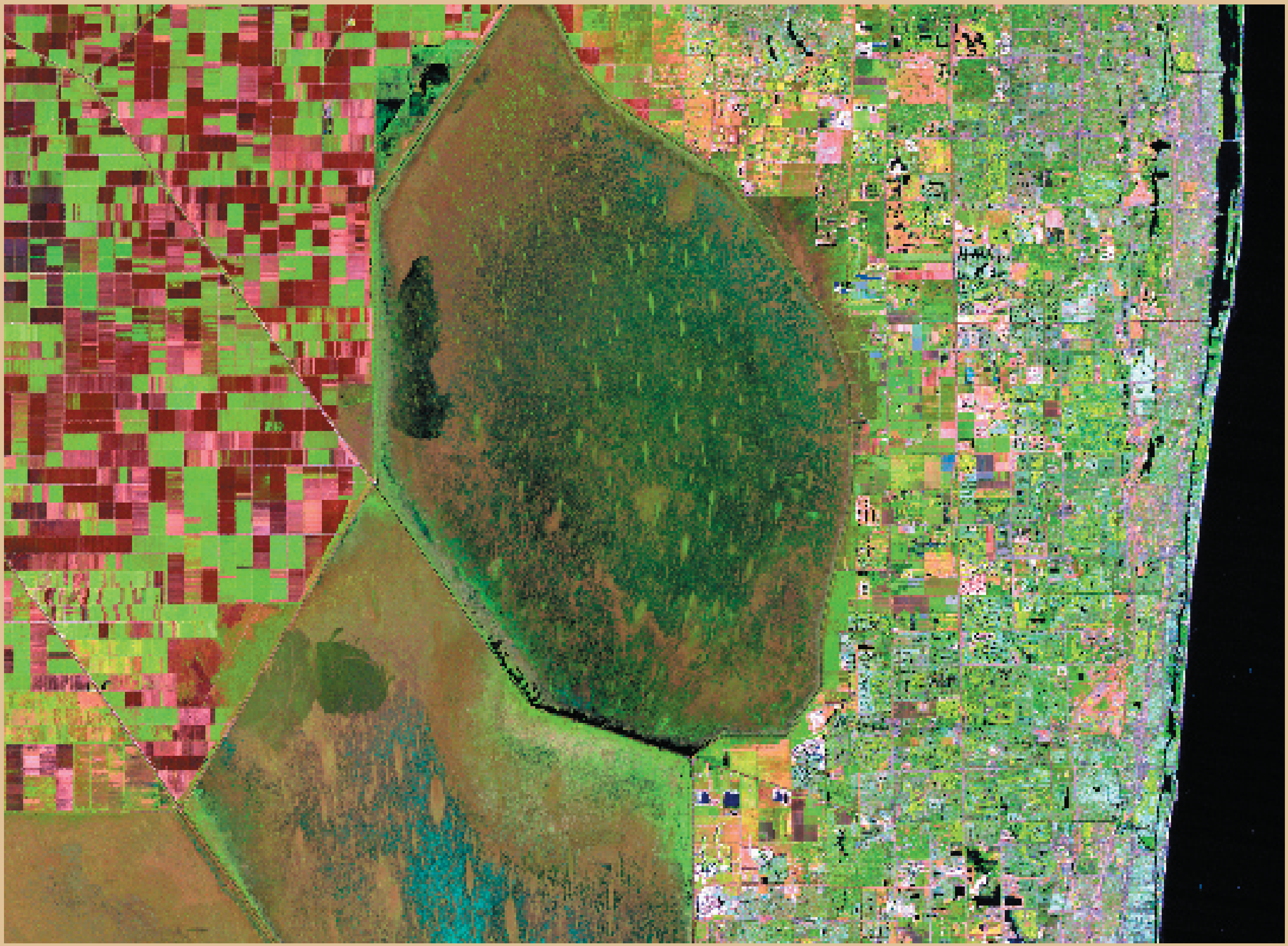
Geography for a Changing World

A Science Strategy for the Geographic Research of the U.S. Geological Survey, 2005-2015



Circular 1281

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On The Cover

The challenges for society and environment that are created through human use of land and water resources are exemplified in this U.S. Geological Survey (USGS) image developed for Florida Everglades restoration (Jones and others, 2003). Created from a winter 2000 Landsat image, patterns within this single view strikingly illustrate human transformation of the land surface for agriculture, commerce, flood prevention, water use, and biological resource conservation. Specifically, the image shows a portion of southeast Florida where the urban coastal area interfaces with the rural interior. The image shows an area extending along the Atlantic Ocean coast from Lake Worth on the north (top) to Pompano Beach on the south. The eastern portion of the image shows the dense urban development common along the southeast Florida coast that requires water control infrastructure for flood control and water supply. The lineations crossing the image diagonally are canals and drains. The three segmented dark areas are water conservation areas retaining some of their natural surface configuration. Light streaks in the conservation areas are tree islands rising above surrounding wetland vegetation and open water. The checkered area on the west (left) side of the image is the Everglades Agricultural Area.

What drives such human modification of land surfaces? At what rate do changes occur? How do these modifications affect other environmental processes or alter society's vulnerability to natural hazards such as drought or floods? What tools are needed to answer these questions and most appropriately communicate our understanding to those who guide resource decisionmaking? The USGS geography science strategy presented in this document provides the foundation for addressing these important societal questions.

Geography for a Changing World

A Science Strategy for the Geographic Research of the U.S. Geological Survey, 2005-2015

By Gerard McMahon, Susan P. Benjamin, Keith Clarke, John E. Findley, Robert N. Fisher, William L. Graf, Linda C. Gundersen, John W. Jones, Thomas R. Loveland, Keven S. Roth, E. Lynn Usery, and Nathan J. Wood

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Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

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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. They charged the SPT with creating "a succinct strategy to define, organize, manage, and grow the scientific activities of the Geography Discipline over the next 10 years (2005-2015), within the broad outlines of the USGS Strategic Plan." The SPT's primary objective was to develop a strategy for USGS geography science 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 for geographic science at USGS.

In developing this science strategy, the SPT reviewed the USGS Strategic Plan, other USGS discipline plans, and recent external reviews 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 175 people, including scientists and managers from the USGS and 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, Calif., Sioux Falls, S. Dak., Rolla, Mo., and Denver, Colo.) provided SPT members with perspectives on the opportunities and potential science priorities during the next 10 years.

The input provided the foundation for defining 9 interrelated science goals and 6 operational objectives. By undertaking the scientifically challenging and vital research activities outlined in this science plan, the USGS will attend to the Nation's most pressing science issues that are consistent with the USGS mission and that are likely to benefit from the unique perspective and methods of the field of geography.

The SPT extends sincere thanks to the many contributors to 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, capabilities, and the enormous dedication of USGS geographers. We look forward to the consideration and implementation of this science plan.

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Executive Summary

This report presents a science strategy for the geographic research of the U.S. Geological Survey (USGS) for the years 2005-2015. The common thread running through the vision, mission, and science goals presented in the plan is that USGS geographers will provide national leadership to understand coupled human-environmental systems in the face of land change and will deliver pertinent information to decisionmakers on the vulnerability and resilience of these systems. We define land change science as the study of the human and environment dynamics that give rise to changed land use, cover, and surface form.

A number of realities shape the strategic context of this plan:

- The Department of Interior Strategic Plan focuses on meeting society's resource needs and sustaining the Nation's life support systems, underscoring the importance of characterizing and understanding coupled human-environmental systems.

- In redefining its mission in the mid-1990s, the USGS envisions itself as an integrated natural science and information agency. The USGS will assume a national leadership role in the use of science to develop knowledge about the web of relations that couple biophysical and human systems and translate this knowledge into unbiased, reliable information that meets important societal information needs.

- The following trends will influence USGS geography-oriented science activities over the next decade. Most of the emerging earth science issues that the USGS will address are geographic phenomena. A growing international concern for aligning society's development activities with environmental limits has led to an articulation of a science agenda associated with global environmental change, vulnerability, and resilience. Earth science investigations have evolved toward the study of very large areas, and the resulting huge volumes of data are challenging to manage and understand. Finally, scientists and the public face the challenge of gaining intelligent insights about geographic and environmental processes from these data, with the ultimate goal of guiding resource-management decisions.

The first four science goals in the plan support understanding the human and environmental dynamics of land change. Each science goal has an associated set of strategic actions to achieve the goal. These goals and actions are consistent with national science priorities and the Department of Interior and USGS missions, take advantage of existing expertise, and lead to the strengthening of critical geographic research capacities that do not exist in other USGS disciplines.

Goal 1: Characterize and quantify land surface status and trends to provide a framework for understanding change patterns and processes from local to global scales.

- **Strategic Action 1.1:** Establish a center of excellence focusing on land change science.

- **Strategic Action 1.2:** Expand global capabilities to map and measure land cover and land-cover change at multiple scales that are locally relevant yet globally consistent.

- **Strategic Action 1.3:** Determine how much of the annual national and global land changes result from natural and human influences.

- **Strategic Action 1.4:** Establish an operational global ecosystem monitoring system that continuously measures and characterizes the current status of ecosystem goods and services to estimate and explain deviations from normal conditions.

- **Strategic Action 1.5:** Establish a consistent, repeatable methodology that identifies the changes in the topographic form of the Nation at appropriate intervals.

- **Strategic Action 1.6:** Develop and implement a strategy that leads to a clearer understanding of the characteristics and changes in the urban environment.

- **Strategic Action 1.7:** Develop spatially explicit reconstructions of the land use and land cover of the North American landscape to provide the context and baseline for future resource management and public policy.

Goal 2: Identify local, regional, national, and global drivers of land change to forecast plausible land change scenarios over the next 20-50 years.

- **Strategic Action 2.1:** Establish an ongoing capability of assessing the social, economic, political, technological, and environmental influences on land change.

- **Strategic Action 2.2:** Conduct studies on the geographic variability of the types of responses associated with specific drivers (such as globalization, new technology, and policies) on land change and determine how those responses operate at different scales.

- **Strategic Action 2.3:** Validate the theoretical basis of land-use change by using data from landscape-dynamics research.

- **Strategic Action 2.4:** The USGS researchers will partner with the scientists outside of USGS in developing land change simulation models.

Goal 3: Understand past, present, and future environmental consequences of land change to support better management of their effect on people, environment, economy, and resources.

- **Strategic Action 3.1:** Conduct research on the consequences of land change on climate, water, carbon cycle, ecosystems, invasive species, and societal concerns.

- **Strategic Action 3.2:** Conduct research on specific consequences of land-use and land-cover patterns and changes for environmental health and public safety issues, particularly at the boundaries between developed and wildland areas.

- **Strategic Action 3.3:** 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.

- **Strategic Action 3.4:** Conduct research on the feedbacks between land change and environmental systems and resources.

Goal 4: Improve the scientific basis for vulnerability and risk assessment, mitigation, response, and recovery related to the human and environmental dynamics of land change.

- **Strategic Action 4.1:** Establish a center of excellence focusing on vulnerability and resilience science and the integration of science with decisionmaking.

- **Strategic Action 4.2:** Investigate effects of land-use and land-cover change, such as urbanization and resource use, on creating hazards and human-environment system vulnerability.

- **Strategic Action 4.3:** Improve research capacity to model vulnerability and resilience to natural and anthropogenic hazards.

- **Strategic Action 4.4:** Improve understanding of the influences of societal perceptions, policies, and land-use practices on societal vulnerability and resilience.

- **Strategic Action 4.5:** Develop and implement a monitoring program that provides perspectives at multiple scales of vulnerability and resilience to adverse land change.

- **Strategic Action 4.6:** Develop and apply innovative geographic and economic methods to assess the effects of proposed scenarios for hazard mitigation strategies and risk management.

- **Strategic Action 4.7:** Provide innovative geographic methods and techniques to help secure the safety of the Nation in emergency response and recovery efforts.

Accomplishing these first four science goals will require a sustained investment in the geography-related core competencies of the USGS: integration of natural and social science (transmitting science results to decisionmakers and the public in forms that are useful for promoting the welfare of the Nation); regional geography (applying the concepts and tools of geography to understand processes and interactions characteristic of regions); remote sensing (comprehensive monitoring of the Earth at multiple resolutions); and GIScience (geographic information systems, data management techniques, visualization, remote sensing, and spatial statistics and modeling). The last five science goals in the science plan address these core competencies.

Goal 5: Develop credible and accessible geographic research, tools, and methods to support decisionmaking related to the human and environmental consequences of land change.

- **Strategic Action 5.1:** Establish a science and decisionmaking focus within the vulnerability and resilience science center of excellence.

- **Strategic Action 5.2:** Improve our understanding of the motivations and processes used by decisionmakers to manage and adapt to land change.

- **Strategic Action 5.3:** Develop innovative and effective mechanisms for identifying needs and opportunities for science to support decisionmaking.

- **Strategic Action 5.4:** Develop a national toolbox of metrics, indicators, models, and decision support systems that characterize the environmental, social, and economic consequences of land change.

- **Strategic Action 5.5:** Conduct multidisciplinary case studies to support environmental policy analysis and hazard risk-reduction efforts.

- **Strategic Action 5.6:** Develop and apply methods for examining the value, format, and transfer of knowledge for societal decisionmaking and policy analysis.

Goal 6: Develop and test hypotheses about the use of geographic regions to understand the human and environmental dynamics of land change.

- **Strategic Action 6.1:** Include a regional geography emphasis within the land change science center of excellence.

- **Strategic Action 6.2:** Take a leadership role in working with the USEPA, States, and other Federal agencies in completing the USEPA Level IV Ecoregion framework.

- **Strategic Action 6.3:** Provide ongoing assistance to scientists in the USGS and DOI in the development and use of regional frameworks.

- **Strategic Action 6.4:** Conduct research to answer questions associated with four priority issues related to regional frameworks: regional identity, regional boundaries, hierarchical relations, and regional ecosystem functioning.

- **Strategic Action 6.5:** Use a hierarchical local-regional-national-global approach to improve understanding of the phenomena and processes that cause land change.

- **Strategic Action 6.6:** Articulate a set of scaling rules for describing the mechanisms of land change that can be used for generalizing local study findings to larger scales.

- **Strategic Action 6.7:** Establish regional data observatories and archives in conjunction with USGS programs, the NSF Long-Term Ecological Research (LTER) Network, National Ecological Observatory Network (NEON), the National Acid Precipitation Program, NOAA, NASA, and other organizations that collect earth-science and biological data.

Goal 7: Observe the Earth at all scales using remote sensing to understand the human and environmental dynamics of land change.

- **Strategic Action 7.1:** Survey the requirements of the DOI, USGS, other government agencies, and the international remote sensing community for environmental data and monitoring, and define the remote sensing capabilities needed for current and future applications.

- **Strategic Action 7.2:** Investigate new technologies for Earth observation and define the specifications for the remote sensing capabilities needed to meet current and future Earth observation and monitoring requirements.

- **Strategic Action 7.3:** Undertake an aggressive role in the development and continuation of the Nation's participation in the Global Earth Observation System of Systems (GEOSS).

- **Strategic Action 7.4:** Consolidate and convert the Nation's vast and dispersed historical aerial photography into an electronically accessible USGS remote sensing archive in a format that enables studies of the Earth's land-cover/land-use history.

- **Strategic Action 7.5:** Develop a plan for the preservation of USGS remote sensing archive data that ensures the long-term availability of those data to support science investigations.

- **Strategic Action 7.6:** Conduct research on advanced data access and mining capabilities that leads to robust use of the USGS remote sensing archive for the purpose of gaining knowledge about the Earth's dynamic history at multiple scales and temporal periods.

- **Strategic Action 7.7:** Conduct research that leads to the calibration of all appropriate USGS remote sensing assets.

- **Strategic Action 7.8:** Define and test protocols for determining the uncertainty, accuracy, and precision of products derived from USGS remotely sensed data.

- **Strategic Action 7.9:** Define the analytical methods needed to make better use of data from current and future remote sensing instruments for accurate measuring and mapping of landscape properties, including land-cover status, ecosystem services, and surface form.

- **Strategic Action 7.10:** Establish training and outreach activities that provide technical advice and support needed to incorporate USGS remote sensing capabilities into the DOI and USGS programs and projects.

Goal 8: Provide timely, intelligent access to new and archived USGS geographic data needed to conduct science and support policy decisions.

- **Strategic Action 8.1:** Establish a GIScience center of excellence.

- **Strategic Action 8.2:** Improve understanding of *The National Map* user needs, both inside and outside of the USGS.

- **Strategic Action 8.3:** 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 8.4:** Research and develop design and symbolization specifications and innovative methods that support *The National Map* viewer and other geographic data displays on a large variety of display devices.

- **Strategic Action 8.5:** Research and develop automated methods for generalization to support multiple-scale display and delivery of *The National Map* and other USGS geographic data.

- **Strategic Action 8.6:** Build a critical mass of USGS scientists familiar with and able to exploit new developments in spatial data mining and knowledge discovery in supporting *The National Map* and other large spatial databases.

- **Strategic Action 8.7:** Develop specifications and analytical methods and tools for use in producing widely used, high-priority data layers for *The National Map*.

Goal 9: Develop innovative methods of modeling and information synthesis, fusion, and visualization to improve our ability to explore geographic data and create new knowledge.

- **Strategic Action 9.1:** Address research questions on the topic of information synthesis and fusion.

- **Strategic Action 9.2:** Address research questions on the topic of map and geographic database projections.

- **Strategic Action 9.3:** Address research questions on the topic of geographic visualization.

- **Strategic Action 9.4:** Research and develop methods and techniques in modeling and geostatistics to exploit geographic data.

During the next 10 years, the focus of USGS geography activities will change from an emphasis on production-oriented cartographic excellence to an emphasis on research as a full partner in USGS science efforts. The transition to a research and science emphasis will require a transformation of the USGS geography culture. Key objectives of this transformation include vigorous leadership, research-oriented science management, effective communication, focused growth in the addition of researchers, an effective annual science planning process, and the use of education to increase the understanding and use of geography to serve the USGS and DOI missions. Six operational objectives will stimulate progress in attaining the science goals and provide benchmarks for evaluating progress in the transformation of the geography culture at USGS.

- **Objective 1 –** Greatly enhance the leadership on behalf of research-based geography at USGS.

- **Objective 2 –** Increase the number of experienced, competent geography science managers that are excited about and committed to managing scientists on behalf of the science plan priorities.

- **Objective 3 –** Communicate and highlight the competencies of USGS geographers, identify the science needs of potential collaborators, and establish ongoing relationships with the geographic research community outside of the USGS.

- **Objective 4 –** Develop and implement a USGS geography workforce plan that supports a critical mass of geography researchers able to sustain a high level of excellence in research and applications on behalf of the priorities identified in the geography science plan.

- **Objective 5 –** Develop a more efficient, focused process to guide the annual science planning.

- **Objective 6 –** Expand geographic awareness of scientists at the USGS and DOI.

This plan charges the USGS with developing sound scientific approaches that will support assessments of land change and its human-environmental consequences, create innovative GIScience tools and methods for the entire USGS, and enhance the benefits of USGS science for decisionmaking. The science described in this plan addresses large, compelling challenges. The successful accomplishment of the plan requires engaging multiple disciplines in the physical, biological, and social sciences, considering the entire land area of a large Nation, and recognizing that the Nation's changing landscape must be considered in a global context.

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NRC Board of Earth Science and Resources

LIST OF ACRONYMS

AAG – Association of American Geographers
BLM – Bureau of Land Management
CEOS – Committee on Earth Observation Satellites
CRADA – Cooperative Research and Development Agreement
DEM – Digital Elevation Model
DHS – Department of Homeland Security
DOI – Department of the Interior
EDGE – Equipment Development Grade
EDC – Earth Resources Observation System (EROS) Data Center, USGS
ESD – Earth Surface Dynamics Program
FEMA – Federal Emergency Management Agency
FEWS NET – The Famine Early Warning Systems Network
FWS – U.S. Fish and Wildlife Service
GEO – Group on Earth Observation
GeoMAC – Geospatial Multi-Agency Coordination
GEOSS – The Global Earth Observation System of Systems
GIMMS – Global Inventory Monitoring and Modeling Studies
GIO – Geographic Information Office
GIS – Geographic Information System
GPS – A Global Positioning System
GSC – Geography Science Council
IGOS – International Global Observation Strategy
IR – Infrared
NSDI – National Spatial Data Infrastructure
LIDAR – Light Detection and Ranging
LTER – Long-Term Ecological Research
MODIS – Moderate Resolution Imaging Spectroradiometer
MSS – Multispectral Scanner
NAS – National Academy of Sciences
NASA – National Aeronautics and Space Administration
NAWQA – National Water-Quality Assessment Program
NDVI – Normalized Difference Vegetation Index
NEON – National Environmental Observatory Network
NGA – National Geospatial-Intelligence Agency
NGPO – National Geospatial Programs Office
NHD – National Hydrography Dataset
NLCD – National Land-Cover Database
NOAA – National Oceanic and Atmospheric Administration
NPS – National Park Service
NRC – National Research Council
NRS – National Refuge System
NSDI – National Spatial Data Infrastructure
NSF – National Science Foundation
RGE – Research Grade Evaluation
RSR – Research Scientist Record
SPT – Science Planning Team
TM – Thematic Mapper
UCGIS – University Consortium for Geographic Information Science
USAID – U.S. Agency for International Development
USDA – U.S. Department of Agriculture
USEPA – U.S. Environmental Protection Agency
USGS – U.S. Geological Survey
WBD – Watershed Boundary Dataset
WWF – World Wildlife Fund
3-D – Three-Dimensional

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Introduction

How will urban, suburban, and exurban development over the next 50 years affect biodiversity management throughout the National Refuge System?

Given that climate changes of the past 300 years have occurred at the same time as rapid agricultural development, what are the relative effects of climate change compared to the human activities on regional, continental, and global landscapes?

How do humans affect the rates and spatial patterns of the spread of harmful, non-indigenous species and pathogens such as tamarisk, non-native fishes, and West Nile virus?

How do different land-use patterns and regulatory scenarios potentially affect the risk of property losses in earthquake-prone areas?

What are the environmental and social changes arising from the multiple uses of Federal public lands, and how do these uses affect the sustainability of coupled human-environmental systems?

What are the ecosystem indicators of threats to the overall integrity of human and environmental systems?

Each of these questions falls within the scope of the U.S. Geological Survey (USGS), whose mission includes science leadership and excellence directed at describing and understanding the Earth; minimizing losses of life and property from natural disasters; managing water, biological, energy, and mineral resources; and enhancing the quality of life (U.S. Geological Survey, 2000). The questions also are inherently geographic, focusing on the evolving character of the Earth's surface, the ways in which natural and social phenomena and processes interact to create unique places, and on the influence that local places have on a broader temporal and spatial realm.

