National Mapping Program

USGS Digital Cartographic Data Standards

Overview and USGS Activities

Geological Survey Circular 895-A

USGeoData

USGS DIGITAL CARTOGRAPHIC DATA STANDARDS

USGS Circular 895-A: Overview and USGS Activities
B: Digital Elevation Models
C: Digital Line Graphs from 1:24,000-Scale Maps
D: Digital Line Graphs from 1:2,000,000-Scale Maps
E: Land Use and Land Cover Digital Data
F: Geographic Names Information System
G: Digital Line Graph Attribute Coding Standards

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U.S. Geological Survey
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OVERVIEW AND USGS ACTIVITIES

By Robert B. McEwen, Hugh W. Calkins, and Benjamin S. Ramey

USGS Digital Cartographic Data Standards

Edited by Robert B. McEwen, Richard E. Witmer, and Benjamin S. Ramey

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Geological Survey Circular 895-A

1983

United States Department of the Interior

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Geological Survey

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First printing 1983
Second printing 1983
Third printing 1984

Library of Congress Cataloging in Publication Data

McEwen, Robert B.
USGS digital cartographic data standards.

(Geological Survey circular ; 895–A)
Bibliography: p.
Supt. of Docs. no.: I 19.4/2:895–A
1. Cartography—Data processing. I. Ramey, Benjamin S. II. Calkins, Hugh W. III. Title. IV. Series.
QE75.C5 no. 895–A 557.3s [526'.028'54] 83–600139
[GA102.4.E4]

Free on application to Distribution Branch, Text Products Section,
U. S. Geological Survey, 604 South Pickett Street, Alexandria, VA 22304

FOREWORD

In recent years, the disciplines of cartography and geography have undergone a rapid and striking reorientation as the techniques for digital collection and manipulation of data have evolved from fledgling laboratory procedures into dominant and driving forces that now pervade the disciplines. Digital techniques have provided a variety of new and powerful capabilities to digitally collect, manipulate, analyze, and display spatial data. However, this evolution also has introduced a number of new and complex problems. One of the most pressing problems, and one which is receiving particular attention at present, is the issue of digital cartographic data standards.

The U.S. Geological Survey (USGS) has been actively developing digital cartographic and geographic techniques for over a decade and has taken significant steps to develop and define in-house standards governing the various types of digital cartographic data that are being collected and archived in a national digital cartographic data base. The in-house standards are expressed in the form of specifications documents that were prepared to govern collection of the data and in the form of user guides that were prepared for distribution with the data.

In an effort to fulfill lead agency requirements for promulgation of Federal standards in the earth sciences, the documents have been assembled with explanatory text into this USGS Circular consisting of separately bound chapters. This Circular describes some of the pertinent issues relating to digital cartographic data standards, documents the digital cartographic data standards currently in use within the USGS National Mapping Division, and details USGS efforts to define national digital cartographic data standards.

Chapter A is an overview in which the major issues involved in developing digital cartographic data standards are discussed and the activities of the USGS related to digital cartographic data production and standards development are described in detail. Succeeding chapters comprise the pertinent documents that establish USGS in-house standards for the various types of digital cartographic data currently produced by the National Mapping Division--that is, digital elevation data, digital planimetric data, digital land use and land cover data, and digital geographic names data.

This compendium of relevant material is prepared to serve as a benchmark and to assist ongoing efforts to establish acceptable standards and conventions for both Federal agencies and the public.

Dallas L. Peck
Director,
U.S. Geological Survey
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PREFACE

This Circular is the result of the efforts of numerous individuals who have contributed to the research, development, and preparation of various digital cartographic and geographic standards for the National Mapping Division of the U.S. Geological Survey. The individuals named as chapter authors represent both the originators of the various concepts as well as the writers who expanded and clarified these ideas. Their contributions, either to the concepts or the writing, are of such magnitude as to warrant crediting as authors.

Atef A. Elassal was largely responsible for the original data structures and computer file formats that are used for the Digital Line Graphs and Digital Elevation Models. The attribute coding scheme was first developed by members of the Digital Applications Team under the direction of Robert B. McEwen. The Geographic Names Information System was conceived and developed by Sam Stulberg and Roger L. Payne. The Geographic Information Retrieval and Analysis System was developed by Robin G. Fegeas, K. Eric Anderson, Stephen C. Guptill, Cheryl A. Hallam, and William B. Mitchell. The small-scale Digital Line Graph data structure and attribute coding scheme was developed by Warren E. Schmidt and Michael A. Domaratz.

The Circular was compiled in part from various user guides and technical instructions of the National Mapping Division. These documents were originally prepared by several individuals; credit is acknowledged to G. Michael Callahan, A. Joan Szeide, William R. Allder, Vincent M. Caruso, Hugh W. Calkins, Donna Cedar-Southworth, and Cheryl A. Hallam. The compilation of the various guides, instructions, and other material into the Circular format was performed with major assistance by Clark H. Cramer, Eloise R. Byrd, and Cynthia L. Cunningham.

We acknowledge these substantial contributions that have led to this publication.

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Abstract

The discipline of cartography is undergoing a number of profound changes that center on the emerging influence of digital manipulation and analysis of data. Perhaps the most fundamental distinction between the digital representation of cartographic data and the conventional printed graphic is the need to explicitly and unambiguously code the attributes and spatial relationships among the various data elements. It is also necessary to follow acceptable practices for automated data processing. These requirements have led to the development by the USGS National Mapping Division of several documents that establish in-house digital cartographic standards.

In an effort to fulfill lead agency requirements for promulgation of Federal standards in the earth sciences, the documents have been assembled with explanatory text into a USGS Circular. This Circular describes some of the pertinent issues relative to digital cartographic data standards, documents the digital cartographic data standards currently in use within the USGS, and details the efforts of the USGS related to the definition of national digital cartographic data standards. It consists of several chapters; the first is a general overview, and each succeeding chapter is made up from documents that establish in-house standards for one of the various types of digital cartographic data currently produced.

OVERVIEW

INTRODUCTION

In recent years the disciplines of cartography and geography have undergone a rapid and striking reorientation as the techniques for digital collection and manipulation of cartographic and geographic data have emerged from fledgling laboratory procedures into dominant and driving forces that now pervade the disciplines. This reorientation has accelerated since the late 1970's with rapid advances in minicomputer and microcomputer technology and a steady downward trend in hardware prices that have placed digital spatial analysis capabilities within the reach of ever-increasing numbers of earth scientists and land managers. Digital techniques have provided the disciplines with a variety of new and powerful capabilities to digitally collect, manipulate, analyze, and display spatial data. However, this emergence has also introduced a number of new and complex problems. One of the most pressing problems, and one which is receiving particular attention at present, is the issue of digital cartographic data standards.

The U.S. Geological Survey (USGS) has been actively developing digital cartographic and geographic techniques for over a decade and has taken significant steps to develop and define in-house standards governing the various types of digital cartographic data that are being collected and archived. The USGS is also actively supporting ongoing efforts to define digital cartographic data standards applicable throughout the industry.

The purpose of this Circular is to describe some of the pertinent issues relative to digital cartographic data standards, to document the digital cartographic data standards currently in use within the USGS, and to detail the efforts of the USGS related to the definition of national digital cartographic data standards. It consists of several chapters. This first chapter is composed of two parts. The first part discusses the issues involved in developing digital cartographic standards, and summarizes the present USGS activities related to the development of such standards as a part of current digital data production programs. The second part presents a historical summary of digital cartographic activities at the USGS. Succeeding chapters are articles, user guides, and coding documents that have been separately prepared but which should be assembled in a single set of references. This compendium of relevant material is prepared to serve as a useful benchmark and to assist ongoing efforts to establish acceptable standards and conventions both for Federal agencies and the public. The documents that make up the succeeding chapters of this Circular represent the status of USGS digital cartographic data standards at this time and were developed to govern operational production programs for digital cartographic data collection.

