A DATA FOUNDATION FOR THE NATIONAL SPATIAL DATA INFRASTRUCTURE

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

National Academy Press
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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.

Support for this study by the Mapping Science Committee was provided by the Defense Mapping Agency, the U.S. Geological Survey, the Bureau of Land Management, and the Bureau of the Census.

Copies of this report are available from

Mapping Science Committee
Board on Earth Sciences and Resources
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Cover: A computer-generated perspective looking southeast toward Massanutten Peak in the Harrisonburg, Va., area. The perspective was generated by combining three U.S. Geological Survey digital data products: elevation data, line graph data, and orthophotography (the digital orthophoto for this area is shown as Figure 2 within the report). Figure courtesy of R. DeAngelis of the U.S. Geological Survey, Reston.

Printed in the United States of America

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PREFACE

The Mapping Science Committee serves as a focus for external advice to the federal agencies on scientific and technical matters related to spatial data handling and analysis. The purpose of the committee is to provide advice on the development of a robust national spatial data infrastructure for making informed decisions at all levels of government and throughout society in general.

Within the context of the above mission statement, the committee issued a report in 1993, *Toward a Coordinated Spatial Data Infra structure for the Nation,* that articulated its vision on how spatial information handling might best be approached from an organizational perspective. There are, of course, many specific issues that are raised when examining what a national spatial data infrastructure (NSDI) encompasses. The committee, with liaison from the Federal Geographic Data Committee (FGDC; operating under the aegis of the Office of Management and Budget), is undertaking a series of focused studies to examine individual components of the NSDI. The need for this study was discussed at a joint meeting of the FGDC and the Mapping Science Committee on February 2, 1993. One purpose of the study was to initiate a discussion aimed at identifying activities and data products that would support the NSDI. During the course of its study, the committee became convinced that a solid foundation of spatial data could enable (with the appropriate standards) the sharing and exchange of spatial information among the entire user community and alleviate many of the problems of spatial data integration.

In assembling the present report the committee struggled with a variety of concepts, competing priorities for spatial data production and data management, accuracies and resolution, and definitions. The committee did not think that it was within the scope of this study to suggest specific mechanisms for how such a foundation and framework data should be produced; these will reflect a variety of governmental and private sector priorities and will be market driven. In addition, the committee recognized early in its study that questions of resolution and accuracy were highly dependent on the specific applications. As such, the purpose of this report is to discuss general principles and guidelines that would help make the NSDI more robust.

Through five committee meetings and several ad hoc meetings of portions of the committee (meetings of opportunity), the present committee reached agreement on the content of the report. Those members of the committee whose terms ended in December 1993 were active participants and contributors to these meetings but were not present at the June 1994 meeting when agreement was finally reached; they did, however, have the opportunity to review and comment on the report.

One of the factors that influenced the committee in reaching its approach to the report was Executive Order. 12906 ("Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure," signed by President Clinton on April 11, 1994). This order identifies three specific framework data categories that should be available by 1998 for support of the decennial census in the year 2000. These three categories were prominent in the committee's deliberations from the outset of our study. In late 1993 the FGDC assembled a working group of its own on framework geospatial data, with its report to be ready near the end of 1994. Several members of the Mapping Science Committee met with this working group in May 1994 to discuss various concepts related to the FGDC working group's task. There was a fairly high degree of coincidence among many of the concepts in this report and those being developed by the FGDC working group.

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EXECUTIVE SUMMARY

The purpose of this report is to identify a foundation that provides a common reference system for the generation and exchange of spatial data. The Mapping Science Committee (MSC) believes it is in the public interest for government to play a leading and facilitating role in coordinating the development of spatial data and to make those data available for public use and exchange.

Spatial data are expensive to generate, maintain, and integrate with other data. No single federal, state, or local agency can effectively respond to all possible spatial data needs of their constituencies. Nor can a single level of accuracy, consistency, or currentness be reasonably applied to all data products or applications. With a common locational registry for spatial data of all kinds, data produced for one application can be integrated more readily with other data. Without this, data sharing and exchange are impeded. Data sharing can minimize duplication, reduce long-term costs, and streamline analysis and decision making. Mechanisms to integrate and exchange digital spatial data are a fundamental component of the national spatial data infrastructure (NSDI). However, to effectively share spatial data, a common foundation of selected data is needed.

The MSC defines the *NSDI foundation as the minimal directly observable or recordable data from which other spatial data are referenced and compiled.* This foundation will assist in the integration of disparate spatial data sets and enable sharing. It will be of enormous benefit to federal agencies, state and local governments, the private sector, and the public at large.

Data that are derived from, or tied to, the foundation and meet a set of criteria identified in this report are referred to as *framework* data. They are generally needed by all levels of government and the private sector. It is logical for these to be integrated with the foundation and accessible to anyone. Specifications for integrating framework data with the foundation also are identified in this report. Examples of framework data themes are presented to demonstrate full and partial adherence to the specifications and to prioritize spatial data activities.

RECOMMENDATIONS

1. **The MSC recommends that geodetic control, orthorectified imagery, and terrain (elevation) data be considered the critical foundation of the National Spatial Data Infrastructure.**
2. **The Federal Geographic Data Committee (FGDC)should be responsible for coordinating the development andcertification of a foundation and for its maintenance and availability. Programs to acquire the data that comprise the foundation should be accelerated to ensure that the foundation is adequate to meet the needs of the NSDI, particularly for the integration of other data. Data partnerships among federal agencies, state and local governments, the private sector, and others should be a key component of these programs.**
3. **Specific spatial data themes should be designated as framework data.**

   Three specific spatial data themes—transportation, hydrology, and boundary elements—were designated by President Clinton as priorities or framework in order to support the decennial census in the year 2000 (Executive Order 12906, April 11, 1994; "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure").

4. **The Federal Geographic Data Committee should (a) coordinate identification of the various components of existing framework data through its clearinghouse, (b) encourage efforts to integrate those data with the foundation, and (c) identify gaps in data coverage and encourage the establishment of programs that include partnerships to populate these framework data themes.**

   Although coordinated by the FGDC, individual federal agencies will need to identify funds for specific activities (including partnerships) related to the compilation, maintenance, quality control, certification, and access of the foundation and framework data.

5. **To accomplish the needed compilation, maintenance, quality control, and access of the foundation and framework data, additional research and development efforts are required to technically support these activities.**

Research topics should include data integration, intelligent query systems and distributed networks, improved data maintenance procedures, and standards for data certification.

The FGDC has made significant progress in the past few years. The metadata content standard and the spatial data transfer standard developed over the past few years are superb examples of some of the efforts involving standards that are needed to enhance the NSDI. Recognition of the NSDI was advanced significantly by three factors: Executive Order 12906 (April 11, 1994), FGDC leadership at the cabinet level, and policy-level participation in the FGDC by federal agencies. The executive order contains a series of challenges for the FGDC. For instance, the development of a spatial data clearinghouse is much needed, as is further work on standards. Without such activities, the ability to bring diverse data sets together is severely impaired. The MSC believes this report will be useful in clarifying some of the issues related to establishment of the foundation and spatial data framework for the nation.

1

INTRODUCTION

We live in an age of information, and in recent years the nation has made unprecedented investments in both information and the means to assemble, store, process, analyze, and disseminate it. Given the high costs of these activities, the nation needs to develop policies that are designed to invest and allocate information resources wisely and to ensure the greatest possible efficiency, effectiveness, and equity in the use of information.

