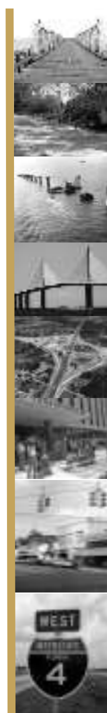
Surveying & Mapping Handbook Aerial Photogrammetry Chapter

Surveying & Mapping Office

Celebrating 100 Years of Innovation, Mobility and Economic Development

Introduction

- http://www.dot.state.fl.us/surveyingandmapping/



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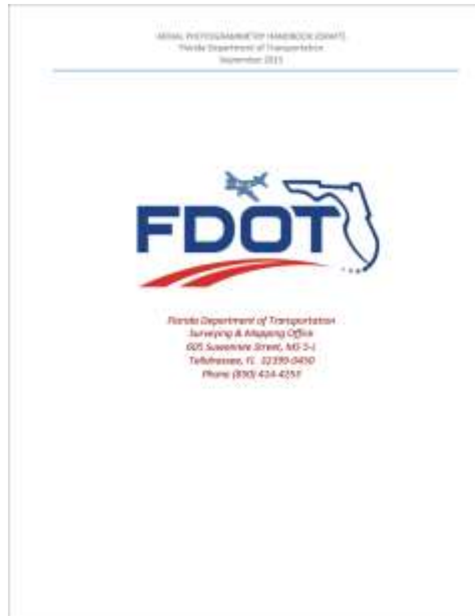
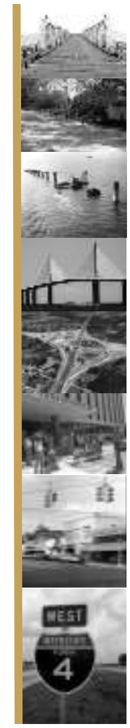
Agenda

- Background
- Definition
- Purpose
- ASPRS Positional Accuracy Standards for Digital Geospatial Data
- FDOT Photogrammetry Handbook
- ASPRS
- Questions

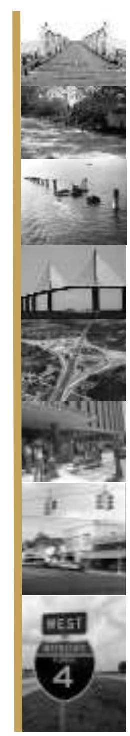




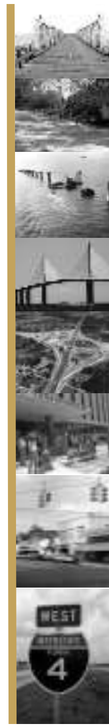
Background

- Since the sun setting of the “Department Location Survey Manual” there has been no Department guide for the use of Photogrammetry on transportation projects.
- With the advent of digital cameras we are moving away from the traditional photo scale requirements since these film and paper based criteria have little meaning in the digital photography/softcopy world.
- The new ASPRS Positional Accuracy Standards for Digital Geospatial Data (EDITION 1, VERSION 1.0. - NOVEMBER, 2014) requirements are based on the Ground Sample Distance (GSD) of the final digital orthophotography as a basis for imagery specifications.


ASPRS Positional Accuracy Standards for Digital Geospatial Data



Definition



- *"Photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomenon."*
  - Slama, C. (Ed.). (1980). Manual of Photogrammetry (Fourth ed.). Falls Church, Virginia, USA: American Society of Photogrammetry.
- Ground sample distance is the ground distance represented by a single pixel on the image.
  - The raw camera GSD or "source" GSD is governed by the camera focal length, the flying height, and the size of a pixel in the camera CCD (Charged Coupled Device).

$$\frac{f}{H} = \frac{Ps}{GSD}$$

f = Focal Length
H = Height above ground,
Ps = Camera Pixel Size
GSD = Ground Sample Distance

In **digital imaging**, sensor native pixel size (P_s) is fixed. Specified GSD is achieved only by varying the imaging altitude. Image scale is simply:

