Solicitation of Comments

THE COMMITTEE FOR SPECIFICATIONS AND STANDARDS
Professional Practice Division
The American Society of Photogrammetry
210 Little Falls Street
Falls Church, VA 22046

Accuracy Specification for Large-Scale Line Maps

A map spatial-accuracy draft standard for maps at scales of 1:20,000 or larger has been prepared (September, 1984) by a committee of the ASP and is published for comments.

ABSTRACT: *New interest in spatial accuracy standards for large-scale (1:20,000 or larger) line maps has been prompted by recent court decisions in California. The lack of a generally understood and accepted standard of map accuracy in terms of quantifiable and verifiable error definitions was a primary factor in this litigation. A committee of the American Society of Photogrammetry has prepared a draft standard (specification) for 1:20,000 scale or larger line maps. Comments are requested from all factions interested in maps and their spatial accuracies.*

1. INTRODUCTION

LITIGATION in the courts of California has promoted new interest in the establishment of spatial accuracy standards for 1:20,000 scale or larger line maps. During the court proceedings it became clear that suitable standards for accuracy, based on a broad consensus, using generally understood quantifiable error concepts, and providing a clear procedure for verification, did not exist. The American Society of Photogrammetry (ASP) has organized a technical committee to prepare appropriate specifications with the intention of eventually proposing them as consensus standards for map accuracy.

National Map Accuracy Standards have served for many years as standards for small-scale maps. These maps are usually prepared for universal applications and form part of a national map atlas. Accordingly, an arbitrary standard of accuracy and standardized scales are essential. Large-scale maps, on the other hand, tend to be prepared for specific purposes. In these instances, a clear understanding of the user's requirements is essential for efficient preparation of an acceptable map. The standard should be free of such quantifiably vague terms as "in accordance with good professional practice." Statements of accuracy should be in terms familiar to the map user and in terms of quantities obtained from the map by the user. The standard should also be stated in terms familiar to the map producer. Finally, there remains the requirement that a procedure for testing be defined. The testing must be of the final map product as understood by the map user, namely, of ground coordinates, and be accomplished in a clearly understood and theoretically correct manner.

Estimates of errors in other quantities often extracted from maps, such as distances, areas, and volumes, can be computed from reliable information concerning ground coordinate accuracies. Accordingly, in the interest of satisfying user's requirements, accuracies are expressed in terms of coordinate values.

The proposed specification for spatial accuracy for large-scale line maps follows. It has been prepared over a period of approximately four years by the ASP Specifications and Standards Committee. The Committee was composed of interested persons selected from both users and producers of large-scale maps. Each member had extensive experience in his re-

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spective field. During the preparation of the draft specification, the specification was presented for discussion and comments in public sessions at both the Denver (March, 1982) and Niagara Falls (October, 1980) meetings of the ASP/ACSM. Results of these sessions have been considered by the Committee and, when appropriate in the judgement of the Committee, integrated into the current draft of the specification. To produce a voluntary consensus standard, it is essential that comments from a broad interest base be considered. Accordingly, it is requested that your comments be sent to

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2. Proposed Specification (Standard)

The following characteristics are intended to improve the usefulness of maps by facilitating the communications between the map user and producer:

- The specification pertains to topographic and planimetric line (monochrome) maps at scales of 1:20,000 and larger.
- Statements of accuracy are in terms of error types most generally *understood by the map user*.
- The testing of maps for accuracy is *optional*. Maps may be tested to assure compliance with the required accuracy by using accepted field survey procedures and statistical methods as defined in this specification.

2.1 Horizontal accuracy specification

2.1.1. Class 1—Horizontal. To meet this specification, horizontal errors must not exceed the measures of allowable horizontal coordinate errors specified in Table 1 (E. or M.). Ground coordinates of test points are derived from measurements on the delivered map. This table approximately corresponds to an accuracy statement that 90 percent of well-defined points be within 0.43 mm (or 1/47 inch) of their correct planimetric position as measured on the map at delivery scale.

2.2 Vertical accuracy specification

2.2.1. Class 1—Vertical. To meet this specification, vertical errors must not exceed the measures of allowable vertical errors specified in Table 2. Elevations of test points are derived from interpolation between contours on the map. For purposes of testing elevations, the ground point may be shifted by an amount equal to the allowable horizontal ground coordinate error for the corresponding accuracy class, map scale, and error definition (see Table 1).

2.3 Lower accuracy maps

For maps of lower accuracy, the error values stated in Table 1 and Table 2 are increased by a factor corresponding to the accuracy class. Only two additional classes are specified, i.e., Class 2 and Class 3. The allowable error values for a Class 2 and a Class 3 map equal those for a Class 1 map multiplied by two and three, respectively.

