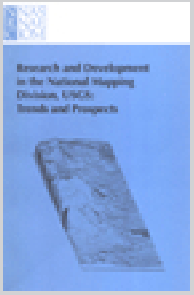

Research and Development in the National Mapping Division, USGS: Trends and Prospects

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RESEARCH AND DEVELOPMENT IN THE NATIONAL MAPPING DIVISION, USGS: TRENDS AND PROSPECTS

Mapping Science Committee
Board on Earth Sciences and Resources
Commission on Geosciences, Environment, and Resources
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

Upon request of the director of the U.S. Geological Survey (USGS), the Mapping Science Committee was established in 1987 to provide guidance to the USGS on mapping and geography issues. In the request, the suggested initial charges to the committee were as follows:

1. Examine the needs for the geographic and cartographic data provided by the USGS. Do the Survey's current mapping activities and products adequately address these needs?
2. Examine and advise on USGS programs of research and development of hardware and software for original data acquisition, processing, storing, marketing, and distribution of digital cartographic data and synthesized information products to the user community.
3. Examine the scope and content of the USGS's activities in geographic information systems (GIS) and recommend their role in assembling and maintaining digital data bases from within the USGS and from other sources.
4. Respond to specific requests for guidance on mapping and geography.

The committee issued a report, *Spatial Data Needs: The Future of the National Mapping Program*, in January 1990, which specifically addressed the first and third of these charges and provided general guidance on the second. This report is directed toward the second charge—concentrating on the research and development (R&D) activities within the USGS National Mapping Division (NMD).

The committee was briefed on the R&D components within NMD during its meetings between July 1987 and April 1989; these meetings, however, focused more on the issues presented in the committee's previous report. The USGS briefed the committee on its R&D activities at a meeting in November 1989, and additional materials and plans were provided subsequently by the USGS.

The committee wishes to thank staff of the National Mapping Division, who contributed information for its deliberations.

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EXECUTIVE SUMMARY

The Mapping Science Committee believes that the National Mapping Division (NMD) of the U.S. Geological Survey (USGS) should expand its research activities. We also believe that NMD research should span the spectrum from applied to fundamental; from improved methods for determining user data product requirements to advanced visualization and modeling of spatial and temporal land-cover changes; from advanced hardware and software for acquiring, extracting, storing, managing, processing, analyzing, and outputting spatially referenced digital data to standards for the electronic transfer of spatial data. Within NMD, the key should be balance—maintaining the production and processing of spatially referenced digital data in the face of ever changing user needs and changing technology.

The majority of NMD's current research and development (R&D) program is focused on the immediate (1 to 4 years) needs associated with the specification and implementation of an advanced cartographic system (Mark-II). Although we understand and appreciate the need for such a focus on operational system development activities, we also believe that increasing emphasis should be given to the fundamental and long-term applied aspects of spatial data handling in support of national needs.

The committee was frustrated in its attempts to recommend a balance between fundamental research and system development efforts because the overwhelming focus of NMD's current activities is the Mark-II development effort. In fact, little fundamental research is being done at this time. Only when all the R&D plans prepared by NMD and discussed in this report become ongoing activities would an appropriate balance be achieved. However, NMD does not have the resources (either scientific and budgetary) to carry out the ambitious program presented in its plans.

There is much to be done, both within NMD and throughout the broader mapping community. NMD should craft its research agenda to satisfy its mission needs in both the short- and long-term while still addressing the larger needs of the mapping infrastructure. Accurate and up-to-date spatially referenced information will form the basis upon which resource management and other important decisions will be made. NMD should provide leadership in the research required to support these national spatial data needs.

RECOMMENDATIONS

1. The committee recommends that the National Mapping Division develop a multiyear research agenda and commit the necessary resources to undertake the priority research.

2. The committee recommends that the National Mapping Division establish an external grants program to use the expertise of the academic and industrial sectors in addressing portions of its research agenda.

3. The committee recommends that the National Mapping Division maintain technological and institutional flexibility in meeting its operational needs to ensure that current development efforts (e.g., Mark-II) can accommodate changing user needs and technological capabilities.

4. The committee recommends that the USGS, and the National Mapping Division in particular, continue to pursue and expand the development of standards, procedures, and specifications for spatially referenced digital data.

5. The committee recommends that the National Mapping Division develop programs to produce and facilitate a wider variety of "non-standard"

spatial data products in support of diverse user requirements for data and information within and beyond federal agencies.

To achieve sustained development on both national and global scales, accurate and timely information on the characteristics of the environment is crucial. A robust national mapping infrastructure is vital to achieving this goal. Establishing and sustaining this infrastructure, however, requires an expanded NMD research commitment—to both fundamental and applied research. This commitment must be well coordinated with other federal and state agencies and with academia and industry as well.

1
INTRODUCTION

Two of the initial charges (see the Preface) to the Mapping Science Committee requested by the Director of the U.S. Geological Survey (USGS) were addressed in the committee's 1990 report, *Spatial Data Needs: The Future of the National Mapping Program*.[1] That report analyzed the USGS mapping programs in light of the user requirements and geographic information system (GIS) involvement of the broader community. This report assesses the research and development (R&D) plans and activities within the USGS National Mapping Division (NMD) and is responsive to the charge: "Examine and advise on USGS programs of research and development of hardware and software for original data acquisition, processing, storing, marketing, and distribution of digital cartographic data and synthesized information products to the user community." This report focuses on the R&D plans and activities of NMD. The committee recognizes that the Geologic Division and the Water Resources Division of the USGS also conduct a substantial amount of research using GIS and other techniques, but we did not attempt to analyze the applications research components of these two divisions.

Over the years, NMD's R&D orientation has been focused more toward the applied, operational system development aspects of the cartographic process central to its major mission, producing a wide variety of printed maps, and it remains so. Meanwhile, NMD's mission has grown to include the production of digital cartographic data bases.

When examining NMD's R&D efforts, the committee was aware that the USGS is primarily a data producer and that others largely determine the use of its data. Applications within NMD serve primarily to help it learn about potential value to the broader user community of the various data sets that it collects or manages.

Much R&D needs to be done, both in NMD and throughout the mapping community. Within NMD, the key should be balance—between production of the printed map and spatially referenced digital data in the face of ever changing user needs and changing technology.

In our previous report,[1] the committee identified the critical need for a coordinated and efficient national spatial information "infrastructure" to facilitate sharing and communicating spatial information resources. Future map making will be just one aspect of a larger enterprise—one focused on acquiring, manipulating, and distributing spatial data in various forms to solve problems and meet various spatial information needs. Because the demand for consistent geographic data is so vast, the committee concluded that the most important function of NMD in the future is for it to act as the overall administrator of the national geographic (or spatial) data infrastructure. Indeed, the Department of the Interior (DOI) was recently given the responsibility for "archiving and distributing space- and land-based earth science data"[2] as part of the U.S. Global Change Research Program. Acceptance of the responsibility for performing this task is a major step toward NMD's assumption of a broader data administration role.

This increased administrative role would require NMD to emphasize, for example (1) managing existing data sets, (2) identifying, characterizing, providing access to, and, in some cases, capturing other data sources, and (3) providing directories and catalogs with browse capabilities. Together, these functions would define a comprehensive data administration/management role. In carrying out such an expanded administrative role, a range of R&D activities is critical not only to advancing the understanding of spatial data in general but also to maintaining up-to-date technological capabilities and improving NMD data products to meet changing user requirements. This future spatial data user community is diverse (see Table 1), involving, for example, the recreational user, industrial and governmental planners and resource managers, and academics with teaching and fundamental research information needs.

NMD's current R&D program focuses on the immediate (1 to 4 years) needs associated with the specification and implementation of an advanced

TABLE 1 Examples of User Communities

Business: sales, advertising, and marketing managers; product planners; site location, marketing, credit, and financial analysts; recruiters; demographers; statisticians; and actuaries.
Economic Development: chambers of commerce, economic development agencies, lending institutions, and economic planning and financial consultants.
Education Administration: facility and transportation planners, principals, and school boards.
Engineering: engineering, transportation, architecture, and environmental planning and design.
Facility Management: public housing agencies, architects, space planners, and facility managers.
Health Services: groups involved with organizing the geographical distribution and access of health manpower and facilities.
Infrastructure Management: groups involved in the management and maintenance of facilities comprising the national infrastructure: roads and highways; bridges; tunnels; railroads; airports; ports and harbors; and gas, electric, water, sewer, telecommunication, and pipeline networks.
Logistics and Distribution Management: logistic, circulation, and distribution managers, dispatchers, and schedulers; the postal service; private package and document delivery services; over-the-road freight haulers; and logistical support agencies of the U.S. Department of Defense and other governmental agencies.
Mineral Assessment and Extraction: groups involved with the exploration and extraction of mineral resources other than oil and natural gas.
National Defense: combat arms and support services of the national defense establishment when involved in field operations and training.
Petroleum Exploration and Production: groups involved with the exploration and extraction of oil and natural gas both on- and off-shore.
Political Administration: groups involved with the administration of local, state, federal, and other elections and/or the political redistricting process.
Public Health: groups involved with the tracking, analyzing, and reporting of contagious diseases and other hazards to public health.
Public Transportation: groups involved with the movement of people on public carriers.
Publishing and Media: public and private organizations involved in the collection, production, and distribution of cartographic products and geographically related statistical data.
Real Estate Information Management: groups involved in the marketing, sale, transfer, management, and taxation of real property.
Renewable Resource Management: groups involved with the conservation and exploitation of the earth's renewable resources: air, water, fish and wildlife, forests, and agricultural and range lands.
Research: groups involved in theoretical or applied research requiring the use or management of spatially indexed information.
Surveying, Mapping, and Data Conversion: groups involved in the preparation of control, engineering, and property surveys; the production of large-scale planimetric, topographic, ownership, and utility system maps; and the conversion of said maps and drawings to a digital format.
Teaching: groups directly involved with the instruction of students at all academic levels.
Urban and Regional Planning: groups involved in land use planning and land use code enforcement.

After F.L. Hanigan, ed., "The GIS Forum," *ARC News*, Winter 1990, pp. 16-17.

cartographic system (Mark-II). This system, which is being developed parallel to and cooperatively with the Defense Mapping Agency's (DMA) Mark-90 modernization effort, is designed to automate the production and revision of the standard series of USGS maps (both analog and digital forms) on a more timely basis. Although the committee understands and appreciates the need for such a focus, we also believe that more emphasis should be given to both the fundamental and long-term applied aspects of spatial data handling in support of national needs. To date, only a small part of the R&D effort within NMD is associated with such activities.

NMD is currently aligning its research plans within seven initiatives and its development activities in six categories. For each, a single coordinator is responsible for advising NMD management of the activities and suggesting areas that need further attention.

