 Requirements
Open Terrain	0.10m	0.10m	FVA	0.245m
Urban Terrain	0.14m	0.13m	SVA	0.363m
Weeds & Crops	0.25m	0.15m	SVA	0.363m
Brush Lands	0.16m	0.14m	SVA	0.363m
Fully Forested	0.33m	0.21m	SVA	0.363m
Consolidated	0.22m	0.13m	CVA	0.363m

Table 3-16. Further Comparison of FVA, SVA and CVA with ASPRS NVA and VVA Statistics

<table>
<tr><th>Land Cover Category</th><th>NSSDA's Accuracy_z at 95% confidence level based on RMSE_z x 1.96</th><th>NDEP's FVA, plus SVAs and CVA based on the 95th Percentile</th><th>NDEP/USGS Accuracy Term</th><th>ASPRS Vertical Accuracy</th><th>ASPRS Accuracy Term</th></tr>
<tr><td>Open Terrain</td><td>0.10m</td><td>0.10m</td><td>FVA</td><td rowspan="2">0.12m</td><td rowspan="2">NVA</td></tr>
<tr><td>Urban Terrain</td><td>0.14m</td><td>0.13m</td><td>SVA</td></tr>
<tr><td>Weeds & Crops</td><td>0.25m</td><td>0.15m</td><td>SVA</td><td rowspan="3">0.167m</td><td rowspan="3">VVA</td></tr>
<tr><td>Brush Lands</td><td>0.16m</td><td>0.14m</td><td>SVA</td></tr>
<tr><td>Fully Forested</td><td>0.33m</td><td>0.21m</td><td>SVA</td></tr>
<tr><td>Consolidated</td><td>0.22m</td><td>0.13m</td><td>CVA</td><td>N/A</td><td>N/A</td></tr>
</table>

(b) Explanation of Example Vertical Accuracy Test Data. The two outliers shown in Figure 3-1, typical for LiDAR datasets, are the very reason why the NDEP initially developed SVA and

CVA procedures based on 95th percentile values as opposed to the NSSDA procedure which assumes all errors follow a normal error distribution and computes vertical accuracy at the 95% confidence level ($Accuracy_z$) as $RMSE_z$ * 1.9600. ASPRS (2014) also uses the 95th percentile to compute VVA for the very same reason. The rightmost column of Table 3-14 shows how these two outliers would unfairly skew the $RMSE_z$ values for weeds & crops and fully forested if these $RMSE_z$ values were multiplied by 1.9600 to estimate vertical accuracy at the 95% confidence level per NSSDA procedures. If the $RMSE_z$ of 25-cm for weeds & crops was multiplied by 1.96 to estimate vertical accuracy at the 95% confidence level in weeds and crops, the result would be 49-cm, exceeding the 36.3-cm standard; and if the $RMSE_z$ of 33-cm for fully forested was multiplied by 1.96, the result would be 65-cm, again exceeding the 36.3-cm standard. The same is true if multiplying the consolidated $RMSE_z$ of 22-cm by 1.96; the entire dataset would have unfairly failed because of a few outliers that often occur in dense vegetation, normally beyond the control of the data provider. However, because the *USGS Lidar Base Specification Version 1.0* correctly specified FVA (based on 1.9600 * $RMSE_z$ in open terrain only), plus SVA and CVA based on 95th percentile values, the dataset passed – as it should. The ASPRS, 2014 standards provide additional guidance on (1) the selection and distribution of QA/QC check points, (2) on the treatment of "low confidence areas," and (3) on analysis of vertical accuracy statistics. The vertical accuracy of this example LiDAR dataset would be reported in the metadata by one or both of the following methods:

When the SOW was based on USGS or FEMA specifications or standards:

Tested 0.10 meter Fundamental Vertical Accuracy (FVA) at 95 percent confidence level in open terrain using $RMSE_z$ * 1.9600

Tested 0.13 meter Consolidated Vertical Accuracy at 95th percentile in all land cover categories combined

Tested 0.13 meter Supplemental Vertical Accuracy (SVA) at 95th percentile in urban terrain areas

Tested 0.15 meter Supplemental Vertical Accuracy (SVA) at 95th percentile in weeds and crops

Tested 0.14 meter Supplemental Vertical Accuracy (SVA) at 95th percentile in brush land areas

Tested 0.21 meter Supplemental Vertical Accuracy (SVA) at 95th percentile in fully forested areas

When the SOW was based on ASPRS, 2014 standards:

Tested 0.12 meter Non-vegetated Vertical Accuracy (NVA) at 95 percent confidence level using $RMSE_z$ * 1.9600

Tested 0.167 meter Vegetated Vertical Accuracy (VVA) at 95th percentile

(c) Low Confidence Areas. For stereo-compiled elevation data sets, photogrammetrists should capture two-dimensional closed polygons for Low Confidence Areas where the bare-earth DTM may not meet the overall data accuracy requirements. Because photogrammetrists cannot see the ground in stereo beneath dense vegetation, in deep shadows or where the imagery is otherwise obscured, reliable data cannot be collected in those areas. Traditionally, contours within these obscured areas would be published as dashed contour lines. A compiler should make the determination as to whether the data being digitized is within NVA and VVA accuracies or not; areas not delineated by an obscure area polygon are presumed to meet accuracy standards. The extent of photogrammetrically derived obscure area polygons and any assumptions regarding how NVA and VVA accuracies apply to the photogrammetric data set must be clearly documented in the metadata. Low Confidence Areas also occur with lidar and IFSAR where heavy vegetation causes poor penetration of the lidar pulse or radar signal. ASPRS recommends that Low Confidence Areas for lidar be required and delivered as two-dimensional (2D) polygons based on the following four criteria: (1) nominal ground point density (NGPD); (2) cell size for the raster analysis; (3) search radius to determine average ground point densities; and (4) minimum size area appropriate to aggregate ground point densities and show a generalized Low Confidence Area (minimum mapping unit). Specific details on Low Confidence Areas are provided in Appendix C of these USACE standards, specifically Annex C, Section C.8 of the *ASPRS Positional Accuracy Standards for Digital Geospatial Data.*

e. Comparison with Prior Standards. Table 3-17 presents common horizontal accuracy classes for digital planimetric data, approximate GSD of source imagery for high accuracy planimetric data, and equivalent map scales per legacy NMAS and ASPRS 1990 accuracy standards. The values for the approximate GSD of source imagery only apply to imagery derived from common large and medium format metric cameras. The range of the approximate GSD of source imagery is only provided as a recommendation, based on the current state of sensor technologies and mapping practices. Different ranges may be considered in the future depending on future advances of such technologies and mapping practices.

Table 3-17 Comparison of ASPRS 2014 horizontal accuracy standards with legacy standards

ASPRS 2014				Equivalent to map scale in		Equivalent to map scale in NMAS
Horizontal Accuracy Class $RMSE_x$ and $RMSE_y$ (cm)	$RMSE_r$ (cm)	Horizontal Accuracy at the 95% Confidence Level (cm)	Approximate GSD of Source Imagery (cm)	ASPRS 1990 Class 1	ASPRS 1990 Class 2	
1.25	1.8	3.1	0.625 to 1.25	1:50	1:25	1:32
2.5	3.5	6.1	1.25 to 2.5	1:100	1:50	1:63
5	7.1	12.2	2.5 to 5	1:200	1:100	1:127
10	14.1	24.5	5 to 10	1:400	1:200	1:253
20	28.3	49.0	10 to 20	1:800	1:400	1:507
30	42.4	73.4	15 to 30	1:1,200	1:600	1:760
60	84.9	146.9	30 to 60	1:2,400	1:1,200	1:1,521
100	141.4	244.8	50 to 100	1:4,000	1:2,000	1:2,535
200	282.8	489.5	100 to 200	1:8,000	1:4,000	1:5,069
500	707.1	1,223.9	250 to 500	1:20,000	1:10,000	1:21,122
1,000	1414.2	2,447.7	500 to 1,000	1:40,000	1:20,000	1:42,244

Tables 3-4 through 3-11 of these USACE standards provide threshold values for assessing the horizontal and vertical accuracy of digital geospatial data at the 95% confidence levels as a function of pixel size for digital orthophotos; map scale and ground sample distance (GSD) of source imagery for planimetric mapping; and $RMSE_z$ and point density for LiDAR data. Contrary to film camera technology discussed in Chapter 4, USACE does not specify "best practice" parameters for digital technology because modern digital sensors all provide greater flexibility and options for achieving required results. USACE policy is to specify required deliverables and acceptance criteria without specifying how those deliverables are to be produced.

3-3. Lineage of Map Accuracy Standards. The lineage and evolution of map accuracy standards is described in the sections below. Map accuracy standards that are discussed due to their impact on photogrammetry and LiDAR include:

a. National Map Accuracy Standards (NMAS, 1947). The NMAS was published by the Bureau of the Budget in 1947 and for a half century provided simple criteria for assessing the horizontal and vertical accuracy of maps published with a defined map scale and contour interval. The NMAS pertained to *relative accuracy* because *absolute accuracy* was virtually undeterminable prior to the advent of GPS technology and a geocentric datum.

(1) Horizontal Accuracy. The NMAS defines the horizontal Circular Map Accuracy Standard (CMAS), as follows: "For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, the error shall not exceed 1/50 inch. These limits of accuracy shall apply in all cases to positions of well-defined points only. Well-defined points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as bench marks, property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings), etc. In general, what is well defined will be determined by what is plottable on the scale of the map within 1/100 inch." Table 3-18 provides horizontal Circular Map Accuracy Standards for common published map scales where CE90 equals circular error at the 90% confidence level. Circular error is the same as radial error.

