ISSUES IN DIGITAL CARTOGRAPHIC DATA STANDARDS

Report #1

Papers from the Joint ACSM/ASP Session on Digital Cartographic Data Standards at the 1982 meeting of the American Congress on Surveying and Mapping, Denver, Colorado

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July, 1982

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The committee operates under the auspices of the American Congress on Surveying and Mapping. This work of the Committee is being funded by U.S. Geological Survey Grant #14-08-0001-G-787. Production assistance has been provided by The Ohio State University Research Foundation (RF Project 714484). Permission to reprint these papers has been given by ACSM.

PREFACE

This report is the first in a series discussing the work of the National Committee for Digital Cartographic Data Standards. It contains three of the four papers presented at the session on Digital Cartographic Data Standards held at the Spring meeting of the American Congress on Surveying and Mapping and the American Society of Photogrammetry in Denver, Colorado in March of 1982. The first paper by Moellering, the committee chairman, was the keynote paper for the session and describes the conceptual background to the problem of digital cartographic data standards, the general topics one might consider for standards, and proposes the organization and structure for the committee. The second paper by Barr discusses the linkages between cartographic data standards and work going on with multipurpose cadastres. The third paper by Merchant presents the work of an ASP committee relating to large scale map accuracy. The fourth paper by Calkins and Anderson discussing the linkages between cartographic standards and geographic information systems was not available for printing.

The committee is now in the first stage of work, that of defining the issues involved in specifying digital cartographic data standards. Other papers will be produced and made available to the public as the work progresses.

Harold Moellering
Series editor

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THE CHALLENGE OF DEVELOPING A SET OF NATIONAL DIGITAL CARTOGRAPHIC DATA STANDARDS FOR THE UNITED STATES

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ABSTRACT

Continuing activity in the development of digital cartographic data bases has necessitated a movement towards identifying commonalities between such data bases so that groups, agencies, and individuals can exchange information. Concurrent with the development of a national digital cartographic data base, the U.S. Bureau of Standards has asked the U.S. Geological Survey to spearhead the effort to develop digital cartographic data standards. The American Congress on Surveying and Mapping has offered its good offices to form a National Committee for Digital Cartographic Data Standards in order to bring together all segments of the cartographic community to participate in the development of such standards.

I. INTRODUCTION

The last two decades have seen the development of a host of new kinds of cartographic products, many of which have been digital. The emergence of such digital cartographic products has reflected the tremendous growth in numerical and analytical cartography through this same time period. The field has seen a huge increase in the number of cartographic information and display systems. The broad proliferation of such cartographic data bases in the Federal sector has been such that the National Mapping Division of the U.S. Geological Survey has been nominated as the lead agency to develop and manage a national digital cartographic data base (DCDB). Many other individuals in the State, private, and research sectors of the country now also perceive that many efficiencies are to be gained by the the establishment of a national DCDB. More recently the U.S. Bureau of Standards has asked the USGS to establish digital data standards for earth science information systems and to propose those as national geoscience standards. The fact that the need for this work has become even more urgent has been recognized by the strong recommendation of the National Research Council Panel to Review the Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying, July, 1973, to continue the development of the DCDB on a national basis (National Research Council, 1981, pp. 4-5). As part of this overall effort, and in conjunction with the establishment of the national DCDB, the Office of Cartographic Research of the National Mapping Division is in the beginning stage of inquiry relating to a set of national digital cartographic data standards. The goal of this effort is to standardize the specification for the digital cartographic information process such that digital cartographic information from diverse sources can be used by others directly or can be straightforwardly converted into a usable form. These principles, after ample comment and discussion, will subsequently be codified into a national standard.

This paper explores some of the underlying conceptual considerations involved, examines in a very general way some approaches to the problem, and finally, proposes an organizational sructure to implement the process of developing such digital cartographic data standards. It is intended that this work form the initial discussion point to begin this process.

II. CONCEPTUAL CONSIDERATIONS

At the outset one must explore several theoretical issues which will provide the conceptual basis for developing the discussion pertaining to such standards. These theoretical issues are real and virtual maps, cartographic data levels, and the surface and deep structure of cartographic information.

Real and virtual maps

In recent years a number of cartographic products have been developed which have many of the characteristics of conventional maps, but are fundamentally different. For example, an image on a CRT display can look very much like a conventional map, but yet it is highly transient and can disappear with the push of a button. Data stored in computer memory can be easily converted into a map by plotting or CRT display, but it does not fit the conventional definition of a map. Moellering (1980) solved this conceptual problem by developing the notions of real and virtual maps. Two fundamental attributes which can be used to distinguish between classes of real and virtual maps are: 1) permanent tangible reality and 2) direct viewability. Figure 1 illustrates the situation by developing a four-class definition based on these two attributes. For example, a conventional real map has a permanent tangible reality and can be rolled up and carried around. It is also directly viewable in that the information in it can be directly read by a human viewer. Any cartographic product which lacks one or both of these two attributes is called a virtual map. In contrast, a CRT image is directly viewable, but it is highly transient, has no permanent reality, and therefore is a virtual map type I, meaning that it

PERMANENT TANGIBLE REALITY	DIRECTLY VIEWABLE AS A CARTOGRAPHIC IMAGE: YES	DIRECTLY VIEWABLE AS A CARTOGRAPHIC IMAGE: NO
YES	REAL MAP Conventional Sheet Map Globe Orthophoto Map Machine Drawn Map Computer Output Microfilm Block Diagram Plastic Relief Model	VIRTUAL MAP-TYPE II Traditional Field Data Gazetteer Anaglyph Film Animation Hologram (stored) Fourier Transform (stored) Laser Disk Data
NO	VIRTUAL MAP-TYPE I CRT Map Image a) refresh b) storage tube c) plasma panel Cognitive Map (two-dimensional image)	VIRTUAL MAP-TYPE III Digital Memory (data) Magnetic Disk or Tape (data) Video Animation Digital Terrain Model Cognitive Map (relational geographic information)

FIGURE 1. CLASSES OF REAL AND VIRTUAL MAPS

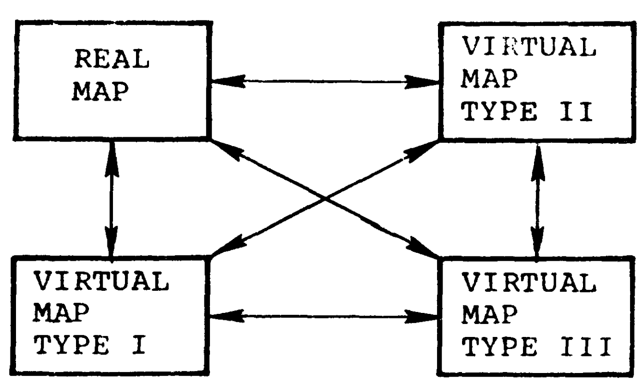

FIGURE 2. TRANSFORMATIONS BETWEEN REAL AND VIRTUAL MAPS

has many map-like characteristics, but is not a true real map. The data from which the CRT image is generated has neither a permanent tangible reality nor is it directly viewable. However it is directly convertable into a real map or into a CRT image. This is defined as as virtual map type III. A type II virtual map has a permanent tangible reality, but it is not directly viewable and examples of such maps may be as sophisticated as a laser data disk or as simple as a set of field data. Most of the type II maps can be converted into type III virtual maps. One should note that in all cases that virtual maps can be converted into real maps.

