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Facing Tomorrow's Challenges—
U.S. Geological Survey Science in the Decade 2007–2017

Circular 1309

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

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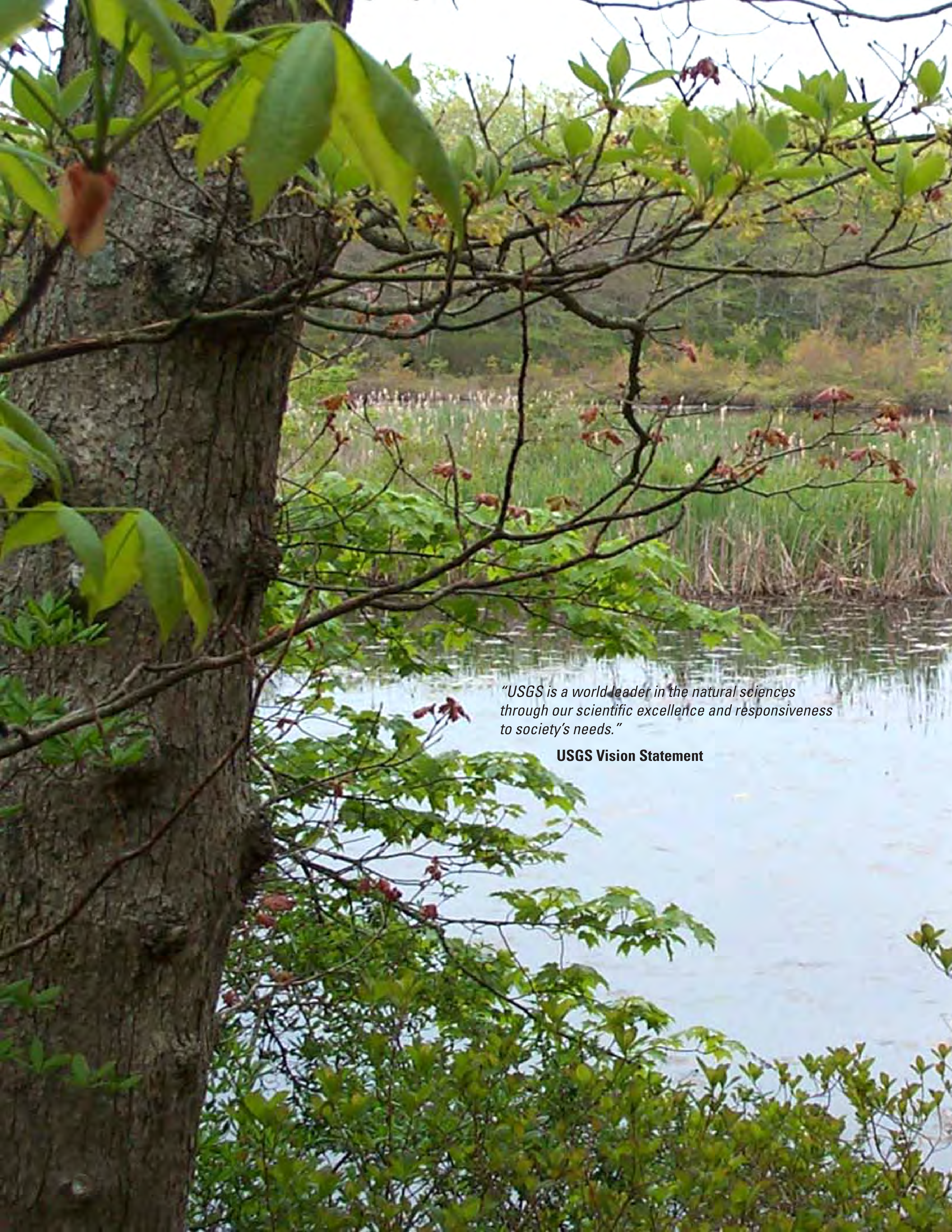
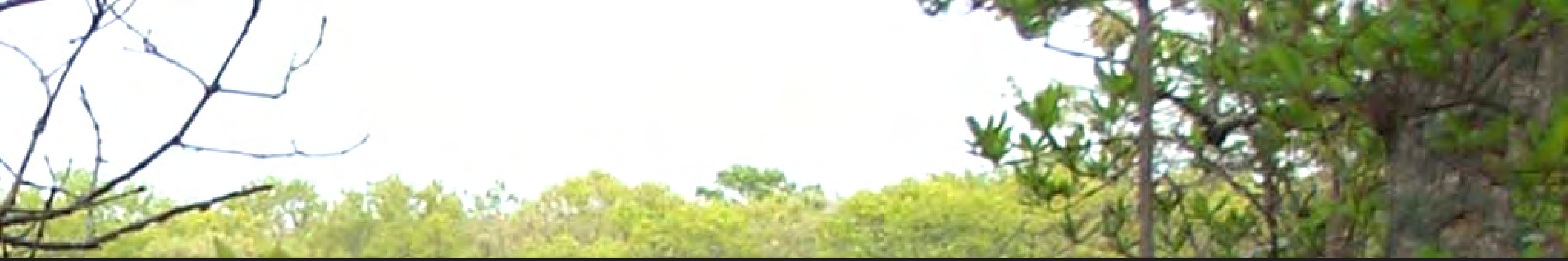


"USGS is a world leader in the natural sciences through our scientific excellence and responsiveness to society's needs."

USGS Vision Statement



Foreword
Facing Tomorrow's Challenges—
U.S. Geological Survey Science in the Decade 2007–2017

In 1996, the U.S. Geological Survey (USGS) drafted a strategic plan that considered the internal and external drivers and challenges we faced at that time. It was intended as a 10-year view of the future, establishing goals that would guide the USGS into the next century. It served its purpose well—but the drivers and challenges the Nation faces today are markedly different from those of 1996, and by 2006 the USGS needed a new strategic science vision.

The science strategy presented in this document was prepared by the Science Strategy Team (SST), a group of USGS scientists selected for its broad range of expertise, experience in strategic thinking, and proven customer relationship-building skills. The charter (see Appendix) tasked the SST to develop "… a comprehensive vision, with science goals and priorities that unite all bureau capabilities toward challenges for the future …." The major objective was to guide planning over the next decade by identifying opportunities for the USGS to better use its remarkable scientific capabilities to serve the U.S. Department of the Interior (DOI) and the Nation. The resulting high-level strategy does not reflect all aspects of USGS work; in fact, it does not directly deal with the details of many things that the USGS does extremely well and that are critical to the mission. The intent is that the science strategy will outline areas where natural science can make substantial contributions to the well-being of the Nation and the world. This strategy is intended to inform long-term approaches to USGS program planning, technology investment, partnership development, and workforce and human capital strategies.

This science strategy builds upon a hierarchy of planning documents. It provides a science-based response to the overarching DOI strategic plan and is a follow-up to the 1993 publication, "The U.S. Geological Survey: A Vision for the 21st Century." The present document differs from two previous strategic plans (those of 1995–2005 and 2000–2009), which were heavily operational in their focus. The current portfolio of USGS monitoring and research efforts has evolved under comprehensive planning processes at a variety of organizational levels. Planning documents have been produced at the discipline, program, center, team, and project levels. All of these previous planning efforts contributed to this report.

The process of developing the strategy was launched at a meeting of the full SST in early February 2006. Team members initially reviewed a range of strategy documents from a spectrum of governmental and nongovernmental sources. Within the USGS, the SST sought input from USGS program coordinators, senior scientists, an advisory group of about 50 USGS researchers selected for their breadth of expertise, a USGS leadership training class, and ultimately, the entire USGS workforce. Subsets of the SST met with groups of employees at several USGS worksites. A Customer Listening Session that focused on developing the science strategy was held in Washington, D.C., May 1, 2006, and SST members attended a session of the DOI Research and Development Council to brief and obtain information from key DOI partners. The SST thanks the many participants inside and outside the USGS for putting their time and energy into aiding in the development of this report.

As they reviewed this enormous amount of material, the SST looked for topics or directions that were innovative and transformational, served key clients and customers, had long-term national significance, allowed for expanded partnership opportunities, were integrative, and had an obvious USGS role. Ultimately, the choice of strategic science directions from within this framework was guided by the view that complexities of measuring, mapping, understanding, modeling, and predicting the status and trends of natural and managed resources in the United States transcend the traditional USGS structure and require broad interdisciplinary thinking and action. The science strategy thus defines priority areas and opportunities where the USGS can serve the Nation's pressing needs. This strategy unites and integrates all USGS capabilities and takes advantage of its strengths and unique position as a nonregulatory Federal science agency with national scope and responsibilities. Implementing these strategic directions will not only enable the USGS to be the best science agency it can be but will also strengthen the Nation with the information needed to meet the challenges of the 21st century.

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Abbreviations

BLM	Bureau of Land Management
CDC	Centers for Disease Control and Prevention
CSLF	Carbon Sequestration Leadership Forum
DOI	U.S. Department of the Interior
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FWS	U.S. Fish and Wildlife Service
GEON	Geoscience Network
GCMRC	Grand Canyon Monitoring and Research Center
IOOS	Integrated Ocean Observing System
LTER	The Long Term Ecological Research (LTER) Network consists of more than 1,800 scientists and students collaboratively studying ecological processes over extended temporal and spatial scales. The 26 LTER sites cover a diverse set of ecosystems. The National Science Foundation established the LTER program in 1980 to support research on long-term ecological phenomena in the United States. http://www.lternet.edu/
NASA	National Aeronautics and Space Administration
NEON	National Ecological Observatory Network
NIEHS	National Institute of Environmental Health Sciences
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NSF	National Science Foundation
NWS	National Weather Service
SST	Science Strategy Team
USFS	U.S. Forest Service
USGS	U.S. Geological Survey

Executive Summary

In order for the U.S. Geological Survey (USGS) to respond to evolving national and global priorities, it must periodically reflect on, and optimize, its strategic directions. This report is the first comprehensive science strategy since the early 1990s to examine critically major USGS science goals and priorities.

The development of this science strategy comes at a time of global trends and rapidly evolving societal needs that pose important natural-science challenges. The emergence of a global economy affects the demand for all resources. The last decade has witnessed the emergence of a new model for managing Federal lands—ecosystem-based management. The U.S. Climate Change Science Program predicts that the next few decades will see rapid changes in the Nation's and the Earth's environment. Finally, the natural environment continues to pose risks to society in the form of volcanoes, earthquakes, wildland fires, floods, droughts, invasive species, variable and changing climate, and natural and anthropogenic toxins, as well as animal-borne diseases that affect humans. The use of, and competition for, natural resources on the global scale, and natural threats to those resources, has the potential to impact the Nation's ability to sustain its economy, national security, quality of life, and natural environment.

Responding to these national priorities and global trends requires a science strategy that not only builds on existing USGS strengths and partnerships but also demands the innovation made possible by integrating the full breadth and depth of USGS capabilities. The USGS chooses to go forward in the science directions proposed here because the societal issues addressed by these science directions represent major challenges for the Nation's future and for the stewards of Federal lands, both onshore and offshore.

The six science directions proposed in this science strategy are summarized in the following paragraphs. The ecosystems strategy is listed first because it has a dual nature. It is itself an essential direction for the USGS to pursue to meet a pressing national and global need, but ecosystem-based approaches are also an underpinning of the other five directions, which all require ecosystem perspectives and tools for their execution. The remaining strategic directions are listed in alphabetical order.

Understanding Ecosystems and Predicting Ecosystem Change: Ensuring the Nation's Economic and Environmental Future

In collaboration with others, the USGS reports on the state of the Nation's terrestrial, freshwater, and coastal/marine ecosystems and studies the causes and consequences of ecological change, monitors and provides methods for protecting and managing the biological and physical components and processes of ecosystems, and interprets for policymakers how current and future rates of change will affect natural resources and society. The USGS works in collaboration with others to understand the distribution, interactions, condition, and conservation requirements of organisms in an ecosystem context, and predicts changes to biodiversity resulting from land-cover change, climate change, and other impacts to ecosystems. The USGS and its partners will advance understanding, through research, of ecosystem structure, function, patterns and processes, and will develop new products, including standardized national maps of ecosystems in the United States. They will also provide regularly updated reports on the status of ecosystems and assessment of trends that will help communities and managers make informed decisions that take into account ecosystem health and sustainability.

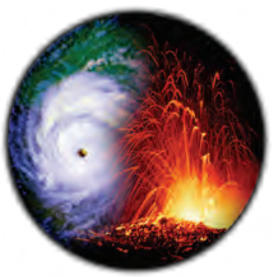
Climate Variability and Change: Clarifying the Record and Assessing Consequences

The USGS scientists will meet the pressing needs of the U.S. Department of the Interior, policymakers, and resource managers for scientifically valid state-of-the-science information and predictive understanding of climate change and its effects. Studies of the interactions among climate, earth surface processes, and ecosystems across space and time will contribute directly to the strategic goals of the U.S. Climate Change Science Program. To answer questions about how the world is changing, the USGS will expand its already strong research and monitoring initiatives in the science of carbon, nitrogen, and water cycles, hydroclimatic and ecosystem effects of climate change, and land-cover and land-use change. The USGS will continue studies of paleoclimate and past interactions of climate with landscapes and ecosystems, and apply the knowledge gained to understanding potential future states and processes. Expanded and modernized USGS observing networks of land, water, and biological resources will be crucial to rigorous analyses of future responses to climate change. The USGS will provide robust predictive and empirical tools for managers to test adaptive strategies, reduce risk, and increase the potential for hydrologic and ecological systems to be self-sustaining, resilient, or adaptable to climate change and related disturbances.

Energy and Minerals for America's Future: Providing a Scientific Foundation for Resource Security, Environmental Health, Economic Vitality, and Land Management

The USGS energy and minerals resource research will be broadened to contribute more comprehensively to discourse and decisions about future natural resource security, environmental effects of resource use, the economic vitality of the Nation, and management of natural resources on U.S. Department of the Interior, Federal and other lands. A wide-ranging, multidisciplinary approach is used to understand and evaluate how the complex life cycle of occurrence, formation processes, extraction methods, use, and waste products of energy and mineral resources influence, or are influenced by, landscape, hydrology, climate, ecosystems, and human health. Cumulative knowledge, long-term data, and new understanding of resource origin and assessment methodologies will improve the reliability and accuracy of national and global assessments and information products, especially as the energy mix evolves and new requirements for rare and scarce materials used by the Nation emerge. Information from the USGS resource cycle increasingly will be put in economic terms so that policymakers can more clearly weigh competing alternatives. Through partnerships and collaborations, USGS natural resource knowledge and expertise helps advance the Nation's economy and improve its competitiveness.

A National Hazards, Risk, and Resilience Assessment Program: Ensuring the Long-Term Health and Wealth of the Nation



The USGS collects accurate and timely information from modern earth observation networks, assesses areas at risk from natural hazards, and conducts focused research to improve hazard predictions. In addition, the USGS works actively with the Nation's communities to assess the vulnerability of cities and ecosystems and to ensure that science is effectively applied to reduce losses. The USGS will develop a national risk-monitoring program, built on a robust underpinning of hazard assessment and research, to visualize and provide perspectives at multiple scales of vulnerability and resilience to adverse land change and hazards. Accurate observations, focused research, and timely communications will safeguard people and property and keep natural hazards from becoming natural disasters.

The Role of Environment and Wildlife in Human Health: A System that Identifies Environmental Risk to Public Health in America

The USGS can contribute substantially to public health decisionmaking. The USGS monitors wildlife, is at the forefront of identifying wild animal disease reservoirs, and maintains critical knowledge about wild animal disease transmission to humans, drinking-water contaminants, air-dust-soil-sediment-rock contaminants, pathogens in recreational water, and the use of wild animals as sentinels of human health. To employ this expertise in support of the Nation's health needs, the USGS will fully integrate its massive data holdings and environmental science expertise to produce a national database and atlas of geology, and ecology-sourced diseases and toxicants. Once this atlas is in place, the USGS will partner with allied health science agencies to support spatially related health research.

A Water Census of the United States: Quantifying, Forecasting, and Securing Freshwater for America's Future

The USGS will develop a Water Census of the United States to inform the public and decisionmakers about (1) the status of its freshwater resources and how they are changing; (2) a more precise determination of water use for meeting future human, environmental, and wildlife needs; (3) how freshwater availability is related to natural storage and movement of water, as well as engineered systems, water use, and related transfers; (4) how to identify water sources, not commonly thought to be a resource, that might provide freshwater for human and environmental needs; and (5) forecasts of likely outcomes for water availability, water quality, and aquatic ecosystem health caused by changes in land use and land cover, natural and engineered infrastructure, water use, and climate.

The six strategic science directions outlined here are themselves interrelated. Their interaction, correlation, and interplay reveal the complexity of the Earth's natural, physical, and life systems. Developing new understanding, therefore, requires a "systems" approach that calls upon the full range of USGS capabilities. The USGS, with its breadth of scientific expertise, can provide an important perspective on the entire web of interrelated natural processes that affect national and global well-being.

Understanding the implications of these intricate linkages requires that data and information be readily shared among USGS scientists and collaborators, and with our partners and customers in forms suited to their needs, interests, and responsibilities. Thus, expansion of information technology to allow for seamless data and information sharing is an important component of the USGS science strategy. However, information technology is only one of the technological areas that will require continual updating. The USGS must keep abreast of advances in areas, such as environmental sensors, microbiology, nanotechnology, and many others that are now, or will become, critical to the mission. Therefore, the SST has identified two critical crosscutting science directions that are essential for the success of the science strategy:

Data Integration and Beyond

The USGS will use its information resources to create a more integrated and accessible environment for its vast resources of past and future data. It will invest in cyberinfrastructure, nurture and cultivate programs in natural-science informatics, and participate in efforts to build a global integrated science and computing platform.

Leveraging Evolving Technologies

The USGS will foster a culture and resource base that encourages innovation, thereby advancing scientific discovery through the development and application of state-of-the-art technologies.

The next decade poses formidable challenges, but it also holds unprecedented opportunities for USGS science to improve the economic and environmental health and prosperity of people and communities across the Nation and around the world. The USGS looks forward to applying the full breadth and depth of its scientific capabilities to meet the challenges of the 21st century.

Introduction

Formidable 21st century challenges form the backdrop for this U.S. Geological Survey (USGS) science strategy. Society must deal with a series of national and global trends that have major natural-science implications. First, the emergence of a global economy affects the demand for all resources. The world's natural resources, and the materials produced by people from those resources, are being used on a scale that is modifying the terrestrial, marine, and atmospheric environments upon which human civilization depends. The use of, competition for, and natural threats to resources on the global scale will affect the Nation's ability to sustain its economy, national security, quality of life, and natural environment. Second, the last decade has witnessed the emergence of a new paradigm for managing Federal lands—ecosystem-based management. By understanding the status of U.S. natural resources, how natural resources interrelate and change with time, and how resilient they are to future natural and human-caused threats, decisionmakers will be able to ensure the security of the Nation, the vitality of its economy, the health of its environment, and the well-being of its citizens. Third, the U.S. Climate Change Science Program (2005) predicts that the next few decades will see rapid changes in the Nation's and the Earth's environment. Land and resource managers will need to understand the local and regional implications of climate change, anticipate its impacts, and prepare for expected effects to reduce the potential for disaster. Finally, the natural environment continues to pose risks to society from volcanoes, earthquakes, wildland fires, floods, droughts, invasive species, variable and changing climate, and natural and anthropogenic toxins, as well as animal-borne diseases that affect humans. Some of these risks may be increased by changing climate and will be increased by the movement of the Nation's population into harm's way in coastal, earthquake-prone, and wildfire-prone areas. Understanding those health, resource, and hazard risks, better defining their probabilities, and forecasting their effect on the status and future of society are essential for a resilient and prosperous United States.

This decadal USGS science strategy will be implemented at a time when the Nation can benefit greatly by using natural science information in its decisionmaking. The USGS is well positioned to address the challenge of providing this information. It is the Nation's and the world's leading natural science and information agency. The workforce of nearly 9,000 scientists and support staff, distributed in about 400 locations, collects and interprets data from tens of thousands of hydrological, biological, and geological sampling sites throughout the Nation, its coastal zones, and Continental Shelves; these efforts, combined with its extensive remote-sensing capabilities, allow the USGS to map and understand Earth processes and changes. The USGS is uniquely suited to address the broad scope of natural-resource and natural-science issues facing the U.S. Department of the Interior (DOI) and the Nation, by using scientific tools at scales ranging from microscopic to global. The USGS brings a special set of temporal perspectives that range from deep geologic time to recent historic scales, and, with its predictive capabilities, to look to the future. The USGS does not have regulatory or land-management responsibility and has a worldwide reputation for objective, unbiased science. For the 127 years of its existence, the USGS has used its earth-science expertise to provide decisionmakers at all levels of government and citizens in all walks of life with the information and tools they need to address pressing societal issues and to help ensure the sustained health, welfare, and prosperity of the Nation. Over the last decade, the USGS: enhanced the Nation's understanding of the causes and the impact of natural hazards, wildlife disease, invasive species, and climate change; deepened the Nation's understanding of the economics related to water use and the potential for abundant high-quality water; contributed to the creation of new industries in minerals and gas hydrates; and provided for the testing of new theories of land management and prevention of loss through the availability of long-term information and a national array of interdisciplinary monitoring activities that includes remote sensing, imaging, seismic monitoring, streamgaging, and field study. The USGS maintains a broad scope of research activities and long-term data sets, such as:

- information relating to natural hazards, including earthquakes, tsunamis, volcanoes, landslides, and coastal erosion; energy and mineral resources; and geologic processes that affect the Nation's land and coasts;
- real-time flood data and information on the quality and quantity of surface- and ground-water resources;
- information critical to animal health, identifying and dealing with invasive species, biological species management, and ecosystems; and
- geospatial data, topographic maps, and satellite images critical to emergency response, Homeland Security, land-use planning and resource management.

As outlined in the body of this report, the USGS can build upon previous strengths and achievements by leveraging its talents and skills to undertake comprehensive and integrated studies that examine the Earth as a system in which biosphere, hydrosphere, lithosphere, and atmosphere are interrelated. This report recommends implementing a series of six science directions that were chosen to build on existing strengths and to optimize the USGS response to major natural science issues facing DOI and the Nation during the next decade. The Science Strategy Team (SST) considered a broad spectrum of information from inside and outside the USGS before deciding on the directions to emphasize. All these areas of emphasis are already being researched to some extent within the USGS, but the challenges of the future call for a substantial increase in, and integration across, disciplines of the current levels of effort. Central to the SST deliberations on the content of each of the six directions was a structured framework that addressed the need to (1) identify and measure key variables, (2) map the resulting data spatially, (3) understand the fundamental natural science processes involved, (4) monitor essential variables over time, (5) predict or forecast the future course of natural science events, and (6) engage stakeholders in the use of this information for problem-solving. Implementation of the strategic directions, likewise, will address these themes. The strategic directions are listed below. The ecosystem strategy is listed first. The remaining strategic directions are presented in alphabetical order.

Understanding Ecosystems and Predicting Ecosystem Change

- A new, comprehensive focus on terrestrial, freshwater, and coastal/marine ecosystems will be implemented. Knowledge of ecosystems is critical to the well-being of the Nation because ecosystems provide the natural resources and other goods and services that humans require. Understanding, mapping, monitoring, modeling, and advising DOI and the Nation on ecosystems are critical to balance land-use and land-change issues with human needs. Ecosystem studies require the full power of an integrated systems approach and thus are a perfect fit with USGS capabilities and strengths. During the next decade, the USGS will emphasize the fundamental research, mapping, and monitoring necessary to assess the Nation's ecosystem function, as well as begin to document and forecast change. Working with partners, the USGS will develop new products, including standardized national maps of ecosystems in the United States and regularly updated status and trends assessments, that will help communities and land and resource managers make informed decisions about sustainable resource use. The ecosystem strategy outlined in this report has a dual nature. It is itself an essential direction for the USGS to pursue in order to meet a pressing national and global need, but ecosystem-based approaches also underpin the other five directions, which all require ecosystem perspectives and tools for their execution.

Alpine tundra is projected to be vulnerable to changing climate. Here, scientists are collecting soils for chemical analysis. Loch Vale Watershed, Rocky Mountain National Park. Photograph by M. Hartman.

Climate Variability and Change

- The USGS scientists will meet the pressing needs of the U.S. Department of the Interior, policymakers, and resource managers for scientifically valid state-of-the-science information and predictive understanding of climate change and its effects. Studies of the interactions among climate, earth surface processes, and ecosystems across space and time will contribute directly to the strategic goals of the U.S. Climate Change Science Program. To answer questions about how the world is changing, the USGS will expand its already strong research and monitoring initiatives in the science of carbon, nitrogen, and water cycles, hydroclimatic and ecosystem effects of climate change, and land-cover and land-use change. The USGS will continue studies of paleoclimate and past interactions of climate with landscapes and ecosystems, and apply the knowledge gained to understanding potential future states and processes. Expanded and modernized USGS observing networks of land, water, and biological resources will be crucial to rigorous analyses of future responses to climate change. The USGS will provide robust predictive and empirical tools for managers to test adaptive strategies, reduce risk, and increase the potential for hydrologic and ecological systems to be self-sustaining, resilient, or adaptable to climate change and related disturbances.

Energy and Minerals for America's Future

- Two issues will dominate the energy and minerals resources picture in the future. One is the potential for domestic scarcity driven by global economic circumstances. The other is the likelihood that environmental impacts from energy and mineral extraction and consumption will factor more strongly into how we use resources. The strategy for future research in these areas is to link the resource and environmental sides of an expanded set of energy and mineral issues into a set of comprehensive resource "life cycle" studies.

A National Hazards, Risk, and Resilience Assessment Program

- The USGS is positioned to prepare the Nation to more effectively plan for, and deal with, natural hazards by implementing a national hazards risk and resilience assessment program. The USGS will enhance its ability to collect the critical information from modern earth-observation networks and deliver the data in real time, and we will expand its role as a primary source of the research to improve hazard assessments and predictions. In addition, the USGS and its partners in academia will work actively with the Nation's communities to assess the vulnerability of cities and ecosystems and to ensure that science is effectively applied to reduce losses. This risk and resilience assessment program will become an indispensable national asset over the next decade.

The Role of Environment and Wildlife in Human Health

- Nothing is more important to the Nation than the health of its citizens. A recent report by the National Health Statistics Group, at the Centers for Medicare and Medicaid Services of the U.S. Department of Health and Human Services, projects that U.S. health spending will continue to rise, reaching 20 percent of the gross domestic product by 2015 (Borger and others, 2006). The environment is one of the major determinants of human health. The USGS has the most comprehensive databases, sampling programs, and research programs, not only for determining national backgrounds of natural and anthropogenic toxins but, equally important, for understanding the processes by which these materials migrate through the environment. Zoonotic diseases (those transmitted from animals to humans), such as avian flu and West Nile virus, are major concerns in the United States and abroad. USGS biologists and ecologists have played a major role and will continue to do so in providing information to health professionals on the biologic pathways involved in disease transmission. The USGS will fully integrate its massive data holdings and produce a national database and atlas of geology, and ecology-sourced diseases and toxicants. Once this atlas is in place, the USGS will partner with allied health science agencies to support spatially related environmental health research.

A Water Census of the United States

- Water issues are critical to the Nation. A U.S. General Accounting Office (2003) report from July 2003 stressed that we do not have an adequate picture of water availability at national, regional, and local levels. The report stated, "National water availability and use has not been comprehensively assessed in 25 years." The Council of State Governments (2003) recently reported, "Water, which used to be considered a ubiquitous resource, is now scarce in some parts of the country and not just in the West as one might assume. The water wars have spread to the Midwest, East, and South as well." Water "…conflicts are occurring within states, among states, between states and the federal government and among environmentalists and state and federal agencies." Tribal governments "… are pursuing several legal battles to reclaim their water rights." Indeed it is time for a comprehensive water census of the United States, and the USGS will undertake this effort.

