USGS
science for a changing world

Facing Tomorrow's Challenges: USGS Science in the Coming Decade



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



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

Long Pond, located within the Long Pond Greenbelt, near Sag Harbor, New York. USGS ground-water and surface-water monitoring data obtained from the South Fork are available at http://waterdata.usgs.gov/nwis/.

A Science Vision for Addressing Societal Needs

Preface

In 1996, the 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 our 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 their 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 in order to serve the Department of the Interior 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 of critical importance to our mission. The intent is that the Science Strategy will outline areas or potential growth that will 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 and over a range of time frames. Planning documents have been produced at the Discipline, Program, Center, Team and Project levels. All of these previous planning efforts were important inputs 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 non-governmental sources. The SST sought input from USGS Program Coordinators, Senior Scientists, an advisory group of approximately 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 work sites. A Customer Listening Session that focused on developing the Science Strategy was held in Washington, D.C., on May 1, 2006, and SST members attended a session of the DOI Research and Development Council to brief and obtain input from key DOI partners. The SST thanks the many participants both 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 U.S. environment 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 our capabilities and takes advantage of our strengths and our unique position as a non-regulatory 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.

Marty Goldhaber and Kevin Gallagher
Co-chairs, Science Strategy Team

Introduction



USGS Climate Change Research

The USGS 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 locations from within the Nation, its coastal zones, and continental shelves; these efforts, combined with its extensive remote sensing capabilities, allow the USGS to map and understand land use/land change trends across the Nation. The USGS is uniquely suited to address the broad scope of DOI's and the Nation's natural-resource and natural-science issues, employing 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 our predictive capabilities, 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 help assure the sustained health, welfare, and prosperity of the Nation's citizens.

The 21st century poses formidable challenges. To meet them, the USGS must leverage its talents and skills to undertake comprehensive and integrated studies that examine the Earth as a system including atmosphere, biosphere, hydrosphere, and lithosphere. The USGS needed to reflect on and refine its strategic science directions to ensure it can respond appropriately to evolving national and global needs and priorities. This report is the first bureau-wide science strategy since the early 1990's to define science goals and priorities that unite all USGS capabilities toward meeting the challenges of the present and the future. The science directions outlined here represent priority growth opportunities that build on traditional USGS discipline-based research and observation in order to meet the needs of the Nation.



The development of this Science Strategy is shaped by rapidly evolving national and global trends, which have important natural-science implications. The emergence of a global economy affects the demand for all resources. Use of the world's natural resources, and of materials produced by people from those resources, is occurring on a scale that may adversely modify the terrestrial, marine, and atmospheric environments upon which human civilization depends. The use of and competition for natural resources on the global scale, and natural threats to those resources, may affect the Nation's ability to sustain its economy, national security, quality of life, and natural environment.

The last decade has witnessed the emergence of a new paradigm for managing Federal lands—ecosystem-based management. By understanding the status of those natural resources, how those resources are interrelated and change with time, and the probability of the natural threats, decision makers will be able to assure the security of our Nation, the vitality of its economy, the health of its environment, and the well-being of its citizens. The natural environment also poses 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. 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 impact on the status and future of our society, is essential for a resilient and prosperous United States. Predictions from the Climate Change Science Program (CCSP, 2005) are that the next few decades may see rapid changes in the Nation's and the Earth's environment. This decadal USGS Science Strategy will be implemented at a time when the Nation can benefit greatly by using natural science information in its decision making.

This report contains recommendations for implementing a series of six science directions, which were chosen to build on existing strengths and optimize the USGS response to major natural science issues facing DOI and the Nation during the next decade. The team considered a broad spectrum of input from inside and outside the USGS before deciding on the best 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 the current levels of effort.



• A new, comprehensive focus on ecosystems will be implemented. Ecosystem studies are critical to the well-being of the Nation because they link the functioning of the natural environment with human needs. Understanding, mapping, monitoring, modeling, and advising DOI and the Nation on our ecosystems are critical in order to balance land-use/land-change issues with human needs. Ecosystem studies require the full power of an integrated systems approach and are thus a perfect fit with USGS capabilities and strengths. During the next decade, the USGS will provide the fundamental research, mapping, and monitoring 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.



• 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. 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 our environment. Zoonotic diseases (those transmitted from animals to human) such as avian flu and West Nile virus are major concerns both in the United States and abroad. USGS biologists and ecologists have played a major role and will continue to do so in providing input to health professionals on the biologic pathways involved in disease transmission. The USGS will use this environmental health expertise and work with a range of partners to implement a warning system of environmental risk to human health in the next decade.



• Water issues are critical to the Nation. A U.S. General Accounting Office report from July 2003 stressed that we do not have an adequate picture of water availability at national, regional, and local levels. They stated, "National water availability and use has not been comprehensively assessed in 25 years." The Council of State Governments 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." As detailed below, it is indeed time for a comprehensive water census of the United States, and the USGS will undertake this effort.



• The USGS is positioned to prepare the Nation for more effectively planning for and dealing with natural hazards by implementing a national hazards risk and resilience assessment program. We will enhance our ability to collect the critical information from modern earth-observation networks and deliver the data in real time, and we will expand our 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.



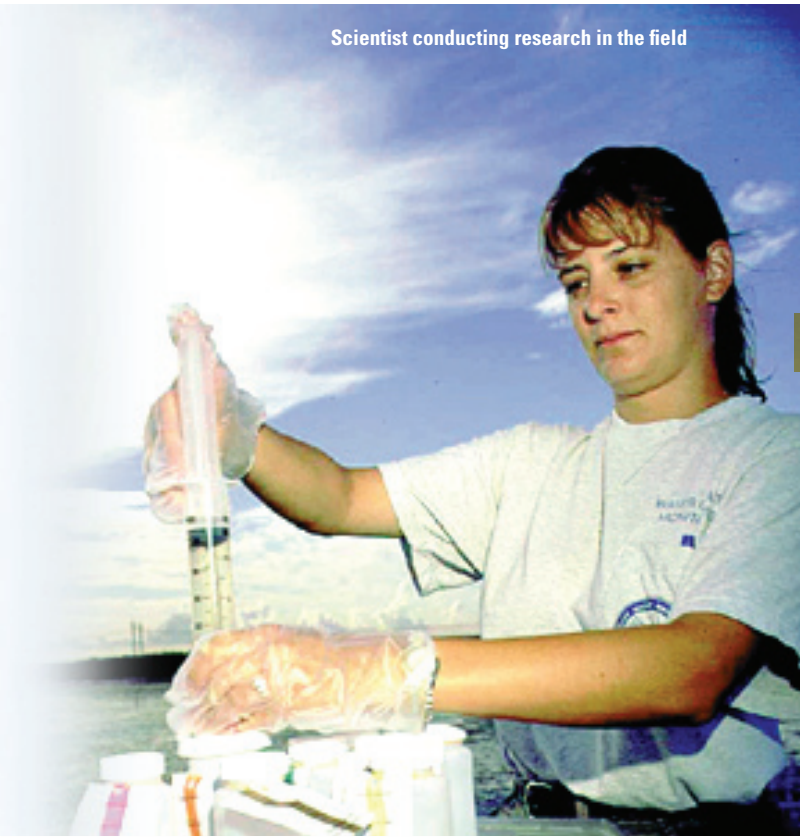
• The complexity of the Earth's climate system presents challenges that are beyond the capability of any single discipline to address and instead require an integrated systems approach. The unparalleled USGS observation and research networks, combined with extensive modeling capabilities and broad temporal perspective, allow us to relate the complex interactions of climate change with previous, ongoing, and future changes in land, water, and biological resources. We will enhance our present climate change studies to take full advantage of our expertise.