The Mapping Science Committee (MSC) focuses its attention on a particular type of data—spatially referenced digital data. Spatial data[1] establish the positions of objects or activities on the surface of the Earth. Applications need to use data that have the appropriate accuracy. Some applications might require a positional accuracy of 1 mm and others 1 km. Although many applications are satisfied with two-dimensional analysis, there is an increasing demand for position in three dimensions.

In the past few years the MSC has focused its discussions on the concept of a national spatial data infrastructure (NSDI) and addressed specific aspects of its development and use. A previous National Research Council report[2] defined the concept of the NSDI to be "the means to assemble geographic information that describes the arrangement and attributes of features and phenomena on the Earth." The primary purpose of the present report is to address an important issue within the overall structure of the NSDI—namely, identification of a foundation that provides a common reference system for the generation and exchange of spatial data. The MSC believes that it is in the public interest for government to play a leading and facilitating role in research and production activities to develop spatial data and to make those data available for public use and exchange. Many of the production activities will take advantage of the capabilities of the private sector through contracts and other arrangements; to a certain extent, market forces will further push the production, maintenance, and distribution of certain data sets. This report:

- identifies three categories of spatial data that form the foundation for the NSDI,
- identifies minimum specifications required to integrate other spatial data with the foundation, and
- recommends specific activities that should be pursued to achieve an integrated and accessible NSDI.

NEED FOR SPATIAL DATA

People need spatial data to establish the position of identified features on the surface of the Earth. But why is position important? First, knowledge of the location of an activity allows it to be linked to other activities or features that occur in the same or nearby locations. Location allows distances to be calculated, maps to be made, directions to be given, and decisions to be made about complex issues. Examples range from local to national scale and address issues such as land-use planning and zoning, transmission corridors, new shopping centers or schools, siting of landfills, environmental regulation, and emergency relief; the potential list of uses is enormous.

Currently the bulk of the spatial data knowledge of the nation is embodied in the agencies, people, and technologies that make and use the nation's maps. These maps include commercial road maps for drivers, property maps maintained as land records, nautical charts used by mariners, floodplain maps used to determine control measures and the need for flood insurance, and the extensive series of basic topographic quadrangle ("quad") maps provided by the U.S. Geological Survey (USGS), which historically have had a wide range of users from hikers and hunters to resource planners.

The needs for spatial data are continually changing and include address matching, real-time monitoring of weather observations, water quality modeling, and countless other types of analyses requiring much more information than is traditionally represented on maps. These analyses may require real-time animation, scene comparison, data overlay, buffering, and other operations that cannot be supported by analyses of paper maps alone. This is not to say that paper maps are no longer needed but rather that their production should no longer be the primary driver for spatial data production.

Digital spatial data have become a critical ingredient in the decision-making process for government and business alike and can be an important agent of improved productivity in many sectors of the economy. Digital information has become increasingly important in effective siting of public and private facilities. Processing of spatial data also can lead to greater efficiency in the logistical operation of vehicles, with concomitant savings in fossil fuel use and reduction of pollution and traffic congestion. Likewise, spatial data are essential to responsible development or preservation of natural resources such as agricultural soils and wetlands.

As a consequence, spatial data that are customarily represented on maps and aerial photos are migrating to computer storage. The technology of data conversion is surprisingly complicated. And there is much more to moving spatial knowledge from paper to computers than simply digitizing current paper maps. Although digitizing paper maps automates the printing of more paper maps, it does not by itself support analytical needs.

What is needed is a realignment of priorities from paper map production to that of digital data production, which supports both digital analysis and paper map products. This requires rethinking the production process, retraining staff, adopting new technologies, and setting aside old attitudes.

The people in the NSDI will be profoundly affected by the technical complexity of converting spatial data from paper to computer data bases. Seemingly endless technical issues, such as differences in data models, data content, data quality, and data transfer must be resolved. Attention must be given to the problems of data redundancy, standards, and training in the new technologies. The incentive to make the conversion has to do with the ease with which digital data may be shared by many users with diverse spatial data needs.

IMPORTANCE OF SHARING SPATIAL DATA

People need to share spatial data to avoid duplication of expenses[3] associated with generation and maintenance of data and their integration with other data. In paper map form, data sharing is obstructed if scales differ, if projections differ, if symbologies are not uniform, if legends do not identify all map items, and so on. In digital form most of these same problems exist and must be taken into account. Often, the spatial data produced for one application can be applied in others, thus saving money by sharing data. Mechanisms to facilitate the use and exchange of digital spatial data are a major justification for developing and expanding the NSDI.

A recent example demonstrates society's need for digital spatial data sharing at a level not now available. Analysis of problems resulting from major flooding in the upper Mississippi drainage basin during the summer of 1993 demonstrates the benefits of sharing digital spatial data for potential damage assessment[4] and forecasting results of mitigation scenarios. Had they been available, digital data layers such as geodetic control, digital elevation, hydrology, wetlands, street centerlines, geology, soils, and existing flood control structures could have been integrated with other information (e.g., meteorological, levee conditions and breaks, and other local data) to forecast the extent of flooding at a given river stage. An analytical system supported by digital spatial data could have determined routes of drainage and water absorption by soils and substructures. In addition, automatic traffic routing at each stage of flooding could also have been supported, allowing emergency services and commercial transportation planning to be put in place before crises of street and bridge loss occurred. These same data layers, if available, could be shared now that the flood is over to develop dynamic models of dike restoration or addition and to model impacts of alternative floodplain land-use scenarios. The availability and use of these data should lead to decisions that could help mitigate future financial loss and personal tragedies.

DATA SHARING AND DATA QUALITY

Each application has its own data requirements, including data resolution or precision, locational and attribute accuracy, logical integrity and semantic consistency, completeness, and temporal currentness. Response to an emergency 911 call may require positional accuracy of perhaps 10 m, while a surveyor of a property boundary will require measurements having a resolution in units of perhaps 1 cm. Land cover data bases for the nation could incorporate hundreds of themes, while mapping surface material for highways may require only tens of categories. Several of the themes for mapping forest resources might require frequent updating (e.g., annually or semiannually), whereas soil mapping may be accomplished with less frequent updates.

Data quality is an important component of data sharing because people need to know the reliability of interpretations and decisions based on the data generated by one agency and used in an application by another organization. No single federal, state, or local agency can effectively respond to all the possible spatial data needs of their constituencies. Nor can a single level of accuracy, consistency, or currentness be reasonably applied to all data products or applications. Table 1 presents examples of spatial data applications and their corresponding precision or resolution requirements.

To provide the necessary assurances of data quality, data sets may be evaluated according to guidelines and strategies set forth in the Spatial Data Transfer Standard (SDTS; FIPS Publication 173[5]). For example, when evaluating positional accuracy, data may be compared with other data sets of higher positional accuracy for the necessary registration and control. Table 1 shows this in the form of a hierarchy, where the less precise applications depend on source data of greater resolution. Notice that the most accurate layer is not essential for all applications. It is an oversimplification that the most precise or accurate data are always the “best” for a given application. Computational requirements, time available to reach a decision, and precision of other data to be integrated may in fact preclude the need for the most precise data in every application. It is true, however, that one data-producing agency must often depend on another data producer for source data, which points once again to the importance of sharing data and of integrating data from multiple sources.

