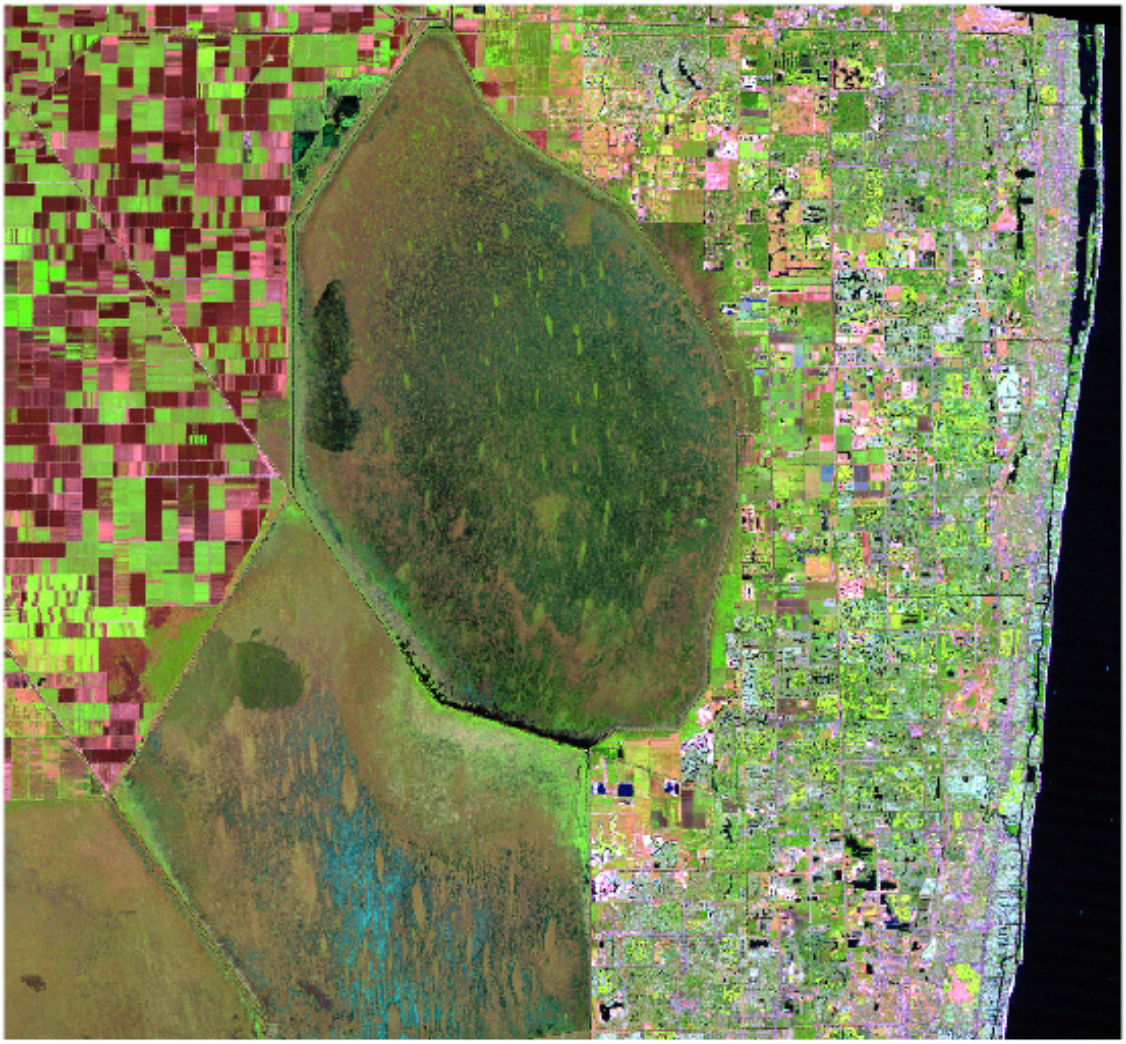
Geography for a Changing World

A science strategy for the Geographic Research of the U.S. Geological Survey, 2005-2015



Geography for a Changing World

A Science Strategy for the Geography Discipline Of the U.S. Geological Survey, 2005-2015

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Preface

In early 2004, the Associate Director (Barbara J. Ryan) and Acting Chief Scientist (Mark L. DeMulder) for Geography at the U.S. Geological Survey (USGS) established a Geography Science Planning Team (SPT) composed of scientists representing all USGS disciplines and the geography academic community. The SPT was charged with creating "a succinct strategy to define, organize, manage, and grow the scientific activities of the Geography Discipline (GGD) over the next 10 years (2005-2015), within the broad outlines of the USGS Strategic Plan." Given this charge, the objective of the SPT was to develop a science strategy for GGD scientific activities over the next 10 years by analyzing the strategic context provided by regional, national, and global scientific issues and needs, identifying focused research opportunities associated with these issues, and evaluating the implications of these opportunities on the operation of the GGD.

In developing this science strategy, the SPT reviewed the USGS Strategic Plan, other USGS discipline plans, and recent external reviews of the GGD by the National Research Council. The SPT also examined science and strategic plans of other Federal agencies and of national and international earth science organizations. Through a series of panel discussions, the SPT heard from more than 150 people, including scientists and managers from the GGD, other USGS disciplines, and from within the U.S. Department of the Interior; representatives of other Federal and State agencies; industry leaders; university faculty; and professional societies. These meetings (convened in Reston, VA, Sacramento, CA, Sioux Falls, SD, Rolla, MO, and Denver, CO) provided SPT members with a broad perspective on the strategic opportunities and science priorities for the GGD during the next 10 years.

Input from all these sources provided the foundation for defining 10 interrelated science goals and 8 operational objectives. By undertaking the scientifically challenging and vital research activities outlined in this science plan, the GGD will attend to the Nation's most pressing geography-related science issues that are consistent with the USGS mission and well-suited to being addressed over the next decade using the unique perspective and methods of the field of geography.

Sincere thanks are extended to all who participated in this strategic planning process. This science plan has been reviewed extensively by colleagues in the earth science community, both within and outside the USGS, and has benefited greatly from these reviews. As a result of our participation in this effort, we have a much greater awareness of and appreciation for the diverse scientific programs and capabilities of the GGD and the enormous dedication of its staff. We look forward to the consideration and implementation of this science plan.

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Executive Summary

This report presents a science plan for the Geography Discipline of the U.S. Geological Survey (USGS) for the years 2005-2015. The report describes 10 science goals that address pressing strategic issues facing the Nation in the next decade and that are consistent with the USGS's mandated role as a Federal science agency charged with providing long-term monitoring, research, and assessments. In general these goals focus on science-based understanding of the relations among changing land use, humans, and the environment.

Goal-oriented investigations typically will be at the regional or national scale; however, more localized studies and demonstration projects also will be conducted, either on Federal lands or in other areas of national interest, to develop principles and methods that can be applied more broadly. The goals are intentionally ambitious for a Geography Discipline of the current (2004) size, and success will depend on extensive collaboration with other USGS disciplines, other Federal agencies, State agencies, and academic colleagues.

The first four goals define future thrusts in a traditional area of international leadership for the USGS Geography Discipline--studies of landscape change:

1. **Increased knowledge of the status of the global land surface and how it is changing.**
2. **Improved understanding of the local, regional, national, and global drivers of landscape change.**
3. **Increased capability to forecast plausible landscape changes over the next 20-50 years.**
4. **Improved understanding of the environmental consequences of landscape change.**

These first four goals are interrelated. Predicting the consequences of land-cover change and developing a more precise understanding of basic landscape dynamics requires better means of monitoring ongoing changes in land use and cover and the development of new insights and understanding of the factors leading to change. Predictive models that forecast land-use changes and their consequences on ecosystem integrity and sustainability are critically needed. We need to better understand the connection of the sequence of land-use change, land-cover alteration, and ecosystem response.

Understanding society's vulnerability and resilience to hazards will represent a second area of important Geography Discipline emphasis over the next decade. Two goals will guide activities in this area:

5. **Increased understanding of societal vulnerability to hazards.**
6. **Improved scientific basis for mitigation, preparation, response, prevention, and recovery from natural and anthropogenic hazards.**

The field of geography's long-standing intellectual tradition of studying the relation between society and the biophysical environment provides a framework for developing an integrated physical, biological, and social understanding of the relation between hazards and the

ways that society is both vulnerable to and capable of mitigating the adverse effects of hazards. Two areas of traditional geography research are important for understanding and minimizing the societal effects of hazards. The first is geography's historic emphasis on the human consequences of landscape change. The second is the recognition that the potential effects of natural landscape changes can be mitigated by changes in the human system.

The final four science goals are associated with a traditional core competency of the Geography Discipline--Geographic Information Science (GIScience):

7. **Innovative methods to support intelligent access to large data sets associated with earth-science activities within and outside of the USGS.**
8. **Innovative methods for knowledge creation from and exploitation of geographic data.**
9. **Innovative use of models to distill and synthesize geographic data to create new knowledge.**
10. **Timely availability of relevant, complete, consistent, and accurate geographic data that support the USGS mission, including the integration and certification of data from others and production of data when no other sources are available.**

By addressing these GIScience goals Geography will not only improve the scientific basis for understanding landscape change and its consequences but will provide capabilities needed by all USGS disciplines to accomplish their missions.

The Geography Discipline's ability to respond to each of these goals will require a sustained investment in strengthening the geography-related core competencies of the USGS. In addition to the need to strengthen the research and operational capabilities related to GIScience, investment in other geography core competencies by the Geography Discipline and the USGS must include remote sensing (comprehensive monitoring of the Earth at multiple resolutions), regional geography (applying the concepts and tools of geography to understand processes and interactions characteristic of regions), and integrating natural and social science (transmitting science results to decisionmakers and the public in forms that are useful for promoting the welfare of the nation).

Although this report does not contain a detailed implementation plan, it does describe eight operational objectives directed at strengthening the core competencies of regional geography, remote sensing, and the integration of natural and social sciences; improving the annual science planning of the Discipline; promoting a vibrant research culture; and educating science colleagues and the public about the capabilities and potential contributions of the Geography Discipline. These objectives include:

1. **Establish regional geography as a core competency of the USGS and promote USGS leadership in ensuring the theoretical and institutional vitality of this field.**
2. **Establish and improve USGS remote-sensing research capability and increase the use of remote-sensing data for near real-time monitoring of the effects of changing land cover and land-surface conditions associated with natural and anthropogenic hazards.**

3. **Establish the USGS as a leader in methods and techniques to improve and expand the use of natural and social science to support societal decisionmaking.**
4. **Develop a more efficient, focused process to guide annual science planning.**
5. **Proactive participation of Geography Discipline scientists and managers in the Bureau's science activities and in the science activities of the broader community of geography and earth science researchers.**
6. **Attract and maintain a critical mass of geography researchers able to sustain a high level of excellence in work on the priorities identified in the Geography Science Plan.**
7. **Expand the geographic awareness of scientists at USGS and DOI.**
8. **Achieve national leadership in efforts to improve the geography competence of the general population, and leaders in business, government, and nongovernment interest groups.**

USGS has a major leadership role in describing the Nation's changing landscape and explaining the environmental and societal consequences of these changes. This plan charges the Geography Discipline with developing sound scientific approaches that will support assessments of these changes and their consequences. The science described addresses large, compelling challenges; it requires engaging multiple disciplines in the physical, biological, and social sciences; considers the entire land area of a large Nation; and recognizes that the Nation's changing landscape must be considered in a global context. Achieving the science goals outlined in this report will require a bureauwide effort.

Introduction

The science strategy presented in this plan identifies strategic geography-related opportunities and science activities that will make a unique contribution to the USGS mission during the next 10 years (2005-2015). The plan describes science goals, desired outcomes, and strategic actions that will guide the geography-related activities of both the GGD and the Geospatial Information Office (GIO).

Over the next decade, the context for all USGS science activities will be influenced by several trends. Most, if not all, of the emerging earth science issues that the USGS will address must be studied as geographic phenomena; that is, location matters in the way these issues are studied and the ways the information generated by these studies is used. The core geographic research competencies of the USGS, including GIScience, remote sensing, and regional geography, have become increasingly powerful and afford new opportunities for knowledge development and use. Earth science investigations have evolved toward the study of very large areas (e.g., nations, continents, and the globe), and the resulting huge volumes of data are challenging to manage and understand. An even greater challenge is to gain intelligent insights about geographic and environmental processes from these data that can be used to guide resource-management decisions. Finally, the field of geography has evolved over the last 50 years from a largely descriptive science to a science concerned with understanding. While the emphasis on understanding has led to increasingly sophisticated uses of quantitative methods and technology, modern analytical methods must be blended with traditional observational and qualitative geographic methods to obtain the knowledge needed in Earth science investigations.

Geographers have an intellectual point of view and a set of tools and methods that enable a unique contribution to the USGS mission within this strategic context. In a way that is very different from other USGS disciplines, geographers understand earth processes in terms of place-based distributions, patterns, networks and flows at a variety of scales. The intellectual traditions of geography are founded on the study of human-environmental interactions and on recognition of the value of place-based knowledge developed by integrating information from multiple disciplines for a specific location. Geographic tools and methods, ranging from geographic information systems (GIS) to remote sensing, geospatial visualization, modeling, and data mining, provide a research, monitoring and assessment infrastructure that support GGD's unique contribution to the USGS mission of providing scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect quality of life.

Mission of the Geography Discipline

The mission of the USGS Geography Discipline over the next 10 years will be to understand and predict landscape change and its environmental consequences and society's vulnerability and resilience to natural and anthropogenic hazards in order to protect lives and property and provide the needed scientific information for decisionmaking (fig 1). The research, monitoring and assessment infrastructure of the Geography Discipline will be used to address

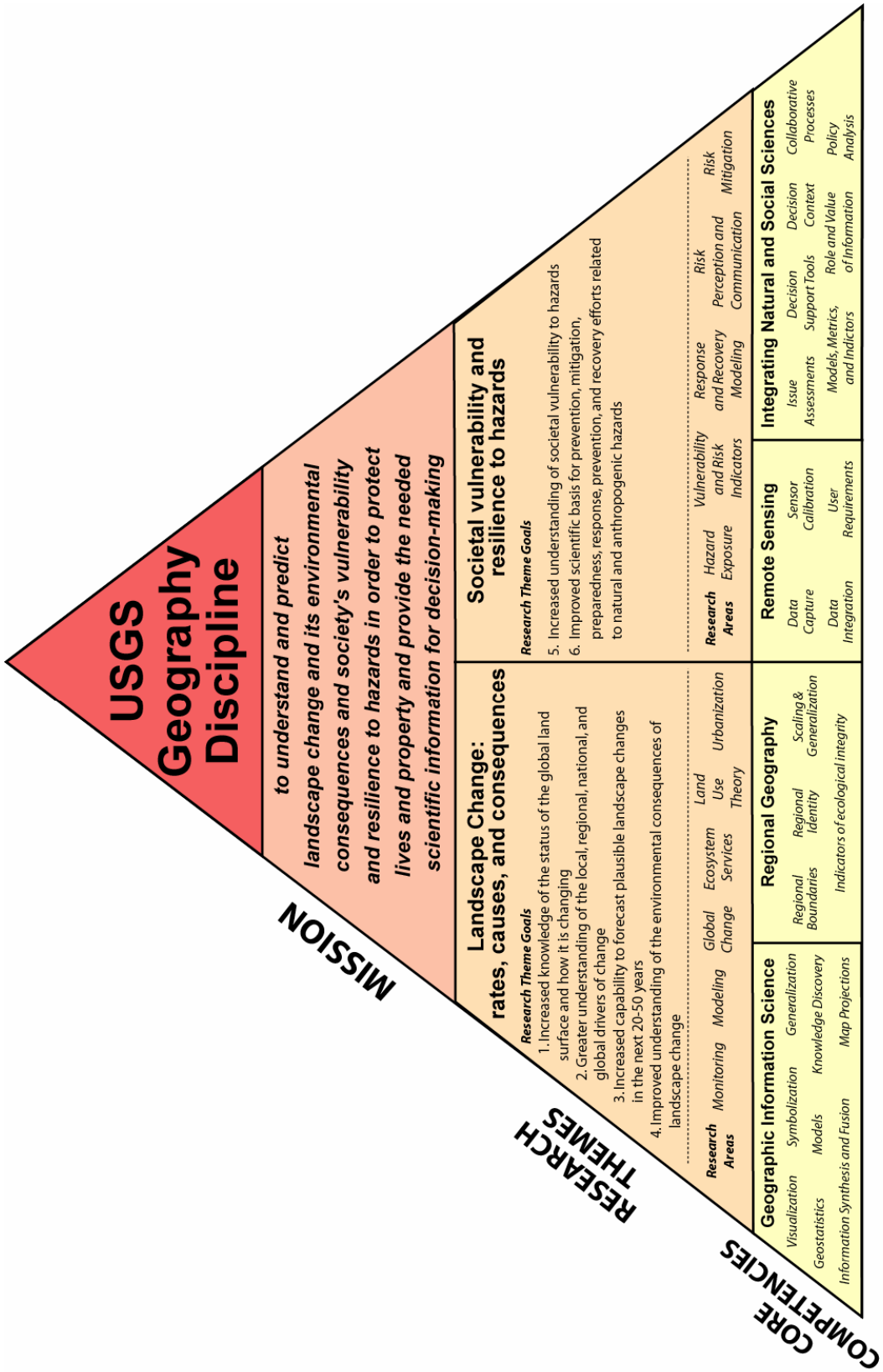

Figure 1: Mission of the USGS Geography Discipline, 2005-2015

two themes of importance to society:

- What are the rates, causes, and environmental consequences of landscape change?
- What is the societal vulnerability and resilience to hazards?

The SPT used several criteria to assess information from the panel sessions and written material and identify these priority themes, choosing to focus on:

- A few themes that the GGD can address better than any other organization, where we can make a defining contribution and become the first place that people think of for this kind of information.
- Themes where global and continental influences affect national interests and wellbeing.
- Themes that are compelling, with a potentially large payoff in both science and practical terms.
- Themes that are large, requiring numerous researchers and technicians, many years, and appropriate resources.
- Themes important to society and likely to require well-informed human responses in the near future.
- Themes where the science activities require the most up-to-date developments in technology, data, theory, or scientific collaboration, with the reasoning that important contributions are more likely in areas where new research and data management capabilities have recently emerged.
- Themes that require integrated, multidisciplinary collaboration that will benefit all USGS disciplines.
- Themes that are aligned with major national science priorities described in the National Research Council reports *Grand Challenges in Environmental Sciences, Rediscovering Geography, Research Opportunities in Geography at the U.S. Geological Survey, Weaving a National Map, and Finding the Forest in the Trees*.

Landscape change is the alteration of land use and land cover, ecosystem functions, and land-surface form and function resulting from natural and human influences. Human influences include urbanization, building dams, and harvesting of forests, and natural influences include long-term (climate variability) and short-term (wildfire) events that interact with the landscape at multiple temporal and spatial scales. Geography studies of landscape changes rely on and integrate information from monitoring (e.g., remote sensing, sampling), assessment (e.g., ecology, hydrology, climatology, geology, and urban planning), and research (i.e., developing and testing hypotheses and modeling) to describe and understand landscape change and its consequences. The evolution of USGS landscape change leadership called for in this plan is consistent with and responsive to calls from the national and international scientific communities to expand the understanding of landscape change and its effects on global climate change, biotic diversity, and ecosystem functioning. The importance of this understanding is heightened because of the role of landscape change on the vulnerability and sustainability of humans, their settlements, and ecosystem services in general.

The USGS has a long history of science excellence and leadership in assessing both acute (e.g., earthquakes) and chronic (e.g., invasive species) hazards. There has been less sustained effort by the USGS or other federal agencies to understand society's vulnerability to hazards and how to mitigate and improve society's resilience to such hazards. A critical gap exists that USGS geography activities can address; the role of geography in addressing these information

needs complements and magnifies the value of the Bureau's physical and biological expertise.

Four core competencies of geography make up the research, monitoring and assessment infrastructure that will be used to understand the rates, causes and consequences of landscape change and society's vulnerability and resilience to hazards:

1. *Geographic Information Science* (GIScience) includes the traditional mapping activities related to managing, modeling, and representing geographic data, phenomena, and processes, as well as human cognition of geographic information, representation of uncertainty, spatial analysis and modeling, scale, and geographic ontologies. GIScience also includes spatial statistics, geospatial visualization, and data mining, methods that are becoming essential for earth-science applications and research that focus on spatial patterns and distributions, networks, and diffusion and distance decay.

2. *Remote Sensing* includes monitoring the Earth with space-, airborne-, or terrestrial-based sensors, allowing non-damaging observation of the Earth's surface at multiple scales and resolutions. Remote sensing allows the observer to see the earth in ways that cannot be seen with the human eye, revealing patterns and connections among environmental systems that otherwise would be hidden. Repetitive remote sensing of the earth's surface permits change analysis, particularly for land use and land cover that represents the combined influences of human and natural processes.

3. *Regional Geography* includes applying the concepts and tools of geography to develop an integrated understanding of processes and interactions that are characteristic of regions. This perspective enables geographers to recognize and consider complexities of places and regions that are not recognized in other single USGS discipline, making possible a unique level of understanding of place.

4. *Integrating Natural and Social Science* includes bringing physical sciences and the social sciences together to better understand and translate the consequences of landscape change in regard to the welfare of the Nation. The increased demand for science-based information produced by the USGS is driven by several factors, including: decentralized decisionmaking, with an increased emphasis on citizen involvement; an explosion of sometimes contradictory earth-science information from a wide range of sources that is easily accessed using the Internet; widespread availability of tools, such as geographic information systems (GIS), that have expanded the potential for integrating earth-science information with mapped information about human priorities (e.g., land-use plans) and assets (e.g., transportation infrastructure and housing values).

The Contribution of Geography to the USGS Mission

The USGS mission requires that the USGS anticipate and respond in a timely manner to a broad array of local, regional, national, and global earth-science issues. Geography has a unique role in accomplishing this mission. Geography provides a powerful world view; it is the science of space and place, distributions and patterns, and networks and flows--all explored at a variety

of scales. In geography, location and scale matter. The scale of observation affects both the description and understanding of processes and phenomena that are occurring at a place. Emphasis on space and place is the defining characteristic of geography. In this regard, geography is unique in that the other USGS disciplines have topical definitions: geology as the science of the Earth, hydrology as the science of water, and biology as a life science.

Geography also supports the USGS mission by integrating vertical characteristics that define a place as well as the horizontal connections between places. This perspective on understanding place provides a logical platform for integrating data, explanation, and predictions resulting from the studies of USGS scientists (e.g., geologists, hydrologists, biologists, and geographers) as well as social scientists concerned with the societal impacts of the phenomena described by USGS scientists. Geographers also recognize that this place-based knowledge is scale dependent. Identification of scales at which the characteristics of a place (or region) can be most clearly distinguished from those of an adjoining place (or regions) can provide clues about the geographic scope of the processes that shape a place.

Geography supports the USGS mission with an array of geographic methods and tools. An understanding of the consequences of landscape change on environmental and societal systems must account for the spatial structures and processes of these systems. The tools of geography, such as GIS, visualization, remote sensing, spatially explicit models, and an understanding of how science-based knowledge can be used to support public policy decisions, can be used with the conceptual understanding derived from the geology, hydrology, and biology disciplines to develop information that is science-based and useful to society.

Finally, geography supports the USGS mission by providing a rich intellectual tradition that focuses on the interactions of humans with the environment and on the interrelations of the economy, society, politics, and culture and the biophysical identity of a place. Geographers seek an understanding of how human actions modify or transform the environment and of the consequences for humans of changes in the biophysical environment. For example, the prospects of acute (e.g., landslide potential) or chronic (e.g., sea-level rise) land-cover changes can influence local zoning decisions and regional or national infrastructure investments. Geographers who study the influence of social processes on a place may seek to explore and understand the socio-economic forces that shape the physical pattern of the landscape. Geographers seek to mitigate adverse environmental or societal impacts by understanding how landscape change and its associated risks are perceived by the public and by decisionmakers and evaluating the effects of alternative policies on humans and the environment.