This report is organized in three major chapters. Chapter 2 discusses NMD's current *plans* for technological development of its cartographic and production systems and its research initiatives. The material presented is extracted from internal NMD planning documents, and it discusses specific activities that NMD is either currently undertaking or planning through its R&D program. The committee is aware, and the reader should note, that most of the specifics presented in this section are *proposed* activities. At present, research is constrained by the sizable commitment of resources (funds and personnel) to the Mark-II development effort. Chapter 3 discusses R&D opportunities both within the USGS and throughout the broader spatial data infrastructure (e.g., federal and non-federal governmental entities, the private sector, and universities). Chapter 4 presents the committee's conclusions and recommendations. The recommendations are made within the context of the committee's recommendations in its earlier report.[1]

2
CURRENT R&D PLANS IN NMD

To date, the National Mapping Division has clearly concentrated on system-development aspects of an R&D program. These development activities are designed to facilitate its role as a major federal information supplier, both in more efficient internal operation and in response to needs of the user communities. Although NMD has focused its developmental activities on product generation, plans indicate an NMD desire for fundamental research activities—on the spatial data models required to handle its data and a variety of data applications. However, resources directed toward these efforts are limited. Plans for NMD's R&D activities and the FY 1990 level of effort (in full-time equivalents, FTEs, which approximate person years) are summarized in Table 2. (See Appendix A for more specific information about current activities.)

DEVELOPMENTAL PLANS AND ACTIVITIES

The Mark-II System

NMD is developing a major advanced mapping system, Mark-II, to satisfy National Mapping Program requirements through the year 2000. During the acquisition phase, NMD is coordinating the system's development and procure-

TABLE 2 USGS Research and Development Plans and Activities

	Level of Effort, FTEs in FY 1990
DEVELOPMENTAL PLANS AND ACTIVITIES	57.2
Modernization—Mark-II System: Activities directly related to the modernization of the NMD map production system, including the specification, procurement, testing, and installation of state-of-the-art hardware and software for the production of cartographic data in graphic and digital form. Part of this system is related to the Mark-90 system under development by DMA.	6.7[a]
Modernization—Product Generation: Development and engineering activities required to maintain and enhance current NMD production operations, focusing on the integration into NMD's production capabilities of proven off-the-shelf advanced digital technology to support production of standard and thematic graphic products.	14.7
Standards: Establishment of standards to support technical aspects of NMD data production, data base, product generation, and product distribution operations.	5.6
Rules: Work related to the definition and documentation of feature data specifications, including feature, attribute, and attribute value definitions incorporated into the DLG-E model; delineation, extraction, and representation rules; product inclusion conditions, symbol specifications, and generation rules.	11.1
Technology Transfer: Development and coordination activities to inform, instruct, and assist users of USGS and other mapping organizations (OMO) data of data characteristics and optimal utilization technologies, focusing on GIS, image processing, and digital cartography technology.	3.8
DLG-E Development: Activities related to the implementation of the DLG-E model, including the phase II prototyping plan as the following (former) Mark-II modules: GIS interface, text data collection, content conversion, and the DLG-E processor.	13.0

	Level of Effort, FTEs in FY 1990
RESEARCH PLANS AND ACTIVITIES	34.2
Theoretical Spatial Data Handling: Research on spatial data base management, data structures, formats, spatial data processing and manipulations, error propagation, AI and GIS techniques, and advanced visualization methods.	0.5
Techniques Development: Activities related to the development and testing of new and innovative techniques for data manipulation, problem solving, and visualization.	7.0
Remote Sensing and Image Processing: Research on sensor and processing systems, data acquisition technologies, and data manipulation.	12.1
Thematic Mapping: Research related to the collection, analysis, and display of thematic data sets. Includes development of custom techniques and classifications for specific categories of data and subsequent integration of these with base category or other data.	0.9
Data Applications: Activities demonstrating the analysis and application of spatial data from USGS and OMO sources. Technologies used include GIS, image processing, 3-dimensional modeling, and customized thematic map generation.	0.3
Global Change: Use of spatial data handling techniques for research on global change issues.	10.4
Data Collection, Management, and Dissemination: Activities related to the collection, management, and dissemination of USGS and OMO data holdings. This is principally directed to data concerning global change.	3.0

[a] The Mark-II system affects almost all of the other development activities; thus the total effort is actually greater than the 6.7 FTEs indicated.

ment with the DMA, which has taken the lead in developing an automated mapping system (DMA's Mark-90). The Mark-90 system is being designed to meet the Department of Defense's map production needs and digital data requirements.

Mark-II development activities are directly related to the development of the Mark-90 system, including specifications, procurement, testing, and installation of the hardware and software for production of cartographic data in graphic and digital forms.

The current Mark-II development strategy calls for procurement of all system capabilities through the DMA's System Center, with delivery scheduled between 1991 and 1995.

Mark-II has been designed to collect, populate, and maintain the National Digital Cartographic Data Base (NDCDB) and to generate products from it. The NDCDB will contain digital representations of the 1:24,000-, 1:100,000-, and 1:2,000,000-scale map series. This topologically structured data base will support the production of the 1:24,000-scale printed maps, and digital subsets will be made available to the user community for use in GIS or other applications. The digital data will be written in the Spatial Data Transfer Standard (SDTS) format for exchange with the user community.

Because of national security concerns, many details of the Mark-90 and Mark-II R&D are classified. The committee did not examine classified material and therefore cannot critique the systems' components in detail. From the unclassified information provided on the overall status and direction of the effort, Mark-II appears, in concept, to meet NMD's data acquisition, revision, and production requirements. It was designed essentially and has evolved to meet the needs of maintaining an up-to-date data base to support the production of *existing* NMD products. Because these products will likely evolve to meet changing user requirements, it is vital that the technological capability of Mark-II be flexible enough to continue fulfilling those needs.

Product Generation

Product development encompasses both high-volume, standard hard-copy maps and thematic maps, often one of a kind. Development and engineering activities focus on maintaining and enhancing *current* NMD hard-copy production. A large part of the effort involves examination of the production process for 1:24,000 maps in terms of digital production without sacrificing accuracy, readability, or content. This activity is closely linked to the rules and standards development activities.

These plans and activities focus on integrating proven GIS and image processing techniques into NMD's production capabilities and may result in upgrading current production prior to full implementation of Mark-II capabilities. In addition, the effort plans to evaluate the utility of the Mark-II system, which focuses largely on high-volume products, for production of many one-of-a-kind products. The objective of the product generation effort is not to replace the entire production line but to improve specific parts of it when off-the-shelf technology can replace either aging equipment or improve the current (often manual) techniques. As part of this effort, NMD will develop a production model using existing technology that would minimize additional development costs.

Even though product generation for topographic maps and thematic maps may appear quite different, they share a number of software, data bases, data formats, and hardware needs. One of these commonalities includes the integration of the current GIS/commercial symbolization capability within the production centers (thus requiring the creation and maintenance of a "digital symbol library"). NMD will develop a prototype of these digital standards and use them to cooperate with vendors of existing commercial GIS software to develop digitized symbol libraries.

Standards Development

As the organization with lead responsibility for creation and maintenance of the NDCDB (and possibly an expanded geographic data base system), standards development is central to NMD's mission. Standards define NMD's expectations for product content, including formats, topologic structure, treatment of features on graphic products, degree of generalization, and symbolization specifications. They also include definition of products of uniform consistency and content. Standards need to be established in the context of well-defined policy. Through configuration management and the technical instructions/documentation program, NMD is establishing a highly structured system for maintaining and defining standards.

In 1983, NMD and the Federal Interagency Coordinating Committee on Digital Cartography undertook an ambitious program to develop the SDTS. It is a conscious effort to consider the needs of the entire spatial data community.

The standards mission of NMD includes: (1) awareness of technology, applications, and programmatic changes and priorities that define new products and system designs within NMD's operations and those of other agencies, (2) the establishment of standards to ensure that standards precede production and that they are well coordinated with existing production operations and products, (3) the documentation and distribution of standards and related materials through the technical instructions program, (4) maintenance of documentation to produce notices of change, (5) provision of interpretation and assistance to the mapping centers and others in applying the standards, (6) assessment of product conformance to standards or quality assurance, including geometric accuracy, spot checks of digital products, review of printed products, and response to user concerns, and (7) initiation of corrective action when needed for the standards or their use.

Core standards activities involve the technical instructions program, configuration management, and implementation of SDTS. Before 1981, standards were expressed principally as topographic instructions. By then, the need to include digital products had become clear, and a technical instructions program was initiated. It is designed to exercise control of the content, distribution, and maintenance of the standards. As part of the Mark-II development, NMD needs to determine what degree of control or configuration management should be exercised over these standards to make them acceptable.

Configuration management activities are an accounting mechanism for maintaining a basic capability. The identification and ultimate alteration of configured items is a highly structured process, particularly for Mark-II development. It consists of identifying configured items, assigning responsibility for each item to an office, and identifying discrepancies in hardware and software, documentation, and procedures. The configuration management activity also handles and initiates changes that are warranted and approved by a configuration control board. Verification and auditing procedures are used to monitor the implementation of baseline and authorized changes.

The SDTS should facilitate the exchange of spatial information among agencies and between different hardware and software systems. Work with the SDTS includes testing the standard and conducting workshops throughout the user communities (federal, state, and other organizations). The SDTS, as proposed, has four parts: definition and references; the data transfer specification (ISO 8211); statements relating to data quality, lineage, accuracy, consistency, and completeness (user-supplied information); and the list of cartographic features that supply the model definitions. Phase one testing was completed in 1988 and phase two testing was completed recently. In July 1990, NMD submitted the SDTS to the National Institute of Standards and Technology for processing as a Federal Information Processing Standard (FIPS). The objectives of doing so are to: (1) promote the SDTS as a distribution mechanism for spatially referenced data, (2) reduce redundant data collection efforts, (3) clarify federal agency responsibilities, (4) coordinate standardized data content and quality without requiring others to use a standardized data format (conversion should be transparent to the users), (5) improve data user efficiency by minimizing redundant data maintenance, and (6) broaden the access and creative use of data in GIS.

Rules Development

Rules development, which began as a necessary part of product generation, has grown into a broader activity. In addition to writing rules for generating products, the effort includes defining the nature of features, their attributes, and how and when data are collected. Current rules development centers on implementation of Mark-II: documenting the concept, specifications, principles, and the rules for automated product generation. The digital line graph-enhanced (DLG-E) data model is being used. It is a feature-based model used to capture and store the relevant geographic objects that can be portrayed on a map. The first step in using the model is to determine the features to be collected and to define the domain of features—a major undertaking. As of November 1989, only 55 of the 203 identified geographic features had been considered.