TABLE 1. Example Applications of Spatial Data and Their Common Resolution Requirementsa

Horizontal Resolution	Example Applications
0.001 m (1 mm)	Crustal motion, geodynamics, geophysics
0.01 m	Property surveying, civil engineering
0.1 m	Cadastral mapping, utility location
1 m	Facilities management for utilities
10 m	Mapping, soil, and wetlands mapping, National Biological Survey
100 m	Small-scale mapping
1,000 m (1 km)	Ice flows, global change research

[a] Exceptions to these requirements will depend on specific user needs.

CHALLENGE OF DATA INTEGRATION

The sharing of spatial data involves more than just ensuring that data are in digital form and that the metadata (information on data quality, accuracy, lineage, currentness, etc.) are included with the spatial data. As data are drawn from many producing organizations—each source (private, local, state, or federal) may have a possibly different application —there are likely to be differences in data definitions as well as in resolution, accuracy, and other data quality components. Users need to integrate spatial data to process it and understand its patterns. Methods for spatial data integration can range from very simple to very complicated processing steps, depending on the application and the differences in the type of data (see Figure 1).

FIGURE 1 As an example, the shape and location of a given shoreline can differ depending on the scale. As one goes from large scale to smaller scales, the abstractions involved in representing the feature become larger. However, if this shoreline had been compiled using accurate foundation data, these misrepresentations would be easier to handle in an integration process.

For example, data sets to support emergency response have often been created from USGS Digital Elevation Models and the Bureau of the Census' TIGER (Topologically Integrated Geographic Encoding and Referencing) files, registered to geodetic control. Facilities management applications may depend on cadastral maps (often produced at the county level) for identifying utility hookups. Integrating data can require merging position, merging attribute categories, correcting geometry or topology, and/or revising data definitions to embed the contents of one data set into another.

Data integration is not solely limited to positional registration. A hydrologist integrating two data sources may have as first priority the need to preserve the topological integrity of tributary flows rather than the need to locate them precisely. Integrating data from two different census decades may require statistical correction of attributes enumerated for different census tract boundaries. To take an actual example, some of the USGS Level II Land Cover categories are drawn or modified from categories in the Anderson et al. (1976) system,[6] whereas other categories are drawn from the Defense Mapping Agency's Digital Chart of the World. These data sources contain varying data definitions; thus, some conceptual revision is necessary to integrate all the sources.

Regardless of the type of operation (geometric, topological, statistical, or conceptual), data integration requires a specific spatial reference to be successful. The reference might be a set of registered data layers, a set of data themes, a published standard for evaluating logical consistency, or some combination of these. The choice of a single and unified reference provides a foundation for full integration of all other data into a common framework. That is, integrating some data to one reference and other data to another reference will not necessarily integrate all data to each other. This is especially true for spatial data processing, where it is common to combine multiple themes of data from many different sources.

For a single application, the principle of a single reference is straightforward, and one chooses the most convenient reference strategy. Within an organization, where a single data set may be used for multiple applications, data integration becomes more problematic as every integration process requires time and money. It is advantageous to adopt a single reference strategy and integrate data for any application to that reference, to minimize integration costs. For the nation as a whole, if each data producer relied on a different reference, data sharing, data exchange, and data integration would be impeded. Removing this impediment will strengthen the NSDI.

NOTES

1. The MSC continues to use the term "spatial data" in the context of "geographically" referenced data. The Federal Geographic Data Committee recently started to use the term "geospatial" within the same context.
2. *Toward a Coordinated Spatial Data Infrastructure for the Nation* (1993), Mapping Science Committee, National Research Council, National Academy Press, Washington, DC, 171 pp.
3. The Office of Management and Budget (OMB) determined that federal spatial data activities amounted to about $4.4 billion in FY1994; this number resulted from a data call described in OMB Bulletin 93-14. Most analysts agree that an equal or greater amount is spent on spatial data activities by state and local governments and the private sector.
4. For additional information on how spatial data were used in response to the flooding, see V. Speed (1994), "GIS and Satellite Imagery Take Center Stage in Mississippi Flood Relief," *GeoInfo Systems 4* (1), 40-43.
5. Spatial Data Transfer Standard, *Federal Information Processing Standard Publication 173,* National Institute of Standards and Technology, Gaithersburg, MD.
6. J. R. Anderson, E. E. Hardy, J. T. Roach, and R. E. Witmer (1976). A Land Use and Land Cover Classification System for Use with Remote Sensor Data, *USGS Professional Paper 964,* 28 pp.

2

NSDI FOUNDATION

Experience has demonstrated that collection of accurate spatial data can be an extremely costly and time-consuming process. Strategically focusing resources for data collection and maintenance efforts is a challenge to federal, state, and local governments and the private sector. As addressed in the previous chapter, data-sharing activities and partnerships are becoming increasingly attractive. Both, however, require a foundation that will enable the integration of data from multiple sources. The data that make up this foundation will create a convenient and common reference for the compilation of other spatial data.

DEFINITION OF A FOUNDATION

A useful metaphor to understand the needs for a NSDI foundation can be taken from building construction. A solid foundation of concrete or other material is first put in place; then a framework of steel beams is connected to the foundation to create a structure to support the building's interior and exterior. The foundation must be coherent and stable, such that the structure can be expanded upon with confidence in its reliability and integrity. In the same way, a foundation of spatial data serves as a reference for integrating other data themes. As these themes are developed and integrated with the foundation, a structure will be created that can support and sustain the NSDI.

As used in this report, the *foundation* is comprised of spatial data themes that are the minimal directly observable or recordable data to which other data are spatially referenced and from which other digital spatial data may be compiled.

Based on its members' collective experience, the MSC has identified three types of data as the foundation—geodetic control, digital terrain elevation, and digital orthorectified imagery. Geodetic control is required to systematically register all other information with a locational component. This is a primary data set in the NSDI, as it forms the footings of the foundation. A fully integrated NSDI cannot exist unless all data types are mathematically registered to a common foundation of geodetic control.

Two other types of data are included in the foundation. Digital terrain elevation data add horizontal and vertical measurements to the foundation and provide a fabric that approximates the Earth's surface. Digital imagery that has been orthographically corrected records a picture of the landscape. Both of these data types are registered to geodetic control. Spatial data for many applications then can be reliably integrated with this foundation.

DATA THAT FORM THE FOUNDATION

Geodetic Control

The accepted geodetic reference system in the United States is the North American Datum 1983 (NAD-83) established by the National Geodetic Survey (NGS) of the National Oceanic and Atmospheric Administration (NOAA) as the first-order horizontal reference system for the nation. Vertical control is referenced to North American Vertical Datum 1988 (NAVD 88). This system is well monumented on the ground for both horizontal and vertical control, and in many cases the control network has been densified by state and local users. On a global scale, the World Geodetic System-1984 (WGS-84) is used by the Department of Defense as its reference for the Global Positioning System (GPS). The difference between NAD-83 and WGS-84 is extremely small, and both can be used interchangeably for all but the most stringent situations. The NGS has a plan[1] for an updated national spatial reference system based on GPS measurements. This new reference system would be made compatible with the existing NAD-83 and NAVD 88.

For many applications the geodetic control network may be transparent; that is, the geodetic data may never be "used" directly in an application. This transparency will work as long as the data that are used to represent various spatial data themes are tied to the geodetic control. The accuracy of the location of a spatial feature will vary according to the goals of the application. In addition, existing accuracy requirements will likely change with future improvements in data collection capabilities and/or user requirements. Because of the availability of GPS (particularly differential GPS technologies) and their decreasing costs, highly accurate locations of newly acquired spatial data are being tied to geodetic control at an accelerating rate.

