GEOGRAPHIC MAPPING AND ANALYSIS AT THE UNITED STATES GEOLOGICAL SURVEY

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ABSTRACT

The United States Geological Survey (USGS) completed once-over coverage of the conterminous United States with 1:24,000-scale topographic maps in 1992. Since then, the USGS has focused its efforts on increased participation by private industry in map production and revision. Increased emphasis has also been placed on data acquisition, improved access to the products of the USGS, and advances in applying map data. The USGS has taken over responsibility for Landsat 7 to ensure a steady stream of readily available, inexpensive satellite data useful for land surface resource mapping and monitoring. Efforts have also been expanded to understand the processes taking place on the landscape. To accomplish these objectives, the USGS uses three programmatic thrusts: (1) cooperative topographic mapping, (2) land remote sensing, and (3) landscape analysis. These programs strengthen geography in the USGS. Among the activities that the USGS has undertaken to ensure improved access to complex map data are "map-on-demand" kiosks, the Terra Server, the Digital National Atlas, Center for Integration of Natural Disaster Information, the National Elevation Dataset, and Gateway to the Earth. The geographic research program in the USGS has been revamped to address the questions of critical importance to each of the programmatic thrusts. Studies are taking place to compare different technologies for acquiring elevation data, to investigate new methods of using remotely sensed data, and to gather base geodetic and map data in the United States as well as in such places as Antarctica. The USGS is also conducting research and applications in disaster response, urban dynamics, land surface trends, human health in the environment, and other topics help provide the understanding of processes needed for adequate decision-making. Research is being done on how scientific information is used in the decision-making process and how to improve decision-support systems. Using a life-cycle approach to plan for our cartographic and other scientific data and information will help improve their availability, accessibility, and applicability. This approach helps the USGS monitor

the needs for cartographic and geographic information and continually improve digital and analog maps.

INTRODUCTION

The U.S. Geological Survey (USGS) strategic plan (USGS 1999) identifies three types of scientific activities, which have been further defined by the Science Council[1] as follows:

> Long-term data collection and monitoring: the systematic collection of multi-purpose, long-term, data, the preparation of attendant metadata, and the storage, maintenance, and distribution of those data.
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> Research and development: scientific inquiry based on hypothesis testing; a known product or customer is not necessary, and the result is the development of new models, tools, or knowledge. There can be a high degree of risk involved with this work. This is not to be confused with engineering or systems development.
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> Assessments and application: the interpretation, application, or synthesis of well-established knowledge usually gained from long-term data collection or research and development. This has a customer focus. Projects start with the end in mind, and there is a high confidence that we can deliver useful results.

Traditionally, the National Mapping Program of the USGS has focused on long-term data collection and monitoring, with a much smaller proportion of its efforts devoted to the other two scientific activities. The classic data collection activity is the 1:24,000-scale topographic map series, which achieved once-over coverage of the conterminous United States in 1992. Although research and applications have taken place throughout the program's history, recent developments have encouraged greater emphasis on these activities.

It is of little wonder that mapping activities play such a major role in the USGS. After all, the USGS was formed in 1879 to direct the "classification of the public lands and examination of the geological structure, mineral resources, and products of the national domain" (USGS 1986). The value and need for maps was well understood in 1879 when the USGS was formed. The authority to conduct topographic surveys is inherent in its organic act. Maps of all types have been increasingly valuable to the economy of the United States since that time.

In 1998 the gross domestic product (GDP)[2] of the United States was $8.79-trillion (Bureau of Economic Analysis 2001). At that time the economic sectors relying on

[1] The Science Council was composed of the Associate Division Chiefs for Science (now Chief Scientists) in each of the disciplines represented in the USGS.
[2] Real gross domestic product – the output of goods and services produced by labor and property located in the United States (BEA 2001)

geospatial data had an estimated value of $3.56-trillion (National Association for Public Administration 1998). Thus, at that time approximately 40% of the U.S. GDP relied on geospatial data. That percentage is likely to increase as geographic information systems, the global positioning system, and other geospatial technologies find more applications throughout the economy. Other studies have found maps to be of significant economic value to society as well (Bernknopf and others 1993, Bhagwat and Viju 2000, Oxford Economic Research Associates 1999).

It is not new or surprising that much of the economy relies on geospatial data. Throughout history maps have been critical to exploring for resources, defending territory, building infrastructure, and defining trade routes. Most national mapping agencies (NMA), both civil and military, have been established to further the economic purposes of the nations either directly or indirectly. The USGS is no exception.