• 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 utilize resources. The Nation's planners need accurate domestic and global assessments of energy and mineral resources to guide our strategic planning. Our existing definitive assessment programs will be enhanced by state-of-the art research on resource genesis and estimation and will be broadened to include an environmental perspective on the impacts of extraction and use of existing and emerging resource commodities.

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. 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 data and information sharing is an important component of the USGS science strategy. But 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 our 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 accomplish all of the 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 decision makers that is appropriate to the level of the challenges they face. Equally essential for decision makers will be the objectivity and credibility of the scientifically rigorous information that is a hallmark of the USGS, along with its unbiased, non-regulatory perspective. The USGS chooses these science directions not because they are easy but because they are difficult, will require the best of our organization to fulfill, and will provide information needed for solutions to the challenges facing the Nation.


Scientist conducting research in the field

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

The USGS throughout its 127-year history has contributed significantly 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 Department of the Interior and to the Nation.

Strategic Science Directions

The team proposes six strategic science directions:

- Understanding Ecosystems and Predicting Ecosystem Change:
  Ensuring the Nation's Economic and Environmental Future
- The Role of the Environment and Wildlife in Human Health:
  A Warning System for Environmental Risk to Public Health in America
- A Water Census of the United States:
  Quantifying, Forecasting, and Securing Freshwater for America's Future
- A National Hazards, Risk, and Resilience Assessment Program:
  Ensuring the Long-Term Health and Wealth of the Nation
- Climate Variability and Change:
  Clarifying the Record and Assessing the Consequences
- Energy and Minerals for America's Future:
  Providing a Scientific Foundation for Decision Makers

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

Background

Ecosystems, in their multiple forms, constitute the Earth's biosphere and support human existence. The plants, animals, microbes, and physical products from ecosystems provide people, as components of ecosystems, with the energy, water, biomass, medicine, and mineral resources needed to sustain human societies. Resilient, functioning ecosystems build soil, pollinate 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 ecosystems to continue providing these benefits they must be well managed, especially in the face of increasing pressures on global and national ecosystems. A proactive approach to managing ecosystems will require an advanced understanding of ecosystem distribution, condition, and function. The ability to accurately predict 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. Effectively managing ecosystems requires communication of the results from those analyses in a form useful for policy and decision makers.

Ecosystems are inherently "multidisciplinary," with biological, geological, and hydrological components. The USGS is the only Federal agenct 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 to BLM, NPS, FWS, and other land-and resource-management agencies, whose needs for integrated ecosystem science are growing as they increase their emphasis on ecosystem-based management.

Statement of Strategic Science Direction

In collaboration with others, the USGS studies the causes and consequences of ecological change, monitors and reports on the state of the Nation's ecosystems, offers managers options for protecting and managing the biological and physical components and processes of ecosystems, and interprets for policy makers how current and future rates of change will affect natural resources and society. The USGS and partners 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.

Large-scale, rapid change is now taking place in natural systems. Growing human populations and significant 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 may reduce the resilience of ecosystems to future environmental change. Permafrost melting, landscape fragmentation, forest clearing, river regulation, and coral reef bleaching are causing self-maintaining systems that evolved over millennia to become less resilient. People value these ecosystems in their own right; in addition, 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 thorough knowledge of the types and distributions of ecosystems and their attributes and 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 and their environment that maintain ecosystem processes within a range of historical variability. The United States currently lacks scientifically sound indicators of ecosystem condition, comprehensive maps of ecosystem distributions, a rigorous ecosystem monitoring program, and a network of intensive research sites representative of ecosystems important to land managers. As a result, changes in ecosystem condition, whether for better or worse, will likely not be recognized, diagnosed, or understood. These deficiencies hamper our 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 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 major industries. 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, the Heinz Center Report on the State of the Nation's Ecosystems (Heinz Center, 2003 and 2006), the Millennium Ecosystem Assessment (2003), and the report of the U.S. Commission on Ocean Policy (2006), call for coordinated and comprehensive ecosystem-based management. 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, and living resources that promotes conservation and sustainable use in an equitable way (UNEP/CBD, 2000), has emerged as a key component of the sustainable development paradigm. Both the Millennium Assessment and the State of the Nation's Ecosystems report 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 expand a priority focus on ecosystem science and will become recognized as the Nation's source for integrated science in support of decision making and ecosystem-based management strategies. In collaboration with others, USGS ecosystem scientists will develop a comprehensive, standardized geospatial ecosystem framework to support the mission of land management agencies 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. 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 will develop around several key themes:

- Research into how ecosystems work, and how and why they change;
- Monitoring of ecosystem status and trends through use of objective, scientifically based indicators;
- Mapping of the Nation's ecosystems;
- Development of techniques for managers to use in managing, protecting, restoring, and evaluating ecosystems and the services they provide; and
- Assessment tools that will enable the Nation to incorporate understanding of ecosystem properties and processes into decisions that affect the health and welfare of human societies and the environment.

Strategic Actions

- Recognizing that ecosystems provide the framework for scientific understanding of the physical and biological processes that support life on Earth, identify ecosystems vulnerable to ongoing changes of climate, contamination, and land use. Quantify the consequences of ecosystem change to water quality and quantity, health, hazard risk, biodiversity, and other ecosystem services to human society.
- Conduct long-term research, monitoring, and modeling with academic and agency partners to identify and understand ranges of variability in ecosystems at local, regional, and national scales. Identify environmental thresholds that signal transitions between ecosystem states.
- Coordinate, develop, and regularly update a standardized national map of ecosystems and their physical and biological components, at scales appropriate to land-manager needs, to facilitate the ability to assess, monitor, manage, and restore ecosystems.
- Develop a multi-partner, robust assessment of the status and trends of the Nation's ecosys---tems. Work with State and Federal agencies and other entities to form a National Advisory Committee on Ecosystem Health 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.
- Enhance understanding of the ecology of invaders and factors in the resistance of habitats to invasion, forecast probabilities and locations of future invasions, provide methods and information to assess and manage risks and develop methods to prevent and control invasive species and minimize their environmental impacts.
- 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.
- In an ecosystems context, using studies of abundance, distribution, life history strategies, and dispersal and migration abilities, evaluate the vulnerabilities of the Nation's species to stressors including land use change, climate change, contaminants and invasive pests, diseases, and competing species.

- Provide a public-access delivery system for integrated geospatial data that can be used to delineate ecosystems. Evaluate spatially explicit trends in their state and behavior.