There are twelve different kinds of transformations between real and virtual maps as shown in figure 2. For cartographers and other spatial scientists those transformations define most operations on map data and can be expressed as transformations between map states t(S1 → S2). Therefore the task of digitizing cartographic information is t(R → V3) while entering numerical data tables associated with the map is t(V2 → V3). Since most interactive analysis systems include a CRT map display and usually the capability for creating a hard copy map, transformations t(V3 → R), t(V3 → V1), t(V1 → V3) and t(V1 → R) are involved. In fact such a cartographic analysis and design system can be schematically depicted in terms of these transformations as shown in figure 3. Such a system has a raw data input with digitizing and data entry transformations. Notice that once inside the interactive system the information is always in a V1 or V3 virtual state which illustrates the highly manipulable nature of these two map states. Ease of manipulation is a primary advantage of these two states in such interactive systems. Since such a system uses man-machine interaction, the map display is read and interpreted by the operator of the CRT terminal which involves a transformation from the CRT image to map image in the mind, t(V1 → V1), a cognitive map. Inside of this interactive CRT system is where data processing, analysis and map display occur. At some point a solution to the problem is reached which needs to be documented or preserved. At that point hard copy output is generated in the form of real maps, t(V3 → R), and other output. The advantage of this sort of transformational view of cartographic information is that it can be used as an aid in the conceptual design of such cartographic data analysis and display systems, as well as aid in the conceptual understanding of the nature of maps.

Cartographic data levels

Any computer-based system which analyzes spatial or cartographic data must have some way in which that data is organized, manipulated and subsequently managed. Most work on cartographic data structures has been directed towards specific implementations of data structures for specific systems. More recent work has moved in a direction of more generalized data structures as illustrated by the work of Peucker and Chrisman (1975), Haralick and Shapiro (1979) and the symposium organized

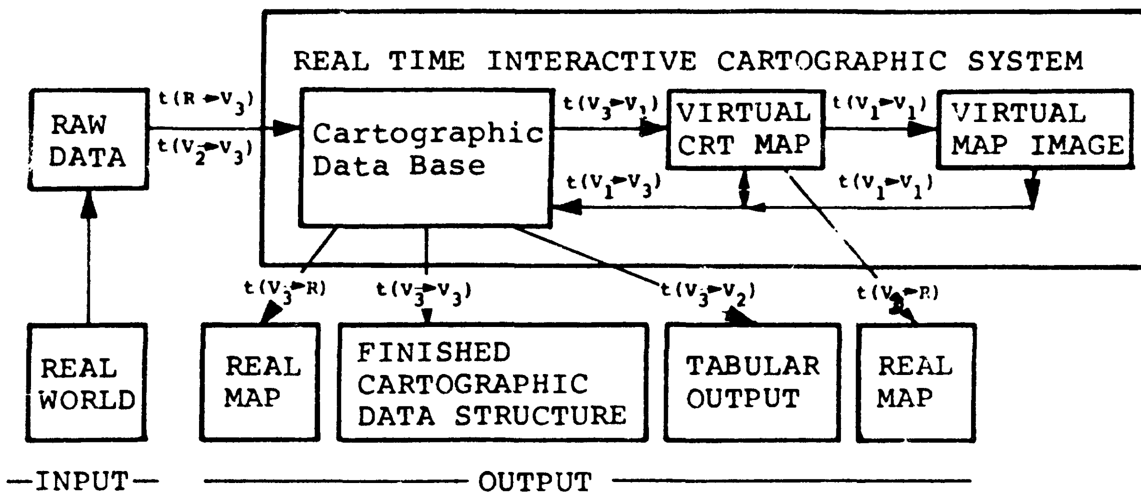

FIGURE 3. SIMPLIFIED DIAGRAM OF A REAL TIME INTERACTIVE CARTOGRAPHIC SYSTEM USING THE CONCEPT OF REAL AND VIRTUAL MAPS.

by Schmidt (1977). Some of this work has moved in the direction of identifying fundamental topological aspects of cartographic data structure for specific data domains. Nyerges (1980) has identified six specific levels of cartographic data organization, which puts the data structure problem into perspective:

1) Data reality - the real world and Data pertaining to it concerning cartographic entities and relationships between them.

2) Information structure - a formal model that specifies the organization of information pertaining to a specific phenomenon. It includes data classes and relationships between them and acts as a skeleton for the canonical structure.

3) Canonical structure - a data model representing the inherent structure of a data set which is independent of specific applications and systems which manage such data.

4) Data structure - a logical data organization designed for a particular system in which specific relationships and links are implemented.

5) Storage structure - a specification of how a particular data structure is stored in data records in a particular system.

6) Machine encoding - the physical representation of how the structure is held in the physical devices of computer system hardware.

When one discusses the question of cartographic data structure, relationships or attributes, there must always be an awareness of these levels of cartographic information and which specific level is being addressed. An explicit recognition of these levels provides a clearer conceptual understanding of the specificity or generality of information being examined, and permits a clearer elucidation of the cartographic relationships being captured in the data structure.

Surface and deep structure

When one has a real map which presents a graphic image of some part of the real world, that graphic image is in essence an iconic replica of that segment of the spatial domain being portrayed. As such this real map provides the image which contains many explicit and implicit spatial relationships of interest to cartographers, geographers, and other spatial scientists. The graphic image is known as the surface structure, while spatial relationships are known as the deep structure of the map (Nyerges, 1980). When one converts this cartographic information into the digital data domain, it is clear that the concepts of deep and surface structure also apply as shown in figure 4. Early cartographic data structures were designed mainly for display purposes and were almost exclusively surface structure representations of cartographic reality. The situation frustrated many analytical cartographers and geographers because such data structures could not conveniently be used for analytical purposes. The reason, of course, is that deep structure relationships necessary for spatial analysis were not preserved. Most modern cartographic data structures preserve some proportions of the deep and surface structures. Therefore the primary purpose of the use of a particular cartographic data structure will influence the proportions of deep and surface structure present in that implementation. It is interesting to note that there is a striking relationship between deep/surface structure and real/virtual maps. It turns out that for the most part that surface structure representations are usually converted into real maps or virtual type I maps as CRT images whereas deep cartographic structure is usually a type III virtual map and some times a type II virtual map. It is the combination of these two fundamental concepts along with an awareness of cartographic data levels that adds a critical insight into the problem of cartographic information organization in general and cartographic data structure specifically.

III. THE CHALLENGE OF DIGITAL CARTOGRAPHIC DATA STANDARDS

With the movement towards establishing a national digital cartographic data base, the parallel work on digital cartographic data standards becomes even more important. An initial survey by the author has produced 13 aspects of the standards question which must be examined. At the outset it should be said that these 13 categories are tentative and are presented here only as a vehicle for discussion.

I. Terminology and logical representation - At the outset one needs to precisely define the technical terminology to be used in subsequent discussions. It turns out that earlier work by Commissiom III of the International Cartographic Association will form the basis for the discussion. Similarly, standard methods for representing these logical relationships contained in the cartographic information models and data structures must be established.

II. User requirements - The standards requirements of agencies, companies and individuals who will use the DCDB must be compiled.

III. Digital map accuracy - Current work on large-scale map accuracy will form the basis for this task. Small-scale standards for accuracy must be established as well.