The six strategic science directions outlined above are themselves interrelated. Their interaction, correlation, and interplay reveal the complexity of the Earth's natural, physical, and life systems. Therefore, developing new understanding requires a "systems" approach that calls upon the full range of USGS capabilities. The systems approach is the major underlying theme of the entire USGS science strategy. Because climate affects all life on earth, the expanded USGS climate studies are inevitably linked to ecosystem, health, water, hazards, and energy issues. The USGS energy and minerals strategy will be broadened to deal not only with resource availability, but also with a broad spectrum of related land, water, and environmental concerns. This of necessity links the energy and minerals strategy to the USGS ecosystem, water, and climate studies.

The USGS, with its breadth of scientific expertise, can provide an important perspective on the entire web of interrelated natural processes that affect national and global well-being. To fully realize the extent and implications of these intricate linkages, this science strategy also identifies two cross-cutting science directions that are essential to the success of future USGS science: data integration, in which accessibility of data and information crosses multiple disciplines, geographic, temporal, and political boundaries to reach scientists, collaborators, partners, and customers in forms suited to the needs, interests, and responsibilities of each; and leveraging evolving technologies, in which innovative sensors and technologies have the potential to transform not only scientific methods, but also the questions that scientists ask. The USGS must keep abreast of advances in areas, such as environmental sensors, microbiology, nanotechnology, and many others that are now, or will become, critical to the mission.

The societal issues that these science directions address pose major challenges for the Nation's future and for the stewards of Federal lands. These directions will require the full breadth and depth of USGS energies and skills. The scope of each science direction is such that the USGS will need to work with partners to achieve all of its goals. Yet those goals can only be fully achieved by building on the foundation provided by the broad span of scientific expertise found in the USGS. The ability to explore these science directions across local, state, and national scales will enable the USGS to provide needed information to decisionmakers that is appropriate to the level of the challenges they face. Equally essential for decisionmakers will be the objectivity and credibility of the scientifically rigorous information that is a hallmark of the USGS, along with its unbiased, nonregulatory perspective. The USGS chooses these science directions not because they are easy but because they are critically important, will require the best of the organization to fulfill, and will provide information needed for solutions to the challenges facing the Nation.

The USGS is a public agency. Public support of science is primarily justified by three rationales (Sarewitz and others, 2004):

- Scientific advance is necessary to solve particular societal problems;
- Scientific advance provides the information necessary for making effective decisions; and
- Scientific advance is necessary to create new wealth.

Throughout its 127-year history, the USGS has contributed substantially to the national well-being in all these areas. The implementation of this science strategy over the next decade will strengthen and enhance this tradition of science in service to the U.S. Department of the Interior and to the Nation.

Mallik gas hydrate production test research project, 2002, in the Mackenzie Delta of the Canadian Arctic: The location was chosen because the research site has a high concentration of known gas hydrates. The project was conducted by an international consortium, including the U.S. Geological Survey, Geological Survey of Canada, U.S. Department of Energy, Japan, India, Germany, and the energy industry.

Understanding Ecosystems and Predicting Ecosystem Change:

Ensuring the Nation's Economic and Environmental Future

Background

Ecosystems constitute the Earth's biosphere and support human existence. The plants, animals, microbes, and physical products from ecosystems provide people, as components of those ecosystems, with the energy, water, biomass, medicine, and mineral resources needed to sustain human societies. Resilient, functioning ecosystems build soil, enhance pollination of crops, purify water, provide raw materials, regulate the atmosphere, cycle nutrients, and detoxify waste. These and other ecosystem services collectively provide the basis for all life on Earth.

For terrestrial, freshwater, and coastal/marine ecosystems to continue providing these benefits, human interactions with ecosystems need to be well managed, especially in the face of increasing global pressures. A proactive approach to managing ecosystems will require an advanced understanding, gained through research, of ecosystem structure, function, condition, and distribution. The ability to project future ecosystem states in response to societal pressures is vital to ensuring that ecosystems continue as the essential life-support systems for the Earth. Understanding ecosystems and predicting ecosystem change requires robust scientific assessments and modeling of ecosystem conditions as climate and human-induced land changes occur. There is a need to catalog and describe the set of human activities that impact ecosystems. Effectively managing ecosystems requires communication of the results from those analyses in a form useful for decisionmakers.

Ecosystems are inherently "interdisciplinary," with geographical, biological, geological, hydrological, and other components. The USGS is the only Federal agency that combines scientific expertise in biology, hydrology, geology, and geography and thus is uniquely positioned to advance understanding of terrestrial, freshwater, and marine ecosystems, and predict ecosystem change. The USGS, DOI's science bureau, provides science information not only to Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, and other land- and resource-management agencies, but to others throughout the world whose needs for integrated ecosystem science are growing as they increase their emphasis on sustainability and ecosystem-based management. In addition to forming an excellent science foundation for managing ecosystems across the Nation, the information, understanding, and tools and systems approach provided by this strategic direction will serve as a critical underpinning for the other USGS science directions.

There are many linkages between ecosystems and the other science strategies described in this science vision for USGS. For example, the effects of natural hazards can be greatly exacerbated by unstable ecological conditions. Debris flows from earthquakes or storms are made worse in the absence of vegetative cover on hillsides. The infilling of wetlands and subsequent build-up of infrastructure reduces the buffering capacity of coasts from hurricanes. Energy and mineral development can drastically alter local environments, as in the case of mountain-top mining and energy production, major contributors of greenhouse gas emissions. Development, resource use, and ecosystem modification alter and often increase the exposure of humans and wildlife to vectors of disease and contamination. Although there is often public conflict between uses of freshwater for societal and environmental needs, there is also growing recognition that the environmental uses of freshwater provide priceless services of purification, flood control, fish and shellfish provision, recreation, and spiritual renewal. Ecosystems not only directly respond to changing climate, but strongly affect global climate through feedbacks in surface reflectance and water and heat regimes. The distribution pattern of ecosystems on earth and the ability of ecosystems to cycle and store carbon and water are increasingly recognized as crucial components of the Earth's climate system.

Ecosystems are also inherently "multiscalar," spatially and temporally. They are usually recognized and managed at site-specific (local) scales, but are also described at broader scales from regional to global. Many natural resource conservation programs focus on ecosystems as an ecologically meaningful geographic area within which to assess, monitor, and understand biodiversity (species and populations) in terrestrial, freshwater, and marine environments.

Statement of Strategic Science Direction

In collaboration with others, the USGS monitors and reports on the state of the Nation's terrestrial, freshwater, and marine ecosystems, and studies the causes and consequences of ecological change, provides methods for protecting and managing the biological and physical components and processes of ecosystems, and interprets for policymakers how current and future rates of change will affect natural resources and society. The USGS works in collaboration with others to understand the distribution, interactions, condition, and conservation requirements of organisms in an ecosystem context, and predicts changes to biodiversity resulting from land-cover change, climate change, and other impacts to ecosystems. The USGS and its partners will advance understanding, through research, of ecosystem structure, function, patterns and processes, and will develop new products, including standardized national maps of ecosystems in the United States. They will also provide regularly updated reports on the status and trends of ecosystems that will help communities and managers make informed decisions that factor ecosystem health and sustainability into the decision process.

Large-scale, rapid change is now taking place in all natural systems throughout the world. Growing human populations and substantial alterations to landscapes, oceans, and the atmosphere have caused widespread changes in the global distribution and abundance of organisms. Changes in biodiversity alter ecosystem processes, productivity, and structure, and often reduce the resilience of ecosystems to future environmental change. Permafrost melting, landscape fragmentation, mining scars, forest clearing, and coral reef bleaching are just some of the many examples of ecosystem change. People value ecosystems in their own right, and as they decline, or even collapse, the environmental foundations upon which human society has been built may begin to erode.

Effective management of ecosystems and natural resources depends on a thorough knowledge of the types and distributions of ecosystems and their attributes, in concert with a comprehensive understanding of ecosystem processes and function. However, understanding of ecosystem condition, change, and causes of change is currently hampered by incomplete knowledge of the connections between and among species, including humans, and the environment. The United States currently lacks scientifically sound indicators of ecosystem condition, comprehensive maps of ecosystem distributions, and a rigorous ecosystem monitoring program. As a result, changes in ecosystem condition, whether for better or worse, will likely not be recognized, diagnosed, or understood at a national scale. These deficiencies hamper the Nation's ability to understand, forecast, and mitigate ecosystem change, assess ecosystem vulnerability to human activities, and avoid damage to regional and global ecosystems.

The state and fate of ecosystems and the services that they provide to human societies, previously of interest mainly to earth scientists and environmentalists, are rapidly emerging as a global concern of citizens, governments, and industry. There is an increasing need to identify adaptation and mitigation outcomes for climate-sensitive ecosystems; understanding how ecosystems evolve by adapting to change has become one of the cornerstones of the U.S. Climate Change Science Program. Recent reports by blue-ribbon panels, including the Heinz Center Report on the State of the Nation's Ecosystems (Heinz Center, 2002, 2006), the Millennium Ecosystem Assessment (2005), and the report of the U.S. Commission on Ocean Policy (2004), call for coordinated and comprehensive ecosystem monitoring and management. The National Ecological Observatory Network (NEON), a new 30-year National Science Foundation initiative, has been established to study ecosystem dynamics in a set of reference sites representative of the Nation's major ecosystem types. There is growing realization that it is impossible to separate economic development from the environment and that environmental degradation can undermine economic development.

Ecosystem management, defined as a strategy for the integrated management of land, water, mineral, energy, and living resources that promotes conservation and sustainable use in an equitable way (United Nations Environment Program/Convention on Biological Diversity, 2000), has emerged as a key component of the sustainable development paradigm. The Millennium Ecosystem Assessment (2005) and the State of the Nation's Ecosystems reports (Heinz Center, 2002, 2006) conclude that many ecosystems are compromised in their ability to provide the goods and services that sustain human societies. These reports, and a growing awareness of the critical links between people and their environment, underscore the importance of ecosystems for healthy societies.

Strategic Focus

In the coming years, the USGS will develop a priority focus on ecosystem science. As with other USGS programs, it will draw from, and expand upon, the agency's strengths in monitoring, research, modeling, and geospatial representation. The USGS will become recognized as the Nation's source for ecosystem science in support of decisionmaking and ecosystem management strategies at multiple scales. The goal will be to develop and convey a fundamental understanding of ecosystem distributions, and their components and dynamics, for terrestrial, freshwater, and marine ecosystems. Research will be conducted at a range of place-based scales, and results from this work will contribute to national-scale assessments. The

USGS ecosystem research will seek to answer several fundamental questions that underpin ecosystem science: (1) How do ecosystems work? (2) What are the appropriate indicators of ecosystem condition? (3) How are ecosystems changing? (4) What are the causes of these changes? (5) What are the probable consequences of these changes? (6) What are the consequences of different ecosystem management approaches? (7) What science support decisionmaking and management tools can be offered to policymakers, managers, and stakeholders?

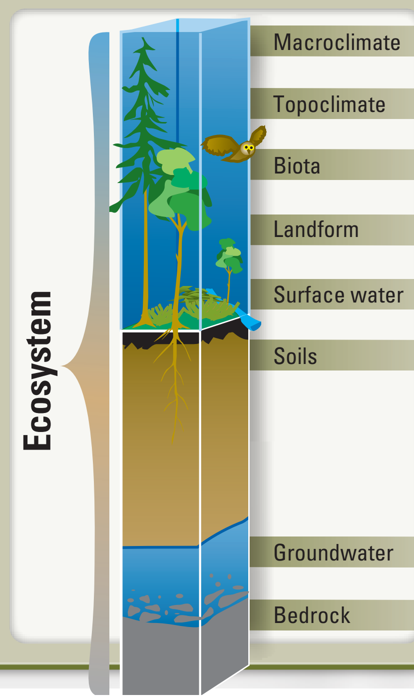
At national scales, the USGS and partners will develop a comprehensive, standardized geospatial ecosystem framework to support the mission of land management in America, and will establish a nationwide ecosystem monitoring program. They will develop and use critical indicators of ecosystem condition to provide regional and national assessments of ecosystem status and trends and will conduct basic and applied process research to understand the causes, consequences, and mechanisms of ecosystem change. Research will emphasize understanding the range of variability, both historical and human-driven, that can be accommodated by ecosystems before they experience irreversible change. The scientific basis for describing baseline conditions, as well as effective methods of monitoring, remediating, and restoring contaminated ecosystems, will be developed. Methods for protecting, mitigating, restoring, or adapting to human-caused and natural change will be developed, tested, and disseminated. The USGS will evaluate, forecast, and communicate the direction and uncertainties associated with ecosystem change beyond critical thresholds.

The USGS ecosystem science strategy, like all the strategies in this report, will be conceptualized in a "measure, map, understand, monitor, predict, and engage" framework, and will develop around several key themes:

- Research on how ecosystems work, and how and why they change;
- Development of a national geospatial ecosystems model that makes use of improved understanding of the relations among the biological (including species, natural communities, and land cover) and nonbiological (including physiography, lithology, hydrography, and climate) components of ecosystems, to provide decisionmakers and stewards of Federal and other lands with the means to better anticipate the consequences of changes in ecological processes or human activity on the ecosystems under their care;
- Monitoring of national ecosystem status and trends through use of objective, scientifically based indicators;
- Development of techniques for managers to use in managing, protecting, restoring, and evaluating ecosystems and the services that they provide;
- Development of ecotoxicological methods and techniques to measure, test, and evaluate the impact of continuing and emerging contamination threats to ecosystems and their biological components in terrestrial and aquatic environments; and
- Development of assessment tools that will enable a better understanding of ecosystem properties and processes for use in decisionmaking about the health and welfare of human societies and the environment.

What is an Ecosystem?

An ecosystem is an integrated system of organisms interacting with their physical environment. The cycling of energy and materials through these organisms and their environments (including soil, sediment, water, and the atmosphere) is a key ecosystem process. The distribution, composition, and abundance of organisms in space and time, the nature of their physical environment, the processes that support them, and the manner in which they respond to natural and human-driven change are the principal foci of ecosystem science. Ecosystems provide a framework for understanding the diversity of the Earth's physical and biological processes. Because organisms interact with the physical environment at all scales on Earth, from microbes around tree roots to the global biosphere, the boundaries around specific ecosystems are by definition a human construct. Nevertheless, defining discrete ecosystem units can be useful for management or conservation purposes.



The vertical structure of an ecosystem, showing the spatial integration of biological and nonliving components. Reproduced with permission from Robert G. Bailey (1996), Ecosystem Geography, Springer-Verlag, New York.

Strategic Actions

To provide science and decision-support tools for policymakers, resource managers, and the public, and to enable these stakeholders to better anticipate and predict the outcomes of their decisions, the USGS, in collaboration with partners, will:

- Conduct basic, place-based research into ecosystem structure, function, and processes. Characterize and quantify: (a) interactions between the biological and nonbiological components of ecosystems; (b) natural and anthropogenically caused ranges of ecosystem variability; (c) ecosystem biogeochemistry and soil ecology; (d) biodiversity conservation requirements; (e) ecological needs for water; (f) consequences of change to ecosystem components and processes; (g) the ecology of invaders, factors in the resistance of habitats to invasion, and methods to prevent and control invasive species so as to minimize their environmental impacts; (h) the effects of multiple interacting stressors at different levels of biological organization and temporal and spatial scale; and (i) vulnerabilities of the Nation's species and natural communities to stressors, including land-use practices, climate change, contaminants and invasive pests, diseases, and competing species.

- Coordinate, develop, and regularly update scientifically rigorous, standardized, geospatial classification models and maps of national ecosystems at scales appropriate

Elves Chasm, one of the many hanging gardens within the Grand Canyon. Photograph by Jeffrey Lovich, U.S. Geological Survey.

Ecosystem Monitoring Partnerships

The value society places on healthy ecosystems has led to a need for national and global ecosystem monitoring initiatives. Global ecosystem monitoring and reporting on levels of ecosystem protection are mandated by the intergovernmental Convention on Biological Diversity. Another intergovernmental protocol seeks to classify and subsequently map standardized global ecosystems as part of the Global Earth Observation System of Systems (GEOSS); USGS is the global task leader for this priority activity. Nationally, there are ongoing and emerging efforts to develop environmental indicators for routine statistical reporting on the state of the Nation's environment: examples include the Heinz Center State of the Nation's Ecosystems assessment, the National Ecosystem Observation Network (NEON), and the Council on Environmental Quality's Collaborators on Indicators for the Nation's Environment (CEQ/CINE) initiative. The USGS can make substantial contributions to all of these efforts. The Bureau of Land Management and the National Park Service have expressed interest in ecosystems as a standardized land unit basis and environmental context for assessing Federal lands. The USGS will partner with key Federal agencies, intergovernmental consortia, and national and international nongovernmental organizations to ensure that the best scientific information about ecosystems is available for decisionmakers.

Seney National Wildlife Refuge, Michigan. Source: John and Karen Hollingsworth obtained photograph from U.S. Fish and Wildlife Service Digital Library system**.**

to land-manager needs, to facilitate the ability to assess, monitor, manage, and restore ecosystems, as well as anticipate the outcome of changes in ecological processes or human activity on those ecosystems. Test different ecosystem classification and mapping approaches to investigate their utility for different management applications. Develop national ecosystem maps from a study of the connections between physiographic setting, geologic setting, climate, hydrologic regime, biogeochemistry, ecological processes and biotic distributions and interactions. Conduct long-term research on these relations at a set of reference study sites representative of major ecosystems in the nation, using existing long-term study sites [for example, LTER (Long-Term Ecological Research), NEON (National Ecosystem Observation Network), and existing USGS and other U.S. Government agency sites, such as U.S. Department of Agriculture (USDA) Forest Service Experimental Forests] and new sites to fill ecosystem representation gaps. Conduct complementary research at sites where substantial changes have occurred to identify changes unique to human-affected systems, thereby using the reference sites to distinguish among changes from human effects and changes expected due to the natural variability inherent in such systems, or changes due to biological perturbations, such as invasive species.

- Identify ecosystems vulnerable to ongoing changes of climate, contamination, and land use. Quantify the consequences of ecosystem and land-use change to water quality and quantity, health, hazard risk, biodiversity, and other ecosystem services to human society.

Eastern Land Change

Land change, the modification of the cover, use, and management of land, is one of the most obvious of all environmental changes. Land change results from natural forces and human actions; however, contemporary land change has largely been the result of human modifications. To better understand the status of ecosystems, the USGS is currently documenting the rates, causes, and consequences of contemporary land-cover and land-use change across the United States. Results of the analysis of the Eastern United States between 1973 and 2000 illustrate the complexity of the geography of land change. The average overall amount of Eastern U.S. land change between 1973 and 2000 was 12.5 percent, meaning that 207,000 km^2 of the 1.65 million km^2 area changed one or more times. However, the average amount masks the geographic variability of change, which ranged from a low of 2.0 percent in the Blue Ridge ecoregion to a high of 24.9 percent in the Southern Coastal Plain ecoregion. Most change was connected primarily to timber harvesting and urban growth. Across the East, agricultural lands are being converted to forest or are reverting to forest due to agricultural abandonment. Urban expansion, as measured by the increase in developed cover, is expanding and accelerating across the East. Other land-cover types, such as mining, water, and wetlands, are changing, but the rates of change are modest. The local importance of those changes may best be understood at the ecoregion level.

The consequences of the change on ecosystems are important. Land change alters the structure and function of ecosystems and can limit the availability of goods and services that are essential for ecosystem health and societal well-being. Land change directly impacts habitat quality and biodiversity, provides pathways for the spread of invasive species, and affects atmospheric chemistry, weather and climate, water quality and quantity, and other environmental systems. Because the resilience of ecosystems varies geographically, understanding change in a geographical and ecosystems framework is essential for managing the consequences of change.

Evaluate spatially explicit trends in ecosystem change. Identify environmental thresholds that signal transitions between ecosystem states. Advance understanding of the historical impacts (backcasting) of land-use change on ecosystems by documenting past land-use/land-cover conditions from historical remotely sensed imagery.

- Develop a multipartner, robust assessment of the status and trends of the Nation's ecosystems. Work with State and Federal agencies and other entities to form a National Advisory Committee on Ecosystem Information that will develop objective and rigorous indicators of ecosystem condition and publish regular assessments of ecosystem condition and trends in a nationally coordinated, regularly updated series of regional ecosystem assessments.

- Expand and modernize USGS observing networks by using new and emerging technologies for long-term observations of the physical and biological resources that directly and indirectly respond to land-use/land-cover change, climate, contaminants, and other drivers of ecosystem structure and function. Adopt and implement the National Science and Technology Council's Committee on Environment and Natural Resources (National Science and Technology Council, 1997) national environmental monitoring framework to assess and monitor ecosystems (1) at key, long-term, representative sites (for example, NEON, LTER, and USDA Forest Service Experimental Forests), (2) in a spatially extensive set of field locations (for example, National Water-Quality Assessment sites, Environmental Assessment and Monitoring Program sites, Breeding Bird Survey sites, and Landfire sites), and (3) through remotely sensed extrapolations of point data on ecosystems to regional ecosystem distributions and processes.

- Develop credible forecasts of responses to ecosystem stressors, including land use, climate change, contaminants, invasive species, and other threats to ecosystems, thus applying new knowledge of the thresholds that signal ecosystem decline and collapse. Use this information to develop "alternative ecosystem futures" scenarios, with well-defined uncertainty assessments that integrate biophysical, economic, social, and policy drivers. Develop scenarios of possible changes in species ranges and ecosystem distributions caused by changing climate environments using a geospatial ecosystem model that links the connections among physiographic setting, geologic setting, climate, hydrologic regime, biogeochemistry, ecological processes, and biotic distributions and interactions. Forecast possible ecosystem "migrations" by linking climate change models, models of current ecosystem distributions, and research-derived understanding of climate controls on ecosystem distributions.

- Work with DOI partners to evaluate and test restoration or mitigation methods and technologies for increasing ecosystem resilience to disturbances. Develop quantitative and standardized metrics with which to evaluate success or failure of restoration techniques in different types of ecosystems. Provide a public-access delivery system for integrated geospatial data that can be used to delineate user-specific ecosystems.

Vision of 2017

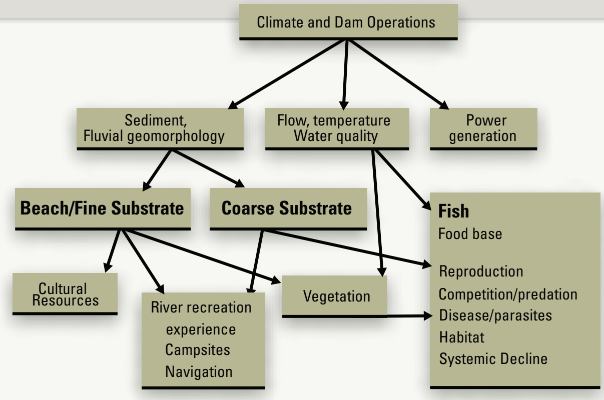
The USGS is the Nation's source for integrated science and assessment in support of ecosystem management in America. USGS scientists collaborate with others to provide definitive information on the nature, pattern, rates, and causes of ecological change across the Nation and on the consequences of change to human health and safety, ecosystem function and resilience, and the resources upon which human societies are built. A collaborative effort, led by USGS, provides regular assessments of the state of the Nation's ecosystems. These assessments of ecosystem conditions and trends inform decisionmaking on a routine basis. USGS science and methods provide the basis for continued conservation of natural and managed ecosystems, and, along with critical information on ecosystem functioning, underpin restoration efforts as well. In-depth understanding of ecosystem processes is integrated into simulation models that enable scientists and managers to forecast future ecosystem conditions. Comprehensive, multiscaled, online digital maps of the Nation's ecosystems and their physical and biological components are routinely used for management, education, and portrayal of change over time. Real-time ecological data, images, maps, and research findings are available to the public on interactive USGS Websites, along with scientific explanations of the state of ecosystems that are useful for scientists, for policymakers, and for the public.

Land use has dramatically altered the distribution and composition of forest lands in the Eastern United States, changing the structure and function of these ecosystems. The extensive loss of bottomland hardwood forests, for example, has affected water quality, increased the risks of flood, and altered the distribution and abundance of animals that depend on these forests, such as the ivory-billed woodpecker.

Integrated Ecosystem Science for Colorado River Management: A Case Study

The Colorado River is one of the most highly regulated and heavily used river systems in the world. Two principal reservoirs, Lakes Powell and Mead, along with 49 other large reservoirs, store and release water according to equations designed to maximize hydroelectric generation and to sustain cities, industry, and agriculture in an arid region. More than 30 million people depend on Colorado River water. The Colorado River Compact of 1922, negotiated by the seven basin States and the U.S. Government, divided use of Colorado River water between the upper and lower basin. All the water in the river was allocated to various societal uses. Water allocations were made during the wettest 10-year period in recorded history; paleoclimatic reconstructions and historical measurements have shown that the long-term average flow is 20 to 25 percent less than the amount of water allocated by the Compact. Today, with increasing demand for western water and recognition of the effects of river regulation on native fishes, riparian vegetation, estuarine wetlands, and the Sea of Cortez, the Colorado River faces many challenges.

The Colorado River and its watershed make up a system; changes upstream affect species and processes downstream. The Grand Canyon Monitoring and Research Center (GCMRC), an integrated USGS facility, is working to understand the important section from Lake Powell through the Grand Canyon to Lake Mead. Hydrologists and hydroclimatologists monitor past and current trends in river flow and provide interpretations and forecasts that are used by river managers to regulate flow. Water-quality experts report on the temperature and nutrient and contaminant loads of Lake Powell and the Colorado River downstream. These data are used by the National Park Service for the health and safety of visitors to Lake Powell, and, along with flow records, provide crucial information for management of the Colorado River ecosystem below Glen Canyon Dam. Research efforts focus on defining causal relations and identifying relations among physical, biological, recreational, and cultural processes. Sediment geologists using models, remote sensing, and innovative change-detection techniques calculate sediment budgets that are used to identify crucial habitats for endangered humpback chub and other fishes. Sediment transport patterns are critical to the stability of sand bars and beaches for camping, riparian vegetation, and protection of cultural resources of the Grand Canyon. Fisheries biologists add knowledge of sediments to information on food webs, water temperature, and the movements of nonnative species that prey on young humpback chub to develop a comprehensive picture of the dynamics of endangered fish populations. Terrestrial ecologists use maps and information on sediment movement to interpret the patterns of native and nonnative vegetation, such as tamarisk. Surveys of wildlife-vegetation interactions are used to monitor the populations of endangered Kanab ambersnails and southwestern willow flycatchers.



Conceptual model of the physical, biological, recreational, and cultural connections of the Colorado River ecosystem below Lake Powell. USGS scientists with expertise in archeology, fisheries, geospatial mapping, hydroclimatology, hydrology, sediment geology, and plant, animal, and aquatic ecology work together to understand the river system and provide managers with the best possible interpretations of how the system functions.

The Colorado River ecosystem from Lake Powell to Lake Mead is managed in an ecosystem context as part of the Grand Canyon Resource Protection Act of 1992. GCMRC is the cornerstone of the Glen Canyon Adaptive Management Program mandated by the Act. In addition to monitoring and basic research, adaptive management includes experiments, such as experimental flows, where scientists work together to evaluate physical, biological, and cultural responses to different management techniques. Already the results of the different experiments are providing new knowledge about ecosystems, and the findings are being included in management decisions. Common databases and frequent interactions among GCMRC scientists and their collaborators enable them to develop essential scientific information for optimizing the myriad uses and ecosystem needs of the Colorado River.

