



ASPRS Accuracy Standards for Digital Geospatial Data

The following material is considered DRAFT FOR REVIEW and is being published at this time to encourage wide dissemination and comment. Comments should be forwarded via email to AccuracyStandard@asprs.org no later than February 1, 2014. The current plan is to review all comments and finalize the document for ASPRS Board approval in March 2014.

Background

In the summer of 2011, the ASPRS Photogrammetric Applications Division (PAD) and Primary Data Acquisition Divisions (PDAD) held a series of conference calls with the intent of forming a committee to update and revise the existing *ASPRS Map Accuracy Standards for Large Scale Maps*. The existing standard is primarily intended for published maps and has several shortcomings when applied to new digital technologies. Currently, there is no consistent and appropriate accuracy standard that applies specifically to new technologies for digital geospatial data.

In November 2011, a meeting was held to present a draft concept developed by Dr. Qassim Abdullah, Woolpert, Inc., and to initiate the effort to update and revise the existing accuracy standard. This outline was based on discussions during the initial teleconferences as well as Abdullah's extensive past work on the subject through his *PE&RS* "Mapping Matters" column. Several conference calls were held to assimilate more information, identify, discuss and resolve key issues. A Hot Topic session was presented at the ASPRS 2012 Annual Conference to solicit additional feedback from the membership. During this session, an updated accuracy table was presented by Dr. Dave Maune, Dewberry, based on the concepts outlined in the initial draft concept and additional work Maune was doing related to an update of the U.S. Army Corps of Engineers engineering manual sections on mapping guidelines and standards. This table was further revised over the summer and an updated version was presented at the ASPRS/MAPPS 2012 Fall conference. After the 2012 fall conference, a subcommittee chaired by Maune and including Abdullah, Karl Heidemann, U.S. Geological Survey, and Doug Smith, David Smith Mapping, developed a complete working draft of a new standard. The initial draft was reviewed by the overall committee. Additional comments, modifications and contributions were incorporated into the current version, which is now being submitted for review and comment by the overall ASPRS membership.

Objective

The objective of the *ASPRS Accuracy Standards for Digital Geospatial Data* is to replace the existing *ASPRS Accuracy Standards for Large-Scale Maps*, 1990, and the *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, 2004, with new accuracy standards that better address digital orthophotos and digital elevation data. The new 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. The new standard addresses geo-location accuracies of geospatial products and it is not meant for regulating classification accuracy of thematic maps.

To supplement these standards, Appendix A provides a background summary of other standards, specifications and/or guidelines relevant to ASPRS but which do not satisfy current requirements for digital geospatial data. Appendix B provides horizontal accuracy/quality examples for digital orthophotos based on ten common pixel sizes, horizontal accuracy/quality examples for planimetric maps with ten common map scales, plus vertical accuracy/quality examples for ten common vertical data accuracy classes. Appendix C provides accuracy testing and reporting guidelines; and Appendix D provides relevant accuracy statistics and an example for computing vertical accuracy in vegetated and non-vegetated terrain consistent with these *ASPRS Accuracy Standards for Digital Geospatial Data*. All accuracies are assumed to be network accuracies unless specified to the contrary for projects requiring local accuracies only¹.

Digital Imagery

Whereas film photographs are commonly qualified by photo scale, a digital image file does not have a scale *per se* and can be displayed and printed at many different scales. **Ground sample distance (GSD)** provides a better metric for digital imagery. However, as explained in

¹ *Network accuracy* refers to the uncertainty in the coordinates of mapped points with respect to the geodetic datum at the 95-percent confidence level, and ultimately linked by National Spatial Reference System (NSRS) monuments that are tied to Continuously Operated Reference Stations (CORS). *Local accuracy* refers to the uncertainty in the coordinates of points with respect to local control points not connected to the NSRS.

the “Talking Digital” highlight article in the December 1998 issue of *Photogrammetric Engineering and Remote Sensing (PE&RS)*, collection GSD, display GSD, and product GSD, from the same source digital imagery, can be very different. For this *ASPRS Accuracy Standard for Digital Geospatial Data*, it is assumed that “GSD” refers to the collection GSD unless the ortho imagery is re-sampled to a coarser resolution in which case the GSD will be equivalent to the product GSD. For this document’s purposes, the **GSD is the linear dimension of a sample pixel’s footprint on the ground in the source image**; and it is assumed that “pixel size” is the real-world’s ground size of a pixel in a digital orthophoto product after all rectifications and resampling procedures have occurred. Furthermore, in these standards, GSD is intended to pertain to near-vertical imagery and not to oblique imagery, also recognizing that GSD values can vary greatly in cities and mountainous areas.

Methodology

As indicated in the *National Standard for Spatial Data Accuracy (NS-SDA)*: “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.” In these ASPRS standards, the independent source of higher accuracy for QA/QC check points should be at least three times more accurate than the required accuracy of the geospatial dataset being tested.

Elevation datasets rarely include clearly-defined point features, and it is extremely difficult and expensive to acquire surveyed vertical check points at the exact same horizontal coordinates as lidar mass points. Consistent with best practices, Triangulated Irregular Networks (TINs) of elevation datasets are interpolated at the horizontal coordinates of vertical check points in order to interpolate elevations at those coordinates for the dataset being tested. This is one reason why it is advantageous to utilize high density elevation datasets so that interpolated elevation errors are minimized. When terrain is flat or has uniform slope, interpolation errors are significantly reduced; this is the reason why vertical check points should be surveyed on flat or uniformly-sloped terrain, with slopes of 10 percent or less.

The ASPRS horizontal accuracy standard is based on accuracy classes using root-mean-square-error (RMSE) statistics, whereas the ASPRS vertical accuracy standard is based on accuracy classes using RMSE statistics in non-vegetated terrain, and 95th percentile statistics in vegetated terrain. Horizontal Class I products refer to highest-accuracy survey-grade geospatial data for more-demanding engineering applications, Class II products refer to standard, high-accuracy mapping-grade geospatial data, and Class III and larger class products refer to lower-accuracy visualization-grade geospatial data suitable for less-demanding user applications.

It is the responsibility of the data provider to do whatever it takes for

the data to meet accuracy standards. This includes, but is not limited to, the bias removal (removal of the mean errors in x, y or z by what is commonly called an “x-bump”, “y-bump” and/or “z-bump”) prior to delivery. The client may also add a post-delivery requirement that the mean error in any direction should not exceed the target RMSE by more than 25%, for example, even if the RMSE accuracy standards are satisfied. Data providers may agree to do this voluntarily and should do so voluntarily if a systematic error can be identified in their data. However, it could be a costly and contentious issue if there is concern that the QA/QC check points may be less accurate than the control points used by the data provider. Ultimately, it is the client (end user) who must decide whether remaining biases, identified post-delivery, should be removed, or whether they want to avoid the delays and extra cost of removing them. Regardless, mean errors that exceed 25% of the target RMSE, whether identified pre-delivery or post-delivery, should be investigated to determine what actions, if any, should be taken.

Accuracy Standards for Aerial Triangulation or INS-based Sensor Orientation

The results of the aerial triangulation (if performed) or the INS-based sensor orientation play a main role in determining the accuracy of the final mapping products. Therefore, Table 1 provides the required 3-dimensional accuracy of aerial triangulation or the INS-based sensor orientation as measured on the ground using stereo photogrammetric measurements and ground check points. Ground controls points used for aerial triangulation should be at least three times better than the expected accuracy of aerial triangulation. For example, in order to produce a 15 cm orthophoto with Class I accuracy, the ground control to be used for the aerial triangulation should have RMSE_{xyz} of 2.5 cm considering the required aerial triangulation RMSE_{xyz} of 7.5 cm (1/2 the orthophoto’s pixel size).

Horizontal Accuracy Standards for Digital Orthophotos

Table 1 includes three standard ASPRS horizontal accuracy classes (I, II, III) applicable to digital orthophotos produced from digital imagery with any ground sample distance (GSD), as well as variable lower-accuracy classes for orthoimagery. It is the pixel size of the final digital orthophoto being tested that is used to establish horizontal accuracy classes for digital orthophotos.