As computer technology evolves, and as the disciplines of cartography and geography gain experience in the application and adaptation of digital techniques, the needs of those who use digital cartographic data will change. USGS digital cartographic data standards will evolve to meet the changing needs.

MAJOR ISSUES IN DEVELOPING DIGITAL CARTOGRAPHIC DATA STANDARDS

In the past, the discipline of cartography has been governed largely by conventions established through centuries of practical applications, rather than by systematically devised standards. The standards developed by and for the discipline were promulgated primarily to assure positional accuracy and consistent symbology on the printed map. For example, in the United States, explicit written standards have existed since 1941 pertaining to the positional accuracy of maps produced by Federal agencies. In that year, the then Bureau of the Budget issued the "Standards of Accuracy for a National Map Production Program." This document was subsequently revised and retitled on June 17, 1947, as the "United States National Map Accuracy Standards" and remains in effect today. Similarly, the symbology on printed topographic maps produced by the Geological Survey has been controlled largely through issuance of in-house documents that specify in considerable detail the criteria for graphic representation of the various features and other information shown on a map. Conscientious adherence to these very basic standards for accuracy and symbology in the production of the USGS Topographic Map Series has resulted in an accurate and dependable set of multipurpose base maps of remarkably uniform quality and appearance.

Today, however, the cartographer must deal not only with the traditional printed map, but also with a vast and rapidly growing volume of cartographic data in digital form. The basic standards of positional accuracy and consistent graphic representation that have so ably governed the production of printed maps in past years are certainly vital in defining and understanding the emerging world of digital cartographic data. However, as experience with digital cartographic data has grown, it has become clear that the positional and symbolization standards devised for the printed map provide a less than adequate guide when translated literally for the digital environment.

Perhaps the most fundamental distinction between the digital representation of cartographic data and the conventional printed map is the need, in the digital realm, to explicitly and unambiguously encode the spatial relationships among the various elements of the data. In graphic form, these relationships are implicitly conveyed and usually grasped by even the novice map user. In the digital realm, the explicit coding of spatial relationships is referred to as topological structuring and is absolutely necessary if the digital cartographic data are to be employed for the spatial analysis of geographic relationships. Topology, as defined for digital cartography and spatial analysis, requires that all lines be explicitly linked to nodes (ends of lines or line junctions) and that all areas be explicitly linked to their bounding lines (arcs). Although the concept is relatively simple to state and to understand, there are several distinct and viable methods and structures for digitally encoding these spatial relationships. Clearly, a standard for topological coding would be desirable if a proliferation of incompatible representation schemes is to be avoided. However, for both historical and technical reasons there are currently two major structuring schemes in use in the USGS.

One major scheme is oriented toward efficient digital representation of polygon (areal) cartographic data characterized by lines delimiting nonoverlapping homogeneous characteristics. The lines have no meaning other than to delimit the polygons. This scheme was developed for digital encoding via the Geographic Information Retrieval and Analysis System (GIRAS). The structure is described in detail in Chapter E of this Circular. The other major scheme is oriented toward efficient digital representation of planimetric cartographic data that consist of point (zero-dimensional), linear (one-dimensional), and areal (two-dimensional) features. In this scheme, lines may delimit homogeneous areas as in the polygon-oriented scheme, but more often the lines define inherently linear features such as roads and streams. This scheme was developed for digital encoding via the Unified Cartographic Line Graph Encoding System (UCLGES) of the planimetric information found on the various USGS Topographic Map Series. The structure is described in detail in Chapters C and D of this Circular. Considerations for either resolving the differences in favor of either a single structure or for the acceptance of a limited number of schema with suitable translation software are currently under discussion.

A second distinction between the traditional map and the digital representation of the map is the need, in digital representation, to numerically encode the attributes of the cartographic data that are normally conveyed to the reader of a printed map via color, line weight, varying symbology, labels, and so on. Some types of cartographic attributes are relatively easy to encode digitally. Highway classifications, route numbers, and the population of a town are examples. Other types are much more difficult. The notion of continuity of a stream or highway network is easily conveyed graphically through the varied symbolism on a printed map but is extremely difficult and unwieldy to define numerically in the digital representation. The concept of feature coincidence, such as a boundary along a highway or stream, is an aspect of cartographic information that is readily portrayed on the printed map but is sometimes quite difficult to unambiguously encode in the digital cartographic representation. As is the case with topology, a virtually limitless number of schemes are technically feasible for digitally encoding cartographic attributes. The actual numbers used to represent a feature are of far less concern than the global rationale of the coding strategy. Without a governing standard, a variety of mutually incompatible schemes will doubtlessly arise and will have a profound influence on future use of the data in geographic information systems.

A third crucial distinction between the traditional printed map and cartographic data in digital form arises from the fact that digital cartographic data must consist of a serial coded bit stream of information; that is, the data are in fact irrevocably, and sometimes inhospitably, bound into the existing computer environment that was not developed with spatial data handling in mind. Only as such, can digital cartographic data be manipulated via computer hardware and associated operating system software developed and produced by the automated data processing (ADP) industry. If the discipline of cartography is to effectively exploit technological advances in the ADP field, digital cartographic data must be structured, coded, and formatted to be reasonably compatible with data standards set forth by the ADP industry.

Within the three broad issues of topological structuring, attribute coding, and compatibility with ADP standards, several specific concerns related to standardization have surfaced. These are:

1. Terminology -- A precise definition of technical terms is necessary to insure effective communication.
2. Data Interchange Format -- The high cost of collecting digital cartographic data requires data exchange to minimize duplication of effort and maximize the use of general-purpose data bases. This in turn has precipitated a need for common interchange formats.
3. Data Quality -- Digital cartographic data quality depends on a number of factors, including the quality, accuracy, scale, and currency of the source materials, the data collection quality controls, and procedures used to check and verify the data. Ideally, every distinct unit of digital cartographic data should include explicit information defining the quality of the data set. Standards are needed to define levels of quality with a uniform interpretation.
4. Compatability With Standards in Related Disciplines -- Digital cartographic data standards should be compatible with similar standards set forth by the various related disciplines, including, for example, remote sensing, photogrammetry, geodetic and land surveying, digital image processing, and computer graphics.

BACKGROUND OF USGS DIGITAL CARTOGRAPHIC AND GEOGRAPHIC PROGRAMS

The USGS has Federal responsibility for preparing and making available multipurpose maps and fundamental cartographic data to meet the requirements of users throughout the United States. The role of the USGS National Mapping Division (NMD) in this mission is to prepare and make available topographic maps and associated base category data, such as hydrography, hypsography, and transportation systems. The NMD is actively adopting computer technologies to support this mission (Southard and Anderson, 1983; Starr and Anderson, 1982).

Geological Survey activities in digital cartography and geography began in the early 1970's with research work in the then fledgling field of automated spatial data analysis. Production of digital land use and land cover data began in 1973 in response to increasing demands by natural resource managers for development of digital techniques to collect, manipulate, and analyze earth science data. This program has evolved considerably over the years but continues today.