The Colorado River in Grand Canyon National Park. Photograph by Jeffrey Lovich, U.S. Geological Survey.

Extinctions and Invasions — Threats to Biodiversity

The Nature Conservancy calculates that one-third of the plant and animal species in the United States are at risk of extinction (The Nature Conservancy and the Association for Biodiversity Information, 2000). Extinction rates throughout the world are estimated to be 100 to 1,000 times their pre-human levels (Pimm and others, 1995). Species invasions have dramatically expanded with the world's increased globalization. What are the ecosystem consequences of these alterations in biodiversity?

Extinction is one way in which biodiversity influences ecosystems. Localized extinctions or significant changes in abundances may have large effects on ecosystem function. The hunting of sea otters to the brink of extinction by Russian fur traders in the 1800s resulted in the subsequent collapse of Pacific coastal kelp forests, which were grazed away by sea urchins released from sea otter predation. This same ecological event is now repeating off the western coast of Alaska, although the dramatic removal of sea otters during the last decade has been by killer whales. Killer whales shifted prey about 10 years ago from seals and sea lions to sea otters (Estes, 1998). The resulting loss of kelp forests in Western Alaska is accompanied by population declines in fish supported by kelp beds and in fish-eating marine birds.

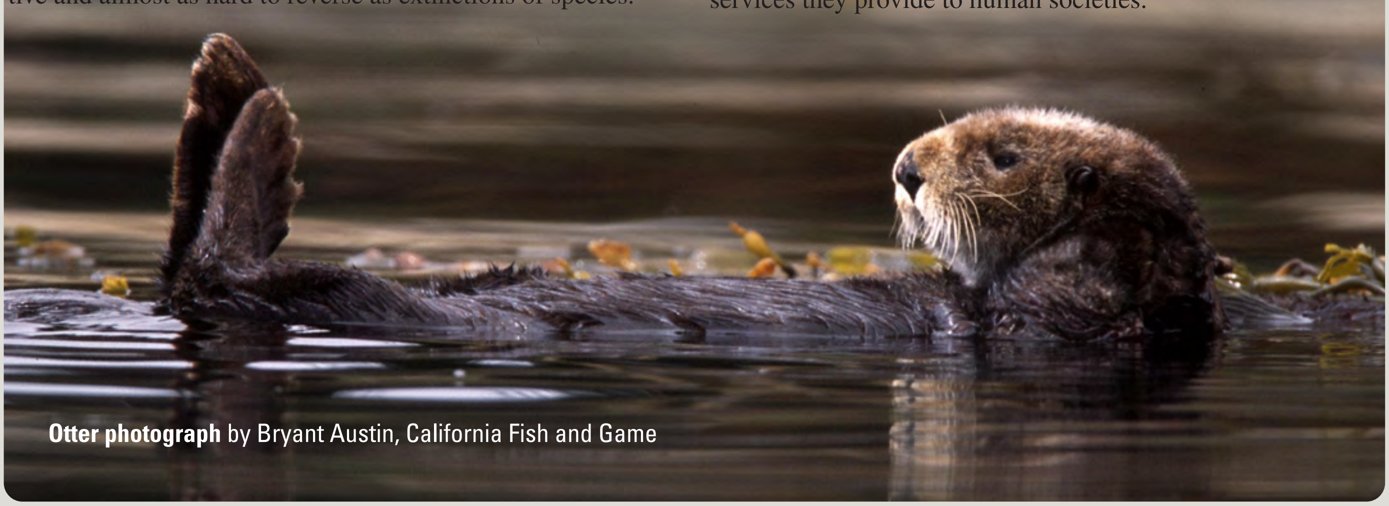
Insectivorous birds include more extinction-prone species than any other group of birds (Sekercioglu and others, 2004). The loss or decline of insectivorous birds in locations from orchards to coffee plantations results in increases in insect pests and plant damage. As invertebrate pests develop resistance to insecticides, and as pesticide use is restricted for other reasons, the ecosystem service provided by insect-eating birds is increasingly valued. Scavenging birds are important in the recycling of nutrients, leading other scavengers to dead animals and limiting the spread of disease to human communities. In 1997 more than 30,000 of the world's 50,000 rabies deaths took place in India, where feral dog and rat populations had exploded after the introduction of a new drug for cattle caused a precipitous decline in vulture populations.

Introductions of species to ecosystems can be as destructive and almost as hard to reverse as extinctions of species.

European green crabs in their natural habitat are smaller than those in invaded habitat. Photograph by Jeff Goddard, University of California, Santa Barbara.

Invasive species can rapidly and seriously degrade the quality of natural and managed lands and waters by altering natural processes and reducing biodiversity. Certain species, such as tamarisk, have dramatic effects on regional water balances; others, such as cheatgrass, permanently shift disturbance regimes from infrequent to annual fires, which suppress the native vegetation while allowing introduced grasses to flourish. Control methods that land managers use may also affect habitat. High-quality scientific studies on invasive species are urgently needed by DOI and other Federal land management agencies, Tribes, States, and communities throughout the United States and around the world. The USGS needs to take an interdisciplinary approach to create ecological forecasting models of harmful species distribution and effects and to develop an early detection and assessment capability for the Nation.

The consequences of altered biodiversity may be far-reaching to ecosystems and human societies. Disturbance regimes, feedbacks to climate, and cycling of nutrients and water are all influenced by the traits and diversity of organisms. Scientists are only beginning to understand the consequences of changes in biodiversity on ecosystems and the services they provide to human societies.



Otter photograph by Bryant Austin, California Fish and Game

Climate Variability and Change:
Clarifying the Record and Assessing Consequences

Background

Climate influences every aspect of life on earth, affecting human health and well being, water and energy resources, agriculture, forests and natural landscapes, air quality, and sea levels. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report of 2007 summarizes overwhelming evidence that global warming, due to human activities since 1750, is unequivocal. In addition to increases in global average air and ocean temperatures, observations find widespread melting of snow and ice, rising sea levels, widespread changes in precipitation amounts, ocean salinity, wind patterns and increasing occurrences of extreme weather, including droughts, heavy precipitation, heat waves, and intensity of tropical cyclones (Intergovernmental Panel on Climate Change, 2007). Objective and interdisciplinary science is needed to understand more clearly the complexity of global climate issues. The science will play an essential role during the next decade in helping communities and land and resource managers understand local and regional implications, anticipate effects, prepare for changes, and reduce the risks of decisionmaking in a changing climate.

With its long-term observational networks, extensive databases, and diverse scientific expertise, the USGS can provide the broad perspective needed to expand understanding of current climate variability, climate change, and their effects on the Nation's resources and economy. The USGS is working with local, State, and Federal partners to understand past climate variability and deliver credible future forecasts of climate-change effects on land, water, ecological and biological resources. DOI partners and other land and resource managers will benefit from its wealth of data, predictive models, and decision-support capabilities as they face the challenge of adapting to, or mitigating the risks of, climate change on ecosystems, biota, land and water resources, and communities across the Nation and around the world.

Statement of Strategic Science Direction

The USGS scientists will meet the pressing needs of the U.S. Department of the Interior, policymakers, and resource managers for scientifically valid state-of-the-science information and predictive understanding of climate change and its effects. Studies of the interactions among climate, earth surface processes, and ecosystems across space and time will contribute directly to the strategic goals of the U.S. Climate Change Science Program. To answer questions about how the world is changing, the USGS will expand its already strong research and monitoring initiatives in the science of carbon, nitrogen, and water cycles, hydroclimatic and ecosystem effects of climate change, and land-cover and land-use change. The USGS will continue studies of paleoclimate and past interactions of climate with landscapes and ecosystems, and apply the knowledge gained to understanding potential future states and processes. Expanded and modernized USGS observing networks of land, water, and biological resources will be crucial to rigorous analyses of future responses to climate change. The USGS will provide robust predictive and empirical tools for managers to test adaptive strategies, reduce risk, and increase the potential for hydrologic and ecological systems to be self-sustaining, resilient, or adaptable to climate change and related disturbances.

Climate change from massive and rapid restructuring of the global carbon cycle is one of the greatest global-scale experiments of all time, defined half a century ago as "a large-scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future" (Revelle and Suess, 1957). Although climate change is a natural, continuous Earth process, global climate cycles are now clearly being perturbed by increasing greenhouse gas emissions from human activities (U.S. Climate Change Science Program, 2005). Climate variability and warming over the past century have already had measurable effects on ecosystems, societies, economies, and health. Climate change contributes to sea level rise and to the frequency and intensity of wildfires, floods, crop failures, and outbreaks of disease and insect damage. Even though average precipitation is increasing as the climate warms, changes in the amount, timing, and distribution of rain, snow, and runoff are challenging the ability to manage the Nation's water supply. In the Arctic, where the average temperature has risen at almost twice the rate of the rest of the world since 1950, shoreline erosion, permafrost melting, and ecosystem changes are drastically reshaping landscapes, habitats, and economies. Projected changes in temperature and precipitation patterns in response to increasing greenhouse gas emissions throughout the twenty-first century are expected to intensify the effects on species, ecosystems, societies, economies, and health in many areas of the world (Intergovernmental Panel on Climate Change, 2007).

The consequences of global climate change and increasing carbon dioxide are of increasing public concern, and with good reason. The direct effects of warming, including heat-related deaths, such as those that occurred in Chicago in the 1990s or in Europe in 2006, are compounded by myriad indirect effects of climate change on various societal infrastructures, such as power blackouts and increasingly variable water supplies in many parts of the country. The barrage of media coverage of the consequences uncovered by scientists, from increasing disease outbreaks to acidification of the oceans, is now a daily occurrence. Complex and nonlinear physical, chemical, and biological interactions are becoming an increasingly important focus for climate change assessments and basic research (Burkett and others, 2005). As an example, nonclimatic variables, such as land use, fertilization or pollution, and variance in the way species respond to environmental factors, all combine to influence the way ecosystems respond to climate. When interactions among components of a system are not directly proportional, the system is considered nonlinear. Nonlinear relations are more common than not, but there is little insight into when biological thresholds will be crossed, much less on the implications for species, ecosystems, and the services society expects from the environment. Scientific insight into the direct and indirect, including nonlinear, effects of climate change on local and regional resources ought to be the catalyst for changes in planning and management of land, water, and other natural resources in the United States and elsewhere. If we can understand the linkages, we can better manage and adapt. During the next decade, the United States and other nations need to develop scientifically rigorous response strategies in anticipation of climatic events that are directional and increasingly variable. These strategies need to be proactive, effective, and adaptable. USGS will work closely with its many partners to produce the understanding and the tools necessary to anticipate, mitigate, or adapt, thereby minimizing the effects of climate change.

The USGS occupies a strong and unique role in the U.S. climate change science community and contributes directly to the U.S. Climate Change Science Program (CCSP). USGS is recognized for its research and monitoring efforts in the fields of hydrology, climate history, land-use and land-cover change, wildlife health, ecosystem science, carbon and other geochemical and nutrient cycles. The USGS contributes directly to the CCSP's intellectual framework of whole-system understanding of global change, including the interrelationships among climate change, ecological systems, and human activities. USGS long-term data sets together with its breadth of multidisciplinary scientific expertise—spanning geology, biology, hydrology, geography, and remote sensing—enables it to deliver integrated information, predictive scenarios, and technological tools for managing the Nation's water, land, plant and animal populations more effectively. Over the next decade, the USGS climate-change program will improve the integration and utility of climate-change research results to land and water management agencies.

Climate Change in Alaska

Arctic climate is warming rapidly and will continue to do so. Warming in the Arctic is causing changes in nearly every physical and biological process, and the consequences to wildlife, vegetation, people, and infrastructure are already being observed. Temperatures have increased sharply in recent decades, especially in spring and winter. River discharge has increased, spring snowmelt occurs earlier, snow cover has declined, and rainstorms are increasing. These changes have altered the delivery of carbon and nutrients from landscapes to aquatic ecosystems. Permafrost is warming, melting, and retreating northward. Given the large spatial variability in the rates and extent of physical change, current monitoring is inadequate (Arctic Climate Impact Assessment, 2004).

The ability to monitor, and thus understand, the responses of vegetation, animals, and ecosystem processes to these physical changes also is inadequate. Treeline and tundra are expected to move north and to higher elevations. Although expanding forests may store more carbon aboveground from the atmosphere, warmer soils may release as much carbon or more (Wickland and others, 2006; Striegl and others, 2005). Insect outbreaks and wildfires are likely to increase in severity. Reductions in sea ice are shrinking marine habitat for polar bears, ice-inhabiting seals, and some seabirds. Species ranges are expected to move northward, bringing new species to the Arctic—and animal diseases that also may affect people (West Nile virus, avian influenza). Broad arrays of observations will be needed to understand what climate change means to these vast yet variable landscapes.

A principal focus of USGS research in boreal forests and the Arctic is based on the hypothesis that the soils there, which contain large amounts of carbon, could release substantial amounts to the atmosphere as soils warm and microbial decomposition converts the soil organic matter to carbon dioxide and methane. Both of these are greenhouse gases. It is plausible that the rates of emission from vast areas in Canada, Alaska, and Siberia could approach, within an order of magnitude or so, the rates of greenhouse gas emissions from fossil fuel burning. Given this prospect, additional monitoring and research are highly warranted.

The challenge is to understand which landscapes are more or less responsive to climate change and how such landscapes will change over the coming decades (Arctic Climate Impact Assessment, 2004).

Arctic warming also poses serious threats to existing and planned infrastructure. Shoreline communities and facilities are increasingly exposed to storms and shoreline erosion. Thawing ground is disrupting transportation, buildings, and pipelines. Winter periods when ice roads and tundra are sufficiently frozen to permit travel have already declined from 200 days to 100 days per year in some parts of Alaska, affecting oil and gas extraction and forestry industries (Hinzman and others, 2005). Monitoring networks to measure and minimize the hazards to communities and industries are either nonexistent or so widely spaced that they provide mere anecdotes instead of comprehensive information (Arctic Climate Impact Assessment, 2004).

A concerted and sustained USGS effort in Alaska, launched as part of the 2007 and 2008 International Polar Year, will establish and operate physical and biological monitoring networks, increase scientific collaborations within and outside the USGS, and clearly communicate findings.

Photograph of thermokarst and dying forests on the Tanana Flats in central Alaska taken in 1999 by Torre Jorgenson.

Strategic Focus

The USGS will apply its traditional strengths in monitoring, research, integration, modeling, and analysis to help the Nation understand and prepare for climate change and its effects. By drawing on scientific strengths in land surface dynamics, sea level and coastal dynamics, hydrologic dynamics, and ecosystem dynamics, three strategic areas of monitoring, research, and assessment will form the foundation of the USGS climate change strategy:

(1) Monitoring: Shifts in abundances, distribution, behavior, phenology, and genetic makeup have been documented in a number of species in response to changing climate. Populations tend to shift their distributions poleward or upward in altitude, or as in some species in the Arctic, landward, as sea ice diminishes. A systematic effort to monitor and document these changes will allow the possibility that ecosystem management may be able to compensate and manage for resilience. USGS will develop new assessment biological techniques to be applied to species, populations, and physical variables within and between ecosystems with climate change as the major variable in common. USGS also will continue to gather and analyze information about land-cover and land-use change, water, earth surface processes, species, and ecosystem function, and integrate these into the National Climate Change Response research program. The long-term data records for which USGS is so highly respected are the underpinnings of understanding and insight into the interaction of climate with the Earth's physical and biological environment. By collaborating with other agencies and scientists, and serving as the clearinghouse for multiagency monitoring networks that collect climate-change-effects information across public lands, USGS will be able to answer questions about how the world is changing for the science community, public, and managers of public lands. One example is to develop, with partners, a national-scale understanding of baseline physical and biological soil characteristics as a basis for evaluating their responsiveness and resistance to climate change and other anthropogenic influences. USGS will establish altitudinal transects at different latitudes within the United States to begin systematic and coordinated examination of changes in plants and animals and the physical environment for ecosystem managers of vulnerable environments. Altitudinal transects would be patterned after, and coordinated with, GLORIA, the international Global Observation Research Initiative in Alpine Environments that measures range expansions and contractions in mountains worldwide. Through monitoring and analysis, USGS will provide a steady stream of descriptive and interpretive products in hydrology, glaciology, land cover, landscape, geochemistry and biogeochemistry, sea-level changes, phenology, species distributions, and ecosystem function.

(2) Research: The USGS will conduct research to advance the knowledge of processes that are crucial to predicting the future evolution of global climate and to understand the land, water, environmental, and societal consequences of changing climate. This research includes improving understanding of the terrestrial carbon cycle, especially in rapidly changing arctic, alpine, and boreal environments, understanding how disruptions of other major biogeochemical cycles, such as nitrogen, interact with carbon cycle changes in a wide range of ecosystems, and understanding the effects of changes in land-surface interactions and hydrologic systems (rivers, ground water, and soil moisture) because of shifting patterns of precipitation and temperature. With a focus on environmental consequences, research will emphasize the linkages between climate and land-use change on biogeochemical cycles, disturbance frequency, land-surface processes, and biodiversity and species interactions in terrestrial, aquatic, and marine environments. Mechanistic models will be developed to portray understanding of global change processes at all scales from point-scale to global. Studies of the probability and consequences of abrupt changes and thresholds will be used to clarify the nature of change and the effects on the environment and society. For example, studies of the thresholds and potential ecosystem health effects of climate change are critical to DOI's understanding and management of the Nation's treasured natural resources.

A National Phenology Network

Phenology is the study of the times of recurring natural biological phenomena, especially in relation to climate. It is recording when the first robin arrives in the spring, or when the lilacs bloom. Records of shifts in phenology, or seasonal timing of flower development or other vegetation changes, animal migrations, hibernations, and the seasonal activity of cold-blooded animals, do more than simply provide powerful indicators of climate variability and change. Variations in phenology have consequences for individuals and can scale up to broader ecological dynamics. Spatially replicated phenological studies at the continental scale can reveal much about the ecology and status of species, communities, and ecosystems (Post, 2003). The timing of pollen and spore production influences human health. The ability of pollinators to arrive at the right time affects agricultural productivity. Large-scale patterns of response to climate can be detected with a national phenology network. This type of information will become increasingly important to natural resource managers as they develop scientifically appropriate responses to climate change (Inouye and others, 2000; Betancourt and others, 2005). The USGS will work with other agencies, nongovernmental organizations, and universities to implement a national phenology network and develop the tools to analyze the data at multiple scales.

(3) Assessment: USGS will develop forecasting tools, including simulation models and adaptation methodologies, which resource managers can use to test management options for, and potential effects on, land, water, biological and ecosystem resources. This assessment will require integration of disciplinary research in the development of complex models of ecosystem dynamics and land-surface-vegetation processes. Feedbacks and linkages between water, land use, soil, ecosystems, and climate change will be studied and modeled at a range of scales so that understanding and interpretations can be useful to resource managers, policymakers, and the public at local, regional, and national levels. Existing watershed and ecosystem scale process models will continue to be refined and applied to sites and regions of interest to resource managers. Simulations of coupled continental and global scale land-surface, ocean, and atmospheric processes will continue to inform global climate models about crucial feedbacks between the atmosphere, biosphere, and oceans. Models and methodologies are not perfect predictors of future events, and as such the levels of confidence and uncertainty with which they are intended to forecast the potential effects will need to be fully communicated. For example, important questions we face in defining climate-change effects on water resources are related to the potential changes in the timing and amounts of runoff, ground-water recharge and discharge, snowpack, and soil moisture decades into the future. It is critical that information about climate uncertainties, in conjunction with other factors, such as land-use and water-use changes, be included into forecasting tools to better plan for the development and management of America's future water resources. The same is required for ecosystems, landscapes, coastal systems, energy development, and human health.

Calving glacier. Source, Steven Schwarzbach, U.S. Geological Survey.

Nearly all climate change scenarios assume the global supply of primary energy will grow and continue to be dominated by fossil fuels until at least the middle of the century. This means the concentration of carbon dioxide in the atmosphere will continue to increase. Greater understanding of the global carbon cycle may improve understanding of ways by which carbon can be effectively removed from the atmosphere and safely stored and otherwise sequestered. Carbon capture and storage options have the potential to reduce overall mitigation costs and perhaps increase the flexibility in achieving greenhouse gas emissions reductions, but many questions remain regarding the geological and geochemical conditions for optimal storage. Potential technical storage methods are in oil and gas fields, unminable coal beds, and deep saline formations (Intergovernmental Panel on Climate Change, 2005). The USGS possesses critical expertise for developing the scientific understanding necessary to storing carbon in geologic reservoirs.

The DOI is directly responsible for managing 1 out of every 5 acres of land in the United States, including vast water, ecosystem, and other trust resources. DOI is on the front line of response and decisionmaking regarding climate change and its complex implications for management of multiple resources. The diverse analytical skills of USGS will be brought to bear in providing understanding and tools for land and resource managers to be effective in a world where it is less certain how the climate is changing. The concept of stationarity—that the recent past is a good predictor of the future—no longer holds. There is a need to develop new, process-based constructs to answer resource

Climate Change Response: Enhanced Assessment of Temperate Ecosystems

A system of long-term transects that compose an enhanced and systematic assessment of the ecological, hydrological, and climatological variables associated with a warming climate will be used to document and gather data to model and predict changes in vulnerable ecosystems and populations. This systematic method of studying response to climate change will include a complexity of responses and scales, and will involve multiple tools and disciplines from genetics to demography to remote sensing within and across ecosystems. USGS will collaborate with universities and other partners to set up a series of landscape-scale permanent transects from low to high elevations, repeated at different latitudes from subtropic to boreal (width to be determined). These large-scale transects will permit USGS scientists to look at the center and margins of species ranges, as well as coordinate climate-change studies of responses in a range of ecoregions and their transition zones. The transects will include vascular and nonvascular plants, vertebrate and invertebrate wildlife, and the physical environment. This systematic effort will allow a synthetic overview for major ecosystems of the United States and allow for predictive modeling of ecological responses to climate change in the United States.

Tents dot the Greenland landscape at a research camp in July 2006. Scientists from many organizations, including the USGS/NSF National Ice Core Laboratory, are working on the National Science Foundation's West Antarctic Ice Sheet Divide Project to collect deep ice cores in central West Antarctica during 2007–09. The cores provide information, such as temperature, precipitation, atmospheric gas composition, and volcanic eruptions that help researchers better understand the changing climate. Photograph by Brian Bencivengo, U.S. Geological Survey.

planning and management questions. What scientifically grounded understanding can USGS provide to the Bureau of Reclamation and others for planning and managing water resources? How can managers of the National Park Service and National Wildlife Refuge increase the resilience of populations and ecosystems in their care to climate-related disturbances? What do we need to know regarding the structure and function of the Nation's soils to manage them under changing climates? What are the interactions between climate and disease that influence wildlife, forest, and human health? What are the interactions between climate change, energy resource extraction, and feedbacks to the environment on DOI lands? Where are the geologic formations most conducive to safe and effective geologic carbon storage? These kinds of questions illustrate the breadth of topics USGS can contribute to across the Nation, and also emphasize the linkage of the climate change science strategy with all other science strategy directions. Within climate change science, USGS has a timely and urgent opportunity to contribute directly to the present and future health and welfare of the Nation.

Strategic Actions

- Create, expand, and modernize existing USGS observing networks using new and emerging technologies for long-term observations of the physical and biological resources that directly and indirectly respond to climate. Explicitly design observational transects for ecosystem response to climate change along altitudinal gradients at different latitudes on Federal lands within the United States that integrate hydrological, climatological, chemical, and biological variables into a national assessment of ecosystem, species, and population responses to climate change—observed and predicted.

- Provide national-scale integration of multiagency monitoring networks that collect information on climate-change effects across public lands, especially those managed by DOI, and make these data and their synthesis products widely and publicly accessible.

- Report regularly on the Nation's environmental and natural resource condition and response to climate change. Evaluate and interpret regional and national trends, potential thresholds, and consequences of climate change to decisionmakers, emphasizing what is known and what is uncertain about effects on the Nation's land, water, and ecosystems and their biota.

- Increase understanding through research of the direct and nonlinear interactions between climate and physical, chemical, and biological forces that influence the structure and functioning of ecosystems and the goods and services they provide. At local to regional scales, understand the implications for plant and animal species, landscapes, and human communities; at the global scale, understand the implications to climate, biosphere, and oceans.

- Continue and expand hydroclimatological research to understand the feedbacks between climate and hydrology that affect the timing, intensity, and duration of floods and droughts, the effects of changing seasonal snowpacks, and how these relate to water quality and freshwater supplies for society and the environment.

- Reconstruct climate paleohistory and climate-related ecological, biological, and physical responses, building on current strengths, to understand patterns of natural variability and provide a baseline to better understand changes currently taking place, as well as future scenarios.

- Enhance understanding of the linkages between climate and the major biogeochemical cycles in soil, vegetation, freshwater, and oceans. In addition to the carbon cycle, studies of the interactions of carbon with nitrogen, phosphorus, and water are crucial. Participate in national and international efforts to develop and improve models of global systems that include land surface–atmosphere-ocean linkages, ice–albedo feedbacks, permafrost processes, vegetation change linkages to land surface properties, and landscape change. Through research and modeling, provide the scientific understanding for evaluating options to manage carbon sources and sinks by identifying the size, variability, and potential future changes to reservoirs and fluxes of carbon within the Earth system.

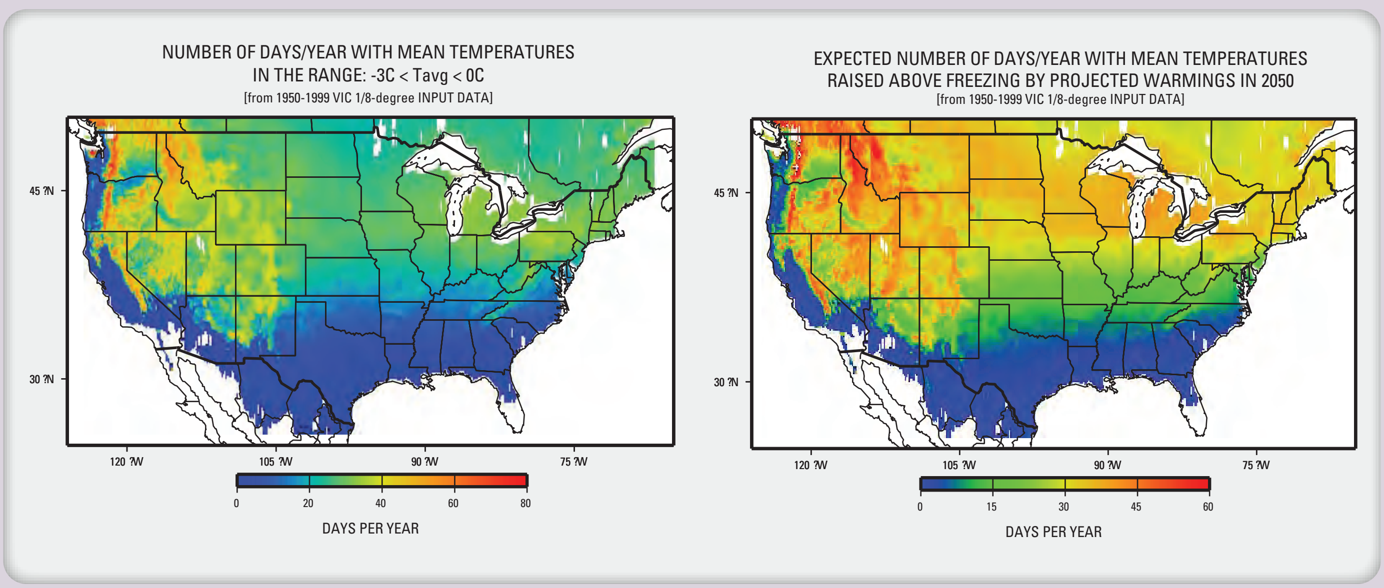
- Develop adaptation and mitigation methodologies with resource management partners, particularly in DOI, that can be used to minimize the effects of directional and nonlinear climate change on the Nation's land, water, ecosystems, and biological populations.
- Continue to refine, apply and interpret watershed and ecosystem process models to assist the Nation's natural resource managers to adapt to climate change. Deliver USGS predictive modeling and decision-support capability that resource managers can use to forecast the responses of policy and management decisions on land, water, biological, and ecosystem resources because of changes in land use and land cover, natural and engineered infrastructure, and climate.