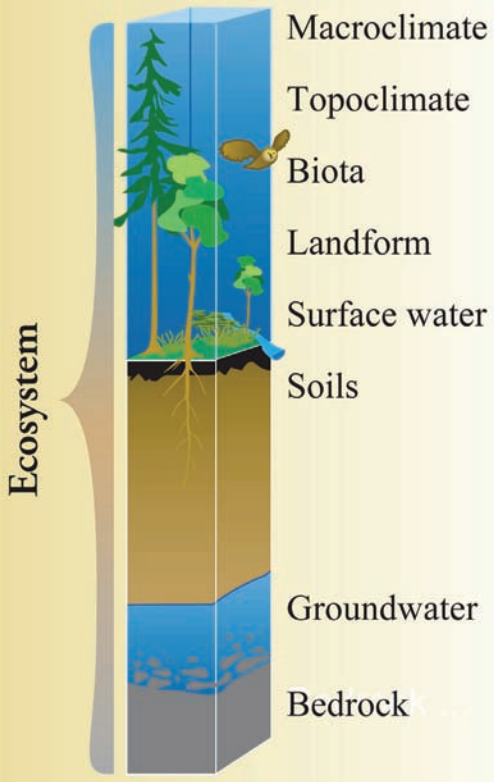
- Develop credible forecasts of responses to ecosystem stressors, including land use, climate change, pollutants, invasive species, and other threats to ecosystems, applying new knowledge of the thresholds that signal ecosystem decline and collapse. Use this information to develop "alternative ecosystems futures" scenarios that integrate biophysical, economic, social, and policy drivers.

Vision of 2017

The USGS is the Nation's source for integrated science and assessment in support of ecosystem management on public and private lands. 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 decision-making 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 incorporated into integrated simulation models that enable scientists and managers to forecast future ecosystem conditions. Comprehensive, multi-scaled, 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 scienists, for policy makers, and for the public.

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 soils, sediments, waters, 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 interactions of organisms and the physical environment occur 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.



Ecosystem Monitoring Partnerships

The value society places on healthy ecosystems has led to a need for both 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 GEOSS (Global Earth Observation System of Systems); 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: 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 significant 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 non-governmental organizations to ensure that the best scientific information about ecosystems is available for decision makers.

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 both 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 near Cisco, UT
USGS, Photo

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 20-25 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 river below. 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 relationships

and identifying relationships 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 non-native 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 non-native vegetation such as tamarisk. Surveys of wildlife-vegetation interactions are used to monitor the populations of endangered Kanab ambersnails and Southwestern willow flycatchers.

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 incorporated into management decisions.

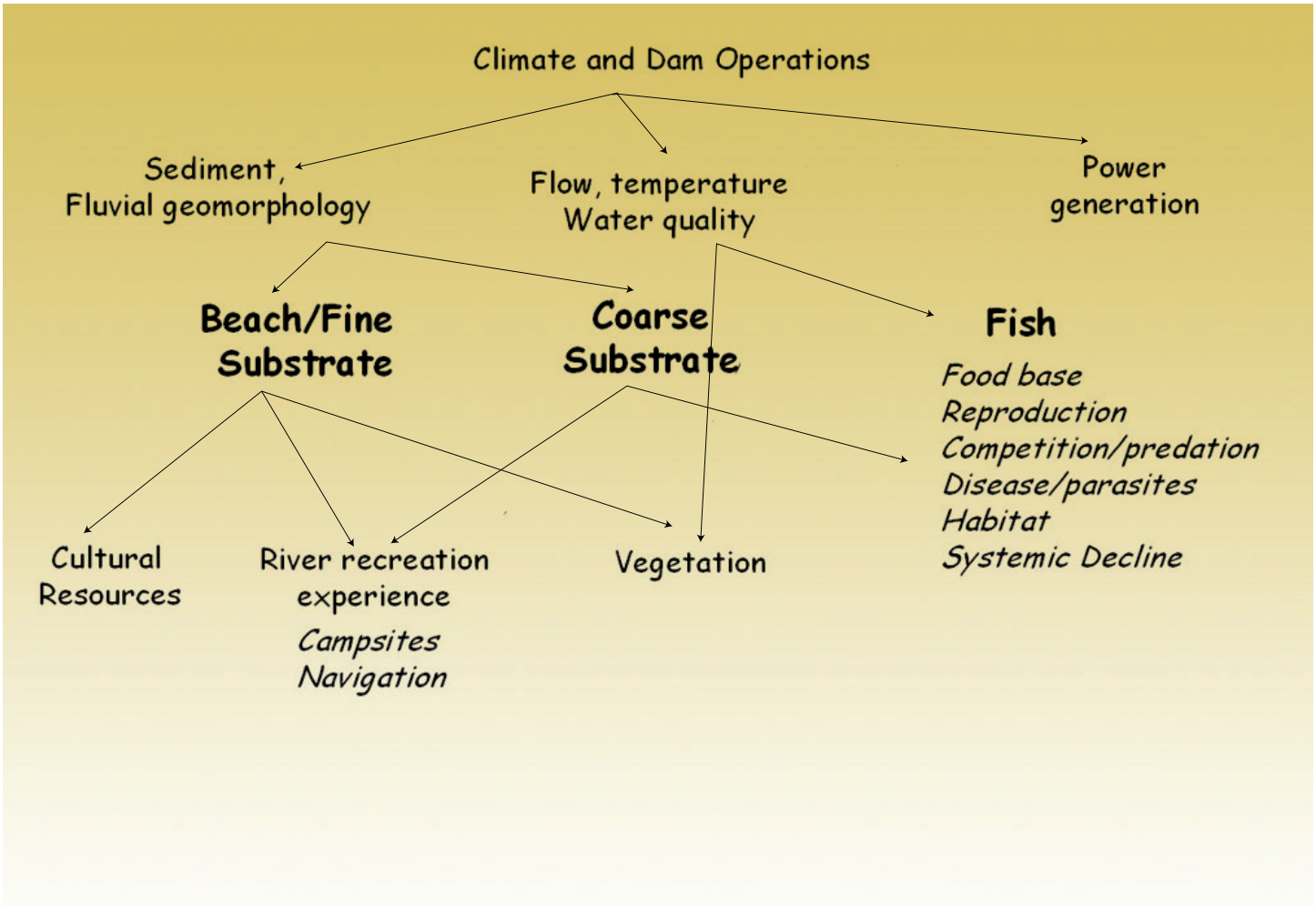


Figure: Conceptual model of the physical, biological, recreational, and cultural connections of the Colorado River ecosystem below Lake Powell. USGS scientists with expertise in archeology, fisheries, geospatial mapping, hydroclimatology, hydrology, sediment geology, and plant, animal, and aquatic ecology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

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.

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 increased 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, 2006). 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



Otters: Raft of male sea otters in Elkhorn Slough, CA. The California sea otter population has decreased for a second consecutive year, according to last May's annual sea otter survey. Photograph by Warren Worthington, USGS.

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. 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 can 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 both 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.

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 both natural forces and human actions; however, contemporary land change has largely been the result of human modifications. In order 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 km2 of the 1.65 million km2 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 understood at the ecoregion level.

The consequences of the change on ecosystems are significant. 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.