Working with Others

The success of this science plan will require scientists and managers at all levels of the GGD to assume responsibility for identifying and incorporating partners in the planning and execution of Geography Discipline science activities. The greatest synergy will occur when there is a broad understanding of the objectives and scientific priorities of all disciplines in the USGS; this necessitates both initiative and good communication skills on the part of all GGD scientists and managers. Exciting opportunities exist for collaboration and partnerships with

other USGS disciplines, Department of Interior (DOI) agencies outside the USGS, state geographic information agencies, academia, the private sector, professional associations, and international agencies and institutions. An important objective of this collaboration is to avoid duplication of efforts or redundant investments.

Other USGS Disciplines. The USGS Strategic Plan (2000) identified the need for the agency to integrate and coordinate scientific investigations, particularly at the planning and research-design stage. Geography is poised to facilitate the integration of USGS scientific information and help provide scientific results to decisionmakers in a way that can be readily used. The GGD will have an important role in collaborating with all disciplines to provide accurate, current geospatial data, particularly associated with elevation, hydrography, and land cover, in a timely manner. Collaboration with the GIO, which has responsibility for *The National Map*, will be especially important. *The National Map* will provide the Nation with a consistent geospatial framework for geographic knowledge, public access to high-quality, geospatial data and integrated information from multiple partners. Full implementation of *The National Map* will require the integration of data from all USGS disciplines and extensive GIScience research.

Other U.S. Department of the Interior (DOI) Agencies. As the only science agency in the DOI, the USGS has a special role in meeting the scientific needs of other DOI agencies--the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS), the Bureau of Land Management, the U.S. Bureau of Reclamation (USBR), the Bureau of Indian Affairs, the Office of Surface Mining Reclamation and enforcement, and the Minerals Management Service--in managing Federal lands. The USGS provides objective scientific information and interpretation to these agencies and helps them in determining the types of monitoring required for gauging the success of resource-management policies.

Among the management needs and issues of DOI land-management agencies are: understanding the mechanisms associated with the spread of invasive species and how to model the vulnerability of public lands to the introduction and spread of such organisms; forecasting the landscape conditions in areas adjoining Federal lands in the next 50-100 years, particularly near parks and refuges; forecasting the ecological effects of landscape changes; accessing up-to-date geospatial data regarding roads, park boundaries, land cover, and vegetative cover, particularly in remote areas; accessing to historical aerial photos and other historical records in a georeferenced format that allows analysis of historical data on ecological conditions; and continuously updating landscape characterizations in and around the Nation's 270 national parks and monuments.

Other Federal Agencies. The GGD has numerous opportunities to collaborate with Federal agencies outside the DOI, particularly the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), Department of Energy, Department of Defense, U.S. Forest Service, U.S. Environmental Protection Agency, Federal Emergency Management Agency, and National Science Foundation. Interagency integrated science initiatives, including the Climate Change Science Program also are important forums for USGS geographic science. The multidisciplinary approach to problem solving necessitates that this kind of collaboration be expanded. For example, NASA's Earth Science Enterprise provides another outstanding opportunity for exciting science collaboration.

State and Local Agencies. State and local agencies can play a vital role in enhancing the relevance of GGD science initiatives for regional decisionmaking processes. The GIO's National Spatial Data Infrastructure (NSDI) partnership offices, usually collocated with other USGS discipline offices, can help ensure that GGD science objectives reflect an understanding of local and regional issues and that collaborative efforts are based on mutually beneficial objectives. Partnerships with local customers can enhance communication between Geography scientists and local parties and help in securing the best data for research needs. NSDI partnership offices can host local meetings on relevant science issues, keep channels of communication open between partners and the USGS, and pursue reimbursable agreements for GGD researchers. To realize these benefits, communication and coordination between NSDI partnership staff and GGD program coordinators must be strengthened

Academia. The GGD does not have a strong tradition of successful collaboration with the academic community and must work to develop and expand such collaboration. Stronger ties can be established in several ways, including cooperatively funding graduate students, developing a strong postdoctoral hiring program, and providing support for temporary sabbatical appointments. To achieve its science goals, the GGD will need access to cutting-edge research techniques and facilities that may not exist within the USGS. Opportunities for research collaboration are particularly strong in the area of GIScience needed to fully implement *The National Map*, including geospatial visualization, generalization, data fusion, and geospatial data mining and knowledge discovery.

Private Sector. The GGD has an extremely strong partnership with the private sector through a cooperative research and development agreement (CRADA) and other agreements in the production and distribution of maps. In order to serve the Nation better, the GGD must maintain this partnership, particularly in the full implementation of *The National Map*. Understanding the needs and goals of private-sector partners will ensure that collaboration is mutually beneficial. Opportunities for collaboration are particularly promising in the GIScience area.

Professional Societies. The GGD must continue to improve its visibility and cooperate with a wide range of professional societies, such as the Association of American Geographers. As members of a broader earth science community, GGD scientists must actively participate in professional meetings and in writing, reviewing, and editing scientific journal articles and books. Further, professional societies have made substantial investments in education and outreach, and the GGD can explore opportunities for greater collaboration in these areas. Large organizations, such as the Ecological Society of America, Geological Society of America, and the American Geophysical Union are new targets of opportunity for integrating the geographic perspective into the earth and biological sciences. Technical societies, such as the American Society of Photogrammetry and the Cartographic and Geographic Information Society, also are important potential venues for GGD professional participation.

International Agencies and Institutions. Cooperative efforts with earth science agencies in other countries are essential given the present transition to a more global economy, the global nature of many earth science problems (such as climate variability), and the clear need for global monitoring. GGD leadership and participation in international characterizations of land cover

and elevation can contribute to the development of national economic and security policies.

The GGD will focus its science efforts during 2005-2015 on understanding landscape change and its consequences on the environment and society's vulnerability and resilience to hazards. These efforts will be supported by geography's infrastructure, consisting of four core competencies: GIScience, remote sensing, regional geography, and integrating natural and social science. Geography also will bring these competencies to bear in collaboration with other science partners, particularly with scientists from other USGS disciplines and other DOI bureaus. By the end of this 10-year period, the intent of the SPT is that the GGD will be recognized as a world leader and a valued science colleague, inside and outside the USGS, in the application of these core competencies to understanding and predicting landscape change and its consequences and reducing society's vulnerability and improving its resilience to hazards.

Highlight: Connecting Our Past and Revitalizing Our Future

The emphasis on landscape change and hazards and the four core competencies of geography represent a significant philosophical and operational evolution for the GGD from its course in recent decades. This evolution results in a set of responsibilities for the GGD that are more in accord with the important role of geography in the scientific advances achieved in the early years of the USGS. Geographers were an integral part of the science accomplishments of USGS at the inception of the agency. The agency could not undertake investigations of the nation's mineral, fuel, and water resources, for example, without accurate topographic maps to serve as a framework for data representation and analysis. Because of the importance of mapping, early USGS directors developed a powerful mapping operation, staffed with the nation's best cartographers and financed by up to half of the USGS' annual budget. Cartographers collaborated with scientists from other disciplines, particularly geologists, in employing expert judgment and the scientific method to synthesize data and observations from exploratory expeditions into maps. These maps integrated local and regional information useful to both scientists and the general public. The mapping of the Nation, an enormous enterprise that generated more than 55,000 topographic quadrangles worth more than a trillion dollars by the 1990's, provided a geographic foundation for scientific investigations of the USGS geologic, hydrologic, and biological disciplines.

During the 20th century, while the USGS Geography Discipline was building a foundation of data to serve science, the disciplines of geology, hydrology, and biology (inside and outside the USGS) were practicing science, pressing forward with question-driven research to investigate natural processes. Geographic research science dwindled in the USGS through the early decades of the 20th century. In contrast, the quantitative research approaches developed in the field of geography during the 1950's became widely used outside the USGS, with emphasis on the spatial dimensions of natural and social processes and the connections between nature and society

When James Anderson began building the USGS's remote sensing and land cover analytic capabilities during the 1970's, geography was revived as a science partner in the USGS and served an important leadership role in these two areas. Despite the remote sensing and land use/land cover successes, however, geography as a discipline in the USGS is still not a full-fledged science partner with the other disciplines. While the agency has almost 1,000 practicing Ph.D. scientists in geology, hydrology, and biology, less than a score of Ph.D. geography researchers work at the USGS (National Research Council, 2002).

Highlight: Connecting Our Past and Revitalizing Our Future (continued)

The USGS faces a host of science issues that must be addressed using geographic research approaches. Geologists, hydrologists, and biologists require improved understanding of the spatial components of the processes they study. Partnerships with geographic researchers (not just geographic data suppliers) across all USGS disciplines offer promising avenues for explaining and predicting natural phenomena. The significance of human influence on natural phenomena also makes the participation of geographers a high priority. For the USGS to maximize the potential of its geology, hydrology, and biology disciplines during the next decade, it will need to rely on the core competencies of geographic science.

When the USGS was founded, geographers were full partners in basic and applied science activities associated with assessing the nation's resources, participating in the western survey and in founding the Association of American Geographers and the Geological Society of America. Geography was an integral contributor to the intellectual spark that ignited great science achievements in the early years of the USGS. This strategic plan presents a new vision and describes how geography's world view and core competencies can address strategic needs faced by the USGS over the next decade, as well as the importance of using these competencies in concert with partners inside and outside of the USGS. The focus on landscape change and hazards represents an opportunity to recapture the intellectual spark and make an important contribution to the success of the USGS mission.

Landscape Change: Rates, Causes, and Environmental Consequences

Overview

Landscape change can be defined as the alteration of land use and land cover, ecosystem functions, and surface form by natural agents and human activity. Human-induced changes can include the expansion of cities, building of dams, and the harvesting of forests, while naturally-induced landscape changes can be caused by climate variability, flooding, and wildfire. The study of landscape change observes, analyzes, and models how land cover changes and interacts with the water, energy, and climate cycles, and how human beings affect the Earth's surface. Geographic studies of landscape change, include the integration of information from remote sensing, chemistry, ecology, climatology, geology, and urban planning and the use of models of national and global terrestrial systems and their effects on air, water, and other important resources.

Landscape change is one of the pivotal issues in the discipline of geography because it is a major force in modifying climate, ecosystem goods and services, economic welfare, and human health at multiple scales (Slaymaker, 2001). Land-use and land-cover changes are perhaps the most noticeable forms of global environmental change, and the effects of local landscape change are cumulative and attain a global importance (Turner and Meyer, 1991). Improved information and understanding on the broad consequences of landscape change are essential to our ability to mitigate and manage the effects on human and environmental systems.

Landscape change has surfaced as one of the critical issues of the 21st century. As a critical societal and scientific issue rooted in the discipline of geography, it must be a central and primary focus of a USGS 10-year geographic research strategy.
Consider the following challenges:

- The mission of the USGS is focused on understanding the nature and implications of change, whether geologic, hydrologic, biologic, or geographic. The National Research Council (NRC) report on future research opportunities in the USGS recommends that the USGS undertake research on the significant ecological and economic consequences of land and water use changes (National Research Council, 2001a).
- Because changing land cover is a primary cause of changes in biogeochemistry, climate, and ecosystems, the Climate Change Science Program (CCSP) has made land use and land cover change one of seven core science themes (Climate Change Science Program, 2003).
- The NRC report on Grand Challenges in the Environmental Sciences identified land-use dynamics as one of the high-priority research issues of the 21st century and called for the development of a "systematic understanding of changes in land uses and land covers that are critical to biogeochemical cycling, ecosystem functioning and services, and human welfare" (National Research Council, 2001b). The NRC concluded that the spatial patterns of landscape dynamics are significant factors that increase the vulnerability of places and people to all kinds of environmental perturbations.

- The Intergovernmental Panel on Climate Change (IPCC) focuses on land cover as a central agent in the alteration of the carbon cycle, and ultimately as a key factor in climate vulnerability.
- The International Geosphere-Biosphere Program (IGBP) emphasizes changes in landscape conditions as a central contributor to changes in atmospheric chemistry, ecosystem dynamics, the hydrologic cycle, and climate.
- The Integrated Terrestrial Observing System has established the Global Observation of Forest Change/Global Observation of Landscape Dynamics initiative to combine national efforts to provide the baseline data needed to better manage the consequences of environmental change.

Strategic Science Activities

This science plan contains four science goals addressing the first important societal issue identified in the introduction: What are the rates, causes, and environmental consequences of landscape change? By focusing on these four science goals (Figure 2) , the GGD will improve the scientific basis for addressing the challenges and priorities identified above. A fundamental tenant is that understanding landscape change issues will require a perspective that spans local to global scales. To achieve this perspective, the USGS must expand its landscape-change research and establish a national geography monitoring infrastructure that provides information needed by the public. Following is a summary of the goals, outcomes, and strategic actions that must be addressed over the next ten years.

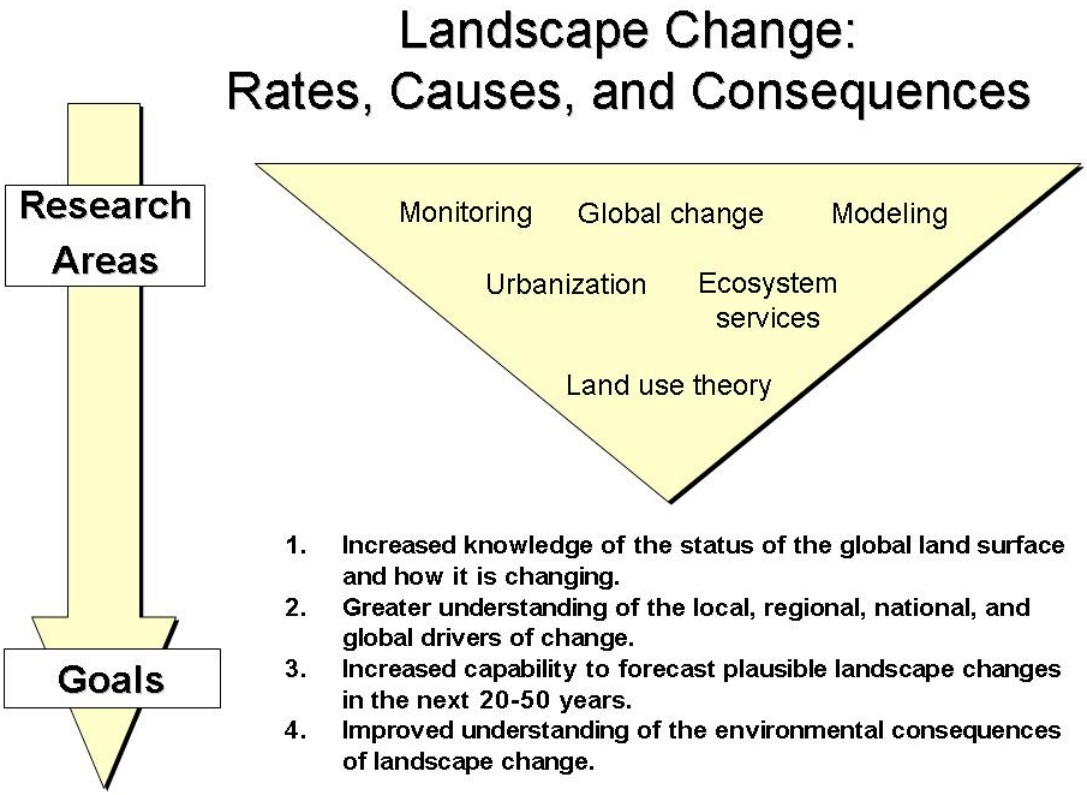

Figure 2: Priority research related to landscape change and the associated goals of this research.

Goal 1: Increased knowledge of the status of the global land surface and how it is changing.

Outcome*:* USGS maps of global land cover and changes in land cover are used by USGS and other researchers to improve understanding of how changes and patterns of changes affect atmospheric, hydrologic, biological, and human systems.

Strategic Action: Expand global capabilities to map and measure land cover and land-cover change at multiple resolutions that are locally relevant yet globally consistent.

Strategic Action*:* Determine how much of the national and global landscape changes annually as a result of natural and human influences. This entails ongoing research to document the full extent of natural and human disturbances occurring at global and national levels, including information on the location, type, and extent of change with sufficient characterization to permit an assessment of the consequences of change.

Strategic Action: Establish a consistent, repeatable methodology that identifies the changes in

the topographic form of the Nation at appropriate intervals. Assessments of the changes in the Nation's topography and land cover will be completed periodically (e.g., 5 years) using advanced topographic mapping and monitoring methods.

Outcome: An urban land-change monitoring program places local and regional urban growth in a national perspective that gives policymakers and planners a framework for clarifying and prioritizing the effects on economic development, environmental quality, and quality-of-life objectives.

Strategic Action: Develop and implement a strategy that leads to a clearer understanding of the characteristics and changes in the urban environment. A strategy to combine sampling and mapping in a regional geographic framework is needed to better understand the geographic dimensions of urbanization and the unique issues associated with urban growth from local to national levels.

Outcome : A operational global ecosystem monitoring system that continuously measures and characterizes the current status of ecosystem goods and services and estimates deviations from normal conditions. This system enables U.S. land managers and resource-assessment experts to use near real-time information for policy and management decisions.
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Strategic Action: Develop a suite of indicators of ecosystem health and productivity that can be used to monitor ecosystems throughout the Nation.

Strategic Action: Design a science program to carry out the specific research that leads to an operational monitoring system within 5 years using the core competencies of the GGD to provide near real-time assessments of the status of ecosystems.

Outcome : A spatially explicit reconstruction of the land use and land cover of the North American landscape provides the context for enlightened resource management and public policy.

Strategic Action: Working cooperatively with other USGS disciplines, assemble the land-use and land-cover history of North America. This will span the periods from pre-settlement to the present and provide a geospatial representation of the evolution and effects of human settlement across the once-natural landscape.

Goal 2: Improved understanding of the local, regional, national, and global drivers of landscape change.

Outcome : An understanding of the land-use and land-cover changes associated with the specific drivers of change leads to the development of plausible scenarios for predicting change. Research will provide decisionmakers with knowledge on the rates and types of

landscape changes that can be expected given specific drivers (e.g., technology, economics, policy, legislation).

Strategic Action: Establish an ongoing capability of assessing the social, economic, political, technological, and environmental influences on landscape change.

Strategic Action: Conduct studies on the geographic variability of the types of responses associated with specific drivers (e.g., globalization, new technology) on land-use change.

Strategic Action: Multiple-scale (e.g., local, regional, national, and global) investigations of the consequences of change resulting from land management practices, legislation, technology, globalization, and other drivers must be conducted to determine how historical change, land-use theory, and resource capacity interact to affect future landscape change.

Goal 3: Increased capability to forecast plausible landscape changes over the next 20-50 years.

Outcome*:* USGS models for predicting land-use and land-cover changes provide decisionmakers and scientists with objective projections given plausible scenarios of change at local, regional, and national scales. This capability contributes directly to assessments of the potential consequences of future changes on the Nation's economy and environment.

Strategic Action: Validate the theoretical basis of land-use change by using data from landscape-dynamics research. The advancement of land-use change theory will be focused on providing a theoretical basis for improved land-use and land-cover change predictions.

Strategic Action: The USGS will partner with the scientists outside of USGS in developing land-use and land-cover change prediction models and will conduct research leading to a community model for predicting land use and land cover change.

Goal 4: Improved understanding of the environmental consequences of landscape change.

Outcome: The USGS provides ongoing objective assessments of the environmental consequences of landscape change resulting from natural or human influences. This leads to better management of the consequences of change and provides a framework for understanding the potential ramifications of change on people, the economy, environment, and resources.

Strategic Action: Through partnerships, the core competencies of geography, and the results of the landscape-dynamics research described previously, research will be conducted on the consequences of landscape change. This research will explore the consequences of past, present, and future landscape patterns and dynamics. Coupled models that link landscape change to

selected environmental processes will be needed to conduct this assessment. Research will focus on the six primary themes of ecosystem services, biogeochemical cycles, climate variability, water issues, invasive species, and public health concerns.

Strategic Action: Conduct research on specific consequences associated with the effects of land-use and land-cover patterns and changes on environmental and public safety issues that occur at the urban-natural landscape interface.

Outcome: Operational capabilities for addressing the consequences of landscape change will be used to better understand fire regimes, the reintroduction of fire, and post-fire condition of relevant ecosystems. Special attention will be given to fire issues at the urban-natural landscape interface.

Strategic Actions: Conduct research leading to improved capabilities to assess wildfire conditions, predict wildfire potential, prioritize treatment areas and monitor effectiveness of fire treatments to support risk-reduction efforts in the urban-natural landscape interface.

Outcome*:* The USGS provides a national perspective on the effects of landscape change on the distribution of invasive species, diseases, and human health. This includes ready access to integrated hazard-assessment data, models, and reports to support risk-reduction efforts at the local, national, and international scale.

Strategic Action: Collaborate in the development of hazard-assessment models.

Strategic Action: Conduct research and develop innovative methods to support intelligent access to hazards-assessment information inside and outside of the USGS.

Establishing an Improved Landscape-Change Research Capability

The GGD has a substantial investment in several important aspects of the four landscape-change research goals. The USGS has developed a substantial capability to map the land use and land cover of the Nation and to assemble the elevation data needed to understand changes in surface formation. The USGS must continue to provide the data and understanding of contemporary landscape characteristics that are the foundation for all landscape-change research. The USGS is beginning to address questions relating to the geographic dimensions of landscape change (e.g., How fast is the land changing? what sectors are most dynamic? How do changes vary from region to region?). Because of the investment in baseline database development and in studies of landscape change, the USGS Geography Discipline is in a position to apply these data to gain an understanding of the consequences of landscape change. It is imperative that the current capabilities continue to be supported and encourage to expand.

To meet the challenges of the future, the following steps must be taken:

- A period of intensive implementation planning is needed to address the design issues that will ensure consistent and scientifically credible research. The key to success will be to follow the principle "design nationally and globally and implement regionally." National designs will permit consistent regional implementation and allow meaningful regional comparisons and national synthesis.

- A landscape-change center of excellence must be established to provide the core competencies and scientific leadership needed to meet these goals. A core of researchers will be needed to develop plans, conduct critical research, conduct national assessments, and synthesize regional and topical information. This group can provide the leadership in the establishment of the real-time monitoring capabilities and can work across the USGS to ensure that interdisciplinary opportunities are identified and realized.

- The addition of a minimum of 16 additional doctoral-level researchers is needed. If the USGS is committed to being an international leader in landscape-change research. To address the diverse research issues associated with the landscape-change science goals and to be able to compete at the highest scientific levels, the skills of the staff involved in this research must be broadened and the education levels raised. The land-cover mapping capabilities already available must be expanded by the addition of geographers with remote-sensing skills and regional geography and biogeographical expertise suited to global-scale investigations. The driving forces research requires an investment in geographers and economists with a strong understanding of the role of social, economic, political and technological drivers in regional settings. Staff with modeling expertise will be particularly important for land-cover change modeling and the studies of the consequences of change. Finally, expertise in geospatial statistics and sampling designs also will be needed.

- Additional funding will be needed to engage academic and industry experts in landscape-change research. Several aspects of this research theme are particularly well suited to collaboration with university investigators. The driving forces research can capitalize on regional experts in Departments of Geography around the country. The development of land-cover change prediction capabilities also will benefit from academic collaboration. The study of the consequences of landscape change is ideally suited to interdisciplinary collaboration within the USGS, as each discipline contributes expertise needed to understand the primary thematic issues.

- Landscape-dynamics research is highly visible because of the importance of this theme in major national and international science initiatives. The USGS has a unique historical and institutional commitment in this area with the ability to conduct research at spatial extents and temporal frequencies that are difficult for other organizations. While the USGS has considerable credibility in this area, this credibility relies on the continued commitment and greater participation by the USGS in major science initiatives of the CCSP, IGBP, NSF, and other premier scientific organizations.

Strategic Partners

As previously stated, some key partnerships can be with colleagues within the USGS. Scientists from all disciplines will be a powerful team for investigating the consequences of landscape change. Several Federal agencies conduct research in aspects of landscape dynamics. NASA and the USGS have the most robust programs and are natural collaborators. NASA has research interests in all areas except the drivers of change topic and focuses on basic issues rather than assessments. As a result, a strategic collaboration between agencies should be pursued. The USEPA also has a strong interest in landscape change, with particular interest in the consequences of change. The CCSP was established as a forum for interagency cooperation on CCSP research themes. Because the USGS has provided leadership for the CCSP Land Use and Land Cover Change research element, it would be prudent to use the CCSP umbrella for establishing collaborations with participating CCSP agencies. Also, previously mentioned participation in international forums is critical to the success of USGS landscape-change research, and agency support and encouragement should be given to USGS scientists engaged in this activity.