Vision of 2017

The USGS scientists use decades of observational data and long-term records to interpret the consequences of climate variability and change to the Nation's biological populations, ecosystems, and land and water resources. USGS scientists provide expert advice on risks to infrastructure, human safety, and environment based on years of collaboration among scientists thinking across disciplinary lines. USGS regional and national assessments of critical resource interdependencies are used, discussed, and interpreted by policymakers, natural resource managers, and the public to make decisions on a daily basis.

Hydroclimatology

A number of recent studies have documented the effects of warming trends over the past 50 years on hydroclimatology. In the Western United States, there has been less snow and a shift toward more rain (Knowles and others, 2006), earlier spring snowmelt (Stewart and others, 2005), less spring snowpack (Mote, 2003), and earlier greening of vegetation (Cayan and others, 2001). Similar hydroclimatic changes also have been observed in the Northeastern United States, where snow melts 1 to 2 weeks earlier now than 100 years ago (Hodgkins and Dudley, 2006; Huntington and others, 2004). By documenting the number of days historically close to freezing, USGS researchers are developing maps of vulnerability to increased warming. Knowledge about how climate change affects seasonal snowpacks can be used to forecast future changes in timing and amount of river flow and other ecological responses by vegetation and wildlife that rely on snow for moisture and shelter. Using temperature change projections for 2050, maps can be produced that project the potential number of days above freezing for the Nation. Maps like these will become valuable tools for natural resource managers and decisionmakers needing to anticipate a wide range of outcomes, from water supplies to insect and disease outbreak conditions to wildlife migratory patterns.



Energy and Minerals for America's Future:

Providing a Scientific Foundation for Resource Security, Environmental Health, Economic Vitality, and Land Management

Background

Reliable, accessible, and adequate supplies of energy and mineral resources are essential to sustain the American economy and standard of living. The Nation faces increasing demand for energy and mineral resources, a growing dependence on resources imported from other countries, increasing pressure to consider alternative sources, and a need to minimize environmental effects associated with resource development and use. The Annual Threat Assessment of the Director of National Intelligence before the U.S. Senate Committee on Armed Services (28 February 2006) highlights threats to energy security as playing an increasing role in national policy. Yet energy also is at the nexus of global environmental issues because of the linkage between energy production and greenhouse gas emissions. Mineral resource supply issues are currently (2007) less visible than energy but are no less critical to the Nation's future. Like energy, mineral resource development and use are affected by environmental concerns.

During the next decade, the Federal Government, industry, and other groups will need to better understand the domestic and global distribution, genesis, use of and consequences of using these resources to address national security issues, manage the Nation's domestic supplies, predict future needs, anticipate as well as guide changing patterns in use, facilitate creation of new industries, and secure access to appropriate supplies.

Statement of Strategic Science Direction

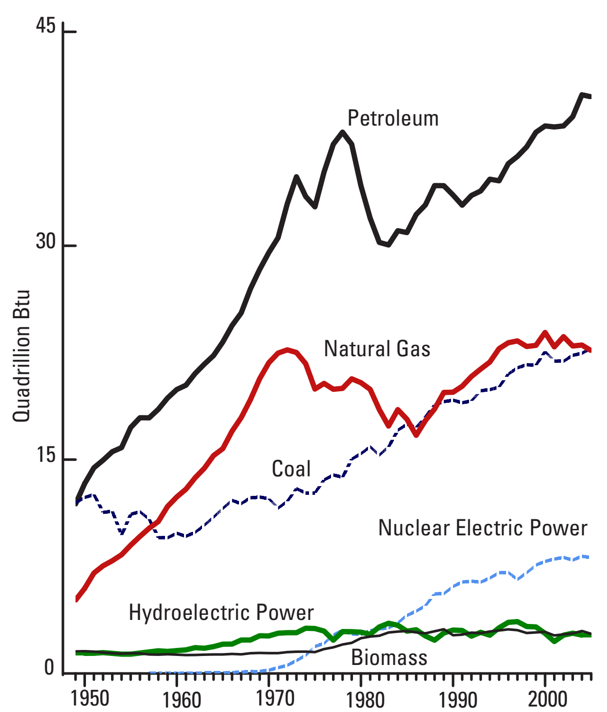
The USGS energy and minerals resource research will be broadened to contribute more comprehensively to discourse and decisions about future natural resource security, environmental impacts of resource use, the economic vitality of the Nation, and management of natural resources on U.S. Department of the Interior, Federal and other lands. A wide-ranging, multidisciplinary approach is used to understand and evaluate how the complex "life cycle" of occurrence, formation processes, extraction methods, use, and waste products of energy and mineral resources influence, or are influenced by, landscape, hydrology, climate, ecosystems, and human health. Cumulative knowledge, long-term data, and new understanding of resource origin and assessment methodologies will improve the reliability and accuracy of national and global assessments and information products, especially as the energy mix evolves and new requirements for rare and scarce materials used by the Nation emerge. Information from the USGS resource cycle increasingly will be put in economic terms so that policymakers can more clearly weigh competing alternatives. Through partnerships and collaborations, USGS natural resource knowledge and expertise helps to advance the Nation's economy and improve its competitiveness.

Energy and mineral resource assessment and research are a traditional strength of the USGS. USGS science that describes the status and trends of these resources provides impartial, robust information necessary for the U.S. Department of the Interior (DOI) to support its missions of managing the Nation's energy and minerals while simultaneously acting as steward of the Nation's land, water, and environmental resources. Collectively, this information advances the scientific understanding of these resources at local to global scales, facilitates the strategic use and evaluation of resources, thereby contributing to the economic health of the Nation, and leads to more effective management of the Nation's land, water, and natural resources.

Energy and mineral resources are the backbone of human food supplies, shelter, economies, and national security. The United States is the largest user of mineral commodities and energy resources in the world, and its economy and standard of living depend on them. Every year, about 25,000 pounds of new nonfuel mineral materials from the earth must be provided for every person in the United States just to maintain the current standard of living (Dorr and Paty, 2002). Because many of these resources are imported from trading partners around the world, the Federal Government, industry, and other groups need to understand the domestic and global distribution, abundance, genesis, and use of these resources to manage the Nation's domestic supplies, anticipate changing patterns in use, predict future needs, and secure access to appropriate supplies. Unbiased, scientifically sound knowledge describing domestic and international energy and mineral resources, therefore, is important to Federal leaders for developing policy about commerce, the environment, and national security. Resource managers in DOI and other Federal land and resource management agencies need to consider energy and mineral resource development in the context of multiple land-use options. State and local agencies and geological surveys, foreign governments, nongovernmental organizations, and industry use energy and mineral resource information and research for their individual needs.

Two issues will dominate the availability of energy and mineral resources in the future: the effects of globalization and the likelihood that land, water, and environmental changes from energy and mineral extraction and consumption will factor more strongly into how societies use resources. The first issue, globalization, results from modernization and international commerce that have spurred the transport of goods among nations. This global economy is increasing the competition

Energy Resource Use in the United States, 1950-2005



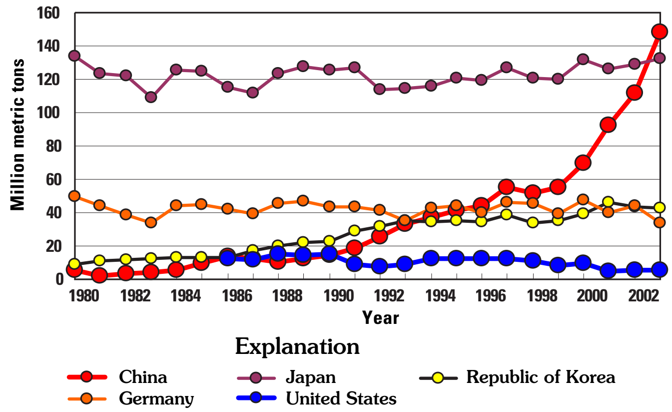
United States energy consumption by source of fuel since World War II. For the past 20 years, consumption of hydrocarbon fuels (petroleum, natural gas, and coal) has steadily increased (Energy Information Administration, 2005).

Overleaf: U.S. Geological Survey oil endowment in graduated green colors superimposed on "Earth at Night" image.

for vital natural resources, many of which are only available in foreign countries because of unique geological circumstances (see Materials and Mineral Resources for the Future, page 24). Developing countries, such as China and India, are leading this global competition; China now consumes more than it produces of certain major resources, and its demand for resources is expected to continue growing. Whereas competition can produce greater availability, it also can drive scarcity, market volatility, and higher prices. Vulnerability to scarcity is not new; during past times of scarcity, such as the two World Wars, the USGS was instrumental in identifying domestic sources for many critical war materials when foreign supplies were not obtainable. Competition also produces innovation to diversify the resource base and find resource substitutions. For example, research and development of alternative fuel sources, such as coalbed methane, gas hydrates (see Potential Energy Resource below), oil shale, agricultural and forestry biofuels and others, are diversifying the Nation's energy mix and lessening its dependence on conventional fossil fuels. USGS information provides an understanding of the domestic and international energy- and mineral-mix pictures and contains baseline data about their occurrence and availability. The breadth of knowledge in the USGS about the formation and extraction of these fundamental energy and mineral building blocks is essential for preparing the U.S. Government and society for an era of global competition and for ensuring that the United States has adequate supplies of energy and mineral resources for the well-being of its citizens.

The second issue, environmental effects, is also not new. The latter half of the 20th century saw increased awareness of environmental contamination (locally, regionally, and globally) from, for example, oil spills, mine tailings, dam failure, acid-mine drainage, acid rain, clear-cut forest management practice, and increasing levels of atmospheric carbon dioxide (see following Carbon Sequestration and section on Climate Variability and Change). The Nation will have to balance the land, water, and environmental effects of resource development and extraction with the benefits of use, and, perhaps most important, it will have to plan for evolving and unanticipated future energy and mineral resource requirements within this broader environmental perspective of sustainability.

Leading Importers of Iron Ore—1980–2003



Rapid economic growth in China has resulted in an accelerated increase in net imports of iron ore since the mid-1990s (Menzie and others, 2004).

Potential Energy Resource

Gas hydrates are unique mixtures of gas (usually methane) and water found in the subsurface in permafrost and continental-margin settings. Gas hydrates represent an immense potential energy resource and are widely distributed around the globe. Much of the gas hydrate resource in the United States is under Federal management. The USGS has been a leader in gas hydrate research for more than 20 years, and USGS scientists have led, or collaborated in, major national and international drilling field programs in northern Alaska and northern Canada, as well as on the Atlantic, Pacific, and Gulf of Mexico coasts of the United States and the continental margins of India. The knowledge gained from these studies is consistent with a government role to support research in fields with great potential public value that are too high-risk, high-cost, and long-term to be conducted by the private sector alone. This research lays the foundation to explore for, conduct tests on, model production from, and develop the knowledge needed to produce gas from gas hydrates. USGS studies also directly contribute to a national strategy for research and development of methane hydrates, which includes a goal to demonstrate the technical and economic viability of methane recovery from arctic hydrates by 2015 and from domestic marine hydrates by 2025. USGS gas hydrate studies together with its studies of other geologically based energy resources allow USGS to continue providing information on those resources currently (2007) being used, as well as those that may be used in the future.

Gas hydrates are formed worldwide in permafrost and marine continental margin settings where appropriate pressures, temperatures, and gas concentrations exist, generally in the uppermost few hundred meters or kilometer below the sea floor (marine settings) or near the Earth's surface (permafrost settings).

Fire in the ice: Although gas hydrates look like ice, they burn if the methane is ignited. Photograph by John Pinkston, U.S. Geological Survey.

Materials and Mineral Resources for the Future

Beginning with the Stone Age and progressing through the Bronze Age, the Iron Age, and the modern industrial age, materials based on mineral resources have played a central role in advancing human civilization. Some minerals have been replaced by stronger and more durable substitutes (iron, then steel, for flint); some have maintained value over the millennia (gold); some have only come into prominence recently as manufacturing transformed the Western World (aluminum and titanium). Currently (2007), the United States imports a huge array of mineral materials, including 100 percent of 16 mineral commodities and more than 50 percent of an additional 26 mineral commodities. Increasing demand for new mineral materials is not likely to diminish in the future. Emerging technologies are requiring increasing amounts of mineral commodities that are unequally distributed around the world. For example, in 2005 the United States imported more than 90 percent of the platinum, indium, and rare earth minerals required for everyday technologies, such as cell phones, computers, and video monitors. Demand for these rare metals is likely to increase as new technologies, such as advanced batteries and fuel cell electronic vehicles, are developed. Use of mineral materials is undergoing a transition whereby science and engineering breakthroughs will dominate the future—a future in which materials will be lighter and stronger, last longer, fill multiple simultaneous functions, cost less per life cycle of the material, and be environmentally friendly. These advances are implemented through material substitutions made possible by understanding materials at the molecular level (nanotechnology), combining materials in new and pioneering ways (superalloys, advanced composites), harnessing new potential from traditional and previously unused mineral materials (powder metallurgy), and mimicking processes found in nature (biomimetics). Because there are few suppliers for many of these unusual materials, this growing demand can result in high prices and the potential for scarcity and market vulnerability. The United States can reduce its vulnerability with knowledge and planning.

The USGS must continue to increase fundamental understanding about the origins of these emerging mineral materials and reduce uncertainty in mineral resource assessments, so that alternative geologic settings for these materials can be considered and diverse supply sources encouraged.

2006 U.S. Net Import Reliance for Selected Nonfuel Mineral Materials[1]

Commodity	Percent	Major Import Sources (2002-05)[2]
Arsenic (trioxide)	100	China, Morocco, Mexico, Chile
Asbestos	100	Canada
Bauxite and alumina	100	Jamaica, Guinea, Australia, Brazil
Columbium (niobium)	100	Brazil, Canada, Estonia, Germany
Fluorspar	100	China, Mexico, South Africa, Mongolia
Graphite (natural)	100	China, Mexico, Canada, Brazil
Indium	100	China, Canada, Japan, Russia
Manganese	100	South Africa, Gabon, Australia, China
Mica, sheet (natural)	100	India, Belgium, China, Brazil
Quartz crystal (industrial)	100	Brazil, Germany, Madagascar, Canada
Rare earths	100	China, France, Japan, Russia
Rubidium	100	Canada
Strontium	100	Mexico, Germany
Thallium	100	Russia, Belgium
Thorium	100	France
Vanadium	100	Czech Republic, Swaziland, Canada, Austria
Yttrium	100	China, Japan, France, Austria
Gallium	99	China, Japan, Ukraine, Russia
Gemstones	99	Israel, India, Belgium, South Africa
Bismuth	96	Belgium, Mexico, China, United Kingdom
Platinum	95	South Africa, United Kingdom, Germany, Canada
Stone (dimension)	89	Italy, Turkey, China, Mexico
Antimony	88	China, Mexico, Belgium
Rhenium	87	Chile, Germany
Tantalum	87	Australia, Canada, China, Japan
Barite	83	China, India
Diamond (natural industrial stone)	82	Ireland, Botswana, Ghana, Belgium
Palladium	82	Russia, South Africa, United Kingdom, Belgium
Cobalt	81	Norway, Russia, Finland, Canada
Potash	80	Canada, Belarus, Russia, Germany
Tin	79	Peru, Bolivia, China, Indonesia
Chromium	75	South Africa, Kazakhstan, Zimbabwe, Russia
Titanium (sponge)	72	Kazakhstan, Japan, Russia
Iodine	71	Chile, Japan
Titanium mineral concentrates	71	South Africa, Australia, Canada, Ukraine
Tungsten	66	China, Canada, Germany, Portugal
Silver	65	Mexico, Canada, Peru, Chile
Zinc	63	Canada, Mexico, Peru, Australia
Nickel	60	Canada, Russia, Norway, Australia
Silicon (ferrosilicon)	60	China, Venezuela, Russia, Norway
Peat	59	Canada
Magnesium metal	54	Canada, Russia, China, Israel
Garnet (industrial)	53	Australia, India, China, Canada
Magnesium compounds	53	China, Canada, Australia, Austria
Diamond (dust, grit and powder)	51	China, Ireland, Ukraine, Russia
Aluminum	44	Canada, Russia, Venezuela, Brazil
Nitrogen (fixed), ammonia	42	Trinidad and Tobago, Canada, Russia, Ukraine
Copper	40	Chile, Canada, Peru, Mexico
Perlite	35	Greece
Vermiculite	31	South Africa, China
Mica, scrap and flake (natural)	30	Canada, China, India, Finland
Cadmium	29	Australia, Canada, Belgium, Peru
Gypsum	27	Canada, Mexico, Spain, Dominican Republic
Sulfur	26	Canada, Mexico, Venezuela
Cement	24	Canada, Thailand, China, Venezuela
Iron and steel	21	Canada, European Union, Mexico, Brazil
Salt	16	Canada, Chile, The Bahamas, Mexico
Pumice	12	Greece, Italy, Turkey
Talc	11	China, Canada, France, Japan
Iron and steel slag	7	Canada, Italy, France, Japan
Phosphate rock	6	Morocco
Iron ore	5	Canada, Brazil, Chile, Australia
Lead	2	Canada, Australia, China, Mexico
Lime	1	Canada, Mexico
Sand and gravel (construction)	1	Canada, Mexico, The Bahamas

[1]Source: U.S. Geological Survey (2007).

[2]In descending order of import share.

These trends—globalization and environmental impacts—point to a future in the Nation of a diversified energy mix (that is, less dependence on imported oil), changing demands for minerals (to support innovative technologies), and a life-cycle approach that links energy and mineral use to the broad effects of that use, from exploration and extraction to recycling and disposal of waste products. In advancing this energy and minerals resource strategic science direction, the USGS builds on its traditional strengths of mapping, assessing, modeling, forecasting, and conducting fundamental research. USGS long-term databases and information summaries must be continued and expanded. But, greater emphasis needs to be placed on the environmental consequences of land use, the water cycle, ecosystem health, and human welfare. USGS assessments and research also must be made integral to public and government discourse about the energy and mineral future of the Nation so that science can inform, advise, and engage decisionmakers. The USGS, with its multidisciplinary scientific expertise in hydrology, biology, geology, and geography, is ideally poised for moving in these expanded directions.

Strategic Focus

It is inevitable that the United States will move in a direction that diversifies its energy sources to reduce its dependence on imports from specific countries and address issues of greenhouse gas emissions. It is equally inevitable that the United States will be involved in building new technologies based on new mineral and living resource components. As these energy, mineral, and living resource requirements evolve, understanding not only the geological consequences of these changes, but also the biological, hydrological, and landscape consequences will poise the USGS to contribute to informed dialog when policy, management, and stewardship issues arise about extraction, use, regulation, and waste management. We anticipate four strategic areas that will focus the next decade of energy and mineral resource research:

(1) Natural Resource Security for the Future

As the Nation's energy mix evolves, the USGS needs to continue to expand its research and assessment portfolio to include a comprehensive suite of energy sources, including hydrocarbon-based (for example, unconventional gas from coal and shale, gas hydrates, oil shale) and nonhydrocarbon-based sources (for example, geothermal resources, uranium, agricultural and forestry biofuels, wind). As the energy mix diversifies, USGS research directions will change in anticipation of, and as a reflection of, national and international trends. Research in mineral resources increasingly will address evolving requirements for rare and scarce materials used in industry and defense. Identifying and understanding the source of new and substitute mineral materials also will require modifying the portfolio of research priorities. To improve the accuracy of assessments, particularly the potential for undiscovered resources, a comprehensive understanding of the Earth system in which the resources occur is essential. Equally important is building upon and maintaining long-term data sets for understanding trends in resource provenance, occurrence, and use.

Carbon Sequestration

Sequestration of carbon dioxide, either geological or in ecosystem soil and biomass, is one strategy for limiting atmospheric accumulation of carbon dioxide from fossil fuel combustion. Globally, the amount of carbon dioxide that must be stored (billions of tons per year) to affect global climate is very large, raising fundamental questions that must be addressed so that stakeholders in Federal and State agencies, Congress, the public, and nongovernmental organizations have the information needed to craft sound public policy.

Carbon dioxide from point sources can be captured and injected into subsurface geological formations. Injection into depleted oil and gas reservoirs, saline aquifer systems, or deep coalbeds has the potential for long-term storage, although uncertainties remain concerning leakage and other effects. The basic processes of carbon dioxide injection and storage in the subsurface are currently (2007) in practice for enhanced oil recovery and natural gas storage in the United States and elsewhere. Enhancement of these practices is central to the work of the international Carbon Sequestration Leadership Forum (CSLF) implemented by the United States. As part of the CSLF, the USGS is addressing questions of carbon storage capacity and integrity, monitoring and verifying storage amounts, geochemical alteration, and displacement of formation water.

Ecosystem carbon sequestration can help restore carbon balance by reestablishing the carbon lost through historical and pre-historical land-cover changes. Direct loss of carbon in living plants from forests, woodlands, and grasslands to the atmosphere occurred upon conversion to agricultural land. Further agricultural land management resulted in the depletion of the large carbon stocks in soil organic matter. Soil organic matter can be built back up, however, with agricultural practices, such as no-till, through conservation programs, and the restoration of degraded lands.

These practices not only have the potential to sequester carbon from the atmosphere through plant carbon fixation and subsequent storage but also benefit soils by increasing soil water-holding capacity and fertility and benefit the waterways of the Nation by reducing sediment transport. Technical and scientific expertise in remote sensing, ecosystem models and on-the-ground measurements can be combined to provide decision-support tools to land and resource managers in the United States and abroad.

(2) Environmental Health

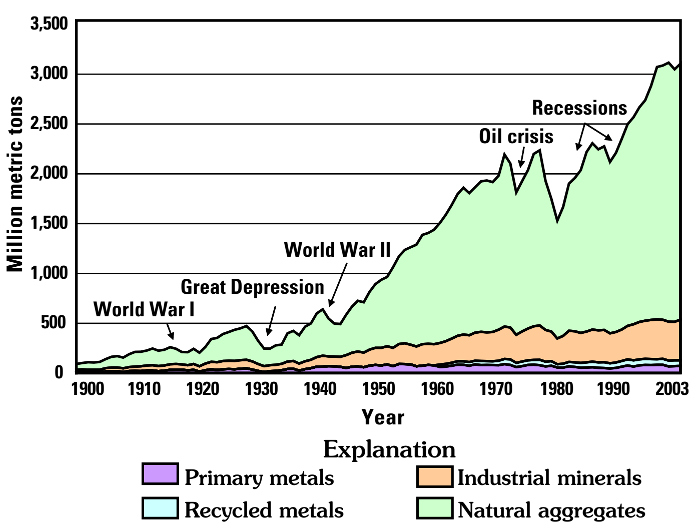
Energy and mineral resources need to be understood in a broader context of the comprehensive life-cycle of the energy or mineral commodity. Assessments need to address the occurrence, formation processes, and extraction methods, as well as how the waste products of energy and mineral resources influence landscape, water, climate, ecosystems, and human health. For example, as the use of biofuels expands, what are the effects to the Nation's biota, water, and land, including the potential ecological effects of genetically modified plant species, current and expected future changes in water quality and quantity from biofuels production, and how does returning currently fallow lands to agricultural or forestry production affect water quality, native plants, migratory birds, and wildlife? When new commodities are used or modified and released in the environment (for example, as nanoparticles), what are the effects on ecosystems and human health? Perhaps the greatest research need is to integrate assessments of fossil energy resources with the consequences of using the fuel—increased atmospheric carbon dioxide levels and climate change. There is a critical need for research on the carbon cycle and on carbon sequestration in geological and in biological reservoirs.

(3) Economic Vitality of the Nation

Research within the USGS can contribute to the American Competitiveness Initiative by identifying, studying, and understanding potential new energy and mineral commodities. This research can provide opportunities for USGS to partner with other agencies or industry in the use of this knowledge to facilitate development of new industries and guide government decisions about the government role in promoting new industries. USGS gas hydrate research (see Potential Energy Resource) is an example where partnering with industry has created opportunities for access to drilling information that otherwise would be too expensive to support independently. Management of the carbon cycle is another example of a field where new industries are likely to develop; although the goals of carbon cycle management are controversial, USGS can contribute objective knowledge to inform the discourse about the realities of geological and biological carbon sequestration that will be useful regardless of the final policy goals. The USGS has detailed knowledge, unmatched by any other Federal agency, of both nature of the crust of the Nation and fluid migration within it. This knowledge is necessary to help guide implementation of geologic carbon sequestration from fixed sources, such as coal-fired power plants. Two examples of USGS research that will fill key gaps in carbon-cycle knowledge are the baseline data contained in a national soil geochemical map and data compilations from models of carbon dynamics in vegetation and soil effected by soil erosion/deposition.

Economic resource valuation has been a component of USGS hydrocarbon assessments, and is increasingly an element of mineral assessments, as well. This economic perspective will be expanded over the next decade to encompass the full life cycle of energy and mineral resource commodities. Although economic research is not a primary purpose of USGS research, achieving natural resource security and sustainability requires that science be used in a broader societal context, in which economic and sociological factors are considered. Partnerships and collaboration in the next decade clearly are important in moving USGS forward on this front.

Mineral Resource Use in the United States



Unprocessed, nonfuel mineral materials put into use annually in the United States from 1900–2003 (after Matos, 2007).

(4) Management of DOI, Federal, and Other Lands

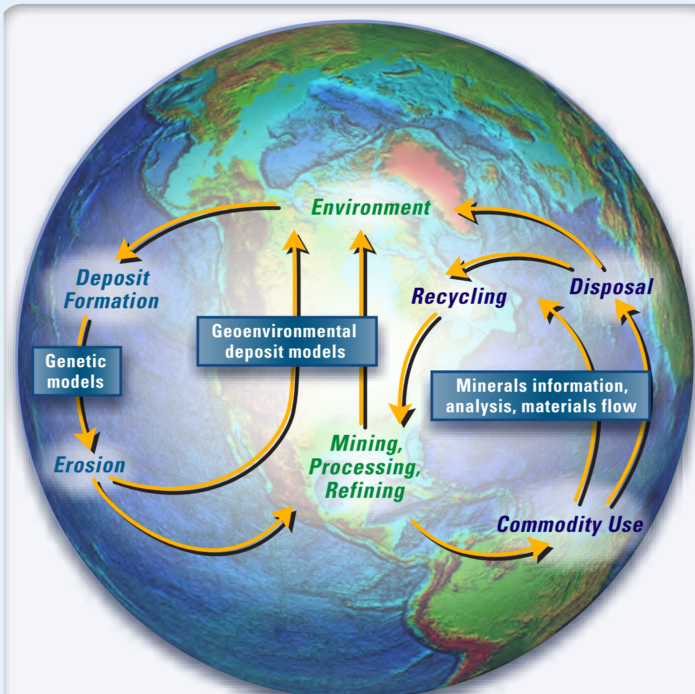
Future decisions about the use of energy and mineral resources on Federal lands will need to accommodate ecosystem-based management practices. U.S. Federal onshore lands, many of which are managed within DOI, will need to accommodate ecosystem-based management practices as they face competing demands for recreation, transport, leasing, conservation, and economic growth. USGS monitoring, assessment, and research must be relevant to managers who require decisions informed by science. Offshore Federal lands, which encompass the continental margin between state limits (generally 3 nautical miles) and 200 nautical miles or beyond, will be under increasing pressure to be opened to mineral mining. Although such mining is currently (2007) marginally viable, it is expected to mature in the next 10 to 20 years; USGS research in understanding marine mineral genesis and distribution will complement DOI leasing and regulatory responsibilities. If the United Nations Convention on the Law of the Sea is ratified by the U.S. Congress, USGS has an important role to play in extending the juridical Continental Shelf beyond 200 nautical miles, particularly in the Arctic, Atlantic margin, and some of the Pacific island territories.