NMD rules development is divided between data extraction and product generation. The extraction specifications will be based on the level of information required for specific data base construction at different scales (e.g., 1:24,000 or 1:100,000); the generalization rules also depend on the scale of the data base. If the data base is to contain more information than the graphics product needs, a variety of other decisions will need to be made in constructing the data base. For example, the data integration applications of the GIS community will require a robust set of attributes for point, line, and area features.

Technology Transfer

For technology transfer, NMD plans to identify the need for all the division's research activities to increase and enhance their outreach efforts. They also present an opportunity for identifying and making available evolving requirements for or innovative applications of NMD data and research results. Such information is important in improving understanding of the changing user needs.

Two principal efforts are planned within this activity: one in technology transfer and one in scientific exchange. Under technology transfer, proposed projects include development of a communication network for users both within and outside NMD and identification of NMD technological expertise and assignment of specific responsibilities for technology transfer.

Under scientific exchange, possible projects include training and technical assistance, a data clearinghouse, documentation, and publications. Training courses could concentrate on applications of NMD data, and they could involve participation in cooperative demonstration projects that apply NMD data. The data clearinghouse could assemble a data base describing the content and availability of NMD data residing outside the NDCDB; it could also investigate methods for the public to access such data. Documentation efforts could include mechanisms to ensure full description of the techniques and results for all demonstration projects. Publications efforts could include updated circulars identifying technology transfer and exchange sources within NMD and development of high-quality graphics production for publications and presentations.

DLG-E Development

Another part of NMD's ongoing development relates to moving the DLG-E data structure from an experimental concept to an operational status. Begun as a research effort a few years ago, DLG-E has been adopted as the data structure for the Mark-II system. In addition to the explicit statement of rules and features that NMD identified (see Rules Development above), it is important that NMD can explicitly identify all elements of the file structures (see Table 3).

Over the past 15 years, NMD has been instrumental in developing several new spatial data models. The original impetus for this work was the Land Use and Land Cover Mapping Program, which required a specific topological structure for handling land-use polygons. When NMD decided to address the broader subject of topographic quadrangles, it developed the digital line graph (DLG) data structure, which could accommodate point and line features in addition to polygonal areas. The DLG data structure has been widely disseminated and is often the de facto standard for interchange between different systems. In a modern spatial data handling environment, there is a strong desire to interact directly with geographical objects that usually consist of different geographical elements. For example, a geographical feature such as an Indian reservation actually consists of a variety of different point, line, and area symbols. A user

TABLE 3 Some DLG-E Definitions

Entity: A real-world phenomenon that is not subdivided into phenomena of the same kind.

Feature: A set of phenomena with common attributes and relationships. The concept of feature encompasses both Entity and Object.

Feature Instance: An occurrence of a feature defined by a unique set of attribute and relationship values.

Object: A digital representation of all or part of an Entity.

Feature Object: A digital representation of an Entity to which only non-locational attributes and relationships are associated. A Feature Object may consist of other Feature Objects and/or Spatial Objects. For the representation of an Entity to be complete, however, a Feature Object must consist of one or more Spatial Objects, either directly or through other Feature Objects.

would like to retrieve and display all these graphic symbols by simple reference to the named feature. When a feature such as a road also forms the boundary of another feature, the data structure must be able to recognize the fact that it is shared by the two features. One such object-oriented data structure is now part of the TIGER system developed by the Bureau of the Census, and the DMA is developing another.

NMD RESEARCH INITIATIVES

In general, current research within NMD is directed toward developing ways to capture, represent, store, display, and use spatially referenced information to meet the mission of the USGS and the broader user community needs. Most of these initiatives relate to creation of spatial data layers and the ways these data are applied to problems, particularly within other USGS divisions. An important area deals with applying spatial data handling capabilities to global change; this new initiative expands NMD's mission beyond national boundaries in response to a defined national need.

This section describes *plans* for research activities in NMD; only a small portion of what is presented is ongoing (see Appendix A). The tables in this section present possible activities within the research initiative condensed from NMD planning documents.

Models of Digital Spatial Data

As one of the pioneering agencies in cartographic data structure development, NMD has been at the forefront of research into spatial data models that meet both cartographic production and GIS application needs. Most current research focuses on possible extensions of the DLG-E data structure.

The DLG-E data model has been designated as the basis for NMD's future digital spatial data holdings. Research needs to continue on testing the DLG-E design concepts, extending the model, and implementing it in a variety of environments. This research is particularly important in the long term because the NDCDB provides the framework for a wide range of applications both within and beyond the USGS.

The DLG-E data structure explicitly defines the logical organization of components and component relationships of the DLG-E model. These data structures can, in turn, be translated into file structures by rules specifying logical implementations of the data structure within a given computing system environment. Many different data and file structures can be generated from a single data model to improve the efficiency and general utility of DLG data products. It is important that alternative implementations of the DLG-E data model be prepared and tested. These initiatives need to be shared with the user community to ensure compatibility.

NMD is aware that although DLG-E is a major step forward in the evolution of spatial data structures, it is not the end of the process. Current research plans include various digital spatial data initiatives (see Table 4). Initiatives include logical extensions of the DLG-E data model to three dimensions and the incorporation of temporal data.

Other research would address data handling needs, including manipulation and analysis capabilities, accuracy assessment, generalization, artificial intelligence, and visualization. The identification of these initiatives suggests NMD's awareness of user needs. As shown in Table 2, NMD allocated only one-half an FTE of effort to any of these activities during FY 1990. Although the proposed research could provide important steps in the evolution of its spatial data handling capabilities, NMD is limited in both budget and the available expertise.

TABLE 4 Spatial Data Handling Issues

Spatial Data Bases
- Conceptual modeling of geographic phenomenon; extensions of the DLG-E data model to 3-dimensions; handling of temporal data.
- Prototype implementation of DLG-E in extensible (object-oriented) data base management systems.
- Evaluation and testing of spatial search and access methods.
- Multiple representations of geographic features.
- Use of active data bases for automatic updating across scales.
- Incorporation of spatial operators and computational geometry techniques within an extensible data base management system.

Manipulation and Analysis
- Interfaces among data bases, GIS functions, and process modeling; modeling of dynamic systems.
- Data integration and analysis at multiple scales (delivering comparable results).
- Location/allocation modeling.
- Methods for manipulating data from variable reporting zones.

Accuracy
- Development of accuracy measures and tests (for both locational and non-locational attributes).
- Propagation of error through GIS processes.
- Indices of data uncertainty and confidence for GIS products.

Generalization
- Effects of aggregation on spatial modeling.
- Development of scale-to-scale statistics, both spatial and temporal.
- Cartographic generalization techniques.

Artificial Intelligence
- Spatial data handling approaches utilizing advanced data base architectures that support AI.
- Knowledge-based decision support systems.
- Knowledge-based cartographic design tools.

Visualization
- Display of quality of spatial information.
- Display of time series, 3-dimensional data.

TABLE 5 Techniques Research Issues

Scientific visualization: Modeling and viewing of 3-dimensional data, including new perspectives for the quality control and revision of DLG and DEM data.	
Data capture and digital map production: Methods of pattern recognition to automate attribute tagging and text placement.	
Access to digital data: On-line status maps and text searching utilities coupled with efficient data transfer.	
Improved raster/vector integration: Procedures for viewing raster and vector data together for analysis and updating of vector data.	
Supercomputing platforms for GIS and image processing: Evaluation of the costs and benefits of using supercomputers for the near-real time applications.	
Interaction with GIS: Use of artificial intelligence and other methods to improve user interfaces to complex geographic information systems.	

Techniques Research

NMD's primary technical needs are improved procedures to capture, store, and display geographical information efficiently. Although much of its R&D in this area relates directly to the Mark-II modernization project, NMD needs to keep up with the rapid changes in computer-oriented hardware and software relating to the creation and use of its data. To meet this need, NMD maintains a research program in new techniques (see Table 5) and has a variety of ongoing technique-related activities to meet short-term goals (see Appendix A). In particular, NMD is evaluating new sensing systems (e.g., radar) and existing hardware and software products. They include several platforms, from micro-computers to high-resolution workstations and supercomputers. NMD is also experimenting with software systems that integrate raster and vector data.

Within NMD, plans include the development and testing of new and innovative techniques for data manipulation, problem solving, and visualization. Most of the plans and activities involve manipulating and using digital cartographic data and remotely sensed imagery in natural resource investigations as well as developing new techniques to facilitate future digital data use.

TABLE 6 Remote Sensing and Image Processing Issues

Preprocessing: Radiometric corrections, geometric corrections, merging of multisource data sets. **Information extraction:** Classification and pattern recognition, enhancement and filtering, image analysis, feature extraction, DEM analysis and generation. **Calibration:** Geometric corrections due to topographic effects, atmospheric corrections, and absolute and relative radiometric corrections. **Interactive and batch processing development.**
SPECIFIC TOPICS IMPORTANT TO THE INITIATIVE • **Mapping** (topographic and cartographic) includes optical and radar systems, extraction of DEMs from stereo pairs, and cartographic correction and requirements. • **Change detection** involves research on automated methods to detect and identify changes from remotely sensed image data for both map updating and global change mapping. • **Expert systems** are of continual interest, and it is important for NMD to keep up with developments and to develop in-house expertise for transferring expert system research to an operational/production environment. • **Awareness of research** involving high-resolution spatial and temporal data is important for data handling, manipulation, and analysis. • **Calibration** research for both geometric and radiometric effects needs to continue.

Remote Sensing and Image Processing

In addition to techniques development, NMD has a specific initiative on remote sensing and image processing. Its scope is broad and usually depends on the types of applications and interests of particular groups. Research in this area is important for NMD to take full advantage of the multispectral-multitemporal digital data acquired from advanced satellite sensor systems. Plans and activities in remote sensing include sensor evaluation and instrumentation (see Table 6). Indeed, NMD may need to expand activities to take full advantage of the information potential inherent in the data to be collected by the Earth Observing System (EOS) planned for the late 1990s. In particular, NMD needs to experiment with new data products used to monitor key land surface parameters, and modeling procedures using EOS and other global data will be essential in fulfilling the needs of global change research.

Through the Global Land Data and Information System (GLDIS) project, NMD is likely to be the major EOS land remote-sensing archive. It is also apparent that remotely sensed data will be a primary input to the mapping process. Therefore, it is important that NMD remain in the forefront of new sensing systems.

Thematic Mapping

Thematic maps derived from a wide range of activities within the USGS (i.e., NMD, the Geologic Division, and the Water Resources Division) include geologic and hydrologic maps, land-use and land-cover maps, national atlases, and results of GIS analyses. NMD is involved with the thematic maps of the other divisions primarily in the final production (printing) process. This initiative emphasizes research related to the collection, analysis, and display of thematic data sets. Plans and activities include development of custom techniques and classifications of specific categories of thematic data and their subsequent integration with base or other thematic data. Research topics of a more immediate nature deal with digital base maps, color electronic prepress preparation, line work scanning, and plotting techniques. Plans for thematic activities for the longer term include standards, data integration, data archiving, revision, derivative products, interactive map design, and visualization.