As the body of knowledge in digital spatial data analysis grew, it became apparent that fundamental cartographic data were needed in digital form to serve as a reliable reference base for digital spatial analysis. In addition, it was anticipated that increasing use of automated equipment and digital cartographic data would improve the timeliness and flexibility of map preparation with a possibility of eventually reducing overall costs. Accordingly, the concept of a National Digital Cartographic Data Base (NDCDB) was adopted, and a project was begun in 1977 to develop the capability to digitize, manage, and distribute base cartographic data consistent with the content and detail of the standard USGS 1:24,000-scale Topographic Map Series (McEwen, 1980). In 1978 the USGS began collecting these base category digital cartographic data in an operational program. The now familiar digital line graphs (DLG's) and Digital Elevation Models (DEM's) corresponding to content and accuracy of standard 7.5-minute quadrangles were the primary products of the program.

Other programs begun by the late 1970's include development of a Geographic Names Information System (GNIS) and development of a national small-scale digital cartographic data base. Work on the GNIS was begun with the objective of building a digital data base of all the names used on the 1:24,000-scale

Topographic Map Series. Collection of data for the national small-scale digital cartographic data base was begun in 1979 from the 1:2,000,000-scale sectional base maps of The National Atlas of the United States of America, and the first phase of this project was completed in mid-1982.

From the outset, it was recognized that basic standards governing data coding, structure, and accuracy were needed to insure the integrity and consistency of data sets. Accordingly, as each distinct digital cartographic data type was conceived and data production initiated, strict standards were developed in the form of in-house specifications pertaining to the accuracy, data structure, and feature coding to be used. It was also decided that USGS in-house standards should emphasize anticipated long-term future data requirements, accuracies, data content, and technical environment to build a comprehensive archival data base from which applications-oriented data could be derived. The specifications and other written documents then formed the basis for several descriptive user guides that were prepared for distribution with the data.

These specifications and their related user guides govern the current collection, processing, and distribution of the various types of digital cartographic data that have been and are being archived in the NDCDB. In the definition of each data type, a concerted effort was made to anticipate trends and hence maximize the useful life of the standards; mechanisms for expansion and evolution were included wherever feasible in recognition of the inevitability of change.

As the application of computer technology to the disciplines of cartography and geography has burgeoned in recent years, so has application of automated methodologies in kindred disciplines within the earth sciences (Frederick and Anderson, 1983). Recognition by Federal agencies of the pressing need for standardization of data elements and representations used in all automated earth-science systems resulted in the issuance of a Memorandum of Understanding (MOU) signed in February 1980 by the National Bureau of Standards of the Department of Commerce and by the USGS of the Department of the Interior.

Under the terms of this MOU, the USGS assumed leadership in developing, defining, and maintaining earth-science data elements and their representation standards for use in the Federal establishment. In addition to developing and maintaining standards, the USGS reviews and processes all requests referred by the National Bureau of Standards for exceptions, deferments, and revision of standards applicable to Federal earth-science information systems; assists the National Bureau of Standards in assessing the need, impact, benefits, and problems related to the implementation of standards being considered for development, or already developed, for use in the earth sciences; and works with other agencies in developing new data standards in the earth sciences.

Given the leadership role assigned to the USGS under the terms of this MOU and the specific tasks that are part of the National Mapping Program, the NMD has assumed responsibility for developing and maintaining cartographic and geographic data elements and their representation standards for use in the Federal establishment.

NATIONAL COMMITTEE FOR DIGITAL CARTOGRAPHIC DATA STANDARDS

Ultimately, the effectiveness of any standard is a function of the degree of acceptance accorded by the user community. This degree of acceptance, in turn, depends upon the responsiveness of the standard to demonstrated needs. Individual users will bear some temporary inconvenience and cost of adhering to a newly instituted standard if it is perceived that the benefit to the community as a whole promises an eventual return exceeding the initial investment of time and effort. Recognizing the need to involve the user community in the digital cartographic standards process, the USGS is actively supporting the work of the National Committee for Digital Cartographic Data Standards (NCDCDS) (Moellering, 1983).

Established in January 1982 and operating under the auspices of the American Congress on Surveying and Mapping, the NCDCDS consists of a steering committee and working groups on (1) Data Organization, (2) Data Set Quality, (3) Features, and (4) Terms and Definitions. Additional working groups may be created as needs are identified. The membership consists of professionals from Federal, State, and local agencies; private enterprise; and the academic community. The stated goal of the NCDCDS is to provide a professional forum for all involved public agencies and professional individuals to express their opinions, assessments, and proposals concerning digital cartographic data standards. The Committee will be requested to review these USGS standards; after sufficient time for circulation, discussion, reformulation, and comment, they will be submitted to the National Bureau of Standards for consideration as Federal Information Processing Standards (FIPS).

The primary tasks of each working group 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. To propose digital cartographic data standards for its technical area.

On completion of these tasks by the individual working groups, the steering committee will issue reports setting forth the proposed standards. It is anticipated that the work of the NCDCDS, with input from the entire user community, will result in digital cartographic data standards acceptable and beneficial to the entire cartographic community.

USGS DIGITAL CARTOGRAPHIC AND GEOGRAPHIC STANDARDS

In accordance with stated objectives, the USGS National Mapping Division is producing four basic types of digital cartographic and geographic data to meet the requirements of users throughout the United States:

1. Digital elevation data;
2. Digital planimetric data;
3. Digital land use and land cover data; and
4. Digital geographic names data.

Strict standards pertaining to accuracy, data structure, and feature codes have been developed in the form of both in-house specifications and data user guides to govern the collection and dissemination of each data type. A copy of each specification and user guide applicable to the four data types listed above is included as a chapter in this Circular. The USGS has taken this initial step in the standardization process to insure data integrity and consistency, to aid in the interpretation of data files, and to thereby encourage acceptance and use of a standardized data base, the NDCDB.

At present, all user guides and specifications describing the standards for the various NMD digital cartographic data types are in draft form pending review. On completion of this internal review, the documents will be reviewed by the USGS Data Standards Committee, other USGS Divisions, the Department of the Interior, and the NCDCDS. The USGS also intends to solicit comments and advice from other Federal and State agencies, private industry, the academic community, and the professional societies in the mapping field. Ultimately, the documents will be submitted to the National Bureau of Standards for adoption as standards applicable throughout the Federal establishment.

USGS DIGITAL CARTOGRAPHIC AND GEOGRAPHIC DATA

Succeeding chapters of this Circular contain considerable detailed information about each of the four data types. However, a brief synopsis follows.

Digital Elevation Data

Digital elevation data are produced and distributed in the form of digital elevation models (DEM's) each corresponding in coverage to the standard USGS 7.5-minute topographic quadrangles, and digital terrain tapes (DTT's) and arc-second DEM's corresponding to 1:250,000-scale topographic maps.

A 7.5-minute DEM may be created from a number of data sources, such as map contour overlays, profiles or terrain models scanned manually in photogrammetric equipment, or from automated orthophoto or stereoplotting equipment (Allder and others, 1983). Currently, the majority of the 7.5-minute DEM's are created using digitizing orthophoto equipment and consist of elevation values spaced at regular 30-m intervals, and referenced in the Universal Transverse Mercator (UTM) coordinate system. The standard DEM format, however, does provide for randomly spaced elevation values and a variety of coordinate referencing systems.

The 7.5-minute DEM's are archived in the NDCDB according to two distinct levels of vertical accuracy: (1) less than 7-m vertical root-mean-square error (RMSE) and (2) 7- to 15-m vertical RMSE. The 7-m vertical RMSE was determined to be a reasonable and attainable standard under a variety of terrain conditions and instrument constraints from 1:80,000-scale high-altitude aerial photographs.

The USGS distributes digital elevation data produced by the Defense Mapping Agency (DMA) from 1:250,000-scale topographic maps in the form of digital terrain tapes (DTT's) and arc-second DEM's.