Strategic Actions

- Develop a multidisciplinary approach to energy and mineral assessments that includes comprehensive accounting of life cycle and environmental (land, water, and ecosystem) effects of energy and mineral exploration, extraction, and use. Refine methodologies for doing this approach quantitatively and in economic terms.
- Develop procedures to evaluate and understand effects of energy and mineral resource use on ecosystem processes, and provide the knowledge base that integrates adaptive ecosystem-based management with energy and mineral policy on Federal lands, allowing managers to consider energy and mineral development in the context of multiple land-use options.
- Develop scientific methods for monitoring and assessing biological and geological carbon sequestration resources, including assessment of interdependencies among land, water, and ecosystem resources that may be affected by carbon management decisions.
- Continue to improve and expand geologic, biologic, and hydrologic understanding of assessment methodology for alternative energy resources as the Nation moves to a more diversified energy mix (such as coalbed methane, oil shale, tight gas sands, shale gas, gas hydrates, geothermal energy, uranium, and biofuels).
- Anticipate, identify, and develop understanding of the occurrence, genesis, and risks associated with using new mineral resources.
- Improve scientific understanding of the origin and occurrence of energy and mineral resource deposits, and use this knowledge to improve the accuracy and reduce the uncertainty of resource assessments.

Materials Flow

Materials flow, in its most literal sense, is a systems approach to understanding what happens to the materials people use from the time a material is extracted, through its processing and manufacturing, to its ultimate disposition. The U.S. Geological Survey (USGS) investigates the life cycle of materials, trends in material use, as well as how materials affect the economy, society, and the environment. The purpose of this work is to understand how and why we use the resources and to identify policies and practices that make resource use more efficient and more protective of the environment. Some materials-flow studies identify and trace trends that, if they continue, could have worldwide economic and environmental effects. For example, a current important trend is the declining share of renewable resources, such as agricultural and forestry products (for example, cotton and wood), and the increasing share of nonrenewable resources, especially construction materials, in overall nonfood, nonfuel material consumption. Another type of materials-flow analysis is the commodity mass balance study, which follows and quantifies the flow of a single commodity through its entire life cycle. Studies have been completed on arsenic, boron, cadmium, chromium, cobalt, lead, manganese, mercury, salt, tungsten, vanadium, and zinc. Commodity-mass balance analyses identify areas where adverse effects could be minimized by reducing waste at the source of the materials, improving the use of waste (recycling), and enhancing efficiencies. Opportunities exist for using this approach in the energy sector.



Life cycle of mineralized systems: Life-cycle analysis of mineralized systems demonstrates how minerals are made available to sustain societies through natural and anthropogenic processes. USGS scientific activities address the entire minerals life cycle.

- Maintain and update the geological and geophysical databases and geochemical baselines used to develop national and global resource assessments. Ensure the data are accessible both internally and externally.
- Continue to produce, update, and improve national and global energy and mineral assessments.
- Make USGS assessments and research integral to public and government discourse about the energy and mineral future of the Nation so that science can inform, advise, and engage decisionmakers.

Vision of 2017

The USGS energy and mineral information and national and global resource assessments remain the standard used by industry and government. Recognizing the broad economic, environmental, and societal consequences of extraction and use, USGS scientists have continuously enhanced their understanding of the genesis of energy and mineral resources and routinely include environmental and life-cycle expertise into studies and assessments. The quantified effects of resource development, use, and recycling on ecosystems, landscapes, hydrology, climate, and human health are an essential part of USGS studies and assessments. Working across and among disciplines, USGS science provides the knowledge base that facilitates integration of adaptive ecosystem management with energy- and mineral-resource policies on Federal and other lands, as well as providing this information for a larger domestic and international audience. Assessments of previously unexploited mineral and energy resources (for example, gas hydrates, uranium, rare-earth metals), including renewable resources, such as agricultural and forestry biofuels, keep pace with evolving geologic and biologic understanding and technological developments. Geochemical-baseline soil maps and ecosystem maps of the Nation are completed and updated. Thus, the energy and mineral strategic science of the USGS includes ecologic, hydrologic, and climate studies in addition to traditional geologic research and assessment.

Gold-mining operation at the Martha mine in the Waihi mining district, New Zealand. The USGS supports research and assessments of minerals, as well as collection of minerals information on a global scale. Photograph by Robert S. Seal, U.S. Geological Survey.

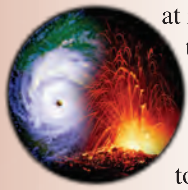
A National Hazards, Risk, and Resilience Assessment Program:

Ensuring the Long-Term Health and Wealth of the Nation

Background

The Nation faces increasing losses from natural hazards, threatening safety, security, economic well-being, and natural resources. Governments at all levels are faced with difficult decisions, balancing growth and development while ensuring the safety of their communities. The USGS is an international leader in natural hazards research, monitoring, assessing, and communicating timely information about hazards. A strength of the USGS is also working with partners to monitor and assess urban and environmental vulnerability and to provide leaders with the information they need to make effective decisions on natural hazards issues.

Statement of Strategic Science Direction



The USGS collects accurate and timely information from modern earth observation networks, assesses areas at risk from natural hazards, and conducts focused research to improve hazard predictions. In addition, the USGS works actively with the Nation's communities to assess the vulnerability of cities and ecosystems and to ensure that science is effectively applied to reduce losses. The USGS will develop a national risk-monitoring program, built on a robust underpinning of hazard assessment and research, to visualize and provide perspectives at multiple scales of vulnerability and resilience to adverse land change and hazards. Accurate observations, targeted research, and timely communications will safeguard people and property and keep natural hazards from becoming natural disasters.

As Hurricane Katrina, the eruptions of Mount St. Helens, the Northridge earthquake, and western wildfires demonstrate, natural hazards are important and continuing threats to the Nation's safety, security, economic well-being, and natural resources. Although sudden extreme events, such as hurricanes, earthquakes, tsunamis, flash floods, wildfires, volcanoes, and landslides, capture the public's attention, equally threatening are the effects of slower, more chronic hazards related to climate change, such as drought and ecosystem collapse. The risks from natural hazards are a function not only of the hazards themselves but also of development patterns and decisions made before, during, and after an extreme event. Much of the Nation's infrastructure and building stock are aging, making them more vulnerable to natural hazards. Expanding urbanization of hazard-prone areas, such as coastal zones, hillsides, floodplains, and wildland-urban interfaces, heightens the risk of future disasters. With disaster-relief costs mounting and private companies increasingly challenged in their ability to recover from catastrophic losses related to disasters, the Nation needs a clear understanding of potential threats, the societal vulnerability to these threats, and the strategies for increasing resilience. Working with partners, the USGS will build this understanding through a national assessment of hazards, societal risks, and vulnerabilities in order to provide managers and policymakers at all levels of government with the tools they need to make better and more cost-effective decisions.

The need for action is urgent. Although until recently the number of lives lost to natural hazards in the United States each year has declined, the economic cost of response to, and recovery from, major disasters continues to rise. Each decade, the cost in constant dollars of property damage from natural hazards doubles or triples. If current trends continue, by 2017 the Nation will face increasing numbers of intense hurricanes making landfall, increasing drought, more destructive wildfires, and expansion of population into coastal and other high-hazard regions of the country. With societal risk and vulnerability to natural hazards rising, governments will be faced with difficult decisions, balancing growth and development with ensuring the resilience and sustainability of their communities. Leaders must make decisions about increasingly complex technical issues, and the information they require contains many uncertainties. How they deal with these issues, how they allocate resources, and how urban areas grow will all determine the Nation's standard of living and ability to compete in a global economy.

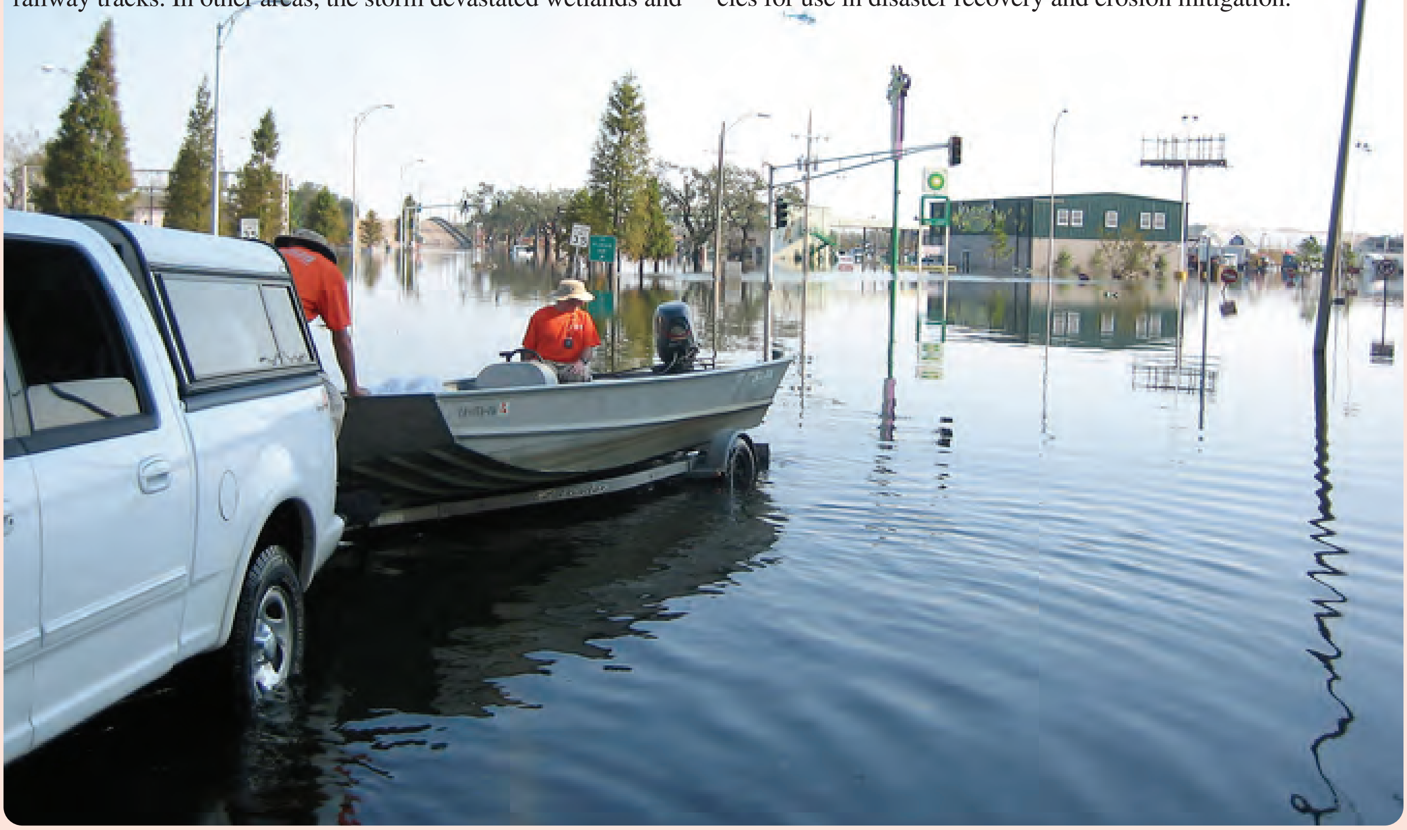
The USGS has statutory and mission responsibilities for using the best science available to help policymakers, emergency managers, and citizens respond to natural hazards and plan for a safer, more resilient society. USGS has the lead Federal responsibility under the Disaster Relief Act (P.L. 93-288, popularly known as the Stafford Act) to issue alerts for earthquakes, volcanoes, and landslides to enhance public safety and to reduce losses through effective forecasts and warnings. The USGS is already recognized nationally and internationally as a primary source for research and information on the causes, occurrence, and consequences of natural hazards.

Other agencies rely on USGS information to help them fulfill their responsibilities regarding natural hazards. USGS real-time streamflow information is essential to the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) for developing its forecasts and carrying out its statutory responsibility to issue flood watches and warnings. The NWS also relies on data from USGS-supported seismic networks as a key input for tsunami warnings. USGS seismic-hazard maps provide information used to develop building codes across the United States. USGS coastal-change vulnerability products provide pre-hurricane forecasts of impacts on infrastructure, essential for evacuation and post-storm recovery efforts. USGS and its Federal partners monitor seasonal wildland fire danger conditions, provide research on effectiveness of postfire recovery strategies for reducing debris flows and fire frequency, and provide firefighters with maps of current fire locations, perimeters, and potential spread. A major focus of work by the USGS and partners will be the development of robust models for prediction of when and where rainfall- and earthquake-triggered debris-flows are likely to occur. The USGS partners with the Federal Aviation Administration, NOAA, and others to help pilots avoid dangerous volcanic ash clouds. To mitigate the hazardous effects of geomagnetic storms on the activities and infrastructure of today's technologically based society, the USGS works cooperatively under the auspices of the National Space Weather Program with NOAA, the U.S. Department of Defense, the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF), providing real-time ground-based magnetometer data for monitoring the changing conditions of the Earth's space environment. These achievements are all possible because the USGS is able to bring a unique combination of disciplines—biology, geology, hydrology, geography, and geospatial information technology—to bear on all these hazards.

Decisions about natural hazards are linked in complex ways with decisions on land use, human health, and natural resources. The USGS is unique in having expertise and ongoing collaborations in all of these fields. We must continue to monitor, predict, assess, and issue warnings of natural hazards. In addition, we must increase efforts to communicate how the Nation is at risk from these hazards and what makes communities more resilient to extreme events and ongoing changes in the environment. By developing a new generation of risk-focused products, including scenarios of damage from likely events, USGS and its partners can help make hazards real to communities and help them understand their vulnerability to the forces of nature.

Hurricane Katrina: Addressing the Need to Assess Coastal Change Hazards

Hurricane Katrina made landfall as a Category 4 storm in Plaquemines Parish, La., on August 29, 2005, and altered the physical, ecological, social, and economic structure of the city of New Orleans and the entire Gulf of Mexico coastal zone in ways that will have enormous long-term effects. USGS studies comparing before and after satellite imagery, georeferenced video and still photography, and laser altimetry have been used to map the extent of flooding and associated volume of water as well as to show that the land loss of wetlands, marshes, and beaches along the coast was enormous. With a storm surge east of New Orleans and along the Mississippi coast of 25 to 30 feet, some wetland areas lost 25 percent of their land area. The before and after images demonstrate how, in many places, high winds, heavy waves, and powerful storm surge picked up tons of sand and silt and pushed them far inland, filling navigation canals, inundating buildings, and burying roadways and railway tracks. In other areas, the storm devastated wetlands and washed away sand beaches, creating submerged sandbars and leaving remaining areas of marsh vulnerable to further erosion. Major parts of the Chandeleur barrier island beaches and dunes were completely eroded (see following photograph), reducing their function as a protective barrier for the eastern Mississippi delta and its settlements. Large areas of nesting grounds for endangered brown pelicans and other birds were essentially eliminated. The land loss also threatens the use of the islands by neotropical birds en route to and from Central America as a major stopover point. Damage was also extensive offshore, where nearly half of the offshore sea-grass beds were damaged with negative effects to the marine mammals, turtles, fish, and ducks that rely on them for their survival. Knowledge about this land loss and associated processes is being used to further refine predictive models of coastal impacts from severe storms. The USGS collects and interprets data in collaboration with NASA, the U.S. Army Corps of Engineers, and the University of New Orleans. The data are available to local, State, and Federal agencies for use in disaster recovery and erosion mitigation.



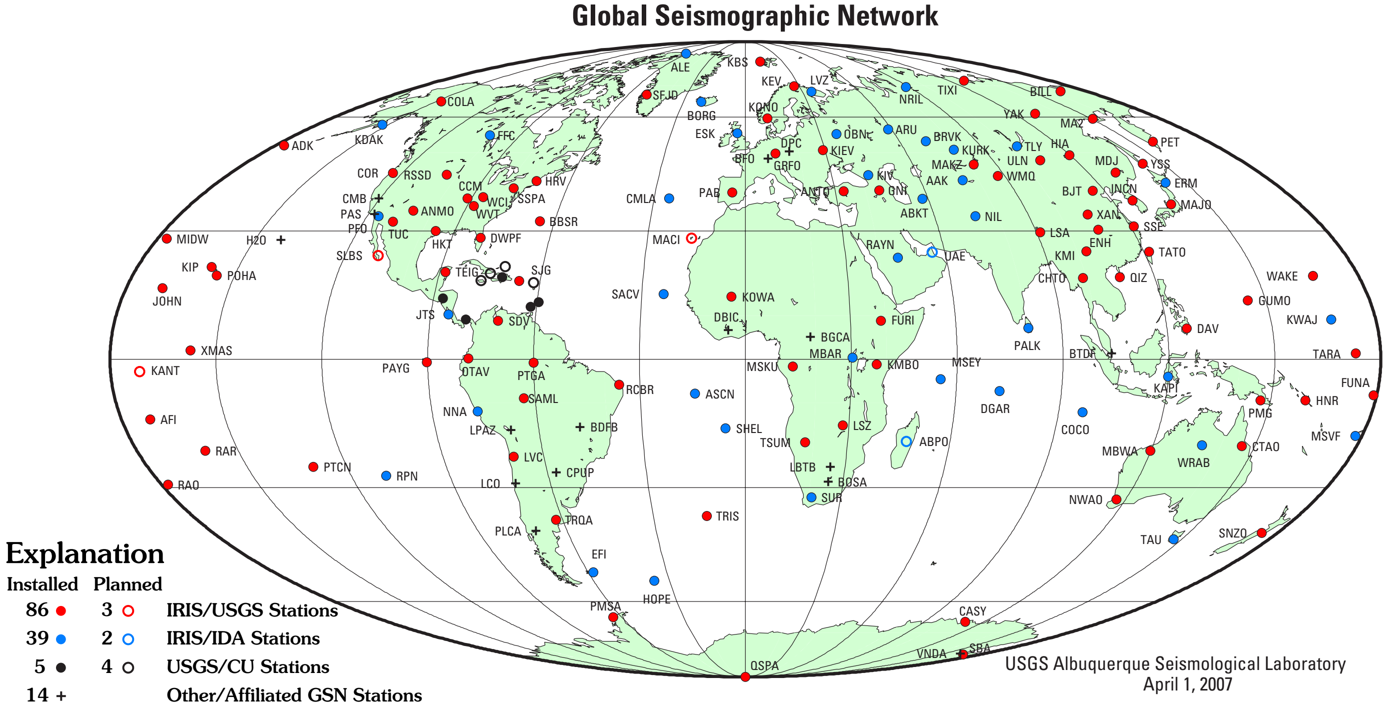
Strategic Focus

A core element of the USGS mission is to provide scientific information in order to minimize loss of life and damage to property from natural disasters. The USGS monitors, integrates, analyzes, and delivers a broad spectrum of natural-science information that enables community leaders to make key decisions on the allocation of resources. These capabilities include assessments of solid earth, hydrological, and biological hazards affecting both ecosystems and the built environment. The USGS leads the Nation in effectively harnessing advances in Geospatial Information Systems (GIS), Internet, and information technologies to develop objective decision-support tools. But to truly manage and reduce risk from natural hazards, the USGS must augment its strengths with partnerships that reduce societal vulnerability, increase community resilience, and engage and inform decisionmakers at all levels. There are five areas where the USGS must focus its hazard efforts in the next decade:

(1) Robust Monitoring Infrastructure: To reach the 10-year vision described here, major foundational investments in robust monitoring networks are necessary for accurate predictions and characterizations of hazards, as well as information critical to response and recovery efforts. Modernization of earthquake, volcano, and flood-monitoring networks, in particular, is essential to help communities prepare for, respond to, and recover from natural hazard events. The need for modernization of these networks was identified as a high priority by the recently released National Science and Technology Council report on Improved Observations for Disaster Reduction: Near-Term Opportunity Plan (U.S. Group on Earth Observations/Subcommittee on Disaster Reduction, 2006) to implement the Strategic Plan for the U.S. Integrated Earth Observation System (National Science and Technology Council, 2005). The main USGS investments needed are as follows:

- Full deployment of the Advanced National Seismic System to improve seismic monitoring of the Nation and the 26 U.S. urban areas at greatest risk from earthquakes
- Development and deployment of the National Volcano Early Warning System to monitor the Nation's 169 volcanoes commensurate with the threats they pose
- Deployment of a stable, core network of USGS-supported streamgages through the National Streamflow Information Program (NSIP) for continuity of data critical for flood warnings, floodplain planning, and other uses
- Expansion of the Marsh Surface Elevation Table Network to evaluate the effects of sea-level rise and hurricanes on coastal wetlands
- Access to advanced technology, such as Light Detection and Ranging (LIDAR), to assess and monitor hazards-related landscape changes, particularly coastal change

Global Seismographic Network



The Global Seismographic Network provides rapid information about earthquakes around the world; it is just one example of the USGS commitment to using its human and technological resources to respond to disasters globally. In recent years, the bureau has partnered with the U.S. Agency for the International Development Office of Foreign Disaster Assistance to respond to volcanic eruptions in Mexico, Ecuador, and the Philippines, landslides and floods in Central America, and earthquakes and tsunamis in Asia and the Indian Ocean, and many other natural disasters. These responses commonly have the goal of infrastructure development, technology transfer, and training in monitoring and hazard assessment.

A wildfire left very little of this home near San Bernadino, California, in October 2003. FEMA photograph by Kevin Galvin.

(2) Technology for Network Communications: During the next decade, the USGS should take advantage of new and emerging technologies for network communications and rapid and useful communications of hazards information. One new communication tool in the earthquake realm is PAGER (Prompt Assessment of Global Earthquakes for Response). This system, which uses the Global Seismographic Network, will provide information to help emergency relief organizations, government agencies, and the media respond effectively to earthquake disasters worldwide. PAGER will distribute alarms by way of pager, mobile phone, and e-mail that will include a concise estimate of impact, in addition to the earthquake location, magnitude, and depth as currently reported. That estimate will include the likely number of people exposed to varying levels of shaking, a description of the fragility of the region's building stock and infrastructure, and a measure of confidence in the system's impact assessment. Associated maps of shaking level, population density, and susceptibility to landslides will be posted on the Internet within minutes of the determination of the earthquake location and magnitude.

(3) Characterizing and Assessing Hazards: Assessing where hazards are likely to occur and how large they are likely to be is essential for making decisions about where to live and build infrastructure. The USGS already provides national seismic-hazard maps that are the model for national assessments worldwide. The USGS has also begun creating urban hazard maps for earthquakes and landslides, taking local conditions into account. By 2017, the USGS will have developed the necessary methodologies and procedures and partnered with local groups to substantially expand urban hazard mapping throughout the Nation. The USGS should further add value and usefulness to hazard assessment by partnering to evaluate the physical and socioeconomic vulnerability of the built and natural environment to multiple hazards. Over the next decade, examples of improved hazard assessment in the USGS should include enhancement of LANDFIRE—an interagency cooperative assessment of wildfire factors—to project changes in vegetation, fire fuels, and fire characteristics over time; development of streamflow characteristics for all locations in the Nation, including areas without streamgages; assessment of vulnerability of hurricane-threatened U.S. coasts to different hurricane types and intensities; and determination of potential for tsunami generation in U.S. offshore waters. Assessments of the vulnerability of national parks and wildlife refuges along the Nation's coasts to sea-level rise and coastal change should be expanded and updated.

(4) Forecasts Based on Understanding Physical Processes: Accurate forecasts and predictions depend on a thorough understanding of the physical processes controlling a hazard's occurrence, distribution, timing, and severity, as well as the effects of hazards on the landscape, the built environment, and human health. Much targeted research already occurs within the USGS and within external research institutions supported by USGS programs; over the next decade, these efforts must be expanded to reduce uncertainties and improve understanding even further. A few examples: Over the next decade, use of paleorecords (also called proxy records in climate and storm research) will improve understanding of long-term trends and improve probabilistic assessments of many hazards. Progress will be made in producing time-dependent earthquake hazard

maps that take into account the changing state of faults and their surroundings and are also an important step toward the elusive goal of understanding earthquake predictability. For volcanoes, research will move the USGS toward an ability to forecast not just the timing of eruptions but their style and magnitude as well. A better understanding of landslide processes will form the basis for real-time landslide and debris flow warning systems. Research on tsunami-generating processes will improve assessments of tsunami hazard potential on the Nation's coasts and worldwide. Promising advances in noncontact data collection and real-time estimates of measurement uncertainty will substantially improve flood estimates. The USGS will act in alignment with the U.S. Ocean Research Priorities Plan to forecast the response of coastal landscapes and ecosystems to extreme events. A greater understanding of wetland and coastal processes will be essential to ameliorate the effects of sea-level rise and hurricanes, like those of 2005, on coastal communities, landscapes, and ecosystems.

(5) Partnerships: By 2017, the USGS will be working with partners in universities and other governmental agencies to monitor the changing vulnerability of our cities and ecosystems due to socioeconomic trends, land-use changes, ecosystem loss, and climate change. We will have developed a national toolbox of societal vulnerability and resilience indicators that, in conjunction with the products generated from monitoring, will allow the USGS to work with communities and the private sector to better understand the risks they face. And we will have the models, metrics, decision-support tools, and portals that provide intelligent access to remotely sensed data and geospatial information for cost-effective risk-reduction, response, and recovery efforts. Communicating and furthering understanding about societal vulnerability will require a multidisciplinary approach, and a coordinated hazard and risk program provides a mechanism to integrate the hazard, land cover, climate change, and risk and vulnerability expertise at the USGS and its partners. In addition to enhanced

Multihazards Demonstration Project in Southern California

The USGS has recognized the urgency of hazards issues and over the past several years has invested substantial time and energy building a hazards initiative. One result of these efforts is a demonstration project for multihazards science, a new collaboration in southern California to reduce vulnerability to natural hazards through the application of science and engineering to community planning and response. Southern California has one of the Nation's highest potentials for extreme, catastrophic losses from a number of natural hazards. Estimates of expected losses from natural hazards in the eight counties of southern California exceed $3 billion per year and are expected to increase as the present population of 20 million grows at more than 10 percent per year. The project will focus on those natural hazards posing a significant threat to life and property in southern California—earthquakes, floods, landslides, tsunamis, and wildfires—and will build on work already underway in the study area. Reducing these future losses requires the commitment and involvement of the southern California community together with the best information about hazard, risk, and cost-effectiveness of mitigation technologies. Long-term sustainable solutions require broad perspectives that recognize the interconnectedness of urban and natural resources. Thus, the USGS will develop a public/private partnership where local partners and other government collaborators in southern California work together to develop and apply the best research to reduce community vulnerability to natural hazards.