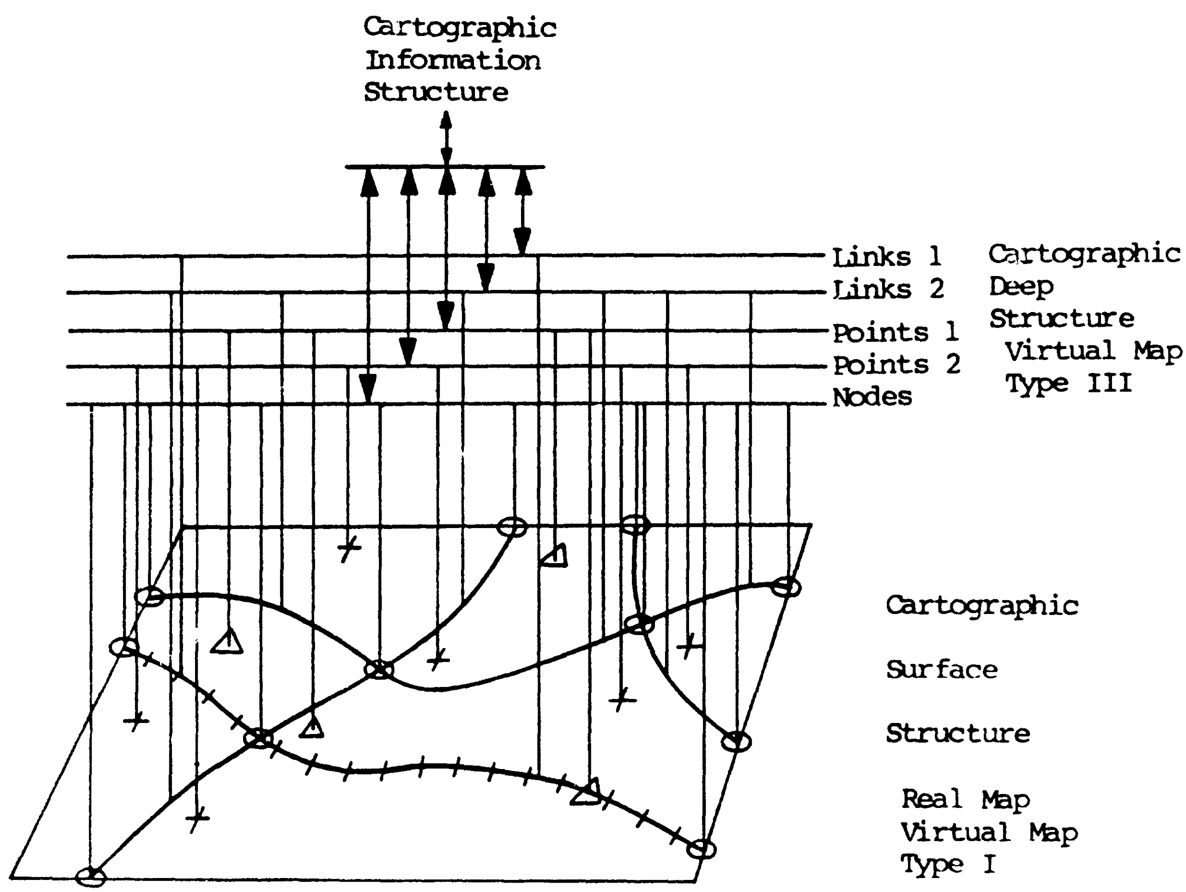

Figure 4. The Relationship Between Deep and Surface Cartographic Structure

IV. Cartographic data models and modules - This work centers on cartographic information levels two and three by Nyerges (1980). There has been very little discussion of this topic and fundamental questions must be addressed and analyzed.

V. Vector data structures - Much work has been carried out on such structures and now is the appropriate time to identify commonalities for such structure and interchange standards.

VI. Elevation data structures - As with vector data structures, much work has been carried out on digital elevation models and now is the time to consolidate various efforts in order to develop standards.

VII. Raster data structures - Work with raster data structures is still in a formative stage of development, but results to date indicate interesting potential for this approach. The raster question is not an either/or question relative to vector structures, but rather a legitimate item for research and discussion in its own right.

VIII. Symbolism, feature codes, and typography - A fair amount of work has been carried out in this area and now is the time to identify commonalities.

IX. Color - Digital color standards for cartography have received very little attention so far. However, it is clear that much work needs to be done and that the results must be compatible with lithographic color capabilities.

X. Geographic names - Name processing and placement is an essential task in the cartographic process.

XI. Format and interchange standards - This is essential for data file exchange. Basic work on this question has already been done.

XII. Digitizing standards - This is one of the fundamental cartographic data input methods and standards at some level of specificity should be established.

XIII. Digital display standards - Fundamental principles of digital cartographic data display in current practice should be codified.

As can be seen, most of these categories mentioned above relate to the deep structure environment of cartographic data. In all cases the scope of each task must be clearly defined and identify the necessary level of generality or specificity required for each standard. A very important concern here is to adjust the level of specificity of the standards such that the cartographic community will benefit from the commonality of them, but yet at the same time will not hinder innovation and future research with such standards.

One of the most interesting challenges is in the area of cartographic data structure. In the not-too-distant past the question of raster and vector data structures was cast as an either/or question. More recent research has suggested that this is not the case. The real question is clarified when one looks at the notions of deep and surface structure in this light. At the level of the surface structure, raster and vector representations of geographic reality are very different for the same graphic scene. However, as one penetrates farther and farther into the deep structure, it is clear that the spatial relationships which are to be preserved in the deep structure are the same for both representations. The real question, then, is at what level in the deep structure do the vector and raster relationships converge, how many such common points are there, and can any of these common points serve as a data structure conversion point. Shapiro and Haralick (1979) have stated the question of converting from one spatial data structure to another as the search to identify homeomorphisms between the two strucures. Here one is searching for such homeomorphisms to serve as a general compatible conversion point between raster and vector cartographic data structures.

When one considers the cartographic data conversion question in terms of homeomorphisms, it is clear that some cartographic structures require more cartographic information for the spatial relationships preserved than others. A straightforward example is that of topological relationships where some cartographic data structures require topological relationships and others do not. This suggests that the cartographic data structure question is not a singular question, but rather is modular in nature in a way analogous to modular software design. It also suggests that homeomorphisms between such data structures will not be singular in nature, but rather varied because conversion between two data structures will depend on a commonality of data structure modules between the two systems. This discussion applies to the raster/vector question as well as to the other kinds of data structure conversions.

It is reasonable to expect that such a systematic investigation will reveal that there are significant gaps in our knowledge. In fact, it is likely that one of the more valuable serendipitous effects of these efforts will be to point out specific areas for more detailed research into the above questions. Once these gaps have been identified, they will be presented to the cartographic community in order to stimulate research in these specific areas and to increase our knowledge and understanding in a systematic way.

One additional question related to the consideration of digital cartographic information and display standards is that of touching points and compatibilities with other neighboring disciplines and standards areas. Preliminary work has identified four major intersection points with other standards areas:

I. Remote sensing and photogrammetry - These two areas are fundamental data inputs to cartography and hence the character of this spatial data flow must be compatible.

II. Geodetic surveying and land surveying - These areas provide additional information and positioning for cartographic information bases.