Geographic variability and the spatial interaction of natural and social processes are fundamental characteristics of the world, and our understanding of the world is incomplete without careful analysis of this variability and interaction. Geographic research improves this understanding by (1) providing a place-based perspective focused on understanding places, (2) considering flows of matter, energy, commodities, people, and ideas between places, (3) integrating knowledge from multiple disciplines or fields to understand the places and their interconnections, and (4) using unique geographic tools ranging from maps to spatial visualization and data mining tools.

Geographic understanding is not defined by any single subject or discipline, such as the case for geology (the science of the earth), biology (the science of life), or hydrology (the science of water). Rather, geography is a science that defines itself by its approach, somewhat like history. History offers understanding of the world by examining the variation of phenomena through time. Geography offers understanding of the world by explaining variation across space. Geography is the science of place and space, an intellectual enterprise that emphasizes the interaction between nature and society by focusing on the characteristics of places or regions, the spatial connections between places, and the variation of social or natural phenomena across scales of analysis (National Research Council, 1997). Because of its particular world view, geography is a logical partner for geology, biology, and hydrology. As a discipline, geography often is integrative, combining the insights of other disciplines and facilitating their investigation with special analytical tools and perspectives.

Geography lies at the heart of the intellectual traditions that support the USGS mission as the Department of Interior's (DOI) primary science agency. This science plan presents a vision for geographic research at the USGS during the decade 2005-2015 by describing nine specific goals that contribute to the vision and mission of the USGS (see Sidebar I-1). For each science goal, the plan identifies a series of strategic actions and linkages and partners for achieving the actions and provides performance measures for judging progress.

The common threads running through the vision, mission, and goals are that USGS geography researchers will provide national leadership to understand coupled human-environmental systems in the face of land change, and they will deliver pertinent information on the vulnerability and resilience of these systems to decisionmakers (see Sidebar I-2 for definitions of key terms). Geographers will lead USGS research associated with the human and environmental dynamics of land change, regional geography, remote sensing, and GIScience (geographic information systems, data management techniques, visualization, and spatial statistics) needed to support land change research. Geography researchers also will provide leadership for cross-discipline integration of the many streams of USGS research, so that the knowledge developed about coupled human-environment systems provides a complete, functional view of the systems.

For example, USGS biologists will benefit from forecasting models for land change that support assessments of future biodiversity prospects in wildlife refuges. GIScience will enhance the creation and implementation of *The National Map* by focusing on fusing information from multiple scales and the use of interactive, dynamic visualization tools to examine multivariate geospatial data sets. USGS geologists who assess the spatial extent and probability of volcano hazards will see the value of their hazard assessment work extended by linking these assessments with an understanding of societal vulnerability, such as the potential property value loss arising from various land management scenarios. Finally, hydrologists will benefit from assessments of land change trends that influence streamflow and water quality. Collaboration with USGS biologists, geologists, and hydrologists, and with scientists from other DOI bureaus, university-based scientists, and scientists from national and international science organizations must be a hallmark of USGS geographic research activity in the next decade.

The remainder of this chapter describes a framework for geographic research at the USGS. Subsequent chapters discuss strategic opportunities for USGS geographic research, the research framework for understanding the influence of land change on human-environmental systems, and science goals associated with core geographic competencies needed to support research on coupled human-environmental systems. The final chapter reviews operational objectives that will enhance the likelihood of success in the plan's implementation.

Sidebar I-1: USGS geography research framework, 2005-2015

Vision: The USGS will lead the Nation in advancing geographic science by improving and expanding earth observation and by integrating natural and social science knowledge for more informed decisionmaking.

Mission:

1. Understand the human and environmental dynamics of land change.
2. Provide leadership in sustaining the Nation's core geography competencies: regional geography, the integration of natural and social sciences, and GIScience, including modeling and remote sensing of earth systems.
3. Develop and apply innovative methods to understand and improve linkages between science and decisionmaking.
4. Establish creative and synergistic partnerships nationally and globally to create new knowledge, leverage resources, and support the geographic mission of the USGS.

USGS geographic science goals for the next 10 years:

1. Characterize and quantify land surface status and trends to provide a framework for understanding change patterns and processes from local to global scales.
2. Identify local, regional, national, and global drivers of land change to forecast plausible land change scenarios over the next 20-50 years.
3. Understand past, present, and future environmental consequences of land change to support better management of their effect on people, environment, economy, and resources.
4. Improve the scientific basis for vulnerability and risk assessment, mitigation, response, and recovery related to the human and environmental dynamics of land change.
5. Develop credible and accessible geographic research, tools, and methods to support decisionmaking related to the human and environmental consequences of land change.
6. Develop and test hypotheses about the use of geographic regions to understand the human and environmental dynamics of land change.
7. Observe the Earth at all scales using remote sensing to understand the human and environmental dynamics of land change.
8. Provide timely, intelligent access to new and archived USGS geographic data needed to conduct science and support policy decisions.
9. Develop innovative methods of modeling and information synthesis, fusion, and visualization to improve our ability to explore geographic data and create new knowledge.

Sidebar I-2: Key science plan terms

Coupled Human-Environment System: This term refers to the interactions between human and environmental systems. It includes the study of the interrelations of people and biological-biophysical-biogeochemical processes, and how their modifications feed back to global environmental changes to affect the sustainability of the overall system. Coupled human-environment system research recognizes that the choices people make about land use depend on the complex interactions between demographic, socio-economic, institutional, physical, biogeochemical, and biological factors.

GIScience: Provides information about *places* on the Earth's surface, knowledge about *where* geographic features are located, and knowledge about *what* is at a particular location.

Hazard: An agent or process of land change that has the potential to harm individuals, societies, and natural resources. Natural or human-induced hazards can manifest themselves as sudden perturbations or slowly increasing stresses beyond the normal range of variability in a system.

Land Change: Land change science is the study of the human and environment dynamics that give rise to changed land use, cover, and surface form. This analysis includes understanding changes in land attributes (for example, type, magnitude, and location) and the effects of those changes on society, the environment, and resources.

Regional Geography: Provides a cross-cutting way of looking at processes and phenomena characteristic of a region, 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 among regions).

Resilience: Ability of a system to mitigate or adapt to potential hazards, as well as respond and recover from effects after an event.

Vulnerability: Potential for loss or damage. The vulnerability of human-environment systems is defined not only by exposure to hazards (both perturbations and stressors) but also in the sensitivity and resilience of the system.

A geography research framework for the next decade

Over the next decade implementation of a USGS geographic research agenda will support a four-part mission to:

1) Understand the human and environmental dynamics of land change;

2) Provide leadership in sustaining the Nation's core geography competencies needed to understand land change dynamics–GIScience, remote sensing, regional geography, and the integration of natural and social sciences;

3) Develop and apply innovative methods to understand and improve linkages between science and decisionmaking; and

4) Establish creative and synergistic partnerships nationally and globally to create new knowledge, leverage resources, and support the geographic mission of the USGS.

The USGS geography mission is aligned with national science priorities that stress the importance of understanding land change and its consequences as part of a coupled human-environmental system (National Research Council, 1995; 1997; 2001a; 2001b; 2002; 2003a; 2003b; Turner and others, 2003; Rindfuss and others, 2004). By providing the basis for well-informed decisions about pressing societal issues in the coming decades, geographic research will support the overall USGS mission, particularly the emphasis on developing integrated knowledge and tools to support the science needs of decisionmakers and citizens. The proposed research activities also build on areas of current USGS geography expertise and, when the plan is completely implemented, it will place geographers in the mainstream of the USGS tradition of science excellence, leadership, and impact.

Land change and human-environmental systems

The fundamental objective of USGS geographic research is to understand the dynamics of land change associated with biophysical systems (such as land-cover, climate, invasive species, volcanoes) and human systems expressed as land use (science goals 1 and 2). This effort requires an understanding of change as part of a coupled human-environmental system (Turner and others, 2003; Rindfuss and others, 2004). Research associated with this science goal occurs in a conceptual framework that links the occurrence, causes, and consequences of land change with human and environmental vulnerability and resilience in the face of change (science goals 3 and 4; fig. 1).

Core competencies

Successful research efforts to understand the human and environmental dynamics of land change (science goals 1, 2, 3, and 4) require a high level of competency in selected aspects of geography's intellectual traditions and methods. Important competencies include the integration of natural and social sciences to support decisionmaking (science goal 5), regional geography (science goal 6), earth observations using remote sensing (science goal 7), and the provision of geographic data, imagery, and knowledge derived from these data (science goals 8 and 9).

Support decisionmaking about coupled human-environment systems

Information developed by USGS science activities has been used for 125 years to assist management decisions related to hazards, the environment, and natural resources. In the next century, policymakers and the general public will require multi-disciplinary, integrated information that sheds light on the operation of the general coupled human-environmental system, and particularly its land-change component.

Partnerships

As demands grow for objective, science-based knowledge about the rates, causes, and consequences of land change and budgets stagnate for most governmental and non-governmental science activities, the USGS will need to develop a sustainable research infrastructure that leverages limited resources to maximum effect. This infrastructure must, as a matter of routine, include procedures and relationships to enhance

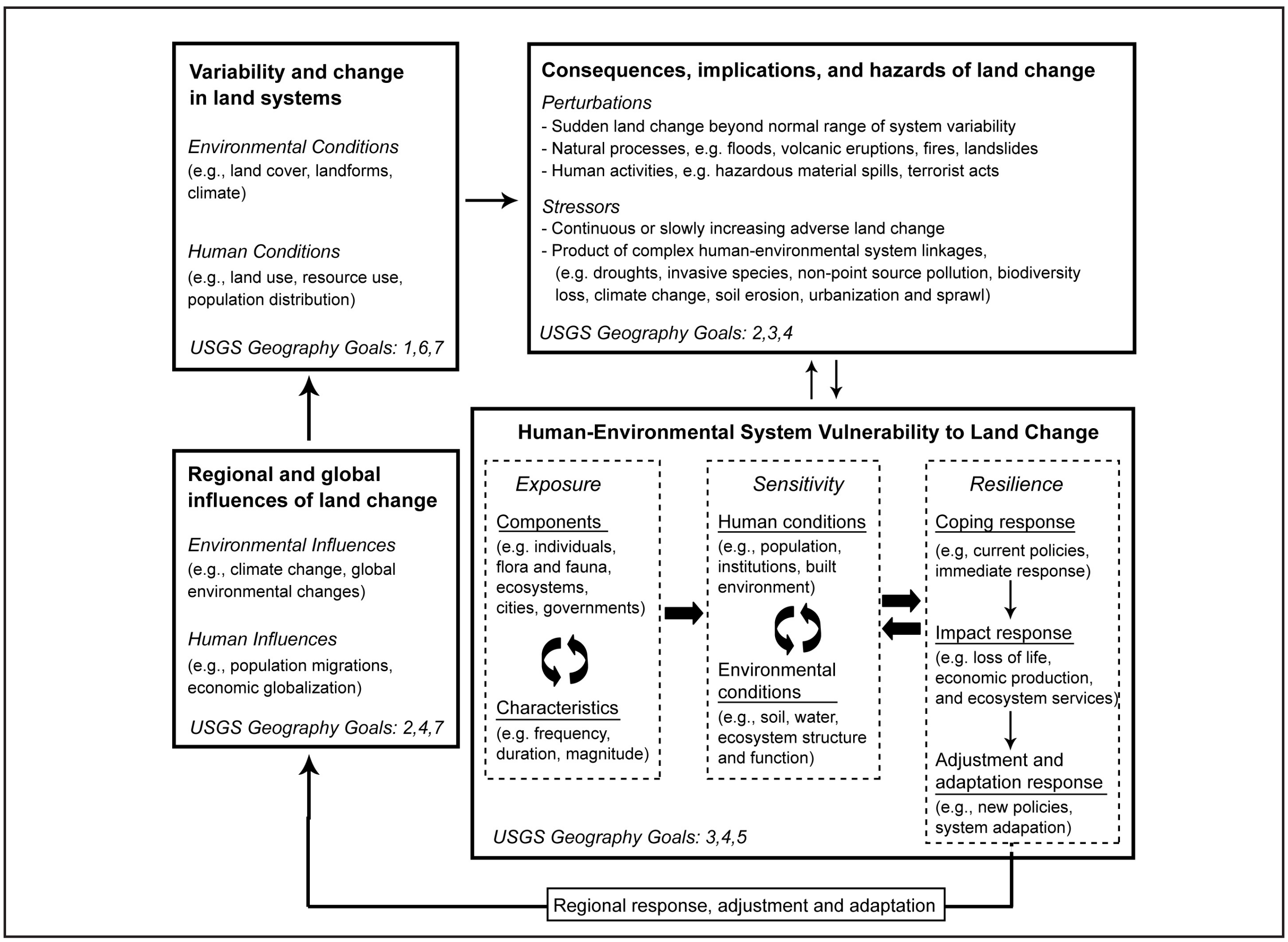


Figure 1. Coupled framework for assessing land change, vulnerablility, and resilience (adapted from Turner and others, 2003).

collaboration among scientists and stakeholders inside and outside the USGS. Collaboration must occur throughout the entire course of science investigation, from identification of underlying issues through the design and implementation of the science activities.

Realizing this research vision

USGS geography science activities during 2005-2015 will focus on understanding coupled human-environmental systems in the face of land change and on providing information on the vulnerability and resilience of these systems to decisionmakers. These efforts will be supported by providing leadership in sustaining the Nation's core geography competencies in the integration of natural and social sciences, regional geography, remote sensing, and GIScience. By the end of this 10-year period, successful implementation of the plan will result in the recognition of USGS geographers as world leaders and valued science colleagues in the areas targeted by this plan. The remainder of this plan provides additional details about the science goals and associated strategic actions.

This research-oriented mission and the associated science goals and actions are intentionally ambitious, given that USGS geography activities for most of the last century have focused on data creation rather than research-based knowledge development. Implementation of this science plan is intended to bring geography into the mainstream of the USGS tradition of science excellence, leadership, and impact (National Research Council, 2002; Highlight 1). Growing the research culture needed to support this ambitious research mission will require leadership that focuses on these science goals with a passionate commitment to excellence. It also will require a critical mass of geography researchers that can build a tradition of geography research excellence and leadership.

Three centers of excellence will serve as the primary vehicles for developing a critical mass of researchers around the priority general research themes (land change science, vulnerability and resilience science, and GIScience including remote sensing). The centers will be primary engines in the growth of a geographic research culture at USGS, providing a focal point and sense of identity for researchers in these priority areas. Center scientists, working with other USGS scientists, will develop and implement a research agenda consistent with the overall priorities of the science plan. Important responsibilities of center scientists will include providing technical expertise to other USGS and DOI scientists, serving as contacts for questions related to the center's subject area, and providing mentoring for young researchers. Scientists affiliated with these centers may work in different geographic locations, although it will be desirable that a core group of researchers be collocated. USGS scientists who are not directly affiliated with the centers but who 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. Centers will be staffed by focused new hires and current USGS scientists. All center scientists will be part of the USGS research grade evaluation (RGE) system.

The Geography Science Planning Team (SPT) recognizes that the number of centers is likely to evolve into a larger number over the 10-year planning period to accommodate the growth of research activities and staff. A logical evolution would include the development of separate centers focusing on vulnerability science, integration of science and decisionmaking, GIScience, and remote sensing.

Highlight 1: Connecting Our Past and Revitalizing Our Future

Research on coupled human-environmental systems in the face of land change represents a substantial philosophical and operational evolution in emphasis for USGS geographers from their course in recent decades. This evolution results in a set of responsibilities 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 as much as one-half of the USGS's 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 1990s, provided a geographic foundation for scientific investigations of the USGS geology, biology, and water disciplines.

During the 20th century, while USGS geographers were building a foundation of data to serve science, USGS geologists, hydrologists, and biologists (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 1950s became widely used outside the USGS, with emphasis on the spatial dimensions of natural and social processes and the connections between nature and society.

Highlight 1 *(cont.)*

When Arch Gerlach and James Anderson began building the USGS's remote sensing and land-cover analytic capabilities during the 1970s, 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).

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 land 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 land change, hazards, vulnerability, and resilience represents an opportunity to recapture the intellectual spark and make an important contribution to the success of the USGS mission.

Geographic research and the USGS mission

Geography provides a powerful world view; it is the science of space and place, distributions and patterns, networks, connections, and flows – all explored at a variety of temporal and spatial scales (National Research Council, 1997, 2002; Hanson, 2004). Geographers seek to understand the vertical characteristics (such as, the interactions of physical, biological, social, and cultural processes occurring in a place) that define a place as well as the horizontal connections between places. In this place-based framework, geographers focus on the relations and dependencies among the processes that define the identity of a place.

Geographers also rely on the synthesis of information developed by the natural and social sciences to understand the interactions among economic, cultural, and biophysical processes that shape the identity and sustainability of a place. Geographic research in this vein is oriented toward understanding how human actions modify or transform the environment and, conversely, how changes in the biophysical environment affect humans. By understanding how land change and human welfare are interconnected and how the risks of adverse consequences are perceived by the public and by decisionmakers, geographers also can assess options to mitigate adverse environmental or societal effects arising from land change, including hazards.

Geographers also depict, manage, represent, and analyze spatial data. Geographic research produces practical tools to monitor and represent spatial phenomena and relationships, facilitate access and use of these data, and create new knowledge from these spatial data. Remote sensing, for example, allows the observer to see the earth in ways that cannot be seen directly with the human eye, revealing patterns and connections among environmental systems that otherwise would be hidden. Other GIScience research supports traditional mapping activities related to managing, modeling, and representing geographic data, phenomena, and processes, as well as spatial statistics, geospatial visualization, and data mining, which are methods that are becoming essential for earth-science applications and research that focus on spatial patterns and distributions, networks, and diffusion and distance decay.

Strategic issues and opportunities for USGS geographic sciences

Geography's research and analytical capabilities are well suited to address strategic science issues faced by the USGS during 2005-2015. The four mission responsibilities defined in the DOI Strategic Plan (2003) provide a general strategic context for geographic research at USGS. The development and application of scientific knowledge should meet the resource needs of society (resource use, recreation) while sustaining the life support systems of the Nation (resource protection, serving communities). The characterization and understanding of the vulnerability and sustainability of coupled human-environmental systems are integral to addressing these DOI concerns.

Following the redefinition of its mission in the mid-1990s, the USGS envisions itself as an integrated natural science and information agency, assuming a national leadership role in using science to develop knowledge about the web of relations that couple biophysical and human systems and in translating this knowledge into unbiased, reliable information that meets important societal needs (National Research Council, 2002). Four trends will influence USGS geography-oriented science activities over the next decade. First, most, if not all, of the emerging earth science issues that the USGS will address must be studied as geographic phenomena, with location acting as a primary parameter associated with research and data (National Research Council, 1997). Second, a growing international concern for aligning society's development activities with environmental limits has led to an articulation of a science agenda associated with global environmental change, vulnerability, and resilience (Clark and Dickson, 2003). Third, earth-science investigations have evolved toward the study of very large areas (such as nations, continents, and the globe), and the resulting huge volumes of data are challenging to manage and understand. Finally, scientists and the public face the challenge of gaining intelligent insights about geographic and environmental processes from these data to guide resource-management decisions.

Future directions for geography at the USGS

Describing and understanding the relation between humans and the environment is a central focus of current monitoring, research, and applications at USGS (such as monitoring biodiversity and earthquake magnitude, assessing flood frequency and the recurrence of volcanic activity, and creating and testing hypotheses about the relation of land use and water quality). Many of these science activities rely on expertise and understanding from a single discipline. While this science often is conducted at a high level – representing national and international leadership – the outcomes of these many discipline-specific streams of research often are not blended to develop an integrated perspective on important societal concerns.

Multi-discipline integration has been a growing focus of USGS geographers over the last decade and will be a major focus for the next decade. In the next 10 years, USGS geographers will provide national leadership in understanding how coupled human-environmental systems respond to change. USGS geographers also will provide pertinent information on the vulnerability and resilience of these systems to decisionmakers. Additionally, USGS will assume national leadership in geographic core competencies in regional geography, the integration of natural and social sciences to support decisionmaking, and GIScience—including remote sensing. These emphases are responsive to national strategic opportunities, and they are consistent with the priorities for USGS science described in a series of reports by the National Research Council (National Research Council, 2001a; 2002; 2003b).

Partners

The success of this science plan will require USGS geographers and managers to assume responsibility for identifying and incorporating partners in the planning and execution of science activities (Sidebar I-3). The greatest synergy will occur when there is a broad understanding of the objectives and scientific priorities of all disciplines in the USGS, necessitating initiative, communication skills, and good will among the participants. An important objective of this collaboration is to avoid duplication of efforts and redundant investments.

Sidebar I-3: Current and potential science partners for geography at the USGS

***Other USGS disciplines*.** The U.S. Geological Survey Strategic Plan (2000) identified the need for the agency to integrate and coordinate scientific investigations, particularly at the planning and research-design stage. Geography researchers are poised to facilitate the integration of USGS scientific information and help provide scientific results to decisionmakers in a way that can be readily used. USGS geographers have an important role in providing accurate, current geospatial data, particularly associated with elevation, hydrography, and land cover, in a timely manner. *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* requires extensive GIScience research.

***Other U.S. Department of the Interior (DOI) Agencies*.** As the primary 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 Bureau of Reclamation, 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 land changes; accessing up-to-date geospatial data regarding roads, park boundaries, land cover, and vegetative cover, particularly in remote areas; accessing 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 national parks, monuments, and wildlife refuges.

***Other Federal Agencies*.** USGS geographers have 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,

Sidebar I-3 *(con't.)*

U.S. Environmental Protection Agency (USEPA), 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 USGS science initiatives for regional decisionmaking processes. The USGS Geospatial Information Office's (GIO) National Spatial Data Infrastructure (NSDI) partnership offices, which are usually collocated with other USGS discipline offices, can help ensure that USGS science objectives reflect an understanding of local and regional issues and that collaborative efforts reflect mutually beneficial objectives. Partnerships with local customers can enhance communication between USGS geographers 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. To realize these benefits, communication and coordination between NSDI partnership staff and geography program coordinators must be strengthened.

Academia. USGS geographers do 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 USGS science goals, geographers will need access to cutting-edge research techniques and facilities that may not exist within the USGS. Simultaneously, academic geographers can gain a better appreciation for the educational needs of USGS employees.

Private Sector. The USGS has fostered strong partnerships with the private sector through cooperative research and development agreements (CRADA) and other agreements in the production and distribution of maps. In order to serve the Nation better, the USGS 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. USGS geographers must continue to improve their 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, geographers 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 USGS 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, represent new areas of opportunity for integrating the geographic perspective into the earth and biological sciences. Technical societies, such as the American Society of Photogrammetry and Remote Sensing and the Cartographic and Geographic Information Society, also are important potential venues for USGS 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. USGS leadership and participation in international characterizations of land cover and elevation can contribute to the development of national economic and security policies.

Goal 1: Characterize and quantify land surface status and trends to provide a framework for understanding change patterns and processes from local to global scales.