(2) Vertical Accuracy. The NMAS defines the Vertical Map Accuracy Standard (VMAS), as follows: "Vertical accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale." Table 3-19 provides Vertical Map Accuracy Standards for common contour intervals where LE90 equals linear error at the 90% confidence level.

Table 3-18. NMAS Horizontal Accuracy Standards for Common Map Scales

Map Scale	Scale Ratio	CMAS CE90 (Feet)
1" = 50'	1:600	1.67
1" = 100'	1:1,200	3.33
1" = 200'	1:2,400	6.67
1" = 400'	1:4,800	13.33

Table 3-19. NMAS Vertical Accuracy Standards for Common Contour Intervals

Contour Interval (Feet)	VMAS LE90 (Feet)
1	0.5
2	1.0
4	2.0
5	2.5

(3) Accuracy Testing/Reporting. The NMAS states "The accuracy of any map may be tested by comparing the positions of points whose locations or elevations are shown upon it with corresponding positions as determined by surveys of a higher accuracy. Tests shall be made by the producing agency, which shall also determine which of its maps are to be tested, and the

extent of the testing." Maps that meet NMAS accuracy requirements note this in their legend with the statement: "This map complies with National Map Accuracy Standards." If a published map does not meet NMAS standards, then all mention of accuracy is omitted from the map legend. Additionally, since NMAS is tied to the scales of published maps, the legend must specify if the map is an enlargement of another published map with a statement such as "This map is an enlargement of a 1:24,000-scale published map."

(4) NMAS Points to Remember. The NMAS remains relevant only for testing and reporting the horizontal and vertical accuracies of graphic maps with a published map scale and contour interval. For large-scale maps used by USACE, NMAS horizontal accuracy reports circular (radial) error at the 90% confidence level (CE90), based on $1/30^{th}$ inch at publication scale. NMAS vertical accuracy reports linear error at the 90% confidence level (LE90), based on one-half the contour interval. The NMAS makes no assumptions regarding a normal error distribution.

b. ASPRS Accuracy Standards for Large-Scale Maps (ASPRS 1990). These standards define accuracy at ground scale, whereas NMAS defines accuracy at map scale. Although thresholds are defined for Class 1 maps, these standards also allow for maps with lower spatial accuracies. "Maps compiled within limiting rms errors of twice or three times those allowed for Class 1 maps shall be designated Class 2 or Class 3 maps respectively." The rms error is the square root of the average of the squared discrepancies between coordinate values derived from the map and coordinate values determined by an independent survey of higher accuracy. A map may be compiled that complies with one class of accuracy in elevation and another in plan. Multiple accuracies on the same map are allowed provided a diagram is included which clearly relates segments of the map with the appropriate map accuracy class. These standards use "well-defined points" to indicate features that can be "sharply identified as discrete points."

(1) Horizontal Accuracy Standard. ASPRS 1990 defines horizontal accuracy as follows: "Horizontal map accuracy is defined as the root mean square (rms) error in terms of the project's planimetric survey coordinates (X,Y) for checked points as determined at full (ground) scale of the map. The rms error is the cumulative result of all errors including those introduced by the processes of ground control surveys, map compilation and final extraction of ground dimensions from the map. The limiting rms errors are the maximum permissible rms errors established by this standard." The limiting rms errors in X and Y are listed in Table 3-20 for ASPRS Class 1, Class 2 and Class 3 maps at common map scales.

Table 3-20. ASPRS 1990 Horizontal Accuracy Standards

Map Scale	Scale Ratio	ASPRS 1990 Class 1 Limiting RMSExy (Feet)	ASPRS 1990 Class 2 Limiting RMSExy (Feet)	ASPRS 1990 Class 3 Limiting RMSExy (Feet)
1” = 50’	1:600	0.5	1.0	1.5
1” = 100’	1:1,200	1.0	2.0	3.0
1” = 200’	1:2,400	2.0	4.0	6.0
1” = 400’	1:4,800	4.0	8.0	12.0

(2) <u>Vertical Accuracy Standard</u>. ASPRS 1990 defines vertical accuracy as follows: “Vertical map accuracy is defined as the rms error in evaluation in terms of the project’s evaluation datum for well-defined points only. For Class 1 maps the limiting rms error in evaluation is set by the standard at *one-third* the indicated contour interval for well-defined points only. Spot heights shall be shown on the map within a limiting rms error of *one-sixth* of the contour interval.” The limiting rms errors in Z are listed in Table 3-21 for ASPRS Class 1, Class 2 and Class 3 maps at common contour intervals.

Table 3-21. ASPRS 1990 Vertical Accuracy Standards

Contour Interval (Feet)	ASPRS 1990 Class 1 Limiting RMSEz (Feet)	ASPRS 1990 Class 2 Limiting RMSEz (Feet)	ASPRS 1990 Class 3 Limiting RMSEz (Feet)
1	0.333	0.667	1.0
2	0.667	1.333	2.0
4	1.333	2.667	4.0
5	1.667	3.333	5.0

(3) <u>Accuracy Testing/Reporting</u>. “Testing for horizontal accuracy compliance is done by comparing the planimetric (X and Y) coordinates of well-defined ground points to the coordinates of the same points as determined by a horizontal check survey of higher accuracy. Testing for vertical accuracy compliance shall be accomplished by comparing the elevations of well-defined points as determined from the map to corresponding elevations determined by a survey of higher accuracy. For purposes of checking elevations, the map position of the ground point may be shifted in any direction by an amount equal to twice the limiting rms error in position.” These standards also state that “discrepancies between the X, Y, or Z coordinates of the ground point, as determined from the map and by the check survey, that exceed *three* times the limiting rms error shall be interpreted as blunders and will be corrected before the map is considered to meet this standard.” “A minimum of 20 checkpoints shall be established throughout the area covered by the map and shall be distributed in a manner agreed upon by the contracting parties.” Check points can be concentrated more heavily in areas of interest. If the

map is not tested for accuracy, but collected in such a manner to ensure compliance with stated class accuracies, then the following statement would appear in the title block: "THIS MAP WAS COMPILED TO MEET THE ASPRS STANDARD FOR CLASS 1 MAP ACCURACY." Maps checked for compliance and found to conform to stated class accuracies would have the following statement in the title block: THIS MAP WAS CHECKED AND FOUND TO CONFORM TO THE ASPRS STANDARD FOR CLASS 1 MAP ACCURACY."

(4) ASPRS 1990 Points to Remember. As with the NMAS, the ASPRS 1990 standards remain relevant only for testing and reporting the horizontal and vertical accuracies of graphic maps with a published map scale and contour interval. The major difference is that the ASPRS 1990 standards indicate accuracy at ground scale so that digital geospatial data of known ground-scale accuracy can be related to the appropriate map scale for graphic presentation. As with the NMAS, the ASPRS 1990 standards are considered obsolete for modern mapping with digital cameras and LiDAR sensors. Table 3-22 compares the horizontal accuracy standards between NMAS and ASPRS 1990 for common map scales. The NMAS uses circular (radial) error whereas ASPRS 1990 uses linear error in x and y directions in terms of $RMSE_{xy}$. The radial RMSE ($RMSE_r$) = $RMSE_{xy}$ * 1.4142. Table 3-23 compares the vertical accuracy standards between NMAS and ASPRS 1990 for common contour intervals.

Table 3-22. Comparison of Horizontal Accuracy Standards: NMAS and ASPRS 1990

Map Scale	Scale Ratio	Horizontal $RMSE_{xy}$ (Feet)			
		NMAS	ASPRS 1990 Class 1	ASPRS 1990 Class 2	ASPRS 1990 Class 3
1" = 50'	1:600	0.777	0.5	1.0	1.5
1" = 100'	1:1,200	1.553	1.0	2.0	3.0
1" = 200'	1:2,400	3.107	2.0	4.0	6.0
1" = 400'	1:4,800	6.213	4.0	8.0	12.0

Table 3-23. Comparison of Vertical Accuracy Standards: NMAS and ASPRS 1990

Contour Interval (Feet)	Vertical $RMSE_z$ (Feet)			
	NMAS	ASPRS 1990 Class 1	ASPRS 1990 Class 2	ASPRS 1990 Class 3
1	0.304	0.333	0.667	1.000
2	0.608	0.667	1.333	2.000
4	1.216	1.333	2.667	4.000
5	1.520	1.667	3.333	5.000

c. National Standard for Spatial Data Accuracy (NSSDA, 1998). The NSSDA implements a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to georeferenced ground positions of higher accuracy. The NSSDA applies to fully georeferenced maps and digital geospatial data, in raster, point, or vector format, derived from sources such as aerial photographs, satellite imagery, and ground surveys. It provides a common language for reporting accuracy to facilitate the identification of spatial data for geographic applications. The NSSDA does not define threshold accuracy values. Ultimately, users identify acceptable accuracies for their applications – as USACE does in Section 3-2 above. The NSSDA comprises Part 3 of the FGDC *Geospatial Positioning Accuracy Standards*. Part 4, *Architecture, Engineering, Construction, and Facilities Management* of the FGDC *Geospatial Positioning Accuracy Standards*, is largely based on the *ASPRS Accuracy Standards for Large-Scale Maps* of 1990. While the FGDC recognizes that standards other than the NSSDA may be used if they are truly appropriate for the project, the FGDC states "the NSSDA may be used for fully georeferenced maps for A/E/C and Facility Management applications such as preliminary site planning and reconnaissance mapping." The applicability of NSSDA is stated as: "Use the NSSDA to evaluate and report the positional accuracy of maps and geospatial data produced, revised, or disseminated by or for the Federal Government. According to Executive Order 12906, *Coordinating Geographic Data Acquisition and Access: the National Spatial Data Infrastructure* (Clinton, 1994, Sec. 4. Data Standards Activities, item d), 'Federal agencies collecting or producing geospatial data, either directly or indirectly (e.g. through grants, partnerships, or contracts with other entities), shall ensure, prior to obligating funds for such activities, that data will be collected in a manner that meets all relevant standards adopted through the FGDC process.' Accuracy of new or revised spatial data will be reported according to the NSSDA. Accuracy of existing or legacy data and maps may be reported, as specified, according to the NSSDA or the accuracy standard by which they were evaluated." As such, the majority of newly collected or acquired geospatial data should be tested and reported according to NSSDA standards and not tested or reported according to previous methods, such as NMAS or ASPRS Accuracy Standard for Large-Scale Maps.