Data Applications Research

NMD's data applications initiative is designed to broaden and strengthen the current research program to include cooperation with outside agencies. Evaluation of NMD procedures and programs helps to ensure that current, proposed, and future products and services meet the end-users' requirements. A variety of cooperative research projects is needed for applications development and product testing. These cooperative research efforts span the range of users from other USGS divisions to other federal, state, and local agency users to private concerns to academic institutions. Such efforts are often conducted on a cost-sharing basis.

TABLE 7 Data Application Issues

Data Types: Evaluation of digital data needs of outside users
- Standards
- Formats
- Scale and resolution
- Linkage to large-scale data
- Expanded attribute tagging

Data Collection, Update, and Dissemination
- Aggregation and generalization
- Documentation and frequency
- Standards for non-NMD data
- Distribution of non-standard products (image maps, etc.)

Analysis Tools and Techniques
- New software systems
- New analytical functions
- New mapping products
- Socioeconomic applications

New User Communities
- Identification of new users
- Increased exposure of NMD digital products
- Innovative use of products
- Expanded user support system

This initiative comprises applications for GIS, image processing, 3-dimensional modeling, and customized thematic map use in analyzing and displaying spatial data.

Research tasks (see Table 7) relating to analysis tools and techniques involve testing new software systems and internally developed analytical techniques. These systems may produce new mapping products to support internal and outside agency applications; these new products could be tested to determine their effectiveness for information transfer and user needs. In addition, conventional NMD data products need to be used with these new tools to see if the products are effectively supported.

To maximize exposure of its products, NMD needs to identify, cultivate, and educate new user communities. Experienced users of NMD data products can often identify the strengths and weaknesses of current and proposed digital data products and standards. Innovative use of the data will strengthen NMD's user base and identify growth areas for future products.

Global Change Research

Scientists from many disciplines have realized the important interactions among the components of the Earth's environmental system. There is now a national focus on the need for improved understanding of the global environment. As scientists from many disciplines begin to define the range of complex interactions among the lithosphere, biosphere, hydrosphere, cryosphere, and atmosphere, the treatment of the spatial and temporal data bases for these components offers several challenges. How can data collected on a local scale be extrapolated to regional or global scales, and what types of generalizations can be made in those extrapolations? How can spatial data analysis techniques be applied to such global problems? How can the resulting data be managed and disseminated? Such questions are interdisciplinary, requiring the attention of the entire scientific community within government, academia, and the private sector.

NMD's research plan in global change has two parallel tracks: investigations of specific (pilot) areas and development of improved spatial analysis techniques applicable to global change issues. Plans include the following:

1. The long-range research objective is to develop geographic models of large spatial extent, from continental to global scale. To meet this objective, site-specific pilot areas will be used to develop and improve measurement, mapping, monitoring, and spatial modeling procedures for land surface conditions, characteristics, and behavior that will link directly to biogeochemical cycles, ecosystem dynamics, and climate and the hydrologic system. Pilot study areas should be of significant geographic extent, and they should be selected for relevance to global change research objectives within the USGS.

2. Spatial analysis techniques will be developed, applied, and tested in the pilot study areas. Examples of required techniques are spatial interpolation that accounts for geographic features, observational strategies that account for scale and temporal variability, procedures for linking information gathered through the analysis of hierarchical data sets from field samples to satellite-acquired information in multistage sampling techniques and/or other innovative spatial sampling strategies, and visualization of model relationships and results.

A critical component of the U.S. Global Change Research Program is the collection, management, and dissemination of earth science data sets that bear on understanding the Earth system and its interactions. The EROS Data Center (EDC) has been identified as the distribution and archiving facility for land-related data collected by sensors of the EOS scheduled to be orbited by NASA in the late 1990s. In addition, the USGS, through EDC, is currently negotiating to become the North American node for the United Nations Environment Programme/Global Resource Information Database (UNEP/GRID).

As recommended by NASA, NOAA, NSF, and the DOI, the USGS is developing a Global Land Data and Information Management System (GLDIS) at EDC to archive, process, and distribute land-related data sets. The goal of GLDIS is to develop improved methods and systems for handling extremely large data sets for global change research. These developments have four primary components. *Data collection* includes the conversion of relevant earth science data from raw form (e.g., aerial photography, radar imagery, and satellite data) into usable digital or map formats. This activity will emphasize methods of digitizing and evaluating the utility, accuracy, and quality of existing earth science data. *Information management* will provide an on-line global land data directory, catalog, and inventory system, which includes on-line image and data browsing capabilities along with network linkages to other data centers and directories. *Data set development* will address the processing of raw or derived data sets to create calibrated and derivative products or enhancements to existing derivative products. *Data management and dissemination* will address data storage, archiving, and dissemination. These activities could include: (a) research on durable, high-density archive media, (b) conversion of existing Landsat data to these media, (c) integration of Landsat, SPOT, and other satellite data with existing earth science data, (d) development of graphic output products, and (e) research on various standard formats for data distribution. The goals of GLDIS are similar to those that should be encompassed with the NDCDB or a prototype of a national spatial data base.

3
RESEARCH OPPORTUNITIES

The explosive growth of spatial data handling technology and applications has whetted the appetite of users for new and improved capabilities to analyze, model, and apply the data to meet their needs. The private sector seems to have satisfied some of these needs through the development of new hardware platforms and software to process the data. Still other needs or desires require innovative R&D to extend data handling and modeling capabilities. Although some results are several years away from the marketplace, the private sector has demonstrated its rapidity to incorporate new spatial data handling advances into commercial products.

To realize fully the potential benefits of new technology, researchers in government, the private sector, and the academic community should work synergistically. The research outlined in the following sections is not of exclusive interest to any particular sector; nor can any one sector accomplish what is needed. Precedents for cooperative activities include: (1) development of advanced mapping systems, wherein the USGS (Mark-II) and the DMA (Mark-90) are developing such systems through both in-house activities and contracts with industry, (2) NSF's establishment of the National Center for Geographic Information and Analysis (NCGIA) to conduct fundamental research on a variety of issues (NCGIA is a consortium of the University of California at Santa

Barbara, the State University of New York at Buffalo, and the University of Maine at Orono), and (3) the support of academic research by industry.

If NMD is to remain responsive to the needs of its current and future users, it must continue to be aware of emerging research problems. For example, some user-based professional associations and societies have attempted to define the research needs of their membership. The Urban and Regional Information Systems Association (URISA) has developed a statement of its research needs (see Table 8). In addition, the NCGIA has generated a statement of its research objectives (see Table 9). A useful analysis of how these two agendas constructively overlap is provided by Craig (1989).[3] He suggests a wide range of research needs from basic science to societal applications. From this analysis, it is apparent that the needs for research on spatial data handling and analysis are driven by applications and decisionmakers who use the resultant information. The remainder of this chapter attempts to identify an appropriate role for NMD in addressing the research agenda of the nation's spatial data user community. The committee strongly believes that the spatial data infrastructure of the nation would benefit greatly if NMD expanded its current research program by cooperating with and funding research with academia and the private sector.

DATA CAPTURE, REVISION, AND MAINTENANCE

To support its long-term mission as a primary spatial data supplier, NMD must be able to create and maintain efficiently and economically an accurate spatial representation of the United States.

Innovative types of data and characteristics should be explored for incorporation into NMD products, including, for example: (1) data at larger scales to support urban development, (2) varying scales and resolutions within a product based on the localized density of information, (3) linkages of NMD data to cadastral information, and (4) additional attributes to support address matching, coordination with TIGER products, and the Environmental Protection Agency's river reach files.

In addition, research is needed to determine the appropriate forms of data capture to support automated systems. This need includes techniques for data aggregation and generalization, especially using GIS and image processing systems. Effective data update methods should also be developed, including techniques, manner of documentation, and acceptable frequency. Standards for unconventional NMD products (e.g., thematic and image maps) need to be

TABLE 8 1987-1988 URISA Research Agenda (from Craig, 1989)

SOCIAL CONCERNS

System Adoption
- Codify concepts and terminology.
- Improve access to literature.
- Research real-world experiences to document actions and conditions that lead to success.
- Develop educational programs for staff and other users.

Social and Legal Impacts
- Document the impacts on the host institution, management, staff, elected officials, and the public.
- Determine criteria such as accessibility, objectivity, and equity that will encourage system utilization by the broadest range of publics and policy-makers.
- Investigate legal imperatives for providing access to data, considering privacy laws, and determine conditions of legal liability for incomplete or inaccurate data.

Management Issues
- Develop effective strategies for day-to-day management, including how to bridge the gap between technicians and the user community.
- Assess the social, political, and behavioral conditions that inhibit data sharing and recommend means for improvement.
- Examine the problems and potential for a distributed corporate GIS, where each unit has its own unique domain of definitions, needs, and hardware.

Economic Factors
- Define a methodology and estimate costs and benefits.
- Measure cost effectiveness and productivity compared to manual systems.
- Explicitly measure the costs of data capture, conversion, and maintenance.
- Attempt to determine the value of "public information."
- Explore the unique aspects of measuring costs, benefits, and decision structures of information systems as compared to other enterprises. To what extent is the uniqueness more profound in the public sector?

TECHNICAL CONCERNS

Data Base Development
- Lower data capture costs through improvements in scanning technology and better utilization of remotely sensed data, especially through incorporation of artificial intelligence techniques.

- Develop data quality standards and methods for "stamping" or documenting the quality. Include both purity and spatial precision as measures of quality.
- Determine the need for access to a variety of human and physical geographic data sets and define an approach for developing a "National Library" to meet that need.
- Develop tools to assist with data base design, procedures for updating, techniques to improve the data base over time, and methods for archiving.
- Develop models for networked systems in governmental organizations where data are distributed to meet operational needs and analysis and problem solving must use the diverse data sets. Identify problem areas such as the need for data refining and the impact of independent upgrades at various nodes.

User Interface and Empowerment

- Improve processing speeds so analysis can be done in "real time." This will require both improvements in hardware and data base structures as well as vastly improved processing algorithms.
- Add to the range of models available to the GIS analyst (e.g., transportation and ecological models). The possibilities are enormous, but a library of such functional modules would be very useful. GIS software might be modified to readily accept such modules; in many cases, the models have been developed, and their usefulness would be enhanced greatly with addition of the graphical component that a GIS could provide. Gaming/simulation packages are another type of useful modules.
- Make GIS software accessible to users with different levels of technical expertise through the use of artificial intelligence, help screens, relational data bases, and software layering.
- Analyze the needs of planners and other public officials, see what potential applications they have for this technology, and develop specifications for products to meet those needs.