Table 1. Horizontal Accuracy Standards for Orthophotos

Horizontal Data Accuracy Class	RMSE _x and RMSE _y	Orthophoto Mosaic Seamline Maximum Mismatch	Aerial Triangulation or INS-based RMSE _x RMSE _y and RMSE _z
I	Pixel size x 1.0	Pixel size x 2.0	Pixel size x 0.5
II	Pixel size x 2.0	Pixel size x 4.0	Pixel size x 1.0
III	Pixel size x 3.0	Pixel size x 6.0	Pixel size x 1.5
...			
N	Pixel size x N	Pixel size x 2N	Pixel size x 0.5N

RMSE_x equals the horizontal linear RMSE in the X direction (Easting), and RMSE_y equals the horizontal linear RMSE in the Y direction (Northing). In Table 1, Class N refers to any accuracy class that suits the project. For example, Class V could have RMSE_x and RMSE_y equal to pixel size x 5.

In Appendix B, Table 4 provides horizontal accuracy examples and other quality criteria for digital orthophotos compiled with ten different pixel sizes ranging from 2.5-cm to 10-meters.

When producing digital orthophotos, the pixel size should never be less than 95% of the GSD of the raw imagery acquired by the sensor; however, so long as proper low-pass filtering² is performed prior to decimation, orthophotos can be down-sampled from the GSD to any ratio that is agreed upon between the data provider and the data user, such as when imagery with 15-cm GSD is used to produce orthophotos with 30-cm pixels.

Horizontal Accuracy Standards for Planimetric Maps

Table 2 includes three ASPRS horizontal accuracy classes (I, II and III) applicable to planimetric maps compiled at any map scale. The Class I accuracy formula is based on the map's Scale Factor, which is the reciprocal of the ratio used to specify the map scale. The derivation of the number 0.0125 in Table 2 is 1.25% of the Map Scale Factor. 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. Then the RMSE in X or Y (cm) = 0.0125 times the Scale Factor. In this example: the Class I RMSE_x and RMSE_y standard would be 1,200 x 0.0125 = 15 cm.

Table 2. Horizontal Accuracy Standards for Digital Planimetric Data

Horizontal Data Accuracy Class	RMSE _x and RMSE _y (cm)
I	1.25% of Map Scale Factor (0.0125 x Map Scale Factor)
II	2.0 x Class I Accuracy (0.025 x Map Scale Factor)
III	3.0 x Class I Accuracy (0.0375 x Map Scale Factor)
.....	
N	N x Class I Accuracy

The 0.0125, 0.025 and 0.0375 multipliers in Table 2 are not unit-less; they apply only to RMSE values computed in centimeters. Appropriate conversions must be applied to compute RMSE values in other units. The source imagery, control and data compilation methodology will determine the level of map scale detail and accuracy that can be achieved. Factors will include sensor type, imagery GSD, control, and aerotriangulation methodologies. Multiple classes are provided for situations where a high level of detail can be resolved at a given GSD, but the sensor and/or control utilized will only support a lower level of accuracy.

In Appendix B, Table 5 provides horizontal accuracy examples and other quality criteria for planimetric maps compiled with ten map scales ranging from 1:100 to 1:25,000. These standards are deliberately tightened from those published in ASPRS, 1990, because of advances in digital imaging, triangulation, and geopositioning technologies. Although these standards are intended to primarily pertain to planimetric data compiled from stereo photogrammetry, they are equally relevant to planimetric maps produced from digital orthophotos, ortho-rectified radar imagery (ORI) from IFSAR, or breaklines compiled from lidar, including intensity imagery, using lidargrammetry.

² Digital sampling requires that a signal be "band-limited" prior to sampling to prevent aliasing (blending or "folding") high frequencies into the desired lower frequency. This band limiting is accomplished by employing a frequency limiting (low pass) filter.

Vertical Accuracy Standards

Table 3 includes vertical accuracy classes for ten accuracy levels relevant to elevation technologies, including mobile mapping systems, unmanned aerial systems, airborne or satellite stereo imagery, lidar or IFSAR.

In Appendix B, Table 6 provides vertical accuracy examples and other quality criteria for digital elevation data. Although this standard defines the vertical accuracy independent from the contour interval measure, appropriate contour intervals are given in Table 6 so that users can easily see the contour intervals that could be legitimately mapped from digital elevation data with the RMSE_z values stated in Table 3 and Table 6. In all cases demonstrated in Table 6, the appropriate contour interval is three times larger than the RMSE_z value, consistent with the *ASPRS 1990 Accuracy Standards for Large-Scale Maps*, compared with the *National Standard for Spatial Data Accuracy* (NSSDA) and *National Map Accuracy Standard* (NMAS) where the equivalent contour accuracy is 3.2898 times larger than the RMSE_z value when assuming that vertical errors follow a normal distribution.

The Non-vegetated Vertical Accuracy (NVA), i.e., vertical accuracy at the 95% confidence level in non-vegetated terrain, is approximated by multiplying the RMSE_z (in non-vegetated land cover categories only) by 1.96. This includes survey check points located in traditional open terrain (bare soil, sand, rocks, and short grass) and urban terrain (asphalt and concrete surfaces). The NVA, based on an RMSE_z multiplier, should be used in non-vegetated terrain where elevation errors typically follow a normal error distribution. RMSE_z-based statistics should not be used to estimate vertical accuracy in vegetated terrain where elevation errors often do not follow a normal distribution for unavoidable reasons.

The Vegetated Vertical Accuracy (VVA), an estimate of vertical accuracy at the 95% confidence level in vegetated terrain, is computed as the 95th percentile of the absolute value of vertical errors in all vegetated land cover categories combined, to include tall weeds and crops, brush lands, and fully forested. For all vertical accuracy classes, the VVA is 1.5 times larger than the NVA. If this VVA standard cannot be met in impenetrable vegetation such as dense corn fields or mangrove, low confidence area polygons should be developed and explained in the metadata as the digital equivalent to dashed contours used in the past when photogrammetrists could not measure the bare-earth terrain in forested areas. See Appendix C for low confidence area details.

Relative accuracy between lidar and IFSAR swaths in overlap areas is a measure of the quality of the system calibration and bore-sighting. A dataset, overall, cannot be any more accurate absolutely than its component parts (swaths) are accurate relative to each other. The requirements for relative accuracy are therefore more stringent than those for absolute accuracy.

- Relative accuracy swath-to-swath is computed as a root-mean-square-difference (RMSD_z) because neither swath represents an independent source of higher accuracy as used in root-mean-square-error (RMSE_z) calculations for tested data compared with QA/QC check points of higher accuracy. In comparing overlapping swaths, users are comparing RMS differences rather than RMS errors.
- To the greatest degree possible, relative accuracy testing locations should include all overlap areas (sidelap, endlap, and crossflights), be evenly distributed throughout the full width and length of each

Table 3. Vertical Accuracy Standards for Digital Elevation Data

Vertical Data Accuracy Class	RMSEz in Non-Vegetated Terrain (cm)	Non-Vegetated Vertical Accuracy ³ (NVA) at 95% Confidence Level (cm)	Vegetated Vertical Accuracy ⁴ (VVA) at 95 th Percentile (cm)	Relative Accuracy Swath-to-Swath in Non-Vegetated Terrain ⁵ (RMSDz/Max Diff) (cm)
I	1.0	2.0	2.9	0.8/1.6
II	2.5	4.9	7.4	2.0/4.0
III	5.0	9.8	14.7	4.0/8.0
IV	10.0	19.6	29.4	8.0/16.0
V	12.5	24.5	36.8	10.0/20.0
VI	20.0	39.2	58.8	16.0/32.0
VII	33.3	65.3	98.0	26.7/53.3
VIII	66.7	130.7	196.0	53.3/106.6
IX	100.0	196.0	294.0	80.0/160.0
X	333.3	653.3	980.0	266.6/533.4

3 Statistically, in non-vegetated terrain and elsewhere when elevation errors follow a normal distribution, 68.27% of errors are within one standard deviation (σ) of the mean error, 95.45% of errors are within 2σ of the mean error, and 99.73% of errors are within 3σ of the mean error. The formula 1.96σ 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 dataset 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, $1.96 \times \text{RMSEz}$ is often used as a simplified approximation to compute the NVA at a 95% confidence level. This approximation tends to overestimate the error range as the mean error increases. A precise estimate requires a more robust statistical computation based on the standard deviation and mean error. 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.

