CHAPTER 8

Map Accuracies

8.1 QUALITY ASSURANCE/QUALITY CONTROL

For the first several decades of mapping from aerial photos utilizing stereoplotters, users could physically see and handle graphical mapping products. Now, the preponderance of end products from a mapping project resides, unseen by the human eye, as a matrix of magnetic spots within an electronic database. Therefore, the user must rely upon the integrity of captured information to maintain the credibility of a mapping endeavor.

8.1.1 Significance of Quality Assurance/Quality Control

The significance of quality assurance and quality control (QA/QC) in contemporary photogrammetry cannot be overly emphasized. QA/QC is an integral factor in the data collection task and cannot be sacrificed to expediency or false economy.

A relatively limited QA/QC effort is usually directed toward field tests to verify the quality of final mapping products. As a consequence, credible judgment must be exercised by both mapper and user in designing a mapping project so that the accuracy of the final output adheres to reliable tolerances.

Quality control should be the watchword of the mapper who is obligated to institute professional quality control procedures. Quality assurance should be ascertained by the user who is committed to performing quality assurance assessment measures.

8.1.2 Funding vs. Quality

In the initiation of mapping projects, the user asks two questions:

- How much will it cost?
- How soon will it be completed?

There is no denying that more stringent mapping requirements are more costly. If the user's funding is insufficient to purchase mapping that will adhere to required accuracy standards, the project should not be undertaken. A judicious reevaluation of user needs may prove that a smaller map scale and/or a larger contour interval would satisfy the needs of the project. In this situation the specifications, but not the accuracy standards, could legitimately be revised to provide a lower cost.

Users must accept the fact that products from a lower accuracy level cannot be electronically manipulated to fulfill the requisites of a higher level product. No amount of computer manipulation will increase the accuracy level of a block of data. Reliable mappers do not diminish standards to provide a lower cost.

8.2 RAMIFICATIONS OF FAULTY MAPPING

Unrealistic product delivery schedules can initiate serious accuracy dilemmas. There can be no denying that human stress resulting from pressures applied to expedite all phases of mapping production promotes mistakes. Faulty mapping can and often does result in very serious consequences.

8.2.1 Rework

If errors are detected during data capture, the mapping can be revised. These errors can originate in the field surveys, aerotriangulation, or compilation stage. Rework may be precipitated also by a change in specifications during the ongoing course of the project. Regardless of the cause, rework is a "triple-pronged" cost penalty:

1. Original cost. Initially, the user must pay the cost to have the original mapping produced.
2. Out of pocket. Either the user or responsible contractor (surveyor or photomapper), depending upon where the fault lies, is faced with the out-of-pocket expense to accomplish corrected mapping.
3. Lost revenue. If responsible for the corrective work, the surveyor or photomapper forgoes any revenue which could be realized doing income-producing work for others during that same period of rework production time.

8.2.2 Abandoned Schedules

When corrections are necessary, the elapsed time could very well be twice the original production schedule. The condition that precipitates the need for rework can occur during any phase of the mapping procedure.

A problem encountered at any point during the course of the production scheme may necessitate additional effort in previous phases. Rework causes irretrievable slippage in the production schedule.

8.2.2.1 Original Schedule

A certain amount of time is required to accomplish the various sequential phases to complete the original mapping. Aerial photographers, surveyors, and photomappers must schedule the work of multiple users and accomplish the work for each on a scheduled rotation.

8.2.2.2 Revised Schedule

If rework is required in any phase, the schedules of all of the users in pursuant phases must be revised to meet this contingency. The time consumed to complete revisions will vary, depending upon the extent of the effort required to accomplish the rework.

8.2.3 Design Failures

In the event that mapping corrections are not detected until well into the use of the maps, there could be design aberrations built into the project for which the mapping was obtained. This may lead to wasted effort on the part of the user or costly design changes during development of the project.

8.2.4 Legal Action

Any of the above factors can and increasingly does lead to costly lawsuits and court action. Both time and money are valuable. If one or the other is needlessly squandered through neglect on the part of the designer, surveyor, or mapper, legal efforts for punitive damage compensation may be initiated.

8.3 MAP ACCURACY STANDARDS

Relevance of an accuracy concept cannot be overly stressed. The design of a mapping project should be guided primarily to assure adherence to the intended accuracy of the end product. Upon these specifications rests the utility of a mapping product.

Uppermost in the minds of both mapper and user should be the precept that if the collected digital data does not meet accuracy standards, the end product is of little value. In fact, inaccurate mapping creates a negative impact in that it encourages a false sense of reliance upon inferior information.