Digital terrain tapes were produced by the DMA by digitizing the contours, ridgelines, and drains from 1:250,000-scale topographic maps and subsequently interpolating elevations to the nearest foot at 0.01-inch intervals at map scale. The 0.01-inch spacing corresponds to a ground distance of 63.5 m between elevation values. The data are referenced horizontally in the UTM coordinate system. Each DTT represents a 1° x 1° block that corresponds to the east or west half of the source 1:250,000-scale map. The DTT's are distributed by the USGS, as produced by the DMA, and do not conform to the standard USGS DEM format.

Arc-second DEM's are produced by the DMA by updating and reformatting existing DTT's, where feasible, and by scanning contours, ridgelines, and drains from 1:250,000-scale maps and subsequently interpolating where DTT coverage is nonexistent or inadequate. Elevation values are recorded to the nearest meter and are spaced at intervals of 3 seconds of arc, referenced horizontally in latitude and longitude coordinates. Three seconds of arc represents approximately 90 m in the north-south axis and a variable dimension (approximately 90 m at the Equator to 60 m at 50° latitude) in the east-west axis due to convergence of the meridians. Like DTT's, arc-second DEM's represent 1° x 1° blocks corresponding to the east or west half of the source 1:250,000-scale map, except in the State of Alaska, where the block size varies with latitude. Arc-second DEM's are structured to conform to the standard USGS DEM format.

Although interpolated elevation values are recorded to the nearest foot in DTT's and to the nearest meter in arc-second DEM's, the vertical accuracy of values in both the DTT's and arc-second DEM's is limited to the inherent accuracy of the contours on the 1:250,000-scale map used as the source for derivation.

Digital Planimetric Data

Digital planimetric data are produced and distributed in the form of digital line graphs (DLG's). Two distinct types of DLG data are currently produced: (1) large-scale DLG data digitized from 1:24,000-scale USGS topographic quadrangles and (2) small-scale DLG data digitized from the 1:2,000,000-scale sectional maps of The National Atlas of the United States of America. The basic applications of DLG data are to support automation of the cartographic processes and automated spatial data analysis.

The DLG file structure is designed to accommodate virtually all categories of planimetric data represented on a conventional line map. Point, line, and area data types are accepted. Each distinct data category (such as boundaries, hydrography, and transportation) is stored as a separate file or subfile in the NDCDB. These separate files are somewhat equivalent to the printing separates used in the conventional map production process. The data are classified at one of three levels according to the editing, enhancements, and spatial structuring performed on the files. The attribute coding scheme is open-ended and can be expanded as needed.

The DLG data format and structure were designed to contain, in digital form, the planimetric data shown on the standard USGS 7.5-minute topographic quadrangles. The attribute coding scheme is designed to accommodate basic cartographic data categories such as elevation, transportation, or boundaries, as well as additional thematic data categories.

The small-scale DLG data were digitized from the 1:2,000,000-scale National Atlas sectional base maps to meet the expressed needs of the USGS and other user agencies for a complete small-scale national data base. These DLG data files are available in a topologically structured format suitable for use with geographic information and spatial data analysis systems. The data are also available in a simplified graphics format (information defining topological structure is omitted) designed especially for automated graphics production. Both formats include feature codes assigned to facilitate automated production of base maps and special-purpose graphics at scales ranging from 1:2,000,000 to 1:10,000,000. Two capabilities are built into this feature coding scheme: (1) the size of a feature is coded to permit selection of features appropriate for the output scale and (2) the type of feature is coded to permit logical aggregations by types (Selden and Domaratz, 1983). Coverage is nationwide, and the data are stored in multistate regional blocks to limit discrete files to a manageable size while minimizing edge-join problems in applications requiring data aggregation. The total number of blocks is 21; 15 for the conterminous United States, 5 for Alaska, and 1 for Hawaii.

Digital Land Use and Land Cover Data

Digital land use and land cover data are derived from land use and land cover and associated maps (1:250,000- and 1:100,000-scale). The source maps depict land use and land cover in polygon format, and the digital data are accordingly structured in a highly compressed arc-segment polygon format designed to facilitate digital manipulation and analysis using the computer programs of the Geographic Information Retrieval and Analysis System (GIRAS) (Mitchell and others, 1977). In tandem, the digital land use and land cover data and the GIRAS software constitute a functional geographic information system suitable for automated analysis of a variety of resource and planning problems.

A separate digital data file is created for land use and land cover and each of four associated data categories: (1) political units; (2) census county subdivisions; (3) hydrologic units; and (4) Federal land ownership. Each file consists of arcs and nodes defining the perimeters of nonoverlapping areas, and numeric codes (polygon labels) that identify the category to which each area (polygon) belongs. To minimize data volume, arcs separating polygons are digitized only once. A system of pointers is used to define the topological structure and uniquely identify the arcs that must be connected to form a given polygon.

The GIRAS software provides the capability to perform a variety of manipulation and analysis functions with the digital land use and land cover data including rotation, translation, and scaling of coordinates; conversion to geographic coordinates and from geographic coordinates to specified map projections; conversion from the arc-segment polygon structure to grid cells; conversion to standard polygon format; production of area summary statistics from polygon or grid-cell data; production of border (perimeter) and adjacency statistics; lengths of particular polygon types from polygon data; and production of a variety of output graphics.

Digital Geographic Names Data

Digital geographic names data are collected and archived via a multipurpose software and data base complex collectively termed the Geographic Names

Information System (GNIS) (Orth, 1980). The GNIS was conceived and developed to meet six basic objectives:

1. To assist the U.S. Board on Geographic Names in establishing uniform name usage throughout the Federal sector;
2. To provide a computerized index of names found on maps compiled by Federal, State, and private organizations;
3. To eliminate the need to create special-purpose data bases containing similar information;
4. To provide an interface for integration of data from other systems for multidisciplinary use;
5. To provide a standard for digital representation of geographic names data; and
6. To meet Federal public information requirements prescribed by law.

The master plan for the GNIS includes five distinct data bases:

1. National Geographic Names Data Base;
2. USGS Topographic Map Names Data Base;
3. Generic Data Base;
4. National Atlas Data Base; and
5. Board on Geographic Names Data Base.

The first four data bases are currently active and addressed in Chapter F. The fifth data base and appropriate documentation will be added at a later date.

The National Geographic Names Data Base is the primary data component of the GNIS and consists of descriptive information pertaining to all named features (except roads, communication towers, and triangulation stations) found on the maps of the USGS Topographic Map Series. Additional information garnered from other graphic and textual sources is being added on a daily basis. The National Geographic Names Data Base is divided into 57 files representing the 50 States, six territories, and the District of Columbia. As many as 29 distinct data elements may be recorded to describe each named feature.

The USGS Topographic Map Names Data Base, as the name suggests, contains descriptive information pertaining to the official names of the individual map sheets in the USGS Topographic Map Series. The data elements include descriptors for current and historical names, location and extent, and scale.

The Generic Data Base is structured to serve as a research tool and as a depository for textual descriptive information for the GNIS. A total of 61 feature categories (designators) are defined and cross-referenced to specific types of features found on published maps. This data base also contains text describing unusual generic information (location, application, reason for unusual application) and a complete bibliography of source materials (other than the USGS Topographic Map Series) employed in the compilation of the GNIS.

The National Atlas Data Base currently contains descriptive information pertaining to the geographic names found in the index of The National Atlas of the United States of America. This data base is intended and structured to eventually serve as an abridged version of the National Geographic Names Data Base.

Access to the various data bases within the GNIS is accomplished via the General Information Processing System (GIPSY) software developed at the University of Oklahoma. GIPSY provides searching and sorting capabilities that allow the user to selectively extract information and assemble logical aggregations of data.