Invasive grass species, which propagate easily after fires, have changed the fire regime to one of more frequent fires that threaten the survival of Joshua trees. USGS research on this fire/invasive species cycle is helping DOI land managers to preserve the Joshua tree forest ecosystem.

hazards research on the causes and effects of natural hazards, future research should identify how land-use and land-cover changes, climate change, new energy sources, and other factors create or amplify hazards and vulnerabilities of human and environmental systems. A national vulnerability-monitoring program would integrate land cover, land use, population and demographic patterns, economic distributions, and hazards information to identify at-risk areas. Geographic methods and tools need to be developed and applied to assess the effectiveness of mitigation, alternative land-use strategies, risk communication approaches, and other risk management scenarios, as well as provide intelligent access to data, knowledge, and predictive models for response and recovery efforts. The effective integration of natural sciences and social science will result in a greatly improved ability to assess the potential risks posed by natural hazards, to mitigate potential impacts, and to respond and recover efficiently when extreme natural events occur.

By building in these five strategic directions, USGS will contribute to effective risk reduction. Monitoring and communications tools will improve real-time forecasting and reporting of the locations and likely impacts of events. National, regional, and local assessments of hazards and risk will result in smaller uncertainty and greater accuracy; the fundamental research to understand the causes and effects of hazards and to predict their occurrence will contribute to more accurate warnings and greater preservation of life and property. Improved monitoring, mapping, and fundamental research also will lead to reduction in the uncertainties associated with loss-estimation models, which translate to cost-effective mitigation strategies and potentially decrease the cost of insurance and reinsurance. The USGS must augment all of these abilities over the next 10 years.

Too much water peaks our curiosity at times, like during this March 2002 flood on the Levisa Fork in eastern Kentucky. Photograph by Steve Pickard, U.S. Geological Survey.

Strategic Actions

- Expand and modernize USGS monitoring and communications capabilities to take full advantage of technology advances in order to deliver robust and reliable products.
- Increase research into the causes and consequences of coastal erosion, earthquakes, floods, geomagnetic storms, landslides, tsunamis, volcanoes, wildfires, and zoonotic diseases.
- Enhance understanding of the linkages among natural hazards, the environment, climate, and society, and the ways by which climate variability and change influence the frequency and intensity of natural-hazard events.
- Develop models with robust predictive capability to support land and emergency managers in short- and long-term hazard mitigation decisionmaking.
- Form an intrabureau hazards working group of scientists from the existing hazards programs and from other linked science thrusts of the USGS, including land use and cover, climate change, wildfire, ecosystems, zoonotic diseases, and coastal and marine geology and ecology.
- Develop a core of USGS and partner researchers focusing on vulnerability science, colocated with USGS hazard program science centers, external agencies, universities and Federal partners. This group will: (a) develop local, regional, and national indicators and visualization tools to understand and communicate societal vulnerability and resilience to natural hazards; and (b) conduct case studies to assess vulnerability and resilience of communities, ecosystems, and economies to specific natural hazards. Build and strengthen ties to existing governmental, private-sector, and academic groups that focus on risk assessment and management, as well as disaster response and recovery.
- Develop a national risk-monitoring program, built on a robust underpinning of hazard assessment and research that visualizes and provides perspectives at multiple scales of vulnerability and resilience to adverse land change and hazards.
- Create a bureau-wide disaster assistance strategy for providing scientific and technical support for hazard assessment, scenario development, disaster preparedness, and response and recovery efforts.
- Develop communication strategies and decision-support products that focus on understanding societal risk and resilience to natural hazards, and develop new individualized ways of communicating hazards and hazard assessments to local audiences and to targeted audiences with different needs.

Vision of 2017

In 2017, the Nation is safer from natural disasters, thanks to a seamless, integrated disaster reduction/monitoring/warning system maintained and operated by the USGS and its partners. Interdisciplinary research into the earth-system processes that drive hazards has led to decision-support systems and models that communities at risk use to make better decisions and safeguard people and property. A network of monitoring stations across the United States provides timely and reliable information on stream levels, volcanic and earthquake activity, wildlife diseases that may affect human health, and other potential hazards. The changing vulnerability of our cities and ecosystems owing to socioeconomic trends, land-use changes, ecosystem loss, and climate change also is monitored. Healthy forest, grassland, and wetland ecosystems prevent natural events like extreme rainfall or lightning strikes from turning into catastrophic floods or fires. Improved communications technology ensures that communities have enough warning to respond to the natural hazards they face.

The National Volcano Early Warning System (NVEWS)

To reduce community vulnerability on the ground and in the air, the USGS National Volcano Early Warning System will monitor the Nation's 169 active volcanoes at levels appropriate to the threats posed. Roughly half of U.S. volcanoes are dangerous because of the manner in which they erupt and the communities and infrastructure within their destructive reach. It is the threat to communities and infrastructure downstream and downwind, including to military and commercial aviation, that drives the need to properly monitor volcanic activity and provide forecasts and notifications of expected hazards.

A systematic assessment of volcanic threat and current monitoring capabilities has identified 57 priority volcanoes that are undermonitored and thus targets for improved monitoring networks.

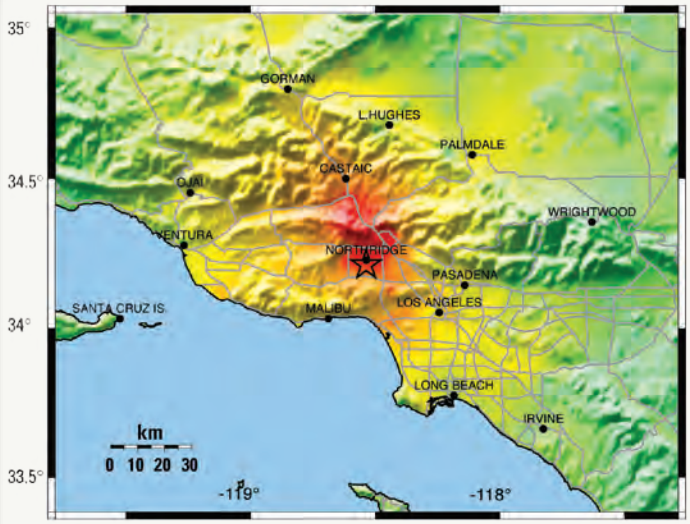
This house in Kalapana, Hawaii, is burned by approaching lava from Kilauea Volcano on Sunday, April 22, 1990. Most of Kalapana was destroyed by lava flows between 1986 and 1990, with 180 homes lost. Photograph by U.S. Geological Survey.

NVEWS aims to reduce vulnerability to volcanic hazards by providing:

- Expanded real-time monitoring to include the most threatening of the Nation's volcanoes
- A 24/7 Volcano Watch Office that takes full advantage of real-time monitoring networks and improves delivery of hazard information to key users
- A National Volcano Data Center that provides high-quality data sets for volcanic-hazards analysis and research
- An external grants program to enhance research collaboration between Federal and academic scientists
- More than a network of instruments, NVEWS connects the monitoring and research efforts of scientists to the emergency managers and general public at both national and local levels to minimize the impact of volcanic activity on the Nation.

Mount St. Helens photograph by U.S. Geological Survey.

Real-time Information for Safer Communities



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

A ShakeMap of a magnitude 6.7 earthquake near Northridge, California, 1994. Simplified versions are quickly available for the news media.

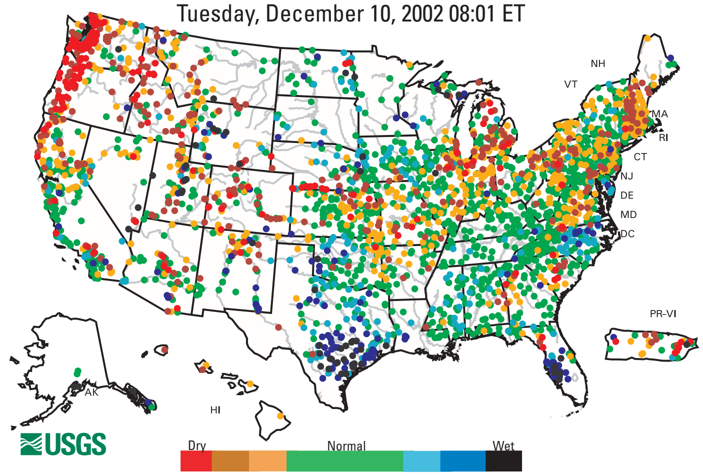
ShakeMaps in Minutes

The USGS is the only agency in the United States responsible for the routine monitoring and notification of earthquakes. The USGS fulfills this role through a national backbone network and support for 14 regional networks in areas of moderate to high seismic activity, integrated to form the Advanced National Seismic System (ANSS). The revolution in information technology has enabled ANSS to achieve dramatic advances in real-time seismic data analysis and rapid earthquake notification. In urban areas, where dense arrays of sensors have been deployed, data from those sensors are used to produce, within a few minutes of the earthquake, a map showing the actual severity and distribution of strong ground shaking caused by an earthquake. Emergency management officials and others use these “ShakeMaps” to direct emergency response to the earthquake at a time when communications from heavily damaged areas may be unreliable. Some form of sensor-based ShakeMap capability now exists for Los Angeles, San Francisco, Seattle, Anchorage, and Salt Lake City. With additional support, this capability can be deployed in all large urban areas with high seismic risk. The success of ShakeMaps depends on adequate ANSS instrumentation and effective USGS partnerships with the user community.

Streamflow Information on Tap

Since 1887, the USGS has operated a streamgaging program to collect information needed by Federal, State, and local agencies for water-related planning, management, and regulatory programs and for flood warning and emergency management. Management strategies that make optimum use of the Nation’s existing water resources or that keep people out of harm’s way require more information in greater detail and in more constrained timeframes than was needed in the past. The National Weather Service uses real-time data from about 4,000 of the approximately 7,000 USGS streamgages to forecast flow conditions on major U.S. rivers and small streams in urban areas. In fact, the most profound change in the USGS streamgaging program in recent years has been the development and widespread use of real-time streamflow data by many partners and the public.

Map of real-time streamflow compared to historical streamflow for the day of the year (United States)
Tuesday, December 10, 2002 08:01 ET



Choose a data retrieval option and select a location on the map
❍ List of all stations in state, ⦿ State map, or ❍ Nearest stations

Explanation - Percentile classes						
●	●	●	●	●	●	●
New low	< 10	10 - 24	25-74	75 - 89	≥90	New high

Water Watch is the official USGS website for real-time streamflow conditions nationwide in relation to historical conditions (*http://water.usgs.gov/waterwatch*). It also connects the user directly to NWIS-Web, the USGS online National Water Information System that provides access to real-time and historical surface-water, ground-water, and water-quality data at *http://waterdata.usgs.gov/nwis/.*

The Role of Environment and Wildlife in Human Health:

A System that Identifies Environmental Risk to Public Health in America

Background

Environmental health threats to the Nation's citizens are an inescapable consequence of the interactions between people and their physical, chemical, and biological environment (Friend, 2006; Plumlee and Ziegler, 2004). As towns and cities expand, the wildland-urban interface broadens and human-wildlife interactions are increasingly frequent. Many public health issues affecting Americans, such as avian influenza, originate outside our borders, requiring the Nation to maintain global vigilance for potential health threats. The emergence of many new human diseases in recent years is directly related to worldwide increases in population density, mobility, and environmental disruption. Major health threats also arise from naturally occurring toxicants and anthropogenically derived environmental contaminants. Such contaminants are increasingly appearing in natural ecosystems. Some of these contaminants are bioaccumulative; they persist in the environment and accumulate in living organisms and tend to increase up the food chain. The health consequences of chronic exposure of low levels of these substances are commonly unknown but potentially important.

There is mounting evidence that environmental factors contribute substantially to many diseases of major public health significance throughout the world. The National Institute of Environmental Health Sciences (NIEHS) attributes an estimated 24 percent of the global disease burden and 23 percent of all human deaths to environmental factors (National Institute of Environmental Health, 2006). The NIEHS 2006 to 2011 Strategic Plan emphasizes that, "The environment represents a key contributor to human health and disease" and cites the need for interdisciplinary teams to "understand how the environment influences the development and progression of disease." The Centers for Disease Control and Prevention (2006) define emerging infectious diseases and environmental threats as health and safety challenges of the 21st century. Understanding environmental and ecological health clearly is essential for protecting the public health of the Nation and the world.

The current (2007) health problems caused by zoonotic diseases (that is, those transmissible between animals and humans, such as West Nile virus and avian influenza) and environmental contamination (for example, mercury in fish, arsenic in water, naturally present asbestos) are not isolated examples. Future generations will continue to be affected by many of the diseases that have emerged or resurged during the past quarter-century, regardless of whether the causes are chemical, microbial, or parasitic. Dealing with emerging and resurging diseases requires the ability to anticipate potential environmental and ecosystem health threats, recognize pathogens or contaminants when they first appear, and respond quickly and appropriately. Because many zoonotic disease outbreaks are evident in wild animal populations before they affect people, wildlife health and disease monitoring serves as an indicator of environmental and ecosystem health and is thus essential to any information system for protecting human health.

Environmentally related diseases inevitably will increase as the isolation previously provided by walls of geographic distance are removed and the opportunity for the spread of once-isolated diseases increases. Public health risks will further intensify as population growth continues, bringing with it associated pressures of development, resource use, and habitat modification. Chemical and microbial contaminants will increasingly affect the quality of water, air, and consumables. These factors make understanding environmental and ecological health a prerequisite to protecting the health of the American public and the world.

Statement of Strategic Science Direction

The USGS can contribute substantially to public health decisionmaking. As the only integrated natural resources research bureau in the Federal Government, USGS is the primary governmental agency responsible for monitoring wildlife (Migratory Bird Treaty Act of 1918) and is at the forefront of identifying wild animal disease reservoirs. With this expertise, USGS science complements and can augment public health decisionmaking in America. In addition, USGS serves as an unbiased translator of environmental information to help address public health needs. USGS scientists have a national scope and transdisciplinary approach to addressing environmental aspects of human health issues and are among the world's experts on wild animal disease transmission to humans, drinking-water contaminants, air-dust-soil-sediment-rock contaminants, pathogens in recreational water, and the use of wild animals as sentinels of human health (see http://health.usgs.gov/). The position of USGS as a nonregulatory agency, with capabilities in environmental monitoring and mapping at all scales from national to local, and the ability to understand environmental and ecological processes, is found nowhere else in the Federal Government. Thus, the USGS is uniquely qualified to provide the information needed to link environmental and human health issues. To use this expertise in support of the Nation's health needs, the USGS will fully integrate its massive data holdings and produce a national database and atlas of geology- and ecology-sourced diseases and toxicants. Once this atlas is in place, the USGS will partner with allied health science agencies to support spatially related health issues.

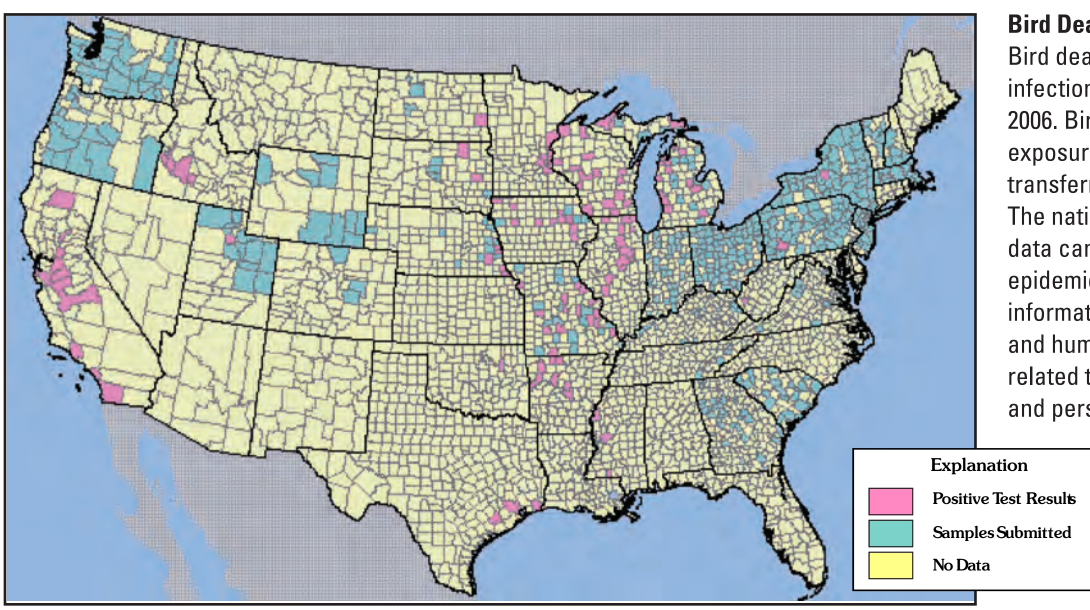
Strategic Focus

The USGS proposes to provide the scientific and monitoring information essential for helping the Nation to identify existing, emerging, and resurging environmental and ecosystem health threats. This strategic goal will be achieved by integrating existing USGS human-health related data, by establishing an interactive information system for environmental threats, thus clarifying potential environmental disease pathways, by forming or strengthening teams to respond rapidly to human health threats, and by enhancing collaborative research with allied public health organizations. These steps will enable USGS to provide the scientific information needed for a clear understanding of the connections among all living things and the environments in which we live. This effort is essential to protect public health in the Nation and around the world.

Overleaf: Photograph of snow geese. Scott Fink, Spokane, Wash.

Expand Access to Existing Data

Advances in medical science at the cellular, organism, and population levels undoubtedly will continue to identify environmental challenges to human health. Once these agents are identified, it will become essential to understand their local, regional, national, and even global distribution to mitigate their effects (see box on Emerging Contaminants). The USGS scientific workforce has the information—biologic, hydrologic, geologic, and geographic—to provide the Nation with powerful tools for characterizing the spatial distribution of environmental health risks to its citizens. USGS databases make up one of the most comprehensive and high-quality arrays of national, regional, and local biologic, organic, and inorganic analyses available from any single source (see database table in this section). Many of these data have been collected over varying time ranging from years to decades. However, the many data



Bird Deaths from West Nile. Bird deaths from West Nile virus infections January 1 to July 11, 2006. Birds are sentinels of human exposure to this virus, which is transferred to people by mosquitoes. The national dead-bird infection data can be translated into an epidemiological tool by adding information on climate, land use, and human demographics that are related to incidence, prevalence, and persistence in human exposure to existing mosquito populations.

sources are scattered across the USGS and not easily available to most users. If consolidated, this array of environmental data and information could provide the USGS partners and customers with unified spatially and temporally referenced sources of human health information.

An important step in the overall goal of protecting public health is to integrate existing USGS databases into an information source that would quickly and easily portray potential environmental health threats and provide the underlying framework for partnering with health agencies in existing and future USGS environmental health studies. Because USGS scientists across the country continually monitor and conduct surveillance of contaminants and wildlife in the environment, the atlas would be continuously updated and provide a source of information to researchers and decisionmakers. The Centers for Disease Control and Prevention (CDC) National Environmental Public Health Tracking Program currently (2007) has links to a number of external data sources, including some USGS databases. The proposed USGS health information system would greatly strengthen CDC's and other human health agency programs by improving their access to all USGS health-related data.

Strengthen Partnerships and Enhance Collaboration with Others

Realizing the full benefit that the USGS can provide to the Nation and the world on public health issues requires enhancing collaborations and partnerships with allied health professionals. Because most USGS expertise resides at the environment-health interface, fostering strong alliances with public health, domestic-animal health, and sister environmental agencies is essential for effective problem-solving. To enable efficient linkages between science needs and resource investments, these alliances require cooperation and regular communication to set priorities, plan and conduct joint studies, and disseminate information, data, and reports.

The USGS has already established partnerships with the CDC, Armed Forces Institute of Pathology, Indian Health Service, and NIEHS that are facilitating collaboration. USGS also has Interagency Agreements with the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture, multiple state universities through the Cooperative Ecosystem Studies Units, thus covering collaborative work related to drinking-water quality, early detection of highly pathogenic avian influenza in wild birds in North America, and other human health needs.

The long-standing relation with EPA will be strengthened further when USGS can provide information on the environmental presence and potential for exposure of the next contaminants of concern for regulation and registration. Existing partnerships with other DOI agencies will be strengthened by the ability to define the role of public lands and fish and wildlife resources in public health protection. This research will provide an opportunity to build new relations with Federal agencies, such as the U.S. Departments of Defense, Health and Human Services (including the Food and Drug Administration), and Homeland Security.

Emerging Contaminants

USGS scientists collected water samples from a network of 139 streams across 30 states during 1999 and 2000. The results show that a broad range of chemicals found in residential, industrial, and agricultural wastewaters commonly occur in mixtures at low concentrations in streams in the United States. The chemicals detected include human and veterinary drugs, natural and synthetic hormones, insecticides, and fire retardants. At least one of these chemicals was found in 80 percent of the streams sampled, and half of the streams contained seven or more. This study was the first national-scale examination of emerging contaminants in streams of the United States.

The National Research Council's analysis of Future Roles and Opportunities for the U.S. Geological Survey (National Research Council, 2001) recognized the interface between earth system science and allied health sciences as an opportunity for the USGS to play a major research role in partnership with other agencies, including Centers for Disease Control and Prevention, National Institute of Environmental Health Sciences, and the U.S. Environmental Protection Agency, to address environment-human health linkages. The USGS among Federal agencies has a unique role: it can apply an extremely broad range of interdisciplinary monitoring activities to track environmental health issues, and it can also interpret the data in the context of key Earth, environmental, and ecological processes. Being able to understand the processes enables the USGS to help anticipate potential environmental and ecosystem health issues before they arise.

Manures from confined animal-feeding operations, such as this chicken house in Ohio, were sampled as part of the Source Characterization Study for Emerging Contaminants project.

Enhance Rapid Response Teams

The USGS has the ability to sample and analyze a broad spectrum of potential human health threats and the expertise to help interpret environmental processes (and possible human health implications) during extreme disease, environmental, and contamination events. USGS has rapid-response capabilities in several areas, most notably volcanoes, earthquakes, and wildlife disease outbreaks important to public health. These efforts could be replicated and should increase the focus of USGS on environmental, ecosystem, and human health aspects of potential human health events. This proposed new effort needs to be broadened to include a collaborative and cooperative rapid response capability for characterizing the scientific underpinnings of events related to human health threats. This capability will focus on providing sound scientific data and modeling future disease outcomes to assist in dealing with catastrophic natural or anthropogenic events, such as newly introduced pathogens, earthquakes, floods, or extreme contamination. This response capability would complement existing USGS rapid response to wildlife disease and to toxicological studies and would provide valuable information to other agencies charged with public health and emergency response.

Tracking the Highly Pathogenic Avian Influenza Virus

Worldwide there is great concern about the spread of the highly pathogenic H5N1 strain of avian influenza, which has caused over 150 human deaths, mostly in Asia. Highly pathogenic H5N1 avian influenza (HPAI H5N1) has also caused the deaths of millions of domestic poultry and numbers of wild birds in many areas of the world. The emergence of this virus has raised many questions that only field and laboratory research will be able to address. One of the routes by which the virus could enter North America is through migratory birds, and USGS biologists have been instrumental in developing and implementing the U.S. Interagency Strategic Plan for the Early Detection of HPAI H5N1 in Wild Birds. USGS field and laboratory scientists were the first on the ground sampling and testing live and hunter-killed wild birds for the presence of the deadly H5N1 virus. Sampling by USGS scientists began in April 2005 in Alaska and has since expanded to the lower 48 States and the Pacific Islands, as the birds that were nesting in Alaska begin their southward migration. USGS researchers have a long history studying wildlife and their diseases and are uniquely qualified to evaluate the role of wild birds in the spread and maintenance of the virus and to identify the risk that migratory birds will carry this deadly strain to North America.

Avian flu sampling

Expand Understanding of Environmental Disease Pathways

Within the framework of proposed collaborative efforts, the USGS will play a key role in analyzing and documenting the pathways and processes by which diseases are transferred from earth sources (rocks, soil, volcanic gases, dusts), water sources (trace metals, pathogenic agents, organic contaminants), and ecological sources (wildlife and plants) to water cycles, ecosystems, food chains—and ultimately to people. Traditional USGS expertise in biology, geology, and hydrology will be combined and integrated to clarify transmission mechanisms. Examples of the application of this expertise are shown in the associated boxes on mercury sensitivity maps and tracking avian influenza virus. Through understanding how these processes work, we will be able to provide public health workers with improved ways to mitigate newly emerging and resurging diseases.

Develop and Implement a National Environmental Health Information System

The ultimate goal of USGS in response to the health challenges ahead is to establish and maintain a national-scale, environmental health information system. The system would serve as a clearinghouse for spatially referenced environmental information (data, research, modeling interpretations) linked to a set of Geographic Information System (GIS) decision-support tools. The system would:

- Map, observe, and monitor the spatial extent of potential zoonotic factors in America, including potential movement patterns of diseases and wildlife;
- Collect and disseminate information from a variety of interagency surveillance networks to locate, identify, and describe sources of environmental contaminants and pathogens;

A partial listing of U.S. Geological Survey (USGS) environmental health-related databases

USGS DATA SOURCE	COMPONENTS OF DATABASE
NAWQA (National Water-Quality Assessment Program) Data Warehouse	Data from 7,600 surface-water sites and 8,100 wells, 30,000 pesticide samples, and 8,800 volatile organic compound samples, 2,600-bed-sediment and aquatic organism tissue samples from 42 basins across the United States.
NBII Wildlife Disease Information Node	A collection of wildlife and human health related web resources, including zoonotic disease fact sheets, website annotations, journal articles, news reports, and maps. A Wildlife Health Monitoring Network linking wildlife disease surveillance data from multiple governmental and nongovernmental agencies is under development.
Canary Database (a collaboration with Yale University Occupational and Environmental Medicine Program)	An extensive database of journal articles on animals as sentinels of human environmental health hazards.
National Wildlife Health Center EPIZOO database	Documents over 25 years of information on epizootics (epidemics) in wildlife. It tracks die-offs throughout the United States and territories, primarily in migratory birds and endangered species.
National Wildlife Health Center (NWHC) DIAGDATA database	A record of specimens (from serum samples to carcasses) sent to NWHC for processing and diagnostic workup. Postmortem examination reports, as well as tests for bacteria, parasites, viruses, and toxic agents, are included.
National Geochemical Survey database	National Geochemical Survey database stream sediment and soil geochemistry approaching a sample density of one sample per 289 square kilometers for the entire Nation and a higher density in many places. Geochemistry of igneous rocks and unconsolidated sediments from throughout the continental United States and Alaska.
BEST-LRMN (Biomonitoring of Environmental Status and Trends-Large Rivers Monitoring Network)	Contaminant concentrations (elements and organochlorines) in fish, fish health indicators, and reproductive biomarkers from the Yukon, Columbia, Colorado, Rio Grande, Mississippi, and Southeastern river basins.
NASQAN (National Stream Quality Accounting Network)	Description of concentrations and flux of sediment and chemicals in the Nation's largest rivers.
NADP/NTN (National Atmospheric Deposition Program/National Trends Network)	Nationwide network of precipitation monitoring sites. Includes data on the chemistry of precipitation. The network is a cooperative effort between many different groups, including the State Agricultural Experiment Stations, USGS, U.S. Department entities. Includes over 200 sites spanning the continental United States, Alaska, and Puerto Rico.
U.S. Coal Quality Database	Detailed analyses of more than 10,000 coal samples from all coal basins in the United States.

- Interpret the pathways and processes through which zoonotic diseases, contaminants, pathogens or vectors might affect human health;
- Produce derivative risk maps that will delineate the degree of potential exposure to environmental sources of disease-causing agents that pose risks to human health in the natural environment; and
- Model and predict how environmental risk factors for human health will evolve in time and space.