Changes in technological, economic, and environmental conditions are requiring NMA's to reexamine their roles. For the USGS this has meant redefining mapping programs, reevaluating map revision activities, increasing emphasis on using partnerships and private contractors for production, expanding efforts to monitor the environment, gaining new understanding of Earth surface processes, and developing capabilities for people to use geospatial information to solve problems and improve decision-making.

At the same time, there is an emphasis on enhancing the ways people can access the wide variety of natural science information provided by the USGS.

EVOLUTION OF A SCIENTIFIC DISCIPLINE

As with all programs, the National Mapping Program (NMP) evolved to meet the changing technological environment and user requirements. The NMP has followed the normal model for the evolution of a scientific discipline (Scientific Assessment and Strategy Team 1994, Kelmelis 1997).

1. **Describing** the phenomena of interest. For instance, early biologists put considerable effort into describing species and providing taxonomy of the species. Although considerable effort is still expended on this, it is not the major thrust of modern biological sciences. The NMP described and continues to describe the land surface; that is, to produce maps of land surface characteristics, such as topography (the initial responsibility of the NMP), land use and land cover, and greenness indices.
2. **Monitoring** changes in the phenomena of interest. At this level, biologists monitor the life cycle of species and the habitat in which they live. Likewise, the NMP monitors the land surface by revising maps, maintaining a long-term archive of aerial photographs and satellite imagery.

3. **Understanding** the phenomena of interest. Biologists attempt to understand the relationship of the species to its environment and how that relationship changes over time. This can be within the life of one member of the species or of the communities' interrelations over many life cycles. Likewise, the NMP conducts research into the causes and effects of changes in the characteristics of the land surface. Thus, an understanding of the processes affecting the mapped variables is developed.
4. **Modeling** the phenomena of interest. Once an understanding of the processes has been developed, models can be constructed to replicate those processes and develop hypotheses of how the process or its manifestation will change under different circumstances. In biology, these models are tested by observing the real world to determine if the individual, species, or community of interest responded in the way the model forecast. The USGS NMP is in the early stages of developing process models of the land surface.
5. **Predicting** the reaction of the phenomenon of interest to changes in its environment. At this point, the models have been tested, and their reliability ascertained. The biologist knows that without X amount of moisture in the environment Y species will die. That is useful information to a decision-maker who must make a decision about species Y or water allocation. Likewise, potential changes in the characteristics of the land surface owing to human or natural causes are of vital importance to scientists and decision makers in many sectors of society. The NMP is beginning to test models of prediction of some land surface phenomena.

Although the evolution of a scientific discipline appears linear in this discussion, it is not. For instance, monitoring is needed to validate models; mapping is needed to provide data to support increasingly sophisticated investigations into the dynamics of phenomena; and there are customers for products of each of the phases of the discipline's evolution. The result for the NMP has been the recasting of the program into geographic mapping and analysis to emphasize the cooperative topographic mapping, land remote sensing, and landscape analysis.

THE NATIONAL MAPPING PROGRAM STATUS AND TRENDS

The NMP conducts work in three major areas. The first two, cooperative topographic mapping and land remote sensing, focus on the "describe and monitor" parts of the scientific discipline evolution as well as the "long-term data collection and monitoring" part of the USGS strategic plan. The third, landscape analysis, focuses on understanding, modeling, and predicting the causes and effects of the condition and changes of the land surface. It addresses the "research and development" and the "assessment and applications" parts of the strategic plan. A life-cycle approach is taken in all programs to address the availability, accessibility, and applicability of the scientific data and information (Kelmelis 1999). Research is conducted to address the needs of all subactivities of the program.

Previously identified trends affecting mapping (Kelmelis 1995) have intensified, including increased demand, increased expectations, improved and more varied data sources, more participants in map and geographic information production and use, and improved capabilities to produce and use data. This intensification has led to changes in mapping at the USGS.

Cooperative Topographic Mapping

The basic map of the U. S. Geological Survey is the topographic map. Many other USGS maps are compiled on or derived from it. One of the unique features of the topographic map is its ability to store and display spatial and object relationships on one document that is easily interpreted by the user. During the 1970s, USGS began efforts to produce maps digitally. Initially, existing data were to be digitized into a vector format. Once digitized, they would form the basis for future updates (Callahan and Olsen 1986, Morrison and others 1987). This approach was planned for the years 1986 to 2000. It soon became clear that it would be too costly to digitize all the information on topographic maps and maintain the digital data on a tile-by-tile basis. It became more expedient to develop a digital orthophoto database of the country. This would provide more up-to-date information more rapidly than could be accomplished by updating individual maps, and it could be updated more rapidly at a much lower cost than could topographic maps.