Digital Terrain

Digital terrain (elevation) data are used to create a digital representation (or model) of the Earth's surface. Digital terrain data have many valuable uses.[2] The data are required in the production of digital orthorectified imagery and together with the imagery can be used to create views of the Earth's surface from any vantage point. Digital terrain data are used to generate several important products and analyses, including volume, slope, aspect, line of sight, and intervisibility. These products at appropriate resolution can be used for civil engineering earth-work computations, stormwater run-off studies, microwave tower site selection, soil stability studies, geological studies, and many more. Digital terrain data also are commonly used to create contour information on many maps.

There are two basic models used to represent digital terrain data: (1) digital elevation matrix (DEM) and (2) triangulated irregular network (TIN); these are schematically shown in Figure 2. The DEM is a grid of elevation values at regular row and column spacing and is generally defined with an origin, the number of rows and columns and their spacing, and a series of elevation values. A DEM is an efficient method of storing terrain data; only elevation is needed as ground location is implied by row and column positions within the matrix. On the other hand, the TIN is a series of points linked into triangular surfaces that approximate the surface. The spacing of points in a TIN are nonuniform, which allows points to be located on critical terrain features. This offers the potential for the terrain to be more accurately modeled with a minimum number of points. A TIN also allows for faithful representation of linear features (geomorphic features), such as ridges, drains, and embankments.

The accuracy of digital terrain models depends on the source of the data, the point density and distribution, and whether or not geomorphic data were used in the production. Sources of digital terrain models vary—from highly accurate ground surveys (e.g., GPS positions) or large-scale photogrammetric surveys to lower-accuracy data created by digitizing contours from paper topographic maps or from small-scale, high-altitude photogrammetric surveys. Regardless of the specific data sources, digital terrain models need to be tied to a geodetic control network.

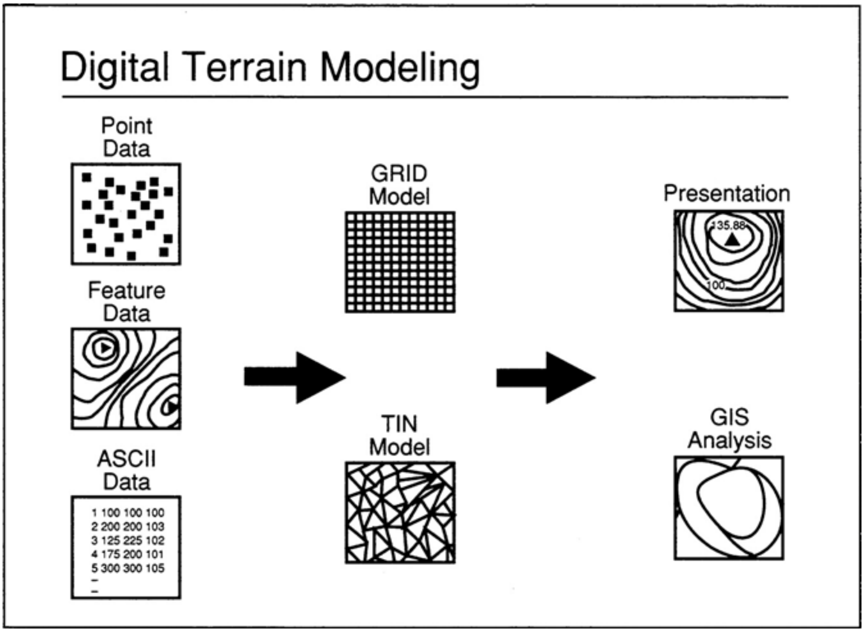

FIGURE 2 Representation of two modeling techniques for digital terrain data.

Digital Orthorectified Imagery

Digital orthorectified images provide a picture of the landscape from which features can be referenced to one another. They are digital raster images produced by differential rectification of aerial photography to geodetic control and terrain elevation data; all sources of distortion are removed, and the image has the properties of scale and accuracy associated with a map. The image can also be derived from digital airborne or satellite sensors. They can represent a range of resolutions based on the altitude and format of the original photography and the scanning process used to produce the digital raster image. Application requirements and costs will ultimately dictate the resolution of the imagery.

An example of a current data product that will meet the needs of a large number of users—the digital orthophoto quarter-quad (DOQ)—is being produced by the USGS, the Soil Conservation Service (SCS), and the Agricultural Stabilization and Conservation Service (ASCS). As specified by the USGS, each DOQ covers a "quarterquad" or roughly a 4 × 4 mile area. A quarterquad image consists of about 40 million pixels; each pixel represents a 1-m^2 area and has a 256-level gray-scale value. The USGS/SCS/ASCS have produced technical specifications for DOQs, and several test data sets have been widely distributed and tested.

When displayed, a DOQ (see Figure 3) looks like an aerial photo on which one can identify such features as roads, houses, trees, and driveways. About 200,000 DOQ images would cover the conterminous United States. DOQs contain coordinate registration points that permit measurement of the location of visible objects to a visual resolution of a few meters. This would allow for addition of other information, such as transportation, to the image base.

Expensive photogrammetric equipment and highly skilled technicians were needed to create the rectified stereo images that have been used for decades. These images have been the primary sources for updating the USGS 1:24,000 quad paper maps. Advances in computer technology now permit application specialists to access DOQs directly, putting a wide range of new users in touch with a rich and timely form of spatial data. DOQs promise to be a

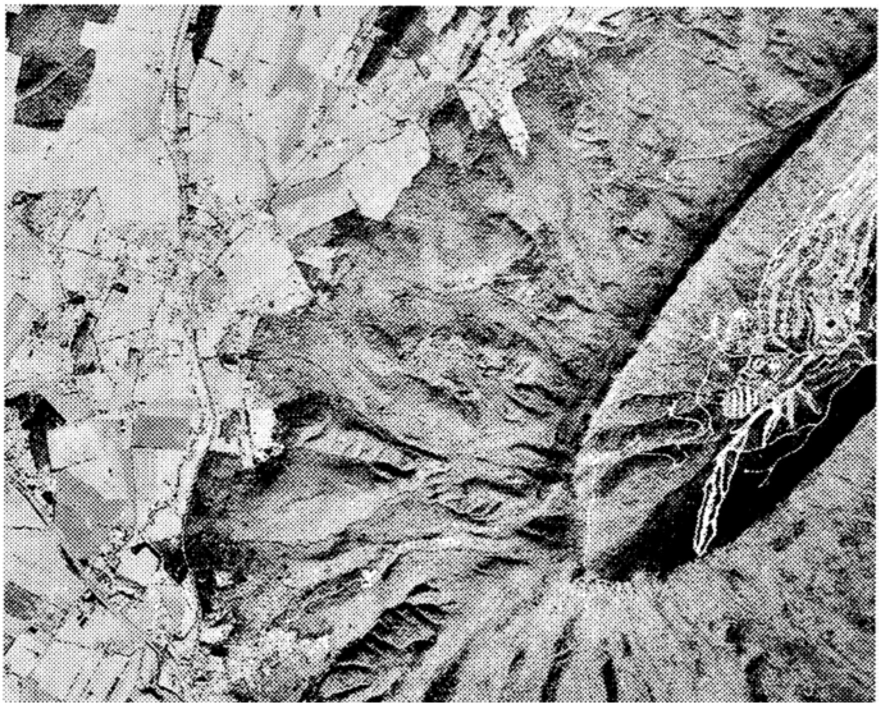

FIGURE 3 Example of a digital orthorectified image from the Harrisonburg SE, Virginia quarter-quadrangle. Pixel size is 1.0 m. The DOQ was used to construct the perspective shown on the front cover of this report.

high-accuracy, low-cost resource supporting many map-making and geographic information systems (GIS) activities in government, academia, and industry.