The National Science Foundation's National Ecological Observatory Network (NEON) initiative could be a particularly important partner for USGS landscape-change research. NEON has similar monitoring objectives as those of the USGS and a goal to answer the question, "What is the pace and nature of biological change?" Importantly, one of the six "grand challenges" of NEON is to provide the infrastructure and data needed to understand land-use and habitat alteration (National Research Council, 2003). The NEON strategy includes partnerships with Federal agencies with programs relevant to NEON objectives. Like the USGS, NEON seeks to understand land-use change consequences at regional to continental scales. Because NEON's research emphasis is compatible with USGS monitoring and assessment objectives, collaboration between these programs is important.

Although USGS geography has been largely focused on mapping functions, it can be argued that the USGS is already the leading Federal agency in landscape-change research. Assuming a more significant national and international leadership role will require expanding and balancing the program to ensure the availability of the exceptional expertise needed to address all four landscape change science goals.

Highlight: Land-Use Change and the Carbon Cycle

Carbon dioxide (CO_2) in the atmosphere plays an important role in regulating the climate of the Earth system. The continuing increase of atmospheric CO_2 concentration has the potential of significantly altering our living environment and affecting the economy at the regional to global scales (IPCC, 2001). However, the pathways that regulate the change of CO_2 concentration in the atmosphere are not well understood and quantified. The National Academy of Science reported that "how land contributes, by locations and processes, to exchanges of carbon with the atmosphere is still highly uncertain" (National Academy of Sciences 2001). One of the largest challenges in the study of local to global carbon cycles is to quantify the impacts of land use and land cover change on CO2 exchange between the terrestrial biosphere and the atmosphere. In fact, establishing accurate estimates of the impacts of historical and current land use patterns and trends on the evolving carbon budget at local to continental scales has been identified as one of the five overarching goals of the US Carbon Cycle Science Plan (Sarmiento and Wofsy, 1999).

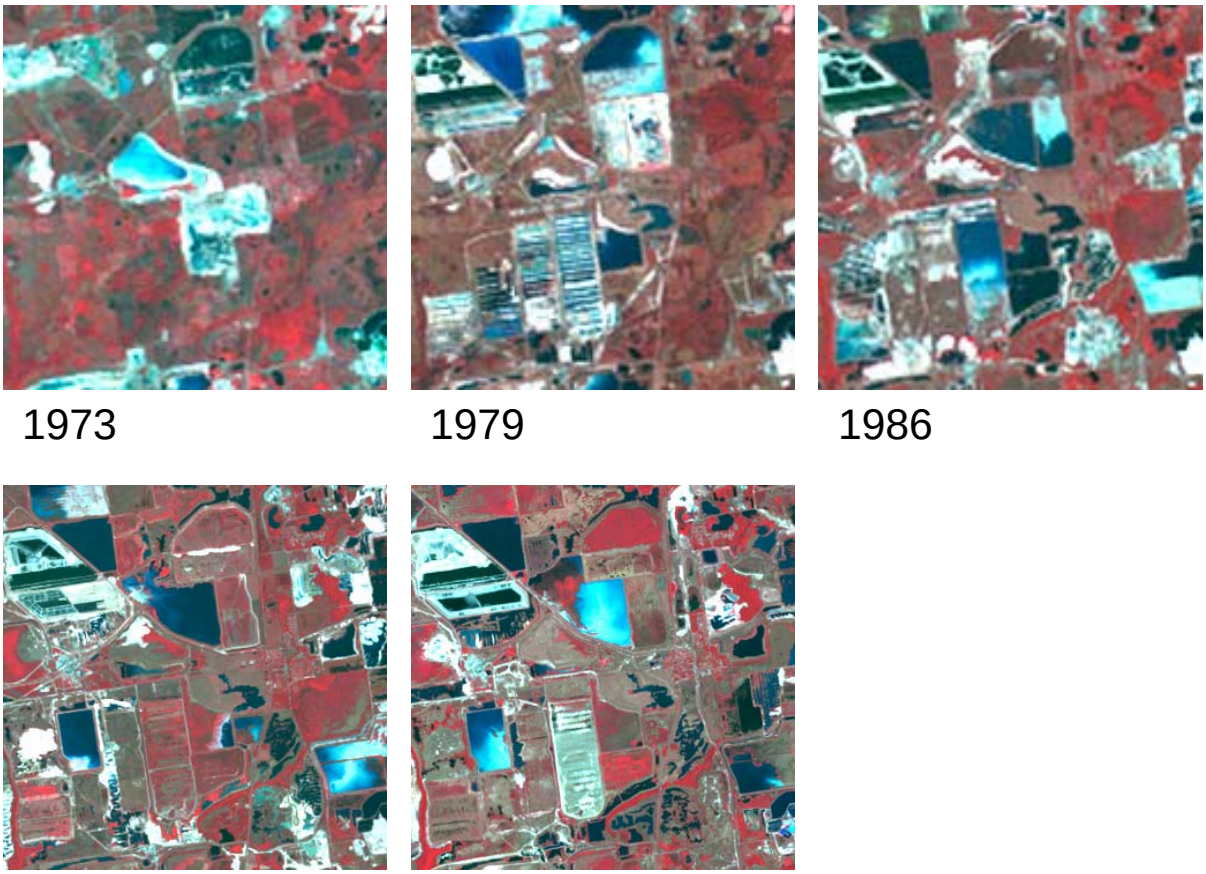
Historical land use change has contributed about 1/3 of the increased CO_2 concentration observed in the atmosphere globally (IPCC, 2000). In North America, land cover and land use change is a dominant driving force of the terrestrial carbon sink. The widespread reforestation that occurred since 1900 in the eastern United States has been sequestering carbon from the atmosphere (Wofsy et al., 1993; Houghton et al., 1999). The heavy use of fertilizers (Matthews, 1994) together with increased atmospheric nitrogen deposition (Schindler and Bayley, 1993; Holland et al., 1997), and improved tillage and crop rotation practices (Paul et al., 1997) also leads to increase store of carbon in soils and biomass. Many studies indicated that a significant portion of the terrestrial carbon sink is related to present and historical land use activities (Houghton et al., 1999; Caspersen et al., 2000).

Although the importance of land use change on carbon dynamics has been recognized, the impacts of land use change on the net exchange of carbon between the terrestrial biosphere and the atmosphere at the regional to global scales are not well understood and quantified. One of the main reasons is the lack of complete, consistent, and spatially explicit land use change databases. The data needed to construct reliable land use patterns and histories have temporal and spatial gaps over large parts of the world. Major efforts are needed to investigate and quantify the rates, patterns, driving forces, and carbon consequences of historical and current land use activities at local to global scales. These land use histories should be spatially explicit and should extend as far back in time as possible to capture the current impacts of past land use disturbances.

Highlight: Monitoring the Cycle of Land-Cover Change

The Landsat record is the longest continuous record of the globe in existence. The value and advantages of Landsat data for monitoring landscape change is illustrated by this sequence of five Landsat images covering a 10-km by 10-km phosphate mining area near Lakeland, FL. From the vantage point over 700 km above the Earth, remote-sensing instruments onboard six Landsat satellites provide a synoptic historical record of the cycle of land-cover changes taking place from 1973 to 2000. The five images offer a false color rendition of the cycle of expansion in which the original pastures and grasslands (shown in mottled red tones) are converted to active phosphate mines (white areas), water-filled mine pits (blues and black colors), to land reclamation (smooth pink colors). During the 27-year period of observation, nearly 80 percent of the land in this area underwent change. Measurements and maps of change, essential elements for investigations of the consequences of change, are possible because the USGS, working in concert with NASA, provides leadership and technical and scientific expertise for global Earth observation.

Figure 3: Changing landcover near Lakeland, Florida.



Societal Vulnerability and Resilience to Hazards

Overview

The intersection of dynamic natural processes and human activities can create environments ripe for calamity. Hazards are agents or processes with the potential to harm individuals, societies, or resources; can be human-induced or of natural origin; and can occur at scales ranging from local to global. Human-induced hazards can originate with landscape change. Urbanization and agriculture can have an adverse effect on water quality and increase the likelihood of floods. Changing land-use patterns, particularly as these changes accumulate at regional, national scales, and continental scales, can enhance the likelihood of certain natural hazards, such as floods and landslides, and alter the pathways for the introduction and spread of invasive species and vector-borne diseases that adversely effect human welfare. Human activities also lead to the creation of technological hazards, such as hazardous material spills, and security hazards (National Research Council, 2002). Natural hazards can be associated with chronic events, such as drought or climate change, or episodic ones, such as volcanic eruptions, floods, or hurricanes. The physical, biological and chemical effects of anthropogenic and natural hazards can pose significant threats to lives and property, with estimated costs of over $60 billion (USD) to the global economy in 2003 (Munich Re, 2003).

Geography's long-standing intellectual tradition of studying landscape processes, both human and natural, and the relation between society and the biophysical environment offers a framework for an integrated physical, biological, and social understanding of the impacts of hazards. Two areas of geographic research are important for understanding and minimizing the societal impacts of hazards. Geographic research emphasizes the human consequences and implications of landscape change. While a hazards geologist describes the historic occurrence and future potential for hazards (e.g., landslides) in a community and a hazards biologist describes the international migration and incidence of an invasive species or a vector-borne disease, a hazards geographer complements these efforts by studying what assets are exposed to the hazards, the conditions that contribute to the potential for loss (e.g., land use decisions) and the societal implications if the hazard occurs. Geographers also recognize that the potential impacts of a changing natural landscape can be mitigated by changes in the human system. Hazards geographers research how hazard-related risks are perceived, how social systems can become more resilient, and how communication of risk and mitigation strategies can inform those who shape and who are influenced by hazard-related policies.

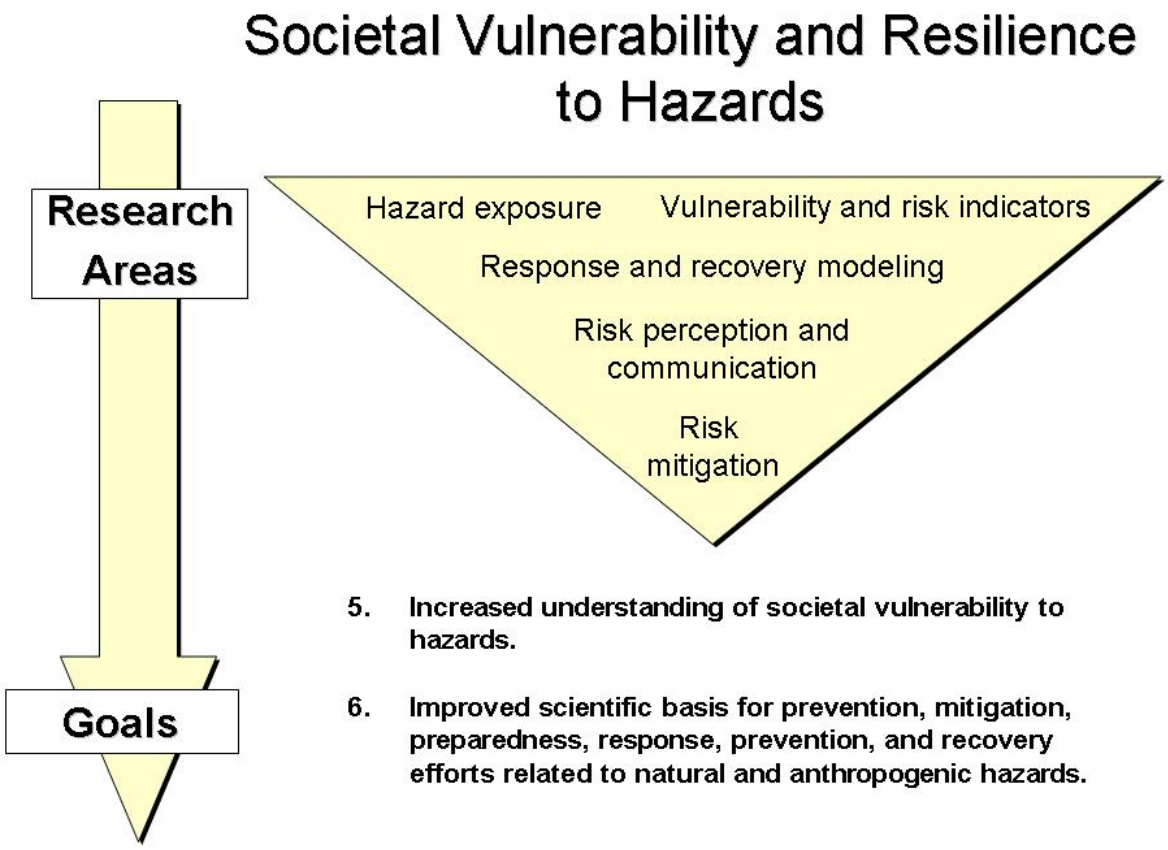


Figure 4: Priority research areas related to societal vulnerability and resilience to hazards and the resulting goals of this research.

By addressing hazards-related science goals (Figure 4), the GGD will provide scientific understanding of the threats to society posed by natural and anthropogenic hazards, which can improve the nation's capacity to reduce and mitigate these threats. Research that increases knowledge about hazard exposure, social vulnerability, societal resilience, risk perception and communication, and mitigation capacity will improve the science available to support societal decisionmaking and hazard-planning efforts.

Developing effective strategies for dealing with natural and anthropogenic hazards will require a broad range of disciplines and participants, including physical and social scientists, engineers, business people, and all levels of government. As Cutter and others (2003) succinctly state, an "understanding of vulnerability beyond an exposure-response framework to a more holistic view that includes exposure, susceptibility, resistance, resilience, and adaptation" is needed. By providing social context to pressing hazard-related issues, geographic research outlined here will enhance societal decisionmaking in regard to hazard risks and improve economic welfare and human health.

Strategic Science Activities

The USGS has a strong history of science excellence and leadership in hazard assessment research in all disciplines and at multiple scales. The research proposed in this plan supports the USGS mission, which explicitly calls on the USGS to provide reliable scientific information to minimize the loss of life and property from natural disasters and to enhance and protect our quality of life. Far less science has been done within the USGS or other agencies, however, to describe and understand societal vulnerability and resilience to hazards. There is no federal agency with a coordinated research program that focuses on potential vulnerability to adverse impacts and resilience strategies from natural and anthropogenic hazards. The USGS Geography Discipline is in a unique position to fill this gap. Assessing the societal vulnerability of hazards and analyzing risk reduction strategies complements the bureau's expertise at hazard assessment and provides the Nation with a holistic understanding of hazards and the threats they pose to society.

The research proposed in this plan supports the USGS mission, which explicitly calls on the USGS to provide reliable scientific information to minimize the loss of life and property from natural disasters and to enhance and protect our quality of life. It also addresses external recommendations for additional geographic research by the USGS. The National Research Council (NRC) report on geographic research opportunities in the USGS recommends that the Geography Discipline continue to exercise national leadership in 1) natural hazards research and risk communication and 2) applied hazards research to improve the nation's explanatory, predictive, and response capabilities. To do so, the NRC recommends that the USGS actively develop vulnerability science through multidisciplinary, place-based approaches. The NRC concludes that this research could bridge the gap between science, policymaking and management.

Societal vulnerability to natural and anthropogenic hazards is one of the critical issues of the 21st century. The Nation needs a clearer understanding of its vulnerability to potential hazards and of strategies for increasing community and national resilience. Lacking a complete understanding of imminent threats to societal assets, policymakers may emphasize post-disaster relief and recovery and, in doing so, set the stage for future catastrophic losses (Pelling, 2003). The Geography Discipline is in a unique position to step forward and assume national leadership in societal vulnerability and resilience research. Understanding societal vulnerability and resilience to hazards will require the use of the GGD core capabilities of GIScience, regional geography, remote sensing, and the integration of natural and social science. The following is a summary of the goals, outcomes, and strategic actions that must be addressed over the next ten years.

Goal 5: Increased understanding of societal vulnerability to hazards.

Vulnerability refers to the potential for loss, both in terms of exposure to a hazard and characteristics that make one group more likely to experience damage than another if both are in a hazard zone. In many cases, the potential for losses from hazards are exacerbated by societal

decisions, such as resource allocation or land use practices. Societal vulnerability to hazards is an important measure and indicator of the status of the human-environmental relationship.

Outcome: An improved research capacity to assess societal vulnerability to natural and anthropogenic hazards.

Strategic Action: Develop a center of excellence in societal vulnerability research. Hire 10-20 researchers and application developers to work on vulnerability and resilience issues. Duties will include research, mentoring, providing technical assistance, and growing the science activities in this area.

Strategic Action: Develop integrated vulnerability models and set of vulnerability indicators applicable at multiple spatial and temporal scales. The models and indicators will stimulate the development of a national set of geographic tools accessible to researchers and land-management and emergency management agencies (Cutter and others, 2003).

Strategic Action: Develop methods and techniques for incorporating and communicating uncertainty as an inherent element of vulnerability and risk assessments.

Strategic Action: Develop and implement a comprehensive monitoring program that provides a national perspective on societal vulnerability to hazards.

Strategic Action: Participate in national and international pre-disaster assessment efforts of the USGS, such as the Volcano Disaster Assistance Program and the Prompt Assessment of Global Earthquakes for Response (PAGER) Team by developing and applying integrated risk and vulnerability assessment methods.

Strategic Action: Conduct case studies on the vulnerability of communities and regions to hazard scenarios at multiple scales in collaboration with hazard assessment researchers in the other USGS disciplines, with a focus on geological (e.g., earthquakes, volcanoes, landslides), biological (e.g., invasive species, vector-borne diseases, threatened species), hydrological (e.g., floods, drought) and other earth science-related (e.g., climate change) hazards..

Outcome: Increased knowledge of the relation of landscape change, such as urbanization, to societal vulnerability.

Strategic Action: Conduct studies on how knowledge of land-use, land-cover, and land-surface changes can be used to model, predict, and(or) mitigate natural and anthropogenic hazards. This includes an analysis on the effects of land-use change, including urbanization, on creating or amplifying natural hazards. Locally-oriented research would examine the relation between urban growth rate and community vulnerability and whether core urban areas are more vulnerable than peripheral zones, while regional and continental scale research would examine vulnerability arising form the effect of landscape change on processes such as drought, climate change, invasive species, and floods.

Outcome: An improved understanding of the influences of societal perceptions, policies, and land-use practices on societal vulnerability and resilience.

Strategic Action: Research and document the influence of perceptions, policies and land use practices of various cultures (e.g. Native American, urban, rural, and international) on societal vulnerability and resilience. Policies and practices include social structures, economic frameworks, institutional frameworks and land-use philosophies. Differences in perceptions and attitudes towards risk, vulnerability, and resilience are highly relevant to societal decisionmaking and policy formation (Frerks and Bender, 2004).

Strategic Action: Develop innovative and effective mechanisms to integrate knowledge of societal perceptions and policies with the development of tools and applications that support emergency-management efforts.

Goal 6: Improved scientific basis for prevention, mitigation, preparedness, response, and recovery efforts related to natural and anthropogenic hazards.

Disasters occur when hazardous events and vulnerable human systems coincide, resulting in disruption or failure of a system or society. An individual's or society's resilience to hazards is defined by the capacity to adjust to threats and mitigate or avoid harm. Understanding the resilience of a society to hazards is critical to understand, and hopefully reduce, the potential for adverse effects from hazards (Cardona, 2004). Geography Discipline research on adaptive capacity to hazards will complement the Department of Homeland Security's (DHS) non-research mission to prepare the Nation for all hazards, initiate mitigation activities, and manage Federal response and recovery efforts.

Outcome: An improved understanding of societal adaptive capacity to minimize or adjust to hazards.

Strategic Action: Develop a resilience modeling approach that incorporates information about exposure, susceptibility, vulnerability, and adaptive capacity into indicators of society's capacity to mitigate natural and anthropogenic hazards at multiple scales.

Strategic Action: Develop and implement a local (e.g., urban), regional (e.g., the Western United States), and continental (e.g., North America) monitoring program that provides a perspective on adaptive capacity and resilience.

Outcome: Innovative geographic methods and techniques to assess the relation between uncertain hazard-assessment outcomes, potential mitigation and management scenarios, and the socioeconomic effects on individuals and communities.

Strategic Action: Continue development of the Land Use Portfolio Model and other models as both research instruments and practical tools for assessing the effects and effectiveness of hazard-mitigation strategies. This includes integration of mitigation approaches developed by other Federal agencies, such as the Federal Emergency Management Agency's (FEMA) HAZUS-MH loss estimation software.

Strategic Action: Conduct studies on risk communication, society's willingness to pay for risk-reduction strategies, and the role of geospatial data in preparedness and mitigation analyses. This includes studies on the cost-effectiveness of the expenditure of public sector funds for regional mitigation and methods for incorporating non-economic ancillary benefits.

Strategic Action: Research and develop innovative geographic techniques to distinguish high-probability/low-consequence events from low-probability/high-consequence events to support public policy decisionmaking (Cutter and others, 2003)

Outcome: Innovative geographic methods and techniques to help secure the safety of the Nation in emergency response and recovery efforts.

Strategic Action: Partner with organizations with emergency management and homeland security responsibilities, such as FEMA and State emergency management departments, to provide geographic support for assessing emergency response and recovery and for applying geographic tools, such as predictive models.

Strategic Action: Continue development of Geospatial Multi-Agency Coordination (GeoMAC) and other models and decision-support tools that provide intelligent access to remotely sensed data, geospatial layers, loss-estimation models, and management frameworks for response efforts.

Strategic Action: Use knowledge of landscape dynamics, land use, societal vulnerability, and societal resilience to research and develop geographic tools that support post-disaster recovery analysis and decision making post-disaster recovery efforts.

Establishing an Improved Hazards-related Research Capability

Research on the societal vulnerability and resilience to landscape change is highly visible and relevant in today's world, both in major science initiatives and in efforts to secure the safety and welfare of our Nation. While other agencies focus on implementing risk-reduction efforts, the USGS brings a unique research foundation of knowledge about land-use, land-cover, and land-surface change that can be used to model, predict, and mitigate natural and anthropogenic hazards.

To solidify the USGS Geography Discipline's position as a national leader in vulnerability research, several strategic actions to be taken. In the short-term, the Geography Discipline needs to develop partnerships with academic departments and other organizations

with mutual research interests. One such opportunity is the annual Vulnerability Assessment Techniques workshops, currently organized by the NOAA Coastal Services Center, the Organization of American States, and the Caribbean Development Bank. The Geography Discipline and the Geospatial Information Office need to begin development of an integrated platform for practitioner access to USGS hazard and vulnerability data, models, and research. Finally, the GGD needs to develop mechanisms to assess research issues and needs of organizations with emergency management and homeland security responsibilities at local and national scales.

In the next 5 years, the Geography Discipline must greatly increase its social science and geographic research staff. Researchers with Ph.D. and masters degrees are needed to conduct research and to develop applications and tools. A core of researchers and application developers should be assembled in a national geographic science center that focuses on understanding and modeling societal vulnerability and resilience to landscape changes, specifically natural and anthropogenic hazards. A distributed network of regional experts also will be needed to foster collaborations with key hazard practitioners, university investigators, and other Federal partners. Areas of knowledge needed for hazards researchers and application developers include regional geography, sociology, economics, statistics, public policy, engineering, remote sensing, computer programming, GIS, and emergency management. In addition to hiring new staff, Geography Discipline research would benefit from Inter-personnel Agreements that would allow USGS researchers to collocate with emergency-management practitioners as a way to better understand societal issues and needs.

Finally, as research efforts outlined here are highly relevant to national and homeland security issues, the Geography Discipline will need to develop mechanisms to ensure the use of USGS vulnerability data, models, and knowledge, such as training materials, workshops, GIS-based tools and Internet-based applications.