III. Geographic information and land records systems - These areas are major users of cartographic information and associated data bases (Barr, 1982, Marble, 1982, National Research Council, 1980)

IV. Computer graphics - Digital display standards for cartography must be compatible with the proposed computer graphics standards (SIGGRAPH, 1977).

It is clear at the outset that an efficient, workable and practical set of digital cartographic data standards will have to mesh efficiently with the four above standards areas. Here areas I and II are major data inputs for digital cartography while area III is a major consumer of digital cartographic information. Area IV of computer graphics specifies one of the standards related to hardware devices and the design of software system components.

IV. A PROPOSED ORGANIZATION TO DEVELOP DIGITAL CARTOGRAPHIC DATA STANDARDS

If such an effort to establish digital cartographic data standards is to be truly successful in establishing a national set of standards, it is clear that a national consensus must be achieved for what constitutes such standards. If a consensus can be reached, then such standards will become universal in a reasonable time frame. If a true national consensus is not reached, then the resulting situation could be as muddled as is the current situation. At the present time about half a dozen groups have tried to address the digital cartographic data standards question in terms of their specific areas and purposes. They include work by the USGS in feature codes and data structure, American Society of Civil Engineers on large scale map accuracy and symbolization standards, Defense Mapping Agency on digital elevation models and feature codes, American Public Works Association on data interchange conventions between municipalities and utilities, and an interagency group of national research laboratories to establish data exchange and format standards.

Now is the time to bring these groups together with all other interested parties to thoroughly assess and discuss the entire question of digital cartographic data standards, and after all sides have been heard, to put forth a proposed set of national standards for digital cartography. The best vehicle through which to focus these efforts is the primary professional association of concern with these matters, the American Congress on Surveying and Mapping. It is proposed here that under the sponsorship of ACSM that a National Committee for Digital Cartographic Data Standards be be established. The professional organization will act as an impartial broker of information and opinion, and will act as the coordinator of these activities. The Committee will assure that all sides will be heard in an effort to achieve a truly national consensus on these issues. It is clear that support will be needed from the primary federal agencies involved, USGS, the lead agency, the National Ocean Survey, and the Defense Mapping Agency. The goals of this standards committee will therefore be:

> To provide a professional forum for all involved Federal, State, and local public agencies, private industry, and professional individuals to express their opinions, assessments, and proposals concerning digital cartographic data standards. After sufficient time for the formulation, circulation, discussion, reformulation, and comment, these proposed standards will be submitted to the U.S. Bureau of Standards to become national digital cartographic data standards.

The organization of the National Committee for Digital Cartographic Data Standards will consist of two primary components: a steering committee and several technical working groups, as shown in figure 5. The steering committee will be composed of a Chairman and twelve members who are from Federal, State, and local public agencies, the private sector, and the universities. Their primary tasks are as follows:

1) To examine and define the scope of these standards efforts in more detail,

2) To define the number, scope and goals of each technical working group,

3) To define general policy for the orderly examination, discussion, and adoption of the standards proposed by the technical working groups, and

4) To issue reports from the technical working groups and the committee in general.

Each technical working group will have a Chairman and from four to ten members who are experts in the specific areas of concern of the working group. Their primary tasks are:

1) To assess the state of current knowledge and understanding in the technical area,

2) To define any gaps in such knowledge and understanding necessary to specify digital cartographic standards in that area,

3) To invite presentations and opinions from all interested parties relating to its standards area,

4) To prepare technical working papers of their deliberations and discussions, and

5) Finally, to propose digital cartographic data standards for its technical area.

An additional component of the committee will be that of liaison contacts. Such contacts will be established with all interested agencies, private companies and professional societies as well as groups responsible for the standards in the major neighboring technical areas.

V. CONCLUSIONS

The current development of digital cartography strongly suggests that now is the appropriate time to begin efforts to explore and define digital cartographic data standards as is evidenced by the mandate given by the U.S. Bureau of Standards. The proposed National Committee for Digital Cartographic Data Standards operating under the auspices of ACSM will be the primary vehicle to initiate and carry out these efforts.

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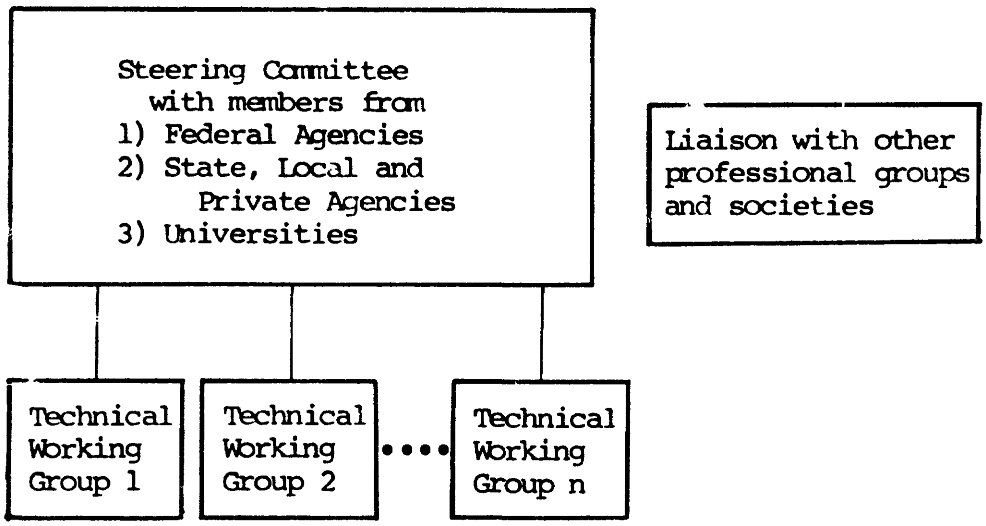

Figure 5. Organization of National Committee for Digital Cartographic Data Standards

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STANDARDS FOR DIGITAL CARTOGRAPHIC DATA THAT SUPPORT THE DEVELOPMENT OF MULTIPURPOSE CADASTRES

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BIOGRAPHICAL SKETCH

MacDonald Barr has served as an urban planner in city and state governments, in regional planning and in university technical assistance programs. He was Director of the Massachusetts Land Records Commission in 1974-76, and Project Manager for the Land Title Registration System Demonstration Project sponsored by HUD in Massachusetts in 1978-80. In 1980-81 he studied the cadastral records systems of Germany and the Netherlands as a Fulbright Research Scholar, based in Bonn, and presently is a fellow of the Lincoln Institute studying information systems at the Department of Geography at Boston University. He holds a Bachelors in Civil Engineering (Princeton, 1955) and a Master in City Planning (M.I.T., 1957).

ABSTRACT

A multipurpose cadastre, as currently being proposed, would be invaluable as a source of data for a digital cartographic data base at the land parcel level. The same is true of the multipurpose land data systems that now operate in several large cities and counties, even though the latter do not identify owners of the land parcels with the same authority as a cadastre. The three major components of such systems which furnish cartographic data are the records of the geodetic network, the system of large-scale base maps, and the overlays to these base maps that delineate the cadastral parcels. Where the cadastral map system is digitized, these take the form of a point file, a file of boundary line segments in vector format, and other optional files locating the major physical features shown on the base maps. If these cadastral records of local governments are to be standardized as convenient sources of digital cartographic data, then the time-consuming process of adoption of the standards by state and local governments must be considered in drafting them.