4 VVA standards do not apply to areas previously defined as low confidence areas and delineated with a low confidence polygon (see Appendix C). 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.

5 For computing lidar and IFSAR relative accuracy swath-to-swath in non-vegetated terrain, elevation differences will not follow a truly normal distribution; elevation differences should be more tightly clustered and the difference histogram should show elevated kurtosis.

overlap area, be located in non-vegetated areas (clear and open terrain and urban areas) at least 3 meters away from any vertical artifact or abrupt change in elevation, on slopes less than 20 percent, and within the geometrically reliable portion of both swaths (excluding the extreme edge points of the swaths). For lidar sensors with zig-zag scanning patterns from oscillating mirrors, the geometrically reliable portion excludes about 5% ($2\frac{1}{2}\%$ on either side); lidar sensors with circular or elliptical scanning patterns are generally reliable throughout.

While the RMSDz value may be calculated from a set of specific test location points, the Maximum Difference requirement is not limited to these check locations; it applies to all locations within the entire dataset that meet the above criteria.

Table 3's right column on (lidar or IFSAR) relative accuracy, swath-to-swath, is unique for tying adjoining flight lines together. Photogrammetry uses photo-identifiable control points, pass points and tie points in aerial triangulation to tie all flight lines together in block triangulation. IFSAR, with side-looking radar geometry, uses ground control points (clearly identified by prism reflectors) to control tie lines which in turn control the primary flight lines; Synthetic Aperture Radar (SAR) imagery is then controlled to the primary lines for merger and mosaicking of data.

Appendix A — Background

Accuracy standards for geospatial data have broad applications nationally and/or internationally, whereas specifications provide technical requirements/acceptance criteria that a geospatial product must conform to in order to be considered acceptable for a specific intended use. Guidelines provide recommendations for acquiring, processing and/or analyzing geospatial data, normally intended to promote consistency and industry best practices.

The following is a summary of standards, specifications and guidelines relevant to ASPRS but which do not fully satisfy current requirements for accuracy standards for digital geospatial data:

- The *National Map Accuracy Standard* (NMAS) of 1947 established horizontal accuracy thresholds for the *Circular Map Accuracy Standard* (CMAS) as a function of map scale, and vertical accuracy thresholds for the *Vertical Map Accuracy Standard* (VMAS) as a function of contour interval—both reported at the 90% confidence level. Because NMAS accuracy thresholds are a function of the map scale and/or contour interval of a printed map, they are inappropriate for digital geospatial data where scale and contour interval are changed with a push of a button while not changing the underlying horizontal and/or vertical accuracy.
- The *ASPRS 1990 Accuracy Standards for Large-Scale Maps* established horizontal and vertical accuracy thresholds in terms of RMSE values in X, Y and Z at ground scale. However, because the RMSE thresholds for Class 1, Class 2 and Class 3 products pertain to printed maps with published map scales and contour intervals, these ASPRS standards from 1990 are similarly inappropriate for digital geospatial data.
- The *National Standard for Spatial Data Accuracy* (NSSDA), published by the Federal Geographic Data Committee (FGDC) in 1998, was developed to report accuracy of digital geospatial data at the 95% confidence level as a function of RMSE values in X, Y and Z at ground scale, unconstrained by map scale or contour interval. The NSSDA states, "The reporting standard in the horizontal component is the radius of a circle of uncertainty, such that the true or theoretical location of the point falls within that circle 95-percent of the time. The reporting standard in the vertical component is a linear uncertainty value, such that the true or theoretical

location of the point falls within +/- of that linear uncertainty value 95-percent of the time. The reporting accuracy standard should be defined in metric (International System of Units, SI) units. However, accuracy will be reported in English (inch-pound) units where point coordinates or elevations are reported in English units The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy 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 NSSDA does not define threshold accuracy values, stating, “Agencies are encouraged to establish thresholds for their product specifications and applications and for contracting purposes.” In its Appendix 3-A, the NSSDA provides formulas for converting RMSE values in X, Y and Z into horizontal and vertical accuracies at the 95% confidence levels. The NSSDA assumes normal error distributions with systematic errors eliminated as best as possible.

- The National Digital Elevation Program (NDEP) published the *NDEP Guidelines for Digital Elevation Data* in 2004, recognizing that lidar errors of Digital Terrain Models (DTMs) do not necessarily follow a normal distribution in vegetated terrain. The NDEP developed Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). The FVA is computed in non-vegetated, open terrain only, based on the NSSDA's RMSEz x 1.96 because elevation errors in open terrain do tend to follow a normal distribution, especially with a large number of check points. SVA is computed in individual land cover categories, and CVA is computed in all land cover categories combined — both based on 95th percentile errors (instead of RMSE multipliers) because errors in DTMs in other land cover categories, especially vegetated/forested areas, do not necessarily follow a normal distribution. The NDEP Guidelines, while establishing alternative procedures for testing and reporting the vertical accuracy of elevation datasets when errors are not normally distributed, also do not provide accuracy thresholds or quality levels.
- The *ASPRS Guidelines: Vertical Accuracy Reporting for Lidar Data*, published in 2004, essentially endorsed the NDEP Guidelines, to include FVA, SVA and CVA reporting. Similarly, the ASPRS 2004 Guidelines, while endorsing the NDEP Guidelines when elevation errors are not normally distributed, also do not provide accuracy thresholds or quality levels.
- Between 1998 and 2010, the Federal Emergency Management Agency (FEMA) published *Guidelines and Specifications for Flood Hazard Mapping Partners* that included RMSEz thresholds and requirements for testing and reporting the vertical accuracy separately for all major land cover categories within floodplains being mapped for the National Flood Insurance Program (NFIP). With its *Procedure Memorandum No. 61 — Standards for Lidar and Other High Quality Digital Topography*, dated September 27, 2010, FEMA endorsed the *USGS Draft Lidar Base Specifications V13*, relevant to floodplain mapping in areas of highest flood risk only, with poorer accuracy and point density in areas of lesser flood risks. USGS' draft V13 specification subsequently became the final *USGS Lidar Base Specification V1.0* specification summarized below. FEMA's Guidelines and Procedures only address requirements for flood risk mapping and do not represent accuracy standards that are universally applicable.

- In 2012, USGS published its Lidar Base Specification Version 1.0 which is based on RMSEz of 12.5-cm in open terrain and elevation post spacing no greater than 1 to 2 meters. FVA, SVA and CVA values are also specified. This is not a standard but a specification for lidar data used to populate the National Elevation Dataset (NED) at 1/9th arc-second post spacing (~3 meters) for gridded Digital Elevation Models (DEMs).
- In 2012, USGS also published the final report of the *National Enhanced Elevation Assessment* (NEEA) which considered five Quality Levels of enhanced elevation data to satisfy nationwide requirements; each Quality Level having different RMSEz and point density thresholds. With support from the National Geospatial Advisory Committee (NGAC), USGS subsequently developed its new 3D Elevation Program (3DEP) based on lidar Quality Level 2 data with 1' equivalent contour accuracy (RMSEz<10-cm) and point density of 2 points per square meter for all states except Alaska in which IFSAR Quality Level 5 data are specified with RMSEz between 1 and 2 meters and with 5-meter post spacing. The 3DEP lidar data are expected to be high resolution data capable of supporting DEMs at 1 meter resolution. The 3DEP Quality Level 2 and Quality Level 5 products are expected to become industry standards for digital elevation data because they will replace USGS' 1:24,000-scale topographic quadrangle map series for most of the U.S. and 1:63,360-scale topographic quadrangle map series for Alaska, which were USGS standard products for nearly a century. The NEEA only addresses elevation datasets; four of the NEEA Quality Levels are represented in Table 6 in Appendix B.

Appendix B — Data Accuracy and Quality Examples

For Classes I, II and III, Table 4 provides horizontal accuracy examples and other quality criteria for digital orthophotos produced from imagery having ten common pixel sizes. For other accuracy classes, use the formula for Class N in Table 1.

RMSEr equals the horizontal radial RMSE, i.e., $\sqrt{(\text{RMSE}_x^2 + \text{RMSE}_y^2)}$. All RMSE values and other accuracy parameters are in the same units as the pixel size. For example, if the pixel size is in cm, then RMSE_x, RMSE_y, RMSE_r, horizontal accuracy at the 95% confidence level, and seamline mismatch are also in centimeters.