Software Critique

- Develop a comprehensive list of major software packages and the major application of each.
- Develop a list of common and exceptional GIS functions.
- Create benchmark tests that would fairly compare systems on features most important to users. Run these tests on the major software packages and report results.
- Determine and document the constraints imposed by selecting particular software, data scales and classification schemes, and data base structures.

TABLE 9 NCGIA Research Initiatives

GROUP I

1. **Accuracy of Spatial Data Bases**: Develop methods for evaluating GIS data and products.
2. **Languages of Spatial Relations**: Develop a theory of spatial relations based on both cognitive/linguistic and mathematical/logical models.
3. **Multiple Representations**: Explore efficient data structures that accommodate resolution-based change and determine how dissimilar representations of the same geographic feature can be related.
4. **Use and Value of Geographic Information**: Look at how decisionmakers use and value information in order to measure the benefits of GIA and GIS.
5. **Architecture of Very Large GIS Data Bases**: Develop and test prototypical systems with high performance.

GROUP II

6. **Spatial Decision Support Systems**: Integrate operations research tools into the GIS environment.
7. **Visualization of the Quality of Spatial Information**: Develop methods for displaying the quality of data.
8. **Expert System for Cartographic Design**: Develop a system to design cartographic displays.
9. **Institutions Sharing Spatial Information**: Explore existing policies, problems, and prospects for sharing data; develop models of political support for sharing.
10. **Temporal Relations in GIS**: Understand the modeling of time and assess the impacts on GIS design, with emphasis on logic and data base issues.
11. **Space-Time Statistical Models in GIS**: As above, with emphasis on statistical models and remotely sensed data.
12. **Remote Sensing and GIS**: Improve the usefulness of remotely sensed data by applying GIS-based tools for data storage, processing, and classification.

developed for transferring data to other users. Such research projects should be developed and tested in conjunction with either a program (e.g., global change and side-looking airborne radar) or a general category of digital data manipulation (e.g., image processing, thematic mapping, and data collection).

NMD's hardware needs in data capture include digital orthophotography generation; image scanning; and low-cost digital stereo photogrammetric digitizers for aerial photography, SPOT, and other remotely sensed data. Software needs are in the areas of digital orthophotography processing, optimal DLG hypsography and digital elevation model (DEM) algorithms, advanced algorithms for satellite image mapping, high-speed algorithms for raster/vector conversion that preserve the accuracy of the original data, and an advanced expert system for image analysis (e.g., improved feature extraction algorithms) for use with advanced satellite remotely sensed data including EOS data.

As GIS and associated technologies become integral to the work of planning and resource management agencies, the demand for thematic data layers will surely increase. Timely, accurate, and current, detailed land-use and land-cover data as well as other thematic products are an immediate need of diverse governmental, scientific, and industrial users for both resource management and analysis of regional and global change. Existing thematic data products such as land-use and land-cover data sets produced by the USGS are at least 10 years old. To develop an intermediate-scale thematic mapping program based on current data, NMD will need to consider new data sources, innovative digital mapping techniques, state-of-the-art image processing techniques, automated cartography, advanced change detection algorithms, and automated procedures for assessing the accuracy of specific thematic data. In addition, considerable software research will be necessary to support both the digital data base and graphic thematic data products from the DLG-E data model.

Additional research involving the application, structure, and accuracy of different thematic data products within a GIS framework would most appropriately be coordinated with other organizations. For example, the NCGIA research initiative on the use and value of geographic information in decision-making is particularly relevant to NMD. The emphasis of this research is to: (1) identify primary and subsequent users of spatial information and explore methods for determining the value of such information, (2) identify problems associated with uncertainty and risk in decision-making from spatially referenced data, (3) develop and test models of decision-making regarding land use and land cover, focusing on the role of information, and (4) evaluate direct and indirect benefits of geographic information in an institution, agency, and/or industrial context.

DATA BASE ORGANIZATION

Many recent successful applications of spatial data can be directly linked to technical advances in computer hardware and software that enable the user to store and retrieve large volumes of spatially referenced information efficiently. It is essential to NMD's future mission that it continue to be well aware of ongoing developments in several areas: (1) read/write mass storage devices, (2) improved data/information cataloging, indexing, and retrieval systems, (3) high data rate, high-capacity computing environments for cartographic and image processing, especially as related to remotely sensed data, (4) high-speed network technology for transmitting spatial data, and (5) interactive systems for processing, analyzing, and displaying digital data.

The fundamental data base concern of NMD must be the basic format used to represent the digital versions of geographic features. Because NMD is committed to the DLG-E data model, the development of an unambiguous set of representation rules for all geographic features is important. Although the initial domain of features has been developed, several representations are possible for each instance of that feature. Work to derive consistent sets of feature-instance representation rules to complete the design of DLG-E should be given priority. Further work on feature classification needs to be conducted for the addition of new layers (e.g., geology and soils), for the use of classification hierarchies as an aid in generalization, and for the preparation of interactive reclassification tools.

Extensions to the DLG-E data model must also be made. These extensions include modeling of 3-dimensional objects using attributes of relationships to improve flow information, expanding spatial models to describe accuracy, and storing and displaying temporal data in a spatial context.

Research on implementing the DLG-E model in a variety of computer environments is important. Implementation of the model in the context of an extensible relational and/or object-oriented data base system should be tested. The goal is a data base system containing multiple representations of the DLG-E features.

The global change research program, in particular, will require considerable research on temporal data models. This research includes: (1) documenting characteristic scales of spatial and temporal changes in various environments for basic social, natural, and applied sciences processes, (2) developing a taxonomy of space-time statistical models to help select appropriate data base structures for representing temporal variability of specific social and natural processes,

(3) implementing algorithms for efficient data update in systems with different characteristic frequencies and scales of temporal variation, and (4) developing and applying computationally efficient methods of multiple representation in the time domain.

As noted in Chapter 2, NMD will establish an archive and data dissemination facility for EOS land data. The EOS will be a major source of global change data that should become available beginning in the late 1990s. Other National Research Council committees[4,5] believe that data should be archived at sites where there are active users. In light of this stated need, NMD should begin to expand its R&D program in data archive functions. The effort should include user needs assessments, test bed activities, advanced data and information design studies, improved algorithm development, and experimentation with new product generation. To meet the goals, NMD scientists at EDC will need to work closely with the EOS science user communities.

SPATIAL DATA DISPLAY

Historically, NMD has been concerned with producing quadrangle-based paper maps. Because future NMD data users would like to access seamless and scale-independent digital data bases, research on multiple representations is important. This research could focus on, for example: (1) developing models for digital description of cartographic features (object-oriented versus spatially addressed models, hierarchical models, conversion between models), (2) examining the relations of the geometry of geographic features to the scale of representation (e.g., self-similarity versus scale dependence), (3) examining problems associated with scale changing, possibly leading to proposed solutions and algorithms based on pattern recognition of feature identification, inference across levels of resolution, and automation of feature simplification and selection, (4) characterizing effects of multiple presentation on error propagation, and (5) determining data base organizations capable of dealing with multiple representations of the same objects.

Hardware and software that improve scientists' ability to visualize complex spatial relationships are also needed. Advanced research topics in visualization of spatial data include: (1) developing and implementing methods for displaying the quality (e.g., reliability and accuracy) of spatial information, (2) testing methods for multidimensional displays of spatial information, (3) evaluating the potential of time sequential (animation) and 2-dimensional (profile) and 3-

dimensional (depth) displays of complex spatial data, (4) developing and implementing methods for displaying hyperspectral multiparameter image data, and (5) developing methods for improving the display of multisource layers of spatial data in image and line form to further understanding of complex environmental processes.

Artificial intelligence and expert systems research are also important in areas of cartographic display. For example, NMD should work closely with the Bureau of the Census on the expert system used for automatic name placement and inset selection for maps supporting the 1990 Census.

APPLICATIONS

As emphasized in the committee's previous report,[1] if NMD is to improve its overall support for the spatial data user community, it needs more information on how those data are used. Spatial data are basic to geographic information systems, considered one of the fastest growing areas of data processing.

In the context of modeling, research on the measurement of accuracy and the consequences of using inaccurate spatial data is essential. Other research is also required to: (1) assess statistical models of spatial data, (2) develop and evaluate techniques for interpolating estimates as a means to overcome problems of variable regions of data aggregation and missing values, (3) develop indices of uncertainty and confidence for spatial data products, and (4) determine the effects of aggregation on spatial modeling.

Languages that enhance spatial modeling are also important research topics. A considerable amount of work is needed to: (1) identify formal cognitive/semantic models of spatial concepts/relationships in natural languages, (2) develop advanced methods for determining reference frames for spatial languages, (3) investigate formal mathematical/logical models of spatial concepts and relations based on topology and geometry, and (4) address the integration of relational based models into a general theory of spatial relations.

Decision Support Systems

Spatial information systems convert spatial data into information to facilitate the decision-making process. In an optimal setting, a GIS would become a spatial decision support system (SDSS). Such a system would integrate analytical models, data base management, graphical display, and report generation in an iterative, man-machine interactive setting. At a minimum, a set of GIS tools linked to an integrated data base should enable the user to conduct exploratory spatial analysis. In a more sophisticated environment, the GIS would enable the user to evaluate a set of alternatives, select the best alternative, implement the system or plan, and monitor the results. GIS technology introduces a further layer of complexity to the environment of decision support systems that is already complex. The task is challenging. Decision support systems have the following characteristics:

- They are designed to handle ill- or semistructured problems;
- They have an interface that is easy to use;
- They enable the user to have full access to the data base;
- They are able to generate a number of alternative scenarios;
- They support a range of decision-making styles; and
- They support interactive and recursive decision-making processes.

Given these challenges, a good SDSS needs to make GIS software accessible to users with different levels of technical expertise through the use of artificial intelligence, help screens, relational data bases, and software layering. In other words, the ultimate value of NMD's spatial data may depend on how well it can support an SDSS. The limiting factors of an SDSS relate most directly to data problems, inadequacy of the analytical functions, and inability to support the type of decision-making process that characterizes many private and governmental forms of decision-making.

Over the past 20 years, the complex problems faced by resource managers and scientists have pushed system developers to create sophisticated spatial data handling tools that integrate and synthesize diverse forms of spatial information. The overriding challenge to GIS developers is to combine the appropriate information in a format that can be easily queried, analyzed, and displayed. The fundamental building block is the appropriateness of the data base (the principal concern of NMD). To be successful, future NMD data products must provide the appropriate data bases.

In addition to maintaining and distributing data products, NMD also needs to keep abreast of changes in the analytical capabilities of automated systems. Commercially available spatial analysis tools today probably fall short of the needs (as expressed in the URISA research agenda[3]; see Table 8) for combining spatial integration, optimal location allocation routines, and statistical analysis in a common operating environment.