Image Scale = P_s/GSD

Since Image Scale = f/H also, therefore f/H = P_s/GSD. Imaging altitude (H) can be derived from:

H = GSD x f/P_s

In the Z/I DMC f = 120mm and P_s = 12μ, to achieve a 20cm GSD:
H = 20cm x 120mm/12μ = 2000m

Imagery Source	f	P_s	f/P_s
Film			
Scanned @ 10μ	152mm	10.0μ	15,200
Scanned @ 10μ	305mm	10.0μ	30,500
Digital			
JenOptik JAS-150	150mm	6.5μ	23,077
Leica ADS-40/52	63mm	6.5μ	9,692
Vexcel UC_D	100mm	9.0μ	11,111
Vexcel UC_X	100mm	7.2μ	13,889
Z/I DMC	120mm	12.0μ	10,000

N.B. A short-hand method in determining imaging altitude is to multiply the required GSD by the fixed f/P_s factor in each imaging system.

PurVIEW
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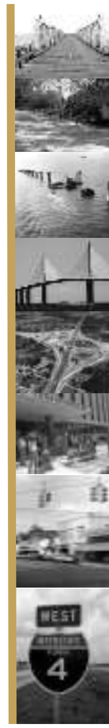
Purpose



- Photogrammetry is one of many valuable remote sensing methods available to today's surveying and mapping professionals, and has a long history of use on transportation projects.
- This handbook sets forth basic guidelines for performing aerial photogrammetric surveys for the Department. It is not intended to be a comprehensive technical manual, rather a supporting document to the Department Procedure *Aerial Surveying and Mapping Standards for Transportation Projects* - Topic No. 550-020-002-i. Consultants are strongly urged to review the procedure document, and refer to the district surveying department for specific project instructions.
- The requirements herein are at the discretion of the Department and may be waived under certain circumstances such as but not limited to; post disaster mapping, research and development, and equipment testing / calibration. It is the Consultant's responsibility to get all such waivers in writing before commencement of work.
- This document is organized into sections related to the typical tasks and deliverables associated with a transportation project employing Aerial Photogrammetric technologies.

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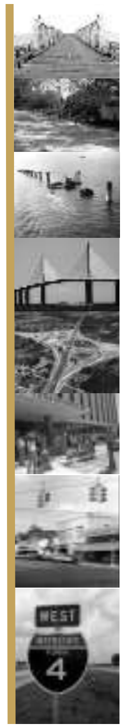
ASPRS Positional Accuracy Standards for Digital Geospatial Data

- 7. Specific Requirements
  - 7.1 Statistical Assessment of Horizontal and Vertical Accuracies
  - 7.2 Assumptions Regarding Systematic Errors and Acceptable Mean Error
  - 7.3 Horizontal Accuracy Standards for Geospatial Data
  - 7.4 Vertical Accuracy Standards for Elevation Data
  - 7.5 Horizontal Accuracy Requirements for Elevation Data
  - 7.6 Low Confidence Areas for Elevation Data
  - 7.7 Accuracy Requirements for Aerial Triangulation and INS-based Sensor Orientation of Digital Imagery
  - 7.8 Accuracy Requirements for Ground Control Used for Aerial Triangulation
  - 7.9 Checkpoint Accuracy and Placement Requirements
  - 7.10 Checkpoint Density and Distribution
  - 7.11 Relative Accuracy of LiDAR and IFSAR Data
  - 7.12 Reporting



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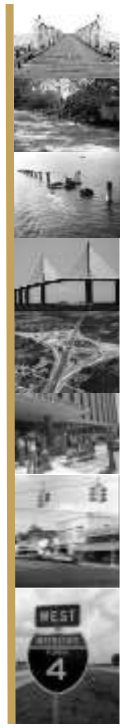
- General Requirements
  - Unless otherwise stated, this section identifies the general requirements common to all aerial photogrammetric products and services performed for the Department.
  - Before Work Begins
    - When a contract is awarded and before any work begins, the consultant will contact the District Surveying and Mapping Office to request the Photographic Designation (PD) number. The PD number shall be included in image file names or labeled on the aerial film so the film can be included in the Central Surveying and Mapping Office Film Library without modifications. The PD number should be referenced in all correspondence and project deliverables.
  - Planning
    - Planning is critical to the success of any survey project. The planning activities should begin with reviewing the project scope and location to develop the detailed aerial survey approach. The approach activities will vary based on project requirements; however there are important elements common to all aerial survey approaches that are worth noting here.