Table 5 provides horizontal accuracy examples and other quality criteria for planimetric maps intended for use at ten common map scales.

Source imagery GSD cannot be universally equated to image resolution or supported accuracy. This will vary widely with different sensors. The GSD values shown in Table 5 are typical of the GSD required to achieve the level of detail required for the stated map scales. Achievable accuracies, and the resulting map accuracy class, for a given GSD will depend upon the sensor capabilities, control, adjustment and compilation methodologies.

Table 6 provides vertical accuracy examples and other quality criteria for ten vertical accuracy classes, each with appropriate contour interval supported by the RMSEz values for users that may require contours to be plotted or displayed.

These vertical data accuracy classes were chosen for the following reasons:

- **Class I**, the highest vertical accuracy class, 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.

Table 4. Horizontal Accuracy/Quality Examples for Digital Orthophotos

Orthophoto Pixel Size	Horizontal Data Accuracy Class	RMSE _x or RMSE _y (cm)	RMSE _r (cm)	Orthophoto Mosaic Seamline Maximum Mismatch (cm)	Horizontal Accuracy at the 95% Confidence Level ⁶ (cm)
2.5-cm (~1 in)	I	2.5	3.5	5.0	6.1
	II	5.0	7.1	10.0	12.2
	III	7.5	10.6	15.0	18.4
5-cm (~2 in)	I	5.0	7.1	10.0	12.2
	II	10.0	14.1	20.0	24.5
	III	15.0	21.2	30.0	36.7
7.5-cm (~3 in)	I	7.5	10.6	15.0	18.4
	II	15.0	21.2	30.0	36.7
	III	22.5	31.8	45.0	55.1
15-cm (~6 in)	I	15.0	21.2	30.0	36.7
	II	30.0	42.4	60.0	73.4
	III	45.0	63.6	90.0	110.1
30-cm (~12 in)	I	30.0	42.4	60.0	73.4
	II	60.0	84.9	120.0	146.9
	III	90.0	127.3	180.0	220.3
60-cm (~24 in)	I	60.0	84.9	120.0	146.8
	II	120.0	169.7	240.0	293.7
	III	180.0	254.6	360.0	440.6
1-meter	I	100.0	141.4	200.0	244.7
	II	200.0	282.8	400.0	489.5
	III	300.0	424.3	600.0	734.3
2-meter	I	200.0	282.8	400.0	489.5
	II	400.0	565.7	800.0	979.1
	III	600.0	848.5	1200.0	1468.6
5-meter	I	500.0	707.1	1000.0	1224.0
	II	1000.0	1414.2	2000.0	2447.7
	III	1500.0	2121.3	3000.0	3671.5
10-meter	I	1000.0	1414.2	2000.0	2448.0
	II	2000.0	2828.4	4000.0	4895.4
	III	3000.0	4242.6	6000.0	7343.1

6 Horizontal (radial) accuracy at the 95% confidence level = RMSE_r x 1.7308, as documented in the NSSDA.

- **Class II**, the second highest vertical accuracy class could pertain to either local accuracy or network accuracy.
- **Class III** elevation data, equivalent to 15-cm (~6-inch) contour accuracy, approximates the accuracy class most commonly used for high accuracy engineering applications of fixed wing airborne remote sensing data.
- **Class IV** elevation data, equivalent to 1-foot contour accuracy, 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 Class IV also serves as the basis for USGS' 3D Elevation Program (3DEP). The NEEA's Quality Level 1 (QL1) has the same vertical accuracy as QL2 but with point density of 8 points per square meter. QL2 lidar specifications are found in the *USGS Lidar Base Specification, Version 1.1*.
- **Class V** elevation data are equivalent to that specified in the *USGS Lidar Base Specification, Version 1.0*.

Table 5. Horizontal Accuracy/Quality Examples for Digital Planimetric Data

Map Scale	Approximate Source Imagery GSD	Horizontal Data Accuracy Class	RMSE _x or RMSE _y (cm)	RMSE _r (cm)	Horizontal Accuracy at the 95% Confidence Level (cm)
1:100	1-2 cm	I	1.3	1.8	3.1
		II	2.5	3.5	6.1
		III	3.8	5.3	9.2
1:200	2-3 cm	I	2.5	3.5	6.1
		II	5.0	7.1	12.2
		III	7.5	10.6	18.4
1:250	3-4 cm	I	3.1	4.4	7.6
		II	6.3	8.8	15.3
		III	9.4	13.3	22.9
1:500	4-10 cm	I	6.3	8.8	15.3
		II	12.5	17.7	30.6
		III	18.8	26.5	45.9
1:1,000	10-20 cm	I	12.5	17.7	30.6
		II	25.0	35.4	61.2
		III	37.5	53.0	91.9
1:2,000	20-30 cm	I	25.0	35.4	61.2
		II	50.0	70.7	122.4
		III	75.0	106.1	183.6
1:2,500	30-40 cm	I	31.3	44.2	76.5
		II	62.5	88.4	153.0
		III	93.8	132.6	229.5
1:5,000	40-100 cm	I	62.5	88.4	153.0
		II	125.0	176.8	306.0
		III	187.5	265.2	458.9
1:10,000	1-2 m	I	125.0	176.8	306.0
		II	250.0	353.6	611.9
		III	375.0	530.3	917.9
1:25,000	3-4 m	I	312.5	441.9	764.9
		II	625.0	883.9	1529.8
		III	937.5	1325.8	2294.7

- **Class VI** elevation data, equivalent to 2-foot contour accuracy, approximates Quality Level 3 (QL3) from the NEEA and covers the majority of legacy lidar data previously acquired for federal, state and local clients.
- **Class VII** elevation data, equivalent to 1-meter contour accuracy, approximates Quality Level 4 (QL4) from the NEEA.
- **Class VIII** elevation data are equivalent to 2-meter contour accuracy.
- **Class IX** elevation data, equivalent to 3-meter contour accuracy, approximates Quality Level 5 (QL5) from the NEEA and represents the approximate accuracy of airborne IFSAR.
- **Class X** elevation data, equivalent to 10-meter contour accuracy, represents the approximate accuracy of elevation datasets produced from some satellite-based sensors.

Table 6. Vertical Accuracy/Quality Examples for Digital Elevation Data

Vertical Data Accuracy Class	RMSEz in Non-Vegetated Terrain (cm)	Non-Vegetated Vertical Accuracy (NVA) at 95% Confidence Level (cm)	Vegetated Vertical Accuracy (VVA) at 95 th Percentile (cm)	Appropriate Contour Interval supported by the RMSEz value	Recommended Minimum Nominal Pulse Density ⁷ (pts/m ²)/ Maximum Nominal Pulse Spacing (meters)
I	1.0	2.0	2.9	3 cm	≥20/0.224
II	2.5	4.9	7.4	7.5 cm	16/0.250
III	5.0	9.8	14.7	15 cm (~6")	8/0.354
IV	10.0	19.6	29.4	30 cm (~1')	2/0.707
V	12.5	24.5	36.8	37.5 cm	1/1.000
VI	20.0	39.2	58.8	60 cm (~2')	0.5/1.414
VII	33.3	65.3	98.0	1-meter	0.25/2.000
VIII	66.7	130.7	196.0	2-meter	0.1/3.162
IX	100.0	196.0	294.0	3-meter	0.05/4.472
X	333.3	653.3	980.0	10-meter	0.01/10.000

7 Nominal Pulse Density (NPD) and Nominal Pulse Spacing (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/m²). 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 formulae: $NPS = 1/\sqrt{NPD}$, and $NPD = 1/NPS^2$. Although typical point densities are listed for specified vertical accuracies, users can select higher or lower point densities to best fit project requirements and complexity of surfaces to be modeled.

Elevation Data Accuracy vs. Elevation Data Quality

In aerial photography and photogrammetry, the accuracy of the individual points in a dataset is largely dependent on the scale and resolution of the source imagery. Larger scale imagery, flown at a lower altitude, produces smaller GSDs and higher measurement accuracies (both vertical and horizontal). Users have quite naturally come to equate higher density imagery (smaller GSD or smaller pixel sizes) with higher accuracies and higher quality.