2.4 Testing map accuracy

The accuracy of the map is tested for purposes of accepting or rejecting the map by comparing ground coordinates (X and Y) or elevations (Z) of at least *20 well-defined mapped features*, as determined from measurements on the map at publication scale, to those for the same points, as provided by a check survey of higher accuracy. The check survey is one which can be expected to produce errors no greater than *one-third* those allowable by the pertinent map accuracy requirements stated as Standard Errors in Tables 1 and 2. The current standard of survey ac-

Table 1E. Class 1. Accuracy Standard in Terms of X or Y Survey Coordinates and in English Units

Typical Map Sheet Delivery Scale* (inches to feet)		Allowable Errors (feet) Standard Error (1 σ)	CMAS**	Maximum Error (3 σ)
1″ to 10′	(1:120)	0.10	0.21	0.30
1″ to 20′	(1:240)	0.20	0.43	0.60
1″ to 50′	(1:600)	0.50	1.1	1.50
1″ to 100′	(1:1200)	1.0	2.1	3.0
1″ to 200′	(1:2400)	2.0	4.3	6.0
1″ to 250′	(1:3000)	2.5	5.4	7.5
1″ to 500′	(1:6000)	5.0	10.7	15.0
1″ to 1000′	(1:12000)	10.0	21.5	30.
1″ to 2000′	(1:24000)	20.	43.	60.

Table 1M. Class 1. Accuracy Standard in Terms of X or Y Survey Coordinates and in SI (Metric) Units

Typical Map Sheet Delivery Scale*	Allowable Errors (metres) Standard Error (1 σ)	CMAS**	Maximum Error (3 σ)
1:100	0.025	0.054	0.075
1:200	0.050	0.107	0.15
1:500	0.125	0.268	0.375
1:1000	0.25	0.54	0.75
1:2000	0.50	1.07	1.5
1:2500	0.63	1.35	1.9
1:4000	1.0	2.1	3.0
1:8000	2.0	4.3	6.0
1:16000	4.0	8.6	12.0

* These map scales are typical for the corresponding accuracy definitions. The final choice of scale depends on the level of detail to be shown both topographically and culturally as well as on spatial accuracy. Appropriate scales for other choices of allowable errors may be obtained by linear interpolation.

** The Circular Map Accuracy Standard (CMAS) requires that 90 percent of well-defined points will be in error by less than the indicated full scale (ground) value (see ACIC (1962), pp. 31-32). For the indicated map scales, the error corresponds to about 1/47th inch (0.54 mm) on the map. However, this standard is defined at *full scale* (ground) values in terms of either standard error (1σ), CMAS, or maximum (3σ) errors. The relationship between standard error (1σ) and CMAS is taken as CMAS = 2.1460 σ for either σ_x or σ_y, assuming $\sigma_{min.}/\sigma_{max.} \geq 0.2$ (see ACIC (1962), p. 59).

TABLE 2. CLASS 1. ACCURACY STANDARD IN TERMS OF ELEVATION

(metres)				(feet)			
Contour Interval	Standard Error (1 σ)	VMAS*	Maximum Error (3σ)	Contour Interval	Standard Error (1 σ)	VMAS*	Maximum Error (3 σ)
0.05	0.015	0.025	0.045	0.1	0.03	0.05	0.09
0.10	0.03	0.05	0.09	0.5	0.15	0.25	0.45
0.50	0.15	0.25	0.45	1.0	0.30	0.50	0.90
1.0	0.30	0.50	0.90	2.0	0.60	1.00	1.80
2.0	0.61	1.00	1.83	2.5	0.75	1.25	2.25
2.5	0.76	1.25	2.28	5.0	1.5	2.50	4.50
5	1.52	2.50	4.56	10	3.00	5.00	9.00
10	3.04	5.00	9.12	20	6.00	10.00	18.00

* VMAS refers to "Vertical Map Accuracy Standard" corresponding to the definition that 90 percent of well-defined points are not in error by more than one-half the contour interval.

curacy and specifications prepared by the Federal Geodetic Control Committee (FGCC) and adopted by the United States National Ocean Survey (NOS) are the basis for design of the check survey.