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- General Requirements (continued)
  - Aerial Photography Mission Plan
    - Planning is critical to the success of any survey project. The planning activities should begin with a graphic aerial mission plan (see Figure 5.2.1a) based on the location and scope of the project should be developed. The mission plan should show proper stereo image model coverage of the project area, as well as other pertinent information supporting the flight mission with the understanding that properly executed the flight will provide sufficient results necessary to achieve the desired survey products.

Aerial Photography Mission Plan Example

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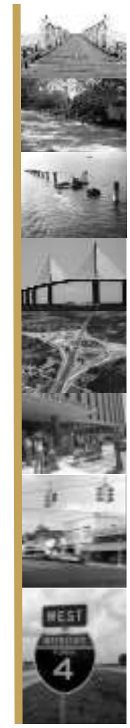

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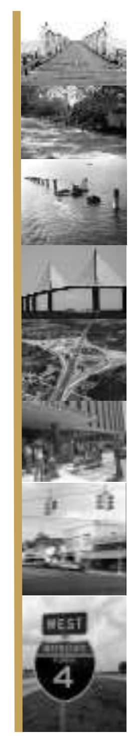
- General Requirements (continued)
  - Ground Control Reconnaissance
  - Ground Control Survey
    - Control Survey Deliverables:
      - The Professional Surveyor and Mapper (PSM) will prepare a certified survey report that shall at a minimum include:
  - Figure 6.4.1a – Ground Control Table Example (County Orthophotography)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	FINAL ADJUSTED HORIZONTAL AND ORTHOMETRIC HEIGHT VALUES FOR MARION COUNTY (PD6027) POST FLIGHT PHOTO POINT												
2	UNITS ARE US Survey Feet (USft).												
3	HORIZONTAL DATUM IS NAD 83/2007.												
4	STATE PLANE ZONE IS FLORIDA WEST.												
5	ORTHOMETRIC HEIGHT DATUM IS NAVD 88												
6	ALL CONTROL STATION VALUES ARE DERIVED BY STATIC GPS OBSERVATIONS FROM PUBLISHED NGS CONTROL												
7													
8		GPS Control Station - Geographic			GPS Control Station - USft			Offset from GPS Station to Photo ID Point - ft			FINAL Photo ID Control - USft		
9	PHOTO_ID	LATITUDE	LONGITUDE	ELLIP_HGT (meters)	NORTHING	EASTING	ORTHO_HGT	Offset - North	Offset - East	Offset - Vert	NORTHING	EASTING	ORTHO_HGT
10	D5100010	29 29 44.73172	-82 24 24.26473	1.7569	1876786.20	526773.97	97.18	0.00	2.00	0.00	1876786.20	526775.97	97.18
11	D5100011	29 28 42.07552	-82 3 20.32535	-4.4967	1870232.35	638460.51	77.18	-2.50	-0.78	0.00	1870229.85	638459.73	77.18
12	D5100012	29 30 29.98811	-81 51 49.10517	10.5297	1881156.88	699540.72	127.11	0.00	0.00	0.00	1881156.88	699540.72	127.11
13	D5100013	29 19 32.46883	-81 58 11.18511	-5.8319	1814716.87	665798.44	72.96	0.00	0.00	1.00	1814716.87	665798.44	73.96
14	D5100014	29 21 52.90874	-81 44 25.40237	-16.3667	1828952.74	738861.52	39.27	0.00	0.00	0.00	1828952.74	738861.52	39.27
15	D5100015	29 17 40.65096	-81 39 9.37229	-27.6545	1803585.22	766847.02	2.34	1.00	0.00	0.50	1803586.22	766847.02	2.84