In 2015, land-use and land-cover changes arising from human activities and variations in atmospheric, hydrologic, and biological systems provide many benefits and improve the quality of life for humans. Unfortunately, the changes also jeopardize the sustainability of many ecosystems, as well as the goods (such as food and construction materials) and services (such as cleaning and recycling water and essential nutrients) that ecosystems provide. The USGS Land Cover Institute routinely monitors and assesses land-cover change at local to global scales and provides definitive information required by researchers and decisionmakers around the world to understand how the types, patterns, and changes in land cover affect valuable and endangered ecosystems. Geographers at the Land Cover Institute provide national and international leadership by defining, monitoring, and explaining the changes, as well as by providing aid in assessing management goals and objectives. The Institute makes the critical connection between data and the analysis that provides the added value of geographic explanation. The resulting information, developed using a "locally relevant and globally consistent" philosophy, allows resource managers to understand the changes, anticipate threats to resources and the environment, develop management strategies, and assess the effectiveness of their plans.

Land change is one of the critical science issues of the 21st century and is perhaps the most important scientific issue rooted in the discipline of geography. Science agendas established by national (for example, National Research Council, 2001a, 2001b; Climate Change Science Program, 2003) and international (for example, International Geosphere Biosphere Program, 1999) organizations have called for acceleration of land change research. Land change is a pivotal issue 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 and is a major responder to climate change (Gutman and others, 2004). Land change directly affects water resources and their management, and alters the habitat for valued species. The foundation of land change studies are descriptions of the status and trends of land cover, land use, and surface form. Such data are essential if we are to understand almost any aspect of land change, including its causes and consequences. Documenting land surface status and trends involves monitoring and mapping to integrate information from personal observation, remote sensing, field inventories and surveys, and spatial models. Land change research also integrates regional geographic perspectives and insights from ecology, climatology, hydrology, geology, urban planning, and other disciplines.

Understanding land change issues also requires a perspective that spans local to global scales. Land change is perhaps the most noticeable form of global environmental change because it occurs locally. The effects of local land changes are cumulative and attain a global importance because of their outcomes in the global ecosystem (Turner and Meyer, 1991). Improved information and understanding of local and global land attributes are essential to our ability to successfully mitigate and manage the effects of land change on human and environmental systems.

Strategic Science Actions

The first step in land change science is to characterize the status and trends of key land attributes (such as type, condition, and patterns) that affect human-environment systems. Critical research questions about land status and trends include:

- What are the current patterns and attributes of land use and land cover at national to global scales that affect the carbon cycle, atmospheric processes, and ecosystem structure and function?
- What are the regional, national, and global rates, patterns, and characteristics of contemporary land-use and land-cover change?
- Where are the current areas of land-use and land-cover change at national and global scales?
- Why do these changes occur in specific ways and in particular locations or regions?

To address goal 1 and answer these questions, USGS geographic research must be expanded by taking several strategic actions. These actions collectively will contribute to a USGS geographic monitoring infrastructure that provides the information needed by scientists, resource managers, and the public considering land change problems.

Strategic Action 1.1:
Establish a center of excellence focusing on land change science

The research outlined here, as well as the research associated with goals 2, 3, and 6, requires a team of established researchers to develop plans, conduct critical studies, make national assessments, and synthesize regional and topical information. This group, organized within the framework of a center of excellence, will provide the leadership to establish real-time monitoring capabilities, working across the USGS to identify and capitalize on research opportunities. Research activities of the center also will benefit from the geographically distributed nature of the USGS, with its regional science centers, dispersed staff, and regional expertise.

The USGS will receive high returns from a relatively modest investment. A center with a minimum of 10 geographic researchers can affect a far-reaching cultural transformation of geography in the USGS and provide the Bureau and its scientists with core intellectual resources related to land change. The center will promote research synergism, provide a focal point for collaborating with external scientists, and foster a culture of research excellence and high productivity.

Sidebar 1.1: Establishing a land change science center of excellence

Linkages:
A land change science center will be an interdisciplinary endeavor. The center will be founded with strong links to the land change research found across the USGS but also must connect with interagency activities in the Climate Change Science Program. Links with NASA on earth observation issues, USEPA on statistical indicators, and U.S. Department of Agriculture (USDA) on a range of forestry and agricultural land topics are particularly important. Academic participation must be planned from the onset in order to ensure that the goals of the center reflect the best practices and capabilities of the land change science community.

Performance Measures:

- A USGS land change center of excellence is established (*within 1 year*).
- The center is staffed initially with 10 Ph.D. scientists with support staff (*within 2 years)* and expanded to 20 scientists (*within 5 years*).
- An international symposium on land change science opportunities and challenges is held and used to form the science strategy for the center (*within 2 years*).
- A land change science plan is prepared and approved by USGS (*within 2 years*).
- Partnerships with key Federal and academic organizations are formalized (*within 2 years*).
- A research strategy and implementation plan is prepared for developing comparable land-cover data for the period 1970 to the present (*within 3 years*).
- A strong focus on regional geography is included (see Goal 6 discussion).

Strategic Action 1.2:
Expand global capabilities to map and measure land cover and land-cover change at multiple scales that are locally relevant yet globally consistent.

The USGS already has a substantial investment in large-area land characterization, with a capability to map the land use and cover of the Nation and to assemble the elevation data needed to understand changes in land surfaces. The USGS is an international leader in global land cover and elevation mapping, but has not invested adequate research resources in this topic to take advantage of the resulting products for knowledge-building research. To meet science goals, USGS geographers must develop a "locally relevant and globally consistent" program for characterizing land-cover change at multiple scales. This strategy must recognize the diverse requirements of land change applications and provide increasingly more accurate and detailed land attributes needed to address current and future applications.

Strategic Action 1.3:
Determine how much of the annual national and global land changes result from natural and human influences.

Managing land change requires understanding the extent of natural variability and natural land disturbances resulting from wildfires, floods, and other natural events, as well as changes caused by human activity. In many cases, land changes result from combinations of natural and human influences, necessitating sophisticated analysis to understand the relative contributions of each causal mechanism. Understanding and explanation depend on research to document the full extent of natural and human disturbances at global and national levels. The required information is a product of an ongoing land monitoring strategy that provides the identification of types and trends of disturbances and that leads to meaningful land management policies.

Strategic Action 1.4:
Establish an operational global ecosystem monitoring system that continuously measures and characterizes the current status of ecosystem goods and services to estimate and explain deviations from normal conditions.

The USGS must develop a multi-disciplinary suite of ecosystem health and productivity indicators that can be used to assess ecosystems throughout the Nation and globally. Resource managers must continually update management strategies to balance short-term, multiple uses of ecosystems with long-term sustainability goals. A global monitoring system will provide near real-time information enabling resource managers and resource-assessment experts to confidently make informed policy and management decisions. Global capability is a requirement because it is only at the global scale that ecosystem influences on climate become clear along with critical biological connections such as migration patterns, biodiversity threats, and invasive species effects.

Strategic Action 1.5:
Establish a consistent, repeatable methodology that identifies the changes in the topographic form of the Nation at appropriate intervals.

Periodic assessments of the changes in the Nation's topography and land cover every 5-10 years will employ advanced topographic mapping and monitoring methods. Understanding the characteristics of a changing surface form and the links between changing land use, land cover, and surface form is an important element of understanding the overall causes and consequences of land change.

Strategic Action 1.6:
Develop and implement a strategy that leads to a clearer understanding of the characteristics and changes in the urban environment.

The urban and built-up landscape offers a particularly unique challenge to land change studies. An urban land-change monitoring program that places local and regional urban growth in a national perspective will give policymakers and planners a framework for clarifying and prioritizing the effects on economic development, environmental quality, and quality-of-life objectives. A strategy to combine sampling and mapping in a regional geographic framework will permit better understanding of the differences in land change issues by region, city size, and function, providing the basis for a full assessment of urban environmental issues.

Sidebar 1.2: Establishing science-driven land status and trends characterization

Linkages:
USGS geographers have an outstanding track record in large-area land-cover analysis and topographic characterization. Improving the capabilities will require a strong research agenda that draws from remote sensing and GIScience goals (7, 8, and 9). Expanding this capability also will require partnerships with NASA and NOAA on earth observation technologies and strategies. Creation of useful science priorities depends on cooperation with the Climate Change Science Program Land-Use and Land-Cover Change Interagency Working Group. The Federal Multi-Resolution Land Characterization consortium will play an important role in defining research and mapping objectives. Additional important cooperators include such programs as the Global Observation of Forest Cover/Global Observation of Landcover Dynamics and the United Nations Food and Agriculture Organization Global Land-Cover Facility.

Performance Measures:

- A strategy for global land-cover mapping and change analysis is designed and tested (*within 2 years*) and operational (*within 5 years*).
- Annual assessments of the overall extent of land change, as well as a determination of the extent of natural compared to human-induced change, are made for the Nation (*within 5 years*) and the globe (*within 10 years*).
- Near-time assessments of indicators of key ecosystem goods and services are made for the Nation (*within 3 years*) and the globe (*within 6 years*).
- A strategy for measuring the extent of surface form change is designed and tested (*within 2 years*) and becomes operational (*within 5 years*).
- The requirements for an urban monitoring system are defined and a monitoring system is designed and tested (within 2 years), and is followed by system implementation (*within 5 years*).

Strategic Action 1.7:
Develop spatially explicit reconstructions of the land use and land cover of the North American landscape to provide the context and baseline for future resource management and public policy.

Changes that have occurred in the past provide the context for understanding contemporary and future land changes. Historical disturbances and settlement patterns directly affect current environmental processes. For example, carbon fluxes that affect atmospheric chemistry and the global carbon budget are literally rooted in the land management practices of the past that affected soil carbon accumulation, vegetation age structures, and total biomass. Reconstruction of the land-use and land-cover history of North America requires close cooperation between USGS geographers and scientists from other USGS disciplines. The history must 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.

Sidebar 1.3: Developing the land-use and land-cover history of North America

Linkages:

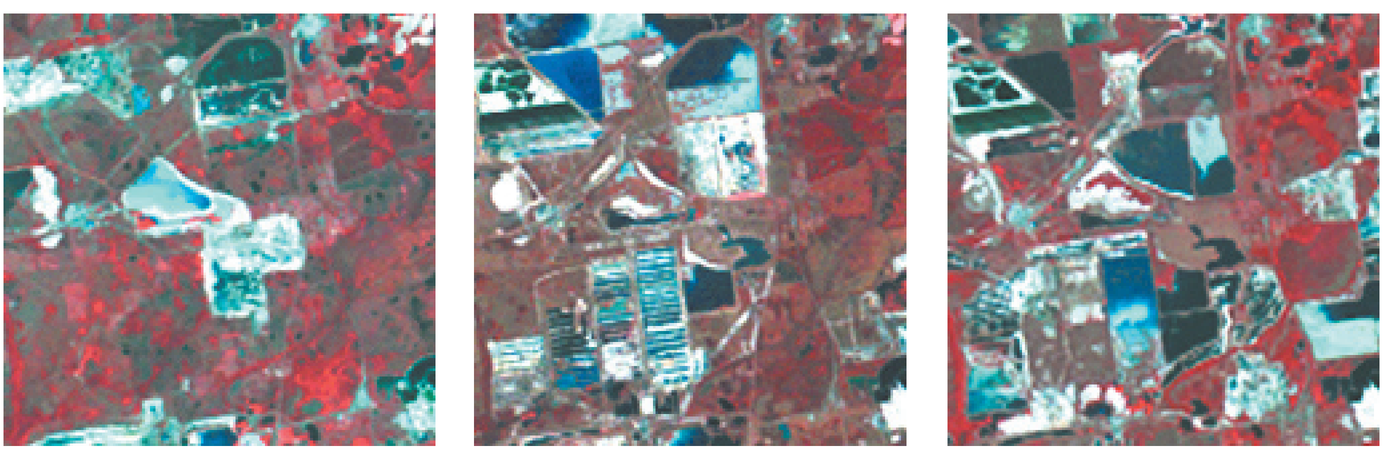
Experiences gained in the Land-Use History of North America initiative establish a starting point for creating a land-use and land-cover history of North America. The history from case studies and synoptic investigations will necessitate a broad consortium of partners, including those in the USGS with considerable biologic, geologic, and hydrologic expertise, and similar specialists from academia and non-governmental organizations.

Performance Measures:

- A meeting of experts is used to establish objectives and scope for a land change history (*within 1 year)*.
- A comprehensive and spatially explicit North America land-use and land-cover history is completed (*within 6 years*).

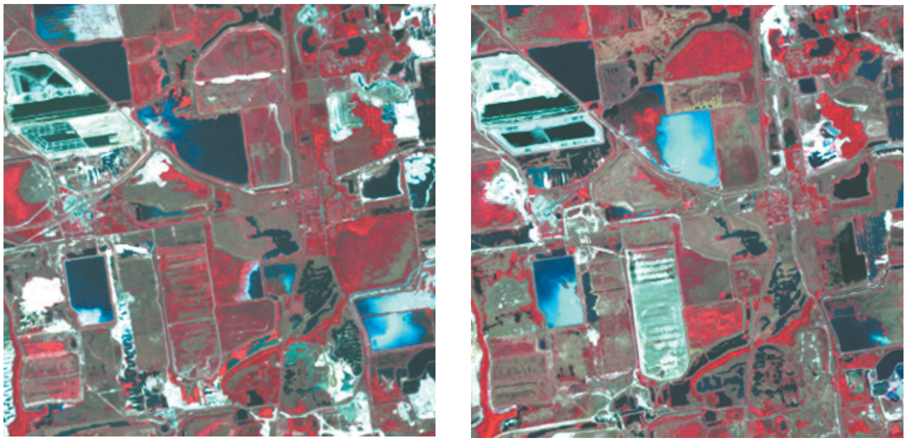
Highlight 2: Monitoring the Cycle of Land-Cover Change

The Landsat record is the longest continuous record of the globe in existence. Five Landsat images (fig. 2) covering a 10-kilometer (km) by 10-km phosphate mining area near Lakeland, Florida illustrate the value and advantages of Landsat data for monitoring land change. From the vantage point of more than 700 km above the Earth, remote-sensing instruments onboard six Landsat satellites have provided a synoptic historical record of the cycle of land-cover changes taking place from 1973 to 2000. The five images offer false color renditions of the process of land change in which the original pastures and grasslands (shown in mottled red tones in the 1973 image) were converted to active phosphate mines (white areas in the 1979 image), water-filled mine pits (blue and black colors in the 1986 and 1992 images), and to reclaimed land (smooth pink colors in the 2000 image). During the 27-year period of observation, nearly 80 percent of the land in this area changed. Measurements and maps of change, essential elements for investigations of the causes and consequences of change, are possible because the USGS, working in concert with NASA, provides leadership and technical and scientific expertise for global Earth observation.



1973 1979 1986

Figure 2. Changing land cover near Lakeland, Florida.



1992 2000

Goal 2: Identify local, regional, national, and global drivers of land change to forecast plausible land change scenarios over the next 20-50 years.

By 2015, the USGS will use knowledge gained from studies of the historical and contemporary driving forces of land change to project possible changes 20 to 50 years into the future. In 2015, the USGS will be the primary Federal agency providing insights into the Nation's future land change scenarios and the possible effects of those changes. Understanding the agents or driving forces that stimulate land change will provide the foundations of this predictive capability. This understanding of the drivers of change will come about because an expanded USGS capability to merge social and natural sciences will create new understanding of the connections between changes and their drivers.

The USGS will provide decisionmakers with assessments of the likely outcomes of various policy options. More specifically, USGS research will provide decisionmakers with knowledge of the rates and types of land changes that can be expected given changes in specific drivers (such as technology, economics, policy, and legislation). In 10 years, USGS models for predicting land-use and land-cover changes will provide decisionmakers and scientists with objective projections given plausible scenarios of change at local, regional, and national scales. This predictive capability contributes directly to assessments of the potential consequences of future changes of the Nation's economy and environment.

Simulation models that generate realistic projections of change for future periods are critical tools for managing the consequences of land change. Models allow decisionmakers and resource managers to illuminate possible outcomes of land changes arising from specific proposed scenarios. Understanding the past, current, and future drivers of land-use and land-cover change makes predictions and evaluations of change possible. The interaction of economic, environmental, social, political, and technological forces at local to global scales shape land-management practices and patterns of land change. By associating historical land change patterns with the forces that stimulated that change, it is possible to create and validate theories about land change. By establishing an in-depth understanding of the relation between drivers and the characteristics of change, it also is possible to improve projections of land-use and land-cover change. Improved change projections will help minimize negative effects of change on the environment and resources, and maximize positive effects. Successful, useful studies of change drivers require the integration of various disciplines from the natural, physical, and social sciences.

Strategic Science Actions

Research on driving forces and land change projection must consider a series of questions governing key theoretical and empirical issues, including:

- What are the primary historic and contemporary human drivers of land change and what will they be in the future?
- What are the relations between changes in land use and land cover at different scales and in different regions?
- How do driving forces affect land change at different scales (for example, local, regional, and global)?
- How could environmental, political, technological, demographic, and economic processes determine land-cover over the next few decades?
- How, and to what extent, do extreme events (such as natural disasters, public health emergencies, and war) affect land change? What is the relative importance of extreme events in land change history?
- What are the geographic data requirements for predicting land-use and land-cover change and consequences at regional, national, and global scales?

Four strategic science actions will advance the USGS capability to apply an expanded understanding of the drivers of land change in models to project land use and land cover 20 to 50 years into the future.

Strategic Action 2.1:
Establish an ongoing capability of assessing the social, economic, political, technological, and environmental influences on land change.

A partnership between USGS and academic institutions will outline a strategy to investigate driving forces for land change. In addition, the USGS must assemble the appropriate expertise needed to cooperatively conduct research on the socio-economic and political aspects of land change drivers. Because the drivers of land change usually are regional in their influence, a national USGS strategy must include regional implementation.

Strategic Action 2.2:
Conduct studies on the geographic variability of the types of responses associated with specific drivers (such as globalization, new technology, and policies) on land change and determine how those responses operate at different scales.

The land change responses associated with specific drivers vary regionally and over time. Over time, the same drivers can have a shifting effect on land change. Understanding how specific groups of drivers affect land change in different regions of the United States is necessary for relevant projections of future land change over large areas. In addition, the USGS must conduct multiple-scale (for example, local, regional, national, and global) investigations of the consequences of change resulting from specific drivers such as land management practices, legislation, technology, and globalization. Multiple-scale research will determine how historical change, land-use theory, and resource capacity interact to affect future land change.

Strategic Action 2.3:
Validate the theoretical basis of land-use change by using data from landscape-dynamics research.

Reliance on empirical evidence alone has limited the conceptual basis for land change projections, a short-coming that the creation of a theoretical framework can alleviate. General theories from the social sciences, such as highest and best use, distance decay, and comparative advantage, can be integrated with an understanding of how geographic variations in climate, landforms, geology, soils, and other physical, chemical, and biological landscape characteristics affect land-use potential. A series of case studies and empirical assessments can provide test cases to develop and test integrated hypotheses about the interaction between cultural and biophysical landscape characteristics that produce land-use change. The development and validation of hypothesis-driven research will improve the theoretical basis for land-use and land-cover change predictions.

Strategic Action 2.4:
The USGS researchers will partner with scientists outside of USGS in developing land change simulation models.

The need for improved simulation of future land cover and land use is being expressed with increasing frequency in the land change science community. The current status of land change projection models is evolving rapidly, but most research is at local scales either within a non-spatial, resource-based econometric framework or in urban settings. Simulation models, on the other hand, must predict change over very large areas to be compatible with the scale of climatic, geologic, hydrologic, and economic drivers. Land change models must couple with other process models to incorporate feedback and with dynamic updating. Research must define coupling strategies that address the influences of ecosystem functioning, such as carbon, water, and energy cycling, on land change projections. Model validation will be a particularly challenging element of this research area. Simulation of past conditions will be a necessary strategy for testing the performance of models, placing more emphasis on the need to understand land-use and land-cover change in both historical and contemporary contexts.

> ### Sidebar 2.1: Establishing capabilities for driving forces and land change projection
>
> **Linkages:**
> The USGS needs substantial expertise and capacity to advance land change projection modeling. The USGS is uniquely qualified to address issues related to large-area projections. Developing the expertise and capability to use land change models will be done through partnerships with organizations that already are investing in simulation modeling. A first step is for the USGS to identify the leading land change modelers and establish collaborative relationships. Much of the science conducted in this area likely will be affiliated with the National Science Foundation (NSF), so the USGS must form academic alliances to enable close connections to NSF sponsored research.
>
> **Performance Measures:**
>
> - A research plan for driving forces and land change projection modeling is prepared that addresses the resources, staff capabilities, critical partnerships, and research priorities (*within 1 year*).
> - Case studies are completed that identify the key drivers affecting regional land change and a synthesis of the geographic variability of the responses to the key drivers is completed (*within 4 years*).
> - The theoretical basis of land change is validated within a regional context and the identification of regional variations of highest and best land uses and comparative advantages of different regions of the country is completed (*within 5 years*).
> - A USGS land change projection model is developed, tested, and validated (*within 5 years*).

Goal 3: Understand past, present, and future environmental consequences of land change to support better management of their effect on people, environment, economy, and resources.

Throughout the 21st century, the continuing conversion of land cover and land use in the United States and throughout the world, along with the migration of labor, jobs, products, and resources associated with a global economy, will result in physical, biological, and social consequences at all scales. One consequence is the introduction of thousands of harmful plants, animals, and diseases to the United States from other countries, which create annual damages in excess of $138 billion. Tamarisk (salt cedar), West Nile Virus, and the snakehead fish are three notorious examples from a current list of more than 6,500 invasive species. Geography's unique suite of analytical capabilities can address the dimensions of these invasions and contribute to the explanation of the dynamics of invasive species.

A decade from now, the USGS Invasive Species Forecasting System will document, map, and predict harmful invasive species and serve as the primary tool used by land-management agencies, Tribes, State and local governments, and citizen volunteer groups for combating invasive species. USGS geographers and biologists will collaborate, using capabilities to monitor and assess land change at local and regional scales and understand the processes underlying the spread of invasive species and pathogens, to track the future distributions and abundance of harmful invaders and to aid in prevention, early detection and rapid response, inventory and monitoring, and restoration efforts. By integrating the physical and biological sciences with high resolution remote sensing and high performance computing in a geographic framework, USGS geographers will lead the Nation's efforts to locate and contain invasive species before they gain dominance and harm our economy and environment.

The public is interested in understanding the consequences of land change for social and economic well-being, sustainability of resources, and preservation of environmental quality. Understanding the consequences of land change at multiple spatial and temporal scales is a fundamental goal of land change science. Such an understanding provides resource managers and decisionmakers with an objective basis for formulating land-use and land-management decisions and practices to mitigate the undesirable aspects of land change.