"An ecosystem approach is critical to resource management, as we grapple with sustainable use of resources in an era of increasing human population and consumption and large, rapid changes in the global environment." (Chapin and others, 2002)



The Role of the Environment and Wildlife in Human Health: A Warning System for Environmental Risk to Public Health in America

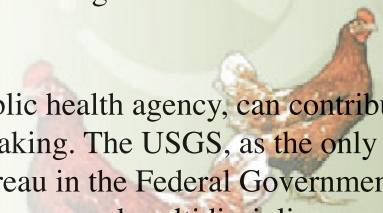
Background





Human health issues are increasingly influenced by induced landscape changes, worldwide travel and trade, urbanization, and changes in human behaviors, resource use, and population centers. These changes have all combined to provide new opportunities for microbes, pathogens, and toxicants to cause increasing problems to human health. Of particular importance are expanding human reservoirs of new and emerging diseases, vectors of those diseases, contaminant concentrations, and changing reservoirs of zoonoses (diseases transmissible between animals and humans).

Environmentally related diseases will continue to increase, as the walls of geographic distance and isolation are removed and the opportunity for the spread of once isolated diseases increases. Public health risks will further increase 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.





The USGS, although not primarily a public health agency, can contribute significantly to public health decision making. The USGS, as the only integrated natural resources research bureau in the Federal Government, employs scientists who bring a national scope and multidisciplinary approach to addressing many aspects of human health issues. These scientists are the world's experts on drinking-water contaminants, wild animals as reservoirs of zoonotic diseases, air-dust-soil contaminants, pathogens in recreational waters, and the use of wild animals as sentinels of human health. USGS capabilities in environmental monitoring and mapping are important components for understanding environmental relations to human health and evaluating probable outcomes of future human health risk factors. Thus, USGS is uniquely qualified to provide the information needed to link environmental and human health issues within America and around the world.

Statement of Strategic Science Direction

The USGS will partner with allied health science agencies to leverage its massive data holdings and environmental science expertise to produce a national database and atlas of geology- and ecology-sourced diseases and toxicants. We will then expand these collaborative efforts to institute and maintain a national-scale, real-time, environmental health threat warning system.

The environment and wildlife play a critical role in issues of human health. Public health threats from emerging infectious diseases, diseases that exist in animals but can affect humans (zoonotic diseases), and environmental contamination are of major concern worldwide. These environmental public health threats are a consequence of the inescapable relationships among people and their physical, chemical, and biological environment. As towns and cities expand, the wildland-urban interface broadens and human-wildlife interactions are increasingly frequent. Many public health issues impacting Americans, such as avian influenza, originate outside our borders, requiring the Nationto 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. Health threats also arise from both naturally occurring toxicants and anthropogenically derived environmental contaminants. Such contaminants are increasingly appearing in natural ecosystems; the health consequences are largely unknown but potentially significant.

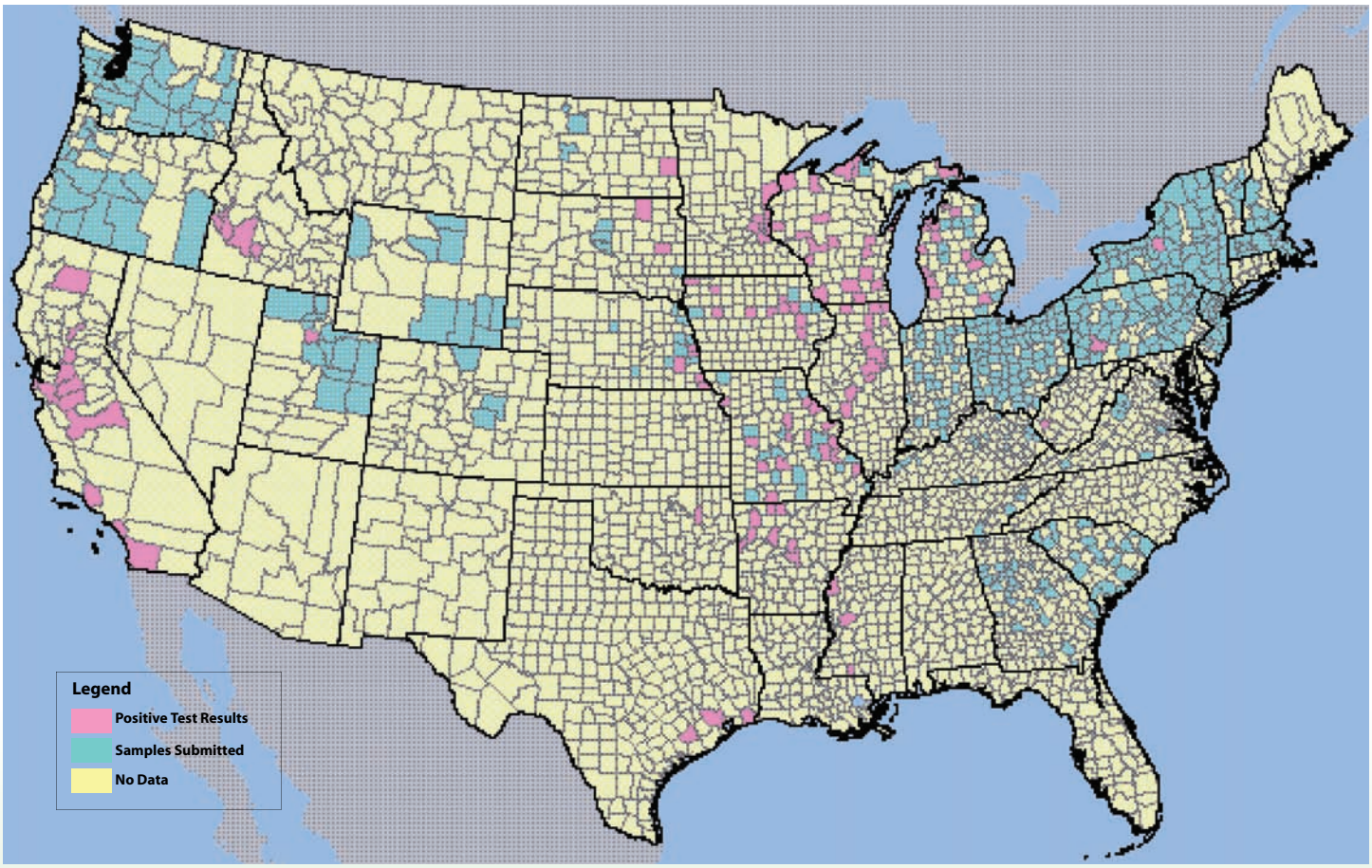
There is mounting evidence that environmental factors contribute substantially to many diseases of major public health significance throughout the world. The National Institute of Environmental Health Sciences attributes an estimated 24 percent of the global disease burden and 23 percent of all human deaths to environmental factors (NIEHS, 2006); their 2006-2011 Strategic Plan states, “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, in CDC Now: Health Protection Goals, define emerging infectious diseases and environmental threats such as toxic chemical spills and wildfires as health and safety challenges of the 21st century. Understanding environmental and ecological health is clearly essential for protecting the public health of the Nation and the world.

The current health problems caused by zoonotic diseases (West Nile virus, avian influenza) and environmental contamination (mercury in fish, arsenic in drinking water) 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. Since 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 an early-warning system for protecting human health.

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, human demographics that are related to incidence, prevalence, and persistence in human exposure to mosquito populations.