Additional work should also include evaluation of: (1) the uncertainty and the risks associated with decision-making (e.g., the economic concept of utility applied to information, the role of information in uncertainty reduction, uncertainty reduction and absorption, and the limits to research for information), (2) the decision models (e.g., the decision-making process, the multiple role of information, information as a product, information as a public good, and the distinctions among data, information, and knowledge), (3) the demand for information (e.g., value as a demand-initiated concept, multilevel user identification techniques, the contrast between supply/push and demand/pull in the development of information systems, and public good aspects), (4) the benefits (e.g., direct and indirect benefits, uncertainty reduction, uncertainty absorption, expanded opportunity, and cost avoidance models), (5) the design of GIS data structures optimized to support decision systems, (6) the investigation of map/image scanning technologies for effective capture of map linework and/or continuous tone images, (7) the development of methods for effectively structuring spatial search algorithms within a GIS framework, (8) the classification of spatial search problems and the identification of gaps in current models, and (9) the investigation of optimal data management procedures for effective use with a variety of spatial data types.

Although the interface between GIS and analytical modeling systems needs improvement, such a linkage is emerging. One important aspect of this linkage is the technological ability to share information. Consider the following two points: the technology provides a means to decrease data collection costs, which can reduce institutional barriers, and organizations can maintain their institutionally independent layer of data and their control over it. As individual agencies and organizations recognize the incentives to share their data with others, technology may break down traditional turf battles and lead to organizational innovation. By providing the base levels of spatial data contained in the NDCDB, the NMD may facilitate new levels of cooperation for divergent users.

Global Change Research: An Example of Spatial Data Applications

As discussed in Chapter 2, the USGS has begun major research initiatives in global change. These initiatives include the identification of suitable test areas for measuring and monitoring change. NMD has also begun to experiment with improved spatial analysis techniques. In addition, the USGS/NMD is developing

GLDIS at the EROS Data Center to archive, process, and distribute land-related data sets. The EROS Data Center has been identified as the distribution and archiving facility for land-related data collected by the EOS.

Four elements are essential to a global change research program: (1) developing improved spatial data analysis, management, and geographic information systems tools and methodologies, (2) identifying, delineating, and characterizing regions and the processes that create regional change, (3) developing methodologies to integrate processes at local and regional scales with those occurring globally, and (4) supporting a program of land-use and land-cover monitoring that is required for analyzing and monitoring changes important to climate change.

A variety of research is required in support of this theme: (1) analyzing the role of land-use and land-cover changes in the monitoring and modeling of climate change, (2) developing techniques and methodologies for dealing with very large spatial data bases, (3) developing quantitative techniques for linking hierarchical data sets at variable scales, and (4) exploring the full potential of remotely sensed data from aircraft and satellites to support measurements, mapping, monitoring, and modeling of significant biophysical and socioeconomic processes.

In addition, other significant research topics include: (1) developing techniques for near-real time indexing and browsing of map and image data of important Earth surface features (e.g., vegetation greenness, biomass, and albedo), (2) implementing advanced systems at regional and global scales to detect and identify significant temporal phenomena rapidly, (3) investigating procedures for producing regional, continental, and global-scale image maps from satellite-derived data, and (4) developing, testing, and evaluating prototype global data sets of value in the study of global change.

RESEARCH OPPORTUNITIES: CONCLUSIONS

A variety of significant research endeavors must be undertaken to improve understanding of our Earth. Just as the USGS has helped to improve knowledge of this vast nation and its potential for development, it should now provide the basic information upon which decisions can be made in our rapidly changing advanced technological society. To achieve sustainable (e.g., land-use decisions resulting in sustainable changes in land cover) development on a global scale, accurate, timely, and reliable information on the state of our national and global environments is critical. A robust national mapping infrastructure is vital to achieving this goal. The establishment and sustenance of such an infrastructure will require an expanded NMD research commitment—one that includes both fundamental and applied research. Underlying this commitment must be coordinated research efforts by federal and state agencies as well as by academia and industry.

4
CONCLUSIONS AND RECOMMENDATIONS

Over the years, research at the National Mapping Division of the USGS has been directed toward development of map products—and for good reasons. However, as the committee found in its earlier report,[1] NMD's role has changed; it now needs to emphasize coordination and management of spatial data in addition to production of maps. Further, new national programs that deal extensively with spatial data (e.g., the Global Change Research Program and the EOS) add new urgency to an expanded NMD mission and its future roles. These new demands, coupled with recent developments in producing digital spatial data, call for a change in NMD's R&D programs. It is imperative that NMD research activities be given greater priority and higher visibility and that they be significantly expanded. NMD research should span the spectrum—from applied to fundamental; from improved methods for determining user data product requirements to advanced visualization and spatial temporal modeling of land-cover changes; from advanced hardware and software for acquiring, extracting, storing, managing, processing, analyzing, and displaying spatially referenced data to standards for the electronic transfer of spatially referenced data. There is much to be done. NMD needs to maintain production and processing of spatially referenced digital data in the face of ever changing user needs and changing technology.

Numerous precedents exist for federal agencies with essentially operational mandates to carry out important research missions. An immediate example is the USGS in general, and NMD in particular. Indeed, within the DOI, the USGS is often considered the principal R&D agency. Unless NMD maintains a leadership role and establishes a strong research presence within the national mapping infrastructure, the nation as a whole will suffer. Accurate and up-to-date cartographic products must form the basis for future management decisions.

RECOMMENDATIONS

1. **The committee recommends that the National Mapping Division develop a multiyear research agenda and commit the necessary resources to undertake the priority research.** NMD's recent organization of its R&D activities into initiatives is a positive step in developing a research agenda. However, the agenda and its implementation need to be more broadly balanced among the various plans and activities presented in Chapter 2. In developing this agenda, NMD is encouraged to use the expertise of other agencies, academia, and industry and to be more responsive to the overall needs of the spatial data user community. Periodic review of the research agenda to measure progress and direction is critical to a sustainable effort.

Productive research themes identified in this document encompass digital cartography, geographic information systems, remote sensing, and image processing and analysis. They include digital spatial data modeling, hardware and software development, land-use and land-cover analysis, monitoring of global change, and management of global change data. Although research in these areas is not mutually exclusive, they present a context for structuring an applied and fundamental research program. The committee's analysis of the current NMD research plans and activities relative to its mission—expanded spatial data (as recommended in the committee's earlier report)[1]—and some needs of the user communities are given in Table 10. This table is an example of how priorities can be presented; however, further refinements of these priorities should be made and updated by NMD with inputs from the spatial data community.

2. **The committee recommends that the National Mapping Division establish an external grants program to use the expertise of the academic and industrial sectors in addressing portions of its research agenda.** This program could help advance spatial data handling and analysis and strengthen the nation's spatial data infrastructure by bringing in new concepts, technological breakthroughs, and operational approaches. Similar external grants programs have

TABLE 10 Relative Importance of NMD's R&D to Its Current Mission, the Research Agendas of URISA and NCGIA, and the Recommended Expanded Role for NMD

NMD's R&D Activity	Overlap with Other NMD Plans and Activities	Relative to Current Mission	Relative to Expanded Role for NMD	Relative to URISA Research Agenda	Relative to NCGIA Research Agenda
1. Modernization: Mark-II System	3,4,6,7, 8,9	A	B	C	C
2. Modernization: Product Generation	4,7,8,9	C	C	C	D
3. Standards	1,4,5,6,9,	A	A	A	A
4. Rules	1,2,3,5, 6,8,9,10	B	B	C	C
5. Technology Transfer	10	D	C	B	C
6. Theoretical Spatial Data Handling	1,3,4,7	C	B	C	A
7. Techniques Development	1,2,10,11	C	C	C	B
8. Remote Sensing and Image Processing	1,2,5,7, 9,10,12	C	B	D	B
9. Thematic Mapping	1,2,3,4, 5,6,7,8, 10,11,12	C	B	B	B
10. Data Applications	5	D	D	C	D
11. Global Change	8,9,12	C	A	D	B
12. Data Collection, Management, and Dissemination	1,7,8, 9,10	C	A	B	C

A = Very important; B = Moderately important; C = Important; D = Related benefitted other divisions of the USGS, both in addressing USGS research needs and in establishing a mutually beneficial relationship with the user community. These programs (e.g., the external grants program for earthquake research in the Geologic Division) could serve as models for an NMD grants program. Other agencies use similar programs to strengthen their internal research activities. A spinoff of such a program would be a strengthened educational base needed for a robust national spatial data infrastructure.

The need for balance between fundamental inquiry and operationally oriented applied research is probably best achieved when all elements of the national mapping infrastructure—government, private sector, and universities—are healthy and focused on common problems.

The committee appreciates the fact that resources are always a problem in establishing such arrangements. The benefits to the national spatial data infrastructure could be significant if these relations were to be expanded. We encourage NMD's aggressively pursuing a stronger resource base to carry out the necessary research and to give such arrangements higher priority.

3. The committee recommends that the National Mapping Division maintain technological and institutional flexibility in meeting its operational needs to ensure that current development efforts (e.g., Mark-II) can accommodate changing user needs and technological capabilities. Any major modernization effort carries the risk of locking itself into technology that may not be flexible enough to meet future needs. The committee senses, based on discussions with NMD staff, that the USGS is aware of this risk in Mark-II development. Mark-II was designed and has evolved to meet the demand for revision and maintenance of *existing* products. Changing user needs indicate that other data products will be desired; therefore, the technological capability of NMD will need to be flexible enough to satisfy these needs.

4. The committee recommends that the USGS, and the National Mapping Division in particular, continue to pursue and expand the development of standards, procedures, and specifications for spatially referenced digital data. Although the USGS has led national efforts on standards development in digital cartography, much remains to be done. Further effort includes the extension and generalization of the spatial data transfer standard to accommodate data elements desired by the data users. It is increasingly important to the spatial data user community to be able to communicate among various vendors' systems, and this interchange is possible only with sophisticated and complete data transfer standards. The leadership and participation of NMD in assisting the Federal Interagency Coordinating Committee on Digital Cartography will continue to be important in establishing and implementing standards throughout the federal government and will increase sharing and integration of digital data to meet national needs.

5. The committee recommends that the National Mapping Division develop programs to produce and facilitate a wider variety of "non-standard" spatial data products in support of diverse user requirements for data and information within and beyond federal agencies. The users have needs for such non-standard spatial data products (e.g., land-use, land-cover, and image maps). In addition, other non-standard products will probably need to evolve to meet the needs of programs such as the Global Change Research Program. NMD needs to be more responsive to these changing user requirements.

CONCLUSIONS

As can be seen from the material presented above, the research tasks that could be undertaken are many and diverse. This need is particularly applicable in improving our understanding of the Earth as an integrated system. Just as the USGS helped to improve knowledge of national territory and its potential for development, it must now rise to the challenge of providing the basic spatially referenced information upon which management decisions can be made in this rapidly changing, advanced technological society. To achieve sustained development on a global scale, accurate, timely, and reliable information on the state of our national and global environments is of critical importance. A robust national mapping infrastructure is vital to achieving this goal, and essential to it is an expanded NMD research commitment—one that includes both fundamental and applied research. Further, the commitment should be well coordinated and include not only other federal and state agencies but academia and the private sector as well.

