New ASPRS Positional Accuracy Standards for Digital Geospatial Data

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Why we needed new ASPRS accuracy standards

National Map Accuracy Standards (NMAS, 1947) specified accuracy thresholds based on scale and contour interval of printed maps only, e.g., CE90 = 1/30th" on map.

National Standard for Spatial Data Accuracy (NSSDA, 1988) defined accuracy reporting methodology for horizontal and vertical accuracy at 95% confidence levels but had no accuracy thresholds. It uses RMSE multipliers based on assumption that all errors are normally distributed – incorrect for LiDAR in vegetated terrain

ASPRS Accuracy Standards for Large-Scale Maps (ASPRS, 1990) also focused on printed maps

English and metric units

Planimetric Coordinate Accuracy		
RMSEx/RMSEy	Typical Map Scale	
0.05 ft.	1:60	
0.1 ft.	1:120	
0.2 ft.	1:240	Ground methods ↑
0.3 ft.	1:360	Aerial methods ↓
0.4 ft.	1:480	
0.5 ft.	1:600	
1.0 ft.	1:1,200	
2.0 ft.	1:2,400	
4.0 ft.	1:4,800	
5.0 ft.	1:6,000	
8.0 ft.	1:9,600	
10.0 ft.	1:12,000	
16.7 ft.	1:20,000	

Class 1, Class 2, Class 3 maps

Class 1, Class 2, Class 3 contours, Class 1, RMSEz = C.I./3

We needed standards for DIGITAL geospatial data

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Highlight Article in March 2015 *PE&RS*

New Standard for New Era: Overview of the 2015 ASPRS Positional Accuracy Standards for Digital Geospatial Data

Visit http://www.asprs.org/Standards-Activities.html to view the new standards in its entirety.

The new ASPRS accuracy standards fill a critical need, vital for map users and makers alike. For centuries, map scale and contour interval have been used as an indication of map accuracy. Users want to know how accurately they can measure different things on a map, and map makers want to know how accurate maps need to be in order to satisfy user requirements. Those contracting for new maps depend on some form of map accuracy standard to evaluate the tradeoff between the accuracy required vs. how much time and expense are justified in achieving it, and then to describe the accuracy of the result in a uniform way that is reliable, defensible, and repeatable.

No prior U.S. accuracy standard comprehensively addresses the current state of mapping technology, which is why the new ASPRS standards were developed. The

Introduction

Effective in November, 2014, the *ASPRS Positional Accuracy Standards for Digital Geospatial Data* (2014) replaced the *ASPRS Accuracy Standards for Large-Scale Maps* (1990) and the *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data* (2004). This standard was developed by the ASPRS Map Accuracy Standards Working Group, a joint committee under the Photogrammetric Applications Division, Primary Data Acquisition Division and Lidar Division, which was formed for the purpose of reviewing and updating ASPRS map accuracy standards to reflect current technologies. A subcommittee of this group, consisting of Dr. Qassim Abdullah, Dr. David Maune, Doug Smith, and Hans Karl Heidemann, was responsible for drafting the document. Draft versions of the standard underwent extensive review, both within ASPRS as well as through public review by other key geospatial mapping organizations, prior to final approval by the ASPRS Board of Directors on November 17, 2014. The new standard is available at: *http://www.asprs.org/Standards-Activities.html*: the ASPRS Standards web page. Readers can then navigate to the *ASPRS Positional Accuracy Standards for Digital Geospatial Data*.

Digital Annex in March 2015 *PE&RS,* Table of Contents

ASPRS Positional Accuracy Standards for Digital Geospatial Data

(EDITION 1, VERSION 1.0. - NOVEMBER, 2014)

Developed by: ASPRS Map Accuracy Working Group*

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See the 26-page full text for details not in the Highlight Article

FOREWORD

The goal of American Society for Photogrammetry and Remote Sensing (ASPRS) is to advance the science of photogrammetry and remote sensing; to educate individuals in the science of photogrammetry and remote sensing; to foster the exchange of information pertaining to the science of photogrammetry and remote sensing; to develop, place into practice, and maintain standards and ethics applicable to aspects of the science; to provide a means for the exchange of ideas among those interested in the sciences; and to encourage, publish and distribute books, periodicals, treatises, and other scholarly and practical works to further the science of photogrammetry and remote sensing.

This standard was developed by the ASPRS Map Accuracy Standards Working Group, a joint committee under the Photogrammetric Applications Division, Primary Data Acquisition Division, and Lidar Division, which was formed for the purpose of reviewing and updating ASPRS map accuracy standards to reflect current technologies. A subcommittee of this group, consisting of Dr. Qassim Abdullah of Woolpert, Inc., Dr. David Maune of Dewberry Consultants, Doug Smith of David C. Smith and Associates, Inc., and Hans Karl Heidemann of the U.S. Geological Survey, was responsible for drafting the document.

ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA

1. PURPOSE

The objective of the *ASPRS Positional 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) to better address current technologies.