To produce a national digital orthophoto database required the production of digital elevation models as well. Thus, aerial photographs from the National Aerial Photography Program (NAPP) were combined with digital elevation models to produce a national orthophoto database. The existing topographic maps were scanned as digital raster graphics to compare with the orthophotos and identify changes. The orthophotos were then used as source material during map updates.

Other national data coverages are components of the topographic map as well. Rivers, streams, and water bodies are important features. A national hydrography database, in vector format, is being constructed (USGS 2001). This will form the framework for more detailed hydrographic data. The boundaries layer has been constructed. The geographic names database is also maintained (Payne 2000, USGS 1995). All of these are layers in the national database. Cultural features and transportation are more problematic, and the USGS is working with other agencies to define a method to compile and update those database layers.

Land use and land cover are natural outgrowths of the land cover information available on a topographic map; however, these data provide far more information than is shown on a traditional topographic map. The multiresolution land characteristics database contains national coverage of land cover data.

Thus, throughout the 1990s the USGS, with its partners, built national coverage for most of the data represented on the topographic map. To do so, cartographers had to disaggregate the topographic map, in digital form, into its component layers. With these layers nearly complete, the next step in building a national digital topographic map is to reintegrate the layers. A customer survey found that the general satisfaction with the disintegrated map layers was high (Gillespie 2001); however, there was an expressed need for more current information. In addition, many users are interested in having USGS data layers integrated or integratable (DeMulder and others 2001). Plans for limited vertical integration have been an expressed part of the plan for a national database of digital map data (Callahan and Olsen 1986). Technology and need have now converged to make horizontal and vertical integration a priority.

Concurrent with the need for vertical integration is the need to improve the resolution and accuracy of the various layers. In essence, the digital national map (DeMulder and others 2001) will be a multiresolution, seamless, integrated or integratable database designed so features can be revised within a reasonable time of when changes take place. A life-cycle approach is being taken. All map and database design is taking place with full consideration of the data management and distribution methodologies. More rapid revision and custom map-on-demand capabilities are hallmarks of the national map. These will require a greater reliance on partnerships and standards development.

Land Remote Sensing

The USGS has been active in remote sensing for many years, first with aerial photography, then with the earliest days of the Landsat (then the Earth Resources Technology Satellite (ERTS)) program. William T. Pecora, the late director of the USGS, and a number of others urged the development of a land-observing satellite that ultimately became Landsat (Johnson 1998). Since the launch of ERTS in 1972, the USGS has had the responsibility to archive, manage, distribute, and develop applications for Earth-observing satellite data. In 1999, the USGS began managing the operation of Landsat 7 as well. Since then, the USGS has established working relationships with 10 international cooperators representing 14 ground-receiving stations and is currently negotiating with others to establish as many as 4 more. This active network of international cooperators ensures near-global availability of Landsat 7 data. Since the launch of Landsat 7, the USGS has archived images of the entire land area (including coastal zones and coral reefs) of the Earth. Multiple images have been collected over most locations. The price per scene has dropped from over $4,000 when private industry managed the satellite to under $600 with USGS management. In addition, the amount of data collected has far exceeded the collection rate prior to Landsat 7.

Although there is little commercial market for raw or minimally processed mid-resolution satellite data, such as that of Landsat 7, there is a healthy and growing value-added industry. In addition, scientists and land managers on limited budgets have a great need for the low-cost, midresolution land remote sensing data.

The USGS has the responsibility for other land remote sensing data as well. This permanent Government archive contains multispectral scanner (MSS) and thematic mapper (TM) image data (1972+) from the National Aeronautics and Space Administration's (NASA) Landsat 1-5 satellites, advanced very high resolution radiometer (AVHRR) data (1986+) from the National Oceanic and Atmospheric Administration's (NOAA) weather satellites, and recently declassified military intelligence satellite photographs (1962-72). The archive is being expanded to include Enhanced TM data from Landsat 7, digital terrain data from the recent Shuttle Radar Topography Mission, and data from new multispectral sensors (MODIS and ASTER) aboard NASA's TERRA satellite. The USGS is now also working with SPOT Image Corporation to acquire and archive 10-meter resolution SPOT images, primarily of North America, in the National Satellite Land Remote Sensing Data Archive. Public access is enhanced through the Earth Observing System Data Gateway and recent implementation of the USGS Earth Explorer System, a search and order interface that permits users to search across multiple product types, use credit cards on a secure server, and check on the status of orders.