The value of digital orthorectified imagery is evident to a number of states and local governments, which collect and use these data as a critical part of their foundation for GIS activities. At the local level, this imagery may be at a much higher resolution than that of the DOQ program, reflecting specific local information needs. At the state level, the needs for the imagery are similar to those for the DOQs; however, current state imagery programs have resolutions ranging from 0.5 to 1.2 m pixels, and some states use color infrared instead of the black and white image sources used in the DOQ program. By and large, the various state programs have specifications similar to those of the USGS/SCS/ASCS program.

Because of their use within a foundation for the integration of other spatial data, national coverage by DOQs or other orthorectified digital imagery programs should be assigned a high priority. The USGS/SCS/ASCS estimated the cost for one-time nationwide DOQ coverage at $180 million spread over a five-year program. Federal-state-local-private partnerships could lead to sharing of both the costs and the benefits and the establishment of this important component of the NSDI foundation. **The MSC recommends that current federal plans for DOQ production be accelerated and that nationwide coverage be achieved through partnerships with states that plan or have similar programs that meet or exceed federal specifications.**

NOTES

1. Draft Implementation Plan for the National Spatial Reference System, 1994, National Oceanic and Atmospheric Administration, 37 pp. This draft implementation plan was reviewed at a forum by the National Research Council's Committee on Geodesy, which issued the report, *Forum on NOAA's National Spatial Reference System* (1994), National Academy Press, Washington, DC, 66 pp.
2. Further discussion of digital elevation models and their use is given by P. A. Burrough in Chapter 3 (pp. 39-56) of his book *Principles of GeographicalInformation Systems for Land Resources Assessment* (1986), Clarendon Press, Oxford.

3

FROM FOUNDATION TO FRAMEWORK

The purpose of establishing a foundation is to ensure that spatial data collection from different sources at multiple resolutions can be integrated through time to create a framework upon which the NSDI data needs may rely. But which spatial data themes should be included in a framework? The assignment of priorities calls for careful judgment of needs and demands for spatial data. Many public policy decisions as well as daily operations and other applications of government rely on spatial data. All spatial data users can identify data themes that are critical to their applications. Organizations recognize their own data priorities, as demonstrated by their willingness to support the needed data collection and conversion activities. These different applications and missions of individual organizations have evolved into the currently dispersed nature of data collection and data stewardship, particularly among federal, state, and local agencies.

For example, the Ohio Geographic Referenced Information Program recently completed a survey of users in urban and near-urban areas of Ohio about their specific spatial data needs. The compilation showed that the spatial elements most frequently identified included geodetic control, parcel boundaries, parcel attributes (e.g., ownership, assessment), municipal boundaries, rights of way, bridges, street centerlines and attributes (including addresses), land use, and hydrography. The largest number of respondents indicated that they desired locational accuracy for their data elements of 2.5 feet or better. Other states have also been active in trying to define their spatial data needs. Lists of needed spatial data will be different, reflecting the mandates of local, state, or federal organizations, and the applications (e.g., growth management, resource use, environmental protection, or provision of social services) for which the information is collected.

Framework data can be referred to as those sets of data, integrated with the foundation, that form the basis for spatial information and analyses. There might be different data sets that would form distinct frameworks; for instance, a framework for natural resource analysis could consist of different data sets than a framework that might be used for urban infrastructure issues. Just as there are multiple profiles within the Spatial Data Transfer Standard, *multiple frameworks could be established.* In addition to the foundation, there may very well be some data sets that are important in many different frameworks. Going back to the building construction metaphor, although foundation construction would be similar, the specific framework might differ markedly between a house or a factory or an office building, even though they probably have similarities in engineering design.

Just as there might be frameworks that differ by type ofanalysis, the framework data requirements also could differ by geographic regions. There is no expectation that the same level of accuracy or even the same framework layers will be compiled (or needed) in the near future over the entire United States. The focus should be on the ability to integrate different levels of spatial data details and accuracy.

The purpose of designating data within a framework is so that spatial data can be compiled and maintained for the benefit of all NSDI users. The MSC believes that some rationale is necessary for selecting and establishing framework data. The committee sug gests that the following criteria are necessary for data to be considered as framework data within the NSDI (additional specifications are addressed later in this chapter):

- broadest national constituency of users—spanning the largest geographic area and supporting the greatest number of applications;
- significant return on investment—in the form of increased productivity and efficiency;
- needed to manage critical resources, for developing policies, or administering programs for preservation and use of resources; and
- serves as a fundamental source to create or leverage other spatial data.

IDENTIFYING FRAMEWORK DATA

A commonly held view about spatial data has emerged among a large and diverse group of spatial data users in federal, state, and local governments as well as in private enterprises. This view[1] states that the productivity and effectiveness of their organizations will be significantly enhanced if their access to spatial data is improved. The MSC believes that it is appropriate for the federal government to play a lead role in making these data available for public use. It is very difficult (and in some cases impossible) for individual agencies, groups, or enterprises to provide all the needed data by themselves.

An impetus behind the 1990 revision of Office of Management and Budget Circular A-16 and the formation of the FGDC was the recognition that cooperation among different agencies would be required if the nation is to have access to the reliable spatial data that are needed. The goal of such cooperation is the minimization of redundancy in data collection and single-purpose spatial data systems (often called “stove-pipe” systems).

The FGDC currently has several subcommittees organized around broad spatial data themes (Table 2). These subcommittees are tasked by Executive Order 12906 to formulate plans for the development of content standards (e.g., definitions, conventions) for their respective data themes. Responsibility for many of these themes is delegated among several federal agencies. The establishment of these subcommittees can be considered as recognition of priority areas. With careful examination, one would be hard pressed to identify one of these themes that does not meet most of the criteria specified above.

As discussed in the MSC’s companion report, *Promoting theNational Spatial Data Infrastructure Through Partnerships,*[2] ideally there should be one data steward for any standard data theme in any geographic area. In many cases, federal agencies will become the de facto custodians (stewards) of certain data themes and data products at the national level. In other cases, state or local agencies will need to be the stewards of certain subsets of data themes. It is not necessary for the federal government to oversee all of these data. It must, however, be able to know where the data reside and be able to quickly obtain the data and integrate them to satisfy various objectives. A stewardship certification program along with directed funding and coordination with regional and local experts should be a vital component of the NSDI.

SPECIFICATIONS FOR FRAMEWORK DATA

As stated above, the purpose of designating spatial data within a framework is to enable the data to be compiled and main-

TABLE 2 Spatial Data Themes of FGDC Subcommittees

Data Theme/Subcommittee	**Agency** Chairing Subcommittee
Base cartographic	USGS
Bathymetric	NOAA
Cadastral	Bureau of Land Management
Cultural and demographic	Bureau of the Census
Geodetic	National Geodetic Survey, NOAA
Geologic	USGS
Ground transportation	Federal Highway Administration
Hydrologic	USGS
Portrayal of certain international boundaries	Department of State
Soils	Soil Conservation Service
Vegetation	Forest Service
Wetlands	Fish and Wildlife Service

maintained for the benefit of all NSDI users. If that is the case, the data must meet minimum specifications, including reliability, currentness and other metadata, integration with the foundation, and availability. All of the data themes shown in Table 2 may not meet these specifications. To meet them, some data themes will need increased production activities, additional research, and integration with the foundation.