Land changes have substantial effects on environmental, economic, and social welfare at all scales. For example, the water cycle depends heavily on vegetation, surface characteristics, and soil properties, while water resources development also influences water quantity and quality (Climate Change Science Program, 2003). Land-use and land-cover change, climate change, soil degradation, and other environmental changes interact to affect ecosystems and the services they provide. The ecosystem effect of these perturbations often is cumulative.

Complex linkages and feedbacks between land change and environmental response further complicate understanding the consequences of land change. For example, changes in land attributes affecting greenhouse gas emissions, albedo, surface roughness, and other variables modify land-atmosphere interactions and therefore affect climate. Subsequent adjustments in climate may then lead to further accelerated changes in land cover and the ways lands are used. Although there is growing evidence of the circular relation between land change and climate variability, the understanding of the different scales of interactions, feedbacks, and consequences is only at an embryonic stage.

Strategic Science Actions

The USGS has a long and distinguished research record related to research on physical and biological systems and processes. Future USGS research associated with this goal must combine the longstanding physical and biological sciences with geographical land change science. The research requires extensive interdisciplinary cooperation to address the consequences of land change at a variety of spatial and temporal scales. The research must provide answers to several questions, such as:

- How will different scenarios of future land change affect the productivity of public and private land, and what are the economic and environmental consequences of changes in land productivity?

- How will land changes affect the form and functioning of ecosystems, including the ability to provide essential goods and services and levels of ecosystem biodiversity, and what are the ecological, economic, public health, and social costs of the changes?

- How does land change affect climate and, subsequently, how does climate change affect the way land is used?

Strategic Action 3.1:
Conduct research on the consequences of land change on climate, water, carbon cycle, ecosystems, invasive species, and societal concerns.

This research will explore the consequences of past, present, and future landscape patterns and types of land change. Understanding the mechanisms of change in both a historical and present-day context is necessary to understand future consequences of land change. The research also must include process-based investigations of local to regional studies and scaling strategies for estimating consequences over very large areas. Coupled models that link land change to priority environmental and social processes also will be needed to develop this understanding. Understanding the connections between land change and environmental and societal consequences of concern to DOI resource managers also is necessary.

Strategic Action 3.2:
Conduct research on specific consequences of land-use and land-cover patterns and changes for environmental health and public safety issues, particularly at the boundaries between developed and wildland areas.

The consequences of land change are potentially more severe at the contact point between people and nature. Human activity can fragment habitat, contribute to water-quality degradation, provide pathways for invasive species, and serve as breeding grounds and transfer points for vector-borne disease hosts. It also creates critical zones where the risks of wildfire and other hazards are high and possibly life-threatening. Research on the causes and effects of land changes at interfaces is particularly important because of the special magnified risks and hazards in such zones (Fisher and Rahel, 2004).

Strategic Action 3.3:
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.

Wildfires are serious threats to the public that pose substantial resource management challenges for lands administered by DOI and other government agencies. The complexity of wildfire issues calls for a special science effort to provide the data, knowledge, and management options for wildfire management. Effective science and management require an improved understanding of the influence of land change and natural ecosystem disturbance on wildfires and an improved capability to define risks and consequences of the fires. This research must explicitly account for feedback among wildfires, ecosystem changes, societal choices, and social welfare.

Strategic Action 3.4:
Conduct research on the feedbacks between land change and environmental systems and resources.

Land change alters environmental systems, which subsequently affects land use and land cover. Understanding the feedback between land change and climate, carbon fluxes, water quantity and quality, and societal resource allocation choices can lead to comprehensive coupled models of environmental behavior. Advanced understanding of the circular relation between land change, environment consequences, and human choices will provide decisionmakers and resource managers with better information on the ramifications of various policies and strategies.

Sidebar 3.1: Assessing the environmental consequences of land change

Linkages:
Because research into the consequences of land change is interdisciplinary, the USGS approach to the issue also must be interdisciplinary. Drawing on all of the core capabilities of geography, the research must be coordinated throughout the USGS and DOI and through interagency forums to other agencies including the Climate Change Science Program, North America Carbon Program, Joint Fire Science Program, and National Interagency Fire Center. The research requires a functioning partnership among USGS geography, geology, water, and biology researchers.

Performance Measures:

- USGS geographers, working with biologists, geologists, and water scientists from across the USGS, must identify research priorities and prepare a research plan (*within 2 years*).
- A national assessment of the contemporary effects of land change on regional carbon dynamics is completed (*within 3 years*).
- National assessments of the consequences of land change on ecosystem services, water quality, and climate variability are completed (*within 10 years*).
- Regional analyses of the threats of land change in the urban-wildland interface are conducted (*within 5 years*).
- A systematic assessment of wildfire risks and consequences on DOI lands is made (*within 6 years*).

Sidebar 3.2: Developing a comprehensive capability to assess the effects and feedback between land change and environmental responses.

Linkages:
The systematic modeling of land change and its consequences demands a research effort spanning all the USGS disciplines. This effort requires geographers to provide a spatial framework and the understanding of the human-environment issues, and the other USGS disciplines to contribute specialized knowledge about ecosystem operations. The effort also will require cooperative partnerships with scientists from academia and other Federal agencies such as the NSF's National Environmental Observatory Network (NEON) initiative, NOAA, and NASA.

Performance Measures:

- USGS geographers, working with biologists, geologists, and water scientists from across the USGS, must identify research priorities and prepare a research plan (*within 2 years*).
- Define the feedback between land change and environmental responses and develop a series of models for assessing system feedback (*within 4 years*).

Highlight 3: Land-Use Change and the Carbon Cycle

Carbon dioxide (CO_2) in the atmosphere plays an important role in regulating the Earth's climate. The continuing increase in atmospheric CO_2 concentration has the potential of substantially altering the environment and affecting the economy at regional to global scales (Intergovernmental Panel on Climate Change, 2001). However, the pathways that regulate the change of CO_2 concentration in the atmosphere are not well understood or quantified. The National Academy of Sciences 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 effects of land-use and land-cover change on CO_2 exchange between the terrestrial biosphere and the atmosphere. The U.S. Carbon Cycle Science Plan identified the establishment of accurate estimates for the effects of historical and current land-use patterns and trends on the evolving carbon budget at local to continental scales as one of its five overarching goals. (Sarmiento and Wofsy, 1999).

Highlight 3 *(cont.)*

Many studies indicated that a substantial portion of the terrestrial carbon sink is related to present and historical land-use activities (Houghton and others, 1999; Caspersen and others, 2000). Historical land-use change has contributed about one-third of the increased CO_2 concentration observed in the atmosphere globally (Intergovernmental Panel on Climate Change, 2000). In North America, land-cover and land-use change is a dominant driving force for the terrestrial carbon sink. The widespread reforestation that occurred since 1900 in the eastern United States has sequestered increasing amounts of carbon from the atmosphere (Wofsy and others, 1993; Houghton and others, 1999). The heavy use of fertilizers (Matthews, 1994) together with increased atmospheric nitrogen deposition (Schindler and Bayley, 1993; Holland and others, 1997) and improved tillage and crop rotation practices (Paul and others, 1997) also has led to increased storage of carbon in soils and biomass.

Although the importance of land-use change on carbon dynamics is widely recognized, the effects of land-use change on the net exchange of carbon between the terrestrial biosphere and the atmosphere at regional to global scales are not well understood or quantified. One of the main reasons for these shortcomings 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. Investigation of the rates, patterns, driving forces, and carbon consequences of historical and current land-use activities at local to global scales requires a major coordinated effort. Land-use histories that are spatially explicit and that extend as far back in time as possible are necessary to specify the current effects of past land-use disturbances.

Goal 4: Improve the scientific basis for vulnerability and risk assessment, mitigation, response, and recovery related to the human and environmental dynamics of land change.

In 2015, natural and anthropogenic hazards will continue to threaten our safety, economic well-being, and natural resources. Their effects will be greatly reduced because our Nation will have shifted from simply repairing damage after every disaster to identifying and reducing the potential for losses before the events. Our Nation will become more disaster resilient – able to manage risks, respond effectively, and recover quickly from sudden or chronic hazards.

The USGS will lead the creation of a scientific basis for this transformation in collaboration with the Department of Homeland Security (DHS), the USEPA, and practitioners from the public and private sectors. The USGS will identify the effects of land-use and land-cover changes on creating or amplifying hazards in vulnerable systems. A national vulnerability and resilience monitoring program will identify at-risk areas for additional USGS research accompanied by focused risk reduction efforts by the DHS, USEPA, and State and local partners. The USGS will develop and apply innovative geographic methods to assess the effectiveness of mitigation strategies and risk management scenarios. The USGS will capitalize on its traditional strengths in GIScience and remote sensing to provide intelligent access to data, knowledge, and predictive models for response and recovery efforts. With an integrated hazard and vulnerability research program, the USGS will provide the Nation with a holistic understanding of the potential for disasters and improve its ability to reduce these risks.

The first three USGS geography science goals focus on the occurrence, causes, and consequences of land change within coupled human–environment systems (fig. 1). Some agents or processes of land change within these systems have the potential to harm individuals, societies, and natural resources. These hazards manifest themselves as sudden perturbations or slowly increasing stresses beyond the normal range of variability in a system (Turner and others, 2003). Sudden perturbations include natural processes, such as floods, volcanic eruptions, fires, landslides, and hurricanes, and human activities, such as hazardous material spills and terrorist acts. Stresses emerge from complex human-environment linkages, where interactions create or exacerbate chronic hazards, such as droughts, invasive species, vector-borne diseases, nonpoint-source pollution, biodiversity loss, and climate change. Changing human land-use patterns have adverse effects on natural resource quality, and such changes increase the likelihood of certain hazards, such as floods and landslides. The changes also provide pathways for the introduction and spread of invasive species and carriers of vector-diseases. Anthropogenic and natural hazards pose substantial threats to lives, property, and resources, with estimated costs of more than $60 billion U.S. dollars to the global economy in 2003 (Munich Re Group, 2003).

Comprehensive risk assessments to reduce future costs focus on the likelihood and potential damages of hazard events. The USGS has a strong history of science excellence and leadership in natural hazard assessment research. The USGS has conducted far less research, however, to describe and understand the potential for loss or damage. Exposure to hazards, along with the sensitivity and resilience of the human-environment system, define the systems' vulnerability (Cutter and others, 2003; Turner and others, 2003). Research into vulnerability will create new understanding of loss and recovery from natural hazards and similar threats (Cutter, 2003). Important research questions in the effort to understand risk and to minimize the loss of life and property from disasters include the following from Turner and others (2003):

- Who and what are vulnerable to the multiple environmental and human changes underway, and where?
- How are these changes and their consequences attenuated or amplified by different human and environmental conditions?
- What can be done to reduce vulnerability to change?
- How may more resilient and adaptive communities and societies be built?

Reducing risks from natural and anthropogenic hazards is one of the critical issues of the 21st century. The Nation needs a clearer understanding of its vulnerability to hazards and of strategies for increasing resilience. Without this understanding, policymakers may emphasize post-disaster relief and recovery and, in doing so, set the stage for future catastrophic losses (Pelling, 2003).

No Federal agency has a coordinated vulnerability and resilience research program, so the USGS has an opportunity to assume national leadership in this topical area. Geography's long-standing intellectual tradition of studying the relation between society and the natural environment complements the Bureau's expertise at hazard assessment, offering a framework for an integrated physical, biological, and social understanding of hazards.

Strategic Science Actions

The National Research Council (National Research Council, 2002) challenged the USGS to develop vulnerability science through multidisciplinary, place-based approaches. In particular, the NRC recommended that USGS geographic researchers continue to exercise national leadership in applied hazards research to improve the Nation's explanatory, predictive, and response capabilities. The NRC concluded that this research could bridge the gap between science and policymaking and management. Realization of these possibilities will require commitment to seven high priority strategic actions.

Strategic Action 4.1:
Establish a center of excellence focusing on vulnerability and resilience science and the integration of science with decisionmaking.

To conduct research outlined here, the USGS must greatly increase its social science and geographic research staff. As part of a national center of excellence, a distributed network of regional experts across the Nation will be needed to foster collaborations with practitioners, university investigators, and other Federal partners. The creation of a center of excellence focused on vulnerability and resilience science follows the recommendation of Cutter and others (2003). This center of vulnerability and resilience science also should lead the research associated with goal 5, integrating science and decisionmaking. The success of vulnerability and resilience science depends on linking science and decisionmaking, so it is logical that all these research activities be collected initially into a single center. As the USGS capability grows in this topical area over a period of several years, a separate center may emerge for science and decisionmaking.

Sidebar 4.1: Establishing a vulnerability and resilience science center of excellence

Linkages:
A vulnerability and resilience science center of excellence should have a multidisciplinary and multi-agency perspective, involving USGS hazard assessment researchers and researchers from the DHS and the academic world. Other Federal partners include the U.S. Agency for International Development, the NOAA Coastal Services Center, the Centers for Disease Control and Prevention, the National Geospatial Agency, and the Department of Defense. Non-federal partners include the Organization of American States and academic researchers with mutual research interests. Other partners include State, Tribal, and local agencies who are involved in hazard assessment. USGS researchers can add value to assessment information by the exploration of vulnerability and resilience. The productive outcome of this new knowledge will be effective mitigation strategies that employ the integration of social and natural sciences in a decisionmaking framework.

Performance measures:

- A USGS center of excellence is established focusing on vulnerability and resilience science *(within 2 years)*.

Sidebar 4.1 *(cont.)*

- The center is staffed initially with 10 Ph.D .scientists with support staff (*within 2 years*) and expanded to 20 scientists *(within 5 years)* with some researchers collocated with external agencies, partners, and universities.
- An international symposium is held to assess the state of vulnerability and resilience modeling research, potential indicators, and possible approaches for national monitoring *(within 2 years)*.
- A bureau-wide symposium is held on the role of the USGS in vulnerability and sustainability science, as it relates to risk assessments and policy development *(within 2 years)*.
- Standards and metrics are developed for assessing vulnerability and resilience to hazards *(within 5 years)*.
- Case studies are completed on the vulnerability of communities and regions to volcanoes, earthquakes, landslides, floods, drought, invasive species, and climate change *(within 5 years)*.
- A national monitoring program is developed to identify at-risk communities and regions *(within 7 years)*.
- A social science research agenda is established for documenting the influence of perceptions and policies on vulnerability *(within 2 years)*.
- Case studies are completed on effects of land change on creating hazards and human-environment system vulnerability *(within 3 years)*.

Strategic Action 4.2:
Investigate effects of land-use and land-cover change, such as urbanization and resource use, on creating hazards and human-environment system vulnerability.

The Nation needs research to determine how our knowledge of land change can be used to model, predict, and mitigate the effects of natural and anthropogenic hazards. Locally oriented research will examine the relation between urban growth and system vulnerability, while regional and continental scale research will examine vulnerability arising from the effects of land change on processes such as drought, climate change, invasive species, and floods. The USGS must seek to gain a greater regional understanding of hazard interdependencies, predictive patterns, and cumulative effects (Subcommittee for Disaster Reduction, 2005).

Strategic Action 4.3:
Improve research capacity to model vulnerability and resilience to natural and anthropogenic hazards.

A national set of vulnerability assessment tools for researchers and practitioners is needed (Cutter and others, 2003). Case studies on the vulnerability of communities, regions, and trade corridors will be conducted in collaboration with USGS hazard assessment researchers, with a focus on geological hazards (such as earthquakes, volcanoes, landslides), biological hazards (such as invasive species, vector-borne diseases, and threatened species), hydrological hazards (such as floods and drought), and other earth science hazards (such as climate change). Additional case studies will include participation in national and international pre- and post-disaster assessment efforts. The ultimate objective of the case studies is to generate integrated models with indicators that are applicable for multiple hazards and at multiple spatial and temporal scales. Simulations and visualizations will improve understanding of the impact trajectory of hazards on societal assets and ecosystem services. The USGS-led vulnerability research will contribute new methods for incorporating uncertainty into our national view of hazards and for communicating uncertainty to decisionmakers and the public.

Understanding system resilience to hazards, defined by its ability to adjust to or mitigate threats, is critical to understanding the potential for adverse effects (Cardona, 2004). USGS resilience research will complement the management-oriented missions of the DHS and USEPA to protect public safety, societal assets, and environmental resources from hazards. Resilience research will focus on developing metrics that incorporate aspects of exposure, sensitivity, and adaptive capacity to natural and anthropogenic hazards at multiple scales.

Strategic Action 4.4:
Improve understanding of the influences of societal perceptions, policies, and land-use practices on societal vulnerability and resilience.

Risk perceptions and policies are important factors in the success of risk reduction strategies (Frerks and Bender, 2004). Case studies addressing perceptions, policies, and strategies will include Native American communities, urban and rural comparisons, and international experiences. Policies and practices of interest include social structures, economic frameworks, institutional frameworks, and land-use philosophies. Additional research will link this knowledge with the development of risk reduction tools and applications.

Strategic Action 4.5:

Develop and implement a monitoring program that provides perspectives at multiple scales of vulnerability and resilience to adverse land change.

A national monitoring program will identify at-risk areas to prioritize additional USGS hazard and vulnerability assessment research and risk reduction efforts of the DHS, USEPA, and local partners. To support the development of a national monitoring program, the USGS will host an international symposium to assess the state of current research.

Strategic Action 4.6:

Develop and apply innovative geographic and economic methods to assess the effects of proposed scenarios for hazard mitigation strategies and risk management.

Decisionmakers face major informational and financial challenges in their efforts to develop and implement hazard mitigation programs that reduce potential losses, increase resilience, and retain community wealth. The USGS will address these challenges by expanding its social and economic research capabilities. The USGS will continue existing economic and geographic research, such as the Land-Use Portfolio Model (Bernknopf and others, 2001) and the Legal-Institutional Analysis Model (Lamb and others, 1993). Research products will assist managers in determining the effectiveness and feasibility of mitigation and risk management under a variety of scenarios. Additional research will include risk communication, society's willingness to pay for mitigation strategies, methods for incorporating uncertainty, institutional factors of mitigation success, and the role of geospatial information in mitigation analyses. Research will also focus on techniques for distinguishing high-probability/low-consequence events from low-probability/high-consequence events for public policy decisionmaking (Cutter and others, 2003).

Strategic Action 4.7:

Provide innovative geographic methods and techniques to help secure the safety of the Nation in emergency response and recovery efforts.

The USGS will partner with DHS and the USEPA, as well as State and local emergency management offices, to provide geospatial support, such as integrated data platforms and geographic analysis, and predictive models for planning and implementing response and recovery strategies. The USGS will continue development of Geospatial Multi-Agency Coordination (GeoMAC; Highlight 4), as well as other models and decision-support tools that provide intelligent access to remotely sensed data, geospatial layers, loss-estimation models, and institutional frameworks for response efforts. An integrated portal that provides varying levels of practitioner access to USGS hazard and vulnerability and resilience data, models, and research is required to take full advantage of these science products. Researchers will examine potential parallels among various USGS hazard activities and the national response to potential terrorist attacks with the objective of improving all responses. Researchers will collocate with practitioners and Federal partners to better understand societal issues and needs. The USGS must ensure the use of generated data, models, and knowledge through the development of training materials, workshops, geographic information system (GIS)-based tools, and Internet-based applications.

Sidebar 4.2: Improving the Nation's ability to mitigate, respond to, and recover from hazards

Linkages:

Partnerships with risk reduction practitioners and agencies will provide the USGS with opportunities to better understand issues and needs and with avenues for applying geographic knowledge, models, and tools. Potential non-federal partners include the United Nations, the Organization of American States, the American Red Cross, MercyCorps International, the Pacific Disaster Center, and the Public Entity Risk Institute. 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. Research will benefit from partnerships with academic researchers.

Performance Measures:

- Application development staff is increased *(within 2 years)*.
- A national all-hazards portal for data, knowledge, and tools is developed *(within 3 years)*.
- An international symposium is held to assess the state of mitigation modeling research and indicators, including economic and institutional metrics *(within 3 years)*.

Sidebar 4.2 *(cont.)*

- Studies on the effectiveness and feasibility of mitigation strategies are completed (*within 2 years*).
- Predictive mitigation models, metrics, and decision-support tools are developed (*within 4 years*).
- Predictive models and decision-support tools that provide intelligent access to remotely sensed data and geospatial layers for response and recovery efforts are developed (*within 3 years*).
- Collocate geography researchers with risk reduction practitioners and agencies (*within 2 years*).
- Collaborate with Federal Emergency Management Agency (FEMA) to develop training materials on research and tools (*within 5 years*).

Highlight 4: Supporting Fire Response Needs for the Nation

Wildland fire is a serious and growing hazard throughout much of the United States, posing a great threat to life and property. During fire seasons, fire coordination centers set priorities for deploying firefighting resources based on human safety, property protection, and natural resource values. To support this decisionmaking, the USGS works closely with experts from Federal fire management agencies and the private sector, and has developed an Internet-based mapping tool referred to as Geospatial Multi-Agency Coordination (GeoMAC). As the sole science agency for the DOI, the USGS also hosts and maintains the GeoMAC Web site.

Since 2001, GeoMAC has disseminated information about fire status and potential to a wide variety of users in the western United States. General users seeking information about location and possible movement of fires in their area will see maps of fire perimeters overlaid on base-layer information, similar to that in *The National Map*. Firefighting practitioners have access to sophisticated potential fire movement maps, status of suppression resources, and proximity of wildfires to life, property, and infrastructure. Daily updates provide current fire perimeter data from incident intelligence sources, GPS data, and infrared (IR) imagery from fixed wing and satellite platforms.

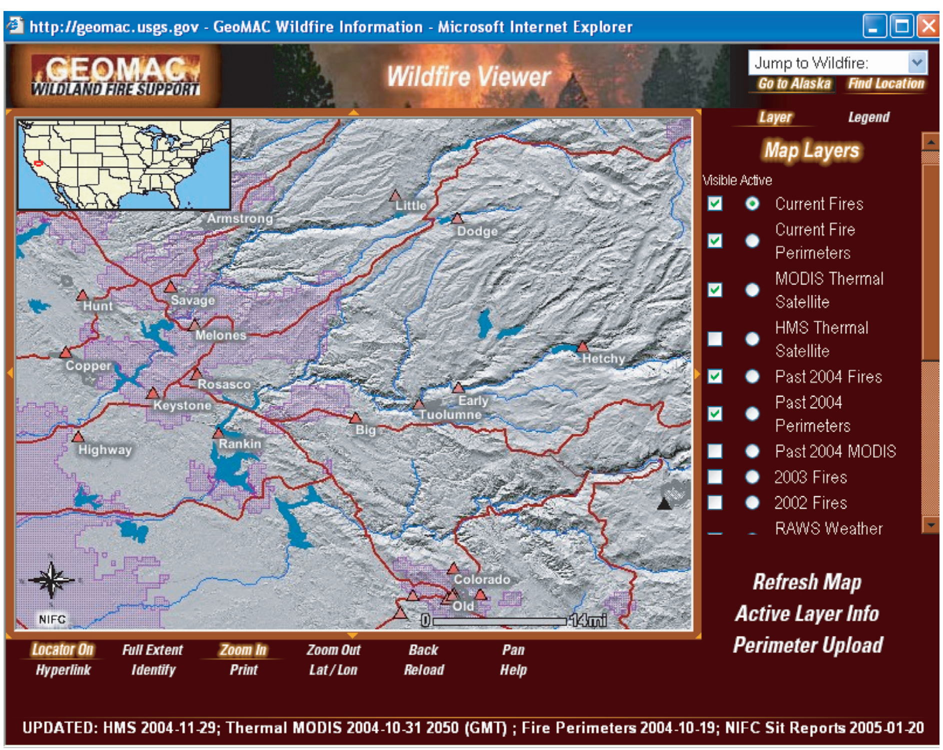


Figure 3. The GeoMAC Web site and mapping application customizes the dissemination mode and type of information supplied to both the general public and to firefighting practitioners.

