Mapping Matters

By Qassim A. Abdullah, Ph.D., PLS, CP**

Your Questions Answered

The layman's perspective on technical theory and practical applications of mapping and GIS

Q: I am looking for a brief but encompassing overview of the map accuracy standard(s) used in the United States of America to evaluate geospatial data accuracies and whether it applies internationally.

Dr. Abdullah: Three map accuracy standards are used in the United States today; listed chronologically, they include:

- The National Map Accuracy Standard (NMAS);
- The American Society for Photogrammtry and Remote Sensing (ASPRS) Standard;
- The National Standard for Spatial Data Accuracy (NSSDA).

In each the three standards, map accuracy is verified by comparing the positions of map point elevations or locations with corresponding positions as determined by ground surveys of a higher accuracy. However, they differ by the statistical means and methodology utilized in presenting the measurement errors.

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Following are Details for Each of the Three Standards:

The National Map Accuracy Standard (NMAS): Still used today, NMAS is the first comprehensive standard developed in modern history for the United States of America. It was first announced by the U.S. Bureau of the Budget on June 10, 1941, and utilizes measurements made on the published map scale. To determine the planimetric accuracy of a map, the standard divides the map into two categories -- maps with scales larger than 1:20,000 and maps with scales of 1:20,000 or smaller, such as the USGS quad maps of 1:24,000, 1:50,000 and 1:100,000. The standard calls for the following accuracy figures:

1. For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale. As an example, a map with a published scale of 1:1,200 (or 1"=100'), 90 percent of the measured checkpoints or mapped features should have a residual of no more than 100.0/30 ft or 3.33 ft.
2. For maps on publication scales of 1:20,000 or smaller, not more than 10 percent of the points tested shall be in error by more than 1/50 inch, measured on the publication scale. As an example, a map such as the USGS quarter quads published with a scale of 1:24,000 or (1"=2,000'), 90 percent of the measured checkpoints or mapped features should have a residual of no more than 2,000.0/50 ft or 40.0 ft

The following table demonstrates planimetric accuracy according to the NMAS for the most widely used map and ortho-photo scales:

Map Scale	Ortho Photo GSD** (ft)	Accuracy at 90% confidence level (ft)
1:1,200 (1"=100')	0.50	3.33
1:2,400 (1"=200')	1.00	6.67
1:4,800 (1"=400')	2.00	13.33
1:24,000 (1"=2000')	N/A	40.0

** Ground Sampling Distance

According to the NMAS, the vertical accuracy as it applies to contour maps on all publication scales shall be such that not more than 10 percent of the elevations tested shall be in error by more than one-half the contour interval. The following table provides examples of the vertical accuracy according to the NMAS for the most widely used contour intervals:

Contour Interval (ft)	Vertical Accuracy at 90% confidence level (ft)
1.0	0.50
2.0	1.00
5.0	2.50
10.0	5.00

The NMAS was created during a time when the technologies were limited to producing paper maps with relatively small scales due to limitations in the photographic sensors and stereoplotters before 1940. Therefore, in order to recognize the recent advances in map acquisition technologies and the digital map production, other standards were adopted to replace this legacy standard.

The American Society of Photogrammtry and Remote Sensing (ASPRS) Standard: This standard, which was first approved by the ASPRS Professional Practice Division in March 1990, is the first to deal with large-scale topographic and engineering-grade maps. The new standard formed the basis for revising the NMAS for both small- and large-scale maps. The major feature of the standard, as compared to the NMAS, is that it indicates accuracy at ground scales versus a published paper map scale. Thus, digital spatial data of known ground-scale accuracy can be related to the appropriate map scale for graphic presentation. The standard places emphasis "on the final spatial accuracies that can be derived from the map in terms most generally understood by the users."

The ASPRS standard defines the accuracy as limiting Root Mean Squares (RMS) errors in terms of the project's survey coordinates for checkpoints as determined by the ground scale of the map. The standard also provides three sets of accuracy figures for maps produced with different accuracy levels. According to the standard, a map with the highest accuracy is called a "Class 1" map, while a map produced within limiting RMS errors of twice or three times those allowed for a Class 1 map are to be designated as Class 2 or Class 3 maps, respectively.

The following table provides examples of the limiting planimetric RMS for Class 1 for the most widely used map and ortho photo scales:

Map Scale	Ortho Photo GSD** (ft)	Limiting RMS Error (ft)
1:1,200 (1"=100')	0.50	1.0
1:2,400 (1"=200')	1.00	2.0
1:4,800 (1"=400')	2.00	4.0

** Ground Sampling Distance

The standard defines the vertical map accuracy as the RMS error in evaluation in terms of a project's evaluation datum for well-defined points only. For Class 1 maps, the limiting RMS error in evaluation is set by the standard at one-third the indicated contour interval for well-

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defined points. The following table provides an example of the limiting vertical RMS for Class 1 at the most widely used contour intervals:

Contour Interval (ft)	Limiting RMS Error (ft)
1.0	0.33
2.0	0.67
5.0	1.67
10.0	3.33

The standard also gives different limiting RMS errors for the spot heights. According to the standard, the spot heights are shown on the map within a limiting RMS of one-sixth of the contour interval. The industry should be careful in endorsing the spot height limitation by this standard for today's mapping activities, however. The new direct acquisition of elevation data using lidar, IFSAR, or digital surface auto-correlation do not yield different accuracies within the terrain model as is the case with the traditional terrain modeling using stereo-compilation.