Strategic Partners

The research efforts outlined here will greatly benefit from partners internal and external to the USGS. Partnerships with hazard assessment researchers in and out of the USGS are needed if the USGS is to provide the Nation with comprehensive understanding of hazards and their potential impacts on society. Partnerships with academic departments with mutual geographic research interests, such as the University of Colorado - Boulder Natural Hazards Center, the University of South Carolina Hazards Lab and the University of Delaware Disaster Research Center, provide opportunities for collaborative efforts and for training new researchers in addressing societal vulnerability research needs.

Partnerships with organizations that have emergency-management and national security responsibilities will provide the USGS with opportunities to better understand practitioner issues and needs. The geographic knowledge, models, and tools generated by efforts outlined here will support risk reduction and the response/recovery operations of numerous agencies and organizations external to the USGS. Potential Federal partners include the Department of Homeland Security, the U.S. Agency of International Development, the Centers for Disease

Control and Prevention, the National Geospatial Agency, and the Department of Defense. Similar partnering opportunities exist with local and state officials, and organizations that represent them, such as the National Association of Counties, the League of Cities, the Urban and Regional Information Systems Association, and the American Planning Association. Partnerships with non-governmental organizations with emergency-management responsibilities, such as the United Nations, the American Red Cross, MercyCorps International, the Pacific Disaster Center and the Public Entity Risk Institute, offer similar opportunities and benefits.

Highlight: Using Science to Protect Swimmers from *E. Coli* Risk

Bacterial contamination of water bodies used for swimming is a significant public health concern worldwide. Most beach monitoring programs use fecal-indicator bacteria (FIB), such as *Escherichia (E.) coli* and enterococci, as indicators of the level of risk to human health. Implicit in the policies that are the basis for monitoring programs is the assumption of a strong relation between FIB measurements taken one day and the public health risk on the following day. Recent studies suggest, however, that FIB levels may vary over space and time in ways that may reduce the effectiveness of existing monitoring and closure strategies. As local, State, and Federal regulatory agencies struggle to understand, address, and remediate local recreational water-quality problems, simple but realistic methods are needed to assess which monitoring approaches and public-health policies will produce the greatest safety with the least amount of cost and lost recreational access.

Researchers from the USGS and University of Chicago examined (1) measures of the efficiency of FIB status tests for *E. Coli* bacteria in recreational water bodies with beaches, (2) the importance of recreational use of the beaches for the local population, and (3) the revenues received by local parks where beaches are used for recreation. The probabilities of a swim area being posted for exceeding or not exceeding a recommended health standard were computed from existing datasets and combined with risk and value estimates to predict the health, recreational, and economic effects of various swim-closure policies. This information illustrated to local managers the risk and cost tradeoffs of incorrect beach management decisions (e.g., keeping a polluted beach open or closing a non-polluted beach). Rabinovici and others (2004) describe this approach and its application at a Lake Michigan beach in Indiana. The results indicate that swim closures, on average, usually came too late to protect swimmers from *E. coli* and failed to produce net economic benefits for swimmers.

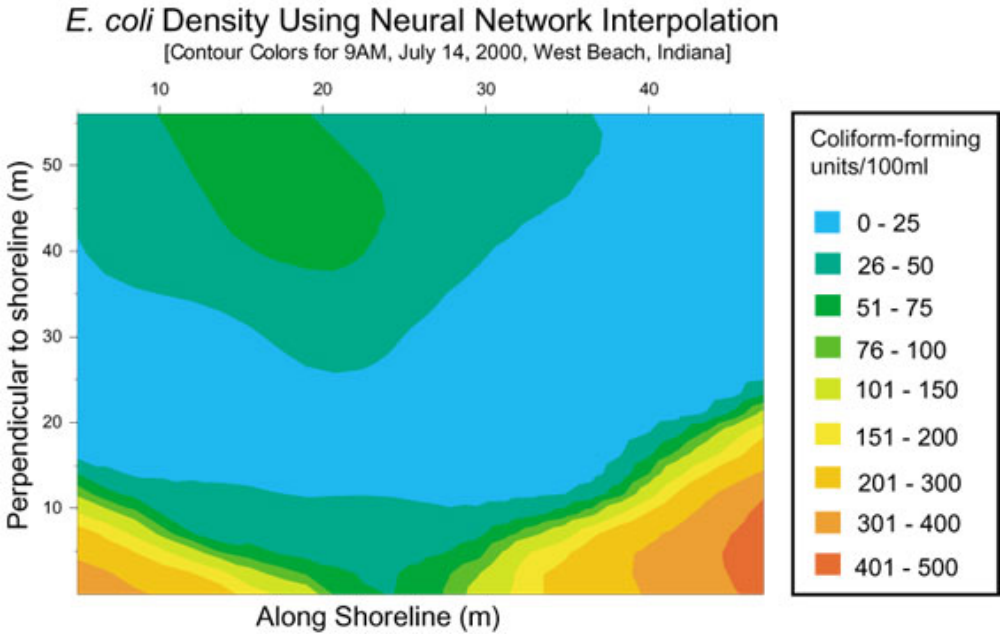
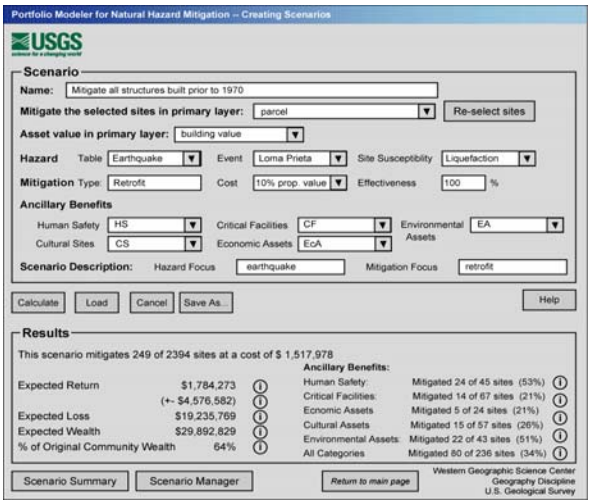


Figure 5. Interpolated map of fecal-indicator bacteria (FIB) density. Some portions of a swim area have FIB densities that exceed a level considered safe (E. coli > 235 coliform-forming units per 100 milliliters of water) while most of the area does not. This situation is problematic for both monitoring managing recreational waters (Rabinovici et al. 2004)

Highlight: Evaluating Hazard-Mitigation Alternatives with GIS-based Decision-Support Systems

Mitigation is a critical strategy for lessening the adverse effects of natural hazards on society. However, communities face major informational and financial challenges in their efforts to implement mitigation programs. As a result, mitigation continues to be implemented on an ad hoc basis, if at all, rather than systematically based on relative risks. Faced with limited resources and competing community values, decisionmakers need practical analytical methods to examine potential mitigation options on the basis of their ability to reduce losses, increase resiliency, and retain community wealth should a catastrophe occur.

To support hazard-mitigation analysis and decisionmaking, USGS researchers developed the Land Use Portfolio Model (LUPM). The LUPM provides a new method for combining hazard information with information about possible mitigation options, their relative costs and benefits, and the uncertainties associated with future outcomes. Economic analyses are based on financial portfolio theory, which strives to maximize expected wealth and minimize uncertainty. Non-economic benefits are included in the analyses to incorporate the multiple dimensions of community vulnerability. To reach maximum usefulness for communities, the LUPM was translated into the Portfolio Modeler, a decision-support system that integrates earth science and socioeconomic data in a flexible, scenario-based GIS environment to assist in the evaluation of alternative spatially specific hazard-mitigation policies. This decision-support tool provides researchers with the ability to study aspects of mitigation policy and provides emergency managers, planners, and other professionals with the ability to estimate and compare the effects of different mitigation strategies on measures of overall community well-being.



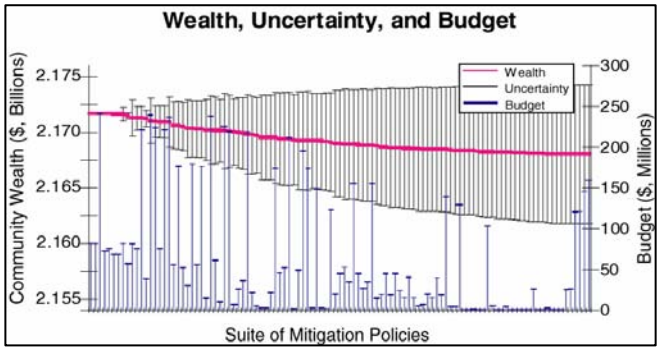


Figure 6. Comparison of a suite of mitigation policies. Comparison, based on community wealth (red line), mitigation budget for each policy (blue bars) and uncertainty (black error bars)

Figure 7. Screen capture of The USGS Portfolio Modeler. A GIS-based decision support system for mitigation analysis.

Highlight: Supporting Fire Response Needs for the Nation

Wildfires are a serious and growing hazard over much of the United States, posing a great threat to life and property, particularly when they move from forests or rangelands into developed areas. During fire season, fire management priorities are set by geographic fire-coordination centers for deployment of fire-fighting resources based on human safety, protection of property, and natural-resource values. Determining these priorities requires more information than printed maps and situation reports provide. In response to these needs, the USGS, working closely with technical and subject matter experts from Federal fire-management agencies and private sector partners, developed an internet-based mapping tool referred to as Geospatial Multi-Agency Coordination (GeoMAC). As the sole DOI science agency, the USGS plays a pivotal role by hosting and maintaining the GeoMAC Website.

GeoMAC is designed to disseminate information about fire status and potential to a wide variety of users in the western U.S. The general user seeking information about the spatial location and possible movement of fires in their area will see maps of fire perimeters that overlay base-map information, similar to that in *The National Map*. Users with responsibility for fire fighting in a given area have access to more sophisticated potential fire-movement maps, status of suppression resources, and proximity of wildfires to life, property, and infrastructure. In order to give fire managers near real-time information, fire perimeter data are updated daily based on input from incident-intelligence sources, GPS data, and infrared imagery from fixed-wing and satellite platforms. The geographic application software customizes the dissemination mode and type of information supplied. GeoMAC has supported the wildfire response community since the 2001 fire season.

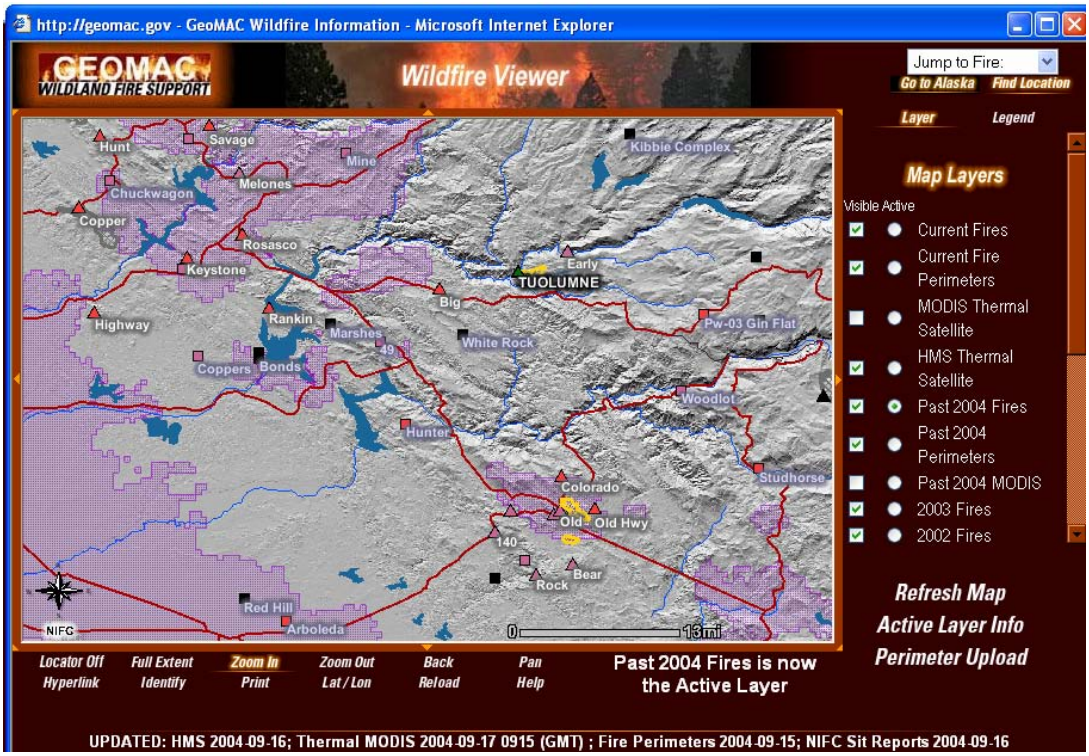


Figure 8. GeoMAC Wildfire Viewer. GeoMAC provides up-to-date information about fire status and potential to a wide variety of users in the western U.S. Users with responsibility for fighting fires in a given area have access to more sophisticated potential fir- movement maps, status of suppression resources, and proximity of wildfires to life, property and infrastructure.

Geographic Information Science

Overview

For much of the 20th century the Geography Discipline focused on developing and producing the topographic map series, the flagship product of the USGS. In a manner uncommon for most scientific products, the topographic map series became an everyday, much-relied-on resource for both scientists and the general public. Base geographic data presented in these maps enabled scientists to plan field investigations and monitoring programs and analyze data, while the general public used the maps to plan and enjoy a range of outdoor activities, such as hiking, canoeing, and hunting.

Beginning in 2001, the Geography Discipline moved to replace this signature USGS geospatial data product with *The National Map*, an Internet-based, interactive map service to meet the Nation's needs for current, base-geographic data and maps. *The National Map* will provide a framework for integrating national-scale geographic information for the eight base themes of elevation, hydrography, land cover, orthoimagery, geographic names, political boundaries, structures, and transportation networks. The database can be used to integrate larger scale versions of information associated with these eight themes and data from other sources, including demographic and agricultural census, natural resource surveys, and other geospatial data needed by the Nation's population. In addition to the unique demands and opportunities associated with *The National Map*, the need to understand national issues in a global context creates additional challenges for the design and handling of geographic databases.

The evolution of these mapping activities and the expansion of our geographic spheres of analysis reflects, in part, an evolution in how geographers understand, represent, manage, and access geospatial information. While mapping once was the primary activity of Geography and encompassed field surveys, photogrammetric methods, cartographic finishing, and publishing, geographic information science (GIScience) has transformed mapping and the entire practice of geography. GIScience has moved beyond being the science behind the traditional mapping disciplines of surveying, aerial photographic interpretation, photogrammetry, remote sensing, and cartography to include a broader scope of issues related to modeling and representation of geographic data, phenomena, and processes; human cognition of geographic information; uncertainty; spatial analysis and modeling, including geographic information systems (GIS); scale; geographic ontologies; visualization; and other similar topics (McMaster and Usery, 2004).

The establishment of GIScience as a discipline for scientific research and inquiry became possible with the emergence of fundamental principles of geographic information and processing. These principles evolved from basic geometric data models, such as raster and vector models, as ways of viewing geographic reality as image and structure representations. From the initial developments in automated cartography and GIS related to map making, GIScience has evolved to allow the examination and understanding of how humans recognize and use geographic information. The fundamental principles of GIScience govern this interaction and

allow us to explore the human-computer interface to maximize use and understanding of geographic information.

Because GIScience provides the foundation for all spatial data products generated by and for the USGS, including *The National Map*, the GGD has been at the forefront of research and development of GIS and GIScience. *The National Map* will remain an important focus of GIScience activities during the next decade, as a collaborative effort between the Geography Discipline and the Geospatial Information Office. *The National Map* advances two aspects of the USGS mission. In a focused sense, *The National Map* supports Geography Discipline efforts to develop reliable earth science information associated with the priority societal issues of landscape dynamics and hazard-risk assessment. In a broader sense *The National Map* provides a foundation for the Nation's economy and government activities, providing information to manage natural resources, enhance the quality of life, and contribute to a sustainable future in partnership with the public and private sector. Citizens can visualize the spatial pattern of physical and cultural characteristics at any location in the country, while scientists can use the data to support investigations that lead to a better understanding of these patterns.

GIScience, however, is not just oriented toward mapping and *The National Map*; it also provides a basis for research into issues such as landscape change, the flow of energy and materials within networks, and the relation of features and activities on the earth's surface. Thus, fundamental scientific research in GIScience is not only a core competency needed to address the priority science issues identified in this plan, but also a fundamental requirement to maintain the products and other scientific research conducted by the USGS.

The Geography Discipline must develop and reassert its leadership role in GIScience. Through collaboration with other major research organizations, such as the University Consortium for Geographic Information Science (UCGIS) and academic departments, the USGS can establish major research objectives in GIScience that meet the needs of all USGS disciplines and *The National Map*. The primary areas of GIScience research over the next 10 years have been identified by UCGIS (McMaster and Usery, 2004), and the USGS will need to place priority science research efforts in the following specific areas that support the USGS mission.

Strategic Science Activities

As noted in the introduction, the priority science issues for the Geography Discipline over the next 10 years include understanding the rates, causes, and consequences of landscape change and the societal vulnerability and susceptibility to hazards. The SPT has identified the following four GIScience-related science goals that will focus the work of the GGD on these issues (fig. 9):

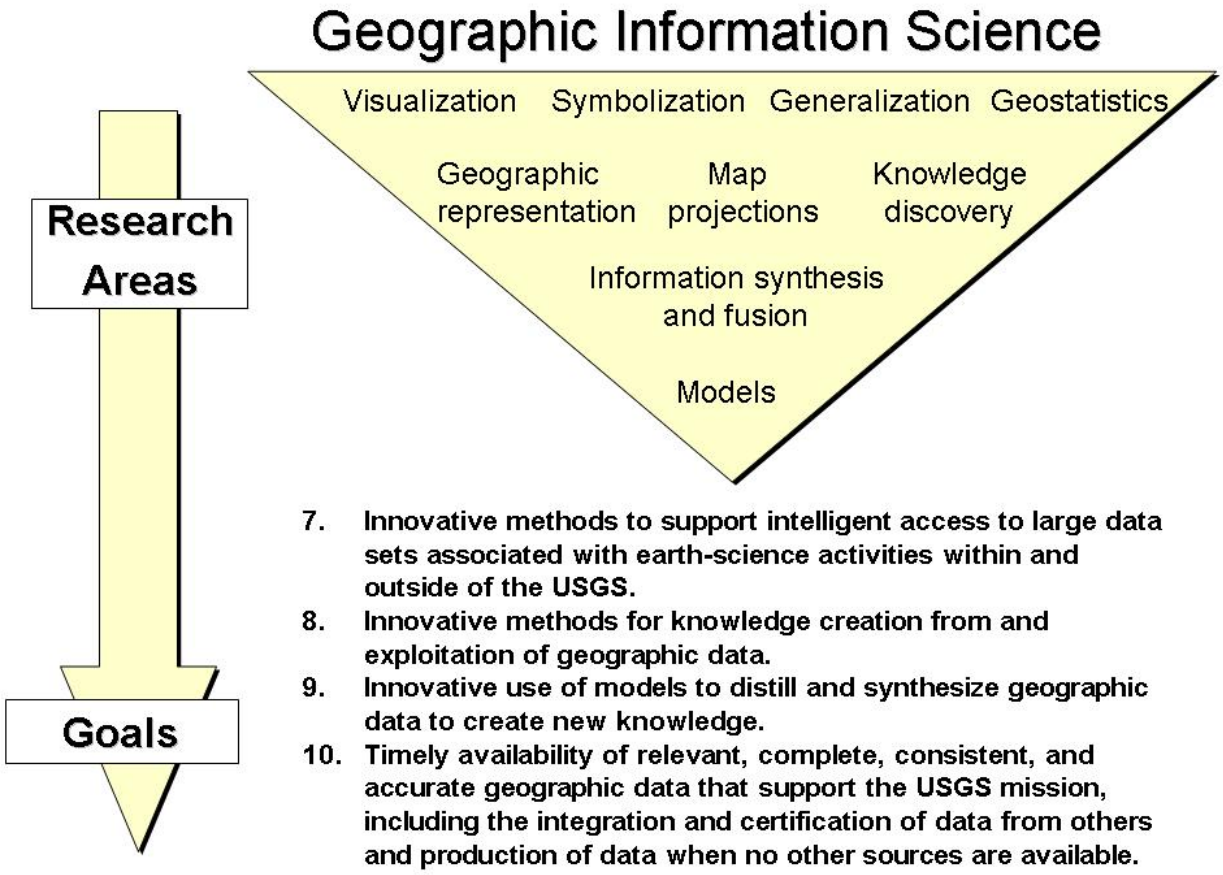


Figure 9. Priority research areas in geographic information science and the associated research goals.

By addressing these GIScience goals, the GGD will not only improve the scientific basis for understanding landscape change and its consequences but will provide capabilities needed by all disciplines in the USGS to accomplish their missions. To achieve this vision, Geography will need to expand its research and activities related to GIScience. Following is a summary of the strategic actions and outcomes associated with each of the four GIScience goals.

Goal 7: Innovative methods to support intelligent access to large datasets associated with earth-science activities in and out of the USGS.

Technological innovation has allowed the capture, storage, processing, and display of an unprecedented amount of georeferenced information about the Earth (Gore, 1998). Gore noted that "The hard part of taking advantage of this flood of geospatial information will be making sense of it, turning raw data into understandable information." Supporting intelligent access to

information contained in large geospatial datasets is an important niche for the USGS, and for the Geography Discipline in particular (National Research Council, 1995).

Outcome: Appropriate representation and symbolization for multiple-scale display of data that are a part of *The National Map*.

Intelligent access to the information contained in *The National Map* and other large USGS geospatial databases is enhanced by understanding what the database users need and by employing sound geographic (especially cartographic) principles to facilitate access to the information.

Strategic action: Improve understanding of *The National Map* user needs, both inside and outside of the USGS. Research and develop innovative and effective mechanisms for continuous assessment of user needs for geographic data and translate those needs into collection, representation, and distribution procedures for the data.

Strategic action: Address research questions on the topic of geographic representation, including data model issues associated with multiple resolution data and data integration and fusion, uncertainty representation, and human cognition of the dimensions of geographic phenomena in a computer environment.
.
Strategic action: Research and develop design and symbolization specifications and innovative methods that support *The National Map* viewer and other geographic data display.

Strategic action: Research and develop automated methods for generalization to support multiple-scale display and delivery of *The National Map* and other USGS geographic data.

Outcome: Operational data-management protocol to manage and access information developed as part of global-change research.

Increasingly, resource management and environmental assessment research requires access to very large datasets. These data are associated with model inputs and outputs. Researchers addressing problems covering large geographic areas, or those using very high resolution geographic data face a formidable challenge to efficiently review model outputs and identify and pursue further research directions.

Strategic action: Address research questions on the topic of spatial data mining (SDM) and knowledge discovery (KD) that are pertinent to The National Map and other large spatial databases. SDM questions associated with appropriate algorithms for handling geospatial data, spatial data access structures, and use of domain knowledge for improved query processing and mining must be addressed. KD issues dealing with computational infrastructure, uncertain, missing, or other data limitations, and pattern or knowledge validation.

Strategic action: Develop pilot global-change modeling data-management protocols with the

Geology Discipline to facilitate the management and further use of data developed as part of global-change models.

Strategic action: Be entrepreneurial and proactive in working with USGS and DOI scientists and managers to develop Bureau and Department strategic plans for managing very large datasets.

Goal 8: Innovative methods for knowledge creation from and exploitation of geographic data.

The development and use of geospatial data associated with *The National Map* and other databases has created both practical and theoretical concerns. From a practical standpoint, research is needed into the integration of data at a variety of scales (i.e., information synthesis and fusion) and the discovery and understanding of patterns in the data (i.e., geographic visualization). The development and testing of hypotheses in the earth sciences creates a demand for models that account for location and spatial interactions and for methods, including spatial statistics, for estimating models. These latter concerns are addressed in the discussion of Goal 9.

Outcome: An improved ability to explore geographic data and create new knowledge from these data.

Strategic action: Address research questions on the topic of information synthesis and fusion, including topics on the use of theoretical models for fusion of disparate (e.g,. different geometry, resolution and accuracy), and use of metadata for automated data fusion.

Strategic action: Address research questions on the topic of map and geographic database projections.