(1) Horizontal Accuracy Standard. Although the NSSDA specifies no specific threshold values, Appendix 3-D of the NSSDA provides statistical relationships between NSSDA and NMAS horizontal and vertical accuracy standards when assuming that horizontal and vertical errors follow a normal error distribution. Table 3-24 provides direct comparisons between NMAS and NSSDA horizontal accuracy standards for common map scales. CMAS (NMAS horizontal radial accuracy at 90% confidence level) = $RMSE_r * 1.5175$ whereas $Accuracy_r$ (NSSDA horizontal radial accuracy at 95% confidence level) = $RMSE_r * 1.7308$.

Table 3-24. Comparison of Horizontal Accuracy Standards: NMAS and NSSDA

Map Scale	Scale Ratio	NMAS CMAS 90% confidence level (Feet)	$RMSE_r$ (Feet)	NSSDA $Accuracy_r$ 95% confidence level (Feet)
1”=50’	1:600	1.67	1.10	1.90
1”=100’	1:1,200	3.33	2.20	3.80
1”=200’	1:2,400	6.67	4.39	7.60
1”=400’	1:4,800	13.33	8.79	15.21

(2) Vertical Accuracy Standard. Similarly, Table 3-25 provides direct comparisons between NMAS and NSSDA vertical accuracy standards for equivalent contour intervals; VMAS (NMAS vertical accuracy at 90% confidence level) = $RMSE_z$ * 1.6449 whereas $Accuracy_z$ (NSSDA vertical accuracy at 95% confidence level) = $RMSE_z$ * 1.9600.

Table 3-25. Comparison of Vertical Accuracy Standards: NMAS and NSSDA

Equivalent Contour Interval (Feet)	NMAS VMAS 90% confidence level (Feet)	$RMSE_z$ (Feet)	NSSDA $Accuracy_z$ 95% confidence level (Feet)
1	0.50	0.30	0.60
2	1.00	0.61	1.19
4	2.00	1.22	2.38
5	2.50	1.52	2.98

(3) Accuracy Testing/Reporting. According to NSSDA standards, spatial accuracy is determined by using root-mean-square error (RMSE) to estimate positional accuracy. “RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product.”

(a) NSSDA Accuracy Testing. The NSSDA presents guidelines for accuracy testing by an independent source of higher accuracy. “The independent source of higher accuracy shall be the highest accuracy feasible and practicable to evaluate the accuracy of the dataset. The data producer shall determine the geographic extent of testing. Horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points in the dataset with coordinates of the same points from an independent source of higher accuracy. Vertical accuracy shall be tested by comparing the elevations in the dataset with elevations of the same points as determined from an independent source of higher accuracy. A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of accuracy testing, well-defined points must be easily visible or recoverable on the ground, on the independent source of higher accuracy, and on the product itself. Graphic contour data and digital hypsographic data may not contain well-defined points. Errors in recording or processing data, such as reversing signs or inconsistencies between the dataset and independent source of higher accuracy in coordinate reference system definition, must be corrected before computing the accuracy value." Because NSSDA states that digital hypsographic data (topographic data above sea level) may not contain well-defined points, well-defined points are only used for horizontal accuracy testing and not required for vertical accuracy testing. The check points that will be used for accuracy testing must be collected separately from the data to be tested and must not be used as control or as any part of the production procedures. "A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications." The NSSDA only provides guidelines for the spatial distribution of check points, and leaves the final placement to the data producers. "Check points may be distributed more densely in the vicinity of important features and more sparsely in areas that are of little or no interest. When data exist for only a portion of the dataset, confine test points to that area. When the distribution of error is likely to be nonrandom, it may be desirable to locate check points to correspond to the error distribution. For a dataset covering a rectangular area that is believed to have uniform positional accuracy, check points may be distributed so that points are spaced at intervals of at least 10 percent of the diagonal distance across the dataset *and* at least 20 percent of the points are located in each quadrant of the dataset."

(b) <u>NSSDA Accuracy Reporting</u>. "Spatial data may be compiled to comply with one accuracy value for the vertical component and another for the horizontal component. If a dataset does not contain elevation data, label for horizontal accuracy only. Conversely, when a dataset, e.g. a gridded digital elevation dataset or elevation contour dataset, does not contain well-defined points, label for vertical accuracy only. Positional accuracy values shall be reported in ground distances. Metric units shall be used when the dataset coordinates are in meters. Feet shall be used when the dataset coordinates are in feet. The number of significant places for the accuracy value shall be equal to the number of significant places for the dataset point coordinates. Report accuracy at the 95% confidence level for data *tested* for both horizontal and vertical accuracy as:

Tested __ (meters, feet) horizontal accuracy at the 95% confidence level
Tested __ (meters, feet) vertical accuracy at the 95% confidence level

"Use the 'compiled to meet' statement below when the above guidelines for testing by an independent source of higher accuracy cannot be followed and an alternative means is used to evaluate accuracy. Report accuracy at the 95% confidence level for data *produced according to procedures that have been demonstrated to produce data with particular horizontal and vertical accuracy values* as:

Compiled to meet __ (meters, feet) horizontal accuracy at 95% confidence level
Compiled to meet __ (meters, feet) vertical accuracy at 95% confidence level

"For digital geospatial data, report the accuracy value in digital geospatial metadata. Regardless of whether the data was tested by an independent source of higher accuracy or evaluated for accuracy by alternative means, provide a complete description on how the values were determined in metadata (Federal Geographic Data Committee, 1998, Section 2)."

(4) NSSDA Points to Remember. The NSSDA implements a statistical and testing methodology for estimating the positional accuracy of maps and digital geospatial data at the 95% confidence level relative to georeferenced ground positions of higher accuracy. It omits specific accuracy thresholds but can be cross-referenced to map scale and contour interval as with the NMAS and ASPRS 1990 standards. The NSSDA assumes all errors follow a normal error distribution. Accuracy of new or revised spatial data should be reported at the 95% confidence level according to the NSSDA. NSSDA accuracy and testing procedures are applicable to data produced to USACE Accuracy Standards for Photogrammetry and LiDAR Mapping, defined in 3-2 above.

d. NDEP Guidelines for Digital Elevation Data (NDEP, 2004). The NDEP guidelines were published in May, 2004 by the Technical Committee of the National Digital Elevation Program (NDEP), established to promote the exchange of accurate digital land elevation data among government, private, and non-profit sectors and the academic community and to establish standards and guidance that will benefit all users. The NDEP guidelines are not meant to replace the NSSDA guidelines, but rather to supplement them. As with the NSSDA, NDEP accuracy requirements also use RMSE in terms of feet or meters at ground scale instead of NMAS' published map scale; however, RMSE is only relevant when errors follow a normal error distribution. When errors do not necessarily follow a normal error distribution, as with Digital Elevation Models (DEMs) in vegetated/forested terrain, the NDEP guidelines use the 95th percentile errors instead of RMSE. To specifically address the challenges and opportunities from LiDAR, the NDEP guidelines were the first to introduce three new terms: Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA); however, these terms are equally relevant to photogrammetrically-compiled DEMs which normally also have poorer accuracy in vegetated/forested terrain.

(1) Horizontal Accuracy Standard. Although primarily focused on the vertical accuracy of elevation data, the NDEP guidelines state: "Horizontal accuracy is another important characteristic of elevation data; however, it is largely controlled by the vertical accuracy requirement. If a very high vertical accuracy is required then it will be essential for the data producer to maintain a very high horizontal accuracy. This is because horizontal errors in elevation data normally (but not always) contribute significantly to the error detected in vertical accuracy tests." The NDEP guidelines further state that "horizontal error is more difficult than vertical error to assess in the final elevation product. This is because the land surface often lacks distinct (well defined) topographic features necessary for such tests or because the resolution of the elevation data is too coarse for precisely locating distinct surface features. For these reason, the NDEP does not require horizontal accuracy testing of elevation products. Instead, the NDEP requires data producers to report the expected horizontal accuracy of elevation products as determined from system studies or other methods."

(2) Vertical Accuracy Standard. Whereas the NSSDA computes one vertical accuracy statistic ($Accuracy_z = RMSE_z * 1.9600$) for the entire project, the NDEP recognizes that land cover types can affect elevation error. "Because vegetation can limit ground detection, tall dense forests and even tall grass tend to cause greater elevation errors than unobstructed (short grass or barren) terrain. Errors measured in areas of different ground cover also tend to be distributed differently from errors in unobstructed terrain. For these reason, the NDEP requires open terrain to be tested separately from other ground cover types. Testing over any other ground cover category is required only if that category constitutes a significant portion of the project area deemed critical to the customer." The NDEP introduces Fundamental Vertical Accuracy, Supplemental Vertical Accuracy, and Consolidated Vertical Accuracy:

(a) Fundamental Vertical Accuracy (FVA). The FVA reports the vertical accuracy of bare-earth elevation data in open terrain (short grass, dirt, rocks, sand) where errors should follow a normal error distribution. The FVA is determined using standard NSSDA tests for $RMSE_z$, where FVA = $Accuracy_z$ = $RMSE_z$ * 1.9600. The FVA is determined from checkpoints located only in open terrain where there is a high probability that the sensor will have detected the ground surface. Initially developed for LiDAR, the FVA indicates how well the sensor performed, whereas the SVA and CVA indicate how well LiDAR returns in vegetation were filtered to determine ground elevations in a gridded DEM or a Digital Terrain Model (DTM) consisting of irregularly-spaced mass points and breaklines. However, the FVA concept pertains equally well to other technologies such as photogrammetry and IFSAR where elevations in open terrain are more accurate than in other land cover categories. Except for rare, specific instances, FVA must always be calculated whereas SVA and CVA may be optional.