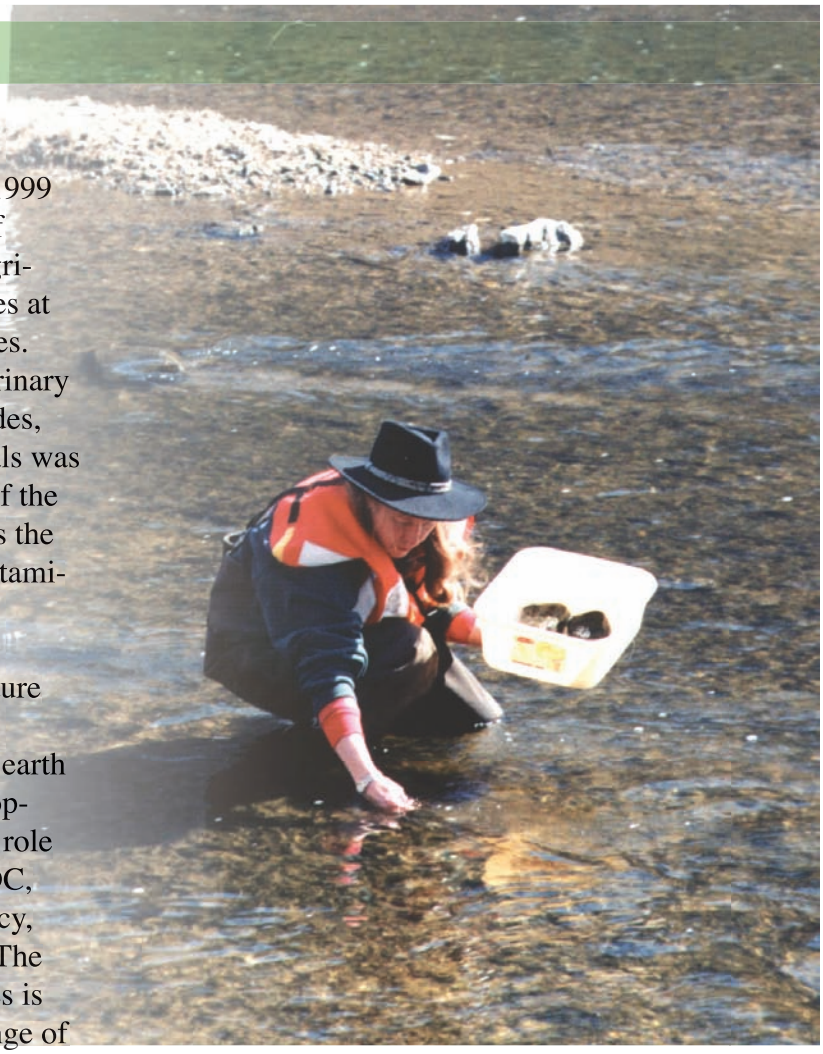
The USGS, though not a public health agency, is “the only integrated natural resources research bureau in

the Federal Government" (U.S. Senate report 109-275 Department of the Interior, Environment, and Related Agencies Appropriations Bill, 2007), and, as the primary governmental agency responsible for monitoring wildlife (Migratory Bird Treaty Act of 1918) is at the forefront of identifying wild animal disease reservoirs. USGS expertise complements and can significantly augment public health decision-making. 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 drinking water contaminants, air-dust-soil-sediment-rock contaminants, pathogens in recreational waters, and the use of wild animals as sentinels of human health. The position of USGS as a non-regulatory 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.



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, human demographics that are related to incidence, prevalence, and persistence in human exposure to mosquito populations.

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% 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 (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 CDC, NIEHS, and the Environmental Protection Agency, to address environment-human health linkages. The unique role of the USGS among Federal agencies is that it can not only apply an extremely broad range of interdisciplinary monitoring activities to track environmental health issues but 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.

Strategic Focus

The USGS proposes to provide the scientific and monitoring information essential for preparing the Nation for emerging and resurging environmental and ecosystem health threats. This will be accomplished by integrating existing USGS human-health related data, by establishing an early warning system for environmental threats, by clarifying 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.

Expand Access to Existing Data

The USGS scientific workforce has the information—biologic, geologic, geographic, and hydrologic—needed to provide the Nation with powerful tools for identifying environmental health risks to its citizens. USGS databases constitute one of the most comprehensive and high-quality arrays of national, regional, and local biologic, organic, and inorganic analyses available from any single source. Many of these data have been collected over time periods ranging from years to decades. However, the many data sources are scattered across the USGS and not easily available to most users. If consolidated, this array of environmental data and information could provide our partners and customers with unified spatially and temporally referenced sources of information.

An important step in the overall goal of protecting public health is to integrate existing USGS databases into an atlas that would portray potential environmental health threats and provide the underlying framework for 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 real-time information to researchers. The CDC's National Environmental Public Health Tracking Program currently has links to a number of external data sources, including some USGS databases. The health atlas would greatly strengthen CDC's program by improving their access to USGS data.



Agencies collaborate to fight wildlife disease, respond to katrina ecological impacts and measure economic impacts of invasive species.
Pictured above: John Baughman, Executive Vice-President, IAFWA; Fran Mainella, Director, NPS; Matt Hogan, Acting Director, USFWS; Kathleen Clarke, Director, BLM; and Patrick Leahy, Acting Director, USGS.

Strengthen Partnerships and Enhance Collaboration with Others

Realizing the full benefit that the USGS can provide to the Nation 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.

USGS has already established partnerships with the CDC, Armed Forces Institute of Pathology, Indian Health Service, and NIEHS that are facilitating collaboration. Interagency Agreements with the Environmental Protection Agency (EPA), the U.S. Department of Agriculture, and Cooperative Ecosystem Studies Units cover collaborative work related to drinking water quality, early detection of highly pathogenic avian influenza in wild birds in North America, and other academic research.

The long-standing relationship with EPA will be strengthened further when USGS can provide information on the environmental occurrence and potential for exposure of the next contaminants of concern for regulation and registration. Existing partnerships with other DOI agencies will be strengthened by our 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 relationships with Federal agencies, such as the Departments of Defense, Health and Human Services (including the Food and Drug Administration), and Homeland Security.

Enhance Rapid ResponseTeams

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 of public health significance. These efforts should increase their focus on environmental, ecosystem, and human health aspects of potential human health events and should 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 to assist in dealing with catastrophic natural or anthropogenic events such as newly introduced pathogens, earthquakes, floods, or extreme contamination events. This response capability would complement existing USGS rapid response to wildlife disease events and to toxicological studies and would provide valuable information to other agencies charged with public health and emergency response.

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 elucidate transmission mechanisms. 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 an environmental health warning system

The ultimate goal of USGS in response to the health challenges ahead is to institute and maintain a national-scale, real-time, environmental health threat warning system. The system would serve as a clearinghouse for health and environmental information (data, research, interpretations) linked to a set of GIS decision-support tools. The system would:

- Map, observe, and monitor the spatial extent of potential zoonotic factors in America, including movement patterns of diseases and wildlife,
- Collect and disseminate information from a variety of interagency surveillance networks to locate, identify, and characterize sources of environmental contaminants and pathogens,
- Interpret the pathways and processes through which zoonotic diseases, contaminants, pathogens or vectors might affect human health,
- Produce derivative risk maps that that will delineate the degree of potential exposure to diseases and contaminants that pose risks to human health in the natural environment, and
- Predict how the impacts on human health might 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), and earth-science information and research (locations and characteristics of major dust sources, geologic terrains naturally enriched in potentially toxic substances, and contaminated waters, sediments, and soils). This system would complement existing and planned Federal environmental health efforts. The health warning system would provide a unique perspective on environmental health issues by incorporating process-based interpretations of environmental health threats.