"…The NSSDA may be referred to as "guidelines" as it defines testing methodology and statistical guidelines. The NSSDA does not determine pass/fail criteria, which is left to the users. Users are encouraged to establish "pass-fail" criteria for their product standards and applications and for contracting purposes. Ultimately, users must identify acceptable accuracies for their applications."

The National Standard for Spatial Data Accuracy (NSSDA): The National Standard for Spatial Data Accuracy (NSSDA), which was released in draft form in April 1998, implements a well-defined statistic and testing methodology for positional accuracy of maps and geospatial data derived from sources such as aerial photographs, satellite imagery, or maps. Accuracy is reported in ground units. This standard is not a true map standard in the same sense that the NMAS and ASPRS standards were meant to be. The NSSDA may be referred to as "guidelines" as it defines testing methodology and statistical guidelines. The NSSDA does not determine pass/fail criteria which is left to the users. Users are encouraged to establish "pass-fail" criteria, for their product standards and applications and for contracting purposes. Ultimately, users must identify acceptable accuracies for their applications. The standard provides the following equation which is based on a 95 percent confidence level to determine the horizontal accuracy of the data without giving any specifics to the absolute value.

$$NSSDA_h = 2.447xRMSE_x = 2.447xRMSE_y \text{ (if } RMSE_x \neq RMSE_y)$$

Or,

$$NSSDA_h = 1.73xRMSE_r \text{ (if } RMSE_x = RMSE_y\text{), where } RMSE_r = \sqrt{(RMSE_x)^2 + (RMSE_y)^2}$$

As you may notice, the NSSDA provides a statistical measure but does not specify an RMS error, which is left to the agreement between vendors and users.

As for the vertical accuracy, in similar fashion the NSSDA provides the following statistical criterion, also based on a 95 percent confidence level and without a specified value for the RMS error.

$$NSSDA_v = 1.96 \times RMSE_v$$

To simplify the matter further, if an agency is soliciting bids for ortho-photo maps with a scale of 1"=100' and 2' contour intervals and requesting vendors to meet the NSSDA standard, that agency needs to specify two accuracy figures for the horizontal and vertical accuracy based on a 95 percent acceptance criterion. Most likely these two figures will be specified as:

- Horizontal accuracy according to NSSDA = 1.73 ft
- Vertical accuracy according to NSSDA = 1.30 ft

It is safe to assume that the agency based its accuracy figures on RMS error values adopted from the ASPRS standards for that map scale and contour intervals. I will leave the task of verifying this assumption to the reader as it is a good exercise to examine the relations and formulas introduced earlier in my answer.

As a final note on the subject, I have found that the concept of map standards and the statistics behind them can cause much confusion for many contracting agencies. It should be understood that while some of these standards complement each other, mixing them within the same statement is counterproductive. Here is a typical example found within requests for proposals: "Data to be compiled to meet or exceed a horizontal accuracy of +/- 2 ft RMSE (root mean squares error) at a 95 percent confidence level (1"=200' map accuracy)." A statement written like this does not correctly describe the intended accuracy requirement. A vendor could interpret the 2 ft RMSE reference to mean that 67.6 percent of the data must meet the 2 ft accuracy figure, while the remaining 32.3 percent of the data can have errors as large as two to three times the RMSE, or 4 to 6 ft. If the statement was meant to indicate a 2 ft accuracy with a 95 percent confidence level, the agency will be asking the vendor to provide a dataset whereby 95 percent of the data is accurate to 2 ft, while ONLY 5 percent may have an error in the excess of 4 to 6 ft. The difference between the two stated requirements is huge. If the specification is left the way it was stated in the original example, definite legal issues and court proceedings may be required to satisfy either the vendor and/or the contracting agency.

It is important to understand that the above reasoning and the given figures do not mean that the accuracy requirements at 95 percent confidence is better than the RMSE, it is just a different way to represent the rejection criteria and the threshold. If the agency were correct in expressing their requirement, their statement would be as follows: "Data to be compiled to meet or exceed a horizontal accuracy of +/- 2 feet RMSE or 3.46 ft at a 95 percent confidence level according to the NSSDA standard necessary for 1"=200' maps." In this case, the agency will be in a better position regarding the delivered products as 67.7 percent of the data will have maximum errors of 2 ft while 95 percent of the data will have maximum errors of 3.46 ft. Notice the two terms in the new accuracy statement do not contradict each other, they just provide two different measures of confidence levels and error threshold.

As for the second part of the question, I do not see a reason for not applying these standards in other countries as they employ universal statistical concepts that are not based on certain coordinate systems or local datum. There are not many options available to test data accuracy. The statistical means are universal but the threshold of acceptance or rejection may differ between countries. The non-classified Standardization Agreement (STANAG) published by NATO's Standardization Agency (NSA) on the subject of "Evaluation of Land Maps, Aeronautical Charts, and Digital Topographic Data" for example adopted a Circular Map Accuracy Standard (CMAS) with a 90 percent confidence level similar to the statistical measure adopted by NMAS. The STANAG categorizes map accuracy into five ratings: A, B, C, D, and E. For class A, the STANAG uses exactly the same threshold that the NMAS uses for small-scale or 1/50 inch, measured on the publication scale; class B uses 1/25 inch, measured on the publication scale and so on.

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