Key issues currently facing the USGS include planning for the future continuity of the Landsat data, strengthening our international cooperation in land remote sensing, ensuring that the capacity of the data archive is sufficient to handle the rapidly increasing satellite data holdings, and developing a business model that can sustain the growth of publicly available remote sensing data while building a strong and growing private sector value-added industry. Users have expressed the continued need for data availability, additional reductions in data cost, and the need for new knowledge and tools to be used in applications.

Landscape Analysis

Both Cooperative Topographic Mapping and Land Remote Sensing focus their efforts on the long-term data collection and monitoring part of the USGS strategic plan and the first two phases of the evolution of a scientific discipline described above. Geography is one of the oldest sciences. It has developed into a discipline with an important fundamental research component (Ackerman 1958), as well as one with an expanding role in applications and decision-making. The USGS has recognized this and has focused its geographic research and applications efforts to meet the inherently governmental role. That role includes the need to address fundamental land cover trends analysis (Loveland and others 1999), urban dynamics and other human transformations of the landscape (Acevedo and others 1996), human health in the environment (Guptill and Moore 2000, Moore and Guptill

1999), and many other topics (Kelmelis 1997). The Landscape Analysis subactivity is organized to achieve the following:

- Develop techniques to characterize and map the Earth's land surface at regional to global scales,
- Document changes in the land surface over space and time,
- Understand the causes and consequences of land surface change,
- Model the interaction of natural and human-influenced land surface processes through time, and
- Forecast the response of the land surface to changes in climate, environment, and land use.

This research topic and approach takes advantage of the vast historical data set and current monitoring systems available within the USGS. It builds on the historical responsibilities of the USGS and uses a logical approach to expand the traditional skill set available within the geography discipline.

Basic to research and applications activities is developing and using a sound understanding of the causes and effects of land surface change. These processes are particularly complex. For instance, the processes affecting only one component of the land surface, land cover, include interactions among climate, atmospheric chemistry, biogeochemical cycling, land use, population density, demographics, social and cultural structure, and many other variables.

It is also important that processes themselves be mapped (Kelmelis and Watts 1991). Gaining a more fundamental understanding of land surface processes will provide a basis for such topics as describing and understanding land surface status and trends, the relationship of human health and the environment, global environmental science, and the dynamics of urban environments, to mention only a few. Here again, partnerships are critically important. Cooperative Research and Development Agreements have been established with a number of private industry corporations and universities. Cooperative research activities between USGS geographers and the academic community are increasing and there are more opportunities for promising students, postdoctorate scientists, and professors to perform research and applications work with the USGS.

RESEARCH

Within the geographic mapping and analysis activity, the research has four main goals:

- Understand the land surface and the natural and human-induced processes that affect and are affected by it,
- Advance the state of knowledge of geography, cartography, and geographic information science,

- Maintain and advance capabilities in geographic tools, such as cartography, remote sensing, image processing, visualization, process modeling, geographic information systems, etc.
- Advance the use of scientific knowledge in management and policy decision-making.

These goals support all subactivities.

APPLICATIONS

The primary purpose of a government scientific activity is to help carry out the mission of the government to maintain or improve the condition of the people of the society. Listed below are selected examples of applications of the geographic mapping and analysis work:

- Center for Integration of Natural Disaster Information, which integrates information from many sources and disciplines to aid the response to natural disasters and provide a resource for information useful to mitigate the effects of natural hazards;
- Famine Early Warning System, which provides information for prevention of or early response to famine in participating nations in Africa;
- National Elevation Database, which contains consistent accurate digital elevation data of the United States useful for application by scientists and managers throughout the United States;
- National Hydrographic Database, which is being constructed to contain national coverage of digital hydrographic information useful for hydrologic and biologic analysis, as well as for operational activities;
- Digital National Atlas of the United States, which provides access to more than 100 themes of geographic information and rudimentary analytical tools to the general public, as well as managers; and
- Fire Fuels Inventory, which provides information useful for the predication of wildland fire potential and intensity throughout the United States.

CONCLUSION

Restructuring the USGS NMP from a functional organization to one based on scientific outputs and outcomes gives management an opportunity to better meet the strategic plan of the USGS and be more consistent with the other scientific disciplines within the organization. It enhances our ability to conduct geographic science at all scales to meet the needs of decision-makers and the scientific community. It has the added benefit that it focuses the organization’s efforts on the scientific results that are needed rather than the processes used to achieve the results. This gives the geographers, cartographers, and other scientists the latitude to use whatever methodologies will achieve the needed results while maintaining the scientific values of the organization – scientific leadership, excellence, and impact.

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