In airborne topographic lidar, this is not entirely the case. While it is true that lidar flown at very high altitudes is not as accurate as lidar flown at low altitudes, and it is also true that lidar collected at lower altitudes tends to be denser than that flown at high altitudes and therefore have better definition for the terrain surface (better quality), there is no causal relationship between lidar point density and the vertical accuracy of the points being collected. It is known, however, that at high flying heights above ground level, IMU angular error dominates, particularly in wide collection swath modalities, whereas at low flying heights above ground level, GPS error tends to dominate.

For many typical lidar collections, the maximum accuracy attainable, theoretically, is now limited by physical error budgets of the different components of the lidar system such as laser ranging, the GPS, the IMU, and the encoder systems. Increasing the density of points does not change those factors. Beyond the physical error budget limitations, all data must also be properly controlled, calibrated, boresighted, and processed. Errors introduced during any of these steps will affect the accuracy of the data, regardless of how dense the data are. That said, high density lidar data are usually of higher *quality* than low density data, and the increased quality can manifest as *apparently* higher accuracy.

In order to accurately represent a complex surface, denser data are necessary to capture the surface details for accurate mapping of small linear features such as curbs and micro drainage features, for example. This does not make the individual lidar measurements any more accurate, but does improve the accuracy of the derived surface at locations between the lidar measurements (as each reach between points is shorter). The accuracy of a lidar dataset is rarely (if ever) assessed by measuring the accuracy of discrete lidar points, and so assessments of a lidar dataset are accepted through a surrogate surface (TIN or DEM) made from the points. It is nearly impossible to establish QA/QC check points at the exact coordinates of individual lidar mass points; that is why TINs are interpolated at the horizontal coordinates of QA/QC check points to determine elevation differences at those coordinates. The higher the point density, the smaller the TIN triangles subject to interpolation errors.

In vegetated areas, where many lidar pulses are fully reflected before reaching the ground, a higher density dataset tends to be more accurate because more points will penetrate through vegetation to the ground. More ground points will result in less interpolation between points and improved surface definition because more characteristics of the actual ground surface are being measured, not interpolated. This is more critical in variable or complex surfaces, such as mountainous terrain, where generalized interpolation between points would not accurately model all of the changes in the surface.

Increased density may not improve the accuracy in flat, open terrain where interpolation between points would still adequately represent the ground surface. However, in areas where denser data may not be necessary to improve the vertical accuracy of data, a higher density dataset may still improve the *quality* of the data by adding additional detail to the final surface model, by better detection of edges for breaklines, and by increasing the confidence of the relative accuracy in swath overlap areas through the reduction of interpolation existing within the dataset. When lidar intensity is to be used in product derivation or algorithms, high collection density is always useful.

Appendix C — Accuracy Testing and Reporting Guidelines

Since 1990, ASPRS has used accuracy standards based on RMSE statistics. Since 1998, the NSSDA has advocated the use of RMSE statistics converted into horizontal and/or vertical accuracies at the 95% confidence levels by assuming errors follow a normal distribution and sample sizes are sufficiently large --allowing RMSE values to substitute for standard deviations as mean errors approach zero. Since 2004, the NDEP and ASPRS have both advocated the use of the 95th percentile to estimate vertical accuracy at the 95% confidence level for lidar data in vegetated land cover categories where errors do not necessarily follow a normal distribution.

When errors are normally distributed, accuracy testing can be performed with RMSE values, standard deviations, mean errors, maximum and minimum errors, and unit-less skew and kurtosis values. When errors are not normally distributed, alternative methods must be used. If the number of test points (check points) is sufficient, testing and reporting can be performed using 95th percentile errors. A percentile rank is the percentage of errors that fall at or below a given value. Errors are

visualized with histograms that show the pattern of errors relative to a normal error distribution. Standard deviation is a measure of precision around the mean whereas RMSE is a measure of accuracy relative to the referenced datum. As mean errors approach zero, RMSE and standard deviation values tend to converge. It is not mandatory that mean errors equal zero so long as required accuracies at the 95% confidence levels or 95th percentiles are satisfied.

The spatial distribution of ground control and check points plays an important role in the accuracy evaluation of any geospatial data. First, the strength of the geometry during the orientation reconstruction largely depends on the number of control points and their distribution in the project area. Second, the check point evaluation provides error characterization around the check points, and thus the distribution of check points is essential for obtaining an adequate representation of the entire project area. In both cases, the recommendation is to use as many points as possible (affordable) and try to evenly space the points in the project area. Obviously, it is hard to assure the ideal case, as object space constraints (e.g., limited access, size and location of land cover categories) and, more importantly, economics define the number of points surveyed in a project.

Past guidelines and accuracy standards have typically specified the required number of check points and, in some cases, the land-cover types, but there was no requirement for defining and/or characterizing the spatial distribution of the points. Clearly, it is not simple and/or even feasible at this time, but characterizing the point distribution by some measure and, consequently, providing a quality number is undoubtedly both realistic and necessary. ASPRS encourages research into this topic, peer reviewed and published in *Photogrammetric Engineering and Remote Sensing* for public testing and comment.

In the interim, the following guidelines for the number, distribution across land cover types, and spatial distribution within a project, of elevation data vertical checkpoints are recommended.

Number of Checkpoints:

The 2001-2005 North Carolina Floodplain Mapping Program (NCFMP) required 100 checkpoints in each county, regardless of size. The average area of each county in North Carolina is approximately 500 square miles.

Based in part on the NCFMP experience, FEMA's 2003 *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying* specified 60-100 vertical checkpoints within the project area (assumed to be, typically, a county), depending on the number of land cover types within the project area. FEMA's current *Procedure Memorandum 61 – Standards for Lidar and Other High Quality Topographic Data* requires the same 60-100 checkpoints, but additionally links this quantity to each 2000 square mile area, or partial area, within the project.

Using metric units, ASPRS recommends 100 static vertical checkpoints for each 2500 square kilometer area, or partial area, within the project, consistent with Table 7. This provides a statistically defensible number of samples on which to base a valid vertical accuracy assessment. Vertical check points are not clearly-defined point features. Table 7 also lists the number of static horizontal check points recommended by ASPRS; horizontal check points must be clearly-defined point features, clearly visible on the digital orthophotos or planimetric maps being tested.

Kinematic check points, which are less accurate than static check points, can be used in any quantity as supplemental data, but the core accuracy assessment must be based on static surveys, consistent with NOAA Technical Memorandum NOS NGS-58, *Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)*, or equivalent. NGS-58 establishes ellipsoid height network accuracies of 5 cm at the 95% confidence level, as well as ellipsoid height local accuracies of 2 cm and 5 cm at the 95% confidence level.

Table 7. Recommended Number of Check Points Based on Area

Project Area (Square Kilometers)	Horizontal Testing	Vertical Testing (not clearly-defined points)		
	Total Number of Static Horizontal Check Points (clearly-defined points)	Number of Static Vertical Check Points in NVA	Number of Static Vertical Check Points in VVA	Total Number of Static Vertical Check Points
≤500	20	20	0	20
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

The recommended number and distribution of NVA and VVA check points may vary depending on the importance of different land cover categories and client requirements.

Distribution of Checkpoints Across Land Cover Types:

The 2001-2005 NCFMP defined five general land cover types, and required a minimum of 20 checkpoints in each of those types, as they existed within each county.

Both the 2003 and the current FEMA guidelines reference the same five land cover types, and specify a minimum of 20 checkpoints in each of three to five land cover categories as they exist within the project area, for a total of 60-100 checkpoints. Under the current FEMA guidelines, this quantity applies to each 2000 square mile area, or partial area, within the project.

ASPRS recognizes that some project areas are primarily non-vegetated, whereas other areas are primarily vegetated. For these reasons, the distribution of check points can vary based on the general proportion of vegetated and non-vegetated area in the project. The remaining checkpoints should be distributed generally proportionally among the various vegetated land cover types in the project.