8.3.1 Various Map Accuracy Standards

A number of map accuracy standards are used by those who produce and use maps. Some have been developed for use within individual agencies, and others have been created for a wider range of users. Agencies that may use individual specifications include the Federal Emergency Management Agency (FEMA), U.S. Department of Transportation, U.S. National Cartographic Standards for Spatial Accuracy, and various state and local governments. The deluge of digital data sets being produced by various federal agencies has helped them to come together in a common group known as the Federal Geographic Data Committee (FGDC) and to develop the most recent standards, known as the Geospatial Positioning Accuracy Standards. These standards are also known as the National Standard for Spatial Data Accuracy (NSSDA) and can be reviewed in detail by logging on to the www.fdgc.gov/standards web site.

Although many standards are available, only National Map Accuracy Standards (NMAS), ASPRS Standards, and FGDC NSSDA (July 1998) will be discussed herein. The three standards are nationally recognized to encompass most current spatial data accuracy requirements. NMAS and ASPRS standards are both referenced and discussed in the NSSDA standards.

All standards discussed herein allow for deviation from accuracy standards when the terrain surface on the photo image is obscured by clouds, shadows, or vegetative cover.

8.3.2 National Map Accuracy Standards (1947)

From 1941 to the mid-1990s, most map production organizations, both in public and private sectors, accepted NMAS as an industry standard for both large- and small-scale photogrammetric mapping. Prevailing procedures, techniques, and equipment called for in the NMAS provided predictable mapping products and accuracies. The NMAS were generally developed around mapping products developed by federal agencies such as the USGS and the U.S. Department of Agriculture (USDA). Accuracies specified in the NMAS are stated in terms of the position of a feature on a hardcopy map in relation to its spatial position on the earth. These features may include planimetric features such as buildings and roads, contours (lines of equal elevation), and individual spot elevations.

NMAS, in its elementary interpretation, stipulates levels of accuracy for both horizontal and vertical features:

- Planimetric features: 90% of finite cultural objects should be accurate to within 1/40 in., and 100% should be correct to within 1/20 in. at delivered map scale.
- Contours: 90% of contours should be accurate to within one-half a contour interval, and 100% should be correct to within one full contour interval.
- Spot elevations: 90% of plotted spot elevations should be accurate to within one-fourth of a contour interval, and 100% should be correct to within one-half a contour interval.

8.3.3 American Society for Photogrammetry and Remote Sensing (1990)

ASPRS standards requirements are developed around procedures and equipment used to produce large-scale maps. These standards establish the map accuracy by establishing the difference between the location of a feature in a spatial data set and its true position on the earth. This standard stipulates that the difference should be derived by making comparative measurements of the feature position on the earth using a more accurate method than was used in the photogrammetrically derived feature position (i.e., ground surveys). The difference is stated in terms of root mean square error (RMSE) between the photogrammetrically derived feature position and its corresponding position as measured by a more accurate means. ASPRS standards for large-scale mapping are divided into three classes. They are described as follows:

Class 1 is the most stringent.
Class 2 can contain inaccuracies twice that of Class 1.
Class 3 errors can be triple those of Class 1.

ASPRS standards establish a number of production parameters to confine errors within the enumerated limits. These tolerance levels are expressed as the RMSE of all of the test point inaccuracies encountered by field verification.

Discrepancy in coordinate direction at individual test points can be computed using Equation 8.1. This formula can be utilized for the X, Y, or Z coordinate error.

$$e = v_{map} - v_{test} \tag{8.1}$$

where:

e = X or Y or Z coordinate discrepancy
v_{map} = X or Y or Z map coordinate
v_{test} = X or Y or Z field survey coordinate

To determine the actual RMSE of X, Y, and Z coordinates, the sum of the square of the individual errors must be determined. This can be accomplished with Equation 8.2.

$$E^2 = \sum \left(e_1^2 + e_2^2 + \cdots + e_n^2\right) \tag{8.2}$$

where:

E^2 = sum of the square of the errors
Σ = sum
e_1^2 = coordinate discrepancy at first point
e_n = coordinate discrepancy at nth point

The actual RMSE of any tested group of map data, in ground feet, is calculated by using Equation 8.3.

$$e_{rms} = \sqrt{E^2/n} \tag{8.3}$$

where:

E_{rms} = actual RMSE
n = number of points tested

8.3.3.1 Horizontal Inaccuracies

Comparable horizontal inaccuracy allowances stated by ASPRS standards for ASPRS Class 1 mapping can be determined by using Equation 8.4.