INTRODUCTION

State and local governments in the United States are being urged to organize their cadastral records into modern, continually updated land data systems (Panel on a Multipurpose Cadastre, 1980). An important incentive is the need for a geographic data base for referencing a variety of planning, administrative and regulatory data. The use of digital computers for storing and manipulating this shared data, and delivering the results to local public users, is part of the attractiveness of such a "multipurpose cadastre." The local governments that now are moving in this direction (and their number is limited) thus are creating geocoded data bases with important cartographic components.

Agreement among the users as to their expectations for the format of the cadastral data would be helpful in supporting more widespread commitments of local authorities to develop multipurpose cadastres.

This paper identifies aspects of a multipurpose cadastre which will need to be considered in the process of standardizing the elements of a digital cartographic data base, if they are to serve as parts of such a data base for other users. These are some of the specifics of the intersection of cartographic data standards with geodetic surveying and land surveying, the second of four major intersection areas identified by Moellering in his paper for this session. The paper concludes with a brief review of how the institutions responsible for cadastral records can be engaged in the process of drafting digital cartographic data standards.

Moellering's paper for this session also refers to the six levels of cartographic data identified by Nyerges. Of these, the present paper will deal mostly with the second level--information structure--and how it meets the requirements of the first level--data reality. Standards for the four other, more abstract levels of cadastral data structure have been among the concerns of the CAMRAS projects, with some of the recommendations summarized in Part 3 of the CAMRAS Manual (APWA, 1979).

Definitions

The cadastre has been defined as a record of interests in land, including both the nature and extent of those interests (Panel on a Multipurpose Cadastre, 1980). All of the contents of a cadastre are referenced to one or more legally identified parcels of land, normally units of land ownership, but also including easements and other zones subject to various types of legal restrictions. The traditional county deed records in the United States do not qualify as cadastres because they provide neither a complete inventory of current cadastral parcels nor a listing of all current interests in these parcels. In contrast, county deed records covered by a "parcel index" to all documents filed in the past, say, 50 years would practically qualify as a "legal cadastre." An example is the deed recording system in Warren County, Ohio, consolidated in 1979-80 with the assistance of a demonstration grant from the U.S. Department of Housing and Urban Development.

A cadastre can be defined as "multipurpose" if the parcels which it delineates are used as the spatial framework for an integrated system of land-related data. The five basic components of a multipurpose cadastre are:

1. A reference frame, consisting of a geodetic network;
2. A series of current, accurate large-scale base maps;
3. A cadastral overlay that delineates all cadastral parcels;
4. A unique index number assigned to each parcel; and
5. A series of registers, or land data files, each keyed to parcel index numbers for purposes of information retrieval and linking with information in other files (Panel on a Multipurpose Cadastre, 1980, pages 13-14).

The Overlap Between Cadastral and Cartographic Data

Only the first three components listed above are cartographic data, and therefore the focus of this paper. The fourth component, parcel index numbers, needs to be included in the cartographic data as a link to other parcel data, which can be accomplished by the topological references in the cadastral overlay. However, the format of the identifiers need not be subjected to cartographic standards, except perhaps for the procedures used to abbreviate the numbers.

A multipurpose cadastre would be the logical source for these particular components of a cartographic data base. For the third component, which amounts to a total inventory of land parcels, the cadastre would be the official, definitive record authorized by state legislation. For the second component, the physical features that appear on the base maps, other sources may be available, but the cadastre would be more likely to have complete coverage of the locality at a larger scale. For the first component, geodetic control points, the multipurpose cadastre is a secondary source, recording locations of identified points that have been obtained from other offices, and serving as a comprehensive file on all such points in the locality.

Practically all of these cartographic elements proposed for multipurpose cadastres can be found today in the administrative and fiscal components of modern land data systems that operate at the land parcel level in certain large counties and cities, even though they may lack the current statement of legal interests that would qualify them as legal cadastres. These administrative registers of cadastral parcels support the functions of property tax assessment, regulation of buildings, recording of inspections, etc., and list owners only as a secondary source, which may be a few weeks or months behind the recording of legal changes of ownership in the deed recorder's files. Such administrative files of land data have been referred to as "fiscal cadastres," but the term "Multipurpose Land Data System" is more descriptive. The "MPLDS" of a city or county in the United States should suffice as the official source of the types of data described in this paper for most users of a cartographic data base, until the day when a multipurpose cadastre is organized.

It is interesting to note that the automation of land data files has moved in this same sequence in the Federal Republic of Germany, even though cadastres have been in place there for more than a century. The cadastral registers are fully automated for about a third of the local districts in Germany, and are being installed in the others, with the capacity for delivering the official records for any selected parcel or group of parcels at a computer terminal. However, these electronic registers remain only a secondary source of the identity of owners, and automation of the separate system of legal registers of owners (the "Grundbuch") is still in the experimental stage.

Obviously, only a portion of the data one normally would expect to have in a cartographic data base can be found in the land data system of a local government. Locations of natural phenomena and resources are not normally coded, unless they comprise the boundaries of parcels (e.g., shorelines). On the other hand, the base map of the cadastral system could be useful as a graphic record of locations of natural areas, especially if it reproduces the aerial photo imagery. The need for such procedures to compare parcel-related data with natural area-related data--presumably using the base map--has been a major concern for the designers of cadastral record systems.

If the cartographic data base is intended for plotting of maps at smaller scales than, say, 1:5,000, only selected elements of the parcel files will be relevant. Some of the data generated for maps at much smaller scales bears no relation to cadastral parcels--the regional land use patterns estimated by the "LUDA" program of the U.S. Geological Survey are an example. There would be no benefit from attempting to relate such information to the data structure of a multipurpose cadastre, unless the whole approach to the regional land use data is changed to link with compilations of parcel-level data.

CARTOGRAPHIC DATA ELEMENTS IN THE CADASTRE

This section identifies the specific elements of a digital cartographic data base which may be found in the three cartographic components of a multipurpose cadastre, or of a multipurpose land data system ("MPLDS"). Essentially, this is an agenda for subsequent discussions of the specific cartographic standards with the authorities responsible for cadastral data bases. Questions concerning how then to pursue this agenda are covered in the subsequent section.

Cadastral data appears to qualify as part of the "deep structure" of a map, in the terms described in Moellering's paper for this session. Specifying spatial relationships among real-world phenomena is one of the basic purposes of either a multipurpose cadastre or a MPLDS. The spatial relationships are captured by numerical field measurements, and geographic coordinates may then be used as the medium for recording and expressing the measurements. Presentation on maps is not a primary purpose of cadastral data, although it obviously can help in summarizing the data, searching for errors, etc.

The Point File

The file of uniquely identified points, each with an official location expressed in relation to a plane coordinate system, begins with the network of survey control points in the locality. These points will gradually lose their utility unless a public office assumes responsibility for maintaining them, which means replacing them when displaced or lost, and adjusting the official record of their locations when new field measurements show the previous records to be significantly in error. Some counties in Wisconsin, for example, are taking responsibility for maintaining survey control points in a square-mile grid, at section corners, or even in a half-square-mile grid, at the section quarter-corners (Bauer, 1976).