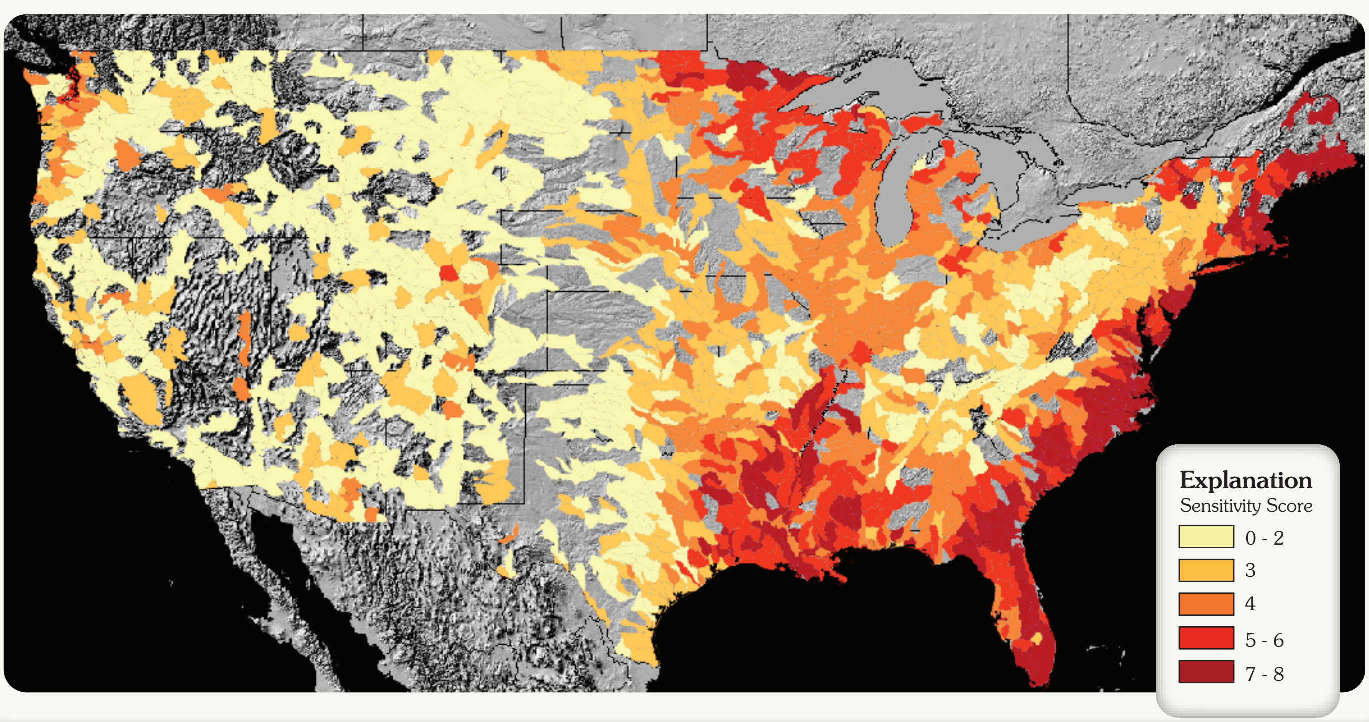
Such a system would be developed across the broad spectrum of USGS disciplines, integrating biological information and research (origins, locations, and types of zoonotic diseases and their vectors), water-quality information and research (local- to regional-scale water contamination issues), earth-science information and research (locations and characteristics of major dust sources, geologic terrains naturally enriched in potentially toxic substances, and contaminated water, sediment, and soil), all interfaced with the GIS and mapping capabilities of the agency. This system would complement existing and planned Federal environmental health efforts. The USGS health information system would provide a unique perspective on environmental health issues by including process-based and modeling interpretations of environmental health threats.

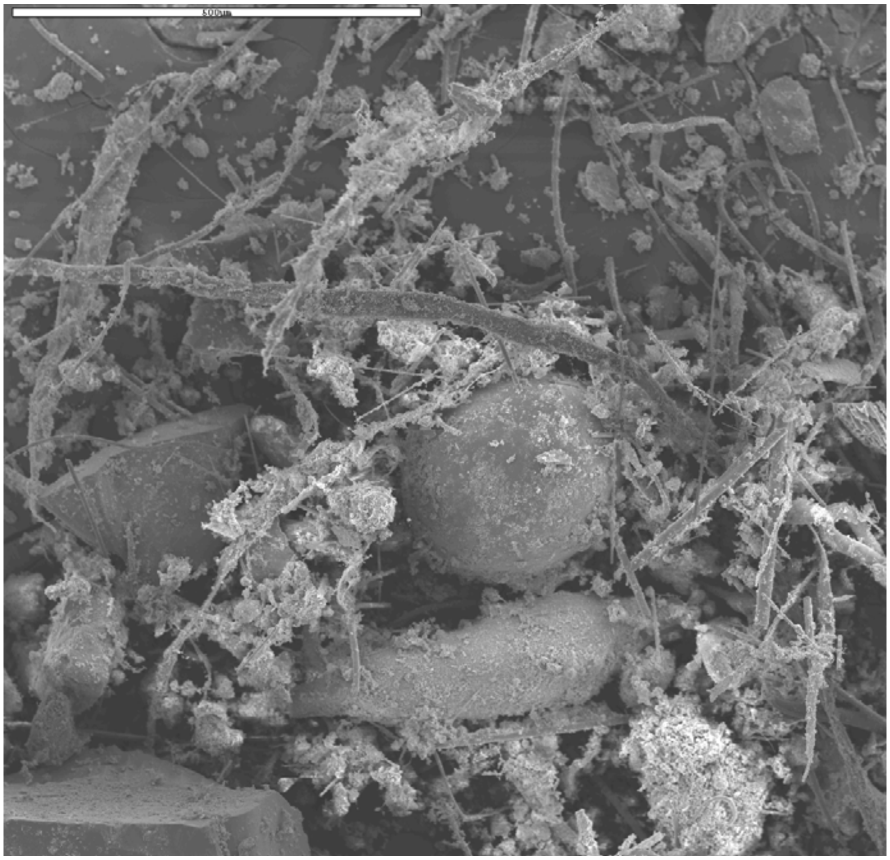
Strategic Actions

- Develop an online data atlas of potential environmental health threats that consolidates USGS data and information and provides data for researchers and public-health agencies to enhance the Nation's ability to respond quickly to current threats and anticipate potential future health threats.

Mercury Sensitivity

This figure shows a mercury sensitivity map for aquatic ecosystems in the contiguous 48 States. Mercury in fish is the primary route of exposure for people and fish-eating wildlife. According to the National Academy of Sciences, over 60,000 children nationwide are born with neurological defects related to mercury exposure. A nationwide map of mercury sensitivity is being developed at the USGS that includes mercury concentrations in fish, information from models of the mercury biogeochemical cycle related to land use and other factors, mercury sources, and mercury residues found in human tissues. The USGS has identified water-quality indicators of mercury vulnerability to predict the areas where production of methylmercury (the most toxic form of mercury) is most likely to take place if inorganic mercury is present. Using information sources, including USGS water chemistry data from more than 55,000 sites and 2,500 watersheds, the USGS created a mercury vulnerability map. The map shows strong geographic trends in the Eastern United States, with the highest vulnerability along the Gulf of Mexico and Atlantic coasts, in the Adirondacks, and in the Great Lakes region. The Western United States has some watersheds with high predicted vulnerability, but no geographic pattern is evident.





The massive dust clouds and resulting dust deposits produced by the collapse of the World Trade Center towers have posed a health concern for individuals exposed during the initial collapse and subsequent cleanup. Interdisciplinary USGS characterization studies provided emergency responders, cleanup managers, and public health specialists with extensive information about the physical, mineralogical, and chemical characteristics of the dusts that pose potential environmental and health concerns. This scanning electron microscope image (white scale bar is 50 micrometers long) shows a typical dust sample, composed of a complex mixture of glass fibers, window glass shards, and particles of concrete, gypsum wallboard, and other materials that made up or were present in the buildings. A fact sheet on this topic can be found at http://pubs.er.usgs.gov/usgspubs/fs/fs05002.

- Create new partnerships, strengthen existing partnerships, and enhance collaboration with other entities charged with responsibility for environmental and public health. Increased levels of collaboration at all levels are needed to address the Nation's environmental health-related issues.

- Enhance rapid and long-term response teams to evaluate short- and long-term health implications of disasters. Identify and assess the changing patterns and root environmental factors related to chronic and emerging diseases.

- Develop and implement a national-scale, environmental health information system that combines biological, water-quality, and geologic information with GIS decision-support tools.

- Publish a report every half decade that includes the status and trends in environmental, animal, and earth science information. The report will describe the way conditions are changing, present new findings relating to public health, and explain the methodological and research contributions that USGS has made and transferred to managers.

Vision of 2017

The USGS has worked with health agencies around the Nation and the world to develop and maintain an international database and atlas of wildlife and geology-sourced diseases and toxicants. Based on these efforts, USGS scientists and collaborators in the medical and allied health sciences have made important contributions to describing and modeling environmental factors affecting human health. Public health workers are developing improved strategies to mitigate diseases and toxicants, based on USGS research to identify and understand the pathways through which toxicants and zoonotic diseases migrate in the environment and the processes by which these health threats are transferred to people from earth, water, and ecological sources. A national-scale, environmental health information system, developed and maintained by the USGS, provides maps to delineate the degree of potential exposure to diseases and contaminants in the natural environment so that decisionmakers can use these map tools to evaluate the risks to human health. USGS scientists provide rapid analyses and model environmental processes to provide a better understanding for dealing with the immediate and potential future health implications of catastrophic natural or anthropogenic events, such as newly introduced pathogens, earthquakes, floods, or extreme contamination.

A Water Census of the United States:

Quantifying, Forecasting, and Securing Freshwater for America's Future

Background

A fresh and dependable supply of water is critical to sustaining life. "The strategic challenge for the future is to ensure adequate quantity and quality of water to meet human and ecological needs in the face of growing competition among domestic, industrial-commercial, agricultural, and environmental uses" (National Research Council, 2004). Many States expect future water shortages and are concerned about how the Federal Government could help them meet that challenge. Also, changing climate patterns will affect freshwater availability at the local and regional levels. Water is a key ingredient for healthy communities, economies, and natural environments of the United States. Yet, no comprehensive census of water information, summarizing the entire scope of freshwater quantity and quality needed for human and environmental needs, currently (2007) exists for America or is planned for the future.

In the past, water availability was viewed primarily in relation to human activity. Now, the use of water for environmental needs is a factor. Inclusion of environmental water needs in decisions about water can lead to "gridlock," in part because insufficient information is available concerning those needs that all parties can agree on. Therefore, it is essential to obtain scientifically rigorous determinations of the timing, quantity, and quality of water needed to meet those environmental water needs. Providing data, understanding, and prediction capabilities relating ecosystem response to hydrologic conditions is the scientific basis needed for overcoming this water "gridlock."

The USGS is the primary Federal agency responsible for scientific evaluation of the natural resources of the United States, including its water and biological resources. The agency has a diverse cadre of scientists and technicians who work on aspects of the status and trends of freshwater quality and quantity for human and environmental needs in the United States at the local, State, regional, and national levels. The USGS also has an existing infrastructure from which it can conduct a regular inventory of natural resources and water use, including water quantity, quality, and environmental water needs, in partnership with local, State, and regional water and environmental agencies. The USGS has the skills needed to better define the geologic framework of aquifers, physical characteristics of watersheds, geochemical aspects of soil, land-cover change, land-use practices, and related environmental factors, all of which affect the movement of water and its quality. USGS also has the biological capabilities needed to relate the presence of individual species, groups of species, and ecosystem function to the quantity, quality, and timing of water movement as well as environmental habitat requirements of those organisms. Its research on past climate variability enables the USGS to provide scientific understanding and modeling perspectives for expected changes in water availability due to ongoing climate fluctuations. Its ground-water flow models are the international standard, and, when coupled with watershed, water-quality, and ecosystem models, will enable decisionmakers to better understand the consequences of water and land-use decisions before such decisions are made.

Statement of Strategic Science Direction

The USGS will develop a Water Census of the United States to inform the public and decisionmakers about:
(1) The status of its freshwater resources and how they are changing;
(2) A more precise determination of water use for meeting future human, environmental, and wildlife needs;
(3) How freshwater availability is related to natural storage and movement of water as well as engineered systems, water use, and related transfer;
(4) How to identify water sources, not commonly thought to be a resource, that might provide freshwater for human and environmental needs; and
(5) Forecasts of likely outcomes of water availability, water quality, and aquatic ecosystem health due to changes in land use and land cover, natural and engineered infrastructure, water use, and climate.

Water is an essential ingredient for healthy communities, economies, and natural environments of the United States. The public and decisionmakers need current, accurate information that summarizes the full range of freshwater quantity and quality required for human, economic, and environmental health now and for the future. Therefore, the USGS proposes to undertake a Water Census of the United States, to meet the need for a comprehensive, scientific accounting of the status and trends in freshwater quantity and quality for human and environmental needs. By regularly and systematically collecting, analyzing, modeling, and interpreting information, the Water Census will provide continuous updates on the status of the quantity of freshwater available; the quality of freshwater needed for various purposes; how quantity and quality of available freshwater changes over time in response to use by humans and the environment, variation in climate, and adaptation of human and environmental use to climate variation; and whether sources of water at present not considered to be a freshwater resource can be made available for human and environmental needs.

USGS scientists sampling fish populations on the Big Wood River near Gannett, Idaho, with a backpack electroshocker. Photograph by Mark Hardy, U.S. Geological Survey.

Fundamental information on how much freshwater is available, and whether that supply of freshwater is increasing or decreasing over time, is essential for the Nation's economic and environmental health. Improvements are needed, however, in the determination of amounts of water used for irrigation, industry, mining, livestock, thermoelectric power generation, public and domestic supply, as well as environmental needs (National Research Council, 2002). Nontraditional sources, such as saline water, water reuse, or offshore freshwater aquifers, also need to be evaluated.

As American population centers migrate to coastal areas and the arid west, where surface-water storage capacity is limited, water shortages will undoubtedly occur. In fact, in parts of the Southwest along the U.S.-Mexico border, because of pumping, ground-water levels already have fallen so far that many perennial streams like the Rio Grande have at times ceased to flow. Cities that rely on ground water (for example, Tucson, Ariz.) need to know how long pumping can be sustained. Conflicts over water are a concern of the States, according to a recent report by the Council of State Governments (2003). Not only is water scarce in some parts of the country, but, the report indicates, "...conflicts are occurring within states, among states, between states and the federal government and among environmentalists and state and federal agencies." Tribal governments' water rights are becoming a factor in water availability concerns, particularly in the Western United States, as for example, in Klamath Lake, Oregon. Many States expect future water shortages and are concerned about how the Federal Government could help them meet that challenge (U.S. General Accounting Office, 2003). Changing climate patterns can affect freshwater availability at the local and regional levels (National Science and Technology Council, 2004). Water availability conflicts also are likely to arise from future needs to develop energy or mineral resources. For example, the large amounts of water needed to produce oil from oil shale could be in direct conflict with community or agricultural needs for water in arid areas. In humid areas, these activity conflicts might relate more to water-quality needs of aquatic ecosystems than to quantity needs of humans. Water requirements (both quantity and quality) also now include the recognized needs of the natural environment, such as aquatic fish, wildlife, and native vegetation communities associated with those water resources.

Strategic Focus

The USGS is the primary Federal agency responsible for scientific evaluation of the natural resources of the United States, including its water resources, and many of its current programs provide the foundation upon which the Water Census of the United States can be built. It is envisioned that the additional information needed to address these challenges, initiated through the Water Census of the United States, will allow a systematic, periodic determination of the following:

- Freshwater quantity and quality present in surface water, ground water, snow and ice, and water infrastructure;
- Freshwater quantity and quality needed to meet human and environmental uses; and
- Changes over time in freshwater quantity and quality in response to changes in climate, land use and land cover, and human and environmental water needs.

The results of the Water Census will provide individuals, communities, and State and national decisionmakers with information on how much freshwater is available in the Nation and whether the supply of, and demand for, freshwater is increasing or decreasing. It will answer the key question of whether there is enough freshwater, in the quantity and quality needed for various uses, to meet present and future human and environmental requirements. The Water Census also will enable scientists to forecast how the quantity and quality of freshwater might change in response to decisions about water or environmental change.

The Water Census will focus on the 21 water-resources regions of the Nation, including their watersheds and associated aquifers (U.S. Geological Survey, 1982) as well as offshore extents (see following box titled Water-Resources Regions). Each region has local and regional aspects of water supply and demand that must be considered in determining where the water is located, how much freshwater is present, the quality of that water, the amount of water used, and if that supply of freshwater is stable, increasing, or decreasing. Strong partnerships among local, State, regional, and Federal agencies, through efforts like the Cooperative Water Program, will ensure that local needs and the goals of the national Water Census are met.

New scientific approaches will be developed to understand and quantify current and future water demand and availability for the Nation. These approaches will be based on a rigorous and systematic quantification of the components of the water cycle. Monitoring networks and research groups within the USGS will establish definitive and scientifically defensible freshwater supply and demand data for the major watersheds and aquifers of the Nation. Research is needed to better define the characteristics of watersheds and aquifers that constrain how much water can be stored and transmitted. The Water Census also will require improvements in the mapping and description of the geologic and geomorphic framework of the Nation's principal aquifers and watershed systems, particularly in coastal areas and regions of fractured rock and karst settings. Research is needed in developing indirect methods of estimating water use where a direct measure of use is not practical or obtainable and for projecting realistic water-use estimates for human and environmental needs in the future.

USGS scientists collecting a biological sample (benthic invertebrates) in the Stony Brook at Princeton, New Jersey. Photograph by Denis Sun, U.S. Geological Survey.

USGS hydrologist lowers water-quality sampling equipment into the Mattaponi River near Beulahville, Virginia.

A major focus for the Water Census of the United States will be the construction of water budgets and water-budget models for all major watersheds and aquifers of the Nation. Water budgets require improved understanding and measurement of the changes in water entering a watershed or aquifer, the amount of water stored, and the amounts of water leaving the watershed or aquifer. Water-budget models will enable the forecasting of likely outcomes in relation to anticipated changes in water entering a watershed or aquifer (wetter or drier climate conditions, human alteration of water movement between watersheds and aquifers) or in water use (for human, environmental, and wildlife needs).

Determining the rate at which the water in an aquifer is replenished requires improved understanding of water movement from the land surface to the water table, a process known as recharge, which in turn requires improved understanding of the underlying geologic framework and permeability of surface soils. How long water stays on the land surface before it moves to streams as runoff, or how likely precipitation that falls on the land surface is to enter the subsurface and be added to an aquifer, is also a function of the type of land cover and land use. These processes, in conjunction with various

Water-Resources Regions

The Water Census will focus on the 21 water-resources regions of the Nation, including their watersheds and associated aquifers (defined in U.S. Geological Survey, 1982); the regions also include offshore freshwater aquifers for water-resources regions along the coasts.

Two current USGS projects, one in the Great Lakes Region and another on the Lower Colorado River between California, Nevada, and Arizona, could be used as pilot, or proof-of-concept, studies for the development of a Water Census. The pilot projects will assess needed improvements in data and data networks that define the resource, improve understanding of the links between the different components of the hydrologic cycle, and determine water use, including environmental needs. These pilot studies will demonstrate the best ways to evaluate freshwater resources and to deliver the information in a manner that is most helpful to planners and policymakers working at local, regional, and national levels. Full implementation of the Water Census for the United States will take what is developed in the pilot studies to other major water-resources regions and would add a national synthesis to provide an overview of the status and trends of the Nation's freshwater resources in formats useful to policy-makers, public officials, and the general public.

geochemical aspects, also are factors in determining the quality of the water in recharge and runoff changes as water moves through a watershed or aquifer. Therefore, the Water Census will provide a better understanding of the relation of environmental needs and land cover and land use on the movement of water in watersheds or aquifers, through scientific quantification of environmental factors and water needs, and regular determination of changes in factors, such as land cover and human land-use patterns.

The quantity of water available for any given purpose is directly related to the quality needed. Watersheds and aquifers can contain water that is not suitable for human drinking purposes but that may be suitable for other uses, such as irrigation, industry, power plant cooling, or water needs of the environment. These nonpotable waters represent part of the water portfolio that in the past have largely been ignored but that will be included in the Water Census.

As USGS scientists analyze data and improve the understanding of linkages between various segments of the Nation's water resources and demands for freshwater, the components of the Water Census of the United States will be refined to ensure that all suitable water in the United States is accounted for and that the status and trends in freshwater quantity and quality for human and environmental needs are clearly understood.

The Water Census of the United States will have benefits for the public and decisionmakers in addition to the systematic, periodic determination of freshwater quantity, quality, and use. Better understanding of the geologic structure of aquifers will improve our knowledge of potential water storage and the hazard posed by land subsidence because of ground-water withdrawals. Improved geomorphic description of watersheds will lead to better rainfall-runoff models and hence better estimates of recharge, runoff variability, and flood prediction. Knowledge of climate variability in relation to drought, especially placed in historical context, will lead to a more comprehensive understanding of drought frequency, severity, and duration for a region. People concerned about the quality of their water supplies will have access to better information about potential contaminants in their water. Knowing the water requirements of certain wildlife species will help people anticipate where animals carrying zoonotic diseases are likely to occur, or how changes in water on the landscape may affect wildlife distribution patterns.

The availability and use of suitable water is crucial to the Nation's economy and natural environment. The goal of this proposed USGS science direction, development of a Water Census of the United States, is to provide citizens, communities, natural-resource managers, and policymakers with a clearer knowledge of the status of their water resources (How much water do we have and what is its quality?), trends over recent decades in its availability and use (How is freshwater supply changing in quantity and quality?), and an improved ability to forecast the availability of freshwater for future economic and environmental uses.

A USGS hydrologist measuring ground-water levels with an electric tape in a monitoring well in Albuquerque, New Mexico (photograph by James R. Bartolino, U.S. Geological Survey). Frequent and consistent measurements of ground-water levels are crucial for understanding the aquifer system and tracking water-level declines.

Strategic Actions

- Better define the ecosystem needs of the Nation's natural landscapes and changing environments, relating the quantity, quality, and timing of water and the physical habitat requirements to the presence of individual species, groups of species, and ecosystem function.
- Expand the time-series data-collection capabilities for status and trends of water quantity, quality, and use, including water-use needs of biota, and make the information available to the public and to decisionmakers in increasingly more useful formats in a nationally consistent manner.
- Promulgate the systematic definition and mapping of land-cover and land-use change for the United States on a continuous basis, to better understand how land-cover and land-use change are related to water quantity,

The Price of Uncertain Water Information

Western States experienced drought in 1976, and 1977 began as another drought year. In early 1977, a forecast for the Yakima River Valley in Washington State indicated that the amount of water available during the irrigation season would be half of the long-term average—not enough for all the users in the basin (Glantz, 1982).

On the basis of the forecast of water availability, orchard owners leased water rights from those irrigators with senior water rights. Some farmers transplanted crops to other basins. Four hundred irrigation wells were installed, at an estimated cost of $9 million. Ranchers sold off livestock. However, by May more water was available than had been projected, due to the return of more typical amounts of precipitation. The inaccurate forecast of water availability resulted in substantial economic consequences for water users in the basin (Glantz, 1982; National Science and Technology Council, 2004).

This example highlights the need to go beyond a description of freshwater availability to also address vulnerability of human populations (and the natural environmental heritage they value) to water shortages or excesses. The Nation needs to know which communities or ecosystems are vulnerable to difficulties because of insufficient freshwater quantity and quality, as well as which communities or ecosystems are particularly vulnerable to too much.

> *"Knowing how much water is available for use, and when water is available, are key for decision makers and the application of water law."*
>
> **National Science and Technology Council, 2004**

quality, and use for human and environmental needs. Use time-series of land-cover and land-use data, climate data, water-use data, and hydrologic data to demonstrate how changes in land use, land-use practices, climate and water use have resulted in changes in the availability and quality of water resources. Such studies are crucial to the validation of predictive models of how future decisions will affect water resources.

- Better characterize watershed, geologic, and geochemical frameworks across America, including changes in water storage and retention capabilities of aquifers and watersheds, through the development and use of new technologies, including geophysics and remote sensing.

- Refine existing ground-water and watershed models, and develop and use new modeling technologies that better reflect system interactions, describe uncertainties, and forecast changes in the hydrologic cycle so that resource managers and decisionmakers will have improved tools for predicting the consequences of their management actions on the quantity and quality of the resource.

- Strengthen partnerships with local, State, regional, and Federal agencies to design and develop a Water Census of the United States that provides these partners, citizens, communities, natural-resource managers, and policymakers with a regularly updated, nationally consistent inventory of water resources and water use for human and environmental needs, and the predictive models that can be used to evaluate potential land- and water-use decisions.

Vision for 2017

A fully integrated real-time network of streamgages, ground-water level measurements, rainfall and evapotranspiration data networks, and water-quality and biological measurement sites will be enhanced and supplemented by remote sensing (state-of-the-art sensors, satellites, and telemetry techniques), combined with analyses and models that are based on long-term records, and coupled with greatly improved water use and

USGS scientists proceeding to make a streamflow measurement on the White River at Newberry, Indiana, using a boat equipped with an acoustic Doppler current profiler (ADCP) and global positioning system (GPS). Photograph by Paul Baker, U.S. Geological Survey.

demand information, geologic and geomorphic delineation of watersheds and aquifers, to provide the best information about the status and trends in quantity and quality of the Nation's freshwater supply. This information is included in realistic analyses and models (in the form of geospatial and visualization technologies, interactive and related online tools, and other new technologies) that will allow local, State, and regional decisionmakers to better estimate the quantity and quality of water available for humans, wildlife, and environmental use. The resulting understanding of the Nation's freshwater supply will provide decisionmakers with the tools needed to overcome "gridlock" regarding water required for the environment and for human uses. The USGS provides quantifiable, scientifically sound information about water quantity and quality, including when and where it is needed, that allows a flexible and informed response by water decisionmakers to a wide range of challenges, including: drought; changing human populations; changing demands for agriculture, industry, and energy production, and to maintain a healthy environment; an accurate comparison of water use by invasive and native species; changing quality of the Nation's water; and consideration of water not now used as a resource (such as saline water, water reuse, and freshwater aquifers offshore along the coasts).

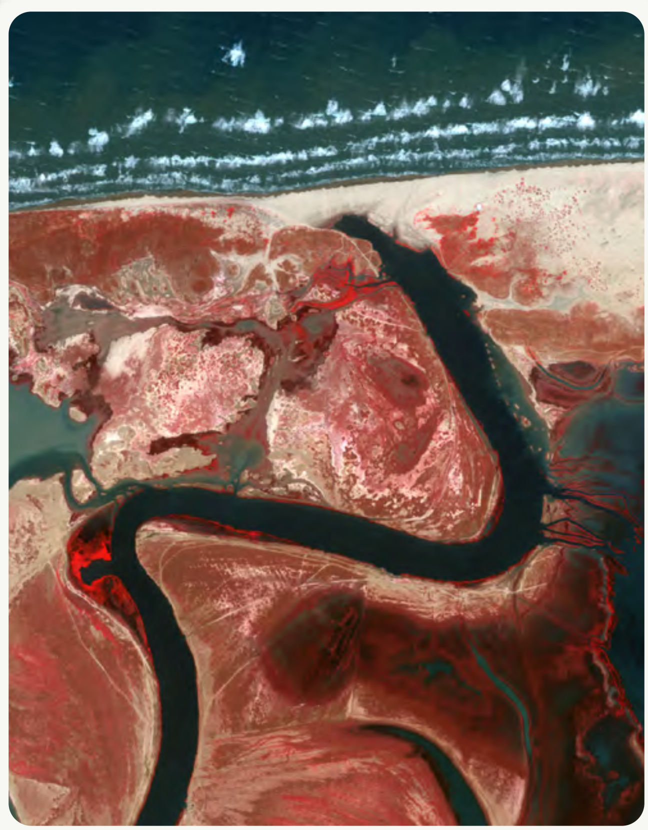
Defining Water Needs of the Environment

Defining the water needs of the environment is particularly challenging. As we move forward over the next decade with the Water Census of the United States, defining those water needs will be critical. An example of how important this is to the overall understanding of freshwater quantity and quality available for human and environmental needs comes from the Rio Grande.