(b) <u>Supplemental Vertical Accuracy (SVA)</u>. The SVA reports the vertical accuracy of elevation data in land cover categories other than open terrain, to include vegetation (where elevations are sometimes higher than true values) and built-up areas (where elevations are sometimes lower than true values). Because these elevations do not necessarily follow a normal error distribution assumed by the NSSDA, SVA values are computed using the 95^{th} percentile errors for each land cover category rather than relying on the $RMSE_z$ * 1.9600. Computed by a simple spreadsheet command, a “percentile” is the interpolated absolute value in a dataset of errors dividing the distribution of the individual errors in the dataset into one hundred groups of equal frequency. The 95^{th} 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. With this method, accuracy is directly related to the 95^{th} percentile, where 95 percent of the errors have absolute values that are equal to or smaller than the specified amount. Individual SVA values are determined for each separate land cover category that represents a significant portion of the area being mapped. A separate SVA is reported for each of the individual land cover categories tested. It is normally optional to satisfy individual SVA standards so long as the overall FVA and CVA standards are met. SVA standards are considered to be target values that are relaxed in difficult land cover categories such as mangrove or sawgrass.

(c) <u>Consolidated Vertical Accuracy (CVA)</u>. The CVA reports the vertical accuracy of bare-earth elevation data in all land cover categories combined, using the 95^{th} percentile. Only one CVA is reported for the entire dataset. CVA and SVA values often approximate the same values that would have been obtained using $RMSE_z$ * 1.9600; when this occurs, this indicates that the errors in other land cover categories also approximate a normal distribution. It is normally mandatory to satisfy CVA standards.

(3) Accuracy Testing and Reporting. Just as with the NSSDA, the NDEP guidelines specify that accuracy testing should be accomplished by testing data against an independent source of higher accuracy. The NDEP recommends specifying the final desired vertical accuracy for all final deliverables as some deliverables may have different accuracies. "For example, when contours or gridded DEMs are specified as deliverables from photogrammetric or LiDAR-generated mass points, a TIN may first be produced from which a DEM or contours are derived. If done properly, error introduced during the TIN to contour/DEM process should be minimal; however, some degree of error will be introduced. Accuracy should not be specified and tested for the TIN with the expectation that derivatives will meet the same accuracy. Derivatives may exhibit greater error, especially when generalization or surface smoothing has been applied to the final product. Specifying accuracy of the final product(s) requires the data producer to ensure that error is kept within necessary limits during all production steps."

(a) Check Points. The NDEP guidelines specify that the independent source of higher accuracy (check points) must be at least three times more accurate than the dataset being tested. NDEP recommends following NSSDA guidance for choosing the spatial distribution of check point locations, described in Section 3-3.c (3) (a), but the NDEP gives additional guidance for terrain and slope parameters in proximity to check point locations. The NDEP guidelines state that check points should be located on flat terrain, so that horizontal errors due to slope or interpolation do not affect the vertical accuracy calculations. Furthermore, check points should never be selected near severe breaks in slope (such as bridge abutments, retaining walls, or edges of roads/ditches) where subsequent interpolation might be performed with inappropriate TIN or DEM points on the wrong sides of the breaklines. While NSSDA recommends a minimum of 20 checkpoints for each project area, NDEP "recommends following the current industry standard of utilizing a minimum of 20 checkpoints (30 is preferred) in each of the major land cover categories representative of the area for which digital elevation modeling is to be performed; this helps to identify potential systematic errors in an elevation dataset. Thus, if five major land cover categories are determined to be applicable, then a minimum of 100 total check points are required." This method became standard industry practice with FEMA's *Guidance for Aerial Mapping and Surveying*, Appendix A, published in 2003 (FEMA, 2003) and remained unchallenged until ASPRS published its recommended number of check points based on project area (ASPRS, 2014) as shown above in Table 3-7.

(b) Horizontal Accuracy Reporting. While the NDEP does not require horizontal accuracy testing, the NDEP requires data producers to report the expected horizontal accuracy of elevation products as determined from system studies or other methods." Horizontal accuracy that is not independently tested would be defined with the “Compiled to Meet” statement outlined in Section 3-3.c (3) (b). Horizontal accuracy that is independently tested would use the “Tested to Meet” statement also outlined in Section 3-3.c (3) (b).

(c) Vertical Accuracy Reporting. The NDEP statements reporting vertical accuracy differ from the NSSDA statements because the NDEP requires the methodology ($RMSE_z$ or 95th percentile) and the land cover categories tested to be identified. FVA should be reported with the following statement:

> Tested __ (meters, feet) Fundamental Vertical Accuracy at 95 percent confidence level in open terrain using $RMSE_z$ x 1.9600.

SVA and CVA accuracy statements must be accompanied by a FVA accuracy statement. When specific land cover categories, other than open terrain, are tested, SVA should be reported with the following statement:

> Tested __ (meters, feet) Supplemental Vertical Accuracy at 95th percentile in (specify land cover category or categories).

When 40 or more check points are consolidated for two or more of the major land cover categories, representing both the open terrain and other land cover categories (for example, forested), a Consolidated Vertical Accuracy assessment should be reported as follows:

> Tested __ (meters, feet) Consolidated Vertical Accuracy at 95th percentile in open terrain and … (specify all other land cover categories tested).

For SVA and CVA, the 5% outliers should be documented in the metadata. For a small number of errors above the 95th percentile, report x/y coordinates and z-error for each QC check point error larger than the 95th percentile. For a large number of errors above the 95th percentile, report only the quantity and range of values.

When testing by an independent source of higher accuracy cannot be completed, report accuracy at the 95% confidence level for data produced according to procedures that have been demonstrated to produce data with particular vertical accuracy values as:

> Compiled to meet __ (meters, feet) Fundamental Vertical Accuracy at 95 percent confidence level in open terrain,” or “Compiled to meet __ (meters, feet) Supplemental Vertical Accuracy at 95th percentile in (specific land cover category or categories), or

Complied to meet __ (meters, feet) Consolidated Vertical Accuracy at 95th percentile in open terrain and … (list all other relevant land cover categories).

LiDAR data are generally always tested for vertical accuracy and will be reported with the "tested" accuracy statements. However, the relationship between flying height, analog film camera characteristics, and final map accuracy are well established; for these reasons, the "compiled to meet" statements can be used for elevation data collected with photogrammetric procedures from analog film.

(4) NDEP Points to Remember. The NDEP guidelines supplement the NSSDA and are applicable for all USACE LiDAR mapping projects and photogrammetric mapping projects that use digital cameras to stereo-compile elevation data.

e. ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data (ASPRS, 2004). These guidelines were published in May 2004 by the ASPRS Lidar Committee, providing official ASPRS endorsement of the NDEP, 2004 guidelines. While the ASPRS guidelines specifically target LiDAR data and the NDEP guidelines more broadly refer to digital elevation data that could be collected from numerous types of different sensors and technologies, the NDEP and ASPRS LiDAR guidelines are nearly identical in their accuracy standards and accuracy reporting, with no significant differences. These ASPRS 2004 guidelines were superseded by the new ASPRS, 2014 standards.

f. FEMA Standards for Lidar and Other High Quality Digital Topography, Procedure Memorandum No. 61 (FEMA, 2010). New elevation data purchased by FEMA must comply with the USGS Lidar Base Specification, summarized below, except where specifically noted in PM 61. Because FEMA's needs for elevation data are specific to National Flood Insurance Program (NFIP) floodplain mapping, FEMA has several unique requirements that differ from the USGS specifications, e.g., specific requirements for surveys of cross sections, bridges and culverts. FEMA maintains a national dataset that estimates flood risk. The data are calculated at the Census Block Group level and are aggregated to the county, watershed and sub-watershed levels. These data assign a risk value and a risk rank to each area. The areas are grouped into 10 classes with an equal number of members based on risk rank. These 10 classes are called risk deciles. Depending on flood risk, FEMA's flood studies may be performed with elevation data from airborne LiDAR, stereo photogrammetry, or IFSAR. "Careful consideration and balance among cost, need, risk, and vertical accuracy is important." FEMA's requirements are only similar to the USGS requirements in the highest specification level, but otherwise differ for lower specification levels.

(1) Horizontal Accuracy Standard. As with USGS, FEMA has no horizontal accuracy standard but relies on calibrated systems and best practices to ensure the horizontal accuracy of its elevation data.

(2) Vertical Accuracy Standard. FEMA's vertical accuracy requirements from LiDAR, photogrammetry and/or IFSAR are a function of flood risk and terrain slope within the floodplain being mapped, as shown in Table 3-26.