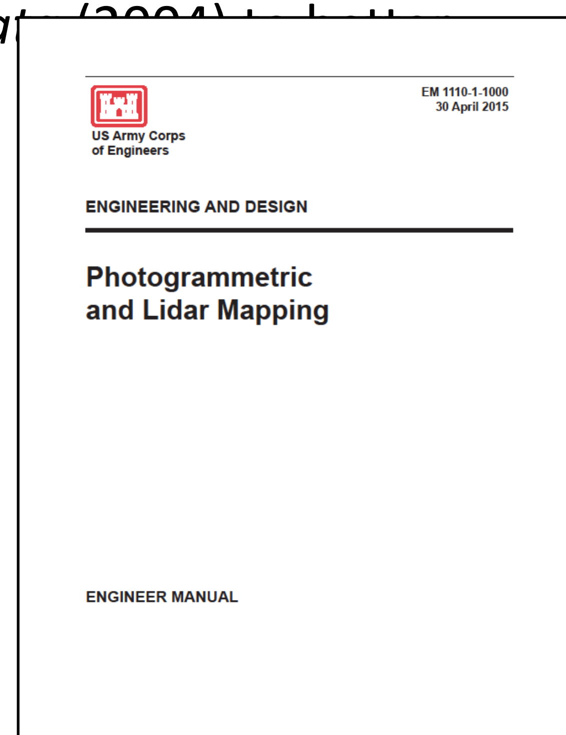
This standard includes positional accuracy standards for digital orthoimagery, digital planimetric data and digital elevation data. Accuracy classes, based on RMSE values, have been revised and upgraded from the 1990 standard to address the higher accuracies achievable with newer technologies. The standard also includes additional accuracy measures, such as orthoimagery seam lines, aerial triangulation ac-

1. Methodologies for accuracy assessment of linear features (as opposed to well defined points);
2. Rigorous total propagated uncertainty (TPU) modeling (as opposed to – or in addition to – ground truthing against independent data sources);
3. Robust statistics for data sets that do not meet the criteria for normally distributed data and therefore cannot be rigorously assessed using the statistical methods specified herein;
4. Image quality factors, such as edge definition and other characteristics;
5. Robust assessment of checkpoint distribution and density;

Purpose of the New Standards

The objective of the *ASPRS Positional 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) to better address current technologies.

I will periodically also reference USACE EM 1110-1-1000, *Photogrammetric and Lidar Mapping*, demonstrating how the U.S. Army Corps of Engineers has already adopted these new ASPRS standards


US Army Corps of Engineers

EM 1110-1-1000
30 April 2015

ENGINEERING AND DESIGN

Photogrammetric and Lidar Mapping

ENGINEER MANUAL

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Outline of the ASPRS (2015) Standards

1. Purpose
2. Conformance
3. References
4. Authority
5. Terms and Definitions
6. Symbols, Abbreviations and Notations
7. Specific Requirements (most of the “meat” is here)

Annex A: Background and Justifications

Annex B: Data Accuracy and Quality Examples

Annex C: Accuracy Testing and Reporting Guidelines

Annex D: Accuracy Statistics and Example

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7. Specific Requirements -- Network Accuracy

- Unless specified to the contrary, it is expected that all ground control and checkpoints should normally follow the guidelines for network accuracy as detailed in the Geospatial Positioning Accuracy Standards, Part 2: Standards for Geodetic Networks, Federal Geodetic Control Subcommittee, Federal Geographic Data Committee (FGDC-STD-007.2-1998). When local control is needed to meet specific accuracies or project needs, it must be clearly identified both in the project specifications and the metadata.

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What's this thing about "Network Accuracy?"

- Dewberry was once hired to determine how two adjoining lidar datasets, both certified as having 1-foot contour accuracy, could have a 2-foot vertical offset along the seamline between these datasets with extremely flat terrain.
- For one dataset, the lidar firm and QC firm both (correctly) referenced their surveys to NGS Data Sheets with network accuracy.
- For the 2nd dataset, the lidar firm and the QC firm surveyed their control and QC checkpoints relative to the same local survey monuments so that any errors canceled out (we found 1-ft to 2-ft errors in commonly-used monuments in that area).

The NGS Data Sheet

See file dsdata.txt for more information about the datasheet.

```
PROGRAM = datasheet95, VERSION = 7.89.3.1
1        National Geodetic Survey,   Retrieval Date = AUGUST 27, 2012
 AJ4599 *********************************************************************
 AJ4599  HT_MOD       -  This is a Height Modernization Survey Station.
 AJ4599  CBN          -  This is a Cooperative Base Network Control Station.
 AJ4599  DESIGNATION -  FAIRFAX COUNTY EAST
 AJ4599  PID          -  AJ4599
 AJ4599  STATE/COUNTY-  VA/FAIRFAX
 AJ4599  COUNTRY      -  US
 AJ4599  USGS QUAD    -  FALLS CHURCH (1994)
 AJ4599
 AJ4599                          *CURRENT SURVEY CONTROL
 AJ4599  ______________________________________________________________________
 AJ4599* NAD 83(2011) POSITION- 38 55 43.18356(N) 077 08 47.67437(W)   ADJUSTED
 AJ4599* NAD 83(2011) ELLIP HT-    52.373 (meters)        (06/27/12)   ADJUSTED
 AJ4599* NAD 83(2011) EPOCH   -  2010.00
 AJ4599* NAVD 88 ORTHO HEIGHT -    84.26   (meters)     276.4   (feet) GPS OBS
 AJ4599  ______________________________________________________________________
 AJ4599  NAD 83(2011) X  -  1,105,247.067 (meters)                     COMP
 AJ4599  NAD 83(2011) Y  - -4,843,853.080 (meters)                     COMP
 AJ4599  NAD 83(2011) Z  -  3,986,192.174 (meters)                     COMP
 AJ4599  LAPLACE CORR    -          -2.36  (seconds)                   DEFLEC09
 AJ4599  GEOID HEIGHT    -         -31.88  (meters)                    GEOID12
 AJ4599
 AJ4599  FGDC Geospatial Positioning Accuracy Standards (95% confidence, cm)
 AJ4599  Type                                        Horiz  Ellip  Dist(km)
 AJ4599  -------------------------------------------------------------------
 AJ4599  NETWORK                                      0.41   0.98
 AJ4599  -------------------------------------------------------------------
 AJ4599  MEDIAN LOCAL ACCURACY AND DIST (067 points)  0.53   1.22     43.81
 AJ4599  -------------------------------------------------------------------
 AJ4599  NOTE: Click here for information on individual local accuracy
 AJ4599  values and other accuracy information.
```