Spatial Distribution of Checkpoints Within a Project:

As noted previously, quantitative characterization and specification of the spatial distribution of checkpoints across a project, let alone across each land cover type within a project, will require significant additional research. The NSSDA offers a method that can be applied to projects that are generally rectangular in shape and are largely non-vegetated, but this cannot, directly, be applied to the irregular shapes of many projects and most land cover type areas:

Check Point Location (from NSSDA)

“Due to the diversity of user requirements for digital geospatial data and maps, it is not realistic to include statements in this standard that specify the spatial distribution of check points. Data and/or map producers must determine check point locations.

“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. (FGDC, 1998)”⁸

ASPRS recommends that, where appropriate and to the highest degree possible, the NSSDA method be applied to the project and incorporated land cover type areas. Where it is not geometrically or practically applicable, data vendors should use their best professional judgment to apply the spirit of that method in selecting locations for checkpoints. The general location and distribution of checkpoints should be discussed between and agreed upon by the vendor and customer as part of the project plan.

Clearly, these recommendations offer a good deal of discretion in the location and distribution of checkpoints, and this is intentional. It would not be worthwhile to locate 50 vegetated checkpoints in a fully urbanized county such as Orange County, California; 80 non-vegetated checkpoints might be more appropriate. Likewise, projects in areas that are overwhelmingly forested with only a few small towns might support only 20 non-vegetated checkpoints. In some areas, access restrictions may prevent the desired spatial distribution of checkpoints; difficult terrain and transportation limitations may make some land cover type area practically inaccessible. Vendors are expected to use their best professional judgment in determining quantity and locations of checkpoints. **In no case shall an NVA be based on less than 20 checkpoints.**

For testing and reporting the horizontal accuracy of digital geospatial data, ASPRS endorses the NSSDA procedures, based on RMSE statistics explained in Appendix A, which assumes that errors follow a normal distribution. The horizontal accuracy of digital orthophotos and planimetric data must be documented in the metadata in one of the following manners:

- “Tested __ (meters, feet) horizontal accuracy at 95% confidence level,” or
- “Compiled to meet __ (meters, feet) horizontal accuracy at 95% confidence level.”

For testing and reporting the vertical accuracy of digital elevation data, ASPRS endorses the *NDEP Guidelines for Digital Elevation Data*, with slight modifications from FVA, SVA and CVA procedures explained in Appendix A, in order to report the Non-vegetated Vertical Accuracy (NVA) at the 95% confidence level in all non-vegetated land cover categories combined, as well as the Vegetated Vertical Accuracy (VVA) at the 95th percentile in all vegetated land cover categories combined. If the vertical errors are normally distributed, the sample size sufficiently large, and the mean error is sufficiently small, NVA at the 95% confidence level may be approximated using the formula $1.96 \times \text{RMSE}_z$ from check points in all open terrain (bare soil, sand, rocks, and short grass) as well as urban terrain (asphalt and concrete surfaces) land cover categories. Strictly speaking, the above formula only holds true if the mean error is zero. As the mean error increases, the above formula overestimates the range of errors. As such, it is useful as a simplified, single parameter approach to verifying the accuracy thresholds. The mean error is considered to be “sufficiently small” so long as the computed NVA satisfies the project specifications; if the NVA specifications are not satisfied, a “z-bump” may be applied to reduce the mean error to zero; if the dataset still fails the NVA specifications, the overall dataset fails unless other errors are identified and corrected. VVA is computed by using the 95th percentile of the absolute value of all elevation errors in all vegetated land cover categories combined, to include tall weeds and crops, brush lands, and lightly- to fully-forested land cover categories. This draws a clear distinction between non-vegetated terrain where errors typically follow a normal distribution suitable for RMSE statistical analyses, and vegetated terrain where errors do not necessarily follow a normal distribution and where the 95th percentile value is fairer in estimating vertical accuracy at the 95% confidence level. The vertical accuracy of digital elevation data should normally be documented in the metadata as follows:

- “Tested __ (meters, feet) Non-vegetated Vertical Accuracy (NVA) at 95 percent confidence level in all open and non-vegetated land cover categories combined using $\text{RMSE}_z \times 1.96$,” and
- “Tested __ (meters, feet) Vegetated Vertical Accuracy (VVA) at the 95th percentile in all vegetated land cover categories combined using the absolute value 95th percentile error.”

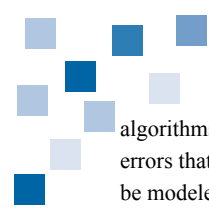
Alternatively, because photogrammetry is a mature technology with accuracies known from the aerotriangulation solutions, the vertical accuracy of digital elevation data (DEMs, breaklines or contours) from stereo photogrammetry may be documented in the metadata as follows:

- “Compiled to meet __ (meters, feet) vertical accuracy at 95% confidence level.”

Bare earth Digital Terrain Models (DTMs) are routinely produced from irregularly-spaced mass points and/or breaklines produced from imagery, lidar or IFSAR data. Uniformly-gridded DEMs are interpolated at pre-defined X- and Y-coordinates from such DTMs. Users should not assume that tested accuracy will be the same whether testing a DTM or a DEM interpolated from the DTM, but the same accuracy standards may be applicable to each, depending upon which deliverable is to be tested.

Vertical errors tend to approach a normal distribution (bell curve) in open, non-vegetated terrain with a large number of check points; the center of the bell curve will approach zero as systematic errors are corrected that impact mean errors. However, in vegetated terrain, vertical errors often do not approximate a normal distribution because

8 Federal Geographic Data Committee. (1998). FGDC-STD-007.3-1998, Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy, FGDC, c/o U.S. Geological Survey, www.fgdc.gov/standards/documents/standards/accuracy/chapter3.pdf.



algorithms for filtering vegetation do not necessarily introduce errors that are truly random, and remaining systematic errors cannot be modeled. It is much more common for elevation errors in dense vegetation to be positive (higher than the ground) as opposed to negative (beneath the ground). Furthermore, there is no universally accepted way to measure the horizontal accuracy of elevation datasets because elevation datasets do not include clearly defined point features needed for testing horizontal accuracy. With lidar and IFSAR sensors, system calibration and bore-sighting are used to control horizontal accuracy.

While breaklines that are photogrammetrically derived are typically derived from a single method, breaklines derived from lidar data may be derived from several different methods and each of these methods may produce breaklines to different levels of quality and accuracy. Currently, there is no standard for testing or reporting breakline accuracies achieved from each different method. Because different breakline collection methods from lidar may impact the accuracy and quality of the final breaklines, the collection method should always be listed in the metadata along with the tested accuracy of the lidar source used to collect the breaklines. The tested accuracy of the lidar source is important as the breaklines cannot be more accurate than the source from which breaklines were compiled. Breaklines may be documented in the metadata with the following statement:

- “Breaklines compiled using (lidargrammetry, terrain drape, 2D digitization, or other methods). Breaklines compiled from source that was tested __ (meters, feet) Non-vegetated Vertical Accuracy (NVA) at 95 percent confidence level; and tested __ (meters, feet) Vegetated Vertical Accuracy (VVA) at the 95th percentile,” or similar statement.

The metadata lineage should include additional descriptions and information on the specified breakline method, as well as quality steps used to ensure consistency between the source lidar data and the compiled breaklines.

Low Confidence Areas

Photogrammetrists commonly 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 shadow, 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. For manually compiled photogrammetric data, the VVA accuracy category does not typically apply. In most cases, a compiler will make the determination as to whether the data being digitized is either within NVA accuracies or not; areas not delineated by an obscure area polygon are presumed to meet NVA accuracies. In some specialized circumstances, VVA accuracy categories may be applicable and could be implemented. In those cases, the specific conditions where the VVA accuracies should be applied should be clearly defined. The extent of photogrammetrically derived obscure area polygons and any assumptions regarding how 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. Although costs will be slightly higher, ASPRS recommends that “low confidence areas” be required and delivered as two-dimensional (2D)

polygons where there are no bare-earth ground points in vegetated areas of 2-acres or larger; the same threshold used by the USGS Lidar Base Specifications for digitizing breaklines for hydro-flattening of inland ponds and lakes. Similarly, low confidence areas should be delineated for vegetated areas where the VVA is greater than 1.5 times the NVA. These thresholds may require further adjustment according to terrain type.