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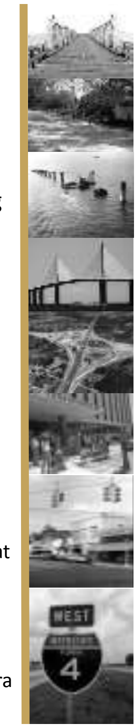
- General Requirements (continued)
  - Equipment
    - It is required that the camera collecting aerial photography at photo scales of 1:3000 or larger be equipped with forward motion compensation and a gyro-stabilized camera mount. On Aerial mapping projects utilizing Airborne GPS (AGPS) the camera system must have a documented bore-sight calibration performed after any repair work involving camera adjustment or removal from camera mount, and within six months of any project imagery acquisition. Additional requirements include the following:
      - Film Camera Specifications
        - A 6-inch (153mm) nominal focal length precision aerial camera equipped with eight (8) precise fiducial marks and having an acceptable calibration report adhering to the Optical Science Laboratory, U.S. Geological Survey specifications is required.
        - Current USGS calibration report. The calibration report shall be obtained every three years or after the camera's optical system has been disturbed, repaired, or modified. Failure to do so shall render the calibration report invalid.
      - Digital Camera Specifications
        - A digital camera capable of producing at least 0.25 feet GSD resolutions and sufficient feature accuracy at the target map scale, specified for the project.
        - Camera manufacturer must a current USGS type certification as defined by the USGS Remote Sensing Technologies Project.
        - Geometric distortions induced by the camera's optical system shall be corrected during post processing using valid calibration data obtained from the camera manufacturer or a facility authorized by the camera manufacturer to provide such data.



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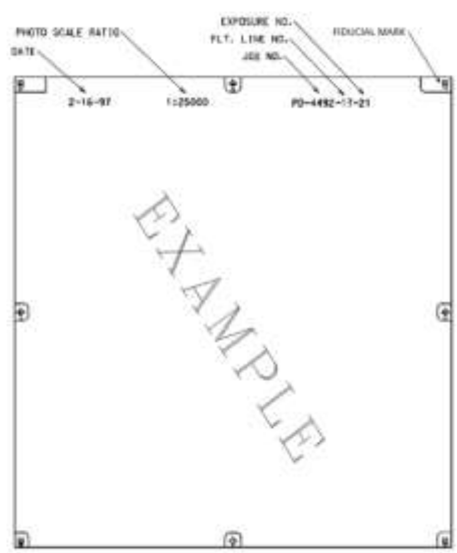
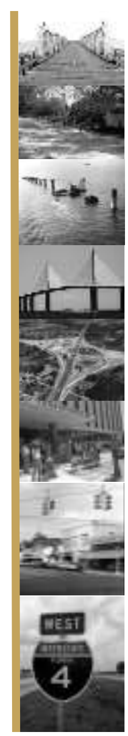
- General Requirements (continued)
  - Digital & Film Exposure Documentation
    - Flight lines shall be numbered from South to North and West to East with the highest numbers ending on the North and East.
    - On all film exposures, each exposure shall be edited across the exposure in a legible manner with; the date, photo scale (expressed as a ratio, Example: 1:25000), job number, flight line number and exposure number.