DIGITAL CARTOGRAPHY IN THE NATIONAL MAPPING DIVISION

BACKGROUND

The National Mapping Division of the USGS is actively adopting computer technologies to support its mission of collecting cartographic data at a national level for the United States and its territories. Early, it was recognized that traditional cartographic methods would someday be replaced by predominantly digital techniques, and the concept of a national digital cartographic data base was embraced during the mid-1970's. The desirability of such a data base was generally accepted, but the process of turning such a general concept into reality was recognized to be fraught with both technical and procedural difficulties. This review is a progress report on the NMD experience to date outlining what has been accomplished, the issues addressed, the concepts and strategies adopted, and finally some of the unresolved problems that are still facing us.

The USGS through the National Mapping Program has the objective of preparing and making available multipurpose maps and fundamental cartographic data to meet the requirements of users throughout the United States. The NMD has concentrated its efforts on base category data as found on topographic maps, such as hypsography, hydrography, and transportation systems. Other Federal agencies and other USGS divisions are responsible for collecting additional map data of public value, identified as nonbase categories. The National Ocean Service is charged with the responsibility for geodetic surveys and for the preparation of aeronautical and nautical charts. The Defense Mapping Agency is responsible for maps and charts on a worldwide basis to meet national defense requirements. The Water Resources Division and the Geologic Division of USGS collect data and prepare thematic maps of hydrologic and geologic information. The Bureau of Land Management has responsibility for cadastral surveys related to the U.S. Public Land Survey System.

The principal activities associated with the NMD portion of the National Mapping Program can be conveniently identified by the conventional types of map products produced--1:24,000-scale topographic maps (the largest activity and the largest scale national map product), 1:24,000-scale orthophotoquads, and 1:100,000- and 1:250,000-scale regional maps. There is also significant activity in land use and land cover mapping at 1:250,000-scale, State and national small-scale maps, and a variety of special maps, including image maps prepared from Landsat data. A major new activity is the development and production of digital (computer-compatible) base category cartographic data to support automated cartography and automated spatial data analysis.

It may be useful to list the base data categories found on the 1:24,000-scale maps as these categories are found in the official manual that authorizes the National Mapping Program.

1. Reference systems -- Geographic and other coordinate systems not including the public land survey system network.
2. Hypsography -- Contours, slopes, elevations.
3. Hydrography -- Streams and rivers, lakes and ponds, wetlands, reservoirs, shorelines.
4. Surface cover -- Woodland, orchards, vineyards (general categories only).
5. Nonvegetative features -- Lava rock, playas, sand dunes, slide rock, barren waste areas.
6. Boundaries -- Political jurisdictions, national parks and forests, military reservations. This category does not fully set forth land ownership or land use.
7. Transportation systems -- Roads, railroads, trails, canals, pipelines, transmission lines, bridges, tunnels.
8. Other significant manmade structures -- Buildings, airports, dams.
9. Identification and portrayal of geodetic control, survey monuments, other survey markers, landmark structures and objects.
10. Geographic names.
11. Orthophotographic imagery.

Not included in this list is the land use and land cover data that were authorized separately to the USGS and should now be considered a NMD responsibility.

The USGS has had several separate research and development activities in digital cartography and automated spatial data analysis (Guptill, 1978). Since the early 1970's, the USGS has done significant work in developing the theory and practice for automated spatial data analysis. Experiments using Landsat data for land use and land cover evaluation were started and continue today. In addition, a practical system of computer programs was developed to batch process the land use and land cover data digitized with automated line-following equipment and to produce topologically structured polygon data files. This was a significant development for it allowed the land use and land cover polygon data then being compiled in graphic form to be entered into the computer for sophisticated geographic spatial analysis. Techniques also were developed to convert the files of polygons into a regular cellular format. Thus it became possible to efficiently overlay multiple data sets.

A Digital Applications Team was formed in 1977 to focus in a single group the scattered ongoing activities and to perform further research, development, and applications (McEwen, 1980). The goal was to develop a prototype capability to digitize, manage, and distribute cartographic data represented by the content and detail of the standard USGS 1:24,000-scale topographic map. This required that numerous systems of computer programs be developed to process cellular arrays (such as elevation data), networks (such as streams), areas (such as political units), and points (such as cultural features). It was determined that the resulting files should be topologically structured and that an extensive set of attribute codes would be required for the extremely high level of information contained on a map. Some types of map information are relatively easy to encode--a highway classification, for example--while other types are more difficult. Maintaining the notion of continuity of a stream network or a highway grid (so easy to see on a printed map) raises many perplexing questions in a computer environment. The data categories, such as boundaries, Public Land Survey System Net, streams, and transportation from 1:24,000-scale maps, were digitized manually for a few pilot projects and batch processed into standard DLG files for entry into a data base. The Division had been operating automated orthophoto equipment since the mid-1970's for the production of 1:24,000-scale orthophotoquads from high-altitude aerial photographs, and a byproduct of this operation is an array of digital elevations that are processed into DEM's. Several thousand quadrangles of raw data existed on tapes, and procedures were developed to process these data and produce a data base.

Recognizing that manual digitizing was an expensive roadblock, action was initiated to develop an automated raster scanning and editing system. The decision to pursue raster technology was made with full recognition of the consequent requirement to develop raster-to-vector conversion and editing procedures and with the anticipation that a symbiotic relationship would develop with digital image processing technology.

The Division operates four production mapping centers, and each was equipped with various pieces of digital equipment (manual digitizing equipment, precise automatic plotters, multistation interactive editing equipment, minicomputers, and teleprocessing terminals). Each mapping center initiated production of digital data files. After initial processing, data are transmitted to the mainframe computers in Reston, Va., for final processing, topologic structuring, and entry into the primary digital cartographic data base in a standardized archival format. The data base system consists of a unified set of custom cartographic computer programs built around the capability of a hierarchical data base management system--a standard capability on the USGS mainframe computer. The custom programs perform entry, update, reformatting, retrieval, and other housekeeping functions such as data security, reports, index maps, and internal management of the digital cartographic files.

The introduction of digital equipment into the NMD mapping centers also led quite properly to automating various phases of the conventional mapping process (Powell, Osick, and Thomas, 1979; Troup and Powell, 1979). Stereophotogrammetric plotters equipped with digital encoders have been used to produce files that, after some editing, can be used to photoscribe a base sheet from several of the map categories. A voice data terminal allows the stereoplotter operator to verbally enter commands and attributes without diverting attention from the optics or plotter controls. A voice synthesizer is used to provide an auditory confirmation of the instructions. While the digital stereocompilation process may be slightly more expensive than traditional preparation of the usual manuscript copy, the almost total elimination of manual scribing results in a cost advantage. At the moment, the digital lines and points so produced do not contain all the information needed to build a topologically structured cartographic data file.

The Division has also had under development since the mid-1970's a Geographic Names Information System with the objective of building a digital data base of all the names used on the 1:24,000-scale USGS Topographic Map Series (Orth, 1980). The name of a feature is entered together with the class of feature (such as stream, mountain, or place) and the coordinates where the name appears on a certain map. Additional data are encoded to describe the link to other maps where the same feature may be continued (often for long distances in the case of features such as rivers). The file also contains textual reference to the decision lists maintained by the Board on Geographic Names. Data encoding and editing are complete for all 50 States. The data base will be valuable for automatic type preparation, for production of gazetteers, and as a source of data for investigating automated names placement--one of the more expensive map-finishing operations that conceptually defies automation.