$$e_{h1} = s_m/100 \tag{8.4}$$

where:

s_m = map scale denominator (feet)

e_{h1} = maximum allowable ASPRS Class 1 RMSE

Once the ASPRS Class 1 inaccuracy is calculated, the error tolerance for ASPRS Class 2 can be determined with Equation 8.5.

$$e_{h2} = e_{h1} * 2 \tag{8.5}$$

ASPRS Class 3 error can be determined with Equation 8.6.

$$e_{h3} = e_{h1} * 3 \tag{8.6}$$

8.3.3.2 Contour Inaccuracies

Comparable vertical inaccuracy allowances stated by ASPRS Class 1 standards, relative to contour interval, can be determined through the use of Equation 8.7.

$$e_{cl} = c_i/3 \tag{8.7}$$

where:

c_i = contour interval

e_{c1} = maximum allowable ASPRS Class 1 error

After computing ASPRS Class 1 allowable errors, Equation 8.8 can be used to determine the allowable error for ASPRS Class 2 contour deviation.

$$e_{c2} = e_{c1} * 2 \tag{8.8}$$

Equation 8.9 can be utilized to furnish anticipated contour deviation for ASPRS Class 3.

$$e_{c3} = e_{c1} * 3 \tag{8.9}$$

8.3.3.3 Spot Elevation Inaccuracies

Maximum allowable errors of spot elevations for ASPRS Class 1 can be determined by applying Equation 8.10.

$$e_{s1} = c_i/6 \tag{8.10}$$

where:

c_i = contour interval

e_{c1} = maximum allowable ASPRS Class 1 error

Once the ASPRS Class 1 allowable error is computed, the ASPRS Class 2 error can be determined by using Equation 8.11.

$$e_{s2} = e_{s1} * 2 \tag{8.11}$$

The ASPRS Class 3 error can be determined with Equation 8.12.

$$e_{s3} = e_{s1} * 3 \tag{8.12}$$

8.3.4 Federal Geographic Data Committee

The NSSDA was established by the FGDC, a group of federal agencies that produce and use geospatial data. A committee was established under the FGDC to update the current NMAS and ASPRS standards, taking into account new technology equipment. This group also recognized that since the 1990s, the demand for digital geospatial data has increased dramatically.

The users and their accuracy requirements are also very diverse. Although the NSSDA uses RMSE in the same manner as the ASPRS standard, the accuracy is reported as the acceptable RMSE at 95% confidence level. The NSSDA refers to and allows for reporting of accuracy in terms of NMAS or ASPRS standards. A spatial data user who wants to specify a spatial data set horizontal and/or vertical accuracy in NSSDA terms could choose an ASPRS Class or NMAS scale and associated accuracy and state it in terms of 95% confidence level (NSSDA). The web site www.fgdc.gov/standards provides detailed explanations and examples of NSSDA accuracy calculations, as well as conversion of NMAS and ASPRS accuracies to NSSDA.

8.3.4.1 Horizontal Standard Error

To calculate the horizontal standard error in terms of 95% confidence level according to NSSDA, log on to the web site www.fgdc.gov/standards and click on Part 1 to find the derivation of the following formulas:

Horizontal Accuracy

The horizontal accuracy calculation assumes one of two scenarios:

- When $RMSE_x = RMSE_y$

  LET $RMSE_r$ = sqrt(2*$RMSE_x^2$) = sqrt(2*$RMSE_y^2$), and

  $Accuracy_r$ = 1.7308*$RMSE_r$

- When $RMSE_x \neq RMSE_y$,

  LET circular $Accuracy_r$ = ~1.2239*($RMSE_x$ + $RMSE_y$)

Vertical Accuracy

$$\text{LET } RMSE_z = \text{sqrt}[\Sigma(z_{data\ i} - z_{check\ i})^2/n]$$

where:

$z_{data\ i}$ = elevation of ith check point in the data set
$z_{check\ i}$ = surveyed elevation of ith check point in the independent test
n = number of points being checked
i = integer from 1 to n

then,

$$Accuracy_z = 1.96 * RMSE_z$$

8.4 PROCEDURAL SUGGESTIONS

Although NMAS and ASPRS standards are not wholly compatible, both serve a meaningful purpose — to assure that both the map producer and the user are aware that it is essential to preserve product quality. A review of accepted NMAS and ASPRS standards would note that accuracies for a specified mapping horizontal map scale and vertical interval are different. Standards will indicate that, for practical purposes, NMAS inaccuracy allowances are bracketed by ASPRS Classes 1 and 2. NSSDA will allow for conversion of NMAS and ASPRS accuracies to a common accuracy, and it is recommended that this method of qualifying accuracy be considered when possible.