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7.1 Statistical Assessment of Horizontal and Vertical Accuracies

- Horizontal accuracy is assessed using $RMSE_x$, $RMSE_y$, $RMSE_r$ plus NSSDA multipliers to compute horizontal accuracy at the 95% confidence level ($ACC_r = 1.7308 * RMSE_r$)
- In non-vegetated terrain only, vertical accuracy is assessed using $RMSE_z$ plus NSSDA multiplier to compute vertical accuracy at the 95% confidence level ($ACC_z = 1.9600 * RMSE_z$)
- Both of the above assume errors follow a normal distribution
- In vegetated terrain, vertical accuracy is assessed by using the 95th percentile (absolute values) – does not assume a normal error distribution
- Representative error thresholds are provided in Annex B tables

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7.2 Assumptions Regarding Systematic Errors and Acceptable Mean Errors

- For computations of 95% confidence levels, it is assumed that data set errors are normally distributed and that any significant systematic errors or biases have been removed; this is the responsibility of the data provider
- These standards recommend that the mean error be less than 25% of the specified RMSE value for the project; if larger than 25%, investigate cause and document in the metadata
- In accuracy testing, don't discard discrepancies >3 * RMSE values without proper investigation and explanation in the metadata; these are not automatically blunders to be discarded

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7.3 Horizontal Accuracy Standards for Geospatial Data

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	$\leq X$	$\leq 1.41*X$	$\leq 2.45*X$	$\leq 2*X$

There are no more horizontal Class 1, Class 2, or Class 3 maps or orthophotos; the horizontal class is in cm (or feet or inches) based on $RMSE_x$ and $RMSE_y$

Because many don't think of their requirements in terms of the RMSE, both ASPRS (Annex B) and USACE (EM 1110-1-1000) provide horizontal examples

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Annex B, Table B.5, ASPRS orthoimagery accuracy examples based on pixel size (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

- **Highest accuracy** exceeds prior standards
- **Standard high accuracy** ~ ASPRS 1990 Class 1
- **Lower accuracy** ~ ASPRS 1990 Class 1.5
- Note: Prior Class 2 RMSEs were 2 x Class 1 RMSEs
- ASPRS now decided against Class numbers/letters
- **The new Class = its $RMSE_x$ and $RMSE_y$**

These are examples, you can specify other $RMSE_x$/$RMSE_y$ values

Additional USACE orthoimagery accuracy examples based on pixel size (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

These three pixel sizes (3”, 6” and 12”) are USACE’s most common for orthoimages

Specify orthos in terms of pixel size, $RMSE_x$ and $RMSE_y$

Don’t specify Class 1 orthos; that term is now obsolete, but if used by others, equate to standard high accuracy

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Annex B, Table B.6, ASPRS planimetric data accuracy examples (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

Several ways to determine what is appropriate

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7.4 Vertical Accuracy Standards for Elevation Data

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*

- There are no more vertical Class 1, Class 2, or Class 3 elevation data or contours; the vertical class is in cm (or feet or inches) based on $RMSE_z$ in non-vegetated terrain
- Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) are new terms
- Do not confuse these "standards" with tested values for NVA and VVA
- Because many don't think of their requirements in terms of the $RMSE_z$, both ASPRS (Annex B) and USACE (EM 1110-1-1000) provide vertical examples also

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Annex B, Table B.7, ASPRS vertical accuracy/quality examples

Vertical Accuracy Class	Absolute Accuracy			Relative Accuracy (where applicable)		
	$RMSE_z$ Non-Vegetated (cm)	NVA at 95% Confidence Level (cm)	VVA at 95th Percentile (cm)	Within-Swath Hard Surface Repeatability (Max Diff) (cm)	Swath-to-Swath Non-Veg Terrain ($RMSD_z$) (cm)	Swath-to-Swath Non-Veg Terrain (Max Diff) (cm)
1-cm	1.0	2.0	3	0.6	0.8	1.6
2.5-cm	2.5	4.9	7.5	1.5	2	4
5-cm	5.0	9.8	15	3	4	8
10-cm	10.0	19.6	30	6	8	16
15-cm	15.0	29.4	45	9	12	24
20-cm	20.0	39.2	60	12	16	32
33.3-cm	33.3	65.3	100	20	26.7	53.3
66.7-cm	66.7	130.7	200	40	53.3	106.7
100-cm	100.0	196.0	300	60	80	160
333.3-cm	333.3	653.3	1000	200	266.7	533.3