By mid-1979 the various digital research and developmental activities at the four mapping centers and within the research staff at the Reston headquarters of the USGS had developed to the point where a major review and assessment were needed. The Chief, National Mapping Division, therefore appointed a Digital Mapping Program Steering Committee to develop detailed plans for the Digital Mapping Program including the identification and evaluation of research and development problems, development of alternatives, and the recommendation of realistic objectives for the program. The intensive review of NMD digital activities by this committee led to the recommendations that (1) sufficient digital data production capability existed to start producing some digital data files and (2) a phased program of additional research and development would be required before the full digital mapping program could be implemented.

CURRENT CONCEPTS AND ACTIVITIES

The NMD is now in continuous production with a capability to provide digital cartographic and geographic data at an accuracy and level of detail equivalent to the 1:24,000-scale USGS Topographic Map Series for cartographic uses (1:250,000-scale for land use and land cover data) and topologically structured to serve geographic information systems. Each 1:24,000-scale topographic map covers a quadrangle of 7.5-minutes of latitude and longitude, there are approximately 55,000 maps required to cover the conterminous United States and Hawaii. In Alaska, except for a few 1:24,000-scale maps around Fairbanks, the largest scale maps are 1:63,360 (1 inch = 1 mile). The country is approximately 80 percent mapped with conventional line maps at these scales, and there has been a major emphasis over the past decade to achieve complete coverage and replace some of the smaller scale maps, such as some 1:62,500-scale maps that date from the years immediately following World War II. The goal of complete up-to-date map coverage is still a number of years away; meanwhile, the level of activity in map revision is growing. The new capability had to be integrated into these ongoing activities.

The scenario that presented itself to the NMD had the following objectives:

1. To continue the preparation of conventional line maps by the most economic methods;
2. To convert the large amount of existing line map data into a computer-compatible form;
3. To establish a digital cartographic data base that would serve in the future as a foundation for geographic information systems; and
4. To reconfigure the conventional mapping process to take full advantage of automation, especially as it will influence map revision.

A number of secondary objectives also have emerged. These include the preparation of a small-scale data base that can be used to prepare special graphics and index maps of a national scope and the development of some data base categories for use at intermediate scales, that is, 1:100,000 to 1:250,000 (Schmidt, 1981; Selden and Domatatz, 1983). These primary and secondary objectives introduce a number of conflicts that require technological and program-management solutions.

The first objective, continuation of an economically viable conventional mapping program, requires that many of the well-established analog photo-mechanical techniques of map preparation be continued. Until recently, at least, our evaluation of completely digital map-making in other mapping organizations worldwide indicated that attempts to totally automate map preparation usually resulted in higher initial costs and that the assumed cost advantages in deriving other maps at smaller scales or in conducting map revision had yet to materialize. Thus, the (former) Topographic Division appeared to be waiting on the sidelines while many mapping organizations pursued automated cartography in the early 1970's with the goal of producing a complete digital map. We will return to this issue in a moment.

The second objective, to convert the large number of existing maps to computer-compatible form, presented two conceptual problems. The first related to the technology to be adopted for digitizing. While equipment capable of digitizing data at the photogrammetric compilation stage of map preparation is available, such equipment is not suited for digitizing existing map separates and is overly restricted by the conventions of the current mapping process. Some data categories (for example, boundaries) cannot be obtained from aerial photographs, and some doubt exists that efficient procedures can be developed to allow a plotter operator to capture all of the information needed to produce topologically structured data files.

The second problem is largely economic. Until a sufficient number of maps are converted to computer-compatible form, the proposed applications will not be realized. Murphy's Law for cartography has two cardinal postulates: (1) map data are always requested by a user over unmapped areas and (2) the area of user interest always straddles some type of zone boundary. Data users' needs require the archiving of a large "critical mass" of data. Until that quantity of data is archived, a great deal of the data will go unused, and many users may think that it is more effective for them to independently digitize the data they need. The capital investment to assemble a data base of "critical mass" can be quite large and the risks, even for a Government organization, are significant. The pressure to show short-term effectiveness while pursuing an essentially long-term goal has all of the elements of private enterprise investment. Thus, the Division has adopted a number of digitizing strategies for data capture.

These strategies require a rigidly defined archival data file structure that is used for entering data into the data base. This defined structure is necessary to avoid a plethora of data formats developed only for an immediate application or for an existing hardware configuration.

At the same time, multiple types of digitizing equipment were installed and software was developed to preprocess the data into the standard format. Manual digitizing tables continue to be used and can be quite effective for data categories consisting of many straight lines or single points. Some manual digitizing tables are integral components of interactive editing systems. A number of photogrammetric plotters have been retrofitted with digitizers to obtain the usual data categories (such as transportation systems, drainage, and contours) that are depicted during compilation of new maps. Digitizing also was conducted under contract where automated line-following equipment could be used effectively. The equipment used to prepare orthophotographs included the capability to simultaneously deliver a matrix of digital elevations. Developmental work is underway in the area of raster scanning of existing map separates and the editing and conversion software needed to change this raw data into the standard data base format.

The third objective, to establish a digital cartographic data base suited to geographic information systems, also has presented a number of problems. Geographic information systems contain their own version of the "chicken-and-the-egg" riddle. On the one hand, they require preexisting digital cartographic data; at the same time, a major part of the justification for digitizing maps is to serve large geographic information systems. Many current prototype geographic information systems have either a deceiving emphasis on color cartographics and marginal quality data or else an emphasis on (expensive) custom-developed thematic data and no link to a general-purpose digital cartographic and geographic data base. The NMD must anticipate future requirements that are now only partially perceived. Considerable effort is being devoted to developing working relations with other Federal agencies having application missions. Meanwhile the budgetary process is being addressed to secure adequate funding, and digital data pricing policy has been put into effect. The concept of using the facilities and expertise of the NMD to provide digitizing and data management for other nonbase categories on request (a digital service center) is still under active consideration.

The fourth and final objective in the NMD plan is to reconfigure the conventional mapping process to take full advantage of automation. The rapidly increasing capability of all types of computers and automated equipment, coupled with decreasing processing costs (more bits for the "buck"), makes this a very desirable goal especially in light of escalating personnel costs. The previously mentioned perspective that led to our delay in producing maps digitally is less true today. The current NMD mapping process as shown in figure 1 is largely a linear sequence of operations, all of which must be accomplished to produce the final product--a printed map. Appended to the process are several digitizing operations that spin off some categories of data for the digital cartographic data base.

Because the process is sequential, any delay in a particular phase--field survey or acquisition of aerial photography--adversely affects all later phases and results in excessive time between authorization of a map and its appearance in printed form. The finality of committing a map (usually a contiguous set of maps in a project) to printing requires that current information on all data categories in a region must be gathered concurrently to converge into a set of coexisting film separates that have one primary purpose--to print the map. Different data categories, however, have vastly different cycles of change, and even adjacent maps in an area may have varying rates of change. It is often impractical to revise a map until sufficient change has occurred in several categories over a sufficient number of adjacent maps to justify a project. Then all categories must be evaluated in the process of focusing on a new printing.

The proposed future mapping process, shown in figure 2, emphasizes the digital cartographic data base and the independent assemblage of data categories, each according to its own requirements for currency and by methods most appropriate to the category. Boundaries might, for example, be encoded from survey records without ever being depicted on a map. Two results of this revised mapping concept are (1) a greatly decreased emphasis on the printed map as the overriding reason for gathering cartographic data for the archival record and (2) a greatly increased flexibility and capability to respond to a variety of data requests, including conventional base maps but also special maps and digital map data. The NMD will become a manager of cartographic data categories and not merely (as in the past) a mapmaker. It is entirely possible that the current practice of printing several thousand copies of every map may become obsolete as advances in high-speed, limited-run printing devices and electronic displays make the preparation and distribution of individually customized maps more viable.