Goal 5: Develop credible and accessible geographic research, tools, and methods to support decisionmaking related to the human and environmental consequences of land change.

In 2015, understanding and managing land change will still be a challenge for policymakers and the general public because of the complexity of these changes and the overwhelming amount of available information. However, the USGS will improve the link between science and decisionmaking by developing a national toolbox of metrics and indicators to characterize the natural, social, and economic implications of land change. Decision-support systems will help users visualize and gain context for decisions regarding these implications. Innovative and effective mechanisms to identify the Nation's needs for science will help focus USGS research. Research about collaborative processes will lead to science-based activities to expand public involvement in decisionmaking. Multidisciplinary teams of USGS natural and social scientists will address pressing societal issues. The USGS will improve its ability to meet the Nation's key science goals by addressing the needs of decisionmakers and the general public.

For more than 125 years, USGS science has supported resource management related to hazards, the environment, and natural resources, providing policymakers and the general public with integrated information to understand and adapt to human and environmental changes. In recent years an increase in citizen involvement in societal decisionmaking has greatly increased demands, opportunities, and expectations for USGS science (Ehlers, 2002). Policymakers and the general public now expect information to be available quickly in a convenient-to-use format that reflects the best available science and that is useful to a broad array of users with varying needs and levels of science knowledge (National Research Council, 2002).

Although the demand for USGS science is rising, the links between science and public decisionmaking often are complicated and obscure. Scientists may not be aware of societal issues where their expertise is needed. The technical nature of scientific research and the language used to report results may not be readily comprehensible to non-scientists. The scales, spatial boundaries, and timeframes of scientific investigations may be different than those needed to support specific management issues. Science reports usually do not explain the uncertainty associated with scientific results, so that users of these reports may not be aware of the implications of scientific uncertainty in making policy decisions (Bradshaw and Borchers, 2000). Research questions related to making the transfer of knowledge from scientist to decisionmakers include:

- What is the decision context in which USGS science information typically is used?
- What roles do scale, resolution, and uncertainty of scientific information play in addressing different types of issues?
- When asked to provide scientific information, how do USGS researchers balance research timeliness and completeness?
- How can science performed with natural boundaries support decisions that have political or social boundaries?
- What science-based tools and products can be developed to support decisionmaking?
- How do we demonstrate the value of geographic information in decisionmaking?
- How can collaborative processes facilitate the use of science in decisionmaking?

Research to improve the links between science and decisionmaking must have a geographic component for several reasons. Geography has the relation between society and nature as one of its primary research traditions. This tradition requires the use and integration of natural and social sciences to better understand the implications of land change. With expertise in geospatial analysis, geographic researchers have an important role in contributing to improved metrics and tools. For example, decisionmakers in jurisdictions with specific geographic definitions, such as a city, county, or state, may find that access to science data through a geographically oriented portal is most useful. The creation of geographic interfaces for decision-support systems will be an important USGS geographic contribution.

The research outlined here focuses on the development of multidisciplinary methods and techniques for science to support policymaking and be understood by the public. This research will establish the USGS as a leader in improving the use of science for societal decisionmaking. Developed methods and techniques will improve the ability of the USGS, its partners, and the general public to use USGS science in addressing societal issues to protect the Nation's safety, economic well-being, and natural resources.

Strategic Science Actions

The National Research Council (2002) charged the USGS to develop research that bridges the gap between science and policymaking and management. As policymaking processes become more diffuse, the NRC contended that the USGS has the responsibility to deliver adequate information in a timely fashion to communities. Fulfilling this responsibility will require fundamental geographic and social science research to find ways to expand public involvement through more easily used decision-support software. Realization of these possibilities will require commitment to six high priority strategic actions.

Strategic Action 5.1:
Establish a science and decisionmaking focus within the vulnerability and resilience science center of excellence.

USGS social science research and application development must draw on the expertise of geographers, economists, sociologists, policy analysts, and other social science disciplines, programmers, and operations engineers. In some cases, specialists engaged in this activity will be collaborators in universities or in private companies. They should serve as a USGS and DOI advisory group and resource for research methods related to the use of science for societal needs, such as multidisciplinary policy analysis, visualization, and needs assessments.

Strategic Action 5.2:
Improve our understanding of the motivations and processes used by decisionmakers to manage and adapt to land change.

The Nation requires research on societal decisionmaking related to land change, the role of science in making land change policy, and the different information needs, incentives, constraints, and timeframes of key decisionmakers and USGS customers. USGS geographic research will provide a better understanding of how local and regional institutional elements become part of the decisionmaking processes. Such research also will provide collaborative models, role-playing simulations, and visualization techniques for understanding decision processes. The USGS will explore current local, State, and Federal policies to better frame the use and communication of science.

Strategic Action 5.3:
Develop innovative and effective mechanisms for identifying needs and opportunities for science to support decisionmaking.

The USGS will evaluate past and current use of the Bureau's science products to determine factors that promote or inhibit their use. Because perceptions often dictate the use of science, the USGS will conduct landscape and risk perception studies of policymakers and the general public. Using case studies, the USGS will conduct research to define its potential contributions to adaptive management of public resources and to identify the Bureau's most likely customers. These studies focused on adaptive management will include the identification of issues and concerns, opportunities for public involvement, areas of potential conflict and resolution, and important areas for further research and application development. The USGS will organize a symposium involving relevant agencies and organizations to assess the breadth of research and applications that expand the use of science.

Strategic Action 5.4:
Develop a national toolbox of metrics, indicators, models, and decision-support systems that characterizes the environmental, social, and economic consequences of land change.

The USGS will develop a set of metrics, indicators, and models tied together by decision-support systems to support management of public natural resources. Parts of such a toolbox are already available, but their assembly into a functional system to describe the interaction of environmental, social, and economic consequences of land change is not yet complete. Geographers must create systems for collecting, storing, displaying, and analyzing basic spatial data, and design easy-to-use interfaces for users who are non-specialists. A national toolbox that is straightforward to access and use can substantially contribute to the engagement of an interested public, allowing citizens to discern the likely outcomes of alternative management scenarios.

Strategic Action 5.5:
Conduct multidisciplinary case studies to support environmental policy analysis and hazard risk-reduction efforts.

Case studies offer the USGS opportunities to analyze environmental policy and hazard risks while refining the Bureau's capabilities to support risk-reduction efforts. USGS geographers also will contribute to case study efforts for environmental and hazard policies by providing generalizations from two of its traditions, an emphasis on nature-society connections and spatial analytic approaches. Decision-support systems are needed to integrate socioeconomic models and physical models of land change with geospatial databases.

Strategic Action 5.6:

Develop and apply methods for examining the value, format, and transfer of knowledge for societal decision-making and policy analysis.

Although USGS geographers will continue to engage extensively in the creation of new data and knowledge, geographic research also must focus on how those data and knowledge are used for decisionmaking and policy. USGS geographers must determine the particular preferences of the end users of USGS geographic products for the types and format of the data they use. Knowledge and technology transfer from research settings to applications are key elements of the USGS mission, but the most useful and efficient approaches to these activities are not well understood. Primary issues awaiting resolution include scale, accuracy, timeliness, and thematic content of geographic data in policy analysis. Resolution of these issues will aid the USGS in creating useful products and will help policy customers make better use of USGS science.

Sidebar 5.1: Improving the use of USGS science in decisionmaking

Linkages:

Geography's efforts to improve the use of science in decisionmaking requires partnering with other USGS disciplines, because their science provides basic explanations for much of the knowledge and many of the data transferred to customers. Additional partners include other DOI Bureaus and Federal agencies that use USGS science, such as the Departments of Defense and Energy, and university departments with mutual research interests. The USGS will foster relationships with organizations that focus on improving the integration of others' science with societal decisionmaking, such as the Congressional Natural Hazards Caucus. To better understand societal issues and needs and to apply new techniques, the USGS will extend partnerships to include local, State and Federal practitioners, and their representatives, such as the National Association of Counties, the League of Cities, and the American Planning Association.

Performance measures:

- A focus on integrating science and decisionmaking is established within the vulnerability and resilience science center of excellence (*within 2 years*).
- Increase social science research and application development expertise (*within 2 years*).
- A Bureau advisory group is established on research issues and methods related to linking science and decisionmaking (*within 3 years*).
- Mechanisms to determine needs and opportunities for USGS science are developed (*within 2 years*).
- An international symposium is held to assess the breadth of research and applications that expand the use of science for decisionmaking and to develop a coordinated research agenda (*within 2 years*).
- A Bureau-wide research agenda on metrics, indicators, and models (*within 2 years*).
- A national toolbox of metrics, indicators, models, and decision-support systems to support societal decisionmaking is developed (*within 5 years*).
- Case studies are completed on the use of decision-support systems to support environmental policy analysis and hazard risk-reduction efforts (*within 3 years*).
- Case studies on the use of collaborative models, role-playing simulations, and visualization techniques for facilitating the use of science (*within 5 years*).
- Methods are developed for demonstrating the value of USGS science (*within 3 years*).
- Training materials and workshop curriculum on the value and use of USGS science information and tools are developed (*within 7 years*).

Highlight 5: Developing Indicators to Support Famine Prevention Efforts

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), which is a U.S. Government funded partnership to provide decisionmakers with timely and accurate information regarding potential famine conditions. They use the information to establish more effective, sustainable networks for food security and response planning. These networks, led by Africans, reduce the vulnerability of groups who are at risk from famine and flood hazards.

The USGS, in cooperation with other Federal agencies and private sector partners, provides the data, information, and analyses to support FEWS NET activity. Using daily satellite images of the continent, USGS researchers create "greenness maps" with standardized protocols. These maps depict surrogate indicators for biomass that cannot easily be measured on a regular cycle throughout the year. An advantage of remotely sensed data is its ability to frequently monitor large areas. Field observations and ground-based measurements enhance the accuracy of the remotely sensed data. Investigators estimate famine potential in future months by combining information on local conditions, weather and climate assessments, hydrologic cycles, and socio-economic data. These estimates are communicated to local decisionmakers, and relief organizations use the resulting predictions to plan the distribution of relief supplies.

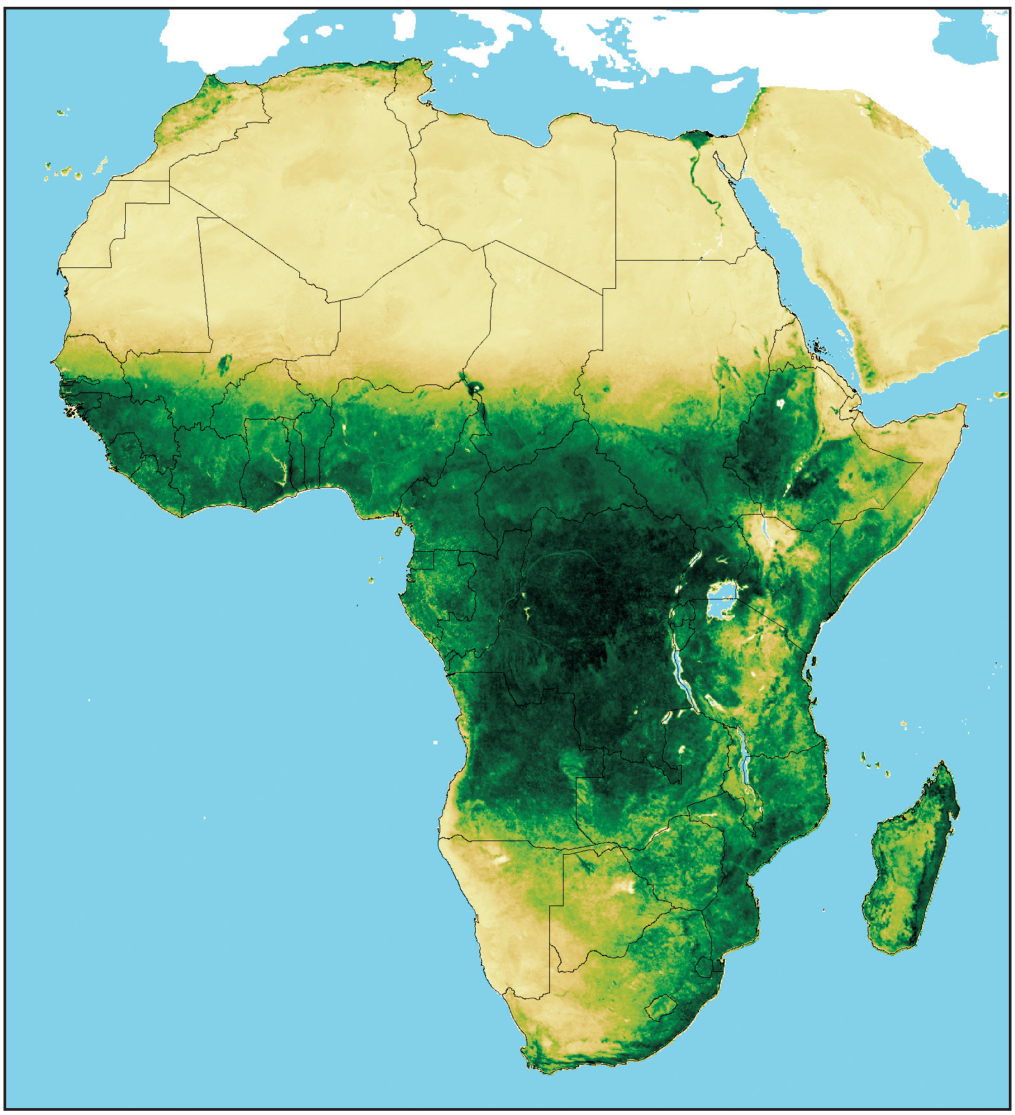


Figure 4. Normalized Difference Vegetation Index (NDVI) data used in FEWS NET activities, with a spatial resolution of 8 km. The NDVI measures the amount and vigor of vegetation on the Earth's surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater vigor and amounts of vegetation. The NDVI is derived from data collected by NOAA satellites and processed by the NASA Global Inventory Monitoring and Modeling Studies (GIMMS). The USGS National Center for Earth Resources Observation and Science (EROS) further develops and processes the data before providing them to the FEWS NET.

Goal 6: Develop and test hypotheses about the use of geographic regions to understand the human and environmental dynamics of land change.

In 2015, States will continue to face requirements to report to the USEPA on water-quality conditions in their State using data collected from a statewide physical, chemical, and biological monitoring network. Scientists use comparative information from relatively natural reference sites to make use support assessments for each waterbody in the State. USGS geographic research and applications are widely used by States in making scientifically sound use support assessments. A USGS maintained library of regional ecoregion frameworks supports monitoring network design and the choice of appropriate reference sites so that the usefulness of monitoring data can be maximized. Integrated USGS regional databases characterizing human factors (such as population, agricultural chemical use, atmospheric deposition, and point sources) and natural factors (such as soil, topography, climate, geology, and hydrology) that influence water quality enable scientists to incorporate monitoring data into powerful predictive water-quality models. USGS geographers work with scientists from State programs and nongovernmental organizations to develop and test regional indicators of ecological integrity and approaches for using indicators to summarize information collected at a local scale for drawing conclusions about regions.

Regional geography provides a cross-cutting understanding of processes and forms that are characteristic of a region. Geographers examine the relations among these processes 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 or within a region) (National Research Council, 1997). A regional perspective enables analysts to deal with complexities of places and regions that include environmental and social systems. In the regional perspective, the spatial framework of the region and the spatial structure of processes lead to integrative explanations. Rather than assess processes topically, one at a time (such as geologic, biologic, or hydrologic processes), the regional approach is to consider all the processes together within a perspective defined by the region.

A central contribution of regional geography is the concept of ecological regions. These regions, which classify the landscape into relatively homogeneous spatial units based on biotic and abiotic associations, are not simply inert containers filled with similar biophysical attributes. Rather, ecological regions are functional spatial entities on the landscape, shaped by human and natural processes. Regions are open systems with internal dynamics that exchange organisms, energy, matter, resources, people, and ideas with adjoining regions. These regional frameworks support sound scientific research on topics ranging from water quality and biodiversity to sustainable development.

Addressing science goals related to the rates, causes, consequences, and risks associated with land change will require a regional geographic perspective and the use of ecological regions. The application of a regional geographic perspective:

- Helps scientists and managers place geographic processes, such as local land 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 spatial (such as regional comparisons and national-scale landscape assessments) and thematic (such as comparative effects of different land change scenarios) points of view.
- Provides a bridge between science activities, often undertaken at local levels, and the needs of decision-makers for information to guide decisions at a regional or national scale.

Strategic Science Actions

The National Research Council (2002) has challenged the USGS to become the integrative regional geography experts for the Nation. Critical research questions about regional geography include:

- How can regions be efficiently and/or objectively defined and validated?

- Is it possible to develop a continuous measure of the ecological potential or capability of a region? How would such a spatially continuous index compare with a discrete index?
- 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 disciplinary perspective?
- How might the inability to draw sharp regional boundaries be best portrayed and validly analyzed?
- What landscape processes are responsible for the patterns observed in regional frameworks at various scales?
- What is the role of spatial heterogeneity within and among ecosystems in the functioning of individual ecosystems and of entire regions?
- What allows ecosystems and ecosystem processes that are characteristic of a region to persist in the face of perturbations?

The rich USGS scientific cultures in geology, hydrology, and biology provide a reservoir of process-based regional expertise. The regional administrative framework of the USGS lends itself easily to support Bureau geographers who serve as regional experts providing advice and products to regional customers. A USGS institutional commitment to seven high priority strategic actions will ensure successful development of a Bureau-wide capability in regional geography.

Strategic Action 6.1:
Include a regional geography emphasis within the land change science center of excellence.

Strategic Action 6.2:
Take a leadership role in working with the USEPA, States, and other Federal agencies in completing the USEPA Level IV Ecoregion framework.

Strategic Action 6.3:
Provide ongoing assistance to scientists in the USGS and DOI in the development and use of regional frameworks.

The regional frameworks designed by geographers will contribute to the interpretation of monitoring data that trace the pulse of environmental and social systems. Such monitoring is a key component of adaptive management used by DOI agencies in land, water, and wildlife systems. Regionalization of data also entails solving the inherent problems in scaling up data collected at the site or local level to regional or global scales, or scaling down data collected at a global scale for use in more restricted regions. Prediction of potential hydrologic effects from global climate change, for example, relies on sensible divisions of continental surfaces into groups of functionally similar regions.

Strategic Action 6.4:
Conduct research to answer questions associated with four priority issues related to regional frameworks: regional identity, regional boundaries, hierarchical relations, and regional ecosystem functioning.

Several regional spatial frameworks commonly are used for Federal resource planning and management, and to help design and implement natural resources research, including frameworks of the USEPA, the U.S. Forest Service, and the U.S. Department of Agriculture. Users of these frameworks often do not have a broad appreciation of the purposes, underlying concepts, and the ability of the hierarchical nature of the framework to support the generalization of findings from one scale to another. USGS geographers will work with scientists from across Federal and State government to understand and use existing frameworks in terms of common and emerging applications. A major challenge for USGS geographers (including those working on *The National Map)* will be to combine information from these various regional frameworks into a single workable database. In recent years, USGS geographers have played a leadership role in establishing a research agenda for the development and use of regional frameworks (Bailey, in press; McMahon and others, in press; Omernik, in press). Continuing leadership is needed to develop an infrastructure to implement the research agenda. By playing a leading role in completing the Level IV ecoregions, USGS researchers and their colleagues in other Federal and State agencies will provide the final component of a hierarchical system that can be used in studies from a local to continental scales.

Strategic Action 6.5:
Use a hierarchical local-regional-national-global approach to improve understanding of the phenomena and processes that cause land change.

The social and environmental drivers for land change have hierarchical characteristics that operate at local, state, national, and global scales. Increasingly large scales encompass increasingly complex systems. Geographers will develop new knowledge, theory, tools, and methods to specify these scale-dependent features, and to aggregate or disaggregate them. The results of these developments will enable improvements in our understanding of how land change operates and will provide improved predictive capability.

Strategic Action 6.6:
Articulate a set of scaling rules for describing the mechanisms of land change that can be used for generalizing local study findings to larger scales.

Landscape processes are connected, regardless of where they occur along a local-global continuum, and influence human and environmental systems at other places and scales that are different from their origins. Geographers have observed that (1) causal mechanisms are best observed at local levels; (2) macro-scale events (such as 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. 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, 2001a, 2002). A better understanding of these scalar relationships will support drawing more powerful regional and national conclusions about the human-environment relation from local-scale monitoring efforts.

Strategic Action 6.7:
Establish regional data observatories and archives in conjunction with USGS programs, the NSF Long-Term Ecological Research (LTER) Network, National Ecological Observatory Network (NEON), the National Acid Precipitation Program, NOAA, NASA, and other organizations that collect earth-science and biological data.

USGS scientists are able to conduct research at unprecedented spatial and temporal scales only because of the collection of long-term local and national data sets. The paucity of long-term regional data sets for many environmental parameters, particularly for land-cover and ecological outcomes, limits our current and future ability to understand the relations between land change and its causes (Jones and others, 1995). The USGS will remedy this critical deficiency by creating databases covering the entire Nation with 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.

Sidebar 6.1: Improving the development, evaluation, use, and understanding of ecological region frameworks

Linkages:
The USGS will assign a high priority to working in partnership with programs that make use of regional frameworks, such as USGS's National Water-Quality Assessment (NAWQA) Program and Priority Ecosystem Studies Program. Priority DOI partners include the Bureau of Land Management, the U.S. Fish and Wildlife Service, and the National Park Service. Priority non-governmental partners include the Association of American Geographers and the American Society of Photogrammetry and Remote Sensing.