Strategic action: Address research questions on the topic of geographic visualization, including Web-based visualizations and interfaces, uncertainty visualization, role of animation, and automatic visualization based on data type, scaling, resolution, accuracy, and other metadata.

Goal 9: Innovative use of models to distill and synthesize geographic data to create new knowledge.

Over the next 10 years, USGS geographers will provide understanding about urgent environmental, natural resource, and economic issues through scientific assessments that provide a local, regional, national, and global perspective on landscape change and its consequences. Models that are simplified descriptions of complex entities or processes, such as landscape change, will make an important contribution to these assessments. Spatial models developed and used by geographers are a subclass of scientific models. These models consume spatially-

oriented input data, such as vector and raster maps, remotely sensed imagery, and aerial photos and produce spatially oriented response information. In formulating models, geographers must identify the relation among key components of complex geographic systems; in doing so they gain a better understanding of these systems. The use of models proposed here and elsewhere in the plan will add value to USGS data, providing an increased understanding of the landscape change processes and an ability to predict future states. The spatial modeling is a logical response to the NRC's recommendation that the USGS become "consumers of their own data" (National Research Council, 2002).

Outcome: Develop an understanding of what spatial models (including their input requirements, methodologies, and outputs) offer as distillers or synthesizers of the terabytes of data created by the USGS.

Strategic action: Research and develop methods and techniques in modeling and geostatistics to exploit geographic data, including:

- What models are best suited to creating value-added data layers that have multiple uses and that use data already served by the USGS and *The National Map*?
- How can models and their results be compared?
- Is it better to couple inputs and outputs from specialized models, or to integrate models into a single operational framework?
- Which models produce unstable and unpredictable outputs when tested at their data limits?
- What methods best facilitate model calibration and validation?
- What mechanisms allow scientists to locate, share, and rapidly implement models?
- How can models and model results best be communicated to scientists, decisionmakers, and the general public?

Goal 10: Timely availability of relevant, complete, consistent, and accurate geographic data that support the USGS mission, including the integration and certification of data from others and production of data when no other sources are available.

The National Map is an important focus of the GGD Science Plan for three reasons. The promise of *The National Map* cannot be realized without substantial GIScience research over the 10-year plan in the areas of visualization, generalization, information fusion, and knowledge discovery and data mining. Development and implementation of *The National Map* will require strategic collaboration and partnerships in both developing data and in designing and undertaking the research necessary to realize the promise of the idea. Finally, *The National Map* provides a useful framework for organizing and managing disparate geospatial databases in the USGS and a single, easy-to-use point of access.

Outcome: Plan for research and development necessary to accomplish *The National Map* vision and develop a partnership strategy for data creation.

Strategic action: Develop implementation plan for *The National Map*, based on detailed understanding of geospatial information needs of users inside and outside the USGS.

Strategic action Serve as a catalyst and collaborator for creating and stimulating partnerships associated with the development of data and the GIScience efforts needed to support *The National Map*.

Outcome: Current, up-to-date, and accurate geographic data that meet user expectations.

Strategic action: Create tools for rapid development and automated updates of core base layers in *The National Map* that support Bureau science.

Strategic Action: Research and develop quality assurance and quality control tools for new and existing geographic data types.

Strategic action: Create a single point-of-access on the Web to data in *The National Map* and to other Federal resource and environmental data.

Strategic action: Develop specifications and analytical methods and tools for use in producing widely used, high-priority *National Map* data layers, elevation, hydrography, and land cover. For example, elevation data research must address issues related to generation of topographic derivatives, develop tools for extraction of hydrologically related elevation variables, data integration (e.g., merging user data into the national elevation databases, combining topographic and bathymetric data layers), and mapping difficult or complex terrain (e.g., areas with low relief or very steep slopes) or heavily vegetated areas. Hydrographic data research should address strategies and methods for integrating data from a range of sources to address complex resource and hydrological problems. Research on new stream and watershed attributes is also a priority. Land cover research priorities have been identified earlier, but GISc capabilities must be applied to develop the critical methods for producing and using multi-scale, multi-temporal land cover data.

Establishing an Improved GIScience Research Capability

To remain on the cutting edge of GIScience and in order to further the goals of scientific research in this area, the USGS must invest in personnel, resources, and infrastructure to support the research. Over the next 10 years, the USGS will have to greatly expand its GIScience research capabilities. At least 10 to 20 additional researchers, both doctoral and master's level, will be needed to address the science activities described here, with specialties to focus on the priorities described above. In addition, these more senior scientists will have to be supported with junior scientists and technicians to help in data gathering and information processing.

Strategic Partners

Post-doctoral appointments, internship programs with universities, and close collaboration between USGS scientists and university researchers are required to meet the objectives of the 10-year vision. Direct support of GIScience research critical to the USGS mission in university environments through a funded research program will be necessary. The USGS will need to play a stronger role in the research agenda for GIScience and work closely with organizations that set the agenda, such as the University Consortium for Geographic Information Science (UCGIS), and the Cartography and Geographic Information Society (CaGIS). The GGD must also establish linkages with data user communities so that data specifications and analytical capabilities are based on both strong science and critical needs. A dialog with the organizations listed as strategic partners throughout this document must be maintained.

Highlight: Map-Projection Software for Global Raster Datasets.

USGS research in GIScience includes fundamental topics such as map and global database projections. In a recent project, USGS researchers determined that many commercial software packages fail to produce correct projection results for global raster datasets, such as USGS Global Land Cover. USGS scientists determined the form and extent of the errors and developed a projection system, now publicly available, that produces correct results. The maps below provide one example of a projection problem. The first map was produced with commercial software by projecting Global Land Cover from geographic coordinates to a Mollweide projection. Note the repetition of Siberian Russia and Alaska on both sides of the map. In the second map the same data projected with USGS mapimg software. This software, developed by the USGS, and other GIScience research results are available at http://mcmcweb.er.usgs.gov/carto_research.

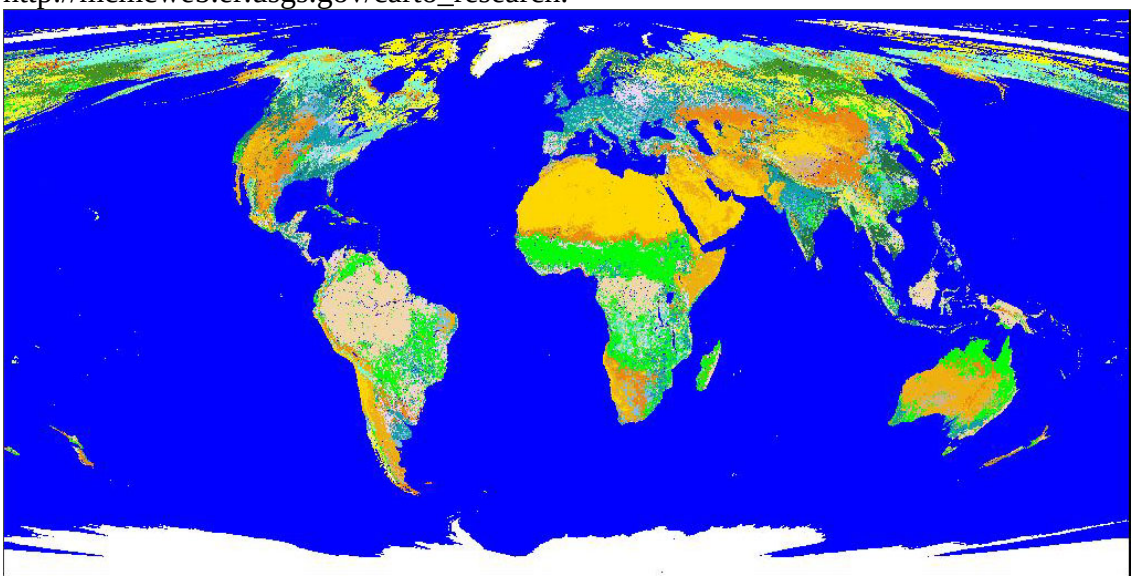


Figure 10a. Global land cover projected with commercial GIS software.

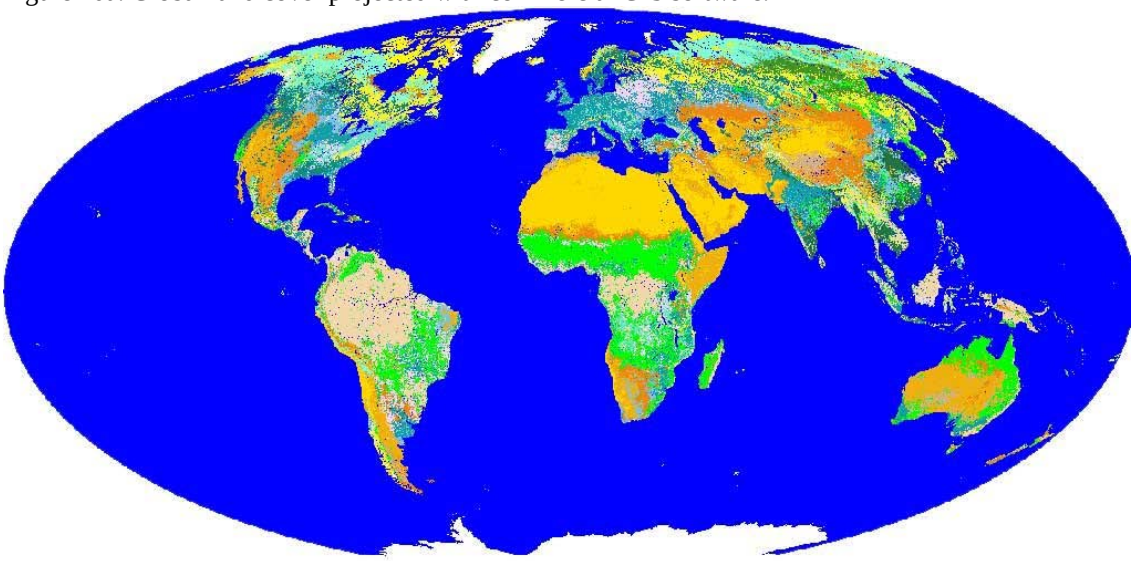


Figure 10b. Global land cover projected with USGS mapimg software.

Regional Geography

Overview

Among the most influential scientific advances of the 20th century was an awakening to the spatial and temporal relations among biological and physical phenomena and the ecosystems in which these phenomena occur. One consequence of this awareness is wide recognition of the importance of healthy ecosystems to the quality of life for humans who are part of these ecosystems. Another consequence is the recognition that resource-management and protection efforts oriented toward a sustainable future must be based on an understanding based on a regional geographic perspective of the Earth's surface.

Regional geography provides a cross-cutting way of looking at processes and phenomena characteristic of a region that other disciplines tend to treat in isolation. Geographers examine the relations and dependencies among these processes both in a vertical sense—integrating the understanding of physical, biological, social, and cultural processes at a single place and horizontally—examining the interactions among these processes occurring between places, such as within a region or even among regions. Geographers recognize that these relations are frequently scale dependent (National Research Council, 1997). This perspective enables geographers to be aware of and consider complexities of places and regions that are frequently not recognized by other disciplines, making possible a level of understanding of place not possible in any other single discipline.

Addressing Geography's science goals related to the rates, causes, and consequences of landscape changes will require a regional geographic perspective. Because many of the earth processes of concern to the USGS are appropriately studied at a regional scale, a regional geography perspective also can support the work of the entire Bureau. The application of a regional geographic perspective accomplishes the following:

- Helps scientists and managers place geographic processes, such as local landscape change, into the larger context that reflects spatial and temporal interactions at a broader scale.
- Stratifies the variability in landscape processes that shape the identity of a place, increasing the likelihood of detecting and understanding environmental responses generated by human activities.
- Allows the extrapolation of data from information-rich locations to those where information is lacking.
- Reduces the costs of monitoring, scientific investigation, and resource management by intelligently guiding data-collection activities.
- Provides a construct for comprehensive assessment from both a spatial (e.g., regional comparisons and national-scale landscape assessments) and thematic (e.g., comparative effects of different landscape-change scenarios) point of view.
- Provides a bridge between science activities, often undertaken at local levels, and the needs of decisionmakers for information to guide decisions at a regional or national scale.

The use of a regional framework can help ensure that the public reaps the maximum return on investments from USGS landscape investigations.

A regional geography perspective is highlighted as a core competency of the Geography Discipline for several additional reasons. In recent years, the Geography Discipline has taken a leadership role in establishing a research agenda for the development and use of regional frameworks, including the development of a plan for a more rigorous approach to understanding the identity and boundaries of ecological regions. Continuing leadership is needed in the implementation of this research agenda and in the development of an infrastructure to support the work (fig. 11). Variants of a place-based study approach, at both local and regional scales, already are widely used in the USGS; however, coordination has been lacking in the development and use of methods and frameworks to guide these multidisciplinary efforts, and opportunities for collaboration and leveraging the strengths of each discipline often are not realized.

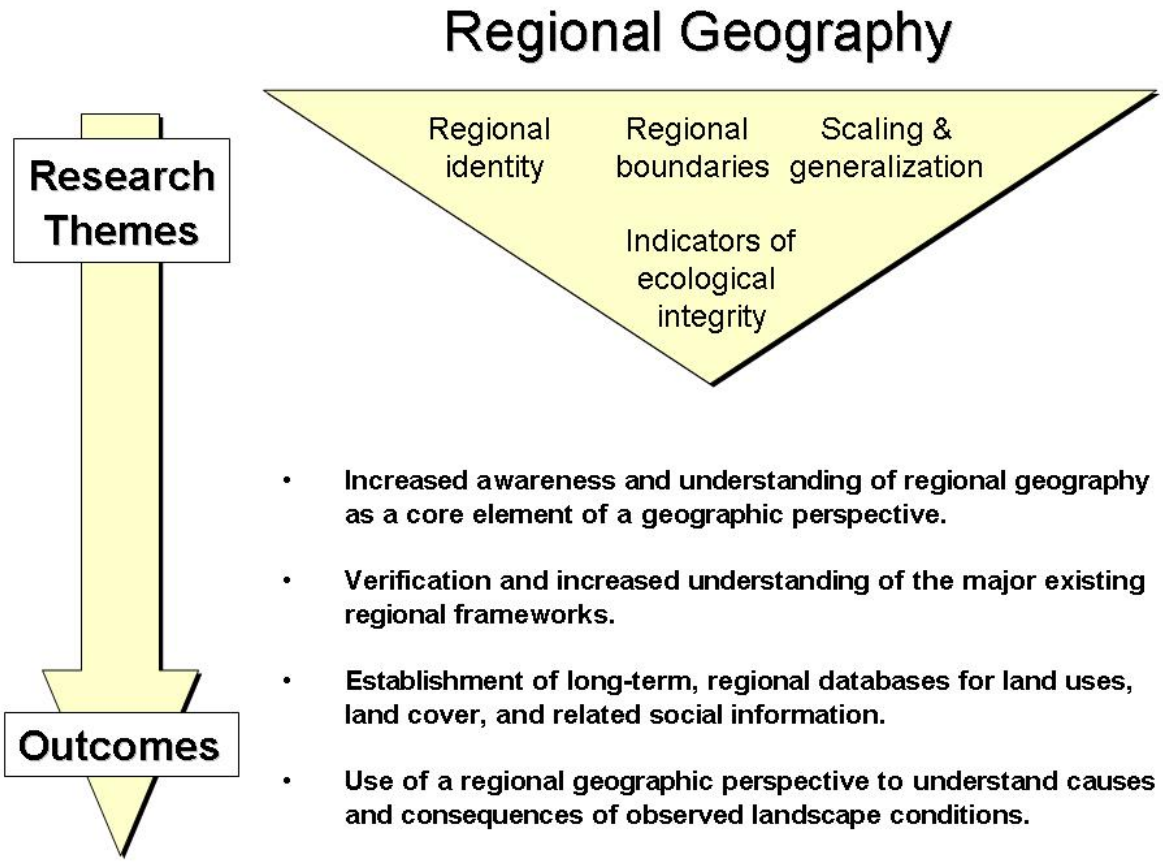


Figure 11: Priority research areas in regional geography and the resulting outcomes of this research.

Strategic Science Activities

Success in the monitoring, assessment, and research activities associated with the science goals identified in this plan will require use of a regional geography perspective. Although a range of regional geography activities occur in governmental, nongovernmental, and academic sectors, the theoretical and institutional framework for these activities are unfocused. An opportunity exists for USGS geography to provide leadership to address this lack of focus. The GGD has been charged by the National Research Council with conducting research that is explicitly integrated and regional, including extensive involvement with regional research outside the USGS. The Geography Discipline is challenged to become the integrative regional geography experts for the Nation (National Research Council, 2002). The Geography Science Planning Team has identified the following regional geography operational objective for the GGD over the next 10 years.

Objective 1: Establish regional geography as a core competency of the USGS and promote USGS leadership in ensuring the theoretical and institutional vitality of this field.

The GGD will provide leadership in increasing the understanding of the regional geography tradition, evaluating major existing regional frameworks, developing long-term regional databases, and using a regional perspective to test hypotheses about the causes of landscape change.

Outcome: Increased awareness and understanding of regional geography as a core competency of the Geography Discipline and an integral part of the intellectual tradition of the field of geography.

Strategic action: Develop a week-long course on the evolving intellectual tradition of regional geography to be presented at the USGS National Training Center.

Strategic action: Organize an international symposium of regional geography experts to assess the state of research practice within this tradition and develop a research agenda, particularly associated with the use of regional approaches to understand landscape dynamics.

Strategic action: Institute a Regional Geography Center of Excellence. Hire 5-10 Ph.D.'s to work on regional geography issues. Duties will include research, mentoring, providing technical assistance, and expanding regional geography science activities.

Outcome: Verification and increased understanding of the major existing regional frameworks.

Several regional spatial frameworks commonly are used in the U.S. for resource planning and management, and to help design and implement natural resources research, including the ecoregion frameworks of the USEPA, the U.S. Forest Service, and the U.S. Department of Agriculture's Major Land Resource Areas framework. Those who use these frameworks often do not have a broad appreciation of the purposes of the framework, the concepts underlying the identity and boundaries of the frameworks, and how the hierarchical nature of the framework does or does not support the generalization of findings from one scale to another.

Strategic action: Take a leadership role in working with the USEPA, States, and other Federal agencies in completing the Level IV ecoregion framework.

Over the last 10 years researchers based at the USEPA Corvallis, Oregon lab have worked with States, universities, other Federal agencies, and non-governmental organizations to develop and publish a series of state-level ecological region maps. These relatively large-scale (developed using information at an approximate scale of between 1:24,000 and 1:100,000) ecological regions depict areas with relatively homogeneous biotic and abiotic conditions that are expected to have ecological conditions distinct from adjoining regions. Approximately 10 States remain to be done; the USGS is publishing a series of maps for the states that have been finished. Support from the USEPA for this effort has declined, which provides an opportunity for the USGS Geography Discipline to take a leadership role in the completion of the project and in assisting States and others in the use and evaluation of these regions.

Strategic action: Provide ongoing assistance to scientists in the USGS and the DOI in the development and use of regional frameworks in the design of interpretive studies (e.g., to control for variability) and in the interpretation of data collected as part of the studies (e.g., generalizing from local data to regional conclusions.

Strategic action: Conduct research to answer questions associated with four issues related to regional frameworks: regional identity, regional boundaries, hierarchical relations, and regional ecosystem functioning (Grigg, 1965; Usery, 1994; McMahon and others, in press).

***Identity framework issues*:**

- How can regions be efficiently and(or) objectively defined and validated?
- Are universally measured landscape dynamics characteristics available that provide for the extrapolation of correlated characteristics from place to place?
- What are the ecosystem processes that are important in controlling the regional factors within and between distinctive regions?
- Is it possible to develop a continuous measure of ecological potential or capability? How would such a spatially continuous index compare with a discrete index? For what

purposes could a continuous representation be more suitable than a discrete one, and vice versa?

- What are the strengths and weaknesses of different regionalization approaches (e.g., quantitative multivariate statistical analysis or qualitative assessment) for understanding the rates, causes, and consequences of landscape change?

- What insights regarding the nature of landscapes and the processes that affect them are provided through integrated regional frameworks that are not possible when relying on a single discipline?

- Can indices be developed that allow the comparison of relative vulnerability of regions for different natural and anthropogenic hazards?

Boundary framework issues:

- How might the inability to draw sharp regional boundaries be best portrayed and validly analyzed?

- How do regional boundaries change through time? What drives these changes?

- How does heterogeneity of environmental conditions and ecosystem processes affect the definition of regional boundaries?

Hierarchical framework issues:

- What are the key landscape properties of interest at a particular level (scale) of a regional framework? What is the characteristic variability of processes at any level of the framework? What landscape processes are responsible for the patterns observed in regional frameworks at various scales?

Regional ecosystem functions:

- What is the relation between biological diversity and ecosystem structure and function at local and regional scales?
- What is the role of spatial heterogeneity within and among ecosystems in the function of individual ecosystems and of entire regions?
- How do types, intensities, and durations of disturbance affect the characteristics of ecosystems and regions?
- What allows ecosystems and ecosystem processes that are characteristic of a region to persist in the face of perturbations?
- What measures of regional ecosystem behavior can best be used to track responses to ecosystem stresses?
- How do human-induced landscape changes affect ecosystem form and function?
- What are the feedbacks between regional landscape change and climate at various scales?

- How can we account for ecosystem processes and responses to landscape changes that occur over temporal scales of years to decades to centuries?
- What methodological advances are needed to monitor regional-scale relations between ecosystem structure and function and landscape change in a spatially explicit fashion?

Outcome: Establishment of long-term, regional databases for land use, land cover, and related social information.

The effectiveness of USGS science is founded on the collection and maintenance of long-term environmental datasets. We are able to conduct research at unprecedented spatial and temporal scales only because of the collection of long-term national datasets. The paucity of long-term regional datasets, particularly for land cover and ecological outcomes, limits our current and future ability to understand the relations between landscape change and the status and trends of ecological resources (Jones and others, 1995). Databases covering the entire Nation should contain region-specific data on critical land-cover types, including forests, grasslands, agriculture, and human settlement and industrial uses, and complementary demographic, economic, and institutional data. It is important that these data include information about classification accuracy or other measures of uncertainty associated with data collection and processing.

Strategic action: Establish regional data observatories and archives developed and operated in conjunction with the NSF Long-term Ecological Research (LTER) network, NEON, the National Acid Precipitation Program, NOAA, and NASA, and other activities and organizations that collect earth-science data.

Strategic action: Collaborate with the USGS Geology Discipline's Earth Surface Dynamics Program and Priority Ecosystem Studies Program in developing these observatories.

Outcome: Successful use of a regional geographic perspective to develop and test hypotheses about causes of observed landscape conditions.

Landscape processes are connected, regardless of where they occur along a local-global continuum, and have effects at other places and scales. From a geographic perspective, answers to research questions about landscape dynamics frequently are scale dependent. In examining landscape change mechanisms, geographers have observed that (1) causal mechanisms are best observed at local levels; (2) macro-scale events (i.e., national and global scale) are not always best explained by reducing them to local-scale events; and (3) macro-scale processes do not always deterministically structure local-scale events. Landscape phenomena and processes are hierarchically nested in complex ways. Interactions across scale are not linear but involve thresholds and abrupt changes between different conditions, and outcomes vary considerably locally and regionally (National Research Council, 1997; 2001: 2002).

Strategic action: Use a hierarchical local-regional-national-global approach to improve understanding of the phenomena and processes that cause landscape change.

Strategic action: Sharpen the understanding of and articulate a set of scaling rules for describing the mechanisms of landscape change that can be used for generalizing local study findings to larger scales.

Strategic action: Conduct research to answer several questions about the regional characteristics of landscape change.

- Which level of focus in hierarchical regional framework is appropriate for a particular across-region comparison or extrapolation?

- Are there associations of landscape patterning and(or) processes that are characteristic of regions at a particular scale? Is there a relation between these associations across scales, such that associations at one scale can be predicted from knowledge of associations at another scale?

- What scale of regional analysis can assist most effectively in predicting landscape change components associated with wildfires or invasive species?

- Do different regions, defined at a particular scale, have different landscape matrices; that is, do different landscape elements and components that play a dominant role in the functioning of the landscape differ among or within regions?