Another effect of emphasizing data categories in a data base will be the ability to manage a particular category according to the full range of its applications and not be constrained by the printed representation. Digital elevation data can define contours or can be in the form of an array that is more suitable for other applications, such as in an analysis with Landsat multispectral data. Digital elevations also can be extracted from the data base to drive a controller on automated orthophoto instruments and thus eliminate the requirement for an operator in the scanning operations. The evolution of automated cartography seems to lie not so much in the area of automating the conventional

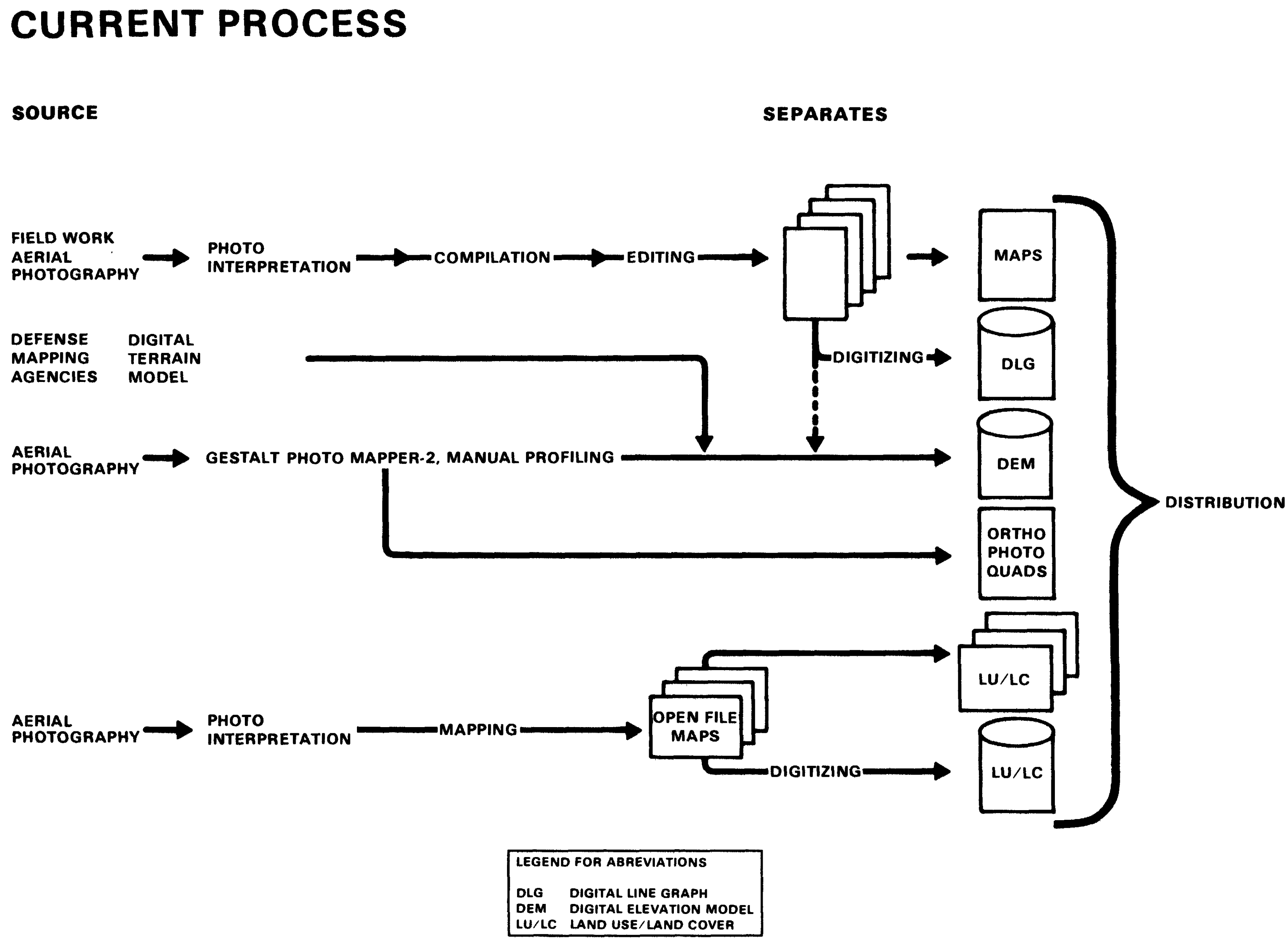

Figure 1.--Current mapping process of the USGS National Mapping Division.

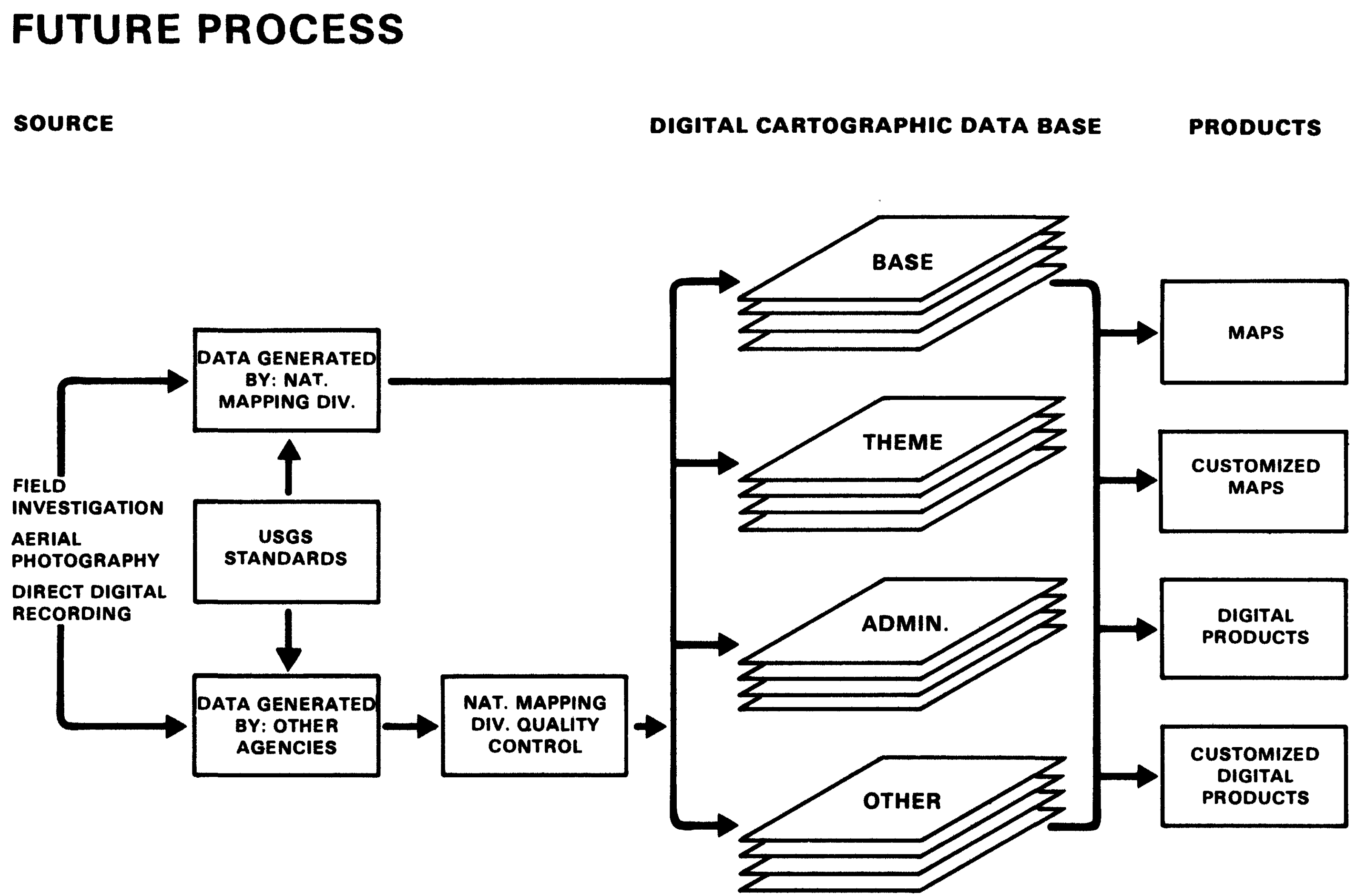

Figure 2.--Proposed future mapping process of the USGS National Mapping Division.