Strategic Actions

- Develop an online atlas of potential environmental health threats, which consolidates USGS data and information and provides real-time data for researchers and public-health agencies to enhance the Nation's ability to respond quickly to current threats and anticipate potential future threats.
- Strengthen partnerships and enhance collaboration with other entities charged with responsibility for environmental and public health. Increased levels of collaboration 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, real-time, environmental health threat warning system that combines biological, water-quality, and geologic information with GIS decision-support tools.

Vision of 2017

The USGS has worked with health agencies around the Nation to develop and maintain a national database and atlas of geology- and ecology-sourced diseases and toxicants. Based on these efforts, USGS scientists and our collaborators in the medical and allied health sciences have made significant contributions to characterizing environmental factors impacting 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, real-time, environmental health threat warning system, developed and maintained by the USGS, provides risk maps to delineate the degree of potential exposure to diseases and contaminants in the natural environment that are risks to human health. USGS scientists provide rapid analyses and environmental process 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 events.

In its broadest sense, the environment is one of the major determinants of human health and well-being. Healthy environments promote individual and community health: unhealthy environments can create substantial morbidity, mortality, and disability, in addition to sapping the economic welfare of societies.
Institute of Medicine of the National Academies, Roundtable on Environmental Health Sciences, Research, and Medicine.



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. USGS, Photo



USGS scientists sampled manures from confined animal feeding operations, such as this one in New York, as part of the Source Characterization Study. USGS, Photo



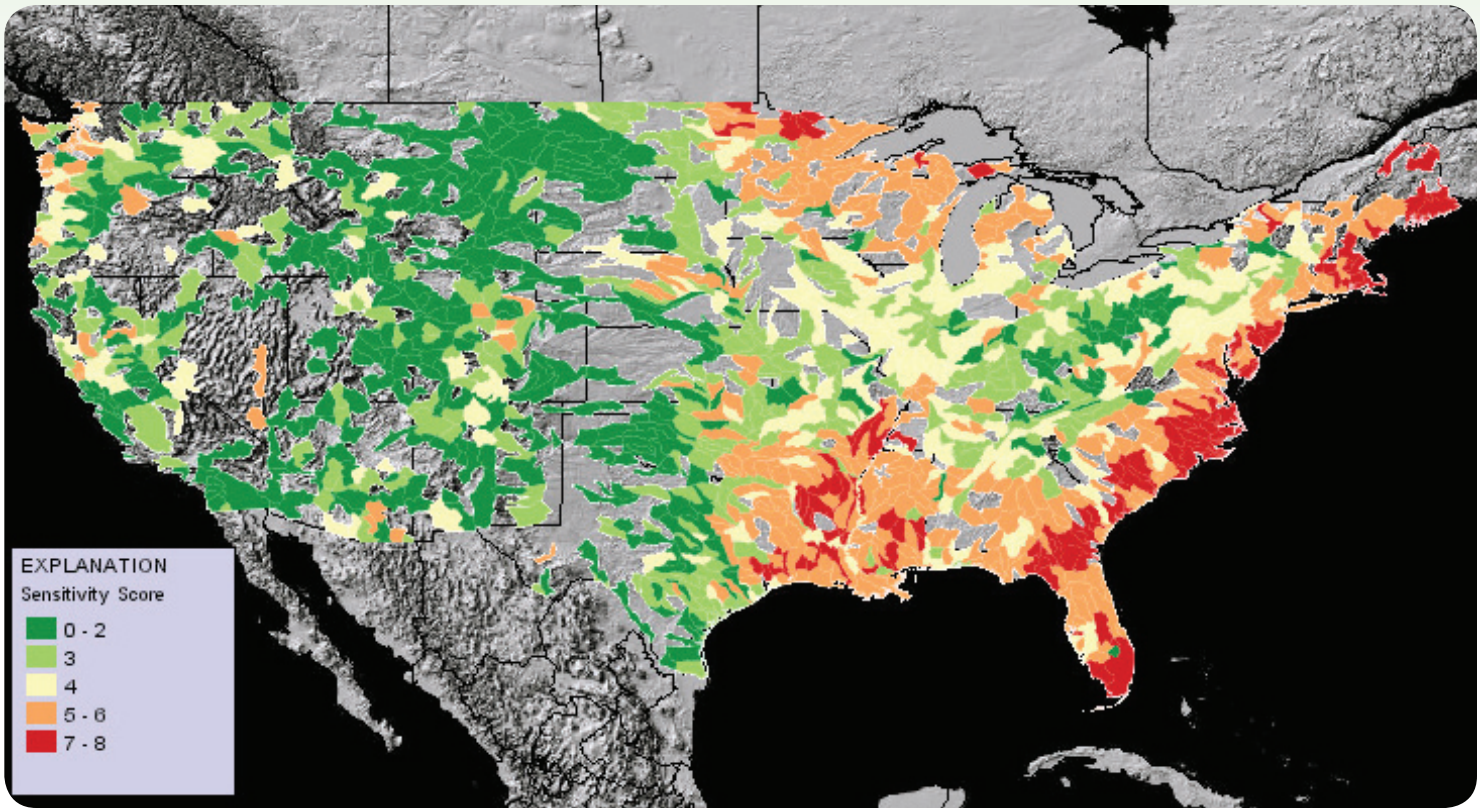
Pressurized filtration unit used to filter liquid waste samples from the Source Characterization Study for Emerging Contaminants Project. Filtered samples were analyzed for a suite of human pharmaceuticals and household and industrial compounds. USGS, Photo

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 140 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 H5N1 HPAI 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.