Establishing an Improved Regional Geography Research Capability

Not a single governmental, academic, or non-governmental institution in the U.S. currently is capable of completing all the activities described in this section. Regional geography research expertise and capabilities are widely distributed and largely uncoordinated. The USGS has a unique institutional foundation and mission, however, which allow it to assume a leadership role in undertaking the work described here, both by its own scientists and in collaboration with others. Realization of these possibilities requires a USGS institutional commitment to assuming leadership responsibilities, and to undertaking a number of strategic activities.

Over the next 10 years the GGD will have to greatly expand its own regional geography research capabilities. At least 10-20 additional researchers, both doctoral and masters level, will be needed to complete the research and other regional geography science activities described here. A particular emphasis should be placed on the addition of scientists with expertise in the development, use, and evaluation of regional frameworks, the characterization of social and ecological processes associated with regions, the understanding of scaling relationships in describing these processes, and the use of information developed at one scale to characterize conditions at a different scale.

Strategic Partners

The GGD will not be able to achieve these outcomes on its own. Assuming a national regional geography leadership role will require communicating and coordinating with partners in government, universities, and non-governmental agencies. The GGD will need to work closely with scientists from other USGS disciplines in the design and application of regional frameworks; in the development of improved understanding of physical, chemical, ecological, and social processes that are characteristic of regions; and in the transfer of this process information across scales. The USEPA and the U.S. Forest Service have a strong interest in the development and use of regional frameworks for resource management and for understanding of the effects of landscape change. Universities are especially important partners, both in undertaking work related to the priorities described here and in training new researchers who will have the ability to address regional geography research needs.

Highlight: Choosing an Ecological Region Framework to Guide Global Change Investigations.

Geology, topography, climate, ecosystems, and other factors vary across the surface of the Earth and interact in many complex ways. A number of geographic regional frameworks, based on interrelations in the spatial patterns of these factors, have been developed for the contiguous United States, including frameworks published by the U.S. Forest Service and the World Wildlife Fund (WWF). These ecological region (or ecoregion) frameworks have been used to design, monitor, analyze and implement management plans for a variety of purposes, including forest and watershed management and the protection of endangered species. The basis for recognizing and defining regional boundaries, however, varies among these frameworks. How should potential users choose which ecoregion systems to employ in their work?

Thompson and others (in press) tried to address this question by examining the relations between biological and climate data along three latitudinal transects across the United States for three ecoregion frameworks, including the framework used by the WWF. Along a 35° N latitudinal transect, the WWF ecoregion boundaries align reasonably well with major changes in bioclimatic variables, especially in the western United States. Changes in the number of unique plant species and in species richness along this transect also register well with this framework's ecoregion boundaries. The correspondence between the WWF ecoregion boundaries and the distributions of species is not surprising--WWF boundaries are based on a framework, originally developed by Omernik (1995) and then modified by the WWF (Olson and others, 2001), to reflect distinct assemblages of species and ecological communities of conservation interest to the WWF. These regions were designed to represent relatively large land areas with regional boundaries that approximate the extent of natural communities prior to European settlement. Thus, the WWF ecoregion framework is likely to be most useful to organizations that have conservation or management goals at a similar taxonomic resolution and spatial scale as those of WWF.

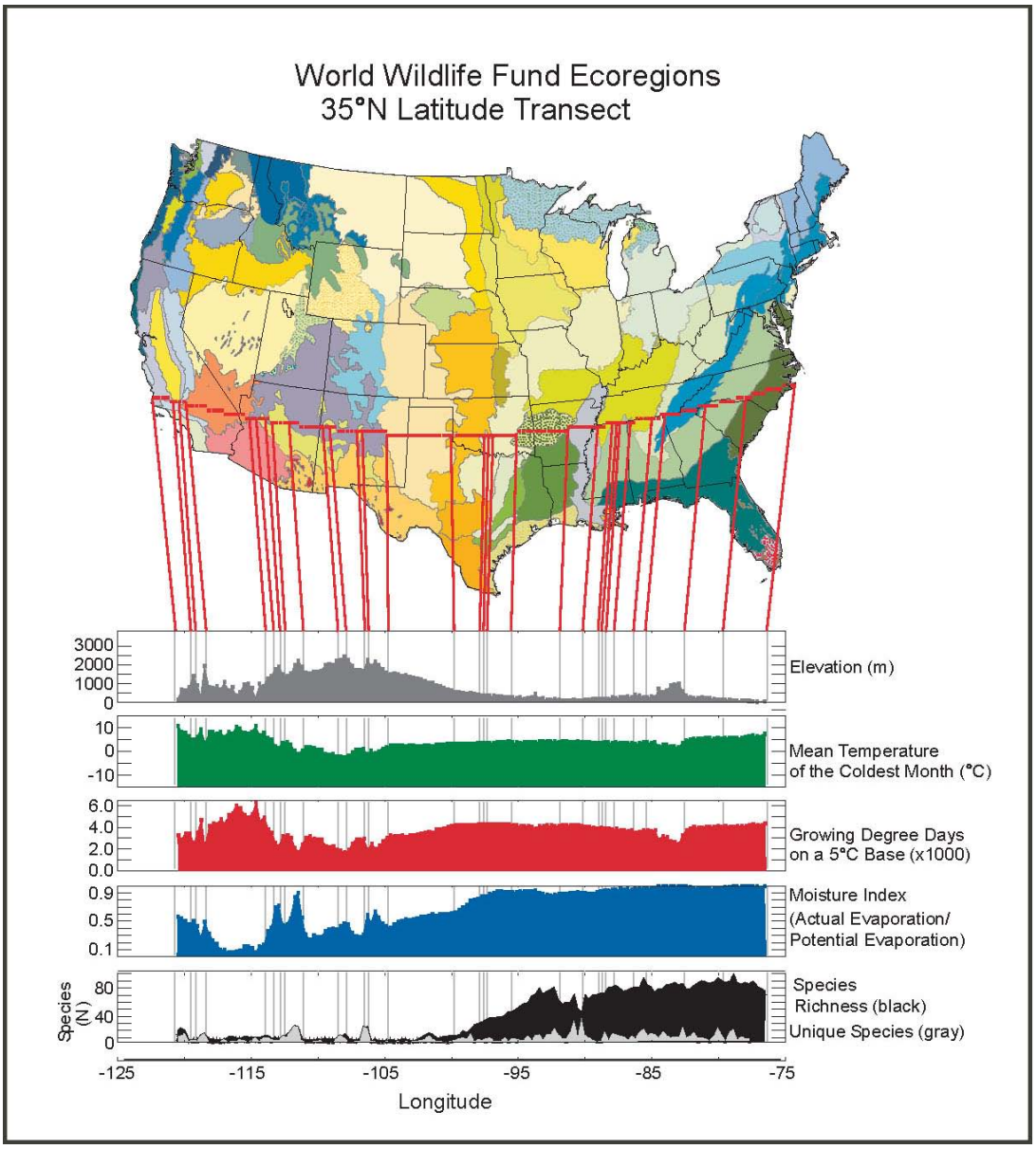


Figure 12: World Wildlife Fund Ecoregions: 35° N Latitude Transect.

The data were plotted at 25-kilometer intervals along each transect: (A) boundaries between adjacent WWF ecoregions; (B) elevation (m); (C) mean temperature of the coldest month (°C); (D) growing degree days on a 5°C base (Newman, 1980); (E) a moisture index calculated as annual actual evaporation divided by annual potential evaporation (Thornthwaite and Mather, 1955, 1957; Willmott and others, 1985); and (F) species richness (i.e., the number of woody species per grid point) and the number of unique species for each grid cell summed with the number of unique species in the grid cell directly to the east.

Remote Sensing

Overview

Remote sensing is a core competency of geographic research, essential to almost all mapping activities, and a cost-effective and integral part of our national arsenal of resource assessment, environmental management, and environmental-monitoring capabilities. Whether using the multi-resolution capabilities of optical sensors (e.g., Landsat's Thematic Mapper, Terra MODIS), or data from the growing collection of new sensors based on radar, lidar, and other non-imaging technologies, there is a strong need to understand, improve, apply, and advocate remote sensing. Without remote sensing, it will be difficult to meet USGS environmental-monitoring, mapping, and science goals.

The NRC (2001a) determined that the USGS must make greater use of remote sensing in its investigations. The role of remote sensing has grown in importance as a source of objective data from which landscape conditions can be mapped and measured. Remotely sensed data are widely used in the Geography Discipline and throughout the USGS. In the Geography and Water Disciplines, land-cover mapping and land cover change studies rely on remote sensing expertise to interpret the spectral and spatial attributes of remotely sensed images. Biological investigations of habitat status and ecosystem productivity rely on measures of canopy attributes such as density, leaf area, and phenology. Geology and Geography studies of surface formation relating to geomorphic change and geological hazards rely on new remote sensing technologies and data. To meet the NRC challenges during the next 10 years, the USGS will need to:

- Provide access to a rich archive of historical aerial photography and calibrated historical and contemporary remotely-sensed data.
- Contribute a steady stream of remotely-sensed data to USGS and other scientists suitable for near real-time assessment of changing land-surface conditions, including the effects of natural and anthropogenic hazards.
- Operate a landscape characterization program that translates remotely-sensed data into accurate maps and measures of land use and land cover, ecosystem properties, and surface form. Of equal importance will be the USGS paradigm shift in landscape characterization from baseline mapping to dynamic and rapid identification of conditions and changes with map and measurement accuracies significantly improved over those achieved today.

Remote sensing is a core USGS competency that historically has commanded national and international respect. Maintaining this respect will require a clear vision of the future and research that is focused on the critical elements enabling the USGS to meet the Nation's geography monitoring and assessment needs (fig. 13).

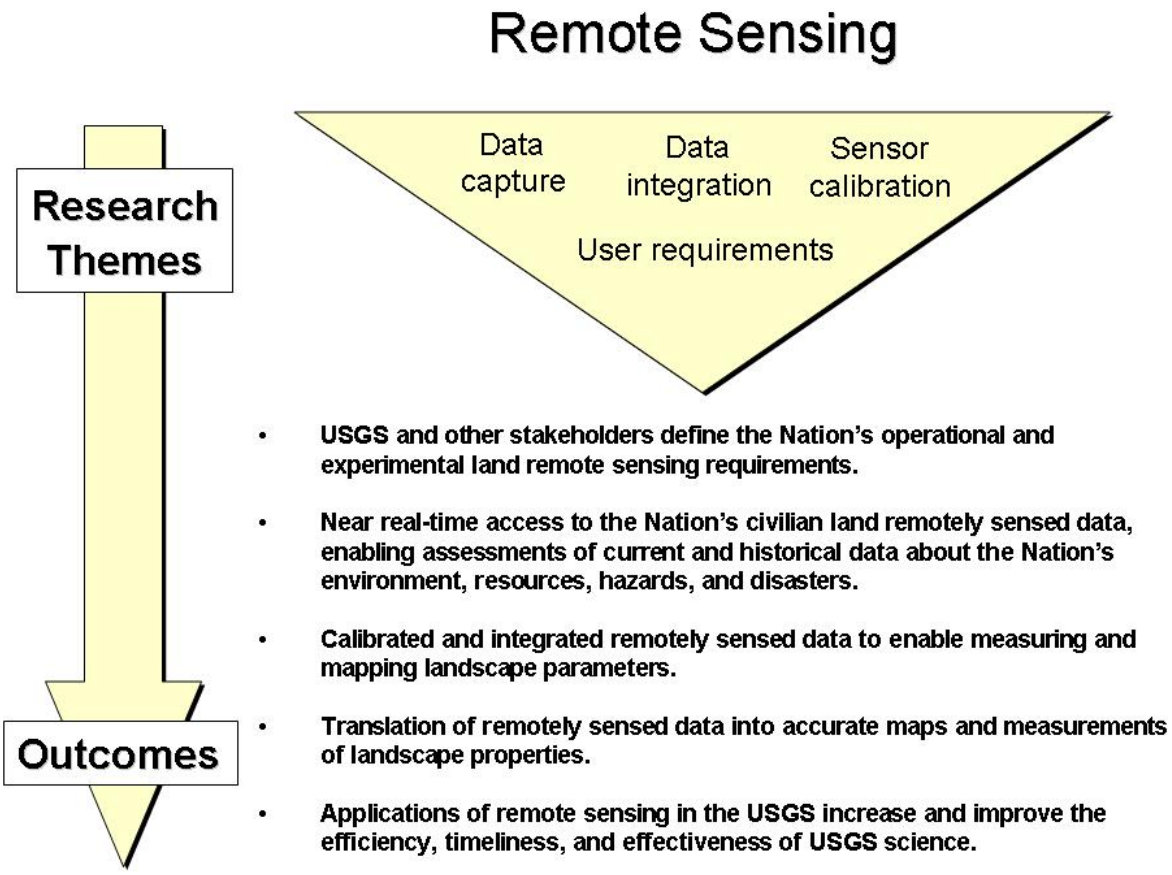


Figure 13: Priority research areas in remote sensing and the resulting outcomes of this research.

Strategic Science Activities

The USGS has a significant investment in remote-sensing research. The research underway generally has focused on several critical methodologies: data access and archiving, calibration and validation, and mapping strategies. In addition, the USGS has a substantial investment in developing applications of remotely sensed data. Continuation of these methodological and application activities is essential. However, as a core competency in Geography, remote-sensing research over the next 10 years must be focused on defining and developing the capabilities needed to understand the Earth's environment. Improving the characteristics and quality of environmental data is vital to the USGS monitoring and assessment goal.

In order to meet the overarching goal of providing the Nation's geography monitoring and assessment infrastructure, USGS investment in remote-sensing research must expand to accomplish the following remote sensing operational objective:

Objective 2: Establish and improve USGS remote-sensing research capability and increase the use of remote-sensing data for near real-time monitoring of the effects of changing land cover and land-surface conditions associated with natural and anthropogenic hazards.

This objective entails defining requirements and capabilities and conducting research and development that enables the use of remote sensing to operationally monitor the Earth's environment. Meeting this goal will require a broad understanding of the needs for remote sensing across the USGS and consideration of the unique capabilities that GGD has and requires in the future as science issues are identified. A multimission perspective is essential, including the capabilities of both government and commercial remote-sensing programs. This includes the unique National Technical Means assets of our national intelligence and defense agencies.

The following outcomes and strategic actions will enable achievement of the remote sensing operational objective:

Outcome: Requirements of the USGS and other stakeholders for remotely sensed data will define the Nation's operational and experimental land remote sensing capabilities.

Strategic Action: Survey the requirements of the USGS for environmental data and monitoring, and define the sensing capabilities needed to cost effectively and accurately produce the required data and information. This includes determining which of the emerging capabilities are candidates for technology development. For example, given the broad use of lidar data, the USGS should pursue research that leads to the systematic national collection and application of lidar measurements. Implied in this function is a more aggressive role in the development and continuation of the Nation's global Earth Observation capabilities.

Strategic Action: Investigate new technologies for Earth observation and define the specifications for the imaging and non-imaging remote-sensing capabilities needed to meet current and future Earth observation and monitoring requirements.

Outcome: The USGS remote-sensing data archive provides near real-time access to the Nation's civilian land remotely sensed data and enables rapid and cost-effective assessments of historical data about the Nation's environment, resources, hazards, and disasters.

Strategic Action: Define the science requirements for historical and contemporary remotely sensed data and develop the specifications for future Earth observation instruments.

Strategic Action: Develop a strategy and capability for consolidating and converting the Nation's vast and dispersed historical aerial photography into electronically accessible USGS remote-sensing archives in a format that enables studies of the Earth's land use history.

Strategic Action: Conduct research on advanced data-mining capabilities that leads to robust access to the USGS remote-sensing archive for the purpose of gaining knowledge about the Earth's dynamic history.

Outcome: Calibrated and integrated remotely sensed data from a range of sensors and scales to enable measuring and mapping landscape parameters and conditions over time to monitor change.

Strategic Action: Conduct research that leads to the implementation of a comprehensive calibration program for all USGS remote-sensing assets that enables, to the extent feasible, conversion pf spectral data to physical values with sufficient consistency to permit comparisons over time.

Strategic Action: Define and test protocols for determining the uncertainty, accuracy, and precision of products derived from USGS remotely sensed data. Understanding the uncertainty of USGS data derived from remotely sensed data is essential for monitoring and assessing landscape conditions and for translating these measures for use by scientists, resource managers, and decisionmakers.

Outcome: Advanced analytical methods enable the USGS to translate remotely sensed data into accurate maps and measurements of landscape properties, including land cover status, ecosystem services, and surface form.

Strategic Action: Define the analytical methods needed to make better use of data from both current and future remote-sensing instruments. This will require identifying the methods needed to transform electromagnetic measures into the data and information needed by the USGS and its customers. Specific capabilities include (1) methods for developing accurate, robust, and flexible landscape-change metrics; (2) development of near real-time landscape condition monitoring capabilities for quantifying ecosystem stress; (3) methods for transforming lidar observations into complete three-dimensional measures of surface form and canopy configuration; and (4) advancements in scaling *in situ* measurements into regional contexts.

Outcome: The number of applications of remote sensing in the USGS is doubled, thereby improving the efficiency of Bureau programs and increasing the timeliness and effectiveness of USGS science.

Strategic Action: Establish an applications program that provides technical advice and support needed to incorporate USGS remote-sensing capabilities into the Bureau's programs and projects. Examples of applications include: monitoring and mapping urbanization with increased frequency to enable improved assessments of the effects of urbanization on water quality and flooding risks; advanced data capture and processing methods that can lead to a new

generation of topographic data that provides the resolution and accuracy needed to permit more reliable assessments of hydrologic processes; improved measurements of vegetation canopy that can be used in operational weather forecasting models, resulting in improved short-term weather forecasts.

Establishing an Improved Remote Sensing Research Capability

The most immediate and ongoing priorities are that the USGS assert its role as a national and international remote-sensing leader by ensuring the continuity of long-term remotely sensed data and that new remote-sensing capabilities needed to meet USGS program requirements are available. Related to these are the research and action needed to ensure the long-term availability of historical data. The deterioration and loss of historical aerial photographs due to the lack of resources for storage and the use of inadequate storage facilities and other threats are real. With assurance that historical and contemporary data are available, the USGS should establish a remote-sensing center of excellence that includes the researchers needed to produce the results specified. As research capabilities expand, GGD's current remote-sensing scientists can begin documenting the requirements and specifications for expanding USGS remote-sensing capabilities.

Clearly, additional scientific personnel are needed to address the strategic actions identified in this section. While the GGD currently has a talented and productive remote-sensing research team, the depth of the team is thin in all critical areas, and 10 to 15 additional researchers are needed immediately. Expertise in signal processing, electromagnetic physics, and electronics must be hired to conduct instrument calibration research. Expertise in algorithm development, including capabilities in pattern recognition and cognitive computing coupled with a clear understanding of the geographic aspects of remote sensing, is needed. Additionally, expertise in spatial and sampling statistics is needed to develop validation protocols and contribute to all other aspects of remote sensing research.

Strategic Partners

The advancement of remote sensing as a critical geographic capability for understanding the Earth's environment has taken center stage due to the strong need for cost-effective mapping, measurement, and monitoring of the dynamic landscape. The Climate Change Science Program (2003) identified a strong role for remote sensing as a means of meeting program objectives related to key science goals in Land Use and Land Cover Change, Human Dimensions, Ecosystems, Carbon Cycle, Water Cycle, and Climate Variability. The Earth Observation Summit of 2003 lead to the establishment of the Group on Earth Observations (GEO) which called for a concentrated international effort, founded on strong national programs, to develop a comprehensive Earth observation system to address economic and environmental issues. The USGS provides leadership in the GEO initiative. The USGS is also a plenary member of the Committee on Earth Observation Systems and the International Global Observation Strategy that strives to achieve maximum use of Earth observations for the purpose of improving the understanding of the state and processes of the Earth's system. The USGS is an international

remote-sensing leader, and through the programs of the Geography Discipline, the USGS must provide the scientific expertise committed by USGS leadership in order to advance the effective use of remote sensing in USGS programs and beyond.

Remote-sensing research requires very specialized capabilities. Rather than accumulate staff in all of the relevant specialties, remote-sensing research should be planned and executed in partnership with other government agencies, industries, and academia. The USGS has a unique capability for handling and processing large datasets. NASA has a unique capability in instrument design and performance. The USGS must have the complementary intellectual expertise to cooperate effectively with NASA scientists. Similarly, universities can provide unique capabilities in basic research related to algorithm development, while the USGS has unparalleled capabilities in large area landscape characterization and mapping. Collaborative pursuit of new paradigms for landscape characterization is the appropriate strategy.

Remote-sensing research in the USGS must be mission driven. Close communication with DOI resource managers must take place so that all research is relevant to the needs of the user community. At the same time, the USGS's long-standing association with the USEPA and U. S. Forest Service is equally important in documenting and assessing the consequences of landscape change and hazards on the Nation's land and water. A strong program affiliation with the CCSP and international equivalents, such as the International Geosphere-Biosphere Program and the CEOS IGOS initiative, are very important. The USGS is an international participant in the global effort to understand the changing Earth system and should assume a leadership role in conduct research with and in support of international science objectives.

Highlight: Applications of Light Detection and Ranging (LIDAR) Technology

The use of three-dimensional (3-D) elevation data is rapidly becoming an important tool in the visualization and analysis of geographic information. The creation and display of 3-D models representing bare earth, vegetation, and structures has become a major focus of research in the past few years. A relatively new remote-sensing technology called Light Detection and Ranging, or LIDAR, has been increasingly accepted as an effective

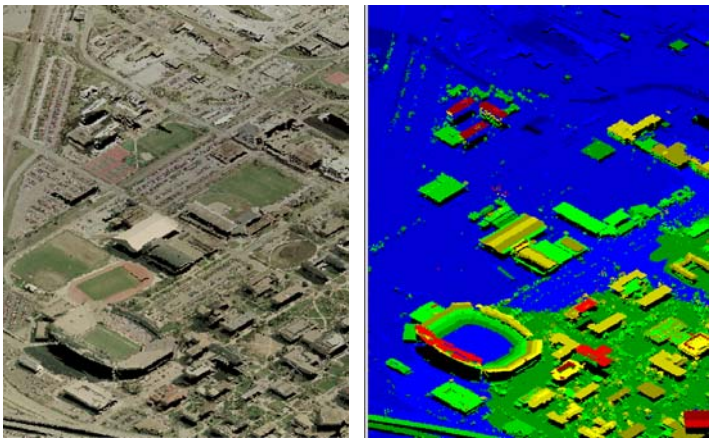


Figure 14a. Elevation and imagery fusion of LIDAR point cloud

and accurate tool for quantifying high-resolution elevation data for bare earth, vegetation ,and structures. LIDAR is an active sensor that records the distance, or range, of a laser fired from an airborne platform such as an airplane, helicopter or satellite. By converting LIDAR data into bare earth, vegetation or structural elevation information, extremely accurate, high-resolution elevation models can be produced to visualize and quantify scenes in three dimensions. Results can be used to produce high-resolution bare-earth digital elevation models; quantitative estimates of vegetative features such as canopy height, canopy closure, and biomass; and models of urban areas such as building footprints and 3-D city models.

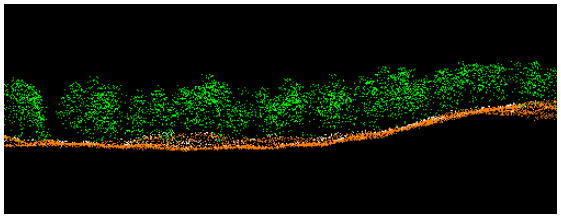


Figure 14b. Vegetation LIDAR point cloud

Current LIDAR research involves improved 3-D visualization techniques, designing methodology to extract vegetation characteristics from LIDAR point clouds, automated feature extraction of urban structures, 3-D modeling, and combining imagery and LIDAR-derived elevation data. In the future, landscape scenarios will be viewed and simulated in 3-D, enabling a more realistic and comprehensive understanding of the simulations and scenes. As computer-processing power continues to improve and new methods are developed for representing massive data sets, users in the future will be able to walk through 3-D "virtual forests" and "virtual cities," allowing a realistic view of the Earth never available before.