Where a public authority also takes some responsibility for maintaining an accurate record of boundary locations, the point file is extended to include the monuments that define these boundaries. By giving each such point a unique idnetity and record of its location, this record can be checked by subsequent field surveys of adjoining tracts, and adjusted as part of a network of lower-order survey control, if necessary. Monuments that mark the boundaries of public rights of way, or of Federal land, or of land that has been registered with a public authority, are examples of potential entries for an extended point file, although records of the responsible public authorities may not be adequate for this purpose.

In the Federal Republic of Germany, where the conversion of the entire cadastral map system to a digital record is undergoing operational tests, the point file has proven to be the key to tieing the new digital maps to the numerical records of field surveys. Every property corner is covered by a separate record in the point file, which includes, in addition to the type of point and its coordinates, the date of the latest survey, the surveying authority, and the level of confidence in the coordinates (Elmhorst, Sellge and Steinhauer, 1980). Many of these points also are monumented. The official record of location of every boudary segment thus is adjustable as new field survey measurements to the monuments become available. Where buildings are included in the cadastral overlay, at least one point on the perimeter of the building is recorded in the point file in the same manner. With such a systematic record of each element of the cadastre, it actually becomes possible to admit much less accurate location coordinates as an interim arrangement to fill gaps in a map system (e.g., digitized from available graphics), subject to updating through a computer terminal when more accurate locations are determined.

The point file of a multipurpose cadastre should be an authoritative source for the data in "base category code 150." of the files listed by the U.S. Geological Survey for its digital cartographic data base, described as "survey control and markers" (USGS, National Mapping Division, 1980, page 17).

The Cadastral Overlay

The essence of the cadastral map is the plot of boundaries of all cadastral parcels, which includes easements and zones covered by other types of restrictions. The boundary line segments in a cadastral overlay also must be topologically referenced to land parcel identifiers. Ideally, these are simply the line segments that connect the boundary corner points identified and located by the point file, as in the German system described earlier. However, for practical reasons, most of the property corners appearing on digitized property maps in this country will only be part of the "shallow structure" of the map, i.e., a graphic presentation, lacking a record of the coordinates determined from field measurements that would make them part of the deep structure. However, by leaving room in the data base for later entry of records for newly located boundary points, deeper underpinnings for the cadastral overlay can evolve.

It appears necessary that the cadastral overlay be stored in a vector data strucutre, to make possible the subsequent adjustment of point and line segment locations simultaneously. Scanners may seem to be the most economical means of digitizing existing graphics of property boundaries, but the subsequent conversion of the resulting raster data structure for the map into a vector structure must be anticipated, recognizing that the latter step may cost up to ten times as much as the initial scanning of the graphics (Starr and Anderson, page 7). Actually, the manual digitizing of point locations should be much more competitive with scanning where cadastral overlays are concerned, as compared with digitizing maps of natural features, because far fewer points are required to describe property boundaries, which tend to have relatively long and straight line segments.

The cadastral overlay is the authoritative source for the data in "base category code 090." of the files listed by the U.S. Geological Survey, and referred to as "boundaries" (USGS, National Mapping Division, 1980). It also should include most shorelines and some streams, channels and other elements of the "Hydrography" category, especially in base category codes 050., "inland wetlands," and 060., "coastal features and coastal wetlands," many of which are boundaries of legally restricted areas.

Features Identified on the Base Map of a Multipurpose Cadastre

The base map probably will be the least standardized of the three cartographic components of a multipurpose cadastre. Some counties that proceed to digitize their cadastral maps may choose to leave the base maps in purely graphic form, as simply the base for the original graphic cadastral overlay. In localities where coordinates of all property corners have been determined by field survey or at least on the detailed subdivision plans, the cadastral map can be generated directly from those coordinates, obviating the need for any base map at all.

Nevertheless, a base map should be anticipated as part of the typical multipurpose cadastre or MPLDS in the United States, and can be a rich source of locational data for a digital cartographic data base, especially where it is plotted on photographic imagery. Even if it is maintained as a line drawing, the base map should show at least waterways, shorelines, road centerlines, railroads, airports, tunnels and other major physical features. Where the users of the cadastre include the public utility systems, the base map probably will locate such things as utility poles and manholes as well. Locations of buildings and pavements also are options for the base map system.

Any or all of the features listed above for base maps may be included in the digitized base map of a multipurpose cadastre. Where all of them are included, this could provide the locational data for substantial portions of the cartographic features in the following base category codes of the U.S. Geological survey (USGS, National Mapping Division, 1980):

Code	Base Category
030.	Streams, rivers, irrigation channels or canals, ditches
040.	Lakes, ponds, reservoirs, springs, wells, glaciers and snowfields
100.	Roads, trails
110.	Railroads
120.	Water Navigation (canals or channels)
130.	Pipelines, transmission lines
140.	Other significant man-made structures

If a county decided to include all of the eleven base categories of cartographic data listed in this section in its cadastral map system, it would have captured most of the features listed by the U.S. Geological Survey for its digital line graphs, with only the following four remaining: hypsography (contours, slopes and elevations), surface cover, non-vegetative features and geographic names.

SPECIAL PROBLEMS IN STANDARDIZING CADASTRAL DATA

Standards for digital cartographic data will relieve some of the burden of system design for local offices needing to create a cartographic data base. But the standards also will impose other burdens such as coding data into formats that may not be the simplest and cheapest for the user at present, and perhaps the acquisition of data processing skills or equipment not otherwise needed to meet local requirements. The drafters of the standards will have to strike a balance between the level of technological sophistication to be offered to the more advanced users, on the one hand, and the number of smaller agencies which will be able to use the standards at all, on the other.

This section enumerates the major constraints on the standardization of cadastral record systems, which must be considered if the cartographic data standards contemplate use of land data from local governments in the data base. The underlying theme of this section, which affects the whole approach to the setting of standards, is the dispersion of the authority for local land records among 3,049 county governments in the United States (four-fifths of which are under 50,000 in population), and a substantial additional number of municipalities that also must be considered.

Need for Support from the State Government

A total of 26 states had issued specifications for local property maps by 1975, and 6 others had issued partiâl specifications (Almy, 1979). Of these 26 states, 16 were engaged directly in statewide property mapping programs. Presumably the responsibility for setting standards for cadastral maps had been delegated by each of the state legislatures to an administrative agency, given the technical nature of mapping specifications. Typically they are delegated to the department of revenue of the state, or its equivalent.

The fact that the mapping specifications are only advisory and not mandated in some of these states is not as significant as the fact that an administrative structure has been created in at least 32 states for the process of setting mapping standards. Further, 3 of the 18 states without cadastral map specifications as of 1975 did have a state program of technical assistance for property mapping.

Each of the responsible state agencies could be expected to be quite familiar with the capabilities and limitations of the local cadastral records agencies within the state, and thus to be a logical initial contact for the development of cartographic data standards for statewide use. Direct contact with all 32 or 35 such state agencies (or perhaps there are more by today) would be out of the question for a group drafting the proposed standards, but national associations such as the International Association of Assessing Officers could be helpful in establishing liaison.

Need for a Local Political Commitment

Digital mapping is not among the programs likely to be mandated by state legislatures in the forseeable future, but will remain under the provisions of enabling legislation at best, or even as strictly a local, "home-rule" option in some states. The county board of supervisors, or its equivalent, will have the final say on whether a standard digital mapping program is undertaken, even if their only formal options are to adopt a standard program defined by the state or none at all. Their decision will depend heavily upon whether savings in current operations can be demonstrated. An evaluation of the economic impact of the adoption of the cartographic data base standards thus will be important if adoption by local governments is expected. One possible outcome of such a study might be an indication of some need for financial assistance from higher levels of government.