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ACRONYMS AND ABBREVIATIONS

AI	Artificial intelligence
DEM	Digital elevation model
DLG	Digital line graph
DLG-E	Digital line graph-enhanced
DMA	Defense Mapping Agency
DOI	Department of the Interior
EDC	EROS Data Center (Sioux Falls, South Dakota)
EOS	Earth Observing System, a proposed NASA Earth monitoring satellite system
EPA	Environmental Protection Agency
FIPS	Federal information processing standard
GIS	Geographic information systems
GLDIS	Global Land Data and Information Management System
GRID	Global Resources Information Database
ISO	International Standards Organization
Mark-II	System being developed by USGS/NMD for production (both digital and hardcopy) of map information
Mark-90	System being developed by DMA for map production and digital data requirements of the Department of Defense

NASA	National Aeronautics and Space Administration
NCGIA	National Center for Geographic Information and Analysis
NDCDB	National Digital Cartographic Data Base
NMD	National Mapping Division of the USGS
NOAA	National Oceanic and Atmospheric Administration
SDSS	Spatial decision support system
SDTS	Spatial Data Transfer Standard
SLAR	Side-looking airborne radar
UNEP	United Nations Environment Programme
URISA	Urban and Regional Information Systems Association
USGS	U.S. Geological Survey, Department of the Interior

APPENDIX A
RESEARCH PROJECTS IN NMD

TABLE A.1 Research and Development Projects Approved for FY 1991

Project Title	Project Leader	Initiative
System Tabulation of Error Propagation	E. Constance	System Development
Systematic Horizontal Adjustment of Positional Error in Digital Line Graphs (SHAPE)	E. Coleman	System Development
SMD/SES Replacement Mapping System	W. Harris	System Development
Development of a Digital Orthophoto Production System	L. Ladner	System Development
Enhancement of the TIGRIS Software's Front End and User Interface for the Standalone Edit System (SES)	M. Faye	System Development
Cartographically Enhanced High Resolution Orthophotography as a Basis for a Multipurpose Cadastre[a]	L. Gaydos	Product Generation
The Development of Standards for the Production of Derivative Maps from GIS Studies[a]	D. Carter	Standards
Modeling Elevation with Triangulated Irregular Networks (TINs)	M. Kumler	Standards
Professional Paper: Automated Cartography and Geographic Information Systems	S. Guptill	Theoretical Spatial Data Handling
Automated Derivation of Stream Network Characteristics from DEM Data[a]	J. Domingue	Techniques Development
Relational Structures for Device Independent Map Composition and Design	E. Fosnight	Techniques Development

Project Title	Project Leader	Initiative
Development of Radar Data Processing Capabilities	J. Thormodsgard	Remote Sensing and Image Processing
Research in Image Quality and Feature Extraction	S. Benjamin	Remote Sensing and Image Processing
Applications of Remote Sensing for Landslide Hazard Assessment	L. Gaydos	Remote Sensing and Image Processing
Extraction of Line, Symbol, Color, and Text Information from Scanned Thematic Maps	B. Wright	Thematic Mapping
Baseline Studies for Monitoring Global Climatic Change in the Arctic Environment	M. Shasby	Global Change

[a] Inactive, will be active in FY 1991.

TABLE A.2 Research and Development Projects to be Completed by End of FY 1990

Project Title	Project Leader
Nominal Filtering Research	E. Fosnight
Digital Line Graph Accuracy Testing and Evaluation System	P. Schubring
A Geological Engineering Application of a Knowledge-based GIS	M. Speak
Assessment of SPOT Stereoscopic Data and Potential Applications to NMD Programs	R. DeSawal G. Kelly
Users Needs for Land Surface Information in Metropolitan Denver in the 1990s	R. Alexander
Attribution of Large-scale DLG Elements from Small-scale DLGs	L. Ladner B. Napier
Digital Elevation Overedge Requirements for Orthophoto Production	L. Ladner
3-Dimensional Scientific Visualization	W. Acevedo
High-resolution DEMs from DLGs	B. Napier
Characterization of Urban Places Using a GIS	L. Gaydos
Desktop GIS Demonstration	S. Benjamin
Systematic Misregistration of Multispectral Data	A. Colvocoresses
Digital Analysis of SLAR Data Sets	P. Chavez
AVHRR Image Map of Antarctica	M. McEwen
GIS Modeling	L. Steyaert
Calibration and Information Extraction from Satellite Image Data	P. Chavez
South Central Alaska Radar Study	J. Jones
Development of Enhanced Vector Capabilities for the MIPS	J. Anderson
Development of Digital Geometric Correction Techniques for SLAR Data Using Ground Control Marked by Trihedral Reflectors	J. Schoonmaker
Fractal Analysis of Land Cover from Satellite Imagery	L. DeCola
Large-scale Digital Orthophoto Product Development Study	E. Zang
GPS-Controlled Photography for Mapping and Revision	G. Williams
The Geography of Terrestrial Carbon	R. Watts

TABLE A.3 Research and Development Projects Completed by May 1, 1990

Project Title	Project Leader
Image Restoration of Remotely Sensed Image Data	D. Meyer
Organization and Integration of U.S. Geo Data in a Undergraduate Program in GIS	F. Beatty
USGS ACS 85	E. Bates
Satellite Image Map of Great Salt Lake West	A. Colvocoresses
Space Image Mapping of Hydrilla in the Potomac River	A. Colvocoresses
Accuracy by RMMC, RTM, EMC, and WMC Analysis of Thematic Maps Using a Personal Computer	K. Lins
Digital Topographic Map of the Future	J. Findley
Spectral Data Base	A. Colvocoresses
Evaluation of LFC Photography from Shuttle Mission 17 for Topographic and Orthophoto Mapping	D. Light

TABLE A.4 Distribution of Full-time Equivalents (FTE approximate person years) by Activity and Location of Personnel, FY 1990.

	ADC	OGCR	OSD	OTM	MCMC	RMMC	WMC	EMC	EDC	Total
DEVELOPMENT ACTIVITIES										
System Development	0	0	1.2 (2.2)	0	4.0 (4.8)	0	0	1.5 (2.0)	0	6.7 (9.0)
Product Generation	0	4.2	0.5	1.0	2.0 (2.5)	1.6 (2.5)	1.5	0 (2.5)	0	10.8 (14.7)
Standards	0	0.1	0	5.0	0.1 (0.3)	0.2	0	0	0	5.4 (5.6)
Rules Development	0	0.1	1.0	2.0 (4.0)	1.0 (4.0)	0 (1.5)	0	0 (0.5)	0	4.1 (11.1)
Technology Transfer	0	2.3	0.5	0	0.5	0	0.5	0	0	3.8
DLG-E Development	0	1.1	2.0	1.0	1.0 (3.0)	0.8 (1.7)	0	0 (0.2)	4.0	9.9 (13.0)
RESEARCH INITIATIVES										
Theoretical Spatial Data Handling	0	0.3	0	0	0.2	0	0	0	0	0.5
Techniques Development	0	0.3	0	0	0	0	1.7	0	5.0	7.0
Remote Sensing and Image Processing	0	5.6	0	0	0	0	4.0	0	2.5	12.1
Thematic Mapping	0	0.1	0.5	0	0	0	0.3	0	0	0.9
Data Applications	0	0.3	0	0	0	0	0	0	0	0.3
Global Change	0	3.1	0	0	0	1.1	2.2	0	4.0	10.4
Data Collection, Management, and Dissemination	0	0	0	0	1.5 (2.7)	0	0.3	0	0	1.8 (3.0)
TOTAL	0	17.5	5.7 (6.7)	9.0 (11.0)	10.3 (18.0)	3.7 (7.0)	10.5	1.5 (5.2)	15.5	73.7 (91.4)

NOTE: Numbers are for FTEs under the NMD Assistant Division Chief for Research; numbers in parentheses are for the entire National Mapping Division, if different.

ADC, Assistant Division Chief for Research
OGCR, Office of Geographic and Cartographic Research
OSD, Office of Systems Development
OTM, Office of Technical Management
MCMC, Mid-Continent Mapping Center
RMMC, Rocky Mountain Mapping Center
WMC, Western Mapping Center
EMC, Eastern Mapping Center
EDC, EROS Data Center

TABLE A.5 Research Proposals Submitted for FY 1991

EASTERN MAPPING CENTER
- Generation of a 7.5-Minute Graphic Map from DLG-3 Data Using Automated Methods
- Character Recognition and Associated Tagging Capabilities of the Scitex 280 System
- New Replacement Data Base Sampler

MID-CONTINENT MAPPING CENTER
- Microcomputer-based Graphic Dictionary for Digitizing Rules
- Evaluation of Image Mapper Software for Producing Text and Collar Placement to NMD Specifications on 1:24,000- and 1:100,000-scale Graphics
- Comparison of Plotter Capabilities for Symbolization
- Parallel Processing Solutions for Digital Cartographic Applications
- Microstation for the MacIntosh for Digital Line Graph (DLG) Production
- Evaluation of ARC/Oracle as a Replacement for ARC/INFO
- Development of Knowledge-based Interfaces for GIS
- Rule Set Development for Automated Vertical Integration of DLG-3 Data
- Review and Correction of Digital Line Graphs Using a Raster/Vector Platform and Applied Mathematical Transformations

EROS DATA CENTER
- Identification of Global and Continental Map Projections
- Automated Extraction of Hydrographic and Woodland Features in Alaska from SPOT Digital Data
- Hyperspectral Data Visualization

ROCKY MOUNTAIN MAPPING CENTER
- Automated Plotting of Symbolized Hypsography from DLG-3 Data
- DLG-E Data Collection Methodologies for Existing Systems Data Applications—Research Initiative
- Raster to Vector Conversion of Scanned Data
- Consolidated Digital to Analog Mapping Process (CODAMAP) Development Using ARC/INFO
- Land-use Modeling and Monitoring on Ecosystems: Colorado Prototype

WESTERN MAPPING CENTER

- Modeling Urbanization Effects on Ecosystems
- Developing Land Surface Characterization Parameters for Input to Hydrologic Models
- An Interactive Distributed Modeling Environment for Methane Flux in Arctic Alaska
- Visualization Tools for the Analysis of Earthquake Focal Mechanisms and Seismicity Patterns
- Improved Estimates of Regional Methane Emissions from Tundra Ecosystems
- Electronic Prepress for Thematic Mapping
- Demonstration GIS for USGEODATA
- Geometric and Radiometric Correction of Scanner Aerial Photographs for Photogrammetric Applications
- Softcopy Aerotriangulation