Figure 14c. Three dimensional virtual city from LIDAR

Highlight: Custodian of the Nation's Global Earth Observations

The USGS is the custodian of the Nation's archive of global Earth observations obtained from aircraft and satellites. From 30 years of Landsat data representing the longest continuous global record of land and water conditions to the daily global images collected from NOAA polar orbiting missions and the NASA Earth Observing System program, and including aerial photography that cover the U.S. and date back to the early 1930's, the USGS has unmatched access to remotely sensed data and analytical capabilities that are needed to map, measure, and monitor the changing Earth.

The Landsat Program housed at the USGS Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, SD is the centerpiece of the USGS Earth observation capability. The primary objective of the Landsat Program is to ensure a collection of consistently calibrated Earth imagery. Since July 1972, six Landsat satellites have used multispectral scanner (MSS) and thematic mapper (TM) instruments to gather images of the Earth's land mass, coastal boundaries, and coral reefs; and to ensure the data acquired are of maximum usefulness in supporting the scientific objectives of monitoring changes in the Earth's land surface and associated environment.

The Landsat Program has been an interagency partnership involving the USGS, NASA, and NOAA in various capacities. Today, the Landsat program is a joint initiative of the USGS and NASA. NASA is responsible for developing and launching the spacecrafts, while the USGS is responsible for flight operations, maintenance, and management of all ground-data reception, processing, archiving, product generation, and distribution. In addition, the USGS conducts research that has led to improvements in the understanding and applications of Landsat and other remotely sensed data.

Integrating Natural and Social Sciences

Overview

Information developed by USGS science activities has been used for 125 years to assist management decisions related to hazards, the environment, and natural resources. Recent developments, however, have significantly increased the demand, opportunities, and expectations for the USGS to improve and expand the usefulness and effect of its science products to society.

One development is increased local and citizen involvement in decentralized decisionmaking on topics with physical, biological, and social science dimensions. An example of this is citizen involvement in reviewing proposed local land use and development regulations that affect property values, storm runoff, and habitat availability. This decentralization has evolved in parallel with an explosion of information accessibility, particularly through the Internet, and analytical capability, such as geographic information and decision-support systems. Expectations among those who rely on USGS data and information also have risen (Ehlers 2002). Information is expected to arrive quickly in a convenient-to-use format, reflect the best possible scientific expertise, and be useful to a broad array of USGS customers whose information needs may vary as widely as the levels of expertise they possess to use the information.

At the same time, the links between science and decisionmaking are often complicated and obscure for both scientist and decisionmaker. The technical nature of scientific research and the language used to report science results may not be readily comprehensible to decisionmakers or citizens. Scientific investigations often are conducted under different conditions, with different spatial boundaries, and in different timeframes than those needed to support specific policy and societal decisions. Uncertainty is not uniformly reported in scientific investigations, and the practical implications of uncertain science findings may not be appreciated by decisionmakers or the public (Bradshaw and Borchers 2000).

The effect of USGS science is enhanced when physical, biological, and social science-based information can be integrated and applied by decisionmakers and citizens to promote local, regional, and national welfare; such efforts are critical to all disciplines of the Bureau. The research discussed in this plan focuses on the development of multidisciplinary methods and techniques, such as decision-support tools, indicators and metrics, policy analysis, and decision research, to communicate and translate science results into forms that can support policy decisions and be understood by the public. Important research themes associated with achieving the maximum benefits of USGS science information include:

- Importance of scale, resolution, and uncertainty of information in addressing different types of issues;
- Tradeoffs between timeliness and completeness of scientific inquiries;
- Role of science performed with natural boundaries to support decisions with political or social boundaries;

- Development and application of science tools and products to support decisionmaking;
- Role and value of geographic information, multidisciplinary decision-support systems (DSS), and visualization in decisionmaking;
- The role of adaptive management, joint fact finding, and other collaborative processes to facilitate the effective use of science in decisionmaking;
- Integration of information developed using science-oriented boundaries (e.g., watershed, ecoregion) into political decisionmaking processes based on administrative boundaries (e.g., city or state boundaries);
- Development and use of metrics and indicators of societal implications of landscape change.

Integrating natural and social science is highlighted as a core competency of USGS geographic science for several reasons. Of all the USGS disciplines, only geography has as one of its primary domains the relation between society and nature, and only geography includes both environmental and behavioral researchers. Geographers bring USGS's physical and biological sciences and the social sciences together to better understand the consequences and implications of landscape change. The development and application of methods by geographic researchers to integrate and use natural and social science information will improve the ability of the Bureau to address key science goals and improve the use of science information by decisionmakers and the public. With expertise in geospatial analysis and DSS development, geographic researchers also have an important role in contributing to improved metrics and tools for decisionmakers (fig. 15). DSS accept data and knowledge generated by natural and social science as input and produce maps and statistical summaries, allowing decisionmakers who deal with environmental issues to experiment with a variety of scenarios.

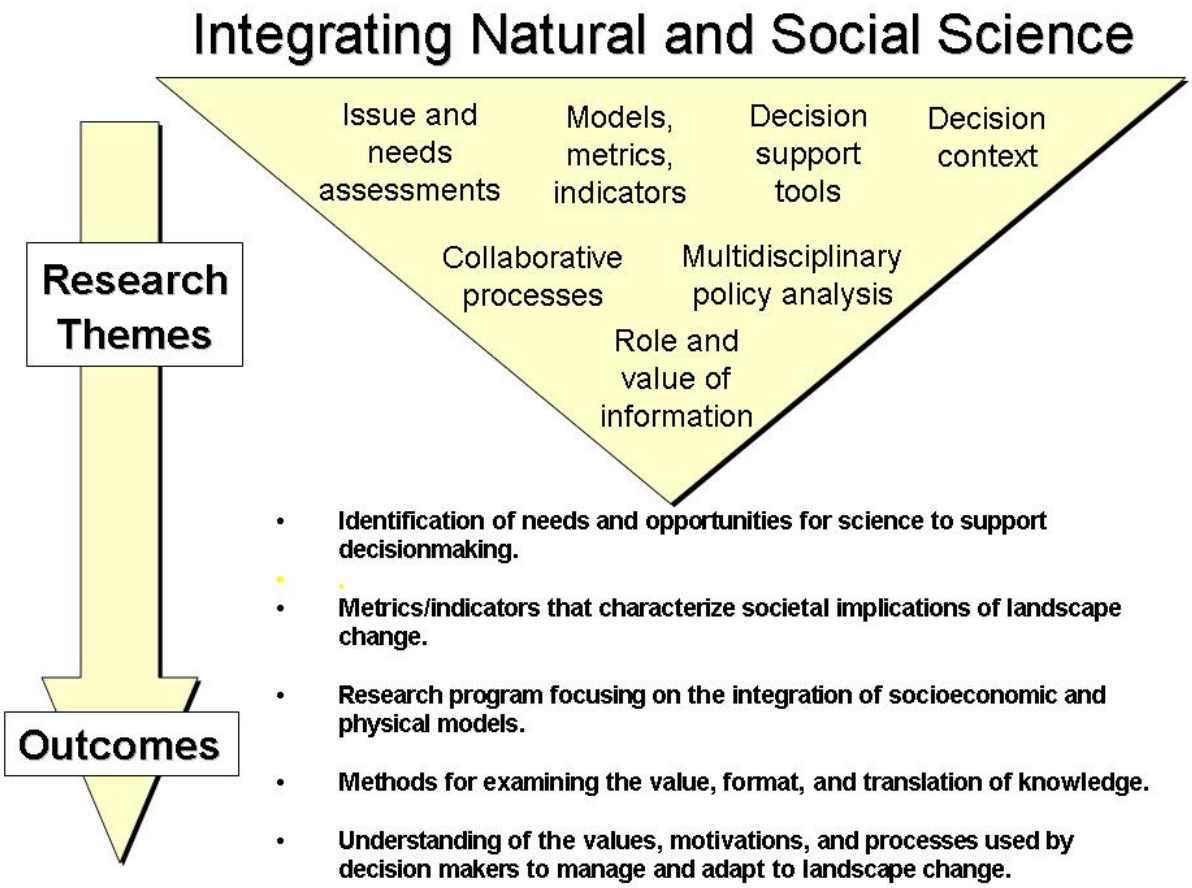


Figure 15: Priority research areas related to integrating natural and social science and the resulting outcomes of this research.

Strategic Science Activities

The priority issues for geographic science in the USGS over the next 10 years focus on understanding the rates, causes, and consequences of landscape change and the societal vulnerability to hazards. Success in addressing the goals outlined in this plan require capitalizing on geography's strengths of natural and social science integration and decision-support systems. The SPT identified the following operational objective for the next 10 years:

Objective 3: Establish the USGS as a leader in methods and techniques to improve and expand the use of natural and social science to support societal decisionmaking.

In the next 10 years, the USGS Geography Discipline, in collaboration with other USGS Disciplines and Federal agencies, will accomplish the following outcomes.

Outcome: Innovative and effective mechanisms for identifying, developing, and evaluating customer needs and opportunities for science to support decisionmaking.

Strategic action: Organize a symposium of relevant agencies and organizations to assess the breadth of research and applications that expand the use of science for decisionmaking and to develop a coordinated research agenda.

Strategic action: Develop and implement continuous customer surveys that focus on identifying decision maker issues, opportunities and needs, including training and GIS-based applications.

Strategic action: Conduct studies in the use and value of collaborative processes, such as adaptive management and joint fact finding, for determining practitioner needs and opportunities.

Outcome: A national tool box of metrics and indicators that characterize societal implications of landscape change and provide context for decisions regarding these implications.

Strategic action: Continue to develop a suite of metrics and indicators applicable at various scales and supportive of a wide audience of decision makers that convey physical consequences and societal implications of landscape change, such as the USGS Famine Early Warning System project. This includes translating nationally and globally defined metrics of a changing landscape into an understanding of the effects of the processes at a local level.

Outcome: A coordinated research program focusing on the integration of socioeconomic and physical models to develop decision-support tools and to conduct policy analysis.

The USGS Geography Discipline has developed expertise in combining socioeconomic models with geospatial databases within a DSS to provide decisionmakers with measures and spatial implications of potential landscape changes and land-management choices. Although adequate to support a limited research agenda, the current level of staff expertise is not sufficient to support all of the Bureau's needs related to the integration, translation, and use of natural and social science information.

Strategic action: Develop a center of excellence in the integration and use of natural and social science research. Hire 10-20 researchers and application developers to expand work on these issues. Duties will include research, mentoring, providing technical assistance, and developing the science activities in this area.

Strategic action: Research and develop decision-support system mechanisms to integrate socioeconomic models with physical models of landscape and earth science processes to enhance the use of USGS science results in policy analysis. Continue to develop the Land Use Portfolio Model, the Tahoe Decision Support System, and other decision-support systems to facilitate the integration and use of multidisciplinary models.

Strategic action: Conduct multidisciplinary case studies on the integration of socioeconomic and physical models to support environmental policy analysis and hazard risk-reduction efforts.

Outcome: Improved methods for examining the value, format, and translation of knowledge in societal decisionmaking, including collaborative processes and visualization techniques.

The Geography Discipline has demonstrated expertise in understanding complex spatial data-collection and analysis programs. Knowledge gleaned from this research provides decisionmakers with an understanding of the cost tradeoffs involved in the use, presentation, and application of science in management decisions.

Strategic action: Conduct studies on the influence of role, scale, accuracy, timeliness, and thematic content of geographic data on societal decisionmaking.

Strategic action: Conduct research and develop techniques that integrate spatial analysis and economic valuation theory to illustrate to decisionmakers the value and potential tradeoffs of geographic information.

Strategic action: Conduct research and develop innovative geographic methods and techniques to present and visualize scientific information that supports societal decisionmaking.

Strategic action: Continue development of GeoMAC and other mapping applications that customize the amount, type, and detail of scientific information presented to decisionmakers.

Strategic action: Develop a series of training materials on improving the use of geographic knowledge and data in decisionmaking with DSS, collaborative processes, and geospatial visualization.

Outcome: Improved understanding of the values, motivations, and processes used by decisionmakers to manage and adapt to landscape change.

Strategic action: Conduct research on the institutional elements of decisionmaking processes at local and regional levels. Using sociological valuation methods, use this research to compare potential decision settings.

Strategic action: Conduct studies on the influence of perceptions and policies on the use and communication of science in decision making.

Strategic action: Continue to develop and facilitate role-playing simulations of collaborative decisionmaking in a variety of decision settings.

Strategic action: Research and develop the use of collaborative processes, such as adaptive

management and joint fact finding, for understanding the societal context for environmental decisionmaking.

Establishing an Improved Research Capability for Integration of Natural and Social Science

Over the next 5 years, the Geography Discipline must greatly increase its social science and geographic research staff. Both doctoral and masters level staff are needed to conduct research and to develop applications and tools. A core of researchers and application developers should be assembled in a national center of excellence that focuses on innovative techniques and methods to understand and improve the use of science in decision making. The Geography Discipline can provide Inter-Personnel Agreements to allow USGS researchers to collocate with social scientists and application developers in other Federal agencies and organizations, such as the NOAA Coastal Services Center and NASA Earth Science Application Centers.

The Geography Discipline should develop an advisory group with the expertise to advise the Associate Director for Geography and geography researchers on research issues, research methods, and the state of the practice related to the integration of natural and social science and the transmittal and use of information arising from this integration. An advisory group could be composed of individuals with expertise in multidisciplinary policy analysis and visualization and needs assessment, and who could be called upon to help with specific issues of DOI concern.

Strategic Partners

The research efforts outlined here will greatly benefit from partners internal and external to the USGS. Improving the use of science in decisionmaking is a common goal of many organizations, and much can be learned from external organizations. The USGS will need social science and economics expertise to carry out the Science Impact program successfully. A study to determine opportunities for the USGS to improve and expand the use of its science in societal decisionmaking should be commissioned and conducted by groups such as the Board on Science, Technology, and Economic Policy (National Academy of Sciences) and The H. John Heinz Center for Science, Economics, and the Environment. Related to improving the science-society interface, the Geography Discipline could follow the NOAA Coastal Services Center and conduct a customer survey every 2 years that focuses on decisionmaker issues and needs, including training and GIS-based applications.

Some primary partners will be researchers in other USGS disciplines, as their science focus will be the foundation upon which the research on integrating natural and social science is conducted. Likewise, partnerships can be developed with other DOI Bureaus that use USGS research in decisionmaking and Federal agencies, such as the Department of Homeland Security, NOAA, and the USEPA. Agencies and organizations with similar research interests in multidisciplinary policy analysis and assessment of decisionmaker issues can be important future partners from whom we can learn much. These include the Environmental Studies Program (Mineral Management Services), the Oregon Natural Hazards Workgroup, the Center for Science and Technology Policy Research (University of Colorado – Boulder), the Environmental and

Societal Impacts Group (National Center for Atmospheric Research), and the National Science and Technology Center (Bureau of Land Management).

The USGS Geography Discipline must develop new partnerships with academic departments and other organizations with mutual research interests, while existing academic partnerships must be strengthened and continued. Partnership universities include the University of New Mexico (economics and policy); Massachusetts Institute of Technology (collaborative processes); Wharton School, University of Pennsylvania (policy and urban systems); Sinte Gleska University (land-use planning and values); and Prescott College (science visualization and delivery).

To complement its research in this area, the USGS also could foster relationships with organizations that focus on improving the integration of others' science into societal decisionmaking, such as the Congressional Natural Hazards Caucus, the National Council for Science and the Environment, and the Center for Science, Technology, and Congress (American Association for the Advancement of Science).

Finally, partnerships with practitioners provide the USGS with opportunities to better understand societal issues and needs and to apply techniques developed by the Geography Discipline. These partnerships can be developed at local and Federal scales and with organizations that represent them, such as the National Association of Counties, the League of Cities, the Urban and Regional Information Systems Association and the American Planning Association.

Highlight: Tahoe Decision Support System

Lake Tahoe, spanning the California-Nevada border in the Sierra Nevada Mountains, is famous for its alpine setting and deep, clear waters. During the last 50 years, human activity in the Lake Tahoe Basin has increased, and significant environmental disturbances have been observed and documented, including loss in lake clarity of about 1 foot per year. USGS scientists, working with the Tahoe Regional Planning Agency, the USEPA, and the Desert Research Institute, are developing the Tahoe Decision-Support System: a tool that will link agency decisions to a desired environmental, social and economic result within the lake basin. A prototype tool, completed in 2002, combined economic, natural science, and geographic analysis to illustrate some of the economic effects of current regulations that restrict urban development in order to control sediment runoff that can cloud the lake.

In the Tahoe decision support system (TDSS), the USGS is identifying links between several environmental thresholds, social conditions, and restoration activities in the basin. TDSS, which includes GIS-based land planning tools that consider socioeconomic and environmental effects of management strategies, will provide an optimization tool to identify alternative management strategies for meeting environmental objectives and analyze the consequences of these alternative future scenarios.

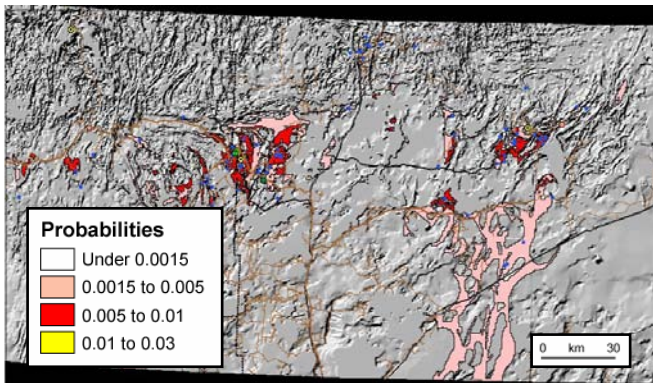
Table 1. Upper Truckee River watershed development scenarios – Tahoe Constrained Optimization Model results.

	Number of developed parcels	Annual sediment load	Value of development rights
Current situation	**1,657**	**63.6 tons**	**$1.65 mil**
Additional development of 200 parcels			
Minimize sediment load	1,857	63.8 tons	$1.81 mil
Maximize property value	1,857	68.9 tons	$2.07 mil
Developing 1657 parcels from scratch			
Minimize sediment load	1,657	21.1 tons	$1.54 mil
Maximize property value	1,657	47.9 tons	$2.19 mil

Highlight: Determining the Value of Higher Resolution Information in Mineral Exploration

Geologic maps are useful in a wide range of applications, including mineral exploration and development, environmental consulting, hazard prevention and protection, engineering applications, and city planning and land use. Finer map resolution and advances in mapping technology and geological understanding have increased the accuracy and precision of geological maps. While it is assumed that advances in technology benefit society, little research has been done to understand and assess the effects of changes in scale, resolution, and uncertainty of the information contained in these maps on addressing societal issues. Researchers from the USGS and the Geologic Survey of Canada analyzed the effect of map resolution on decisionmaking with a study that focused on mineral exploration in the mature Flin Flon and frontier South Baffin Island exploration regions of Canada. The research team developed an economic model that directly linked investment decisions to information contained in public bedrock geologic maps . Maps of different vintages and scales (1:63,360 and 1:125,000) for the regions were compared along with dimensions of estimated exploration efficiency, effectiveness, and risk. The value of the new, finer resolution information to the industry by comparing the exploration investment stimulated by the new information relative to the investment stimulated by an older, coarser resolution map. The model demonstrates that using a higher resolution map increases the efficiency and the effectiveness of the exploration. This results in an expected savings of millions of dollars.

A.) Fine-resolution Geologic Map



B.) Coarse-resolution Geologic Map

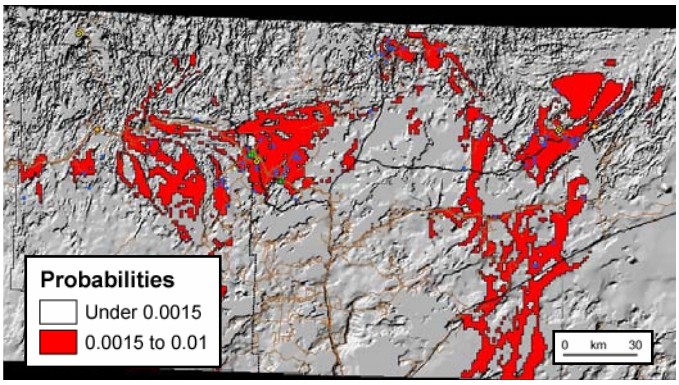


Figure 16. Probability of mineral potential using fine (A) and coarse (B) resolution geologic maps for the Flin Flon Region

Highlight: Monitoring Drought and Flood Hazards for Famine Early Warning Sub-

Saharan Africa is one of the world's most vulnerable regions in terms of food security. In an effort to lower the incidence of drought-induced famine, the U.S. Agency for International Development (USAID) established the Famine Early Warning System Network (FEWS NET). FEWS NET focuses on early identification of potential problems by providing timely hazard and vulnerability information to decisionmakers at the Office of Food for Peace, Office of U.S. Foreign Disaster Assistance, and partners in the international community. USGS researchers cooperate with other Federal agencies (NOAA, NASA, and USDA), university, and private-sector partners to model hazards, such as drought and floods, and provide decision makers with timely and accurate information regarding potential famine conditions. In 2003, FEWS NET directly supported decisionmaking at the Office of Food for Peace leading to the delivery of 3.1 million metric tons of grain valued at $2.2 billion.

Drought monitoring involves calculating a Water Requirement Satisfaction Index (see figure below), a spatially explicit indicator of crop performance based on adequacy of water supply to a rain-fed crop over the growing season. Inputs include satellite rainfall estimates, potential evapotranspiration, soil water-holding capacity, crop type, onset of rains, and length of growing season.

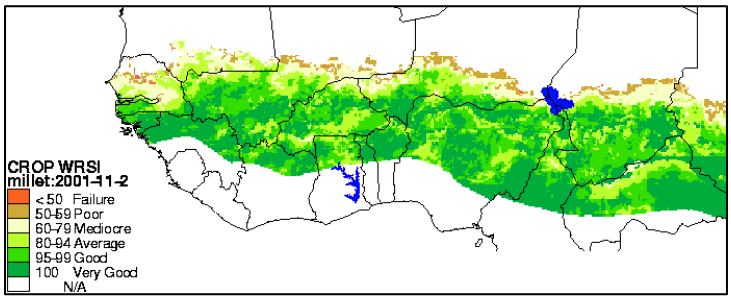


Figure 17a. Water Requirement Satisfaction Index results for millet in the West African Sahel for the 2001 growing season.

Flood modeling with the Geospatial Stream Flow Model requires satellite rainfall estimates, precipitation forecast grids, and digital elevation, soil, and land cover data to produce inundation maps, such as the map shown here. Inundation maps are used by emergency preparedness and response officials to identify localities at risk of flooding and to determine the location of safe zones where populations can move to avoid loss of life and property.

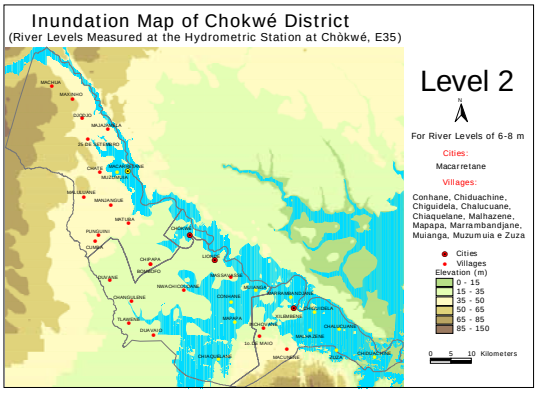


Figure 17b. Inundation map for the Chokwe District in Mozambique.

Operational Objectives

This plan defines science goals that direct Geography science efforts toward understanding landscape change and its consequences, and society's vulnerability to hazards. To stimulate progress in these efforts, several additional operational objectives are presented, including implementing a unified annual science planning process (Objective 4), strengthening the Discipline's science culture (Objectives 5-6), and increasing geography education activities (Objectives 7-8).

Annual science planning in the Geography Discipline

Objective 4: Develop a more efficient, focused process to guide the annual science planning.