2.4.1 Check Survey. The check survey provides horizontal coordinates and elevations on at least 20 well-defined and well-distributed features appearing on the delivered map. These serve as check points for assessing compliance of the delivered map with the accuracy specifications. To provide reasonable assurance that the check survey produces nominal positional accuracy three times better than that required of the delivered map and that the test result is representative of the entire map, the following procedures are established:

- All surveys for Class 1 maps shall be conducted in accordance with the standards of accuracy and specifications published by the NOS of the U.S. Dept. of Commerce. Horizontal surveys by triangulation, trilateration, and traverse shall be conducted by Second-Order Class II methods, or by Second-Order Class I methods if analytical photogrammetric methods are used. Vertical surveys shall be conducted by Third-Order methods. Surveys for checking Class 2 and 3 maps shall be conducted by field procedures of proportionally lower accuracy.
- A minimum of 20 check points shall be distributed throughout the project area in a manner agreed upon by the contracting parties.

The horizontal coordinate system and elevation datums used for map check purposes shall be the same as those on which the map under test is based.

The check survey shall be conducted by one of the following arrangements:

- conducted and adjusted *as part of* the survey used for providing the basic control for map compilation; or
- conducted independently from the survey used for providing the basic control for map compilation.

2.4.2 Compliance Testing. Testing of the delivered map may be accomplished to assure that it complies with the required *accuracies* both in the horizontal and in elevation. The measure of accuracy is taken here as composed of two components: *bias* (systematic) error and *precision*. The bias error expresses the tendency of map feature discrepancies to be of the same magnitude and direction. Precision, on the other hand, expresses the tendency of discrepancies to follow the characteristics of a normal distribution.

Testing of the map is accomplished by standard statistical procedures on both the sample mean ($\bar{\delta}$) to assess the presence of a significant bias error and on the sample standard deviation (s) to assess compliance with precision requirements after the bias has been removed. Hypothesis testing is performed on sample means and sample standard deviations independently on each of the planimetric coordinates (X) and (Y) and on elevation (Z). Both tests are based on a confidence level ($1 - \alpha$) of 95 percent. Tests for significant bias error are based on the "student's t" distribution and tests of precision are based on the "chi-square" distribution in accordance with standard statistical procedures. Explanations and examples of bias and precision testing of maps are provided in Appendix A.

After correction for the average bias error, points which exhibit discrepancies which exceed three times the standard error shall be interpreted as blunders and shall be subject to redetermination.

3. TITLE AND DATA BLOCK

To assure an unambiguous interpretation of the spatial characteristics of the map, the following information shall be included with other appropriate data in the margin or the data block appearing on each map sheet:

- definition of horizontal and vertical datums;
- contour interval including units;
- map scale by means of both a bar scale and representative fraction;
- grid or lines and their values; and
- statement of accuracy
  "Coordinate data extracted from this map can

reasonably be expected to have coordinate standard errors (1σ) on the ground not exceeding

______ (units) in X
______ (units) in Y
______ (units) in Z elevation

For an explanation of accuracy measures and test procedures, see the ASP standards titled "Accuracy Specifications for Large Scale Line Maps."

References

A.C.I.C., 1962. *Principles of Error Theory and Cartographic Applications*, Aeronautical Chart and Information Center, Tech. Report No. 96, Feb.

Pearson, E. S., and Hartley, 1966. *Biometrika Tables for Statisticians*, Vol. I and II, 3rd Ed., Cambridge University Press.

Appendix A
Explanations and Examples of Accuracy Compliance Tests

For purposes of testing maps to assure their compliance with the accuracy requirements, a test of bias error is conducted followed by a test of precision after the bias has been removed. The tests follow conventional hypothesis testing procedures. The tests are made using the discrepancies between the spatial coordinates determined from the map and the corresponding points determined from a check survey. The tests are conducted independently along each of the three coordinate directions. Both tests are one-tailed tests based on a 95 percent confidence level.

The sample mean of test point discrepancies ($\delta\overline{X}$) in the X survey coordinate direction is computed as

$$\delta\overline{X} = 1/n \sum_{i=1}^{n} \delta X_i$$

where $\delta X_i \equiv X^c_i - X^m_i$;
$X^c_i, X^m_i \equiv$ the X survey coordinates of point i from the check survey and as scaled from the map, respectively; and
$n \equiv$ the number of check points.

The sample standard deviation of test point discrepancies (s_x) in the X survey coordinate direction is computed as

$$s_x = \left[\frac{1}{n-1} \sum_{i=1}^{n} (\delta X_i - \delta\overline{X})^2\right]^{1/2}$$

The test for significant map *bias* in the X survey coordinate direction is made by comparing the theoretical statistic ($t_{n-1,\alpha}$) drawn from Table A1 to the sample statistic

$$t_x = 1/s_x\ (\delta\overline{X})\ n^{1/2}.$$

If $$|t_x| \leq t_{n-1,\alpha},$$

the map is accepted as free from bias in the X coordinate direction.