The MSC suggests the following minimum specifications for framework data and their integration with the foundation:

1. **Framework data must be compiled, archived, and maintained in digital form.** Digital form permits the data to be adaptable to different or evolving hardware and software

technologies and facilitates use and exchange of the data. It encourages decentralization of data collection and archiving and exchange of data via telecommunications or other electronic means. That data are digital does not mean they exist in fixed or uniform resolution nationwide. With improvements in data collection technology, resolution will improve. As partnerships are put in place, some local or regional data collection efforts will proceed at different resolutions than in neighboring regions. The MSC accepts this as a realistic and desirable view of early generations of the NSDI.

2. **Framework data must include metadata descriptions.** Metadata descriptions should be in an accepted standard exchange format, itemizing accuracy, currentness, consistency, and completeness. Metadata descriptions at a minimum must include the procedures that have been applied in processing the data, the date(s) of processing, the region of coverage, and the agency or agent. Metadata reports must be integrated with data in a way that facilitates digital additions as subsequent procedures are applied. The FGDC recently approved an NSDI metadata content standard that embodies these descriptions and incorporates a detailed explanation of what is considered as metadata.
3. **Framework data must be mathematically and semantically integrated with the NSDI foundation**, with details of the integration procedure included in the metadata description. Requirements for accuracy and precision dictate a need for a geographical reference system (Earth references) as a basic foundation for the NSDI. Features should be integrated with the foundation to ensure consistency for framework theme integration. Some data represent features whose boundaries are nondiscrete (e.g., gradients), such as soils, vegetation, wetlands, and other natural resource features. While these data do not adhere explicitly to the minimum specifications, they should be compiled using a base that adheres to

minimum specifications. Metadata descriptions need to identify the locational accuracies and the nature of the delineations being described by these data.

4. **Framework data must be available in an accepted, openly publicized, standard data exchange format**. The Spatial Data Transfer Standard (SDTS) is the current Federal Information Processing Standard (FIPS Publication 173). This specification does not preclude exchanging data in other formats.
5. **Framework data must be accessible to the public.** Mechanisms for public access to the data must ensure that currentness and reliability of both data and metadata are preserved and maintained. They must also protect against unauthorized modification of the data source. Users frequently are demanding access to spatial data through electronic media (e.g., tapes, CD-ROMs) or computer networks. As data networks (such as the Internet) proliferate and increase in capability, many people will use them to either search for data through the metadata catalog or obtain the data directly on-line.

PRIORITIES FOR FRAMEWORK

The assignment of priorities is often fraught with disagreement among different parties, which have their own sense of what is most important. **The highest priority should be to ensure that the foundation (geodetic control, terrain, and orthoimagery) is adequate to meet the needs of the NSDI, particularly for the integration of other spatial data.** Although production of some of the data that make up the foundation are under way or are planned, most of it will result from other "product-specific" data collection efforts, often driven by specific mandates. Beyond this, priorities should follow the criteria listed for identifying framework themes (broad national constituency, significant return on investment, etc.) as well as the immediacy of the societal demand. For example, Executive Order 12906 (April 11, 1994) gave framework designation and immediate priority to transportation, boundaries, and hydrology data. These three themes are common to many, if not most, framework considerations. Their availability, probably at a variety of different resolutions or scales, will be applicable to the widest-possible sectors of the nation and will provide a basis for strengthening the concept of the NSDI. Discussion of these three data themes follows.

Transportation

The transportation data network transcends the utility of a common map because it is a base for defining, organizing, and accessing places (and their associated information) within both complex urban environments and rural areas. In a digital format the importance of the transportation network is magnified and its uses are expanded manyfold. What might have served as a guide or descriptor of pathways through a particular geographic area can now be used in routing of commerce and navigation (vehicles, rail, air, and nautical). The network can also serve as a basis for the indexing, analysis, and display of large volumes of tabular and statistical data (e.g., using Census polygons that are defined by transportation features).

One of the more prevalent forms of transportation data are street centerline spatial data (SCSD),[3] and most of the discussion here will focus on these data. SCSD are basically computerized street maps, where streets are represented as centerlines to which attributes of the streets are appended. Almost three decades of practice have proven the value of differentiating between the left and right sides of each street segment and encoding attributes to them such as street names, address ranges, ZIP codes, census and political boundaries, school districts, traffic zones, and congressional districts. Practice also demonstrates the value of including and reconciling nonstreet features in these data bases to form topologically consistent blocks (e.g., water bodies, railroads, political boundaries). The Bureau of the Census has incorporated some of these street features into its TIGER data bases.

Street centerline spatial data should include coordinate references at common, well-defined, line segment endpoints as well as coordinate descriptions of the path of the street (if not straight) between intersections. The SCSD structure accommodates use of coordinates at varying levels of accuracy, allowing economical and pragmatic data-set development with (expensive) high spatial accuracy where needed in urban areas but generally lower accuracy (where acceptable) in rural areas. Although SCSD are often thought of as a data base for urban applications, they support a myriad of natural resource applications in rural areas.

SCSD provide a good example of a framework spatial data theme by virtue of their extensive current use in facility site selection, census operations, socioeconomic planning studies, legislative redistricting, and logistical operations management. Present and near-term developments in personal computers and consumer electronics may expand SCSD use to virtually all citizens in trip planning, route guidance, and electronic atlas applications. The digital data requirements for the Intelligent Vehicle Highway System will likely dictate higher accuracy and more comprehensive attribution than most SCSD developed for GIS applications.

SCSD are important because they express fundamental relationships between street addresses (the most common spatial reference for the built environment) and coordinates and other locational links ("geocodes") mentioned above. SCSD are widely used to link street-addressed data to geographic references for GIS and other desktop mapping applications.

The TIGER files, particularly the attribute data, serve as a major stepping stone toward a mature SCSD for the nation. However, TIGER files lack accurate coordinates registered to the foundation, complete street addressing, and an ongoing maintenance program. **The TIGER files could be integrated with the foundation by the following actions:**

- **improving coordinate accuracy using ortho-rectified imagery that is tied to the geodetic control network;**
- **completing and improving street and address coverage in partnerships with the U.S. Postal Service, 911 emergency agencies, state and local governments, and the private sector; and**
- **establishing an ongoing update facility employing local government partnerships for timely informa tion (transactional updates) about new streets.**

These deficiencies of the TIGER files are recognized by the Bureau of the Census. The importance and timeliness of the societal demand for accurate transportation data are reflected in Executive Order 12906, which calls for provision of such data in order to support the decennial census for the year 2000. Funds should be identified to allow these improvements by January 1998, which is the target date specified in the executive order.

Political, Administrative, and Census Boundaries

In many cases, data on political, administrative, and census boundaries can be partially built from the basic elements comprising the SCSD. As such, much of their geographic accuracy and currentness will depend on the quality of the SCSD data. For this reason, integration of the transportation data theme should precede or accompany integration of the boundary theme. This sequence will reduce error and increase efficiency, thus reducing costs.