NVA and VVA are new terms

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USACE example accuracy specs for Military Construction

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

USACE managers and inspectors still use printed maps on site

These RMSE values tie directly to ASPRS accuracy tables

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USACE example accuracy specs for Civil Works projects

Table 3-27 (Continued)

Project or Activity	Horizontal Accuracy Criteria			Vertical Accuracy Criteria		
<u>MILITARY CONSTRUCTION (CONTINUED):</u>	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

+ 10 more similar continuation pages with footnotes

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Over 60 USACE examples help when managers don't know what RMSE values they should specify

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	≤*X*	≤1.41**X*	≤2.45**X*	≤ 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*

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7.5 Horizontal Accuracy Requirements for Elevation Data

- Photogrammetric Elevation Data: the horizontal accuracy equates to the horizontal accuracy class that would apply to planimetric data or digital orthoimagery produced from the same source imagery, using the same aerial triangulation (AT)/ inertial navigation system (INS) solution
- Lidar Elevation Data: the horizontal error is largely a function of positional error as derived from the Global Navigation Satellite System (GNSS), attitude error from INS, and flying altitude

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One way to estimate Lidar Horizontal Error

$$LidarHorizontalError(RMSE_r) = \sqrt{(GNSSpositionalerror)^2 + \left(\frac{\tan(IMUerror)}{0.55894170} xflyingaltitude\right)^2}$$

The above equation considers flying altitude (in meters), GNSS errors (radial, in cm), IMU errors (in decimal degrees), and other factors such as ranging and timing errors (which is estimated to be equal to 25% of the orientation errors). In the above equation, the values for the "GNSS positional error" and the "IMU error" can be derived from published manufacturer specifications for both the GNSS receiver and the IMU.

If the desired horizontal accuracy figure for lidar data is agreed upon, then the following equation can be used to estimate the flying altitude:

$$FlyingAltitude \approx \frac{0.55894170}{\tan\,(IMUerror)} \sqrt{(LidarHorizontalError(RMSEr))^2 - (GNSSpositionalerror)^2}$$

Annex B provides examples of using these formulas

Annex C includes guidelines for testing the horizontal accuracy of elevation data derived from lidar

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7.6 Low Confidence Areas for Elevation Data

- Where the bare-earth DTM may not meet overall data accuracy requirements (dashed contours in the past)
- Low confidence areas are required and delivered as 2-D polygons based on four criteria:
  - Nominal ground point density (NGPD)
  - Cell size for raster analysis
  - Search radius to determine average ground point densities
  - Minimum size area appropriate to aggregate ground point densities and show a generalized Low Confidence Area (minimum mapping unit)

Details are provided in Annex C, Section C.8

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7.7 Accuracy Requirements for AT and INS-based Sensor Orientation of Digital Imagery

Accuracy of aerial triangulation designed for **digital planimetric data only** (orthoimagery and/or digital planimetric map):

- $RMSE_{x(AT)}$ or $RMSE_{y(AT)}$ = ½ * $RMSE_{x(Map)}$ or ½ $RMSE_{y(Map)}$
- $RMSE_{z(AT)}$ = $RMSE_{x(Map)}$ or $RMSE_{y(Map)}$ of orthoimagery

Accuracy of aerial triangulation designed for **elevation data, or planimetric data** (orthoimagery and/or digital planimetric map) **and elevation data** production:

- $RMSE_{x(AT)}$, $RMSE_{y(AT)}$ or $RMSE_{z(AT)}$ = ½ * $RMSE_{x(Map)}$, ½ $RMSE_{y(Map)}$ or ½ $RMSE_{z(DEM)}$.

This gets complicated, but it says $RMSE_z$ is very important for DEMs but less important for the aerial triangulation of orthoimagery or planimetric maps

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7.8 Accuracy Requirements for Ground Control Used for Aerial Triangulation

Ground control points used for aerial triangulation should have higher accuracy than the expected accuracy of derived products according to the following two categories:

- Accuracy of ground control designed for **planimetric data only** (orthoimagery and/or digital planimetric map)production:
- $RMSE_x$ or $RMSE_y$ = ¼ * $RMSE_{x(Map)}$ or ¼ $RMSE_{y(Map)}$,
- $RMSE_z$ = ½ * $RMSE_{x(Map)}$ or ½ $RMSE_{y(Map)}$

Accuracy of ground control designed for **elevation data, or planimetric data and elevation data** production:

- $RMSE_x$, $RMSE_y$ or $RMSE_z$= ¼ * $RMSE_{x(Map)}$, ¼ $RMSE_{y(Map)}$ or ¼ $RMSE_{z(DEM)}$

Annex B provides examples of these formulas

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7.9 Checkpoint Accuracy and Placement Requirements

- The independent source of higher accuracy for checkpoints shall be at least three times more accurate than the required accuracy of the geospatial data set being tested.
- Horizontal checkpoints must be well defined points, easily visible on the ground and on the product being tested
- Vertical checkpoints must be located to minimize interpolation errors (e.g., no bridge abutments), surveyed on flat or uniformly sloping terrain and with slopes of 10% or less, and avoiding artifacts or abrupt changes in elevations

7.10 Checkpoint Density and Distribution

From Annex C, Table C.1 Required Number of checkpoints 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

Do not extrapolate for larger areas. Once we have statistically significant sampling, additional requirements are relaxed in order to be practical; see section C.2.