The existing Geography Discipline annual science planning process lacks specificity in the guidance for continuing projects (including the principal investigator or project chief and the proposed allotment of money) and potential new projects, resulting in less accountability for determining which desired objective or outcome is most important, how these outcomes will be accomplished, and who will be responsible. Because these objectives and outcomes are not clearly mapped to program (i.e., 5-year plans), discipline, or Bureau priorities, there is no way to determine how well these objectives address the issues considered most important by the Bureau. Further, better coordination of Geography programs with other USGS programs is needed.

Outcome: Adoption a unified approach to annual science planning and a Geography Annual Science Plan that complements Bureau and Department plans.

The Geography Discipline will adopt a new, unified, annual planning process using an approach similar to that used by the Geology Discipline (featured in Highlight). The unified plan would include science opportunities and funding targets for all geography activities, mapped back to the goals of this science plan and the Director's annual guidance. This annual planning process is consistent with the Bureau's planning model and its principles:

- All Bureau planning is collaborative and integrates discipline capabilities to enhance science.
- All programs are Bureau programs, sharing in the success of Bureau science.
- Programs are responsive, flexible, and driven by scientific and customer needs.
- Headquarters and regions both play meaningful roles in program development, management, and implementation--these roles are complementary, not duplicative.
- Balance is maintained between standing commitments and new endeavors, between national and regional/local interests, and between long-term and short-term objectives.
- Risk-taking and innovation are promoted.

- Flexibility exists at appropriate levels to respond during the year to both national needs and regional/local needs.
- All participants are responsible for ensuring that planning is timely, efficient, and effective.

Strategic Action: Implement a unified annual science-planning approach for the Geography Discipline beginning in January 2005. Consult with the Geology Discipline in regard to design and approach.

Science Culture in the Geography Discipline

During the next 10 years, the Geography Discipline will complete a transition from emphasis on production-oriented, cartographic excellence to emphasis on being a full partner in the science activities of the USGS. While the cartographic accomplishments of the Geography Discipline over the last century have made important contributions in support of the science of the USGS, the Discipline's transition to a research and science partnership orientation (e.g., collaborating with other Disciplines to develop and test earth science knowledge claims and moving from describing landscape patterns to understanding why these patterns exist) will require an equivalent transformation in the Discipline's culture.

Success in this transition will require proactive participation in understanding earth science knowledge needs, creating knowledge to serve those needs, and successful development of a critical mass of researchers to support priority science issues and activities. The operational measures presented here will stimulate progress in attaining the science goals and provide a basis for evaluating progress in the transformation of the Geography Discipline.

Objective 5: Proactive participation of Geography Discipline scientists and managers in the Bureau's science activities and in the science activities of the broader community of geography and earth science researchers.

In general, the scientists and competencies of the Geography Discipline need to be better known and visible to scientists in other USGS Disciplines and external to the USGS and to increase participation in collaborative science efforts on behalf of the Bureau mission.

Outcome: Improved communication inside and outside of the USGS aimed at highlighting the competencies of Geography staff, identifying the science needs of potential collaborators, and establishing ongoing relationships with the geographic research community outside of the USGS.

Strategic Action: Publish an online annual directory of Geography Discipline staff that lists current primary project responsibilities, including a digital version that is searchable by keywords.

Strategic Action: Publish an online annual listing of all Geography discipline publications and conference presentations that is searchable by keywords.

Strategic Action: Seek or create constructive opportunities for Geography scientists to proactively communicate and interact with scientists outside of the Geography Discipline.

Strategic Action: Encourage participation by all Geography scientists at or above the GS-12 grade level in professional organizations.

Strategic Action: Use more vigorously the established outlets for communicating Geography science results, such as the Office of Communications, departmental highlights, congressional briefings, departmental briefings, and feature articles in the DOI magazine *People, Land, Water*.

Outcome: Establishment of a standing Geography Science Council in the Office of the Chief Scientist for Geography with representation from GGD programs, other USGS Disciplines, DOI bureaus, the AAG, and the National Research Council Earth Science Board.

A Geography Science Council (GSC) will contribute in several ways to the Geography Discipline's becoming a research and science-oriented partner of other USGS Disciplines. The primary function of the GSC is to serve as a sounding board and provide advice to the Associate Director and Geography senior staff about geography issues across the USGS. By increasing contact with a larger community of scientists with an interest in geography issues, the Geography Discipline will become more aware of important issues and collaborative opportunities. The council also can support senior Geography staff in several important leadership responsibilities, including making sure that Geography's interests and competencies are considered in the science planning of other Disciplines, providing a venue for ongoing recognition of strategic opportunities, and developing champions for Geography in government, industry, and universities.

Strategic Action: Establish the GSC in FY2005, with members from the Geography discipline programs, the other three USGS Disciplines, and several at-large representatives from DOI agencies, the AAG and the National Academy of Science.

Strategic Action: Convene a meeting of the GSC on an annual basis and distribute meeting notes electronically Discipline wide.

Objective 6: Attract and maintain a critical mass of geography researchers able to sustain a high level of excellence in work on the priorities identified in the science plan.

Specific recommendations have been given throughout this science plan about numbers

and expertise needed to achieve critical mass to support research excellence. The intent is to increase the intellectual capabilities and vitality of the Discipline in areas associated with the Discipline's science priorities. Strategic actions include provisions for targeted hiring of new researchers, a path for career advancement and professional development, temporary infusions of new intellectual energy as needed to accomplish strategic priorities, and provision of an infrastructure for publication logistics.

Outcome: Development of six centers of geographic excellence to provide a structure for focused hiring of new Ph.D. level researchers in the areas of GIScience, landscape change, regional geography, integration of natural and social science, remote sensing, and hazard-related vulnerability science.

In the context of this plan, centers of excellence can be thought of as groups of geography researchers possessing special knowledge or expertise in a particular area of concern identified in the science plan. These centers provide an atmosphere and resources for collaborative research to support the USGS mission, particularly in relation to geography science issues. These centers, and the collaboration they foster, are particularly important as the GGD transitions from a production to a science-research orientation. The centers provide a focal point and strengthen a sense of identity in the priority areas identified in the science plan. They also will be a resource to the USGS and DOI and will foster scientific networking among geographers in areas of special interest

The centers of geographic excellence will serve three specific objectives. Center scientists, working with other USGS scientists, will develop and implement a research agenda consistent with the overall priorities of the science plan and supportive of near-term science priorities of the Bureau. Center scientists will provide important support services, including providing technical assistance to other Bureau and DOI scientists, serving as points of contact for questions related to the center's subject area, and providing mentoring to Discipline scientists. Finally, center scientists will have primary responsibility for expanding the Discipline's science activities in substantive areas served by the centers.

Scientists affiliated with these centers need not all work in a single geographic location, although it is desirable that a core group of staff be collocated. Center activities, as described above, are not solely the domain of the center's scientists. Discipline scientists who are not directly affiliated with the centers but have an active interest in the themes addressed by a center can expect center scientists to serve as an important part of their extended intellectual community and that center staff will serve as collaborators and direct colleagues on some projects.

Each center will be staffed by new hires, primarily Ph.D. scientists, but others may be considered to meet specific science plan priorities. All staff scientists will be part of the research grade evaluation (RGE) system.

Strategic Action: Complete detailed strategic planning on the concept of the centers of excellence, focusing on defining the roles of the centers, how they operate organizationally, and how they relate to the USGS regions, programs, and other Geography Discipline centers.

Strategic Action: Complete a pilot version of the center concept for landscape change and regional geography, as part of the implementation of the Land Cover Institute.

Outcome: Increased use of the research grade (RGE) and equipment development grade (EDGE) evaluation systems by geographers, promoting excellence in geographic research and providing a path for career advancement.

The RGE program provides scientists with a career development path that is based on research accomplishments aimed at providing new knowledge and insights into varied and complex Earth-system processes. The emphasis of these research activities changes through time, reflecting the emergence of promising new areas of inquiry and the demand for new tools and techniques. Knowledge gained and methodologies developed by scientists in this program are intended to contribute to the USGS mission, support investigations and operations of other agencies, and help meet Earth-system knowledge needs of the general scientific community. Scientists who participate in the RGE program currently have a full performance level of GS-15.

The RGE and EDGE systems have not been widely used by geographers. A number of strategic actions designed to make these options more attractive to geographers have been identified by the SPT.

Strategic action: Publish clear examples of research accomplishments associated with all grade levels above GS-12, with examples drawn from the Geography Discipline. These examples should be consistent with Bureau RGE/EDGE policies and include examples of partial RGE/EDGE position descriptions.

Strategic Action: Provide appropriate training and mentoring as appropriate for geographers in the creation of research scientist records (RSR) used in the RGE/EDGE evaluation process. Provide a cross-walk between a scientist's 9-factor position description and a 4-factor research position description, and a preliminary assessment of how the scientist would rank in an RGE evaluation.

Strategic Action: Designate a person in the Office of Chief Scientist with formal responsibilities to coordinate, mentor, educate, and encourage geographers who have an interest in the RGE or EDGE programs.

Outcome: A well-trained, intellectually dynamic work force.

Success in the transition of the Geography Discipline from a production to a science focus will depend on the skills and enthusiasm of the Discipline staff, many of whom do not have formal training in areas that support the science goals identified in this plan. The Graduate School Training Program, in operation for more than 20 years, has been an effective means of supporting employees in gaining education beyond the bachelor's level. The program is intended to increase the general scientific, technical, and management skills of discipline

employees rather than to result in an employee receiving a degree. A number of employees in the Geography Discipline who participated in this program used it as a springboard to obtain, at their own expense, an advanced degree. The program has provided a path for some of the Discipline's most successful researchers and research managers to receive the skills needed to accomplish their jobs more effectively.

Strategic Action: Reinstate the Graduate School Training Program in the Geography Discipline to train scientists and science managers and enable them to acquire skills needed to transform the Discipline workforce.

Strategic Action: Encourage scientists who complete the Graduate School Training Program to enter the RGE program.

Strategic Action: As appropriate, allow employees who are taking courses as part of a structured skill-development program to take courses on work time.

Strategic Action: Develop and provide short technical courses that are focused on specific skill acquisition that will support the priorities identified in the science plan.

Outcome: An aggressive expansion of a Geography Discipline postdoctoral program that promotes the science priorities identified in this plan.

Postdoctoral researchers will enhance the skills and intellectual energy of the Geography Discipline and bring fresh views to problems that the discipline strives to solve. Postdoctoral candidates submit a research proposal that responds to a request to address a particular field of study or problem. Support for these programs may come from a variety of sources. Some organizations sponsor and offer their own postdoctoral programs (e.g., NOAA, NASA, and DOE Global Change fellowships and the USGS Mendenhall Postdoctoral Fellowship), while others participate in formal programs established by other organizations (e.g., the National Research Council's Postdoctoral Associateship Program).

Strategic Action: Evaluate and expand participation in the National Research Council Postdoctoral Associateship Program, in support of the science goals of this plan and under the guidance of the GSC.

Strategic Action: Evaluate and expand participation in postdoctoral programs developed in other USGS Disciplines and other organizations.

Strategic Action: Use the postdoctoral program to add expertise in socioeconomic systems to better complement existing strengths in understanding the driving forces of landscape change and to develop and assess estimates of societal vulnerability to hazards and the efficacy of mitigation strategies.

Outcome: Increased creative partnerships with the academic community.

Establishing strategic linkages with universities may be the quickest way to improve the Discipline's critical mass of geography researchers. The Discipline can collaborate with universities in a number of ways, including issuing grants to researchers with special skills or capabilities to accomplish priority research tasks; funding collaborative research by pairing university professors and researchers with GGD scientists to jointly complete priority research tasks; establishing informal communications with university colleagues to begin an evolving dialog that will someday lead to collaboration; hiring faculty as term or part-time USGS staff to work on projects that will benefit from their unique expertise; encouraging USGS staff to serve as adjunct faculty at area universities; encouraging scientist-to-scientist collaboration on outside-funded projects (such as National Science Foundation, NASA, and private granting institutions); and placing staff at universities and other Federal agencies as is done by the Biology Discipline's Cooperative Research Program.

Strategic Action: Prepare a strategy to implement university partnerships that support the science priorities in this plan. This will be accomplished by the Chief Scientist for Geography, with advice from the Geography Science Council.

Geography Education in the Geography Discipline

Every societal issue that falls within in the purview of the USGS mission has a geographic component. A sound understanding of geography is fundamental to addressing these issues. Geography's potential contributions to the USGS mission cannot be realized solely through geospatial data and research activities. Geography education is inextricably linked to data and research activities in the fulfillment of the USGS mission for several reasons:

- Even though most of the data collection and research activities at the USGS involve spatial phenomena and processes, the awareness and understanding of scientists and the public who use USGS science products are limited in regard to geography's tools and methods.
- This limited awareness also extends to another core competency of geography—a geographic perspective that claims that location matters, that a focus on location enables a cross-cutting way of looking at geographic processes and phenomena that define the character of a place, that understanding of a place must take into consideration the relation of that place with its surroundings, and that these issues usually have to be understood at multiple scales.
- USGS geographers have a collective professional responsibility to identify, articulate, and infuse core conceptual and methodological competencies of geography into education programs for both scientists and the general public.
- Geographically well-informed science colleagues and the general public are able to interact more productively with Geography Discipline scientists, use and understand the discipline's products more effectively, and find reasons to support the long-term viability of the Geography Discipline.

Objective 7: Expanded geographic awareness of scientists at the USGS and DOI.

Strategic Action: Complete needs assessment for basic and advanced geography education in the USGS and DOI.

Strategic Action: Develop basic and advanced geography courses to be given at the National Training Center in Denver in collaboration with university partners.

Strategic Action: Use *The National Map* to expand the awareness of geographic concepts, tool, and methods, including the implementation of tutorials on *The National Map* that allow users to explore basic geographic concepts using data in an area of their choice.

Strategic Action: Develop a strategic implementation plan to expand geographic awareness as one of the first assignments of the Geography Science Council.

Objective 8: Recognized national leadership in efforts to improve the geography competence of the U.S. general population and leaders in business, government, and non-governmental interest groups.

Strategic Action: Work with organizations such as AAG, American Geographical Society, the National Council for Geographic Education, and the National Geographic Society to understand geographic educational needs, particularly those associated with landscape change and its consequences.

Strategic action: Build on past geographic educational activities by working with six important groups: educators, government, non-governmental organizations and industry, news media, legislative branch, and internal USGS.

Highlight: Geology Discipline Annual Science Planning Approach

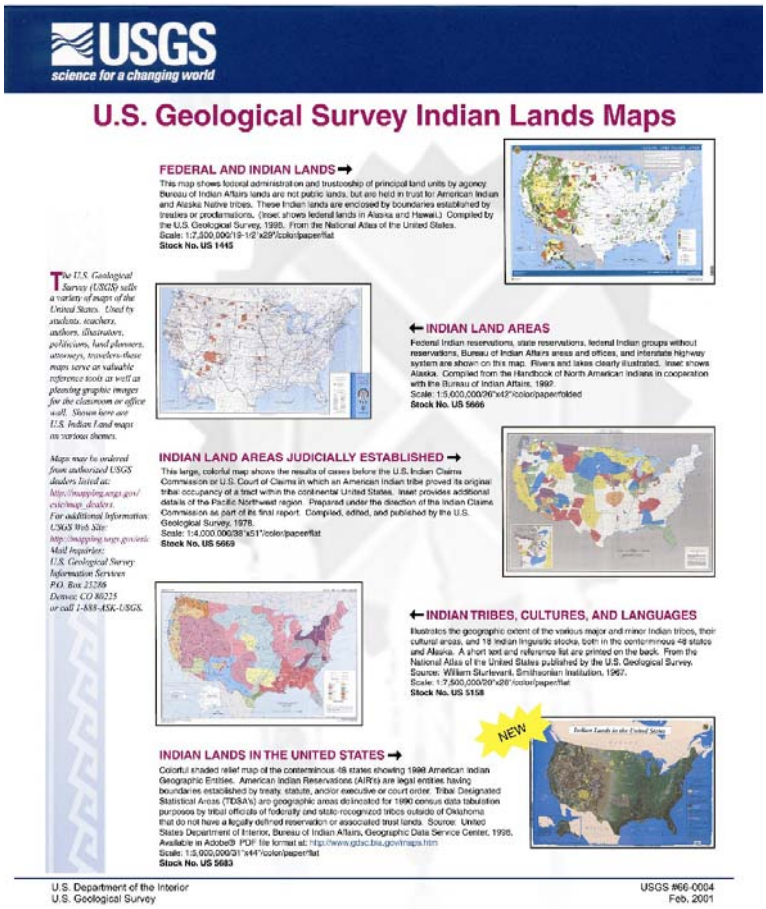
Three documents play a central role in Geology's annual planning approach: the Director's Annual Guidance (issued in February), the Bureau's Annual Program Direction (issued in April) and the Annual Science Plan for Geology (issued in the first week of May). The Director's Annual Guidance sets expectations for program directions in response to Department and Office of Management and Budget directives, congressional actions, and customer expectations. An assessment of these expectations is developed, in part, at the annual meeting of program coordinators and regional executives in the first quarter of the fiscal year. The Annual Program Direction provides additional details on priorities from a Bureau perspective and sets concise national and regional priorities, provides a platform for joint planning, and serves as a bridge between program and project development.

Once the Director's Annual Guidance Document is released, the regions and programs begin the joint process of setting priorities and funding targets for new areas of study and any major changes in program. Part one of the Bureau Annual Program Direction outlines new areas of study for integrated science, and funding targets, and contact information. Part two contains a narrative section describing major changes in programs. The Geology Discipline then releases its Annual Science Plan in early May which complements the Bureau Annual Program Direction. The Geology Annual Science Plan includes descriptions, contacts, and funding targets for new core work and continuing work in USGS geologic programs and is organized by the science goals and science objectives described in the Geology's Science Strategy (Bohlen and others, 1998). The descriptions of work for which new proposals are requested and guidance for ongoing project work are relatively brief, allowing readers to see the entire range of activities being undertaken by the programs and to gain an understanding of the relation of each project to the science goals. The Geology 2004 Annual Science Plan can be accessed at http://nc.water.usgs.gov/geog_spt/.

The development of the Geology Annual Science Plan involves a series of discussions among the regional geologists, program coordinators, the Associate Director for Geology, and team chief scientists. This discussion brings together work that has been done at the national and regional levels by managers and scientists, as well as workshops and meetings with other scientists and managers, stakeholders, partners, cooperators, and customers across regions and disciplines. All ongoing and new project work and results undergo peer and management review for progress toward meeting the goals of the science strategy. Also reviewed are the program accomplishments relative to the 5-year plan that directly supports the science strategy.

Highlight: Geographic Educational Partnerships with Native Americans

The education program staff has been actively working with Native Americans at many levels, including:



USGS
science for a changing world

U.S. Geological Survey Indian Lands Maps

FEDERAL AND INDIAN LANDS →
This map shows federal administration and trusteeship of principal land units by agency. Bureau of Indian Affairs lands are not public lands, but are held in trust for American Indian and Alaska Native tribes. These Indian lands are enclosed by boundaries established by treaties or proclamations. (Inset shows federal lands in Alaska and Hawaii.) Compiled by the U.S. Geological Survey, 1998. From the National Atlas of the United States.
Scale: 1:7,500,000/19-1/2"x29"/color/paper/flat
Stock No. US 1445

The U.S. Geological Survey (USGS) sells a variety of maps of the United States. Used by students, teachers, authors, illustrators, politicians, land planners, attorneys, travelers-these maps serve as valuable reference tools as well as planting graphic images for the classroom or office wall. Shown here are U.S. Indian Land maps on various themes.

Maps may be ordered from authorized USGS dealers listed at: http://mapping.usgs.gov/esic/map_dealers. For additional information, USGS Web Site: http://mapping.usgs.gov/esic/. Mail Inquiries: U.S. Geological Survey Information Services P.O. Box 25286 Denver, CO 80225 or call 1-888-ASK-USGS.

← INDIAN LAND AREAS
Federal Indian reservations, state reservations, federal Indian groups without reservations, Bureau of Indian Affairs areas and offices, and interstate highway system are shown on this map. Rivers and lakes clearly illustrated. Inset shows Alaska. Compiled from the Handbook of North American Indians in cooperation with the Bureau of Indian Affairs, 1992.
Scale: 1:5,600,000/26"x42"/color/paper/folded
Stock No. US 5666

INDIAN LAND AREAS JUDICIALLY ESTABLISHED →
This large, colorful map shows the results of cases before the U.S. Indian Claims Commission or U.S. Court of Claims in which an American Indian tribe proved its original tribal occupancy of a tract within the conterminous United States. Inset provides additional details of the Pacific Northwest region. Prepared under the direction of the Indian Claims Commission as part of its final report. Compiled, edited, and published by the U.S. Geological Survey, 1978.
Scale: 1:4,000,000/38"x51"/color/paper/flat
Stock No. US 5669

← INDIAN TRIBES, CULTURES, AND LANGUAGES
Illustrates the geographic extent of the various major and minor Indian tribes, their cultural areas, and 18 Indian linguistic stocks, both in the conterminous 48 states and Alaska. A short text and reference list are printed on the back. From the National Atlas of the United States published by the U.S. Geological Survey. Source: William Sturtevant, Smithsonian Institution, 1967.
Scale: 1:7,500,000/30"x28"/color/paper/flat
Stock No. US 5158

NEW

INDIAN LANDS IN THE UNITED STATES →
Colorful shaded relief map of the conterminous 48 states showing 1998 American Indian Geographic Entities. American Indian Reservations (AIR's) are legal entities having boundaries established by treaty, statute, and/or executive or court order. Tribal Designated Statistical Areas (TDSA's) are geographic areas delineated for 1990 census data tabulation purposes by tribal officials of federally and state-recognized tribes outside of Oklahoma that do not have a legally defined reservation or associated trust lands. Source: United States Department of Interior, Bureau of Indian Affairs, Geographic Data Service Center, 1998. Available in Adobe® PDF file format at: http://www.gdsc.bia.gov/maps.htm
Scale: 1:3,000,000/31"x44"/color/paper/flat
Stock No. US 5683

U.S. Department of the Interior
U.S. Geological Survey

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- Under the auspices of a Memorandum of Understanding between the USGS and Sinte Gleska University, the USGS has conducted GIS-related workshops for tribal officials, educators, and researchers at their facilities on the Rosebud Sioux Reservation in South Dakota.

- USGS staff have conducted workshops with Sinte Gleska University staff at conferences, such as the National Indian Education Association, and on our own.

- USGS staff has partnered with Sinte Gleska University in creating an online GIS course.

Next Steps

The USGS provides the Nation with reliable and timely earth science information that is used to minimize loss of life and property from natural disasters; to manage energy, mineral, water, and biological resources; to enhance and protect the quality of life; and to contribute to wise economic development and a sustainable future. This science plan describes how the Geography Discipline will carry out its share of this mission for the years 2005-2015.

Ten science goals will focus the research and science activities of the GGD over the next decade. The first four goals define future thrusts in a traditional area of international leadership for the USGS Geography Discipline--studies of landscape change:

1. **Increased knowledge of the status of the global land surface and how it is changing.**
2. **Improved understanding of the local, regional, national, and global drivers of landscape change.**
3. **Increased capability to forecast plausible landscape changes over the next 20-50 years.**
4. **Improved understanding of the environmental consequences of landscape change.**

Two goals will guide activities focused on understanding society's vulnerability and resilience to hazards:

5. **Increased understanding of societal vulnerability to hazards.**
6. **Improved scientific basis for mitigation, preparation, response, prevention, and recovery from natural and anthropogenic hazards.**

The final four science goals are associated with a traditional core competency of the Geography Discipline--Geographic Information Science (GIScience):

7. **Innovative methods to support intelligent access to large data sets associated with earth-science activities within and outside of the USGS.**
8. **Innovative methods for knowledge creation from and exploitation of geographic data.**
9. **Innovative use of models to distill and synthesize geographic data to create new knowledge.**
10. **Timely availability of relevant, complete, consistent, and accurate geographic data that support the USGS mission, including the integration and certification of data from others and production of data when no other sources are available.**

This science strategy will be implemented by the Associate Director and the Chief Scientist for Geography, the Regional Geographers, and the GGD Program Coordinators. To learn more about Geography Discipline activities visit the GGD's World Wide Web site at http://geography.usgs.gov/ .

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