8.4.1 Cautions

There are reservations to be considered in recommending standards unreservedly by the tyro user, because the power of GIS queries can cause the inexperienced spatial data user to become enmeshed in accuracy problems. Mixing of data sets with diverse accuracies or accuracies stated in terms of different standards can be a recurring problem.

8.4.1.1 Historical Acceptance of National Map Accuracy Standards

For many decades NMAS were the predominant guidelines within the photogrammetric community for large-scale and small-scale mapping. For more than ten years there has been a concentrated effort among organized photogrammetrists to sponsor an attitude of stricter accuracy demands for large-scale mapping. Inaccuracy tolerances predicated by NMAS fall immediately below those in ASPRS Class 1, which is in direct agreement with this philosophy of improved quality.

8.4.1.2 Indiscriminate Data Use

There is a tendency, when indiscriminately collecting information to create a consolidated database, for the user to ignore the perils inherent in dissimilar error tolerances incorporated within those data. To the uninitiated, the quality of all of the information within a database can be of equal accuracy. This is a precarious assumption.

Table 8.1 Minimum Accuracy Levels to Employ by Purpose of the Map

Map Class	Purpose of Map
ASPRS1	Final design
	Earthwork calculations
	Volume of pits or piles
NMAS	Route location
	Preliminary design
	Project planning
	Rough terrain
	General planning

8.4.2 Options

With this groundwork in place, two options are suggested.

8.4.2.1 Experienced User

In the hands of an experienced user who thoroughly understands disparate data quality and has complete in-house control over the use of the data, the various classes within the ASPRS mapping standards can be applied with confidence. The user may also decide to state the accuracy in NSSDA terms. This will allow the use of disparate data sets with a clear understanding of the accuracy of each in terms of RMSE at 95% confidence level. This instance presumes that the knowledgeable user is fully aware of allowable errors and their consequential deformations upon the final product.

8.4.2.2 Inexperienced User

In keeping with the doctrine of looking to maintain increased accuracy, users not fully aware of the pitfalls of integrating various accuracy sets may wish to combine the best of NMAS and ASPRS mapping standards. Even though the inaccuracy tolerances for all the ASPRS map classes will be listed in various tables throughout the book, it is recommended that the user limit choices to those suggested in Table 8.1.

After determining the inaccuracies allowed by ASPRS2 and ASPRS3, the user may wish to consider using these standards for mapping projects which are sufficiently tolerant of the magnitude of the errors that they may be capable of generating.

8.5 MERGING DIVERSE DATA

Information systems are a valuable tool in many fields of endeavor, but there are photogrammetric pitfalls in merging data gathered from diverse sources. The greatest hazard may stem from the ability of a computer driven by proper software to accept almost any matrix of digital XYZ data and to create a map to any scale or contour interval. Once data are collected from a variety of sources and assimilated into a single information system database, a tendency to treat all of the information similarly exists. Herein lies the fallacy. All features go into a database as a group of individual coordinate points which are relational to each other through a common geographic positioning grid. However, not all information is collected to the same degree of accuracy. A map is only as reliable as its most inaccurate information layer. Serious thought must be given to the compatibility of information that resides in an integrated database.

8.6 MAPPING SYSTEM ERRORS

Discounting the errors that have already been discussed, there are systemic aberrations in the photogrammetric functions in aerial mapping projects.

8.6.1 Photography

No aerial camera focal plane is absolutely flat. Certain areas of high and low spots and also inherent aberrations in lens systems exist. When using a camera that is calibrated periodically, these are normally not significant problems.

Due to the undulating character of the ground and the varying aircraft height, photograph scale fluctuates within a single exposure as well as between adjacent frames. This situation is adjusted during stereomodel orientation. Normal inherent relief displacement is compensated for in the sterocompilation procedure.

8.6.2 Stereocompilation

Diverse factors are error sources during digital data collection. Some can be attributed to human frailties, while others are dependent on outside influences.

8.6.2.1 Visual Acuity

Visual acuity varies with each photogrammetric technician. In some situations this may affect the vertical map accuracy by an amount approaching as much as one-fifth to one-fourth of a contour interval.

8.6.2.2 Image Definition

Resolution of the photo image may affect the operator's ability to place the reference mark on the true elevation of the image object. This could be a function of weather, film processing, or dispositive processing. Clear, crisp days tend to produce a "hard" or distinct image, and warm, humid days result in a "soft" or hazy image. Hard models allow the reference mark to be placed more precisely in contact with the terrain than soft models.