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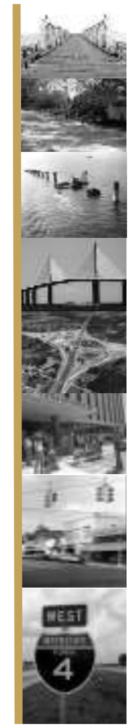
- General Requirements (continued)
  - **Only digital photography will be accepted.** Any film imagery shall be of sufficient quality that when scanned with a calibrated photogrammetric scanner, the resulting digital imagery meets the accuracy requirements for the project based on the same ground sample distance (GSD) accuracy criteria for digital camera imagery presented later in this document. Aerial film developed for design purposes shall be scanned with an appropriate pixel resolution of 5um to 15um. Mapping projects with smaller scale such as County Orthophoto mapping may be scanned with an appropriate pixel resolution of ≤ 25um. The Aerial Surveying and Mapping Consultant shall submit the scanner technical specifications and calibration information to the Department.
  - All digital photographic image files shall be saved to final media using the following file naming convention: AAAABB_CCCC (A=PD number, B=Flight Line number, C=Exposure number). Example: 492201_0010.tif Digital data shall be provided to the Department in a format which is immediately readable by the Surveying and Mapping Office and the Department.
  - Meta Data – All final image files provided to the Department shall have a corresponding named metadata file in Extensible Markup Language (xml) format that meets the CSDGM. Example: 492201_0010.xml



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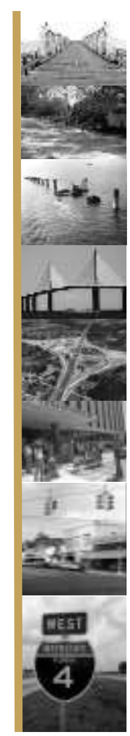
- General Requirements (continued)
  - Airborne GPS Processing
    - Airborne GPS (AGP) a.k.a. Inertial Navigation System (INS) based camera orientation is vital to today's softcopy photogrammetry where typically less ground control is used. Solving for the trajectory of the sensor using post processing technique provides position and orientation of the camera at the time of each exposure.
      - Post Mission Reporting shall at a minimum consist of the following:
        - a) A graphical representation of the vehicle trajectory. Sufficient documentation to verify positional accuracy of camera at exposure events.
        - b) A text file with final post processed exposure events with camera position and orientation (Omega Phi, Kappa and associated accuracies) sufficient for inclusion into an aerial triangulation (AT) adjustment.



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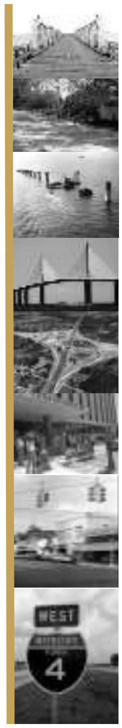
- General Requirements (continued)
  - Aerial Triangulation a.k.a. Aerotriangulation (AT)
    - Unless specifically requested otherwise, all aerial photogrammetry products shall be produced from a robust AT adjustment.
    - "Accuracy requirements for aerial triangulation and INS-based sensor orientation of digital Imagery"
      - The quality and accuracy of the aerial triangulation (if performed) and/or the INS-based sensor orientation play a key role in determining the accuracy of final mapping products derived from digital imagery. For all photogrammetric data sets, the accuracy of the aerial triangulation or INS orientation (if used for direct orientation of the camera) should be at least twice the accuracy of derived products, as evaluated at higher accuracy check points using stereo photogrammetric measurements." (ASPRS, 2014)
    - "Accuracy requirements for ground control used for aerial triangulation"
      - Ground controls points used for aerial triangulation should be at least three times better than the expected Accuracy of aerial triangulation solution (for example, in order to produce an orthophoto with an RMSEr of 15cm, the Aerotriangulation results should have an RMSExyz of 7.5 cm and the ground control used should have RMSExyz of 2.5 cm)." (ASPRS, 2014)

ASPRS. (2014, March 21). Map-Accuracy-Standards-Working-Group.html. Retrieved 2014, from www.asprs.org: http://www.asprs.org/PAD-Division/Map-Accuracy-Standards-Working-Group.html



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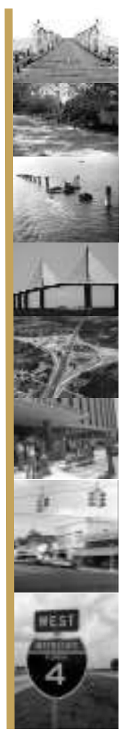
- Orthophotography
  - The source imagery may be re-sampled to produce orthophotography with a larger GSD resulting in a product with less resolution than the source imagery. However the reverse is not acceptable i.e. an orthophotography product may not be re-sampled to have a smaller GSD (higher resolution) than the original source imagery.
  - Orthophotography produced for the Department shall meet the appropriate "Horizontal Data Accuracy Class" necessary to meet project requirements as described in the latest publication of "*ASPRS Accuracy Standards for Digital Geospatial Data*" current at the time of project scoping.