There is also guidance on the distribution of vertical checkpoints across land cover types

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7.11 Relative Accuracy of Lidar and IFSAR (Examples in Annex B, Table B.7)

Vertical Accuracy Class	Absolute Accuracy			Relative Accuracy (where applicable)		
	$RMSE_z$ Non-Vegetated (cm)	NVA at 95% Confidence Level (cm)	VVA at 95th Percentile (cm)	Within-Swath Hard Surface Repeatability (Max Diff) (cm)	Swath-to-Swath Non-Veg Terrain ($RMSD_z$) (cm)	Swath-to-Swath Non-Veg Terrain (Max Diff) (cm)
1-cm	1.0	2.0	3	0.6	0.8	1.6
2.5-cm	2.5	4.9	7.5	1.5	2	4
5-cm	5.0	9.8	15	3	4	8
10-cm	10.0	19.6	30	6	8	16
15-cm	15.0	29.4	45	9	12	24
20-cm	20.0	39.2	60	12	16	32
33.3-cm	33.3	65.3	100	20	26.7	53.3
66.7-cm	66.7	130.7	200	40	53.3	106.7
100-cm	100.0	196.0	300	60	80	160
333.3-cm	333.3	653.3	1000	200	266.7	533.3

Tests single-swath repeatability; tests overlapping swath quality of system calibration/bore-sighting and ABGPS

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7.12 Reporting – Horizontal Accuracy

The horizontal accuracy of digital orthoimagery, planimetric data, and elevation data sets shall be documented in the metadata in one of the following manners:

- “This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a ___ (cm) $RMSE_x$ / $RMSE_y$ Horizontal Accuracy Class. Actual positional accuracy was found to be $RMSE_x$ = ___ (cm) and $RMSE_y$ = ___ cm which equates to Positional Horizontal Accuracy = +/- ___ at 95% confidence level.”
- “This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a ___ (cm) $RMSE_x$ / $RMSE_y$ Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- ___ cm at a 95% confidence level.”

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7.12 Reporting – Vertical Accuracy

The vertical accuracy of elevation data sets shall be documented in the metadata in one of the following manners:

- "This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a___ (cm) $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = ___ cm, equating to +/- ___ cm at 95% confidence level. Actual VVA accuracy was found to be +/- ___ cm at the 95th percentile."[4]
- "This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a ___ cm $RMSE_z$ Vertical Accuracy Class equating to NVA =+/-___cm at 95% confidence level and VVA =+/-___cm at the 95th percentile[5]

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Annex A – Background and Justifications

Legacy Standards and Guidelines

- NMAS, ASPRS 1990, NSSDA, NDEP, ASPRS (2004), FEMA 1998 to 2010), USGS Lidar Base Specifications (through V1.2)

New Standards for a New Era

- Mapping practices during the film-based era
- Mapping practices during the softcopy photogrammetry era
- Mapping practices during the digital sensors photogrammetry era

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Table A.1 Common photography scales using camera with 9” film format and 6” lens

Film Scale	1″ = 300′	1″ = 600′	1″ = 1200′	1″ = 2400′	1″ = 3333′
	1:3,600	1:7,200	1:14,400	1:28,800	1:40,000
Flying Altitude	1,800′ / 550 m	3,600′ / 1,100 m	7,200′ / 2,200 m	14,400′ / 4,400 m	20,000′ / 6,100 m
Map Scale	1″ = 50′	1″ = 100′	1″ = 200′	1″ = 400′	1″ = 1000′
	1:600	1:1,200	1:2,400	1:4,800	1:12,000

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Table A.2 Legacy relationship between film scale and derived map scale

	Common Photography Scales (with 9" film format camera and 6" lens)				Scanning Resolution (um)
Photo Scale	1" = 300'	1" = 600'	1" = 1200'	1" = 2400'	
	1:3,600	1:7,200	1:14,400	1:28,800	
Flying Altitude	1,800' / 550 m	3,600' / 1,100 m	7,200' / 2,200 m	14,400' / 4,400 m	
Approximate GSD of Scan	0.25' / 7.5 cm	0.50' / 0.15 m	1.0' / 0.3 m	2.0' / 0.6 m	21

	Supported Map/Orthoimagery Scales and Contour Intervals			
GSD	3" / 7.5 cm	6" / 15 cm	1.0' / 30 cm	2.0' / 60 cm
C.I.	1.0' / 30 cm	2.0' / 60 cm	4' / 1.2 m	8' / 2.4 m
Map Scale	1" = 50'	1" = 100'	1" = 200'	1" = 400'
	1:600	1:1,200	1:2,400	1:4,800

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Annex B – Data Accuracy and Quality Examples

Legacy Standards and Guidelines

- NMAS, ASPRS 1990, NSSDA, NDEP, ASPRS (2004), FEMA 1998 to 2010), USGS Lidar Base Specifications (through V1.2)

New Standards for a New Era

- Mapping practices during the film-based era
- Mapping practices during the softcopy photogrammetry era
- Mapping practices during the digital sensors photogrammetry era