Low confidence areas within complex or varying terrains are more likely to have poorer vertical accuracy than such areas within flat terrain because fewer ground points result in increased interpolation. Greater interpolation results in less characteristics, changes, and details of the surface being mapped. This form of identifying low confidence areas is the DEM/DTM equivalent of traditional dashed contours; contour lines produced from such DTMs should be dashed within obscured vegetated area polygons. Although optional, ASPRS strongly recommends the development and delivery of low confidence polygons on all lidar projects.

There are two distinctly different types of low confidence areas:

- The first types of low confidence areas are identified by the data producer – *in advance* – where passable identification of the bare earth is expected to be unlikely or impossible. These are areas where no control or check points should be located and where contours should be dashed. They are exempt from accuracy assessment. Mangroves, swamps, inundated wetland marshes are prime candidates for such advance delineation.
- The second types of low confidence areas are valid VVA areas, normally forests that should also be depicted with dashed contours, but where check points *should* be surveyed and accuracy assessment *should* be performed. Such low confidence areas are delineated subsequent to classification and would usually be identifiable by the notably reduced density of bare-earth points.

This allows lidar data providers to protect themselves from unusable/unfair check points in swamps and protects the customer from data providers who might try to alter their data.

Occasionally, a check point may “bust” at no fault of the lidar survey. Such a point may be removed from the accuracy assessment calculation:

- if it is demonstrated, with pictures and descriptions, that the check point was improperly located, such as when a vertical check point is on steep terrain or within a few meters of a significant breakline that redefines the slope of the area being interpolated surrounding the check point;
- if it is demonstrated and documented that the topography has changed significantly between the time the elevation data were acquired and the time the check point was surveyed; or
- if (1) the point is included in the survey and accuracy reports, but not the assessment calculation, with pictures and descriptions; (2) reasonable efforts to correct the discrepancy are documented, e.g., rechecked airborne GPS and IMU data, rechecked point classifications in the area, rechecked the ground check points; and (3) a defensible explanation is provided for discarding the point. An explanation that the error exceeds three times the standard deviation ($>3\sigma$) is NOT a defensible explanation.

If low confidence areas are critical to a project, it is common practice to supplement remote sensing data with field surveys.

Appendix D — Accuracy Statistics and Example

NSSDA Horizontal Accuracy

$$\text{Let: } RMSE_x = \sqrt{\frac{\sum_{I=1}^n (x_{data I} - x_{check I})^2}{n}} \text{ and } RMSE_y = \sqrt{\frac{\sum_{I=1}^n (y_{data I} - y_{check I})^2}{n}}$$

where:

$x_{data I}$, $y_{data I}$, are the coordinates of the I^{th} check point in the dataset,

$x_{check I}$, $y_{check I}$, are the coordinates of the I^{th} check point in the independent source of higher accuracy,

n is the number of check points tested,

I is an integer ranging from 1 to n .

If horizontal error at point I is defined as:

$$ERROR_{rI} = \sqrt{(x_{data I} - x_{check I})^2 + (y_{data I} - y_{check I})^2}, \text{ then horizontal RMSE is:}$$

$$RMSE_r = \sqrt{\frac{\sum_{I=1}^n (x_{data I} - x_{check I})^2 + (y_{data I} - y_{check I})^2}{n}} = \sqrt{RMSE_x^2 + RMSE_y^2}$$

Computing Accuracy according to the NSSDA, where: $RMSE_x = RMSE_y$:

$$RMSE_r = \sqrt{2(RMSE_x^2)} = \sqrt{2(RMSE_y^2)} = 1.4142(RMSE_x) = 1.4142(RMSE_y)$$

The NSSDA assumes that systematic errors have been eliminated as best as possible. If horizontal errors are normally distributed and independent in each of the the x- and y-components, and error for the x-component is equal to and independent of error for the y-component, the factor 2.4477 is used to compute horizontal accuracy at the 95% confidence level. When the preceding conditions apply, the accuracy value according to NSSDA, shall be computed by the formula:

$$Accuracy_r = 2.4477(RMSE_r) = 2.4477(1.4142(RMSE_x)) = 2.4477\left(\frac{RMSE_x}{1.4142}\right) = 1.7308(RMSE_x) \text{ where:}$$

$Accuracy_r$ is the horizontal (radial) accuracy at the 95% confidence level.

NSSDA Vertical Accuracy

$$\text{Let: } RMSE_z = \sqrt{\frac{\sum_{I=1}^n (z_{data I} - z_{check I})^2}{n}} \text{ where:}$$

$z_{data I}$ is the vertical coordinate of the I^{th} check point in the dataset,

$z_{check I}$ is the vertical coordinate of the I^{th} check point in the independent source of higher accuracy,

n is the number of check points tested,

I is an integer ranging from 1 to n .

The NSSDA assumes that systematic errors have been eliminated as best as possible. If vertical errors are normally distributed, the factor 1.9600 is applied to compute linear error at the 95% confidence level. Therefore, vertical accuracy, $Accuracy_z$, reported according to the NSSDA shall be computed by the following formula:

$$Accuracy_z = 1.9600(RMSE_z) \text{ where:}$$

$Accuracy_z$ is the vertical accuracy at the 95% confidence level.

Comparison of NSSDA and NMAS

Per Appendix 3-D of the NSSDA (FGDC, 1998), the relationship between NSSDA and NMAS are defined as follows:

Relationship between NSSDA and NMAS (horizontal):

$$\begin{aligned} CMAS &= 2.1460(RMSE_r) = 2.1460(RMSE_r) = 2.1460\left(\frac{RMSE_r}{1.4142}\right) \\ &= 1.5175(RMSE_r) \\ Accuracy_r &= \left(\frac{2.4477}{1.4142}\right)CMAS \\ &= 1.1406(CMAS) \end{aligned}$$

Relationship between NSSDA and NMAS (vertical):

$$\begin{aligned} VMAS &= 1.6449(RMSE_z) \\ Accuracy_z &= \left(\frac{1.9600}{1.6449}\right)VMAS = 1.1916(VMAS) \end{aligned}$$

Therefore, vertical accuracy reported according to the NSSDA is:

$$\left(\frac{1.1916}{2}\right)CI = 0.5958(CI) \text{ where:}$$

CI is the contour interval, and

$$CI = \frac{Accuracy_z}{0.5958} = \frac{1.9600(RMSE_z)}{0.5958} = 3.2898(RMSE_z)^9$$

NDEP Vertical Accuracy Statistics

Whereas the NSSDA assumes that systematic errors have been eliminated as best as possible and that all remaining errors are random errors that follow a normal distribution, the NDEP recognizes that elevation errors, especially in dense vegetation, do not necessarily follow a normal error distribution, as demonstrated by the error histogram of 100 check points at Figure 1 used as an example elevation dataset for this Appendix.

In vegetated land cover categories, the NDEP uses the 95th percentile errors because a single outlier, when squared in the RMSE calculation, will unfairly distort the tested vertical accuracy statistic at the 95% confidence level. Unless errors can be found in the surveyed check point, or the location of the check point violates NDEP guidelines for location of vertical check points, such outliers should not be discarded. Instead, such outliers should be included in the calculation of the 95th percentile because: (1) the outliers help identify legitimate issues in mapping the bare-earth terrain in dense vegetation and (2) the 95th percentile, by definition, identifies that 95% of errors in the dataset have errors with respect to true ground elevation that are equal to or smaller than the 95th percentile – the goal of the NSSDA.

The NDEP uses the following vertical accuracy terms:

- Fundamental Vertical Accuracy (FVA) — Vertical accuracy at the 95% confidence level in open terrain only where errors should approximate a normal error distribution. FVA check points should be well-distributed and located only in open terrain, free of vegetation, where there is a high probability that the sensor will have detected the ground surface. $FVA = RMSE_z$ (in open terrain) $\times 1.96$.
- Supplemental Vertical Accuracy (SVA) — Vertical accuracy at the 95th percentile in each individual land cover category where vertical errors may not follow a normal error distribution. SVA is computed separately for each major land cover category being tested. SVAs are always accompanied by a FVA.
- Consolidated Vertical Accuracy (CVA) — Vertical accuracy at the 95th percentile in all land cover categories combined.