Boundaries are of great interest to the federal government because any program that has a local revenue-sharing component depends on an authoritative definition of city/town/place-level geography. State, local, and private interests are also increasingly involved as states pass legislation addressing all sorts of issues from funding of municipal pensions for firemen and policemen to taxation on homeowners to car insurance rates. While the Bureau of the Census conducts an annual Boundary and Annexation Survey (BAS), it performs the minimum survey to support that year's programs, and the results of the BAS are not published except in conjunction with the decennial population and housing census.

The line segments in an SCSD data base can be combined to create a number of important jurisdictional or areal data bases. These data can be distinguished as being governmental units, census statistical areas, administrative areas, or some other classification. Governmental units include states, counties, minor civil divisions, incorporated places, and consolidated cities. Census statistical areas include blocks, block groups, tracts, and block numbering areas. Some examples of administrative areas are school districts, police precincts, voting wards, and ZIP code delineations.

The Bureau of the Census determines changes to census statistical areas and limits these changes to once every 10 years. However, political and administrative boundaries might change at any time. For example, a rapidly growing city might annex several towns at its periphery. Since these changes are reported every 10 years for the census, the temporal accuracy of some boundaries cannot be guaranteed. Partnership arrangements, primarily with local and county governments, are essential to maintaining currentness of boundary data.

Hydrology

Hydrologic data include the location, geometry, and flow characteristics of the nation's river and stream network, lakes, and other surface waters. Hydrologic data provide a wealth of information that support a variety of uses—for example, prevention of flood damage, allocation of surface water (including dated agricultural, riparian, and other water rights), sources of nonpoint pollution, minimum stream flows, wetlands preservation, urban water requirements, and recreational interests. Use of hydrologic data with other spatial data sets permits rapid decisions on the advisability of reconstructing or removing various artificial barriers to natural flow by forecasting the effects of each perturbation of flow within a flood setting. With accurate and timely hydrologic data, the Federal Emergency Management Agency (FEMA) could more accurately forecast needs for evacuation, emergency assistance, and long-term mitigation of damages.

Many hydrologic features can be derived directly from the orthorectified imagery and digital terrain (parts of the foundation), to provide the control for identifying stream courses and their flood-plains and other surface waters. Surficial geologic and soil data provide the basis for estimation of both the ground water contribution to streams and the runoff and absorption of precipitation.

Important existing hydrological data that need to be integrated with the foundation include the Environmental Protection Agency's River Reach Files, USGS's Hydraulic Units Files, and FEMA's Flood Fringe and Ways. Several other hydrologic data types also merit consideration. These include (1) stream gauging and sediment load data, (2) water quality data, and (3) data on aquifers.

All of these data are important in national and state water supply planning and quality management.

As far as the framework specifications given above are concerned, current hydrological data products need to be tied directly to the foundation. However, more effort has gone into preserving the topology of the data rather than their accurate positional attributes. In addition, efforts are needed to make these data available in an open exchange format (much of the data are currently only available in a vendor-specific format).

OTHER FRAMEWORK THEMES

The purpose of the specifications for integrating framework data themes to the foundation is to strengthen the NSDI by promoting the benefits resulting from data sharing and the formation of partnerships. There are a large number of spatial data themes that are important in a wide variety of applications. All spatial data users can identify additional data themes that are critical to their own applications. From a national perspective these closely correspond to the data themes of the FGDC subcommittees. Many of the data sets within these themes meet most, if not all, of the suggested criteria for framework data; however, most do not yet meet the recommended framework specifications.

Many of these themes have not yet been compiled in digital form, nor integrated with foundation data. Nonetheless, there is a societal need for these data themes. Examples of such spatial data themes include wetlands, soils, geology, demography, ecosystems, land use, and cultural relations. The wetlands theme has been discussed in detail in a previous MSC report[4] and has obvious importance in land-use planning and environmental considerations. Two broad data themes—cadastres and natural resources—are briefly discussed below as examples of important data that need to be integrated with the foundation and meet other framework specifications to maximize their utility within the NSDI.

Cadastral Data

Cadastral systems are those activities and data associated with land ownership. A single cadastral system incorporates land title and evidence, rights and interests in land, and the spatial extent of title, rights, and interests.

Most of the responsibility for the collection, management, and maintenance of cadastral information lies with the states. Most states pass this responsibility to local governments, such as counties. The federal government has the authority and responsibility for cadastral information on federally held lands.

In 30 states the primary system for defining the spatial extent of cadastral information is the Public Land Survey System (PLSS). This system was originally created by the federal government to facilitate the orderly inventory, settlement, and privatization of western lands. As the territories were granted statehood and the PLSS system was completed, responsibility for maintenance was turned over to the states. A cadastral digital data framework is needed to describe and define interests and rights in real property. Acceleration of a computer-readable file of PLSS data would be a critical step toward achieving this objective. This was recommended by the National Research Council in 1982,[5] and the recommendation has been repeated many times by diverse organizations.[6]

The federal government is responsible for a diverse group of mandates and functions that require cadastral information. These include supporting Native American land tenure, managing land resources on federal holdings (both surface and subsurface), acquiring property for specific projects, regulating real estate financing, agricultural assessment and support programs, environmental assessment, and other public safety and welfare programs. The federal government should develop a flexible SDTS profile for cadastral data and provide incentives to the states to establish digital cadastral data in forms that are easily shared and integrated.

Cadastral data should be compiled and maintained in digital form, should include metadata descriptions, and should be referenced to the foundation. A single formatting system for cadastral information should be chosen for the nation as a whole, in the form of an SDTS profile. Cadastral *boundary* data should be made accessible. However, because cadastral *attribute* information is often subject to personal privacy concerns, it should continue to be controlled locally.

Natural Resources

A variety of data themes describe natural resource features, which are vital to land management, environmental management and protection, and economic development of public and private lands. All of these data themes (e.g., geology, water, ecosystem distribution, soils, wetlands) are valuable and are used in a variety of applications.

Wetlands are a natural resource of critical societal importance for a variety of environmental, biological, and aesthetic reasons, including biological diversity, water quality, wildlife, and fishery production. Completion of the National Wetland Inventory by 1998 (conterminous United States, Alaska by 2000) and its automation by 2004 has been mandated by Congress. There is a diverse user community for wetlands data—federal and state land management agencies, regulatory agencies (all governmental levels), and private sector development groups. Data describing wetland conditions are actually made up of other data, including the presence of hydrophytic vegetation, hydric soils, and wetlands hydrology.[7]

The various soil data sets (provided through the Soil Conservation Service (SCS) not only are critical in delineating wetlands but also have a broader utility in agricultural resource management, conservation, water quality, and erosion control. One ongoing program of the SCS is the National Resource Inventory (NRI), which provides a comprehensive data survey of nonpublic lands conducted on a five-year schedule. There are about 25 data elements (e.g., physical and chemical characteristics of the soil, soil moisture, hydrology, biology) included in the NRI.

Geologic data have well-established value[8] as a basic framework for the management of numerous natural resources, including groundwater, mineral resources, energy resources, and, to a certain extent, soils and related biological resources. Geologic maps are the fundamental source for creating many other kinds of map data, such as landslide hazard maps, earthquake hazards maps, aquifer maps, groundwater vulnerability maps, mineral resource maps, and, in combination with other data sources, soil maps.