Annex B Data Accuracy and Quality Examples

- Examples of AT and ground control accuracy requirements
- Examples of common horizontal accuracy classes for orthoimagery and planimetrics (Tables B.5 and B.6 shown previously above)
- Examples of common vertical accuracy classes (Table B.7 shown previously above)
- Converting ASPRS 2014 accuracy values to legacy ASPRS 1990 and NMAS 1947
- Expressing the ASPRS 2014 accuracy values per the NSSDA
- Expected horizontal errors ($RMSE_r$) in terms of flying altitude

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Examples for typical products with $RMSE_x$ and $RMSE_y$ of 50 cm

Table B.1 AT and Ground Control Accuracy (Orthos and Planimetrics)

Product Accuracy ($RMSE_x$, $RMSE_y$) (cm)	A/T Accuracy		Ground Control Accuracy	
	$RMSE_x$ and $RMSE_y$ (cm)	$RMSE_z$ (cm)	$RMSE_x$ and $RMSE_y$ (cm)	$RMSE_z$ (cm)
50	25	50	12.5	25

Table B.2 AT and Ground Control Accuracy (Orthos, Planimetrics + Elevation Data

Product Accuracy ($RMSE_x$, $RMSE_y$) (cm)	A/T Accuracy		Ground Control Accuracy	
	$RMSE_x$ and $RMSE_y$ (cm)	$RMSE_z$ (cm)	$RMSE_x$ and $RMSE_y$ (cm)	$RMSE_z$ (cm)
50	25	25	12.5	12.5

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Table B.3 Common Horizontal Accuracy Class Examples

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)
0.63	0.9	1.3	1.5
1.25	1.8	2.5	3.1
2.50	3.5	5.0	6.1
5.00	7.1	10.0	12.2
7.50	10.6	15.0	18.4
10.00	14.1	20.0	24.5
12.50	17.7	25.0	30.6
15.00	21.2	30.0	36.7
17.50	24.7	35.0	42.8
20.00	28.3	40.0	49.0
22.50	31.8	45.0	55.1
25.00	35.4	50.0	61.2

Continues to $RMSE_x$/$RMSE_y$ of 1 meter

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Table B.4 Compares with legacy horizontal standards

Common Orthoimagery Pixel Sizes	Associated Map Scale	ASPRS 1990 Accuracy Class	Associated Horizontal Accuracy According to Legacy ASPRS 1990 Standard	
			$RMSE_x$ and $RMSE_y$ (cm)	$RMSE_x$ and $RMSE_y$ in terms of pixels
0.625 cm	1:50	1	1.3	2-pixels
		2	2.5	4-pixels
		3	3.8	6-pixels
1.25 cm	1:100	1	2.5	2-pixels
		2	5.0	4-pixels
		3	7.5	6-pixels
2.5 cm	1:200	1	5.0	2-pixels
		2	10.0	4-pixels
		3	15.0	6-pixels
5 cm	1:400	1	10.0	2-pixels
		2	20.0	4-pixels
		3	30.0	6-pixels

Continues to pixel size of 5 meters

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Table B.8 Compares with legacy vertical standards

Vertical Accuracy Class	$RMSE_z$ Non-Vegetated (cm)	Equivalent Class 1 contour interval per ASPRS 1990 (cm)	Equivalent Class 2 contour interval per ASPRS 1990 (cm)	Equivalent contour interval per NMAS (cm)
1-cm	1.0	3.0	1.5	3.29
2.5-cm	2.5	7.5	3.8	8.22
5-cm	5.0	15.0	7.5	16.45
10-cm	10.0	30.0	15.0	32.90
15-cm	15.0	45.0	22.5	49.35
20-cm	20.0	60.0	30.0	65.80
33.3-cm	33.3	99.9	50.0	109.55
66.7-cm	66.7	200.1	100.1	219.43
100-cm	100.0	300.0	150.0	328.98
333.3-cm	333.3	999.9	500.0	1096.49

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Table B.9, ASPRS recommended Lidar Point Density (NPD/NPS)

Vertical Accuracy Class	Absolute Accuracy		Recommended Minimum NPD (pts/m²)	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

QL2 lidar, the new nationwide standard for the 3DEP

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Table B.10, Expected lidar horizontal errors in terms of flying altitude (based on formulas in Section 7.5)

Altitude (m)	Positional $RMSE_r$ (cm)		Altitude (m)	Positional $RMSE_r$ (cm)
500	13.1		3,000	41.6
1,000	17.5		3,500	48.0
1,500	23.0		4,000	54.5
2,000	29.0		4,500	61.1
2,500	35.2		5,000	67.6

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Annex C Accuracy Testing and Reporting Guidelines

- Checkpoint requirements
- Number of checkpoints required
- Distribution of vertical checkpoints across land cover types
- NSSDA methodology for checkpoint distribution
- Vertical checkpoint accuracy
- Testing and reporting of horizontal accuracies
- Testing and reporting of vertical accuracies
- Low confidence areas
- Erroneous checkpoints
- Relative accuracy comparison point location and criteria for lidar swath-to-swath accuracy assessment
- Interpolation of elevation represented surface

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Table C.2 Low Confidence Areas