Performance measures:

- Establish a regional geography component in the land change science center of excellence (*within 1 year*).
- Complete Level IV ecoregion frameworks for the 11 remaining states (Calif., Ariz., N. Mex., Minn., Mich., Ill., N.Y., Maine, N.H., Vt., and N.J.) (*within 5 years*).
- Collaborate regularly on regional framework issues with USGS and DOI scientists, resulting in at least one peer-reviewed publication each year for each scientist at the land change center of excellence.
- An international symposium is held on regional geography to assess the state of research practice and develop an international regional geography research agenda. A focus of the symposium will be the development of indicators of regional condition, particularly indicators of ecological integrity, and approaches for using these indicators at multiple scales (*within 2 years*).
- Develop an interpretive atlas of the status and trends of ecosystems and environmental resources, updated on a regular (for example, every 5 years) interval, in collaboration with other government agencies and non-governmental organizations (*within 5 years*).
- Develop a more detailed set of research issues and a research plan as part of the regional geography symposium and publish this plan in a peer-reviewed outlet (*within 4 years*).

Sidebar 6.2: Developing regional databases

Linkages:

The USGS will give priority to cooperative working arrangements with the USGS Earth Surface Dynamics (ESD) Program, the NAWQA Program, and the GIO. Other important partners include the Census Bureau, the NSF's LTER and NEON centers, and NASA's Socioeconomic Data Archive Center.

Performance measures:

- Complete a pilot implementation of a regional data observatory and archive with the ESD and NAWQA programs (*within 2 years*).
- Develop, in collaboration with the GIO, the Census Bureau, and private vendors, a long-term, regional database of annual human population estimates at the census block level (*within 5 years*).
- Integrate long-term ecological databases (such as demographics and physical and biological resources) across multiple governmental and non-governmental agencies, and manage data to allow efficient study of issues in a regional framework (*within 10 years*).

Highlight 6: 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. There are several alternative geographic regional frameworks for the contiguous United States, and the basis for recognizing and defining regional boundaries varies among the frameworks. How should potential users choose which ecoregion system to employ in their work? Thompson and others (in press) examined 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 World Wildlife Fund (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. The WWF ecoregion framework therefore 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 the WWF.

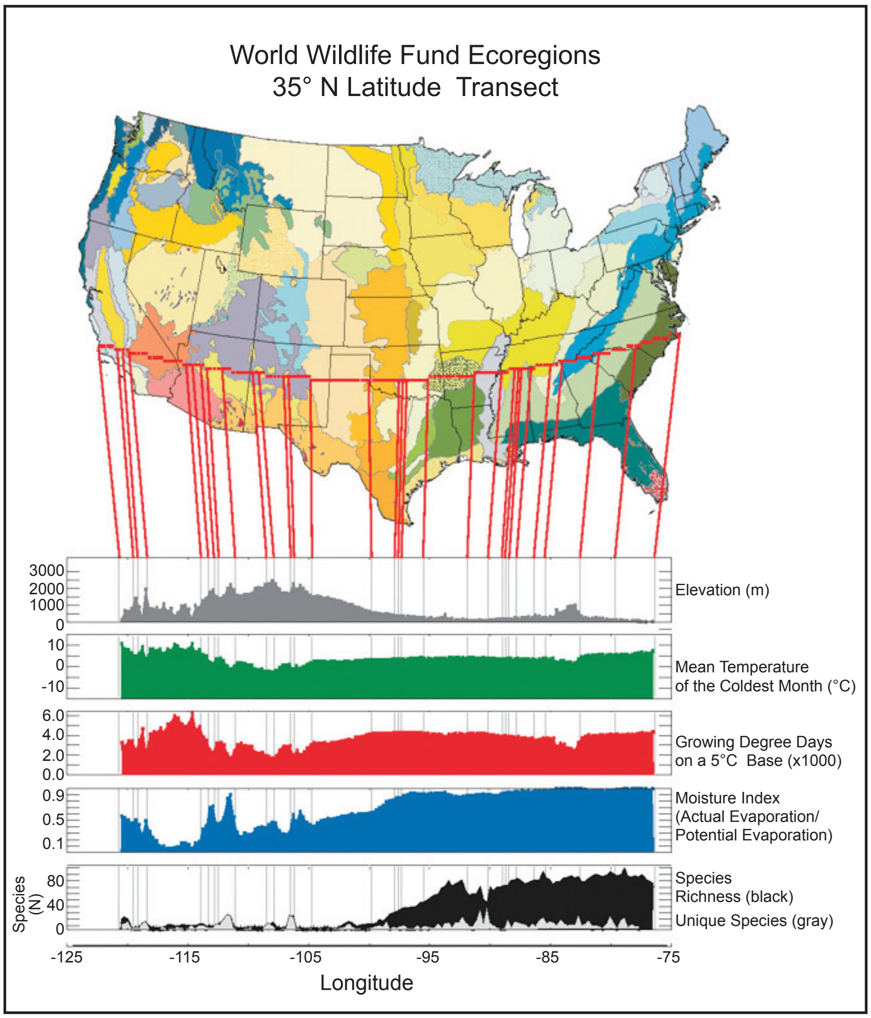


Figure 5. World Wildlife Fund Ecoregions: 35 ° N Transect.

Goal 7: Observe the Earth at all scales using remote sensing to understand the human and environmental dynamics of land change.

In 2015, the USGS will provide ongoing surveillance of the dynamic Earth using a constellation of aircraft- and satellite-based remote sensing instruments. The remote sensing observations will be part of a near-real time terrestrial monitoring system that meets the Nation's needs for timely, accurate, and comprehensive information and knowledge on landscape state and condition and on the broad characteristics of land change. This contribution to the Nation's economic security will lead to improved resource management and environmental health.

Remote sensing science is an important part of geographic research and is essential to identifying, characterizing, measuring, and mapping the Earth's surface and near Earth surface phenomena. Remote sensing is a cost-effective, integral part of our national arsenal of resource assessment, environmental management, and environmental monitoring capabilities. The USGS will need to understand, improve, apply, and provide advocacy for remote sensing, particularly for multi-resolution capabilities of optical sensors (such as Landsat's Enhanced Thematic Mapper Plus and Terra's MODIS) and a collection of new sensors based on radar, light detection and ranging (LIDAR), and other technologies. The USGS cannot meet its science, environmental monitoring, and mapping goals without remote sensing.

The National Research Council (2001a) has challenged the USGS to make greater use of remote sensing in its investigations, and the role of remote sensing has grown in importance as a source of objective data from which landscape conditions can be mapped and measured. The USGS currently uses remotely sensed data for land-cover mapping and land-cover change studies, investigates habitat status and ecosystem productivity, and studies surface formation relating to geomorphic change and geological hazards. To continue addressing the NRC challenge, the USGS will:

- Provide access to a rich archive of historical aerial photography and calibrated historical and contemporary remotely sensed data of all the Earth's land masses.

- 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 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 substantially improved over those achieved today.

Strategic Science Actions

The USGS has a substantial investment in remote sensing. USGS scientists define and direct the acquisition of remotely sensed data sets, such as Landsat; ensure the preservation of and access to remotely sensed data sets; improve access and distribution systems to ensure timely availability of remotely sensed data and products; place increased emphasis on research, education, and awareness of the benefits of remote sensing technology and products; promote the development of data analysis tools and techniques; and promote expanded and enhanced use of remotely sensed data by exploring advancements in remote sensing instrument technology and developing innovative ways to exploit remotely sensed data. Current research 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; such as interferometric research on volcanic and earthquake hazards, and LIDAR analysis for surface forms and tree structures. Continuation of these methodological and application activities is essential.

The remote sensing science actions that follow should be planned through the GIScience Center of Excellence. As the USGS capability grows in the topical area of remote sensing in a period of a few years, remote sensing and other GIScience activities may divide themselves into two separate centers. 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 land change and hazards on the Nation's land and water. A strong program affiliation with NASA, the Climate Change Science Program, and international equivalents, such as the International Geosphere-Biosphere Program, are very important. The USGS is an international participant in the global effort to understand the changing Earth system and must assume a leadership role in conducting research with and in support of international science objectives.

Sidebar 7.1: 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. Examples of the holdings of the archives include aerial photographic coverage of the United States beginning in the 1930s; Landsat data, representing the longest continuous global record of land and water conditions, beginning in the 1970s; and daily global images collected from NOAA polar orbiting missions and the NASA Earth Observing System program. 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 National Center for Earth Resources Observation and Science (EROS) in Sioux Falls, S. Dak., 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. The Landsat Program also ensures the data 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 spacecraft, 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.

Strategic Action 7.1:
Survey the requirements of the DOI, USGS, other government agencies, and the international remote sensing community for environmental data and monitoring, and define the remote sensing capabilities needed for current and future applications.

Documentation of the uses of remotely sensed data within DOI and internationally will provide the foundation for defining Earth observation mission requirements and remote sensing research needs. The USGS will create plans for enhancing application capabilities, conducting research, and promoting new development processes that enable the use of remote sensing to operationally monitor the Earth's environment. An essential multimission perspective for the research and operational activities of the USGS and DOI includes using the capabilities of both government and commercial remote sensing programs as well as the unique National Technical Means assets of our intelligence and defense agencies.

Strategic Action 7.2:
Investigate new technologies for Earth observation and define the specifications for the remote sensing capabilities needed to meet current and future Earth observation and monitoring requirements.

This action includes determining which of the emerging capabilities are candidates for technology development. For example, given the promising uses of LIDAR data, the USGS will pursue research leading to the systematic national collection and application of LIDAR measurements. Initially, research is needed to understand the role of historical and contemporary remotely sensed data so that the products of future instruments are compatible with pre-existing data. The investigation of new technologies must include determination of the advances in processing, multi-temporal assessment, and analysis of these types of data at multiple scales and resolutions.

Strategic Action 7.3:
Undertake an aggressive role in the development and continuation of the Nation's participation in the Global Earth Observation System of Systems (GEOSS).

Scientists, planners, managers, and decisionmakers for Earth resources must have access to the best available data to analyze the continuously changing Earth. USGS geographers, working with others throughout the USGS, will actively pursue a strong international leadership role in GEOSS to ensure access to needed data. It is especially important that the USGS leadership continue to advocate for Landsat continuity as Landsat data provide an unprecedented time series of observations for understanding global land change attributes.

Strategic Action 7.4:
Consolidate and convert the Nation's vast and dispersed historical aerial photography into an electronically accessible USGS remote sensing archive in a format that enables studies of the Earth's land-cover/land-use history.

Archives of historical remotely sensed data, including aerial photography, offer a unique and objective means to reconstruct the history of land change for the Nation. This history provides a yardstick for measuring present and future environmental change. Historical aerial photography exists in public and private archives across the country. The deterioration and loss of historical aerial photographs due to the lack of resources for their storage and use represents a substantial loss of irreplaceable information, constraining our scientific and management capability. The USGS will lead the effort to consolidate and preserve this valuable endangered resource.

Sidebar 7.2: Expanding the use of remote sensing for Earth observation

Linkages:

The most immediate and ongoing priorities for remote sensing at the USGS are that the Bureau must assert its role as a national and international leader in the processing, management, and analysis of remote sensing data. The USGS will maintain the continuity of long-term remotely sensed data and will ensure that new remote sensing capabilities needed to meet USGS and DOI program requirements are available. Remote sensing is a critical geographic method for providing cost-effective mapping, measurement, and monitoring of the dynamic landscape. The Climate Change Science Program (2003) identified a strong role for remote sensing to meet program objectives related to key science goals. The Earth Observation Summit of 2003 lead to the establishment of the Group on Earth Observations (GEO), that 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 also is a plenary member of the Committee on Earth Observation Satellites (CEOS) and the International Global Observation Strategy (IGOS) 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 its geography programs the Bureau will advance remote sensing in partnerships with NASA, NOAA, and the National Geospatial Intelligence Agency (NGA).

Performance Measures:

- Establish a remote sensing science capability within the GIScience center of excellence and prepare an implementation plan (*within 1 year*).
- Complete a user needs assessment of the specific remote sensing data, applications, research, and training needs within the USGS and DOI (*within 2 years*).
- A land remote sensing strategic plan is implemented that lays out the path for meeting the needs of USGS and DOI remote sensing users, and specifies the actions required for the USGS to be an international leader in operational Earth observation (*within 3 years*).
- A USGS strategy is implemented that defines the leadership role of the USGS in advancing global Earth observations and the USGS role in GEOSS (*within 1 year*).
- LIDAR data acquisition program is institutionalized and systematic LIDAR measurements improve digital elevation databases and are used to characterize vegetation structure and biomass (*within 6 years*).
- USGS takes a leadership role in new missions, such as National Polar-orbiting Operational Environmental Satellite System (NPOESS), and use of new remote sensing technologies in order to facilitate cost-effective monitoring of the changing Earth at a variety of scales (*within 5 years*).
- A definitive assessment summarizes the monetary and non-monetary benefits of the Landsat Program (*within 1 year*).

Strategic Action 7.5:

Develop a plan for the preservation of USGS remote sensing archive data that ensures the long-term availability of those data to support science investigations.

Over the past five decades, our Nation has invested billions of dollars for the collection of Earth observation satellite and aerial imagery. During those decades, the USGS established itself as the largest civilian, remotely sensed archive in the world. The National Satellite Land Remote Sensing Data Archive administered by the USGS (Land Remote Sensing Policy Act of 1992 - 15 U.S.C. 5652; P.L. 102-555) has the responsibility to preserve the existing imagery. This task is increasingly challenging as the hardware and software that created the images become obsolete. The USGS also must plan for newer, supplemental Earth observation systems.

Strategic Action 7.6:

Conduct research on advanced data access and mining capabilities that leads to robust use of the USGS remote sensing archive for the purpose of gaining knowledge about the Earth's dynamic history at multiple scales and temporal periods.

Assessment of large-area land change will require access to vast volumes of remotely sensed data with efficient user interfaces. USGS geographers will create new methods to mine and visualize these large data sets to support USGS research in all disciplines.

Strategic Action 7.7:
Conduct research that leads to the calibration of all appropriate USGS remote sensing assets.

The comparison of data from a variety of remote sensing instruments requires USGS geographers to calibrate and integrate data over several time periods, over many geographic areas, and at different resolutions. This cutting-edge effort will require considerable USGS research to develop appropriate methods to bring the Bureau's remote sensing products into alignment with each other. The ultimate objective is to have a consistent remote sensing database that allows comparisons of data over time and across space. The USGS will develop this geographic capability to support monitoring, analysis, mapping, and projection of changes in the Earth's environment.

Strategic Action 7.8:
Define and test protocols for determining the uncertainty, accuracy, and precision of products derived from USGS remotely sensed data.

USGS geographers will develop methods for defining uncertainty and mechanisms for communicating the uncertainty to scientists, resource managers, and decisionmakers so that the data fulfill their potential but are not extended beyond their reasonable capabilities.

Sidebar 7.3: Improving access and use of USGS remote sensing archives

Linkages:
The USGS will ensure the long-term availability of the Nation's remotely sensed data. To ensure that historical and contemporary data are available, the USGS will establish a remote sensing center of excellence that includes the geographic researchers needed to meet data mining, visualization, archiving, and integration challenges. The USGS will work with NASA, NOAA, USDA, and other Federal agencies that acquire remotely sensed data. It will also cooperate with the National Archive and other Federal and State historical experts. In addition, the USGS will work through professional societies, such as the American Society of Photogrammetry and Remote Sensing, to identify opportunities for preserving non-governmental aerial photography holdings.

Performance Measures:

- The availability of historical aerial photography through the USGS remote sensing archive for as far back in time as the 1920s is doubled through the addition of photography from private and government archives (*within 5 years; ongoing to continue to add new records*).
- All aerial photography in the USGS remote sensing archive are converted to electronic records and accessible through the Internet (*within 6 years*).
- Researchers can bring "algorithms to the archive" to mine through massive volumes of data for the purpose of collecting information on specific land characteristics (*within 5 years*).
- Archive preservation program is in place that results in long-term security and viability of USGS remote sensing archive records (*within 3 years*).

Strategic Action 7.9:
Define the analytical methods needed to make better use of data from current and future remote sensing instruments for accurate measuring and mapping of landscape properties, including land-cover status, ecosystem services, and surface form.

USGS geographers will identify the methods and techniques needed to transform electromagnetic measures into the spatial, spectral, and biophysical types of data and information needed by other disciplines in the USGS, DOI, and the Bureau's customers. Example capabilities include (1) methods for developing accurate, robust, and flexible land-change metrics, (2) development of near real-time landscape condition monitoring capabilities for quantifying ecosystem stress, change, and conversion, (3) methods for transforming LIDAR observations into complete three-dimensional measures of surface form, canopy configuration, and structure, and (4) advancements in scaling in situ measurements into regional and global contexts.

Strategic Action 7.10:
Establish training and outreach activities that provide technical advice and support needed to incorporate USGS remote sensing capabilities into the DOI and USGS programs and projects.

USGS geographic innovation in the exploitation of remotely sensed data will directly support the missions of DOI, other civil community agencies, and stakeholders while fostering commercial enterprises through technology transfer. To meet mission responsibilities, the USGS must provide training, outreach, data grants, and support for remote sensing applications development. Examples include monitoring and mapping urbanization with increased frequency to enable improved assessments of urbanization effects on water quality; flooding risks and fire hazards; 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; and improved measurements of vegetation canopy that can be used in operational weather forecasting models.

Sidebar 7.4: Monitoring the changing Earth using remote sensing

Linkages:

Remote sensing research requires specialized capabilities. In addition to research by geographers and remote sensing scientists, the USGS will engage in partnerships with other government agencies, industries, and academia. For example, the USGS has been working with the AmericaView Consortium, which is a consortium of universities across the United States, to expand the understanding and applications of remotely sensed data. The USGS and NASA have worked cooperatively on the Landsat, EO-1, and EOS missions, as well as many research activities. This relationship is critical to the long-term success of the USGS in remote sensing. Similarly, universities provide unique capabilities in basic research related to algorithm development. Fertile topical areas for USGS-led partnerships include large-area land characterization and mapping, as well as the creation of new paradigms for land characterization.

Performance Measures:

- A research strategy outlines the feasibility, approaches, and priorities for calibrating the primary global Earth observation remotely sensed data (such as Landsat, EO-1, and ASTER) managed by the USGS (*within 2 years*).
- All primary global Earth observation remotely sensed data are calibrated so that intra- and inter-sensor comparisons can be made, enabling more detailed and definitive assessments of changing land conditions (*within 10 years*).
- All USGS land data sets derived from remotely sensed data are validated and include appropriate measures of accuracy and uncertainty (*ongoing*).
- A research strategy outlines the high priority methodological developments needed to map and measure land attributes from local to global scales using remotely sensed data (*within 2 years*).
- Improved remote sensing-derived measures of highest priority land attributes enable expanded global monitoring of land change and other key environmental processes (*within 3 years; ongoing*).
- Remote sensing training and outreach programs double the applications of remote sensing within the USGS and DOI (*within 10 years*).

Highlight 7: 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, offers exciting advances in high resolution imagery.

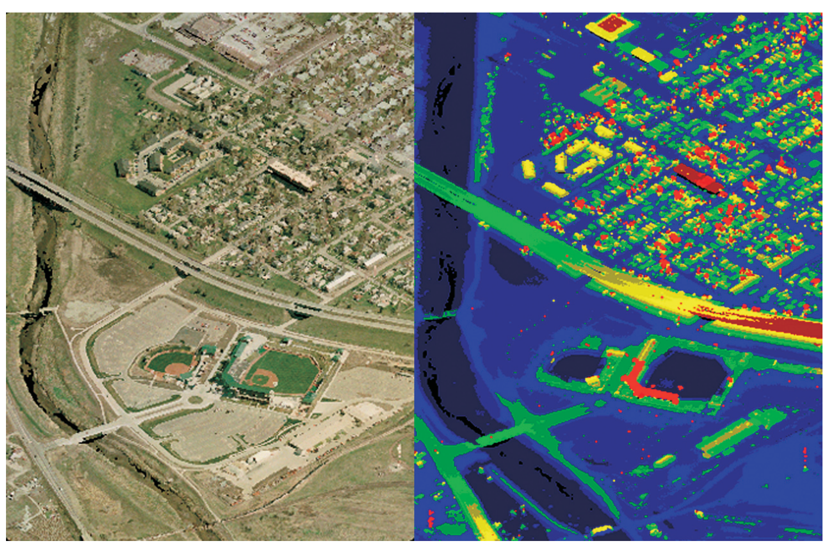


Figure 6a. Elevation and imagery fusion of LIDAR point cloud.

Highlight 7 *(cont.)*

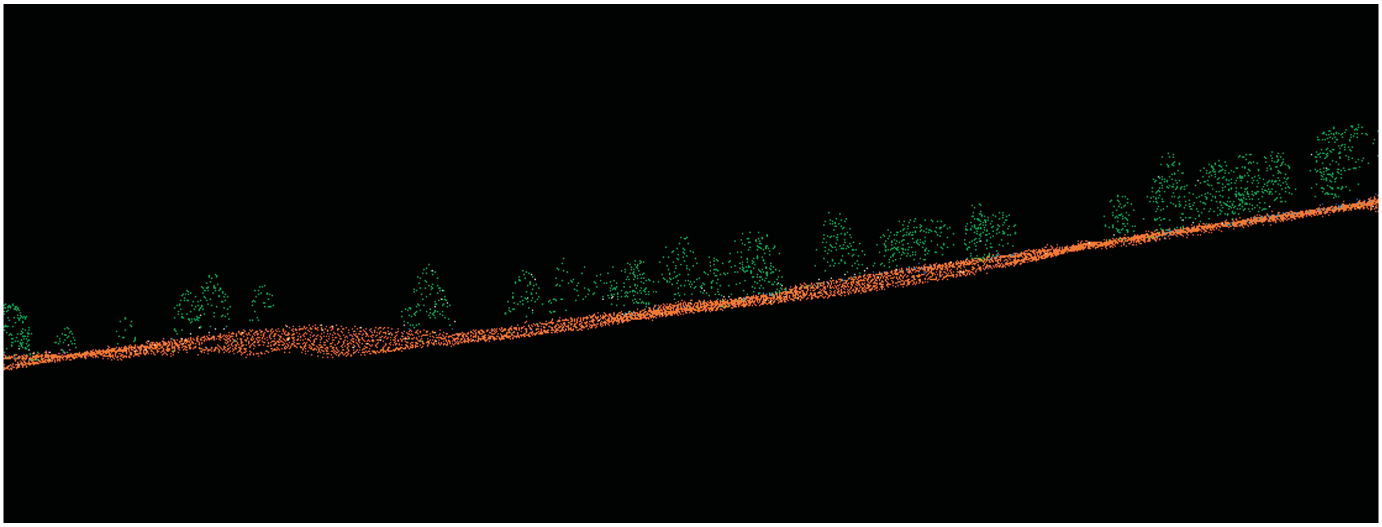


Figure 6b. Vegetation LIDAR point cloud.

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. Conversion of LIDAR data into bare earth, vegetation, or structural elevation information produces extremely accurate, high-resolution elevation models to visualize and quantify scenes in three dimensions. Results permit high-resolution bare-earth digital elevation models, quantitative estimates of canopy height, canopy closure, biomass, and 3-D models of cities that include building footprints.