The utility of all these natural resource data themes would be greatly enhanced if they were more closely tied to foundational control; this would allow the integration that is needed by resource and land managers. The current availability of these natural resource data themes in digital form is somewhat limited, with wetlands and soils digital data more available than geologic data. Wetlands and geologic data lack agreed-upon content (definitional) standards; however, the FGDC standards efforts could make significant progress on content standards in the next few years.

NOTES

1. See, for example, K. Brown (1990), *Local Government Benefits from GIS,* PlanGraphics, Inc., Frankfort, Kentucky; and S. R. Gillespie (1992), The

value of GIS to the federal government, in *Proceedings: GIS/LIS'92 Annual Conference and Exposition,* Anaheim, California, pp. 256-264.

2. *Promoting the National Spatial Data Infrastructure through Partnerships* (1994). Mapping Science Committee, National Academy Press, Washington, DC, 114 pp.
3. A discussion of SCSD and their use within the urban infrastructure is also given in a previous MSC report, *Toward a Coordinated Spatial Data Infra structure for the Nation* (1993), National Academy Press, Washington, DC, 171 pp.
4. Ibid. Wetlands data and their associated issues were discussed explicitly in Chapter 5 and an Appendix.
5. *Need for a Multipurpose Cadastre* (1980). National Research Council, National Academy Press, Washington, DC, 112 pp. *Modernization of the PublicLand Survey System* (1982). National Research Council, National Academy Press, Washington, DC, 74 pp. At the time of these reports, GPS positioning was comparatively expensive; however, GPS probably is now the least expensive and most accurate way of determining position.
6. As an example, see *A Study of Land Information,* Department of the Interior, Washington, D.C., 61 pp. plus appendixes. This study was mandated by the Federal Land Exchange and Facilitation Act of 1988 (P.L. 100-409).
7. For further information on the status of wetland mapping and delineation, see *Toward a Coordinated Spatial Data Infrastructure for the Nation,* National Academy Press, Washington, D.C.
8. National Geologic Mapping Act of 1992 (P.L. 102-285); also see U.S. Geological Survey Circular 1111, *Societal Value of Geologic Maps* (1993) and National Research Council report, *Solid-Earth Sciences and Society* (1993), National Academy Press, Washington, DC.

4

RECOMMENDATIONS

1. **The Mapping Science Committee recommends that geodetic control, orthorectified imagery, and terrain (elevation) data be considered the critical foundation of the national spatial data infrastructure.**

   The foundation consists of spatial data that are the minimal directly observable or recordable data to which other data are spatially referenced and from which other digital spatial data may be compiled. The resulting foundation, which will assist in the integration of disparate spatial data sets and enable their sharing, will benefit federal, state, and local governments; the private sector; and the public at large.

2. **The Federal Geographic Data Committee should be responsible for coordinating the development and certification of a foundation and for its maintenance and availability. Programs to acquire the data that comprise the foundation should be accelerated. Data partnerships among federal agencies, state and local governments, the private sector, and others should be a key component of these programs.**

   Implementation of this recommendation is contingent on the federal government (1) recognizing the importance of this role and (2) making available the requisite authority and resources that are commensurate with the magnitude of the task. The recognition aspect was recently increased with the signing of Executive Order

12906 by President Clinton on April 11, 1994 ("Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure"). If the FGDC is unable to affect the coordination of authority and resources, other arrangements should be put in place to provide this critical activity.

3. **Specific spatial data themes should be designated as framework data.**

   Framework designation should be based on the following criteria:

   - broadest national constituency of users—spanning the largest geographic area and supporting the greatest number of applications;
   - significant return on investment—in the form of increased productivity and efficiency;
   - need to manage critical resources for developing policies or administering programs for preservation and use of resources; and
   - constitutes a fundamental source to create or leverage other spatial data.

   In addition, framework data should meet the following specifications:

   - be compiled, archived, and maintained in digital form;
   - include metadata descriptions that are adequate to reconstruct data collection and processing chronologies;

- be mathematically and semantically integrated with the foundation, with details of the integration procedure included in the metadata description;
- be distributed in an accepted, openly publicized, standard data exchange format; and
- be accessible to the public.

Three spatial data themes—transportation, hydrology, and boundary elements—were designated by President Clinton in Executive Order 12906 as the minimal elements of a framework that should be completed by January 1998 in order to support the decennial census of 2000. This activity should be established concurrently with a concerted federal effort to develop partnerships with the states and other parties. The MSC strongly believes that there is a broader justification for these framework data than just the decennial census; their use will be more widespread. The broad use of TIGER data, initially compiled for the 1990 census, is testament to this view.

4. **The Federal Geographic Data Committee should (a) coordinate identification of the various components of existing framework data through its clearinghouse, (b) encourage efforts to integrate those data with the foundation, and (c) identify gaps in data coverage and encourage the establishment of programs that include partnerships to populate these framework data themes.**

Executive Order 12906 also called for a spatial data clearinghouse. The MSC believes that, as a minimum, the clearinghouse should identify which and where components of framework data exist in government and the private sector. Although coordinated by the FGDC, individual federal agencies will need to identify funds (including partnerships) for specific activities related to the compilation, maintenance, quality control, certification, and access of the foundation and framework data. The FGDC should establish peri odic maintenance cycle procedures appropriate for maintaining the currentness of the foundation and framework data and see they are implemented. Improved methods are needed for integrating framework themes with the foundation. FGDC should encourage the development and implementation of such methods. The new technologies of the national information infrastructure (largely telecommunications driven; e.g., Internet) should be used to distribute and share the foundation and framework data and their associated metadata.

5. **To accomplish the needed compilation, maintenance, quality control, and access of the foundation and framework data, additional research and development efforts are required to technically support these activities.** Many of the same research needs were discussed in a 1991 report (*Research and Development in the National Mapping Division, USGS: Trends and Prospects,* National Academy Press, Washington, DC.) by the Mapping Science Committee. Without an increased understanding of concepts and procedures for these topics, integration of the foundation and framework data within the NSDI will not be achieved except at substantial extra cost and time.

Specific research should include the following needs:

- data integration from multiple sources and spatial, spectral, and temporal resolutions;
- intelligent query systems to facilitate successful browse and access to items in very large data bases and distributed networks;
- improved updating procedures to maintain the foundation and framework data and metadata; and
- standards for certification of the foundation and framework data.

ACRONYMS

ASCS	Agricultural Stabilization and Conservation Service
BAS	Boundary and Annexation Survey, Bureau of the Census
CD-ROM	Compact disk, read only memory
DEM	Digital Elevation Matrix
DOQ	Digital Orthophoto Quarterquad
DTM	Digital Terrain Model
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FIPS	Federal Information Processing Standard
GIS	Geographic Information Systems
GPS	Global Positioning System
MSC	Mapping Science Committee
NAD-83	North American Datum of 1983
NAVD-88	North American Vertical Datum of 1988
NGS	National Geodetic Survey, NOAA
NOAA	National Oceanic and Atmospheric Administration, Department of Commerce
NRI	National Resource Inventory
NSDI	National Spatial Data Infrastructure
OMB	Office of Management and Budget
PLSS	Public Land Survey System
SCS	Soil Conservation Service. USDA
SCSD	Street Centerline Spatial Data Bases
SDTS	Spatial Data Transfer Standard
TIGER	Topologically Integrated Geographic Encoding and Referencing system
TIN	Triangulated Irregular Network
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey, DOI