Vertical Accuracy Class	Recommended Project Min NPD (pts/m^2) (Max NPS (m))	Recommended Low Confidence Min NGPD (pts/m^2) (Max NGPS (m))	Search Radius and Cell Size for Computing NGPD (m)	Low Confidence Polygons Min Area (acres (m^2))
1-cm	≥20 (≤0.22)	≥5 (≤0.45)	0.67	0.5 (2,000)
2.5-cm	16 (0.25)	4 (0.50)	0.75	1 (4,000)
5-cm	8 (0.35)	2 (0.71)	1.06	2 (8,000)
10-cm	2 (0.71)	0.5 (1.41)	2.12	5 (20,000)
15-cm	1 (1.0)	0.25 (2.0)	3.00	5 (20,000)
20-cm	0.5 (1.4)	0.125 (2.8)	4.24	5 (20,000)
33.3-cm	0.25 (2.0)	0.0625 (4.0)	6.0	10 (40,000)
66.7-cm	0.1 (3.2)	0.025 (6.3)	9.5	15 (60,000)
100-cm	0.05 (4.5)	0.0125 (8.9)	13.4	20 (80,000)
333.3-cm	0.01 (10.0)	0.0025 (20.0)	30.0	25 (100,000)

Digital elevation data equivalent of dashed contour lines

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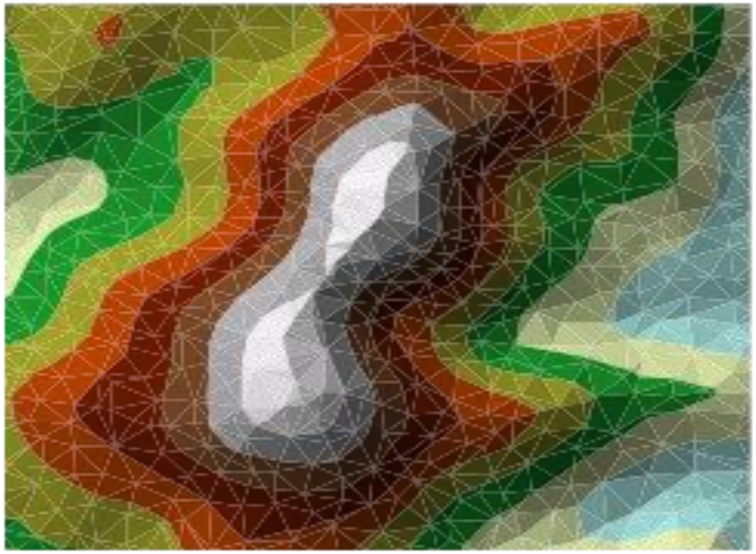
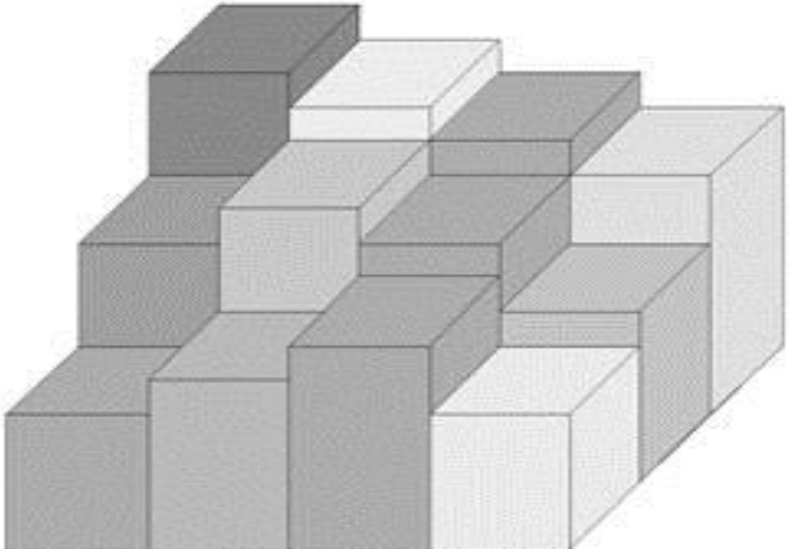
Interpolation of elevation "represented surface"



TIN interpolation should be used to test the vertical accuracy of point based elevation datasets, e.g., lidar



A gridded DEM is already a continuous surface; normally extract the elevation of the pixel, without interpolation

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Annex D Accuracy Statistics and Examples

- NSSDA reporting accuracy statistics (example computations of mean errors, sample standard deviation, RMSE values, and NSSDA horizontal and vertical accuracies at the 95% confidence level
- Comparison with NDEP vertical accuracy statistics
- Computation of percentile

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Simple horizontal accuracy example of statistics

Point ID	Map-derived values			Survey Check Point Values			Residuals (Errors)		
	Easting (E)	Northing (N)	Elevation (H)	Easting (E)	Northing (N)	Elevation (H)	Δx Easting (E)	Δy Northing (N)	Δz Elevation (H)
	meters	meters	meters	meters	meters	meters	meters	meters	meters
GCP1	359584.394	5142449.934	477.127	359584.534	5142450.004	477.198	–0.140	–0.070	–0.071
GCP2	359872.190	5147939.180	412.406	359872.290	5147939.280	412.396	–0.100	–0.100	0.010
GCP3	395893.089	5136979.824	487.292	359893.072	5136979.894	487.190	0.017	–0.070	0.102
GCP4	359927.194	5151084.129	393.591	359927.264	5151083.979	393.691	–0.070	0.150	–0.100
GCP5	372737.074	5151675.999	451.305	372736.944	5151675.879	451.218	0.130	0.120	0.087
Number of check points							**5**	**5**	**5**
Mean Error (m)							**–0.033**	**0.006**	**0.006**
Standard Deviation (m)							**0.108**	**0.119**	**0.006**
RMSE (m)							**0.102**	**0.106**	**0.081**
$RMSE_r$ (m)							**0.147**	**$=SQRT(RMSE_x^2 + RMSE_y^2)$**	
NSSDA Horizontal Accuracy$_r$ (ACC_r) at 95% Confidence Level							**0.255**	**$=RMSE_r \times 1.7308$**	
NSSDA Vertical Accuracy$_z$ (ACC_z) at 95% Confidence Level							**0.160**	**$=RMSE_z \times 1.9600$**	