Figure 6c. Three-dimensional virtual city from LIDAR.

Current LIDAR research involves improving 3-D visualization techniques, designing methodology to extract vegetation characteristics from LIDAR point clouds, automating feature extraction of urban structures, 3-D modeling, and combining imagery and LIDAR-derived elevation data. In the future, 3-D simulations of landscapes will enable more realistic and comprehensive products as computer-processing power continues to improve and new methods are developed for representing massive data sets. Users will be able to walk through 3-D “virtual forests” and “virtual cities,” allowing unprecedented realistic views of the Earth.

Goal 8: Provide timely, intelligent access to new and archived USGS geographic data needed to conduct science and support policy decisions.

By 2015, a host of consumer items will have integrated spatial data into their operations by taking advantage of wireless communications technology, mobile and portable computing devices, global positioning systems (GPS), and The National Map. The National Map will become the preferred gateway for popular access into geographical data for everyday tasks. For example, farmers may walk their fields looking at satellite imagery centered on their location, historians may browse historical air photos while walking through a 19th century industrial plant, and tourist buses may show a digital display of the day's sightseeing circuit that changes themes depending on the tour guide's discussion. Tourists in their seats may see the map differently, with their own customized maps portrayed according to preferences learned by the display system.

The National Map's goal of 7-day update will be achieved, meaning that data are timely and accurate. This will be possible because automated software agents will have "data mined" data sources, seeking out changes on the Earth surface and extracting new map information with only minimal human intervention. This timeliness will lead to myriads of new applications in real estate, emergency management, policing, environmental management, and commerce.

During the 20th century, the USGS developed and produced the Nation's topographic map series, which is the flagship data product of the Bureau. Unlike many scientific products, the topographic map series became a familiar, much-relied-upon resource for the public as well as scientists. The geographic description of the Nation presented on these maps enabled scientists to plan field investigations and monitoring programs, allowed objective analyses, and provided Federal, State, and local agencies a reference base from which new maps could be made. The general public used the maps to enjoy a range of outdoor activities, such as hiking, canoeing, and hunting.

Beginning in 2001, the USGS replaced this signature geospatial data product with *The National Map*, an Internet-based, interactive map service designed to meet the Nation's needs for current base-geographic data and maps. The development of these mapping activities reflects an evolution in how geographers understand, represent, manage, and access geospatial information. Geographic information science (GIScience) has transformed mapping and the entire practice of geography that once encompassed field surveys, photogrammetric methods, cartographic finishing, and publishing. GIScience provides information about *places* on the Earth's surface, knowledge about *where* geographic features are located, and knowledge about *what* is at a particular location. GIScience initially involved, and still includes, the science behind the traditional mapping disciplines of surveying, aerial photographic interpretation, photogrammetry, remote sensing, and cartography. Today it also includes a broader scope of issues related to the modeling and representation of geographic data, phenomena, and processes; human cognition of geographic information; the analysis and use of uncertainty; spatial analysis and modeling, including GIS; scale; geographic ontologies; visualization; and other similar topics (McMaster and Usery, 2004).

Strategic Science Activities

Technological innovation has allowed the capture, storage, processing, and display of unprecedented volumes of georeferenced information about the Earth. Yet large amounts of data have not always led to more information and knowledge. Increasingly as the Internet has become the dominant distribution medium, scientists communicate directly with individual citizens and data consumers, making data and information delivery tasks even more complex. Supporting intelligent access to information contained in large geospatial data sets is an important niche for the USGS (National Research Council, 1995). Important research issues that will address information access needs include:

- Geographic representation topics related to computer data models and structures, and communication of uncertainty.
- Design and symbol representation problems, including display of critical data elements, for portrayal of *The National Map* data on different display devices.
- Generalization research that deals with representing features at different scales.
- Data mining algorithms for handling geospatial data, spatial data access structures, and use of domain knowledge for improved query processing and mining.

Intelligent access to geographical data is an important science focus of the USGS for three reasons, all based on the premise that geographic base data are a critical component of the USGS research infrastructure. First, 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. Second, development and implementation of *The National Map* will require strategic collaboration and partnerships both in developing data and in designing and undertaking the research necessary to realize the promise of the idea. Finally, *The National Map* will provide an efficient framework for organizing and managing disparate geospatial databases needed by USGS scientists and the public-at-large through a single, easy-to-use point of access.

Strategic Action 8.1:
Establish a GIScience center of excellence.

The GIScience center for excellence should lead the planning and implementation of the research associated with goals 7, 8, and 9. The USGS must invest in personnel, resources, and infrastructure to establish a center of excellence focused on GIScience that builds, nurtures, and maintains a core of GIScience researchers to further these goals and actions. Additional researchers, both doctoral and master's levels, will be needed to address the science activities described here, with specialties in GIScience and the themes listed above. Senior scientists will have to be supported with junior scientists and technicians to help in data gathering and information processing.

Sidebar 8.1: Establishing a GIScience center of excellence

Linkages:
The USGS must redevelop 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*. Formal exchanges with other Federal agencies involved with spatial data, such as NGA and the Census Bureau, are highly desirable. USGS geographers also must evaluate linkages with data user communities so that data specifications and analytical capabilities are based on both strong peer-reviewed science and USGS needs. A dialog with the organizations listed as strategic partners throughout this document must be maintained.

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 university-based GIScience research critical to the USGS mission will be necessary.

Sidebar 8.1 *(cont.)*

Performance Measures:

- Establish a center of excellence in GIScience (*within 2 years*).
- Staff the center of excellence initially with 10 Ph.D. scientists with support staff (*within 2 years*) and expand to 20 scientists (*within 5 years*).
- A science plan addressing key topics from goals 7, 8, and 9 that are needed to meet the overall goals of this plan is prepared and approved by USGS (*within 2 years*).
- Establish post doctoral, internship, and visiting scholar relationships with universities with at least 20 scholars in residence (*within 3 years*) and provide continual rotation to maintain the 20 each year.

Strategic Action 8.2:
Improve understanding of *The National Map* user needs, both inside and outside of the USGS.

The USGS will continuously assess user needs for geographic data and translate those needs into collection, representation, and distribution procedures for geospatial data. To be effective, USGS geographers will need to anticipate user requirements for next generation products, such as model results, planning scenarios, and decision support tools.

Strategic Action 8.3:
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.

The USGS faces a monumental intellectual task in addressing questions related to representation of data. As *The National Map* continues its evolution and other more specific products become necessary, geographers will develop solutions to a series of vexing problems still common to geospatial products. Because data for most of the USGS products will come from several sources, the data will initially be in a variety of resolutions and symbolizations, with the boundaries between contiguous coverages that may not match. The solution to these data management problems will have to be automated so that rapid, automatic updating becomes a reality. Human cognition of geographic phenomena will become a substantial topic of research for USGS geographers. In order to present the Bureau's vast data holdings in forms that are useful to people, USGS researchers will need to understand the maps that appear in the minds of the users as well as on their display screens.

Strategic Action 8.4:

Research and develop design and symbolization specifications and innovative methods that support *The National Map* viewer and other geographic data displays on a large variety of display devices.

The USGS is the primary Federal GIScience agency, and part of the responsibility that goes with that identity is to offer standardized guidelines for generators and users of geospatial products. Standard design and symbolization speeds the fusion of otherwise disparate data sets and ensures maximum return for the Nation's investment in collecting the data. Standardization among products will increase their appeal and utility to users and shorten learning times for creators, managers, and users of the data.

Strategic Action 8.5:

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

The National Map and other USGS geospatial products will require the acquisition and display of enormous amounts of data, quantities far greater than can be handled manually. Automated methods for generalization and multiple-scale display or delivery are the only approaches that are viable, but they are not yet a reality. The USGS will conduct considerable research to develop these automated methods, but the Bureau will also require a continuing commitment to improvement of methods to accommodate constantly improving data collection.

Strategic Action 8.6:

Build a critical mass of USGS scientists familiar with and able to exploit new developments in spatial data mining and knowledge discovery in supporting *The National Map* and other large spatial databases.

Increasingly, resource management and environmental assessment research require efficient access and use of very large data sets. USGS researchers also will refine and improve pattern or knowledge validation as part of the Bureau's responsibility for quality control and certification of geospatial products.

Sidebar 8.2: Improving access to geospatial data

Linkages:
The USGS will assign a high priority to partnerships with academic departments of geography to explore innovative mechanisms for involving university faculty and graduate students in research connected to the USGS geographic mission. Linkages with private industry for research and development in geographic information science also will be fruitful.

Performance Measures:

- Establish a single Web point-of-access to the data in *The National Map* and other Federal environmental data (*within 1 year*).
- Develop an ongoing user needs assessment methodology for *The National Map* (*within 1 year*).
- An operational data-management protocol is established to manage and access information from continental- and global-scale databases, using geographic data mining techniques (*within 2 years*).
- Create tools for error detection and elimination, and for automated updates of core base data sets (*within 2 years*).
- Multiple resolution data integration methodology is developed (*within 3 years*).
- Appropriate representation and symbolization are developed for multiple-scale display of data that are a part of *The National Map* and other USGS products (*within 4 years*).
- Complete ontology of features, attributes, and relations for all layers in *The National Map* at all possible resolutions (*within 5 years*).
- Develop appropriate representation and symbolization methods for multiple-scale display of data that are a part of *The National Map* and other USGS products (*within 5 years*).
- Develop methods to automatically generate maps at any scale from *The National Map* (*within 7 years*).

Strategic Action 8.7:
Develop specifications and analytical methods and tools for use in producing widely used, high-priority data layers for *The National Map*.

The land change and vulnerability science goals of this plan give rise to broad and diverse geographic data requirements. USGS scientists will develop detailed specifications for these data to ensure that they are useful in scientific research.

Sidebar 8.3: High priority data for *The National Map*

Linkages:
To support the development of continuously updated base layers for *The National Map*, USGS geographic information researchers will work with scientists and data producers in other Federal agencies, State, local, and Tribal governments, private industry partners, and academia to develop effective geographic information science research for display and delivery of these data. Coordination with research geographers and investigators in other disciplines in the USGS is a prerequisite for successfully addressing the other science goals expressed in this plan. Data specifications below are based on input received during the USGS geography science planning effort.

Performance measures: Landcover data

- Identify the multiscale requirements for national land-cover data (*within 1 year*).
- Develop an implementation plan to produce the needed land-cover data, considering repeat frequencies, attributes, accuracy standards, and methods enhancements (*within 2 years*).
- Develop and implement a strategy for mapping 1992-2001 U.S. land-cover change using National Land-Cover Database (NLCD) inputs (*within 3 years*).
- In selected geographic areas that correspond to science priorities, capture digital versions of archived land-cover photos going back to the early 20th century–and perhaps other archived museum data– to allow investigation of land-cover trends and their effects on biodiversity (*within 5 years*).
- Develop digital archive of historic USGS topographic maps (*within 5 years*).
- Retrospective, comparable national scale land-use/impervious surface data sets from remotely sensed data are developed for every 5 years to the present, beginning in 1970 or earlier, to help analyze long-term environmental response (such as water chemistry, breeding bird surveys data sets) (*within 7 years*)

Performance measures: Elevation data

- Procedures are developed to create topographic derivatives from the base geographic data of *The National Map* on the fly (*within 3 years*).
- Develop tools and a distributed computing-based approach for producing hydrologically-related elevation derivatives consistent with the National Hydrography Dataset (NHD) and watershed boundaries (*within 3 years*).
- A process is developed to receive data back from users and establish a national elevation database (*within 3 years*).
- Develop precise topographic data for sites that are difficult to map, such as areas with very low relief, steep terrain, or heavy vegetative cover, in order to identify microhabitats of interest (*ongoing*).
- Integrate bathymetric and topographic data into *The National Map* (*within 3 years*).

Performance measures: National hydrography data

- A procedure is developed for implementing a user-maintained 1:24,000-scale NHD (*within 2 years*).
- Integrate data about consumptive water use, land-use, fertilizer and pesticide use, and socioeconomic data into NHD (*within 3 years*).

Sidebar 8.3 *(cont.)*

- Integrate catchments and stream channels derived from DEMs with the NHD and contours (*within 3 years*).
- Develop highly attributed NHD data that includes nationally consistent, fully attributed elevation and other landscape derivatives, and smaller headwater streams (*within 3 years)*.
- Perform high quality research on stream networks, including defining a classification of streams into perennial, intermittent, and ephemeral reaches, using digital network data management capabilities that deal with individual mapping differences in a consistent way (*within 3 years*).
- In collaboration with the USGS Water Discipline, develop the capability to use NHD to follow water through the hydrologic cycle and track human water withdrawals and consumptive use. (*within 5 years*).
- Complete data sets needed for deriving watershed catchments, including updating NED, the Watershed Boundary Dataset (WBD), and a high-resolution (for example, 1:24,000-scale) NHD single line stream network (*within the next 3-5 years*).
- Complete development of the 1:24,000-scale NHD, with catchments defined for all stream reaches having boundaries that agree completely with watershed divides from topography maps. A large collection of attributes should be derived for those catchments that can be linked to the NHD flow network. The flow network must be thoroughly quality assured and corrected (*within 5 years*).
- Enhance NHD to include a uniform and scientifically defensible classification of streams into perennial, intermittent, and ephemeral reaches (*within 5 years*).

Goal 9: Develop innovative methods of modeling and information synthesis, fusion, and visualization to improve our ability to explore geographic data and create new knowledge.

By 2015, flooding of local coastal areas will increasingly affect human populations and biological ecosystems. Using high-resolution global data sets and methods for fusing massive volumes of disparate data, USGS scientists will routinely provide global models of areas, populations, and resources of any affected world locality. These models will be instrumental in the efforts to mitigate loss of life and property through preparedness, prevention, and response. Other USGS models that use the same massive data sets and fusion methods will provide risk and hazards assessment modeling for preparedness and prevention of Homeland Security threats.

Spatial modeling is one logical response to the NRC's recommendation to USGS scientists to become "consumers of their own data" to create new knowledge (National Research Council, 2002). Spatial models developed and used by geographers are a subclass of scientific models that consume spatially oriented input data, such as vector and raster maps, remotely sensed imagery, and aerial photos, and produce spatially oriented environmental or human response information. To formulate spatial models, geographers must identify the relations among key components of complex geographic systems; developing this conceptual framework provides scientists with a better understanding of these systems. The use of models adds value to USGS data, providing an increased understanding of the landscape change processes and an ability to predict future states. Research also is needed into the integration of data at a variety of themes and scales, over time, and on methods for the discovery and understanding of patterns in the data, including visualization and automated feature extraction.

Strategic Science Activities

Important modeling research questions include:

- What models are best suited to creating value-added data layers that have multiple uses, using data already served by 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?
- 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?

Geographic information synthesis and fusion research questions that must be addressed include:

- Can a theoretical model be developed and verified that provides a basis for fusing geospatial data sets of different geometry, resolution, and accuracy?
- Can such a model provide a basis for users to automatically combine data through access to metadata that includes resolution and accuracy?
- Can we develop appropriate methods of handling color and contrast issues when combining multiple raster and/or raster and vector data sets?
- Can mathematical tools such as Fourier transforms and wavelets provide a basis for information synthesis and data fusion?
- Can we develop methods to fuse data with widely varying characteristics and can we establish appropriate limits for the fusion of these data sets based on the methods and the basic data characteristics of geometry, data type and scaling, resolution, and accuracy?

Geographic visualization research questions must provide answers to the following questions:

- Can USGS develop appropriate visualizations of geospatial data sets that work in the Web-based interfaces of *The National Map*?
- Does uncertainty visualization provide support to understanding landscape dynamics and hazards?
- Is animation an effective visualization tool for studying landscape change, including hazards? Which types of animations work best?
- Can animation be a part of the visualization interface for *The National Map*?
- Can we develop automatic visualization of spatial data based on data type, data scaling, resolution, accuracy, and other metadata?

Strategic Action 9.1:
Address research questions on the topic of information synthesis and fusion.

USGS geospatial products, including *The National Map,* will combine or fuse data from disparate sources, a seemingly simple task that is fraught with difficulty. In order for *The National Map* and similar products to become a reality, USGS geographers must resolve theoretical questions about how to combine data from different and possibly incompatible time periods, classifications, semantics, geometry, resolution, and accuracy. Metadata, descriptions of the data contained in geospatial products, will assist in the fusion of the input data in an automated fashion, but these capabilities await fundamental geographic research.

Strategic Action 9.2:
Address research questions on the topic of map and geographic database projections.

All map-like products represent the Earth's surface as essentially a flat plane, while the Earth that generates the data has a curved surface. USGS geographers will explore the thousands of methods for projecting the curved Earth onto a flat sheet of paper or onto a flat screen for use in the Nation's primary geospatial databases. Additional issues that must be resolved include automated methods for identifying the projections of geospatial data that are to be combined, and determining transfer algorithms to accomplish the fusion.

Strategic Action 9.3:
Address research questions on the topic of geographic visualization.

The growth of geospatial databases at local to global scales has created a flood of environmental and social data that threatens to overwhelm researchers and decisionmakers. Innovative methods for visualizing statistical data with locational identifiers can speed the search for anomalies as well as for trends and associations within these data. Visualization will improve the interfaces between users (researchers, decisionmakers, and citizens) seeking to capitalize on the USGS storehouse of data and information. Such interfaces can mask the complexities of the database that do not interest the user, while making queries and data handling simple and efficient. These interfaces, along with animated approaches to geospatial databases and automatic visualization await further research and development by USGS geographers. USGS geographers are well positioned to address the issues because they have the greatest knowledge and the easiest access to the databases that will benefit from the innovations.

Strategic Action 9.4:
Research and develop methods and techniques in modeling and geostatistics to exploit geographic data.

Models can extract useable information from otherwise overwhelming data sets. Statistical summaries and predictions can improve the ability of scientists, decisionmakers, and the public to get the best value from Earth science data sets. Spatial statistics provide a primary mathematical support for geographic models and are part of a specialized branch of more general statistical methods. USGS geographers, mathematicians, and computer scientists have a unique contribution to make in the realm of spatial statistics, because they can tailor advances in the field to the needs of models dealing with the nature-society interface. Additional interaction with USGS researchers from geology, hydrology, and biology will permit the creation of new spatial statistical methods specifically designed to address problems in those disciplines.

Sidebar 9.1: Using geographic data to create new knowledge

Linkages:

Because of the strength of modeling and fusion research in academia, USGS geographers will work with university departments of geography and geographic information science to develop new methods and models. USGS geographers will nurture linkages with other Federal scientists (such as biologists, global change experts, and climatologists) to build domain-specific models. Linkage to software developers in private industry will permit USGS researchers to share in advances in commercial products that will be essential to the Bureau's models.

Performance Measures:

- Develop the ability to build and use spatial models to explore geographic data within specific domains and create new knowledge from these data (*within 2 years*).
- Develop an understanding of the offerings of spatial models (including their input requirements, methodologies, and outputs) as distillers or synthesizers of the terabytes of data created by the USGS (*within 3 years*).
- Establish model primitives that can be assembled on an ad hoc basis to create new models within specific domains (*within 3 years*).
- Generalize the domain-specific primitives for multi-purpose modeling within various domains (*within 5 years*).
- Develop an ability to couple models of different types and from different domains to create complex systems (*within 5 years*).
- Develop an efficient model building system that allows users within various domains to construct complex models from the set of basic primitives (*within 7 years*).

Highlight 8: Map-Projection Software for Global Raster Data Sets

USGS research in GIScience includes map and global database projections, a field where few other agencies have any expertise. In a recent project, USGS researchers determined that many commercial software packages fail to produce correct projections for global raster data sets, 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. Commercial software created the first map 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).

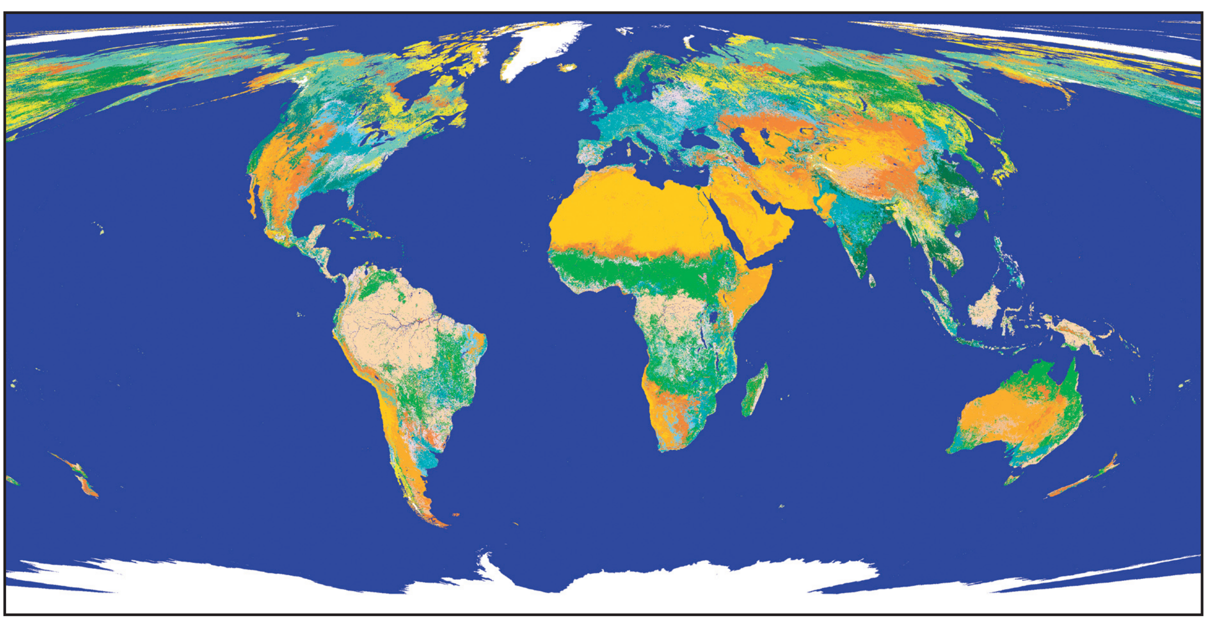


Figure 7a. Global land cover projected with commercial GIS software.

Highlight 8 *(cont.)*

The second map shows the same data in a superior product, projected with USGS *mapimg* software. This software, developed within the USGS, and other GIScience research results are available at *http://carto-research.er.usgs.gov*.