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- Orthophotography (continued)
  - ASPRS Horizontal Accuracy Standards for Digital Orthoimagery (earlier version)

Horizontal Data Accuracy Class	$RMSE_x$ and $RMSE_y$	Orthophoto Mosaic Seamline Maximum Mismatch
0	Pixel size *1.0	Pixel size * 2.0
1	Pixel size * 2.0	Pixel size * 4.0
2	Pixel size * 3.0	Pixel size * 6.0
3	Pixel size * 4.0	Pixel size * 8.0
…	…	…
N	Pixel size *(*N*+1)	Pixel size * 2*(*N*+1)

  - The final quality control verification shall be a comparison of the positions for a sample subset of the map features with ground positions for these features independently collected such that they have a higher horizontal accuracy. The resulting comparisons shall meet the positional accuracy requirements for the map at the 95% confidence level based on the NSSDA and shall be included in the Survey Report.

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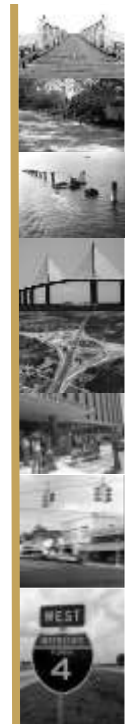

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- Orthophotography (continued)

TABLE B.3 COMMON HORIZONTAL ACCURACY CLASSES ACCORDING TO THE NEW STANDARD[6]

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
27.50	38.9	55.0	67.3
30.00	42.4	60.0	73.4

TABLE B.4 EXAMPLES ON HORIZONTAL ACCURACY FOR DIGITAL ORTHOIMAGERY INTERPRETED FROM ASPRS 1990 LEGACY STANDARD

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
7.5 cm	1:600	1	15.0	2-pixels
		2	30.0	4-pixels
		3	45.0	6-pixels
15 cm	1:1,200	1	30.0	2-pixels
		2	60.0	4-pixels
		3	90.0	6-pixels
30 cm	1:2,400	1	60.0	2-pixels
		2	120.0	4-pixels
		3	180.0	6-pixels

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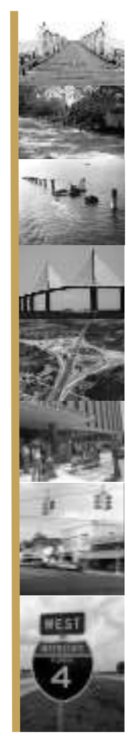

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- ASPRS Planimetric

TABLE 7.1 HORIZONTAL ACCURACY STANDARDS FOR GEOSPATIAL DATA

Horizontal Accuracy Class	Absolute Accuracy			Orthoimagery Mosaic Seamline Mismatch (cm)
	$RMSE_x$ and $RMSE_y$ (cm)	$RMSE_r$ (cm)	Horizontal Accuracy at 95% Confidence Level (cm)	
X-cm	≤*X*	≤1.414**X*	≤2.448**X*	≤2**X*

- ASPRS Vertical

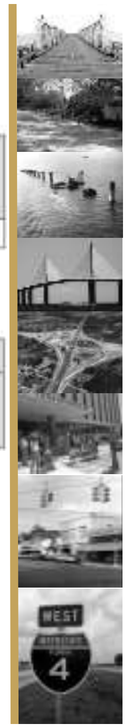
TABLE 7.2 VERTICAL ACCURACY STANDARDS FOR DIGITAL ELEVATION DATA

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)

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

[2] 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.

[3] The method presented here is one approach; there are other methods for estimating the horizontal accuracy of lidar data sets, which are not presented herein (Abdullah, Q., 2014, unpublished data).



Questions?

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