Table 3-26. FEMA Vertical Accuracy Requirements as Function of Flood Risk and Slope

Level of Flood Risk	Typical Slopes	Specification Level	Vertical Accuracy, 95% Confidence Level, FVA/CVA	Nominal Point Spacing
High (Deciles 1,2,3)	Flattest	Highest	24.5 cm / 36.3 cm	≤1 meter
High (Deciles 1,2,3)	Rolling or Hilly	High	49.0 cm / 72.6 cm	≤2 meters
High (Deciles 2,3,4,5)	Hilly	Medium	98.0 cm / 145 cm	≤3.5 meters
Medium (Deciles 3,4,5,6,7)	Flattest	High	49.0 cm / 72.6 cm	≤2 meters
Medium (Deciles 3,4,5,6,7)	Rolling	Medium	98.0 cm / 145 cm	≤3.5 meters
Medium (Deciles 4,5,6,7)	Hilly	Low	147 cm / 218 cm	≤5 meters
Low (Deciles 7,8,9,10)	All	Low	147 cm / 218 cm	≤5 meters

(3) Accuracy Testing/Reporting. FEMA requires a Post-Flight Aerial Acquisition and Calibration Report. FEMA also requires quality reviews and reporting performed by independent QA/QC, i.e., other than the firm performing the aerial data acquisition. Reporting of positional accuracy is in accordance with ASPRS/NDEP standards for FVA and CVA. SVA is tested in up to three land cover categories in addition to open terrain; land cover categories making up 10% or more of the project area (floodplain) should be included in the SVA testing. For smaller projects less than 1,000 square miles, fewer check points for SVA testing are acceptable; the number of check points shall be reduced to control the QA cost to about 10% of the acquisition and processing costs. Processing areas greater than 2,000 square miles must be divided into smaller blocks of 2,000 square miles or less and tested as individual areas; other rules are applied for testing large areas mapped by multiple vendors. Each block of 2,000 square miles or less shall be tested for FVA, SVA, and CFA.

(4) FEMA Points to Remember. FEMA was the first to recognize the need to separately test the accuracy of LiDAR bare-earth elevation data in different land cover categories. FEMA's procedures are focused on needs for floodplain mapping, interested primarily in bare-earth DEMs and less interested in LiDAR point cloud data of interest to others. Nevertheless, FEMA

also recognizes the importance of USGS efforts to promote consistency across LiDAR collections, to get data that are uniform in structure, formatting, content and handling, and to populate the National Elevation Dataset (NED) with nationally consistent data that meet minimum specifications. FEMA contracts for much of its LiDAR data through USGS, using the USGS Lidar Base Specification with minimal modifications.

g. USGS Lidar Base Specification, Version 1.0 (Heidemann, 2012). Based on an earlier draft Version 13, the first official *USGS Lidar Base Specification Version 1.0* was published in 2012 to: (1) establish some degree of consistency across LiDAR collections, mostly with regards to the LiDAR point cloud; (2) to get data that are uniform in structure, formatting, content and handling so that Quality Assurance steps do not have to change with every Scope of Work, to get consistent point cloud deliverables to viably exploit the other benefits of LiDAR data, and to simplify the acquisition and delivery of data that are interoperable and usable by a broad array of federal, state and local users at minimal costs, and (3) to improve the National Elevation Dataset (NED) with nationally consistent data that meet minimum specifications. In addition to accuracy standards, this Lidar Base Specification provides minimum specifications for: (a) Data Collection (multiple discrete returns or full waveform, intensity values, nominal pulse spacing (NPS), data voids, spatial distribution, scan angle, flightline overlap, collection area, collection conditions); (b) Data Processing and Handling (LAS classification, classification accuracy and consistency, GPS times, horizontal and vertical datums, coordinate reference system, units, file size, swath file source ID, point families, raw data deliverable, withheld points, and tiled deliverables); (c) Hydro-Flattening of inland ponds and lakes, inland streams and rivers, non-tidal boundary waters, tidal waters; (d) Deliverables (metadata, raw point cloud, classified point cloud, bare-earth surface – raster DEM, and breaklines); and (e) Common Data Upgrades.

(1) Horizontal Accuracy Standard. Because it is very difficult to identify clearly-defined point features from LiDAR point cloud data and intensity returns, USGS specifies no specific horizontal accuracy standard but relies on LiDAR system manufacturer calibration and field bore-sighting to ensure that laser pulses record the approximate same horizontal coordinates of field calibration site point features when flying north, south, east or west over a field calibration site. Best practices are under consideration by the ASPRS LiDAR Subcommittee.

(2) Vertical Accuracy Standard. For absolute vertical accuracy, USGS specifies Fundamental Vertical Accuracy (FVA) of 24.5 cm = $Accuracy_z$, based on $RMSE_z$ of 12.5 cm; Consolidated Vertical Accuracy (CVA) of 36.3 cm based on 95^{th} percentile; and Supplemental Vertical Accuracy (SVA) target values of 36.3 cm based on 95^{th} percentile for all land cover

types representing 10% or more of the total project area. For relative vertical accuracy, USGS specifies a root mean square difference ($RMSD_z$) of 7 cm or less within individual swaths, and an $RMSD_z$ of 10 cm or less within swath overlap of adjoining swaths. Whereas $RMSE_z$ is used to compute absolute accuracy, $RMSD_z$ is used to compute relative accuracy between comparable datasets.

(3) Accuracy Testing/Reporting. Vertical accuracy of LiDAR data will be assessed and reported in accordance with the guidelines developed by the NDEP and subsequently adopted by ASPRS. The absolute and relative accuracy of the data, relative to known control, shall be verified prior to classification and subsequent product development; this validation is limited to LiDAR relative accuracy swath-to-swath as well as the Fundamental Vertical Accuracy measured in clear, open areas. Supplemental Vertical Accuracy values and the Consolidated Vertical Accuracy are verified after LAS classification of ground points.

(4) USGS Lidar Base Specification Version 1.0 Points to Remember. The *USGS Lidar Base Specification Version 1.0* (Heidemann, 2012) provides minimal specifications for LiDAR point cloud data and for LiDAR-derived DEMs to be placed in the National Elevation Dataset (NED); however, it must be noted that Heidemann, 2012 has since been updated by the *USGS Lidar Base Specification Version 1.2* (Heidemann, 2014) to bring it in conformance with Quality Level 2 (QL2) LiDAR requirements of USGS's 3D Elevation Program (3DEP) for new LiDAR acquired for 49 states (all except Alaska) and U.S. territories.

h. USGS Lidar Base Specification, Version 1.2 (Heidemann, 2014). The *USGS Lidar Base Specification Version 1.2* is nearly identical to Version 1.0, except for higher vertical accuracy and narrower Nominal Pulse Spacing (NPS) for Quality Level 2 (QL2) LiDAR produced in conformance with requirements of USGS's 3D Elevation Program (3DEP). The Fundamental Vertical Accuracy (FVA) is tightened from 24.5-cm to 19.6-cm; the Consolidated Vertical Accuracy (CVA) and Supplemental Vertical Accuracy (SVA) are tightened from 36.3-cm to 29.4-cm; and the NPS is tightened from 2 meters to 0.707-meters in order to achieve a point density of 2 points per square meter. It is in USACE's best interest to support the USGS efforts to promote consistency across LiDAR collections, to get data that are uniform in structure, formatting, content and handling, and to populate the NED with nationally consistent data that meet minimum specifications. Because of the importance of the *USGS Lidar Base Specification Version 1.2*, this specification is provided in Appendix E of this manual. NOTE: Version 1.1, also released in 2014, had a typographical error and was quickly replaced by Version 1.2

i. <u>ASPRS Positional Accuracy Standards for Digital Geospatial Data (ASPRS, 2014)</u>. This new ASPRS accuracy standard (see Appendix C) replaces the *ASPRS Accuracy Standards for Large-Scale Maps* (ASPRS, 1990) and the *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data* (ASPRS, 2004) with new accuracy standards that better address digital orthophotos and digital elevation data that may include high-accuracy, high-density data from mobile mapping systems or Unmanned Aerial Systems (UAS) of the future. The new ASPRS standard includes accuracy thresholds for digital orthophotos and digital elevation data, independent of published map scale or contour interval, whereas the new standard for planimetric data, while still linked to map scale factor, tightens the planimetric mapping standard published in ASPRS, 1990, such that the old Class 1 remains equal to the new Class 1 standards, but with still higher-accuracy Class 0 standards.

(1) <u>Horizontal Accuracy Standards</u>. Class 0 products refer to highest-accuracy survey-grade geospatial data for demanding engineering applications; Class 1 products refer to standard, high-accuracy mapping-grade geospatial data; Class 2 products refer to less-accurate products used for general planning; and Class N products refer to lower-accuracy visualization-grade geospatial data suitable for less-demanding user applications. Whereas Class 1 remains the default standard for high-accuracy mapping-grade geospatial data, it is less accurate than the new ASPRS Class 0 products that are twice as accurate as Class 1 products.