Most local governments can be expected to prefer micro-computers for their automatic data processing for a variety of reasons. The large capital expenditure for a centralized county data processing operation requires a political decision at a level that may be difficult to obtain, in comparison with micro-computer equipment with costs measured in tens-of-thousands rather than hundreds-of-thousands of dollars. Further, most county administrations are located in small cities and towns that are relatively remote from data processing consultants and service bureaus, and welcome the type of equipment that can run on packaged programs. Cartographic data standards intended for local governments must be drafted with this type of processing system in mind.

National associations of local officials will be helpful in providing feedback from local elected officials in the process of drafting cartographic data standards, in the same manner as with state governments. The National Association of Counties has a designated staff liaison person for modernization of land data systems. Endorsement by "NACo" of an appropriate program of cartographic data standards may be as influential in gaining its acceptance as the endorsement of the Building Officials Conference of America has been in the implementation of the standard "BOCA" building code in many parts of the nation.

Need for Continuous Local Updating

If local land records are to be part of a standard cartographic data base, then the individual data elementts must be accessible for updating at any reasonable time by the designated local authority. Data formats that can only be updated in a batch process or through an expensive re-arrangement of an entire map overlay should be avoided. Further, the records for individual points or line segments in a cadastral data base should allow space for recording the date, authority and accuracy of each new data entry, in addition to the locational data. If these needs prove difficult to accommodate, then the local land records should be considered only as sources of the data to be read periodically, rather than as actual components of the standard cartographic data base.

Need for Public Access to the Data

A cadastral records system serves an important function of local government, helping resolve important relationships among its inhabitants concerning their interests in land. Certainly, a normal expectation is that the individual cadastral records should be retrievable within a matter of minutes at the appropriate public office, as a matter of public service. Further, the rights of citizens to inspect the public record concerning their own interests must be guaranteed as a matter of "freedom of information." This has not been a major problem for local land data systems, but may indicate the need to keep them segregated from certain other sources of cartographic data that may contain confidential information.

CONCLUSION

Standards for technical procedures are relevant only when they become institutionalized. The process through which this happens must be anticipated in the drafting of the standards. If new cartographic standards are to apply to data in a cadastral records system, then a slow process of adoption by states and local governments must be anticipated. Nevertheless, the benefits of having standard digital cartographic data generated through the routine administrative processes of local governments can be substantial, and worth the time and effort invested in the adoption process.

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SPATIAL ACCURACY STANDARDS FOR LARGE SCALE LINE MAPS

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ABSTRACT

Recent litigation in the courts of California has promoted new interest in the establishment of spatial accuracy standards for large scale (1/20,000 or larger) line maps. During the court proceedings it became clear that suitable standards for accuracy, based on 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. Seen as an element of interest to those preparing "National Digital Cartographic Data Standards," the current draft of the ASP specifications are presented and discussed.

INTRODUCTION

The unfavorable results of litigation in the courts of California in 1978 regarding a question of map accuracy resulted in new interest in preparation of map accuracy standards. At the annual meeting of the ASP/ACSM in 1979, Frank Moffitt, then president of the ASP, organized a task committee chaired by Morris Thompson to take the first step leading to the acceptance of a true consensus standard of spatial accuracy for large scale line maps. As a result of the recommendations of the Thompson Committee, the Task Committee for Photogrammetric Standards (TCPS) was organized and began its work during the summer of 1979.

It was soon realized that suitable consensus standards for many photogrammetric services would be of great value to the surveying and mapping community. However, reality dictated that initially only a few standards be prepared leaving other tasks for a permanent committee to be formed later. By autumn of 1979 the TCPS had selected three standards to pursue and identified points of contact within the TCPS to facilitate the preparation of the initial draft specifications. The standards and points of contact as initially selected are as follows:

Aerial Photography - Axel Hoffman
Photo Maps - Robert McGivern
Map Accuracy - Dean Merchant

With the formation of the Professional Practice Division within the ASP in February 1981, the TCPS became a permanent technical committee under the new division with the name "Specifications and Standards" (S^2) Committee. Since that time, work has continued on preparation of the original three draft standards. In addition, the S^2 Committee has recently begun work on preparation of a draft standard concerned with map symbology for large scale maps. The point of contact for this work is Robert Jacober.

DISCUSSION

Todays discussions pertain to digital cartographic data standards. Accepting the concept of "deep structure" as suggested by Professor Moellering and Dr. Nyerges, it is clear that standards for digital cartographic materials must eventually deal with the accuracy of spatial relationships. Accordingly, it is of interest to present the progress made by the Specifications and Standards Committee of the ASP in preparation of standards of spatial accuracy for large scale (1/20,000 or larger) line maps. Even though this proposed standard is intended for graphical cartographic presentations, the characteristics of the standard concerning the quantifiable definitions of spatial accuracy and the procedures for testing for compliance should also be of interest to those concerned with digitally based cartographic materials.

The ASP proposed specification for large scale map spatial accuracy is now presented. In its present form it is a 6th draft and contains the amalgamation of the thoughts of many, both users and producers of maps. Compromises have been effected, yet some points remain to be resolved. Your comments on the proposed standard are requested and will be considered by the Committee. Please address your comments to:

Chairman
Specifications and Standards Committee
American Society of Photogrammetry
105 North Virginia Avenue
Falls Church, VA 22046

INTRODUCTION TO STANDARDS

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 specification should be free of such quantifiably vague terms as "in accord 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 specification 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 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, the choice of coordinate accuracies is made.

PROPOSED SPECIFICATION

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

producer.
- This specification pertains to topographic and planimetric line (monochrome) maps at scales of 1:20,000 and larger.
- Statements of accuracy are in terms of ground coordinates as scaled from the map at publication scale or in terms of elevations as interpolated between contours.
- Statements of accuracy are in terms of error types most generally understood by the map user.
- 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. Failure of this accuracy test is the basis for rejecting the map.

Horizontal Accuracy Specification

Class 1 - Horizontal. Maps produced according to this specification equal or exceed the measures of horizontal coordinate accuracy 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% of well-defined points be within 0.54 mm (or 1/47 inch) of their correct planimetric position as measured on the map at delivery scale.

Vertical Accuracy Specification

Class 1 - Vertical. Topographic maps produced according to this specification equal or exceed the measures of vertical accuracy 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 errors for the corresponding accuracy class, map scale and error definition (See Table 1).

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 Class 3. map equal those for a Class 1. map multiplied by two and three respectively. Mixing classes between horizontal and vertical requirements is not advised.

Testing Map Accuracy

The accuracy of the map is tested for purposes of rejecting the map by comparing ground coordinates (X and Y) or elevations (Z) of at least twenty 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 standards of survey accuracy and specifications adopted by the United States National Ocean Survey are the basis for design of the check survey.