sequential process but in bringing categories of data into a cartographic and geographic data base concept and then using the data base for map preparation. Some data categories can be developed relatively quickly and easily and have significant payoffs outside the traditional map. Other categories may be more difficult to acquire or may not require or justify the additional complexity of being structured for the data base. When needed on a map, these categories might be handled much as at present.

DATA STRUCTURE AND DATA MANAGEMENT

Two major issues that must be solved early when dealing with digital cartographic/geographic data are data structuring and data management. Successful resolution of these issues is crucial to the long-term viability of a national data base because, when data are transformed from their graphic (map) representation to a digital form, two things occur:

1. The spatial relationships among various elements of the data that are visually obvious in the graphic form can be completely lost if the digital encoding is not done with extreme care and considerable forethought about future applications.
2. The transformation of cartographic/geographic data from a graphic to digital representation generates very large data volumes that require explicit management strategies to prevent complete chaos in the resulting data base.

Taking the first issue, data structuring, the NMD has recognized the necessity of developing a data base that is topologically structured both for automated cartography and for geographical analysis. Topological structuring essentially maintains the spatial relationships inherent in the data that are usually obvious to the human mind when visually examining a graphic representation of the data. Topology (the mathematical study of the relationships and transformations of geometric configurations) as defined for cartography and automated spatial analysis requires that all lines be explicitly linked to nodes (ends of lines or line junctions) and all areas be explicitly coded to the bounding arcs (lines). All nodes, lines, and areas are completely and unambiguously linked into a completely defined digital line graph that can be interpreted in a computer environment without resorting to human perception and assistance. Maintaining the topology of the data is especially important in applications related to geographic information systems. For example, in geographic analysis, we want to retain the following spatial relationships:

1. The coordinate position of a point with respect to other data elements expressed as points, lines, or areas (this includes map projection parameters);
2. The shape and size of an area (the lines that bound a polygon must be linked to each other and to the polygon they define);
3. The intersection between points, lines, and areas (when a point falls within an area, when a line cuts through an area, and when two areas overlap or intersect);
4. The property of connectivity for lines (through a stream network or a road system, and so on); and
5. The property of adjacency (when two areas share a common boundary).

These relationships have all been previously recognized in the literature on automated geographical analysis and were adopted and developed through the USGS Geographic Information Retrieval and Analysis System (computer programs for land use and land cover analysis) (Mitchell, and others, 1977). These same relationships, plus others, are just now being recognized as equally important to automated cartography. Some of the cartographic relationships are as follows:

1. Coincidence of features. -- When, for example, a road and a boundary occupy the same geographical location, this must be known through explicit coding to appropriately instruct automated plotting equipment which feature

takes precedence in producing a graphic image. Failure to specify this would produce a very unpleasing, and sometimes unreadable, graphic product.

2. Multiple feature coding. -- Often a "line" in digital form has several meanings; for example, it symbolizes a road with a list of attributes, some of which must be translated into cartographic symbols. The same line may also represent part of a boundary. Once again, the initial encoding of the data must contain the relationships necessary for automatic plotting equipment to operate efficiently on a variable string of attribute codes, such as highway type, width, route number, and type of boundary.
3. Data generalization. -- Automated cartographic processes allow for great flexibility in changing the scale of the graphic products. There are, however, limits to the amount of scale change that can be accomplished without serious distortion of the data. There is also potential for cartographic dishonesty in displaying data at a scale larger than warranted by the information content. As scales become smaller, certain features, because of size or proximity to other features, must be deleted from the graphic product. Either very intelligent algorithms will be needed to automatically accomplish such deletions or else explicit topological codes must be entered into the data to identify situations where such adjustments must be made.
4. Data ordering. -- The ordering and placement of the data in the file are of critical importance for automated cartographic operations. Data retrieval, editing, and plotting must be optimized for maximum efficiency. Interactive editing systems and precision plotters have traditionally been rather slow, and, while some improvement may be anticipated, a file structure that permits efficient use of the equipment may be critical to the success of an operation.

The DLG and DEM files may be structured in one of three ways, called levels:

1. Level 1 -- This is the simplest structure which maintains the original (raw) data in a standardized format, coded to prescribed standards, and edited for normal input errors. The main purpose of this level is to meet three needs: (1) to provide a source of digital data quickly; (2) to provide data to users who can complete the structuring process; and (3) to provide data for plotting or display systems of low or moderate cartographic quality.
2. Level 2 -- This structure is designed to support graphic display or plotting equipment of high cartographic quality. The DLG files contain extensive attribute codes that describe the graphic elements. The DEM files are enhanced for consistency and filtered to reduce data volume.
3. Level 3 -- The third structure is used for fully topologically structured data files designed to be integrated into geographic information systems. All topological relationships have been defined for the DLG data, and the DEM data have been modified to be consistent with the corresponding planimetric data (represented by the DLG data file).

These three levels do not easily aggregate in an upward direction. Data collected under criteria and specifications for level 1 or level 2 cannot always be enhanced to level 3, and, to achieve this level, it is often easier and more cost effective to recapture the data in level 3 form. However, the reverse process of extracting level 2 from level 3 data, or level 1 from level 2, is more easily accomplished. This fact is of profound importance in planning data acquisition with a view toward future requirements.

The second issue, data management, is crucial because of the large data volumes generated from graphic products and because automated systems are storing two- or three-dimensional data in a one-dimensional storage medium (sequential bits on a computer tape or disk). Such issues as how to efficiently partition the data base to serve multiple uses, how to reassemble it on demand, and how to maintain quality control as the data base is built and maintained over long periods must be resolved. Another insidious problem is that cartographic data in a computer environment are woefully non-visible; that is, an error that would be perfectly obvious to the eye may not be recognized by the computer and may remain hidden for a long time. Some errors or incompatibilities defy attempts to develop automated logic checks short of extremely extensive and expensive quality-control measures.

Finally, an unsolved problem in automated cartography centers around automatic name placement (Goldberg and Miller, 1983). The USGS Geographic Names Information System contains most of the name information needed for automated map production if the placement problem can be solved. It may be that certain data relationships or structures can be entered when the spatial data are encoded that could facilitate the automatic placement of some or all of the name information required on a map.

CONCLUSION

These are the accomplishments, perspectives, and concerns of the NMD as we move into the development of a national digital cartographic/geographic data base. We have not completely solved all issues, but we believe we have made good progress to date. We currently are encoding and storing our data in a way to minimize data loss and thereby maximize future use of the data. However, all of these future uses have yet to emerge. We are therefore progressing step by step and attempting to assess all the implications of any particular action or design feature of this data base. The complete transition to achieve all of our objectives and reconfigure the mapping process is anticipated to take most of this decade and even beyond. However, the NMD is firmly committed and will increasingly become the manager of the national digital cartographic data categories through sophisticated data base management systems.

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