(a) <u>Horizontal Accuracy Standards for Digital Orthophotos</u>. The pixel size of the digital orthophotos to be evaluated controls the horizontal accuracy standards for orthophotos. The following formulas are applicable for both English and metric units:

– For Class 0 digital orthophotos, $RMSE_x$ and $RMSE_y$ = pixel size * 1 and the orthophoto mosaic seamline maximum mismatch = pixel size * 2

– For Class 1 digital orthophotos, $RMSE_x$ and $RMSE_y$ = pixel size * 2 and the orthophoto mosaic seamline maximum mismatch = pixel size * 4

– For Class 2 digital orthophotos, $RMSE_x$ and $RMSE_y$ = pixel size * 3 and the orthophoto mosaic seamline maximum mismatch = pixel size * 6 …

– For Class N digital orthophotos, $RMSE_x$ and $RMSE_y$ = pixel size * (N+1) and the orthophoto mosaic seamline maximum mismatch = 2 * (N+1)

(b) <u>Horizontal Accuracy Standards for Planimetric Maps</u>. The compilation map scale, or more precisely the map's *Scale Factor*, controls the horizontal accuracy standards ($RMSE_x$ and $RMSE_y$). The Scale Factor is the reciprocal of the ratio used to specify the map scale. For example, if a map was compiled for use or analysis at a scale of 1:1,200 or 1/1,200, the Scale Factor is 1,200; at that scale, $RMSE_x$ and $RMSE_y$ would be 15-cm (1,200 * 0.0125) for a Class 0 map using the formulas below:

– For Class 0 planimetric maps, $RMSE_x$ and $RMSE_y$ (in centimeters) = Map Scale Factor * 0.0125

– For Class 1 planimetric maps, $RMSE_x$ and $RMSE_y$ (in centimeters) = 2 * Class 0 = Map Scale Factor * 0.025

– For Class 2 planimetric maps, $RMSE_x$ and $RMSE_y$ (in centimeters) = 3 * Class 0 = Map Scale Factor * 0.0375 …

– For Class N planimetric maps, $RMSE_x$ and $RMSE_y$ (in centimeters) = (N+1) * Class 0

(2) Vertical Accuracy Standards. The *ASPRS Positional Accuracy Standards for Digital Geospatial Data* (ASPRS, 2014) continues to specify $RMSE_z$ as one-third the appropriate contour interval supported. It establishes recommended minimum Nominal Pulse Density and maximum Nominal Pulse Spacing for LiDAR data; it establishes LiDAR relative accuracy swath-to-swath in non-vegetated terrain in terms of vertical RMS differences ($RMSD_z$) and maximum elevation differences; and it establishes Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) at the 95% confidence levels for ten (10) Vertical Accuracy Classes, chosen for the following reasons:

(a) The 1-cm Vertical Accuracy Class, appropriate for 3-cm contours, is most appropriate for local accuracy determinations and tested relative to a local coordinate system, rather than network accuracy relative to a national geodetic network.

(b) The 2.5-cm Vertical Accuracy Class, appropriate for 7.5-cm (~3”) contours, could pertain to either local accuracy or network accuracy.

(c) The 5-cm Vertical Accuracy Class, appropriate for 15-cm (~6”) contours, approximates the accuracy class most commonly used for high accuracy engineering applications of rotary wing airborne remote sensing data and unmanned aerial systems (UASs).

(d) The 10-cm Vertical Accuracy Class, appropriate for 1-foot contours, approximates Quality Level 2 (QL2) from the National Enhanced Elevation Assessment (NEEA) when using airborne LiDAR point density of 2 points per square meter, and the 10 cm Class also serves as the basis for USGS’s nationwide 3D Elevation Program (3DEP). Such elevation data are equivalent to that specified for QL2 LiDAR in the *USGS Lidar Base Specification Version 1.2* (Heidemann, 2014).

(e) The 15-cm Vertical Accuracy Class, appropriate for 1.5-foot contours, includes elevation data produced to the prior *USGS Lidar Base Specification Version 1.0* (Heidemann, 2012).

(f) The 20-cm Vertical Accuracy Class, appropriate for 2-foot contours, approximates Quality Level 3 (QL3) from the NEEA and covers the majority of legacy LiDAR data previously acquired for federal, state and local clients prior to publication of Heidemann, 2012.

(g) The 33.3-cm Vertical Accuracy Class, appropriate for 1-meter contours, approximates Quality Level 4 (QL4) from the NEEA.

(h) The 66.7-cm Vertical Accuracy Class is appropriate for 2-meter contours.

(i) The 100-cm Vertical Accuracy Class, appropriate for 3-meter contours, approximates Quality Level 5 (QL5) from the NEEA and represents the approximate accuracy of airborne IFSAR.

(j) The 333.3-cm Vertical Accuracy Class, appropriate for 10-meter contours, represents the approximate accuracy of elevation datasets produced from some satellite-based sensors.

3-4. Accuracy Classifications for USACE Functional Applications. Table 3-27 outlines general types of USACE projects and the corresponding data accuracy class of digital geospatial data that is necessary to achieve the required level of mapping for each type of project. The table is intended to be a general guide only, requiring additional engineering judgment. The table does not apply exclusively to airborne photogrammetric or LiDAR mapping activities; some of the required surveying and mapping accuracies identified exceed those obtainable from aerial surveys and must be performed by land surveys. Selection of an appropriate contour interval (CI), for example, is extremely site-dependent and will directly impact the mapping costs. See additional guidance in subsequent chapters dealing with project planning and cost estimating.

Table 3-27: Recommended Surveying and Mapping Specifications for USACE Applications

Project or Activity	Horizontal Accuracy Criteria			Vertical Accuracy Criteria		
MILITARY CONSTRUCTION (MCA, MCAF, OMA, OMAF):	Typical Target (Plot) Map Scale[1] / Scale Ratio 1 in = x ft.	Feature Horizontal. Accuracy[2] $RMSE_{xy}$ cm/ft.	Ground Horizontal Control[3]	Typical Contour Interval cm/ft.	Feature Vertical Accuracy[4] $RMSE_z$ cm/ft.	Ground Vertical Control[5]
Design and Construction of New Facilities: Site Plan Data for Direct Input into CADD 2-D/3-D Design Files						
- General Construction Site Plan Feature and Topographic Detail	1:400 / 33 ft.	10 cm / 0.33 ft.	3rd-I	15 cm / 0.5 ft.	5 cm / 0.167 ft.	3rd
- Surface/Subsurface Utility Detail	1:400 / 33 ft.	10 cm / 0.33 ft.	3rd-I	N/A	5 cm / 0.167 ft.	3rd
- Building or Structure Design	1:200 / 16.7 ft.	2.5 cm / 0.083 ft.	3rd-I	7.5 cm / 0.25 ft.	2.5 cm / 0.083 ft.	3rd
- Airfield Pavement Design Detail	1:200 / 16.7 ft.	2.5 cm / 0.083 ft.	3rd-I	7.5 cm / 0.25 ft.	2.5 cm / 0.083 ft.	2nd
- Grading and Excavation Plans (Roads, Drainage, etc.)	1:600 / 50 ft.	15 cm / 0.5 ft.	3rd-I/II	30 cm / 1 ft.	10 cm / 0.33 ft.	3rd
Maintenance and Repair (M&R), or Renovation of Existing Structures, Roadways, Utilities, etc., for Design/Construction/Plans and Specifications (P&S)	1:400 / 33.3 ft.	10 cm / 0.33 ft.	3rd-I	30 cm / 1 ft.	10 cm / 0.33 ft.	3rd
Recreational Site P&S (Golf Courses, Athletic Fields, etc.)	1:2400 / 200 ft.	60 cm / 2 ft.	3rd-I/II	60 cm / 2 ft.	20 cm / 0.67 ft.	3rd

Table 3-27 (Continued)

Project or Activity	Horizontal Accuracy Criteria			Vertical Accuracy Criteria		
MILITARY CONSTRUCTION (CONTINUED):	Typical Target (Plot) Map Scale[1] / Scale Ratio 1 in = x ft.	Feature Horizontal Accuracy[2] $RMSE_{xy}$ cm/ft.	Ground Horizontal Control[3]	Typical Contour Interval cm/ft.	Feature Vertical Accuracy[4] $RMSE_z$ cm/ft.	Ground Vertical Control[5]
Training Sites, Ranges, Cantonment Areas, etc.	1:2400 / 200 ft.	60 cm / 2 ft.	3rd-I/II	120 cm / 4 ft.	40 cm / 1.33 ft.	3rd
Installation Master Planning and Facilities Management Activities (Including AM/FM and GIS Feature Applications)						
- General Location Maps for Master Planning Purposes	1:4800 / 400 ft.	120 cm / 4 ft.	3rd-II	300 cm/ 10 ft.	100 cm/ 3.3 ft.	3rd
- Space Management (Interior Design/Layout)	1:200 / 16.7 ft.	5 cm / 0.167 ft.	Relative to Structure	N/A	N/A	N/A
- Installation Surface/Subsurface Utility Maps (As-Builts; Fuel, Gas, Electricity, Communications, Cable, Storm Water, Sanitary, Water Supply, Treatment Facilities, Meters, etc.)	1:400 / 33.3 ft.	10 cm / 0.33 ft.	3rd-I 3rd-I	30 cm / 1 ft.	10 cm / 0.33 ft.	3rd
Architectural Drawings:		N/A	N/A	N/A	N/A	N/A
- Site Plans: 1 in = 20 ' (Landscape Planting Plans)	1:240 / 20 ft.					
- Floor Plans: 1/4 in = 1' - 0"	1:50 / 4 ft.					
1/8 in = 1' - 0"	1:100 / 8 ft.					
1/16 in = 1' - 0"	1:200 / 16 ft.					