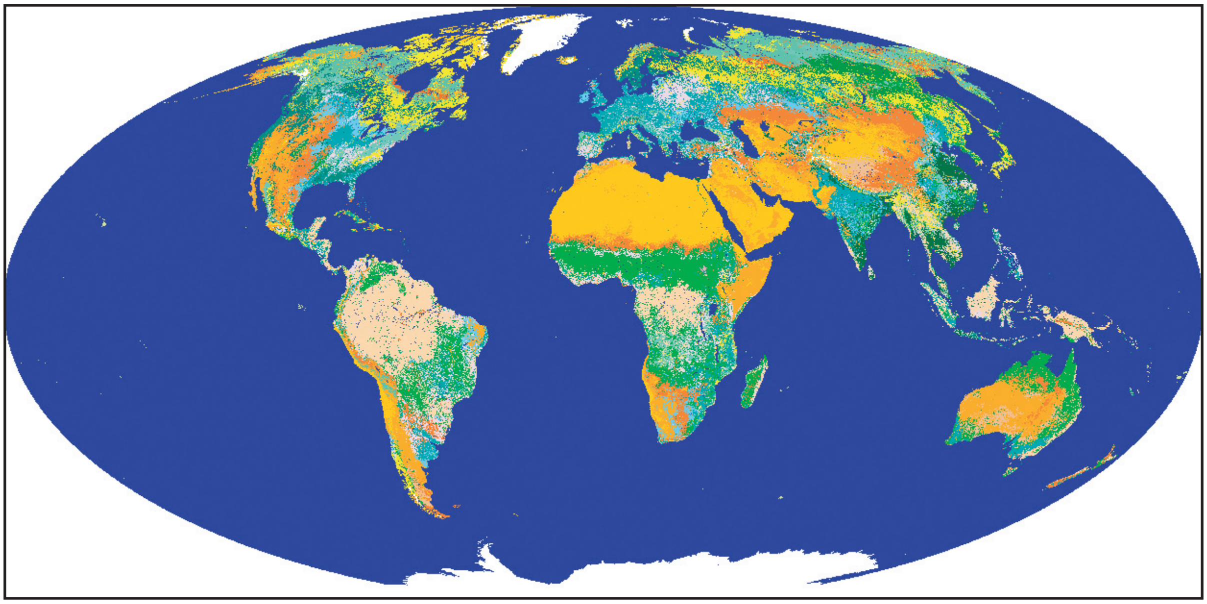


Figure 7b. Global land cover projected with USGS *maping* software.

Operational Objectives

During the next 10 years, the focus of USGS geography will change from an emphasis on production-oriented, cartographic excellence to emphasis on serving as a full research partner in USGS science activities. The transition to a focus on research and science partnerships will require a substantial transformation in the culture of USGS geography. Key components involved in this transformation include leadership, science management, communication, focused growth in the number of researchers, an effective annual science planning process, and the use of education to increase the understanding and use of geography to meet USGS and DOI objectives. The following operational measures will stimulate progress in attaining the science goals and provide benchmarks for evaluating progress in the transformation of geography at USGS.

Objective 1 – Greatly enhance the leadership on behalf of research-based geography at USGS.

Operational strategic action 1: By the end of the transition period, the Associate Director and Chief Scientist for Geography positions should be filled by scientists with recognized research expertise in geography.

The likelihood of realizing the science goals and the other objectives described in this chapter will be increased if both the Associate Director and Chief Scientist for Geography are experienced researchers with a record of competing for external grants, and have publication records equivalent to accomplished academic researchers.

Operational strategic action 2: To encourage a vibrant research culture, geography managers must recognize and reward accomplishments achieved under these science goals through the research grade evaluation system and through the allocation of funds in the annual budget process.

Operational strategic action 3: Proactively seek out collaboration opportunities with other USGS scientists that will advance USGS geography science priorities.

Successful completion of many of the strategic actions described in this plan requires collaboration with non-geographers. USGS geographers should take the initiative to define and contact potential collaborators, many of whom are already conducting geographic research.

Objective 2 – Increase the number of experienced, competent geography science managers that are excited about and committed to managing scientists on behalf of the science plan priorities.

During the science planning process, administrators and scientists identified the lack of research-oriented managers as a major problem. Although this circumstance is an understandable legacy of the cartographic era at USGS with its emphasis on production, production-oriented management is ill-suited to the demands of a new era of geographic science. Growing a corps of managers for geography science will not happen overnight, and will require a mix of training, mentoring, and consideration of alternative methods for increasing the number of science managers.

Operational strategic action 4: Develop a mentoring program to link current and potential geography science managers with exemplary USGS science managers.

A formal mentoring program will allow geography science managers to learn from experienced, successful science managers about a range of issues, ranging from hiring and supporting young researchers to creating a balanced science portfolio for a program.

Operational strategic action 5: Explore innovative approaches to expanding the number of science mangers.

Three options will expand the pool of well-qualified geography science managers. First, experienced managers from other USGS science areas can be assigned for time-limited (1-2 years) service as geography science managers. A second option is the use of a rotational model, drawing on a pool of scientists from across the USGS. Utilized with some success in other parts of the USGS, accomplished scientists rotate into a management role for a period of time (3-5 years) and then return to science positions at the end of the rotation. An advantage of the rotational model is that an increased number of people experience the responsibilities of managing their fellow scientists, and scientists develop a broadened understanding of the importance and challenge of good science management. Finally, science management training that includes both leadership and science management components should be offered to scientists interested in management responsibilities.

Objective 3 – Communicate and highlight the competencies of USGS geographers, identify the science needs of potential collaborators, and establish ongoing relationships with the geographic research community outside of the USGS.

In general, USGS geographers and their accomplishments have been largely invisible to scientists inside and outside of the USGS. Members of other science disciplines in the USGS often have little acquaintance with modern geographic research, and have low research expectations of their geographer colleagues. Visibility is not an aim itself, but in order to successfully collaborate with other scientists on behalf of the science goals of this plan, USGS geographers must be more assertive in reaching out to their counterparts inside and outside of USGS.

Operational strategic action 6: Publish an online, annually updated directory of USGS geographers that lists current primary project responsibilities, including a digital version that is searchable by keywords. Include in the directory scientists from other disciplines who are emphasizing geography in their work.

Operational strategic action 7: Publish an online, continously updated listing of all geography-oriented publications and conference presentations that is searchable by keywords.

Operational strategic action 8: Create constructive, project-based opportunities for geographers to communicate and interact proactively with USGS scientists from all science fields, using vehicles such as the Director's Venture Capital Fund, the Bureau's annual planning activities, and science-related outreach of the National Geospatial Programs Office (NGPO) state liaison offices.

Operational strategic action 9: Establish a standing Geography Science Council (GSC) in the Office of the Chief Scientist for Geography with representatives from Geography program offices, other USGS disciplines, DOI agencies, the Association of American Geographers (AAG), the NRC's Board on Earth Sciences and Resources, and prominent academic departments. The primary functions of the GSC are to increase awareness of geography issues, foster collaborative science opportunities, and serve as a sounding board to the Associate Director for Geography.

Objective 4 – Develop and implement a USGS geography workforce plan that supports a critical mass of geography researchers able to sustain a high level of excellence in research and applications on behalf of the priorities identified in the geography science plan.

This objective recognizes the need to increase the intellectual standards and vitality of USGS geographers in areas associated with DOI and Bureau science priorities. Strategic actions include provisions for focused development of new researchers in centers of excellence, a path for career advancement and professional development, and regular infusions of new intellectual energy through post-doctoral appointments and partnerships with academic geographers. The realization of the objective to increase intellectual standards and vitality will help elevate geography within the USGS to its rightful position as a full-fledged research partner. It also will propel the USGS to a position of national and international prominence in geographic research.

Operational strategic action 10: Develop a detailed implementation plan for three centers of geographic excellence in the areas of land change science, vulnerability and resilience science, and GIScience.

As described in the plan's Introduction section, centers of excellence are organized around groups of geography researchers possessing special knowledge or expertise in a particular area of concern identified in the science plan. These centers are particularly important during the transition from a production to a science-research geography orientation. The centers can provide a focal point for organizing science activities associated with the priorities of the science plan and an initial point of contact for scientists interested in the center's subject area. Each center can be effective with a minimum of 10 Ph.D. scientists, along with 10-15 scientists at a lesser grade level who work to support the research projects. 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. Core researchers include senior scientists who provide leadership and guidance for junior investigators. USGS 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 act as collaborators and direct colleagues on some projects. This includes scientists affiliated with NGPO State liaison offices who already are collaborating with other USGS scientists on integrated science projects. Center researchers will connect with universities and collaborate with academic colleagues. The vitality of the centers will be improved by short-term personnel exchanges. Centers will be staffed by new hires and current USGS scientists. All center scientists will be part of the RGE system.

The land change science center of excellence will primarily address science concerns associated with the land change science (goals 1-3) and the regional geography (goal 6) goals; the vulnerability and resilience science center will primarily address science goal 4 and goal 5 dealing with the integration of science and decisionmaking; and the GIScience center will primarily address goals 7-9. Center-affiliated scientists also will provide expertise and guidance across all three centers in the design and implementation of projects that provide integrated science solutions for geography-oriented science questions.

Operational strategic action 11: Implement the proposed USGS Land Cover Institute as a center of excellence prototype for land change science.

Operational strategic action 12: Develop a mentoring program to link current and new geographic researchers with successful USGS researchers.

Operational strategic action 13: Increase the 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.

Operational strategic action 14: In order to make the RGE/EDGE option more attractive to geographers, the Office of Chief Scientist for Geography should: (1) publish clear examples of research accomplishments associated with all grade levels above GS-11, with examples drawn from the Geography Discipline and including partial RGE/EDGE position descriptions; (2) provide appropriate training and mentoring as appropriate for geographers in the creation of research scientist records (RSR) used in the RGE/EDGE evaluation process; (3) provide scientists interested in the RGE/EDGE program a cross-walk between a scientist's 9-factor position description and a 4-factor research position description; and (4) 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.

Operational strategic action 15: Reinstate the Graduate School Training Program to train geographers and geography science managers; encourage scientists who complete the Graduate School Training Program to enter the RGE program.

Operational strategic action 16: Develop and provide short technical courses that are focused on specific skill acquisition supporting the priorities identified in the science plan.

A successful transformation of the focus of USGS geography from production to research will depend in large part on the skills and enthusiasm of the existing 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 current USGS geographers have used this program as a springboard to obtain an advanced degree. The program has provided a path for some of the USGS's most successful geographic researchers.

Operational strategic action 17: Evaluate and expand participation in the NRC's Postdoctoral Associateship Program and other programs, in support of the science goals of this plan and under the guidance of the Chief Scientist and the GSC.

The postdoctoral program will be especially helpful for adding socioeconomic expertise to understand the forces driving land change, society's vulnerability to the consequences of land change, and the efficacy of mitigation strategies. Support for these programs may come from a variety of sources. Some organizations sponsor and offer their own postdoctoral programs (for example, NOAA, NASA, and Department of Energy's Global Change Fellowships and the USGS Mendenhall Postdoctoral Fellowship), whereas others participate in formal programs established by other organizations (for example, the NRC's Postdoctoral Associateship Program).

Operational strategic action 18: Prepare a strategy to implement university partnerships that support the science priorities in this plan.

Strategic linkages with universities may be the quickest way to improve the critical mass of geography researchers at USGS. The USGS can collaborate with universities in a number of ways, including issuing grants to researchers with needed capabilities to accomplish priority research tasks; funding collaborative research that pairs university and USGS geographers to complete priority research tasks; increasing informal communications with university colleagues; 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 universities; encouraging scientist-to-scientist collaboration on outside-funded projects (such as the NSF, NASA, and private granting institutions); and placing staff at universities and other Federal agencies as is done by the Biology Cooperative Research Program.

Objective 5 – Develop a more efficient, focused process to guide annual science planning.

The existing annual geography science planning should be modified to provide clear, objective, and efficient procedures for setting priorities and funding targets and allocating funds for geographic researchers.

Operational strategic action 19: Adopt an annual science planning process that is consistent with overall Bureau planning procedures and DOI objectives beginning in FY06.

Develop and adopt a unified annual planning process that specifies new and continuing science opportunities and funding targets for all geography activities, mapped back to the goals and strategic actions of this science plan. It should emphasize accountability and measurable results and be coordinated through the Chief Scientist's office so that it can be consistent with the 5-year program science plans. The annual science plan should include descriptions, contacts, and funding targets for new and continuing work and be organized by the USGS Geography science goals and strategic actions. The descriptions of work for which new proposals are requested and guidance for ongoing project work should be 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 development of the annual science plan will involve a series of discussions among the regional science staff, program coordinators, senior scientists, and may include consultation with the Geography Science Council. These discussions synthesize results of consultations 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 program science plans that directly supports the overall science strategy.

Objective 6 – Expand geographic awareness of scientists at the USGS and DOI.

Geography's potential contributions to the USGS mission cannot be realized unless the level of geography awareness is elevated. Almost every societal issue that falls within the purview of the USGS mission has a geographic component, and a sound understanding of geography is fundamental to addressing these issues. Geography education is inextricably linked to 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.

- USGS geographers have a 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 are able to interact more productively with geographers and understand and use geography products more effectively.
- As the geography experts of the DOI's primary science agency, USGS geographers have an obligation to be aware of and respond to the Department's geography-related education and application needs.

Operational strategic action 20: Complete a needs assessment for basic and advanced geography education in the USGS and DOI.

Operational strategic action 21: Develop basic and advanced geography courses to be given at the National Training Center in Denver and other venues in collaboration with university partners.

Operational strategic action 22: Work with the GIO to use *The National Map* to expand the awareness of geographic concepts, tools, 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.

Operational strategic action 23: Develop a strategic implementation plan to expand geographic awareness of USGS and DOI scientists as one of the first assignments of the Geography Science Council.

Operational strategic action 24: 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.

The transition toward a full science-oriented partnership in supporting the USGS's mission will not be completed for several years. During this period, operational actions in leadership, science management, communication, workforce planning, science planning, and geography education will provide momentum supporting the evolution of the geography science culture at USGS. Most of these recommended operational activities can occur in the near-term; many do not require substantial expenditures of new funds as much as a new attitude and approach to conducting the core geographic science business at USGS.

Next Steps

This ambitious science plan describes how USGS will use geography to carry out a vital portion of its mission for the years 2005-2015. Development of geographic data and knowledge through research, assessment, monitoring, and effective communication and collaboration with those who rely on geographic data and knowledge will be cornerstones of the USGS geography contributions to the DOI and the Nation. Achievement of the science goals presented in this plan will require extensive partnerships, communication, and planning as well as leveraging of resources externally and internally across the USGS. The successful implementation of this plan will strengthen and establish new scientific directions that potentially have an enormous benefit to society. Therefore it will be critical to implement the plan well, set up performance measures and goals, carefully measure progress, and solicit critical review. Implementation of this science strategy will be the responsibility of the Associate Director and the Chief Scientist for Geography, with support from geographers located in all USGS science centers. The following steps will key the successful implementation of this science plan:

1) Communicate the ideas in this plan to the Director, the USGS Bureau Program Council, Regional Executives, and other scientists and managers and build support for the plan's priorities.
2) Create an implementation strategy to carry out the strategic actions outlined in the goals and operational objectives that cascades from the Associate Director, through Headquarters and regions, to the science centers.
3) Formulate a Geography Science Council to help establish the implementation strategy and begin implementation.
4) Adopt and use the science goals in planning documents and performance measures.

To learn more about USGS geography activities visit *http://geography.usgs.gov/*.

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GLOSSARY

A

Automated feature extraction – Automated algorithms that enable features to be extracted from larger geospatial data sets.

C

Carbon budget – The sum of the flows of carbon to and from a carbon reservoir.

Carbon flux – The movement of carbon dioxide (CO_2) into and out of the atmosphere.

Carbon sink – A physical site that absorbs or stores carbon dioxide (CO_2), such as the atmosphere, oceans, Earth's vegetation and soils, and fossil fuel deposits.

Clean Water Act – Established the basic structure for regulating discharges of pollutants into the waters of the United States and gives the U.S. Environmental Protection Agency the authority to implement pollution control programs such as setting wastewater standards for industry.

Climate Change Science Program – Integrates Federal research on climate and global change, as sponsored by 13 Federal agencies and overseen by the Office of Science and Technology Policy, the Council on Environmental Quality, the National Economic Council, and the Office of Management and Budget.

Coupled modeling – Linked, interdisciplinary models to provide more realistic models of environmental behavior.

D

Decision-support systems – Systems that integrate socioeconomic models and physical models of land change with geospatial databases to enhance the use of U.S. Geological Survey science results in policy analysis.

E

EROS – USGS National Center for Earth Resources Observation and Science, a science center whose responsibilities include national archive, production, distribution, and research for remotely sensed data and other geographic information.

F

Famine Early Warning Systems Network (FEWS NET) – Research initiative to strengthen the abilities of African countries and regional organizations to manage risk of food insecurity through the provision of timely and analytical early warning and vulnerability information.

G

Geography Science Council (GSC) – The primary functions of a U.S. Geological Survey Geography Science Council are to increase awareness of geography issues, foster collaborative science opportunities, and serve as a sounding board to the Associate Director for Geography.

Geospatial Multi-Agency Coordination (GeoMAC) – The Geospatial Multi-Agency Coordination Group or GeoMAC, is an Internet-based mapping tool originally designed for fire managers to access online maps of current fire locations and perimeters in the conterminous 48 States and Alaska.

Global Earth Observation System of Systems (GEOSS) – National and international cooperative effort to bring together existing and new hardware and software, making it all compatible in order to supply data and information at no cost.

Geospatial Information Office's National Spatial Data Infrastructure (NSDI) – The technology, policies, criteria, standards and people necessary to promote geospatial data sharing throughout all levels of government, the private and non-profit sectors, and academia.

Geographic Information Science (GIScience) – GIScience provides information about *places* on the Earth's surface, knowledge about *where* geographic features are located, and knowledge about *what* is at a particular location.

Global positioning system (GPS) – Use of satellite triangulation to determine coordinate locations for features on Earth.

H

Hazard – An agent or process of land change that has the potential to harm individuals, societies, and natural resources. Natural or human-induced hazards can manifest themselves as sudden perturbations or slowly increasing stresses beyond the normal range of variability in a system.

I

International Geosphere-Biosphere Program (IGBP) – An international scientific research program built on interdisciplinary networking and collaboration.

K

Knowledge Discovery (KD) – Technology that empowers development of the next generation database management and information systems through its abilities to extract new, insightful information embedded within large heterogeneous databases and to formulate knowledge.

L

Land-cover change – Knowledge of past, present, and future land use and land cover can be used to model, predict, and mitigate the effects of natural and anthropogenic hazards.

Landsat – Land Remote Sensing Satellite Program managed by the U.S. Geological Survey. The Landsat Satellite series began in 1972 to gather information about land surface features of the planet. Landsat 5, launched in 1984, and Landsat 7, launched in 1999, are still operational.

Land-Use Portfolio Model – A geographic information system-based tool for community multi-hazard mitigation analysis.

Light Detection and Ranging (LIDAR) technology – An active remote sensor platform.

LIDAR point cloud – A group of three dimensional points that can be used to create an elevation model.

M

Metadata – Information about data.

Moderate Resolution Imaging Spectrometer (MODIS) –Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands.

Multi-temporal assessments – Geographic analysis that incorporates data from multiple time dates to measure change over time.

N

NASA Earth Science Enterprise – An example of a multidisciplinary approach to problem solving that provides an opportunity for science collaboration.

NASA Global Inventory Monitoring and Modeling Studies (GIMMS) – The GIMMS group has been working with the NASA Commercial Remote Sensing Program and the Earth Satellite Corporation to provide scientific data to the Earth Science Enterprise (ESE) community.

National Acid Precipitation Assessment Program (NAPAP) – An interagency scientific research, monitoring, and assessment program on the effects of sulfur and nitrogen oxides on the environment and human health.

National Satellite Land Remote Sensing Data Archive – Residing in the U.S. Geological Survey's EROS Data Center near Sioux Falls, South Dakota, this collection of information is known legally as the National Satellite Land Remote Sensing Data Archive. It is a comprehensive, permanent, and impartial record of the planet's land surface derived from almost 40 years of satellite remote sensing.

Normalized Difference Vegetation Index (NDVI) – A method intended to separate vegetated and non-vegetated lands.

National Environmental Observatory Network (NEON) – Provides a state-of-the-art infrastructure to support interdisciplinary, integrated research and allow scientists to conduct comprehensive, continental-scale experiments on ecological systems. Each observatory is a consortium of universities and government agencies.

NSF Long-Term Ecological Research (LTER) – The National Science Foundation established the LTER program in 1980 to support research on long-term ecological phenomena in the United States.

Photogrammetry – The process of making maps or scale drawings from photographs, especially aerial photographs.

R

Regional Geography – Provides a cross cutting way of looking at processes and phenomena characteristic of a region, 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 among regions).

Remote Sensing – The measurement of an object with a device not in direct contact with the object; includes satellite imagery and aerial photography acquisition.

Resilience – Ability of a system to mitigate or adapt to potential hazards, as well as respond and recover from effects after an event.

Role playing simulations – Integration of video game technology to create more interactive simulations of geographic phenomenon.

S

Spatial Data Mining (SDM) – Methods, such as spatial statistics and data mining, to understand spatial data, discover relationships between spatial and non-spatial data, detect the distribution pattern of certain phenomena, and predict the future movement of such patterns.

Science Planning Team (SPT) – Composed of scientists representing all U.S. Geological Survey disciplines and the geography academic community.

T

The National Map – A consistent framework for geographic knowledge needed by the Nation; provides public access to high-quality, geospatial data and information from multiple partners to help support decisionmaking by resource managers and the public; the product of a consortium of Federal, State, and local partners who provide geospatial data to enhance America's ability to access, integrate, and apply geospatial data at global, national, and local scales.

U

U.S. Agency for International Development (USAID) – Principal U.S. agency to extend assistance to countries recovering from disaster, trying to escape poverty, and engaging in democratic reforms.

U.S. Carbon Cycle Science Plan – A strategy to deliver credible predictions of future atmospheric CO_2 levels, given realistic emission and climate scenarios, by means of approaches that can incorporate relevant interactions and feedback of the carbon cycle-climate system. The program will yield better understanding of past changes in CO_2 and will strengthen the scientific foundation for management decisions in numerous areas of great public interest.

U.S. Environmental Protection Agency Level IV Ecoregion framework – Level IV is a further subdivision of level III ecoregions. The level IV ecoregions were compiled at a scale of 1:250,000 and depict revisions and subdivisions of earlier level III ecoregions that were originally compiled at a smaller scale (Omernik, 1987).

U.S. Geological Survey Invasive Species Forecasting System – Integration of field data with remote sensing data and geographic information system-based predictive models to track the spread of invasive species across the country.

V

Vector-borne diseases – A vector-borne disease is one in which the pathogenic microorganism is transmitted from an infected individual to another individual by an arthropod or other agent, sometimes with other animals serving as intermediary hosts (for example, West Nile Virus).

Vulnerability – Potential for loss or damage. The vulnerability of human-environment systems is defined not only by exposure to hazards (both perturbations and stressors) but also in the sensitivity and resilience of the system.

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