OFFICE OF GEOGRAPHIC AND CARTOGRAPHIC RESEARCH (Reston)

- 3-Dimensional Analysis and Display Techniques
- Digital Revision of New Jersey State Base Map
- Metropolitan GIS—Initiative 2050
- Determining Requirements for a Common User Interface to National Mapping Division Data Bases
- Feasibility of Applying GIS Technology in a Spatial Indexing System for USGS Earth Science Data Bases
- Contingency for Anticipated Cooperative Technology Transfer or Implementation and Development Projects
- Integrating Desktop Publishing and Presentation Graphics Capabilities with GIS, ACS, and Image Processing Systems
- Development of an ADP Communications Network to Link National Mapping Division Research Activities
- ERDAS/ARC-INFO Training Development to Support the Digital Thematic Mapping Unit
- Alternative USGEODATA Distribution Format
- Coordination, Support, and Technological Advancement of CD-ROM Activities
- Continued Coordination of South Central Alaska Radar Study 88-8
- Continued Management of the Bureau's Side-Looking Airborne Radar (SLAR) Research Program
- Development of Digital Geometric Correction Techniques for SLAR Data Using Ground Control Marked by Trihedral Reflectors

- Assessment of Census TIGER Data for Supplementing Land-Use/Land-Cover Classification of Digital Imagery
- Extraction of Line, Symbol, Color, and Text Information from Scanned Thematic Maps
- USEPA/USGS Land-Use/Land-Cover Coop
- Antarctica GIS Pilot Project
- Land Characterization Measurement and Analysis
- GIS Front End for Hydrologic Models
- Applications of GIS for Tracking SLAR Acquisition and Research Requests
- Mortality Surveillance and Spatial Distribution System (MSSDS)
- Interaction of Topography, Vegetation, and Climate in Colorado
- Automatic Change Detection and Identification Using Remotely Sensed Image Data
- Understanding Landscape Dynamics for Global Change Research
- Continued Development and Support of Research Technology Transfer Activities at NSTL
- Evaluation of LAS versus MIPS as Sole Supported System for Digital Image Processing in NMD

OFFICE OF SYSTEMS DEVELOPMENT (Reston)
None

OFFICE OF TECHNICAL MANAGEMENT (Reston)
None

Appendix B
BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS

JOHN D. BOSSLER, *Chairman*

Dr. Bossler, formerly a rear admiral with the National Oceanic and Atmospheric Administration (NOAA), became director of the Center for Mapping at Ohio State University in January 1987. He manages the NASA-sponsored Center for the Commercial Development of Space, initiating activities on geographic information systems, and advises undergraduate students in the surveying program. A native of Johnstown, Pennsylvania, he received a B.S. in civil engineering from the University of Pittsburgh. He had a 27-year career with NOAA and rose to the position of director of Charting and Geodetic Services. During this time, Bossler earned his M.S. and Ph.D. in geodetic science from Ohio State University. He is active in many scientific and professional societies. Currently, he is a director of the National Center for Geographic Information Analysis. He is past president of AM/FM International, the American Congress on Surveying and Mapping, and the Geodesy Section of the American Geophysical Union.

JOHN C. ANTENUCCI

Mr. Antenucci is an engineer, planner, and management consultant specializing in the technical and institutional issues of geographic information management. In 1979, he founded PlanGraphics, Inc. (and is currently president), based in Frankfort, Kentucky, which designs and implements geographic information systems and automated mapping and facilities management systems. He has designed solutions for governmental agencies, states, municipal governments, utilities, and private enterprises both here and abroad. He received both a bachelor's and master's degree in civil engineering from Catholic University and has taken postgraduate studies in city and regional planning. He is a member of the board of directors of the Urban and Regional Information Systems Association and is active in AM/FM International, among other professional organizations.

LAWRENCE F. AYERS

Mr. Ayers is Vice President for International Federal Marketing of Intergraph Corporation. He spent 32 years in government, beginning as a research engineer at the Corps of Engineers ERDL Lab and has had scientific and management assignments at the Defense Intelligence Agency, U.S. Army General staff, and finally with the Defense Mapping Agency (DMA), where he was Deputy Director of Management and Technology (senior civilian). He directed the DMA production program (1979-1982), which included exchange agreements for geographic data with 90 countries. He lead the U.S. delegation to the 1980 U.N. Cartographic Conference and represented the United States at a number of international negotiations on geographic data. His professional society activities are numerous, and he is past president of the American Congress on Surveying and Mapping. Mr. Ayers was selected as a Fellow of the National Institute of Public Affairs and honored by the President (1984 and 1987) for distinguished Senior Executive Service. He received a B.S. in civil engineering from Virginia Polytechnic Institute and State University and an M.S. in public administration from Indiana University.

ROBERT CHARTRAND

As Senior Fellow in Information Policy and Technology at the Library of Congress, Mr. Chartrand has focused on the use of computers and telecommunications in emergency management and hazard reduction. He wrote the congressional report, *Information Technology for Emergency Management*, and co-edited *Strategies and Systems for Disaster Survival*. During his 35-year career in intelligence, in the information industry, and on Capitol Hill, he was involved in a variety of mapping and geographic activities; as a Naval photo intelligence officer and photogrammetrist, at TRW, developing the concept of a large-scale computer simulation with mapping and photographic infrastructure for the Air Force; and at IBM, developing the "overlapping polygon" technique. Mr. Chartrand received a B.S. and M.S. in history and government from the University of Missouri at Kansas City and performed additional doctoral work at Louisiana State University. He received the American Society of Information Sciences Award of Merit, is an AAAS Fellow (past Chairman of its Section T), and was both a decorated Fulbright-Hays lecturer in Italy and the first senior lecturer on information science and technology for the U.N. Development Programme in the People's Republic of China.

DONALD F. COOKE

Mr. Cooke is the founder (1980) and president of Geographic Data Technology, Inc. (GTD), which concentrates on improving and updating the basic TIGER data base and building tools for applications of TIGER. GDT was a major TIGER digitizing contractor to the Bureau of the Census. Before GDT, Mr. Cooke was a founder of Urban Data Processing, Inc. (now Harte Hanks Data Technologies) in 1968. In 1967, he was a member of the Bureau of the Census team that developed the Dual Independent Map Encoding (DIME) system. He is a member of the Urban and Regional Information Systems Association and the American Congress on Surveying and Mapping. Mr. Cooke received a bachelor's degree in administrative science from Yale University and attended graduate school in civil engineering at the Massachusetts Institute of Technology.

DAVID J. COWEN

Dr. Cowen is a professor of geography and the director of the Humanities and Social Sciences Computer Laboratory at the University of South Carolina. For more than 20 years, he has been actively involved in spatial data handling. He currently directs the university's GIS program. He has served as chairman of the Association of American Geographers' GIS Specialty Group and the South Carolina Mapping Advisory Committee. He is a member of the editorial board of *The American Cartographer* and *The International Journal of Geographical Information Systems*. He is also the U.S. delegate to the International Geographical Union's Commission on GIS. Dr. Cowen earned his B.A. and M.A. degrees at the State University of New York at Buffalo and his Ph.D. at Ohio State University.

JOHN E. ESTES

Dr. Estes is a professor of geography at the University of California, Santa Barbara. His research focuses on remote sensing, image analysis, applications of geographic information systems, and the design of knowledge-based systems using artificial intelligence concepts. He has conducted research for NASA, NOAA, DOD, USGS, and USDA and has been a consultant for public agencies, international organizations, and industry. Recently, he assisted NASA in the design of data systems for the proposed Earth Observing System. Dr. Estes contributed chapters 14-19 in *Manual of Remote Sensing*; edited *Remote Sensing Techniques for Environmental Analysis*; and is co-author of the textbook *Geographic Information Systems: An Introduction*. Dr. Estes received an A.B. from San Diego State College and a Ph.D. from the University of California at Los Angeles.

CLIFFORD GREVE

Dr. Greve is vice chairman and chief technical officer of Autometrics, Inc. He has been involved in mapping and geographic information systems for more than 20 years, including a brief stint with the U.S. Geological Survey and then with the U.S. Army Engineer Topographic Laboratories. As president of Autometrics, Inc. (1977—1990), Dr. Greve developed the APPS-IV Analytical Plotter, the AMS/MOSS Geographic Information System, and significant items in the definition and development of the DMA Digital Production System. He was awarded the Fairchild Photogrammetric Award in 1979 and holds a patent on the APPS-IV Analytical Plotter. He has published more than 20 technical papers. Dr. Greve earned his B.S.E. and M.S.E. in civil engineering from the University of Michigan and his Ph.D. in geodesy and photogrammetry from Cornell University.

GIULIO MAFFINI

Mr. Maffini is president and co-founder (1983) of TYDAC Technologies, Inc., a geographic information systems company specializing in the analysis and modeling of spatial data. Before then, he was executive vice president of DPA Group Inc., an economic and management consulting company, and was also active in a variety of urban planning activities in Canada. He is a member of the Canadian Institute of Planners, the Canadian Information Processing Society, the Urban and Regional Information Systems Association, and the American Society of Photogrammetry and Remote Sensing. He received a B.Sc. and B.Architecture from McGill University.

JOHN McLAUGHLIN

Dr. McLaughlin is chairman of the Department of Surveying Engineering, University of New Brunswick, Canada. He has worked on the development of land information systems throughout North America, Colombia, Brazil, the Caribbean, Southeast Asia, India, Australia, and New Zealand. He has been co-chairman of the NAS study on the multipurpose cadastre concept and for the NSF study on land information research. He is currently organizing a national study on surveying and mapping education for the American Congress on Surveying and Mapping. Dr. McLaughlin is co-author of *Land Information Management* and is on the editorial boards of the *CISM Journal, URISA Journal, Journal of Surveying Engineering, Geo-Information Systems*, and *Land Use Policy*. He received a B.Sc.E. and an M.Sc. from the University of New Brunswick and a Ph.D. from the University of Wisconsin.

BERNARD J. NIEMANN, JR.

Mr. Niemann is a professor in the Department of Landscape Architecture, the Institute for Environmental Studies, and Cooperative Extension of the University of Wisconsin at Madison; he also holds an adjunct position in the Department of Urban and Regional Planning. Professor Niemann is Director of the Land Information and Computer Graphics Facility in the School of Natural Resources. He is chairman of the Wisconsin Land Information Board, is past president of the Wisconsin Land Information Association, and serves on the GIS/LIS conference steering committee as the representative of the Urban and Regional Information Systems Association (URISA). He is also editor of the Wisconsin Land Information Newsletter and co-editor of the URISA Journal. During the past 20 years, he has been active in the use of spatial information technology for rural land use and management. Professor Niemann received his F.A.A. from the University of Illinois and an M.L.A. from Harvard University, Graduate School of Design.

BARBARA B. PETCHENIK

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