Table 3-27 (Continued)

Project or Activity	Horizontal Accuracy Criteria			Vertical Accuracy Criteria		
MILITARY CONSTRUCTION (CONTINUED):	Typical Target (Plot) Map Scale[1] / Scale Ratio 1 in = x ft.	Feature Horizontal Accuracy[2] $RMSE_{xy}$ cm/ft.	Ground Horizontal Control[3]	Typical Contour Interval cm/ft.	Feature Vertical Accuracy[4] $RMSE_z$ cm/ft.	Ground Vertical Control[5]
- Roof Plan: (no smaller than) 1/16" = 1' - 0"	1:200 / 16 ft.					
- Exterior Elevations: 1" or 1-1/2" = 1' - 0"	1:10 / 0.8 ft.					
1/8" = 1' - 0"	1:100 / 8 ft.					
1/16" = 1' - 0"	1:200 / 16 ft.					
- Interior Elevations: 1/4" = 1' - 0"	1:50 / 4 ft.					
1/8" = 1' - 0"	1:100 / 8 ft.					
- Cross Sections: 1/4" = 1' - 0"	1:50 / 4 ft.					
1/8" = 1' - 0"	1:100 / 8 ft.					
1/16" = 1' - 0"	1:200 / 16 ft.					
- Wall Sections: 1/2" or 3/4" = 1' - 0"	1:20 / 2 ft.					
- Stair Details: 1" or 1-1/2" = 1' - 0"	1:10 / 1 ft.					
- Detail Plans: 3" = 1' - 0"	1:5 / 0.33 ft.					
1" or 1-1/2" = 1' - 0"	1:10 / 1 ft.					
Area-/Installation-/Base-Wide Mapping Control Network to Support Overall GIS and AM/FM Development[6]	N/A	varies	N/A[7] 3rd-I or 2nd-II	7.5 cm / 0.25 ft.	2.5 cm / 0.083 ft.	N/A[7] 2nd or 3rd
Housing Management (Family housing, Schools, Boundaries, and Other Installation Community Services)	1:9600 / 800 ft.	360 cm / 12 ft.	IIIB / 4th	N/A	N/A	4th

Table 3-27 (Continued)

Project or Activity	Horizontal Accuracy Criteria			Vertical Accuracy Criteria		
MILITARY CONSTRUCTION (CONTINUED):	Typical Target (Plot) Map Scale[1] / Scale Ratio 1 in = x ft.	Feature Horizontal Accuracy[2] $RMSE_{xy}$ cm/ft.	Ground Horizontal Control[3]	Typical Contour Interval cm/ft.	Feature Vertical Accuracy[4] $RMSE_z$ cm/ft.	Ground Vertical Control[5]
Environmental Mapping and Assessments	1:9600 / 800 ft.	360 cm / 12 ft.	IIIB / 4th	N/A	N/A	4th
Emergency Services (Military Police, Crime/Accident Locations, Emergency Transport Routes, Post Security Zoning, etc.)	1:9600 / 800 ft.	360 cm / 12 ft.	IIIB / 4th	N/A	N/A	4th
Cultural, Social, Historical (Other Natural Resources)	1:12000 / 1000 ft.	450 cm / 15 ft.	IIIB / 4th	N/A	N/A	4th
Runway Approach and Transition Zones; General Plans/Section[8]	1:9600 / 800 ft.	240 cm / 8 ft.	3rd-II	150 cm / 5 ft.	50 cm / 1.67 ft.	3rd
CIVIL WORKS DESIGN, CONSTRUCTION, OPERATIONS AND MAINTENANCE ACTIVITIES						
Site Plan for Design Memoranda, Contract Plans and Specifications, etc. for Input to CADD 2-D/3-D Design Files						
- Locks, Dams, Flood Control Structures; Detail Design Plans	1:100 / 8.3 ft.	2.5 cm/ 0.083 ft.	2nd-II	30 cm / 1 ft.	10 cm / 0.33 ft.	2nd
- Grading/Excavation Plans	1:1200 / 100 ft.	30 cm / 1 ft.	3rd-I	60 cm / 2 ft.	20 cm / 0.67 ft.	3rd
- Spillways, Concrete Channels, Upland Disposal Areas	1:400 / 33.3 ft.	10 cm / 0.33 ft.	2nd-II	120 cm / 4 ft.	40 cm / 1.33 ft.	3rd

Table 3-27 (Continued)

Project or Activity	Horizontal Accuracy Criteria			Vertical Accuracy Criteria		
CIVIL WORKS (CONTINUED):	Typical Target (Plot) Map Scale[1] / Scale Ratio 1 in = x ft.	Feature Horizontal Accuracy[2] $RMSE_{xy}$ cm/ft.	Ground Horizontal Control[3]	Typical Contour Interval cm/ft.	Feature Vertical Accuracy[4] $RMSE_z$ cm/ft.	Ground Vertical Control[5]
- Construction In-place Volume Measurement	1:1200 / 100 ft.	30 cm / 1 ft.	3rd-I	N/A	20 cm / 0.67 ft.	3rd
River and Harbor Navigation Projects: Site Plans, Design, Operation, or Maintenance of Flood Control Structures, Canals, Channels, etc. for Contract Plans or Reports.						
- Levees and Groins (New Work or Maintenance Design Drawings)	1:1200 / 100 ft.	30 cm / 1 ft.	3rd-II	60 cm / 2 ft.	20 cm / 0.67 ft.	3rd
- Canals and Waterway Dredging (New Work Base Mapping) [9]	1:2400 / 200 ft.	60 cm / 2 ft.	3rd-II	30 cm / 1 ft.	10 cm / 0.33 ft.	3rd
- Canals and Waterway Dredging (Maintenance Drawings)	1:2400 / 200 ft.	60 cm / 2 ft.	3rd-II	30 cm / 1 ft.	10 cm / 0.33 ft.	3rd
				1.64 ft.		
- Beach Renourishment/Hurricane Protection Projects	1:2400 / 200 ft.	60 cm / 2 ft.	3rd-II	60 cm / 2 ft.	20 cm / 0.67 ft.	3rd
- Project Condition Reports (Base Mapping for Plotting Hydrographic Surveys: line maps or air photo plans)	1:9600 / 800 ft.	240 cm/ 8 ft.	3rd-II	60 cm / 2 ft.	20 cm / 0.67 ft.	3rd
- Revetment Clearing, Grading, and As-built Protection	1:4800 / 400 ft.	180 cm/ 6 ft.	3rd-II	60 cm / 2 ft.	20 cm / 0.67 ft.	3rd

Table 3-27 (Continued)

Project or Activity	Horizontal Accuracy Criteria			Vertical Accuracy Criteria		
CIVIL WORKS (CONTINUED)	Typical Target (Plot) Map Scale[1] / Scale Ratio 1 in = x ft.	Feature Horizontal Accuracy[2] $RMSE_{xy}$ cm/ft.	Ground Horizontal Control[3]	Typical Contour Interval cm/ft.	Feature Vertical Accuracy[4] $RMSE_{z}$ cm/ft.	Ground Vertical Control[5]
Geotechnical and Hydrographic Site Investigation Surveying Accuracies for Project Construction						
- Hydrographic Contract Payment and P&S Surveys	1:4800 / 400 ft.	120 cm / 4 ft.	N/A[10]	30 cm / 1 ft.	10 cm / 0.33 ft.	N/A[10]
- Hydrographic Project Condition Surveys	1:9600 / 800 ft.	240 cm / 8 ft.	N/A[10]	60 cm / 2 ft.	20 cm / 0.67 ft.	N/A[10]
- Hydrographic Reconnaissance Surveys	-	0.10 km / 350 ft.	N/A[10]	60 cm / 2 ft.	20 cm / 0.67 ft.	N/A[10]
- Geotechnical Investigative Core Borings/Probings/etc.	1:12000 / 1000 ft.	450 cm / 15 ft.	N/A[10] / 4th	N/A	5 cm / 0.167 ft.	N/A[10] / 3rd or 4th
General Planning and Feasibility Studies, Reconnaissance Reports, Permit Applications, etc.	1:4800 / 400 ft.	120 cm/ 4 ft.	3rd-II	150 cm / 5 ft.	50 cm / 1.67 ft.	3rd
GIS Feature Mapping						
- Area/Project-Wide Mapping Control Network to Support Overall GIS Development	N/A	Varies	N/A[7] / 2nd-I/II	150 cm/ 5 ft.	50 cm / 1.67 ft.	N/A[7] 2nd
- Soil and Geologic Classification Maps, Well Points	1:12000 / 1000 ft.	450 cm / 15 ft.	4th	N/A	N/A	4th
- Cultural and Economic Resources, Historic Preservation	1:12000 / 1000 ft.	450 cm / 15 ft.	4th	N/A	N/A	4th

Table 3-27 (Continued)

Project or Activity	Horizontal Accuracy Criteria			Vertical Accuracy Criteria		
CIVIL WORKS (CONTINUED):	Typical Target (Plot) Map Scale[1] / Scale Ratio 1 in = x ft.	Feature Horizontal Accuracy[2] $RMSE_{xy}$ cm/ft.	Ground Horizontal Control[3]	Typical Contour Interval cm/ft.	Feature Vertical Accuracy[4] $RMSE_z$ cm/ft.	Ground Vertical Control[5]
- Land Utilization GIS Classifications; Regulatory Permit General Locations	1:12000 / 1000 ft.	450 cm / 15 ft.	4th	N/A	N/A	4th
- Socio-economic GIS classifications	1:12000 / 1000 ft.	450 cm / 15 ft.	4th	N/A	N/A	4th
- Land Cover Classification Maps	1:12000 / 1000 ft.	450 cm / 15 ft.	4th	N/A	N/A	4th
Archeological or Structure Site Plans & Details (Including Non-topographic, Close Range, Photogrammetric Mapping)	1:25 / 2 ft.	0.625 cm / 0.02 ft.	2nd I/II	7.5 cm / 0.25 ft.	2.5 cm / 0.083 ft.	2nd
Structural Deformation Monitoring Studies/Surveys[11]						
- Reinforced Concrete Structures (Locks, Dams, Gates, Intake Structures, Tunnels, Penstocks, Spillways, Bridges, etc.)	Large-scale vector movement diagrams or tabulations	1 cm / 0.03 ft. (long term)	N/A[12]	N/A	1 cm / 0.033 ft.	N/A[12]
- Earth/Rock Fill Structures (Dams, Floodwalls, Levees, etc.) (slope/crest stability & alignment)	Large-scale vector movement diagrams or tabulations	3 cm / 0.1 ft. (long term)	N/A[12]	N/A	1 cm / 0.033 ft.	N/A[12]
- Crack/joint & deflection measurements (precision micrometer)	tabulations	0.2 mm / 0.01 inch	N/A[12]	N/A	N/A	N/A[12]

Table 3-27 (Continued)