Check Survey. The check survey provides horizontal coordinates and elevations on at least twenty 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 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 I. maps are conducted in accordance with the standards of accuracy and specifications published by the NOAA of the U.S. Dept. of Commerce. Horizontal surveys by triangulation, trilaterion and traverse are conducted by Second-Order Class II methods or by Second-Order, Class I methods if analytical photogrammetric methods are used. Vertical surveys are conducted by Third-Order methods. Surveys for checking of Class II. and III. maps will be conducted by field procedures of proportionally lower accuracy.
-The positional distribution of the minimum twenty horizontal check points within the mapped area is chosen with horizontal separations from horizontal control and other horizontal check points of at least 0.10 x D where D is the full scale, maximum diagonal measurement of the rectangular map coverage. At least five horizontal check points are located in each quadrant of the map. The same distribution criteria applies to vertical check points. Horizontal and vertical check points may be the same points.

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

The check survey is conducted by one of the following arrangements:

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

Compliance Testing. Testing of the delivered map is necessary to assure that it complies with the required accuracies both in the horizontal and in elevation. Maps failing these tests will be rejected. 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%. Tests for significant bias error are based on the "Student's t" distribution and tests of precision are based on the "Chi-squared" distribution in accord with standard statistical procedures. Explanations and examples of bias and precision testing of maps are provided in Appendix A.

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 ticks or lines and their values
-statement of accuracy

one of the following statements shall be used to indicate map accuracy:

This map was tested on (date) and found to comply with the ASP map accuracy standards for planimetric coordinate standard errors (1σ) of ____(units) in X, ____(units) in Y, and ____(units) in elevation corresponding to a C.I. of ____(units). This test was supervised by (Name, title, qualifications if appropriate)

This map was compiled by procedures that can reasonably be expected to comply with the ASP map accuracy standards for planimetric coordinate standard errors (1σ) of ____(units) in X, ____(units) in Y, and ____(units) in Z corresponding to a C.I. of ____(units). This map was not tested to verify compliance but was compiled under the supervision of: (Name, title, qualifications if appropriate)

-statement of accuracy compliance testing:

if compliance testing was conducted, one of the following statements shall appear in the data block:

The check survey for purposes of map testing was conducted as part of the survey used for providing the basic control for map compilation.

The check survey for purposes of map testing was conducted independently from the survey conducted to provide basic control for map compilation.

Typical Map Sheet Delivery Scale* (inches to feet)	Map Accuracy Definitions (feet)		
	Standard Error ($1 \cdot \sigma$)	CMAS**	Maximum Error ($3 \cdot \sigma$)
1 to 10	0.10	0.21	0.30
1 to 20	0.20	0.43	0.60
1 to 50	0.50	1.1	1.50
1 to 100	1.0	2.1	3.0
1 to 200	2.0	4.3	6.0
1 to 250	2.5	5.4	7.5
1 to 500	5.0	10.7	15.
1 to 1000	10.	21.5	30
1 to 2000	20.	43.	60

Table 1E. Class 1. Accuracy Map Standard in terms of X <u>or</u> Y Survey Coordinates and in English Units

Typical Map Sheet Delivery Scale*	Map Accuracy Definitions (metres)		
	Standard Error (1σ)	CMAS**	Maximum Error (3σ)
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	1.34	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

Table 1M. Class 1. Accuracy Map Standard in terms of X <u>or</u> Y Survey Coordinates and in SI (Metric) Units.

* 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 accuracy.

** The Circular Map Accuracy Standard (CMAS) requires that 90% of well defined points will be in error by less that 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 (0.54mm) on the map. However, this standard is defined at <u>full scale</u> (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 σ min./σmax. $\geq$ 0.2. (see [ACIC, 1962] pp 59).

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

Table 2. Class 1. Accuracy Map Standard in terms of Elevation

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

Number of Check pts. (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	37.65
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

Table 3. Statistics for Complaince Testing
(Significance Level (α) = 5%)

*Test statistics for the number of check points (n) > 32, can be drawn from existing tables. See, for instance, Pearson, E.S. and Hartley, (1966) "Biometrika Tables for Statisticians, Vol. I & 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 followed by a test of precision is conducted 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 for 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% confidence level.

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

$$\overline{\delta X} = \frac{1}{n} \sum_{i=1}^{n} \delta X_i \qquad (1)$$

where: $\delta X_i \equiv X^c_i - X^m_i$

X^c_i , X^m_i ≡ the X survey

coordinates of point i from the check survey and as scaled from the map respectively

n ≡ the number of check points

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

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

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 3 to the sample statistic:

$$t_X = \frac{1}{s_X} (\overline{\delta X})\, n^{\frac{1}{2}} . \qquad (3)$$

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

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

The test for precision in the (X) survey coordinate direction is made by comparing the theoretical statistic ($\chi^2_{n-1,\alpha}$) drawn from Table 3 to the sample statistic:

$$\chi^2_X = \left(\frac{n-1}{\sigma_X^2} \right) s_X^2 . \qquad (4)$$

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 (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 0.05 metres. This could be typically associated with a scale of 1/2000 for a Class 1 map as indicated in Table 1M. Table A1 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 ($\delta X_i - \overline{\delta X}$) termed the bias-free discrepancy in the X-coordinate direction
-bias-free discrepancy squared $(\delta X_i - \overline{\delta X})^2$

From this basic data, the test statistics for the X coordinate direction can readily be computes as follows:

Compute first the sample mean ($\overline{\delta X}$): $\overline{\delta X} = \frac{1}{24} \sum_{i=1}^{24} \delta X_i = 0.133$ metres

Second, compute the sample standard deviation (s_X):

$$s_X = \frac{1}{24-1} \sum_{i=1}^{24} (\delta X_i - \overline{\delta X})^2 \;{}^{\frac{1}{2}} = 0.442 \text{ metres}$$

next compute sample statistic (t_X): $t_X = \frac{1}{s_X}(\delta\bar{X})n^{1/2} = \frac{1}{0.442}(0.133)(24)^{1/2}$

$|t_X| = 1.47$

Since $|t_X| < t_{n-1,\alpha}$ where $t_{n-1,\alpha}$ is taken from Table 3. for 24 check points, the map is accepted as free from signigicant bias in the X - coordinate direction.

Point (i)	δX_i (metres)	$\delta X_i - \delta\bar{X}$	$(\delta X_i - \delta\bar{X})^2$
1	-0.25	-0.38	0.146
2	-0.15	-0.28	0.080
3	-0.21	-0.34	0.117
4	-0.20	-0.33	0.111
5	-0.32	-0.45	0.205
6	-0.07	-0.20	0.041
7	0.21	0.08	0.006
8	0.55	0.42	0.174
9	-0.23	-0.36	0.131
10	-0.16	-0.29	0.086
11	-0.22	-0.35	0.124
12	0.21	0.08	0.006
13	0.24	0.11	0.012
14	-0.23	-0.36	0.131
15	0.61	0.48	0.228
16	0.12	-0.01	0.000
17	0.92	0.79	0.620
18	1.02	0.89	0.788
19	0.23	0.10	0.009
20	1.22	1.09	1.183
21	0.22	0.09	0.008
22	-0.23	-0.36	0.131
23	-0.24	-0.37	0.139
24	0.14	0.00	0.000

Table A1. Sample Test Data for X-Coordinate Direction

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

$$\chi^2_X = \frac{n-1}{\sigma_X^2} s^2 = \frac{24-1}{(0.05)^2}(0.442)^2$$

$$|\chi^2_X| = 17.97$$

Since $|\chi^2_X| < \chi^2_{n-1,\alpha}$ where $\chi^2_{n-1,\alpha}$ is taken from Table 3. 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 deviation (1σ) as stated in the accuracy specification.

REFERENCES

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

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