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Figure D.1 Actual working example for lidar

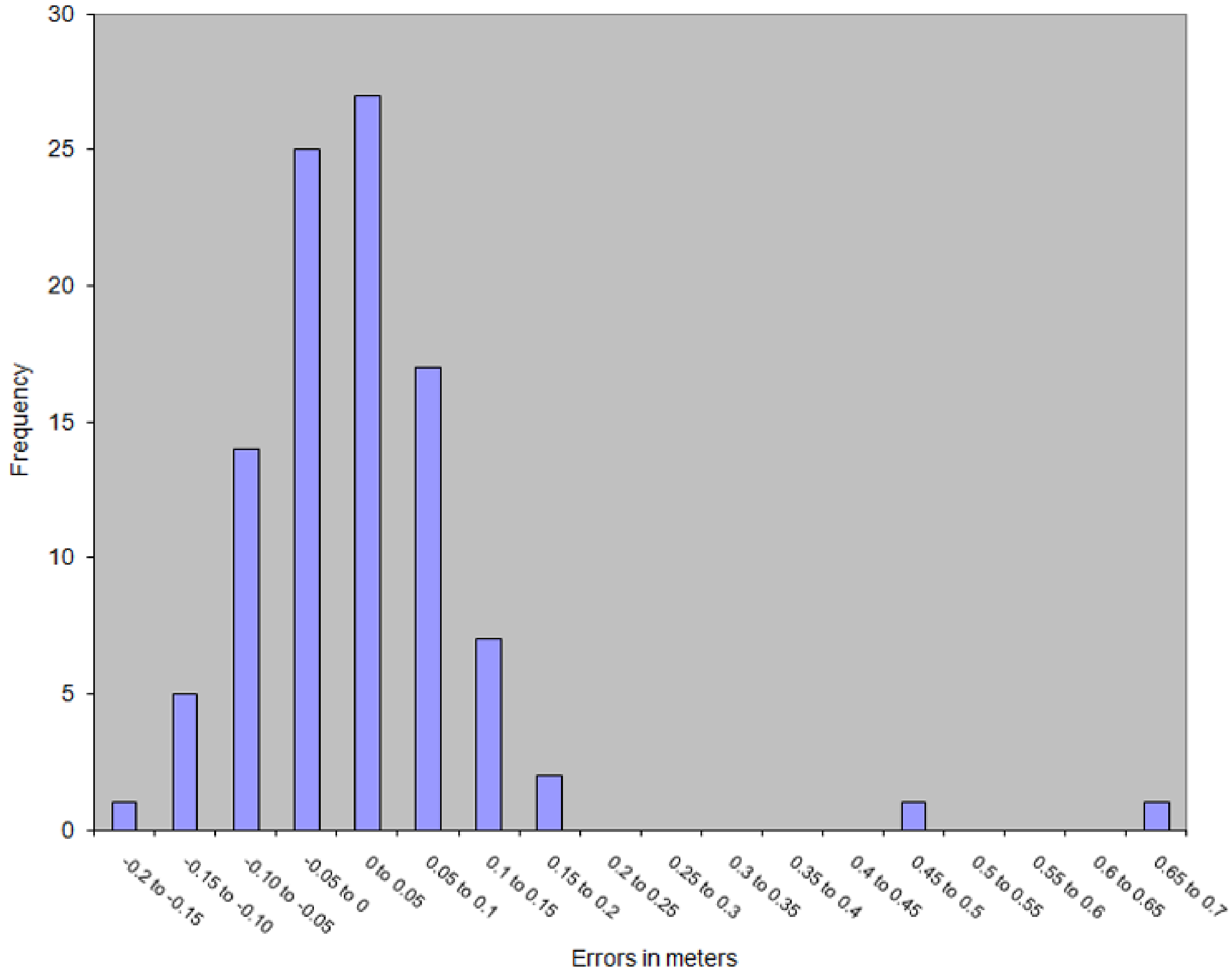

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Table D.2 Traditional vertical error statistics

Land Cover Category	# of Check points	Min (m)	Max (m)	Mean (m)	Mean Absolute (m)	Median (m)	γ_1	γ_2	s (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

γ_1 = skewness
γ_2 = kurtosis
S = sample standard deviation

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Table D.3 compares old (FVA, SVA, CVA) with new (NVA, VVA)

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	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

- NVA is based on $RMSE_z$ (in non-vegetated categories only) x 1.9600
- VVA is based on 95th percentile errors in all vegetated categories combined
- Both estimate errors at the 95% confidence level for reporting purpose

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Any Questions?

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