Project or Activity	Horizontal Accuracy Criteria			Vertical Accuracy Criteria		
CIVIL WORKS (CONTINUED):	Typical Target (Plot) Map Scale[1] / Scale Ratio 1 in = x ft.	Feature Horizontal Accuracy[2] $RMSE_{xy}$ cm/ft.	Ground Horizontal Control[3]	Typical Contour Interval cm/ft.	Feature Vertical Accuracy[4] $RMSE_z$ cm/ft.	Ground Vertical Control[5]
Flood Control and Multipurpose Project Planning, Floodplain Mapping, Water Quality Analysis, and Flood Control Studies	1:9600 / 800 ft.	240 cm / 8 ft.	3rd-I	60 cm / 2 ft.	20 cm / 0.67 ft.	2nd or 3rd
Federal Emergency Management Agency Flood Insurance Studies	1:9600 / 800 ft.	240 cm / 8 ft.	3rd-I	60 cm / 2 ft.	20 cm / 0.67 ft.	3rd
REAL ESTATE ACTIVITIES (ACQUISITION, DISPOSAL, MANAGEMENT, AUDIT)[13]						
Tract Maps, Individual, Detailing Installation or Reservation Boundaries, Lots, Parcels, Record Plats, Utilities, etc.	1:1200/ 100 ft[14]	2.5 cm/ 0.083 ft.	3rd-I/II	60 cm / 2 ft.	20 cm / 0.67 ft.	3rd
Condemnation Exhibit Maps	1:1200/ 100 ft.	2.5 cm/ 0.083 ft.	3rd-I/II	120 cm / 4 ft.	40 cm / 1.33 ft.	3rd
Guide Taking Lines (for Fee and Easement Acquisition), Boundary Encroachment Maps	1:200/ 16.7 ft.	5 cm/ 0.167 ft.	3rd-I/II	30 cm/ 1 ft.	10 cm/ 0.33 ft.	3rd
Real Estate GIS or LIS General Feature Mapping: Land Utilization and Management; Forestry Management; Mineral Acquisition	1:12000 / 1000 ft.	450 cm / 15 ft.	4th	N/A	N/A	N/A[13] 4th
General Location or Planning Maps (DOQs)[15]	1:12000 / 1,000 ft.	450 cm/ 15 ft.	N/A	Varies (NED)[16]	Varies	3rd
Easement Areas and Easement Delineation Lines	1:200 / 16.7 ft.	5 cm / 0.167 ft.	3rd-I/II	30 cm / 1.0 ft.	10 cm / 0.33 ft.	3rd

Table 3-27 (Continued)

Project or Activity	Horizontal Accuracy Criteria			Vertical Accuracy Criteria		
REAL ESTATE ACTIVITIES (CONTINUED):	Typical Target (Plot) Map Scale[1] / Scale Ratio 1 in = x ft.	Feature Horizontal Accuracy[2] $RMSE_{xy}$ cm/ft.	REAL ESTATE ACTIVITIES (CONTINUED):	Typical Target (Plot) Map Scale[1] / Scale Ratio 1 in = x ft.	Feature Horizontal Accuracy[2] $RMSE_{xy}$ cm/ft.	REAL ESTATE ACTIVITIES (CONTINUED):
HAZARDOUS, TOXIC, & RADIOACTIVE WASTE (HTRW) SITE INVESTIGATION, MODELING, AND CLEANUP						
General Detailed Site Plans (HTRW Sites, Asbestos, etc.)	1:400 / 33.3 ft.	10 cm / 0.33 ft.	2nd-II	15 cm / 0.5 ft.	5 cm / 0.167 ft.	2nd or 3rd
Subsurface Geotoxic Data Mapping (Modeling)	1:4800 / 400 ft.	120 cm / 4 ft.	3rd-II	120 cm / 4 ft.	40 cm / 1.33 ft.	3rd
Contaminated Ground Water Plume Mapping (Modeling)	1:4800 / 400 ft.	120 cm / 4 ft.	3rd-II	120 cm / 4 ft.	40 cm/ 1.33 ft.	3rd
General HTRW Site Plans, Reconnaissance Mapping	1:2400 / 200 ft.	60 cm / 2 ft.	3rd-II	150 cm / 5 ft.	50 cm / 1.67 ft.	3rd
EMERGENCY OPERATION MANAGEMENT ACTIVITIES						
(Use basic GIS data base requirements defined above)						

Table 3-27 Explanations:

1 Approximate target map scale appropriate for CADD, GIS, and/or AM/FM paper plots, recognizing that digital geospatial data can be inappropriately displayed at larger scales by zooming in while not actually improving the horizontal accuracy of the data. Target scales are appropriate based on the absolute horizontal accuracy ($RMSE_x$ and $RMSE_y$) of clearly defined features relative to the horizontal datum and the National Spatial Reference System (NSRS) in the U.S. In many instances, design or real property features are located to a far greater relative accuracy than that which can be scaled at the target (plot) scale, such as property corners, utility alignments, first-floor or invert elevations, etc. Coordinates and elevations for such items are usually directly input into a CADD or AM/FM data base.

2 $RMSE_x$ and $RMSE_y$ pertain to the *absolute horizontal accuracy* of digital geospatial data produced from aerial mapping technologies such as stereo-photogrammetric mapping or digital orthophotography. Determined from horizontal control surveys (e.g., total-station surveys), the *relative horizontal accuracy* of mapped features may be more demanding than the *absolute horizontal accuracy* of those features. The relative accuracy of a planimetric feature is defined relative to two adjacent points within the confines of a structure or map, not to the overall project or installation boundaries. Relative accuracies are determined between two points that must functionally maintain a given accuracy tolerance between themselves, such as adjacent property corners; adjacent utility lines; adjoining buildings, bridge piers, approaches, or abutments; overall building or structure site construction limits; runway ends; catch basins; levee baseline sections; etc. The relative accuracy between two points is determined from the end functional requirements of the project/structure (e.g., field construction fabrication, field stakeout or layout, alignment, locationing, etc.)

3 The ground accuracy class pertains to the order and class of horizontal control surveys performed in accordance with standards published by the Federal Geodetic Control Committee (FGCC). Horizontal control survey accuracy refers to the procedural and closure specifications needed to obtain/maintain the relative accuracy tolerances needed between two functionally adjacent points on the map or structure, for design, stakeout, or construction. Usually 1:5,000 Third-Order control procedures will provide sufficient accuracy for most engineering work, and in many instances of small-scale mapping or GIS mapping. Third-Order, Class II methods and Fourth-Order topographic/construction control methods may be used. Base- or area-wide mapping control procedures shall be specified to meet functional accuracy tolerances within the limits of the structure, building, or utility distance involved for design or construction surveys. Higher order control surveys shall not be specified for area-wide mapping or GIS definition unless a definitive functional requirement exists (e.g., military operational targeting or some low-gradient flood control projects).

[4] $RMSE_z$ pertains to the *absolute vertical accuracy* of digital geospatial data produced from LiDAR or photogrammetry. Determined from traditional ground surveys (e.g., differential leveling or trigonometric leveling), the relative vertical accuracy of mapped features may be more demanding than the absolute vertical accuracy of those features.

[5] The ground accuracy class pertains to the order and class of vertical control surveys performed in accordance with standards published by the Federal Geodetic Control Committee (FGCC). Vertical control survey accuracy refers to the procedural and closure specifications needed to obtain/maintain the relative accuracy tolerances needed between two functionally adjacent points on the map or structure, for design, stakeout, or construction. Usually Third-Order vertical control procedures will provide sufficient accuracy for most engineering work, and in many instances of small-scale mapping or GIS mapping.

[6] For installation or base mapping, GIS raster or vector features generally can be scaled or digitized from existing maps or digital orthophotos of the installation.

[7] The control network for any installation should not be determined from aerial surveys but by GPS surveys with dual-frequency GPS receivers. Reference EM 1110-1-1005 (Control and Topographic Surveying).

[8] See FAA No. 405, Standards for Aeronautical Surveys and Related Products, for detailed requirements.

[9] Table refers to base maps upon which subsurface hydrographic surveys are plotted, not to hydrographic survey control.

[10] Aerial and ground survey accuracy classes are not applicable to hydrographic survey control.

[11] Long-term structural movements measured from points external to the structure may be tabulated or plotted in either X-Y-Z or by single vector movement normal to a potential failure plane. Reference EM 1110-2-4300 (Instrumentation for Concrete Structures), EM 1110-2-1908 (Instrumentation of Embankment Dams and Levees), and EM 1110-1-1005 (Control and Topographic Surveying) for stress-strain, pressure, seismic, and other precise structural deflection measurement methods within/between structural members, monoliths, cells, embankments, etc.

[12] Horizontal and vertical deformation monitoring survey procedures are performed relative to a control network established for the structure. Ties to the National Spatial Reference System (NSRS) or the North American Vertical Datum of 1988 (NAVD 88) are not necessary other than for general reference, and then need only USACE Third-Order connection.

[13] Real property surveys shall conform to local/state minimum technical standards and/or recognized practices, and where prescribed by law or code.

[14] A 1:1,200 (1 in = 100 ft.) scale is recommended by ER 405-1-112 (Real Estate Handbook). Smaller scales should be on even 30m (100-ft) increments, e.g., 1:2,400 (1 in = 200 ft.); 1:3,600 (1 in = 300 ft.); or 1:4,800 (1 in = 400 ft.) as shown in Table 3-27.

[15] Go to http://seamless.usgs.gov/website/seamless/viewer.htm and click on Orthoimagery to download digital orthophoto quarter-quads (DOQs).

[16] Go to http://seamless.usgs.gov/website/seamless/viewer.htm and click on Elevation to download digital elevation models (DEMs).

3-5. References.

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