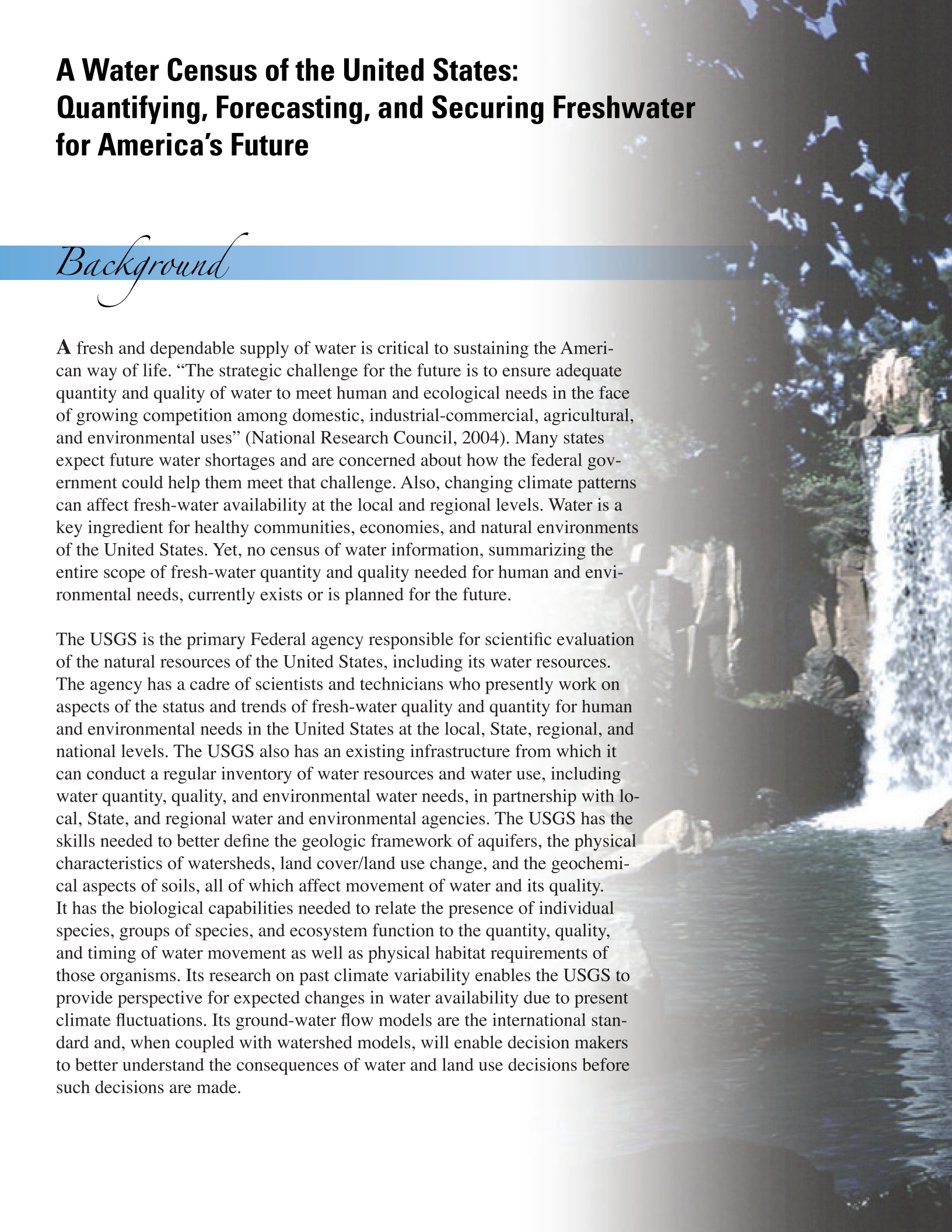
A partial listing of USGS environmental databases

USGS DATA SOURCE	COMPONENTS OF DATABASE
NAWQA (National Water Quality) 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.
NWIS (National Water Information System)	Over 4.4 million historical water quality analyses
NWHC (National Wildlife Health Center)	Complete long-term 50-year database of all avian wildlife mortality across America, with a focus on National Wildlife Refuges.
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
NBII Disease Information node	National Geochemical Survey database-stream sediment and soil geochemistry approaching a sample density of one sample per 289 square km for the entire nation and a higher density in many places. Geochemistry of igneous rocks and unconsolidated sediments from throughout the continental US and Alaska.
Mineral Resource Program Data	Characterization of concentrations and flux of sediment and chemicals in the Nation's largest rivers
NASQAN (National Stream Quality Accounting 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 of Agriculture, and numerous other governmental and private entities.Includes over 200 sites spanning the continental United States, Alaska and Puerto Rico.
NADP/NTN National Atmospheric Deposition Program/National Trends Network	Detailed analyses of more than 10,000 coal samples from all coal basins in the United States
U.S. Coal Quality Database	Enormous amounts of environmental data reside within the USGS. We are presently developing tools that will allow migration of these data to the health atlas



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 incorporates 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.

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 the American way of 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 can affect fresh-water 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 census of water information, summarizing the entire scope of fresh-water quantity and quality needed for human and environmental needs, currently exists or is planned for the future.

The USGS is the primary Federal agency responsible for scientific evaluation of the natural resources of the United States, including its water resources. The agency has a cadre of scientists and technicians who presently work on aspects of the status and trends of fresh-water 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 water 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, the physical characteristics of watersheds, land cover/land use change, and the geochemical aspects of soils, all of which affect movement of water and its quality. It 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 physical habitat requirements of those organisms. Its research on past climate variability enables the USGS to provide perspective for expected changes in water availability due to present climate fluctuations. Its ground-water flow models are the international standard and, when coupled with watershed models, will enable decision makers 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 decision makers about

(1) the status of its freshwater resources and how they are changing,
(2) water use for human and environmental needs,
(3) how freshwater inventories are related to water infrastructure,
(4) the location of 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 variations in freshwater availability due to changing climate conditions or human decisions about how those actions alter the freshwater supply of the Nation

A fresh and dependable supply of water is critical to sustaining the American way of life. Fundamental information on how much freshwater is available, and whether the supply of freshwater is increasing or decreasing over time, is essential for the Nation's economic and environmental health. Improvements are needed 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). Non-traditional sources, such as saline water, water reuse, or offshore freshwater aquifers, need to be evaluated or found.

Water is an essential ingredient for healthy communities, economies, and natural environments of the United States. The public and decision makers 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. The Water Census will provide information on the current 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 not presently considered to be a freshwater resource can be made available for human and environmental needs.

As American population centers migrate to coastal areas or the arid west, where surface water storage capacity is limited, water shortages will undoubtedly occur. In fact, in parts of the southwest and along the U.S.-Mexico border, ground-water levels have already fallen so far due to pumping that many perennial streams like the Rio Grande River 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 Southwestern United States. 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 requirements also now include the recognized needs of the natural environment, such as aquatic fish, wildlife, and native vegetation communities associated with those water resources.

The USGS, the primary Federal agency responsible for scientific evaluation of the natural resources of the United States including its water resources, will provide the information needed to address these challenges through the Water Census of the United States.

The Water Census will be a systematic, periodic determination of

- freshwater quantity and quality present in surface waters, ground waters, snow and ice, and water infra structure;
- freshwater quantity and quality needed to meet hu man and environmental uses; and
- changes over time in freshwater quantity and quality in response to changes in climate, land use/land cover, and human and environmental water needs.

The results of the Water Census will provide individuals, communities, and State and national decision makers with information on how much freshwater is available in the Nation and whether the supply of and demand for freshwater is increasing or decreasing over time. 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 will also 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). 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, and if that supply of freshwater is stable, increasing, or decreasing over time. Strong partnerships among local, State, regional, and Federal agencies, through efforts like the Cooperative Water Program, will ensure that both local needs and the goals of the national Water Census are met.

New scientific approaches will be developed to 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. 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 will also require improvements in the mapping and characterization 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.

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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 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 input (wetter or drier climate conditions, human alteration of water movement between watersheds and aquifers) or in water use (for human or environmental needs).