Table A1. Statistics for Compliance Testing (Significance Level (α) = 5%)

Number of check points (n)*	$t_{n-1,\alpha}$	$\chi^2_{n-1,\alpha}$
20	1.729	30.14
21	1.725	31.41
22	1.721	32.67
23	1.717	33.92
24	1.714	35.17
25	1.711	36.42
26	1.708	27.65
27	1.706	38.88
28	1.703	40.11
29	1.701	41.34
30	1.699	42.56
31	1.697	43.77
32	1.695	44.97

* Test statistics for the number of check points (n) > 32 can be drawn from existing tables. See, for instance, Pearson and Hartley (1966).

The test for *precision* in the X survey coordinate direction is made by comparing the theoretical statistic ($\chi^2_{n-1,\alpha}$) from Table A1 to the sample statistic

$$\chi^2_x = \left[\frac{n-1}{\sigma_x^{\,2}}\right] s_x^{\,2}$$

where σ_x is drawn from Table 1.

If $$|\chi^2_x| \leq \chi^2_{n-1,\alpha},$$

the map is accepted as meeting the accuracy standard in the X survey coordinate direction.

Compliance testing of the map in the Y survey coordinate direction and in elevation (Z) is conducted by the same procedure.

For a numerical example, assume the accuracy specification allows a standard error (1σ) in X or Y of 0.50 metres. This could be typically associated with a scale of 1:2000 for a Class 1 map, as indicated in Table 1M. Table A2 is constructed for the X-coordinate direction for 24 points to represent

- discrepancies (δX_i) between the mapped X-coordinate and the corresponding coordinate determined by a check survey for any check point (i),
- discrepancies reduced by the mean or bias error ($\delta X_i - \delta\overline{X}$) termed the bias-free discrepancy in the X-coordinate direction, and
- bias-free discrepancy squared $(\delta X_i - \delta\overline{X})^2$.

From these basic data, the test statistics for the X-coordinate direction can readily be computed as follows:

Compute first the sample mean ($\delta\overline{X}$):

$$\delta\overline{X} = \frac{1}{24} \sum_{i=1}^{24} (\delta X_i) = 0.133 \text{ metres.}$$

Second, compute the sample standard deviation (s_x):

TABLE A2. SAMPLE TEST DATA FOR X-COORDINATE DIRECTION (METRES)

Point (i)	δX_i	$\delta X_i - \delta\overline{X}$	$(\delta X_i - \delta\overline{X})^2$
1	−0.250	−0.383	0.146
2	−0.150	−0.283	0.080
3	−0.210	−0.343	0.117
4	−0.200	−0.333	0.111
5	−0.320	−0.453	0.205
6	−0.070	−0.203	0.041
7	0.210	0.077	0.006
8	0.550	0.418	0.174
9	−0.230	−0.363	0.131
10	−0.160	−0.293	0.086
11	−0.220	−0.353	0.124
12	0.210	0.077	0.006
13	0.240	0.107	0.012
14	−0.230	−0.363	0.131
15	0.610	0.478	0.228
16	0.120	−0.013	0.000
17	0.920	0.788	0.620
18	1.020	0.888	0.788
19	0.230	0.097	0.010
20	1.220	1.088	1.183
21	0.220	0.087	0.008
22	−0.230	−0.363	0.131
23	−0.240	−0.373	0.139
24	0.140	0.007	0.000

$$s_x = \left[\frac{1}{24 - 1} \sum_{i=1}^{24} (\delta X_i - \delta\overline{X})^2\right]^{1/2} = 0.441 \text{ metres.}$$

Next, compute the sample statistic (t_x):

$$t_x = \frac{1}{s_x} (\delta X)\, n^{1/2} = \frac{1}{0.441} (0.133)\, (24)^{1/2}$$

$$|t_x| = 1.48$$

Since $|t_x| < t_{n-1,\alpha}$, where $t_{n-1,\alpha}$ is taken from Table A1 for 24 check points, the map is accepted as free from significant bias in the X-coordinate direction.

Now, to compute the sample statistic (χ^2_x):

$$\chi^2_x = \left[\frac{n - 1}{\sigma^2_x}\right] s^2_x = \frac{24 - 1}{(0.50)^2} (0.441)^2$$

Since $|\chi^2_x| < \chi^2_{n-1,\alpha}$, where $\chi^2_{n-1,\alpha}$ is taken from Table A1 for 24 check points, the map is accepted as meeting the accuracy standard in the X-coordinate direction.

For this example, the tests indicate that the map meets the accuracy specifications in the X-coordinate direction. In the same manner, checks are made for the Y-coordinate and Z-coordinate (elevation) directions using the specified values of standard error (1σ) as stated in the accuracy specification.