9 Note that the ASPRS 1990 Accuracy Standards for Large-Scale Maps uses $CI = 3.0(RMSE_z)$

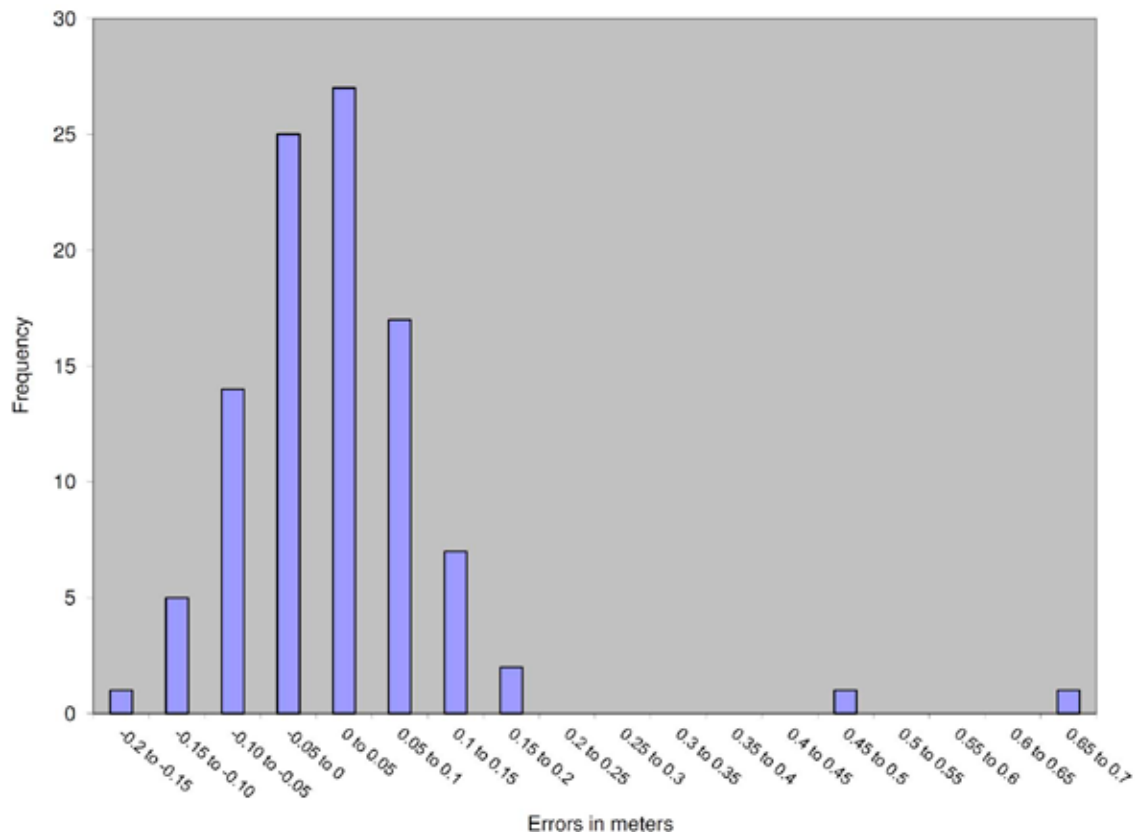


Figure 1. Error histogram of typical elevation dataset, showing two outliers in vegetated areas.

Table 8. Traditional Accuracy Statistics for Example Elevation Dataset

Land Cover Category	# of Check Points	Min. (m)	Max. (m)	Mean (m)	Mean Absolute (m)	Median (m)	Skew	Kurtosis	StdDev (m)	RMSEz (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 9. Comparison of NSSDA and NDEP Statistics for Example Elevation Dataset

Land Cover Category	NSSDA's Accuracy _z at 95% confidence level based on RMSE x 1.96	NDEP's FVA, plus SVAs and CVA based on the 95 th Percentile	NDEP Accuracy Term
Open Terrain	0.10m	0.10m	FVA
Urban Terrain	0.14m	0.13m	SVA
Weeds & Crops	0.25m	0.15m	SVA
Brush Lands	0.16m	0.14m	SVA
Fully Forested	0.33m	0.21m	SVA
Consolidated	0.22m	0.13m	CVA

Table 10. Comparison of NSSDA, NDEP and ASPRS Statistics for Example Elevation Dataset

Land Cover Category	NSSDA's Accuracy _z at 95% confidence level based on RMSE x 1.96	NDEP's FVA, plus SVAs and CVA based on the 95 th Percentile	NDEP Accuracy Term	ASPRS Vertical Accuracy	ASPRS Accuracy Term
Open Terrain	0.10m	0.10m	FVA	0.12m	NVA
Urban Terrain	0.14m	0.13m	SVA		
Weeds & Crops	0.25m	0.15m	SVA	0.167m	VVA
Brush Lands	0.16m	0.14m	SVA		
Fully Forested	0.33m	0.21m	SVA		
Consolidated	0.22m	0.13m	CVA	N/A	N/A

Example Elevation Dataset

Figure 1, plus Tables 8 and 9, refer to an actual elevation dataset tested by prior methods. Table 10 shows how the same checkpoints would be tested per these new ASPRS standards.

Figure 1 shows an actual error histogram resulting from 100 check points, 20 each in five land cover categories: (1) open terrain, (2) urban terrain, concrete and asphalt, (3) tall weeds and crops, (4) brush lands and trees, and (5) fully forested. In this lidar example, the smaller outlier of 49-cm is in tall weeds and crops, and the larger outlier of 70-cm is 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; therefore, the standard deviation and RMSE values are nearly identical. When mean errors are not close to zero, the standard deviation values will always be smaller than the RMSE values.

Without considering the 95th percentile errors, traditional accuracy statistics, which preceded these *ASPRS Accuracy Standards for Digital Geospatial Data*, would be as shown in Table 8. Note that the maximum error, skew, kurtosis, standard deviation and RMSE values are somewhat higher for weeds and crops because of the 49-cm outlier, and they are much higher for the fully forested land cover category because of the 70-cm outlier.

For this same example dataset, Table 9 compares accuracies at the 95% confidence level if using the NSSDA's RMSE x 1.96 compared with the NDEP's 95th percentile. If the RMSEz criterion had been 12.5-cm for all land cover categories, then the NSSDA's vertical accuracy requirement at the 95% confidence level would have been 12.5-cm x 1.96 = 24.5-cm and the dataset would have slightly failed in weeds and crops and significantly failed in the fully forested land cover category – both because of single outliers that often occur in dense vegetation, normally beyond the control of the data provider. However, because the client correctly specified the NDEP's FVA, SVA and CVA criteria, the dataset passed – as it should.

ASPRS Vertical Accuracy Statistics

In the ASPRS standards listed in Table 3, ASPRS defines two new terms: Non-vegetated Vertical Accuracy (NVA) based on RMSEz statistics and Vegetated Vertical Accuracy (VVA) based on 95th percentile statistics. The NVA consolidates the NDEP's non-vegetated land cover categories (open terrain and urban terrain, in this example), whereas the VVA consolidates the NDEP's vegetated land cover categories (weeds and crops, brush lands, and fully forested, in this example). As shown in Table 10 for this example, the NVA would equal 0.12m (12-cm) and the VVA would equal 0.167m (16.7-cm).

Mean Errors

For RMSEz statistics to be valid in open or non-vegetated terrain, there is an assumption that errors approximate a normal distribution, are more or less evenly distributed with positive and negative errors, and have a mean error near zero. But mean errors are rarely zero, even for datasets that pass project specifications. As a “rule of thumb,” there is no need to incur additional costs to apply a “z-bump” to raise or lower an entire elevation datasets to have a mean error of zero so long as the NVA accuracy standard is satisfied, in Tables 3 or 6 for example. Furthermore:

- QA/QC checkpoints, used to determine errors, are normally no more accurate than control points surveyed by the data producer to calibrate the data;
- Control points may NEVER be used as QA/QC checkpoints;
- Using the statistics from the example at Table 8, arguments could be made for application of z-bumps from +2-cm to -4-cm; but it makes no sense to apply z-bumps of different magnitudes to different land cover categories; and,
- Application of one uniform z-bump to all land cover categories will artificially worsen the errors in some categories.

When a dataset fails to pass project specifications, a z-bump may be applied to bring the mean error closer to zero if and when a systematic error has been identified, e.g., when different base stations were used for the control surveys and check point surveys, and their relative elevations were found to be inconsistent when both base stations are surveyed relative to CORS stations.

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