"The Rio Grande is the lifeline for an arid landscape that stretches from New Mexico through Texas to the Gulf of Mexico. The river is expected to support diverse and fragile ecosystems while at the same time supplying water for expanding urban centers, industrial complexes, and longstanding agricultural uses in the Southwestern United States and Northern Mexico. Underlying the river are regional alluvial aquifers that are the exclusive source of drinking water for Ciudad Juarez, Mexico, and Albuquerque, New Mexico, and about one-half of the water supply for El Paso, Texas. These critical aquifers and the river are in direct hydraulic connection, operating as a single water resource—infiltration of the river water recharges these aquifers and, in turn, the aquifers provide life-sustaining base flow in the river. River diversions, reduction in recharge, and increased ground-water pumpage have significantly affected the sustainability of base flow in the river, which supports highly sensitive riparian habitats and native species, such as the endangered Rio Grande silvery minnow" (Anderson and Woosley, 2005).

Rio Grande/Rio Bravo near Taos, New Mexico.

More than maintenance of base flow is involved. The science required for understanding environmental water needs "has evolved from one that simply indicated what minimum flows might be needed to maintain a particular species in a river, to one that recognizes the timing of flow is critical, or the fact that intermittent floods of a particular magnitude are needed to maintain the most suitable river bottom and flood plain form for suitable habitat for native species, or to keep invasive species from becoming established. Furthermore, the physical process of water and sediment movement sets the stage over which is played a complicated set of interactions among the biota. Despite the progress that has been made in the past decade, considerable uncertainty remains about water use requirements for the environment" (National Science and Technology Council, 2004).



Digital Globe's Quickbird satellite infrared image, May 2002; drought conditions, Rio Grande at Gulf of Mexico.

New Methods *of Investigation and Discovery*

Background

The USGS has long been a world leader in natural science monitoring, assessing, and researching. Coupled with a diverse multidisciplinary workforce, extensive monitoring networks, and national and regional scale approaches, the USGS has carved out a reputation for being the “authoritative source” of specific national data sets, such as water quality, cartographic base, land cover and land use, biological resources, and geologic mapping. As the future unfolds, the ability of the USGS to map and integrate these data will be critical for the advancement of all science directions. The conduct of science is changing worldwide. Evolving tools and technologies are revolutionizing processes, extending or replacing research techniques, and sparking new discovery. Advances, such as sensor networks, modeling, and visualization, are changing the scale, quantity, and quality of scientific observations and providing new approaches for exploring long-standing problems. Dramatic increases in computing power, storage capacity, and networking capabilities are widening the scope of investigation and allowing scientists to address increasingly complex questions (National Science Foundation, 2007).

The nature of scientific collaboration also is changing. As the complexity of scientific questions grows, the need for integrated expertise and data from multiple disciplines grows as well. This realization, coupled with advances in information technology, is fueling a worldwide movement to connect the data and research techniques of the world’s scientists, making them accessible to a global science community and transforming the way in which research, engineering, and education are conducted. An international consensus is developing on the need to leverage recent advances in computer science and related technologies to create a next-generation, integrated science computing and collaboration platform that will be as transformational as the Internet (Atkins and others, 2003).

Over the next decade and beyond, as USGS scientists embark upon the strategic directions herein, USGS technological and collaboration capabilities must advance in parallel with its scientific goals and capabilities. To address increasing complexity and to enhance collaboration, the USGS must integrate its data and participate in the emerging efforts to build a global integrated science computing and collaboration platform. In partnership with the earth and environmental science community, the USGS must develop new approaches to index data holding by subject, place, and time and make them available to all through Internet portals. To stay relevant in a fast-changing scientific world, the USGS must stay abreast of key technological developments and routinely adopt new methods of investigation and discovery.

Statement of Cross-cutting Science Direction—Data Integration

The USGS will use its information resources to create a more integrated and accessible environment for its vast resources of past and future data. It will invest in cyberinfrastructure, nurture and cultivate programs in Earth-system-science informatics, and participate in efforts to build a global integrated science and computing platform.

Data Integration and Beyond

The key to advancing new discoveries of the Earth's complex systems and processes lies in the rigorous analysis of system interconnections and feedbacks. Central to the identification and evaluation of these connections is the accessibility of data and information across multiple disciplines, geographic, temporal, and political boundaries. Challenging scientific questions, such as those raised in this science strategy, require the analysis and integration of information and data across scientific disciplines. Data integration within the USGS is a prerequisite for joining international efforts to develop worldwide science collaboration and computing platform that can address future challenges.

Turning this bold vision of worldwide collaboration into reality will take global efforts to develop the cyberinfrastructure and informatics tools necessary to connect the world's science community. Over the next decade, global networks of servers, such as GEON (Geoscience Network) and NEON (National Ecological Observatory Network), will provide access to vast data repositories at unprecedented speeds. The computational power of these global networks will provide on-demand processing of data as it is delivered to the user. Evolving optical networks will provide more efficient retrieval, enabling scientists to interactively visualize and analyze larger volumes of data and more types of results. Traditional downloading of data will be replaced by remote real-time access over optically switched networks with negligible wait times. Evolving informatics tools will provide new capabilities and scientific techniques, such as sophisticated modeling that will enhance predictive capabilities and forecasting, data mining across huge sets of multidimensional data, and 3D visualization of complex problems.

Cyberinfrastructure Defined

"The term infrastructure has been used since the 1920s to refer collectively to the roads, power grids, telephone systems, bridges, rail lines, and similar public works that are required for an industrial economy to function. Although good infrastructure is often taken for granted and noticed only when it stops functioning, it is among the most complex and expensive things that society creates. The newer term cyberinfrastructure refers to infrastructure based upon distributed computer, information and communication technology" (Atkins and others, 2003).

Strategic Actions

- Include planning for long-term data management and dissemination into multidisciplinary science practices.
- Adopt and implement open data standards within USGS and contribute to the creation of new standards through international standards communities.
- Develop and implement a comprehensive scientific cataloging strategy that combines existing data sets resulting in an integrated science catalog.
- Develop a sustainable data-hosting infrastructure to support the retention, archiving, and dissemination of valuable USGS data sets in accordance with open standards.
- Develop and enhance tools and methods that facilitate the capture and processing of data and metadata.
- Identify and support authoritative data sources within USGS programs and encourage development and adoption of standards.
- Build and strengthen the internal workforce augmented by external partnerships in environmental information science.
- Identify and leverage national and international efforts that promote comprehensive data and information management and foster greater sharing of knowledge and expertise.
- Partner with collaborators and customers to facilitate data integration across the worldwide science community.
- Partner in the development of informatics tools and infrastructure that contribute to the evolving global science computing and collaboration platform.

Vision of 2017

Scientific inquiry within and outside USGS and external customers all benefit from the enhanced accessibility of decades of observational data and analysis. The use of open standards and of tools has minimized the difficulty of merging or comparing data sets; searches on a location or topic of interest quickly yield comprehensive research data; and individual scientists can easily identify studies and other researchers relevant to their own work. For example, an individual scientist studying soil geochemistry in the Great Basin connects to a worldwide scientific computing and collaboration platform that includes thousands of USGS and other scientific research databases. She seamlessly visualizes her soil data and compares them to data on paleoclimate, rock geochemistry, dust sources and composition, geomicrobiology of local ecosystems, past and present surface- and ground-water chemistry, and other relevant data sets.

Statement of Cross-cutting Science Direction—Evolving Technologies

The USGS will foster a culture and resource base that encourages innovation, thereby advancing scientific discovery through the development and application of state-of-the-art technologies.

Leveraging Evolving Technologies

Innovative and continually evolving technologies—many of which cannot be foreseen today—have the potential to transform not just science methods but even the questions that science can ask. Several new and evolving technologies that are particularly relevant to the earth sciences are reviewed in this section. The challenges involved in developing the new technologies needed to address complex questions offer ample opportunities for collaboration, resource sharing, and leveraging with other Federal, State, and local government agencies, academic and research institutions, nonprofit organizations, and the private sector. Partnerships have long been a critical component of USGS science programs, and the USGS must be equally proactive in identifying and developing effective partnerships in support of its technology goals. Advanced research on technology is occurring in universities, in other Federal agencies, and in private industry. Over the next decade, USGS should continue to develop creative partnerships with these communities to stay abreast of the latest developments and to identify opportunities to advance USGS science capabilities through innovative technologies.

Nanotechnology

Nanomaterials (products using particles ranging from 1-to-100 nanometers) are rapidly emerging as an important new field of industrial production that is revolutionizing the composition of products as diverse as medical therapeutics, road-building materials, tennis balls, electronics, energy storage devices, and ground-water remediation tools. Some nanomaterials are already produced in large quantities to support demands of medical, agricultural, energy, consumer products, and other industrial markets. The National Science Foundation (NSF) has predicted that nanotechnology will contribute about $1 trillion to the economy by 2015. Today, nanotechnology applications are emerging much faster than the ability to assess and understand their risks and consequences. Only a handful of studies are available to assess the health and environmental effects of these new materials. The exploding development of new uses for nanoparticles creates the potential for broad distribution across the landscape. The same new properties that enhance their value to commerce may affect toxicology and environmental fate. Change that results from application of nanotechnology has serious implications for water, ecosystems, and human health. The interdisciplinary science expertise of the USGS is ideally suited to measure, monitor, and assess the risks of nanoparticles; develop a scientific understanding of their dispersal and remediation; and determine the implications of their properties for environmental persistence, cycling, and toxic effects.

Screen shot of Terrainmap.com, an example of shared data.

Informatics Defined

The term "informatics" refers to the application of information technology in the context of another field. Informatics has been applied to fields as varied as biology, chemistry, the fine arts, telecommunications, geography, business, economics, and journalism. Within the field of science, informatics typically involves the development of new uses for information technology to solve a specific problem or to develop new understanding. Informatics efforts can be as varied as computational methods, modeling, visualization, or data mining. The field of "bioinformatics" focuses on the collection, management, analysis, and dissemination of biological data and knowledge, and has produced information management tools that support genetics and molecular biology. The term "geoinformatics" seems to have been independently coined by several groups around the world to describe a variety of efforts to promote collaboration between computer science and geosciences to solve complex scientific questions. Fostered by leadership within the National Science Foundation, these informatics efforts recognize that the Earth functions as a complex system and that existing information science infrastructure and practice are inadequate to address the many difficult problems posed by this system. For more information, access URL http://paces.geo.utep.edu/research/geoinformatics/geoinformatics_explained_detailed.shtml.

USGS scientist inoculating microbial growth media to determine the number and type of microorganisms carrying out biodegradation in a contaminated aquifer.

Geomicrobiology

Geomicrobiology (sometimes the broader term "geobiology" is used) is the interdisciplinary study of the interactions of microorganisms and earth materials (including soil, sediment, the atmosphere, the hydrosphere, minerals, and rocks). Microbes play a quantitatively dominant role in which geology, biology, chemistry, and hydrology intersect within the Earth's surface (Nealson and others, 2001). Modern molecular techniques (the use of nucleic-acid base sequencing technology to identify the phylogenetic groups present within mixed microbial populations) have significantly extended the classical approaches. Insights gained from the application of new tools have exposed previously unrecognized ties between the biological and geological worlds. Metagenomics (the genomic analysis of microbial communities) may be a tool to characterize the combined functions of microorganisms at a given place in the environment and to track a system's fundamental biotic response to evolving environmental factors. These molecular technologies are at the cutting edge of science. Because of the importance of microorganisms to the earth system, and because of the explosion in the power of tools that are becoming available to understand and describe the functionality of these microorganisms, the USGS should expand its current geomicrobiology research, building upon the excellent work already underway.

Seeing Into the Earth

In recent decades, the medical profession has made use of new technologies that enable it to better peer inside humans through new applications of physics. New technologies, such as Computerized Axial Tomography (CAT) or Computerized Tomography (CT) scans, and Magnetic Resonance Imaging (MRI), are providing a remarkable look inside people, promoting new understanding of diseases and physiological processes. Similar advances have occurred and continue to undergo development in the application of physics for seeing into the Earth, the field of geophysics. Advances in geophysics help us better understand seismic hazards, volcano hazards, ground-water availability, and movement of contaminants in the subsurface. A wide array of technologies is emerging, including many that are derived from the minerals and energy sectors. Research and technologies in this arena encompass use of gravity, magnetic, electrical, electromagnetic, gamma-ray, magnetotelluric, and other physical properties. Together, these represent a broad range of research and techniques that seek to image the region beneath the surface of the Earth by means of the interpretation of physical characteristics, waves, or fields measured at the Earth's surface. Borehole radar cross-hole tomography, electrical resistance tomography, continuous resistivity profiling, ground-penetrating radar, and aeromagnetic surveys are just several among the many technologies USGS must leverage in the future to gain a better understanding of the planet we live on.

Environmental Sensor Networks

Rapid advances in wireless, lightweight sensors portend the emergence of site-specific, regional, national, and global networks of environmental sensors that will expand the scope, efficiency, and accuracy of environmental monitoring efforts of the Nation's natural resources and public lands. The next generation of automated sensors, deployed by the hundreds or thousands, could reduce the need for labor-intensive manual sampling of water, soil, air, vegetation, and wildlife, especially in remote areas. One example of a sensor network—referred

Unsaturated-zone instruments used to estimate ground-water recharge are installed in oil-saturated soils at the Bemidji, Minnesota, research site.

to as “smart dust”—consists of networked populations of wireless “motes,” each containing a solar or battery-operated microprocessor, memory, radio, and one or more sensors for collecting environmental information (temperature, vibration, acceleration, tilt, solar radiation, pressure, soil moisture; many other applications are rapidly emerging) (*New York Times,* 2005). The motes collaboratively sense and log multiple variables over time, relay data, and communicate with a central database that can be queried in real time. Sensor networks recently have been deployed to monitor microhabitats in the underground burrows of nesting birds (Mainwaring and others, 2002); to document pressure, temperature, and movement in glaciers (Martinez and others, 2004); to observe subsurface water flow through soils (Cardell-Oliver and others, 2004); and to measure temperature and humidity gradients in a large redwood tree (Tolle and others, 2005). The National Ecological Observatory Network (NEON) is an NSF initiative to collect and integrate diverse data at a continental scale, allowing scientists to recognize ecological interactions within and across regions, and make forecasts of ecological change. The backbone of NEON is a network of environmental and biological sensors concentrated at 20 highly instrumented core sites distributed across the United States, one in each of 20 climate domains. Participating in the development and use of these networks of sensors is essential for USGS to maintain cutting-edge, reliable, and relevant science in the coming decades.

USGS scientist using a long sampling device to collect a sample of liquid from a municipal wastewater holding pond in Colorado as part of the Source Characterization Study for Emerging Contaminants Project. The sample was analyzed for pharmaceuticals and other wastewater compounds.

Land Imaging

Just as the science strategy of the USGS encompasses a broad range of national concerns that directly lend themselves to the mission of the Nation’s natural resources research bureau, so too does the USGS manage the Nation’s land imagery in support of a broad range of national and international purposes. Since the early days of spaceflight, the USGS has maintained the land imagery archive of the United States at its Center for Earth Resources Observation and Science, which contains nearly 100 years of satellite and aerial photographs of the land surfaces of the Earth. These archives are indispensable to USGS science and other national and international science investigations, among them the very applications described throughout this Science Strategy Team report. Key among these imagery holdings is the archive of the Landsat program, the Nation’s principal land-imaging satellite since 1972. Landsat provides the longest, most continuous land surface imagery of the entire Earth, a record unparalleled among the space and science programs throughout the world. In 2004, the Office of Science and Technology Policy, Executive Office of the President, declared Landsat to be a national asset because of its importance to the economic, environmental, and national security interests.

In 2005, the President’s Science Advisor called for a plan to ensure the long-term continuity of operational land imaging in the United States. That plan (currently in final review by the Administration) proposes that a National Land Imaging Program be established within the U.S. Department of the Interior to ensure continuity of moderate-resolution land imaging for the United States and to look to the future to develop any type of satellite land-imaging capability considered critical to meeting the civil operational needs of the Nation. These needs include scientific and governmental requirements, and encompass a broad sweep of Federal, State, local and tribal functions, including those related to agriculture, national and homeland security, infrastructure planning and management, and management of Earth’s natural resources. With this promise for maturing from the “experimental” phase of Earth observation to a long-term operational framework of land imaging, the science strategy of the USGS and its benefit to the DOI, the Nation, and the world are strengthened.

Spatial Modeling

Rapid advances in the technology of data collection have made it possible for scientists to describe complex systems in multiple dimensions in space and time. Data collection, for the first time in history, is no longer a limitation in many scientific disciplines, because of the accessibility and affordability of vast arrays of sensors and remote-imaging systems. Therefore, the challenge now is to synthesize this information with models and decision-support tools that can be used to communicate the consequences of human actions to decision-makers and resource managers in a language that crosses disciplinary boundaries. Such models are simplifications of datasets and systems that are often too complex to understand and communicate intuitively. This simplification requires tradeoffs in generality, precision, and reality that vary, depending on the objective to understand, to predict, or to control ecological responses to human actions and environmental change. Recent advances in spatially explicit modeling have shown the need to communicate to resource managers and regional planners the potential consequences of management actions through a process of scenario building and landscape visualization in response to land development and climate change. Using this approach, researchers use data from state-of-the-art airborne and satellite imaging systems, sensor networks, and predictive models to develop dynamic alternative landscapes that project future changes on ecosystem condition. These integrated, science-based modeling tools can be used to inform local, State, and Federal decisions by helping stakeholders visualize the effects of alternative futures on valued ecological and socioeconomic endpoints. Ultimately, the wealth of information made possible by state-of-the-art data collection systems can only be fully realized if it is translated by using equally sophisticated modeling tools into a conceptual framework that can be understood and discussed by decisionmakers.

Molecular Genetics and Genomics

Recent technological advances in genetics involving the ability to rapidly sequence an organism's DNA have revolutionized basic understanding of biological and evolutionary processes. Contemporary applications have enhanced the ability to delineate the finest level of biological diversity as expressed through genetic diversity. These genetic tools and methods will increasingly provide sensitive techniques for diagnosing the presence and effects of environmental stresses on species, populations, and ecosystems at risk. For example, a special form of population monitoring considers effects of contaminants on plants and animals. Many contaminants are carcinogens or mutating agents that affect either the structure of DNA, its biological expression, or both. In genetic ecotoxicology, the potential effects of these contaminants on the health of an ecosystem or organisms are evaluated. Conversely, infectious disease is a natural component of all ecosystems. Understanding the role of the microbes (pathogens) causing these diseases enables managers to adopt strategies to modify their influence when necessary. Molecular markers can be used to understand disease processes, develop diagnostic methods, describe incidence and distribution of important pathogens, and develop strategies for prevention and control. Pathogens also can be used to control undesirable and invasive species (that is, biocontrol).

The newest ecological genetic technologies include the use of genomics—the study of an organism's full genetic material, known as its genome. USGS geneticists will increasingly identify and investigate the function and expression of ecologically important genes to shed light on the relations between genotypes (the organism's exact genetic makeup) and phenotypes (the organism's physical properties) by understanding the associated genetic and environmental interactions. Ecological genomics improves the ability to study the effects of evolution, population structure, gene function, and environmental change on specific species.

Another emerging technology is development of genetically modified organisms. These are plants or animals that have had their genetic material altered to exhibit new traits. These "transgenic" organisms potentially can pass their new genes to close, wild relatives. Cloned genes in wild organisms could tip the balance within and among native populations, communities, and ecosystems. Thus, genetic and molecular tools are some of the most universal, powerful, and accessible investigative tools available from science today and in the future. Their application increasingly will play a critical role in USGS research.

Strategic Actions

- Enhance workforce expertise in evolving technologies.
- Encourage internal partnerships between scientists and technologists.
- Identify and establish external partnerships with scientists and technologists, particularly in areas that the USGS does not have core competency.
- Develop "Communities of Practice" that share resources and actively seek to deploy evolving technologies.
- Accelerate the introduction and piloting of new technologies.
- Expand investments in areas where new discoveries and efficiencies have been realized through the application of innovative technologies to existing USGS programs.

Vision of 2017

The USGS cultivates a close partnership between scientists and technologists. Sponsored efforts have resulted in the introduction and use of innovative technologies. Priority investments, the recruitment of specialized expertise, and strategic partnerships have resulted in pilot implementations of breakthrough research techniques leading to new discoveries.

Conclusions

Transforming the U.S. Geological Survey

Like much of humanity, the perspective of scientists was forever changed by the image of Earth beamed back from Apollo 8. The picture of our lone blue planet against the black background of space enlarged the frame of thinking of many scientists forever. Nearly four decades later, scientists are still struggling to understand the Earth as a system, with highly interconnected biosphere, hydrosphere, geosphere, and atmosphere. Many nonscientists, too, have experienced their own transformative moments over the past 30 years, as globalization of economies, instant worldwide communication, and rapid transport of goods have altered old relations among nations and enterprises. John Muir's quote from 1911, "When we try to pick out anything by itself, we find it hitched to everything else in the universe," applies today as we recognize that the phenomenal economic expansion and improved public health of the past few decades have come with environmental costs, some of which may threaten the survival of humanity (Muir, 1911). In fact, the impact of mankind on the planet has expanded to the extent that we live today in what some have called the "Anthropocene"—a new geologic epoch in which humankind has emerged as a globally important force capable of reshaping the face of the planet (Crutzen, 2002; Clark and others, 2005). The ability of humanity to use an understanding of human-induced changes on Earth's environment to help guide the use of the Earth towards positive outcomes is embodied in the term "sustainability." This concept of sustainability symbolizes a desire not only to document what is the human use of the Earth but also to determine what it ought to be (Clark and others, 2005).

As the only integrated natural resources research bureau in the Federal Government, the USGS has a substantial role to play in helping the economy remain strong, the environment remain healthy, and the quality of life in the United States remain high now and into the future. This role is larger than the traditional one of providing expertise in mapping, geology, water, and biology. Major national issues of costly natural disasters, air and water quality, energy and materials needs, newly emerging diseases, invasive species, climate change, and even immigration form a web of linked dependencies among environment, societies, and economies. The USGS must transform its approaches to problem solving not only to address the issues of today but also to prepare for those of tomorrow. The questions are broad, the stakes are high, and the potential is there. No other organization in the Nation has

This photograph of "Earthrise" over the lunar horizion was taken by the Apollo 8 crew in December 1968, showing Earth for the first time as it appears from deep space.

the breadth of multidisciplinary scientific expertise, the extensive national on-the-ground presence, and the wealth of biologic, hydrologic, geologic, and geographic monitoring capabilities and existing data at all scales, from microscopic to global.

The Carnegie Corporation Report on Federal Environmental Research and Development stressed the fragmentation of the Federal environmental research system and noted that it "…is poorly structured to deal with complex, interdisciplinary research on large spatial scales and long-term temporal scales." It also noted that the most dramatic act to reduce fragmentation within the environmental system was the inclusion of the National Biological Service into the USGS. It concluded, "…this consolidation brings together a significant body of life scientists and earth scientists in the same environmental research organization, and thus creates the potential for generating the types of interdisciplinary knowledge and assessment that have often been lacking in the environmental research system" (Carnegie Commission on Science, Technology, and Government, 1997).

The USGS has already made strides to realize its potential. Integration of USGS science activities to provide the Nation with answers to the complex questions it faces is underway. In the preceding sections of this report, we have outlined specific strategic science directions that will accelerate that process. Implementing these science directions will ensure that resource managers and policymakers have the information they need to support decisions affecting ecosystems, water, climate, environmental health, natural hazard, and energy and mineral resource issues. These strategies provide stepping stones towards a larger goal of evolving the USGS into a fully integrated science agency in which the linkages among these strategic directions are explicitly addressed.

The management of the Nation's land, water, and ecosystem resources typically requires weighing tradeoffs among multiple criteria concerning multiple resources. The importance of identifying and understanding critical interdependencies is especially acute in decisions that require anticipating the interactive effects of changes in climate and changes in human resource management. In the not-too-distant future, a scientist will access a comprehensive array of biologic, geologic, geographic, and hydrologic data from past measurements and those being made in real time, use the data for models that describe the present state of the Nation, use high-resolution projections of future climatic states to understand how the situation will change, and provide this information to decisionmakers and the broader public in the forms most suited to their needs. The future holds unprecedented opportunities for USGS science to improve the economic and environmental health and prosperity of people and communities across the Nation and around the world. The USGS looks forward to meeting the challenges of the 21st century.

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Appendix
Charter for Science Strategy Development

Background

Although several strategic plans, science goals and business models have been developed for all or parts of USGS, a comprehensive vision—science goals and priorities that unite all bureau capabilities toward challenges for the future—has not been developed since the early 1990s. Without developing consensus and support for such an overarching vision and strategy, it will be more difficult for USGS programs and leaders to make choices that maximize the effectiveness and impact of USGS science. Many documents have been developed in the last decade that describe both the challenges and opportunities for the scientific community to contribute to our Nation's goals. These source materials and those developed by the bureau and our customers will provide primary source material for the development and discussion of goals and strategies through which USGS can most effectively contribute to society's needs. The USGS Science Strategy (USS) will be created by a small team of scientists from throughout the bureau who develop recommendations for the Bureau Program Council (BPC). An expanded team of technical experts will work with them as they develop ideas. All recommendations and ideas will be reviewed and vetted within USGS and by our stakeholders before finalization.

Scope and Objectives

The USGS Science Strategy (USS) will be a 25–30 page document that is issue driven, has a big picture focus, and is forward-looking with clear concise goals and objectives. The strategy will guide science planning and help identify bureau priorities for the next decade. It should be succinct with a focus on the major scientific and policy drivers for the activities of the USGS. The USS will be consistent with the broad guidelines/outlines of the USGS Strategic Plan and the Department of the Interior (DOI) Strategic Plan and goals. It should consider the full breadth of USGS science independent of sources of funding (e.g., Congressionally appropriated, reimbursable funding for domestic work and international work). The strategy should be largely independent of the organizational structure of the USGS. The focus should be heavily on future opportunities where USGS science can most effectively contribute to the Nation and the world. The focus should also be on the balance of our present scientific portfolio (e.g., monitoring, assessment, and research) and where that balance might be in the future anticipating changing societal questions and needs. It should describe new and/or altered capabilities USGS must develop to exert science leadership and contribute significantly in core areas. Both infrastructure and personnel skills should be considered.

While the USS should be visionary and integrative in science goals, it should also suggest some first-level objectives for each strategic goal. A critical part of the USS should take into account USGS's existing scientific infrastructure, skill mix and science capabilities and provide recommendations for changes necessary to achieve desired outcomes. Suggested changes and strategies for the development or enhancement of capabilities will be monitored through changes in program, regional, and discipline plans. Identifying new and expanded opportunities for cooperation and collaboration with partners should be an important goal of the strategy, as well as a subject of first-level objectives in accomplishing our goals.

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