Biologist conducting water quality survey
USGS, Photo

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. Therefore, the Water Census will provide a better understanding of the relation

of environmental needs and land cover/land use on the movement of water into watersheds or aquifers, through scientific quantification of environmental water needs and regular determination of changes in 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, powerplant cooling, or the environment. These non-potable 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 our understanding of the 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 assure 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 decision makers 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 due to ground-water withdrawals. Improved geomorphic characterization of watersheds will lead to better rainfall-runoff models and hence better flood prediction. Knowledge of climate variability in relation to drought, especially placed in historical context, will lead to a more comprehensive understanding of the probability of drought frequency 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 policy makers 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 terms of both quantity and quality?), and an improved ability to forecast the availability of freshwater for future economic and environmental uses.

Strategic Actions

- Expand time-series data-collection capabilities for status and trends of water quantity and quality, and make the information available to the public and to decision makers in a nationally consistent manner.

- Characterize watershed, geologic, and geochemical frameworks and storage and retention capabilities of aquifers across America, through development and use of new technologies including geophysics and remote sensing.

- Refine existing ground-water/watershed models, and develop and employ new model technologies that better reflect and forecast changes in the hydrologic cycle and that meet the needs of decision makers.

- Better define the ecosystem needs of our 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.

- Strengthen partnerships with local, State, regional, and Federal agencies to design and develop a Water Census of the United States that provides citizens, communities, natural-resource managers, and policy makers with a regularly updated, nationally consistent inventory of water resources and water requirements for human and environmental needs.

- Define and map land-cover/land-use change, and relate these changes to changes in climate, water movement patterns, energy development, aquifer recharge, aquifer retention, stream flow, and water demand.

Vision of 2017

A fully integrated real-time network of streamgages, ground-water level measurements, rainfall and evapotranspiration data networks, and water-quality measurement sites will be enhanced and supplemented by remote sensing (state-of-the-art satellite, smart technology, and telemetry techniques), combined with analyses and models that are based on long-term records, and coupled with significantly improved geologic and geomorphic delineation of watersheds and aquifers, to provide the very best information about the status and trends in quantity and quality of the Nation's freshwater supply and demand. This information is incorporated into 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 decision makers to better estimate the quantity and quality of water available for wildlife, humans, and environmental use. 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 decision makers to a wide range of challenges including drought; changing human populations; changing demands for agriculture, industry, energy production, and to maintain a healthy environment; an accurate comparison of water use by invasive and native species; changing quality of our Nation's waters; and consideration of waters not now used as a resource (such as saline waters, water reuse, and freshwater aquifers offshore along our coasts) .

"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).



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



Ground- and surface-water samples were filtered and processed in a mobile laboratory immediately after sample collection. USGS, Photo



Larry Buschmann installing a staff gage at USGS 06930060 Big Piney below Ft. Leonard Wood, MO. USGS, Photo

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 fresh-water quantity and quality available for human and environmental needs comes from the Rio Grande.

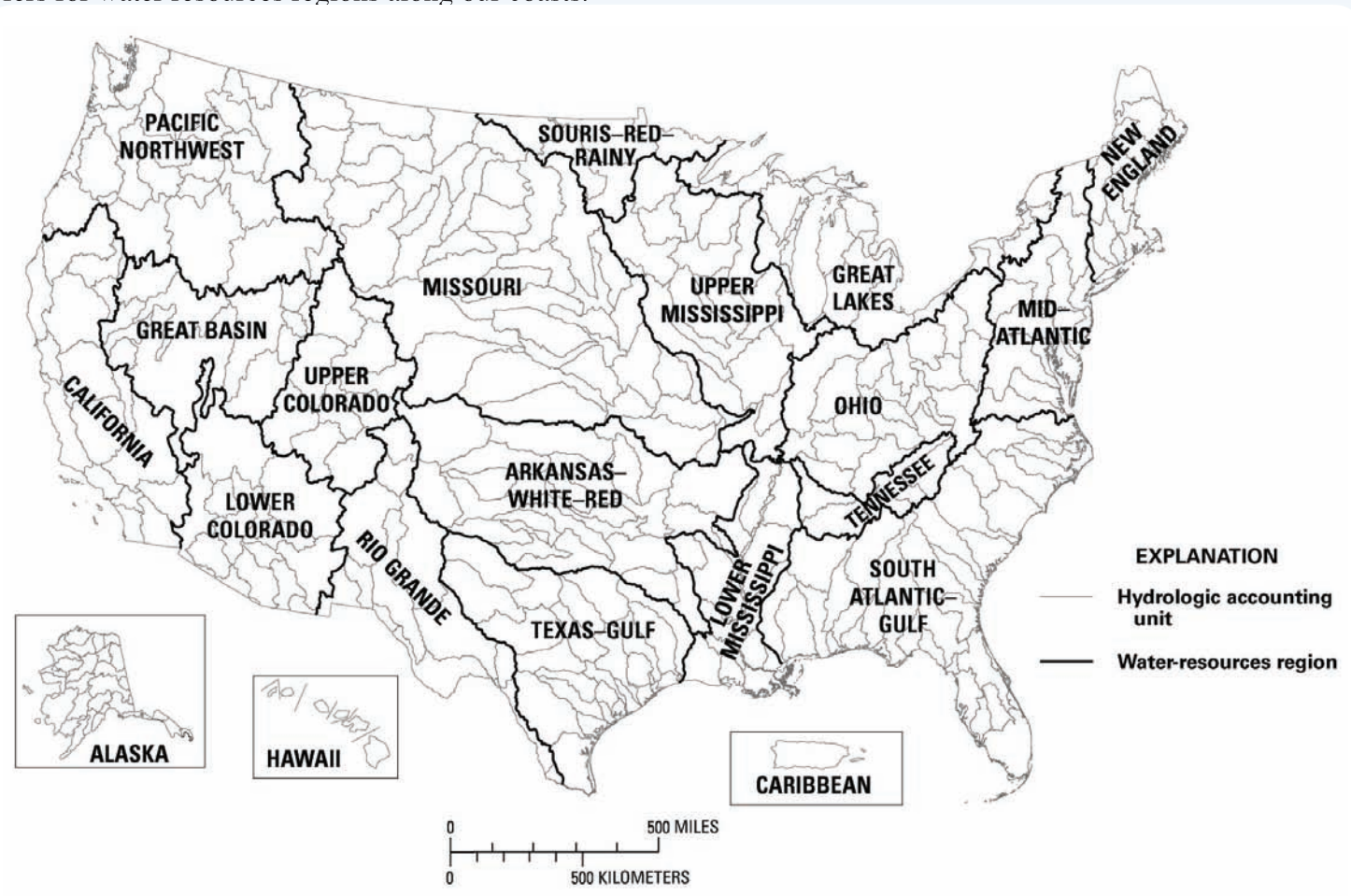
"The Rio Grande is the lifeline for an arid landscape that stretches from New Mexico through Texas to the Gulf of Mexico. The river is expected to support diverse and fragile ecosystems while at the same time supplying water for expanding urban centers, industrial complexes, and long-standing agricultural 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 groundwater 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).



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 magnitudes 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)

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 our 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 policy-makers 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.

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 significant economic consequences for water users in the basin (Glantz, 1982). (National Science and Technology Council, 2004).

This example highlights the need to go beyond characterization 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 due to insufficient freshwater quantity and quality, as well as which communities or ecosystems are particularly vulnerable to too much.

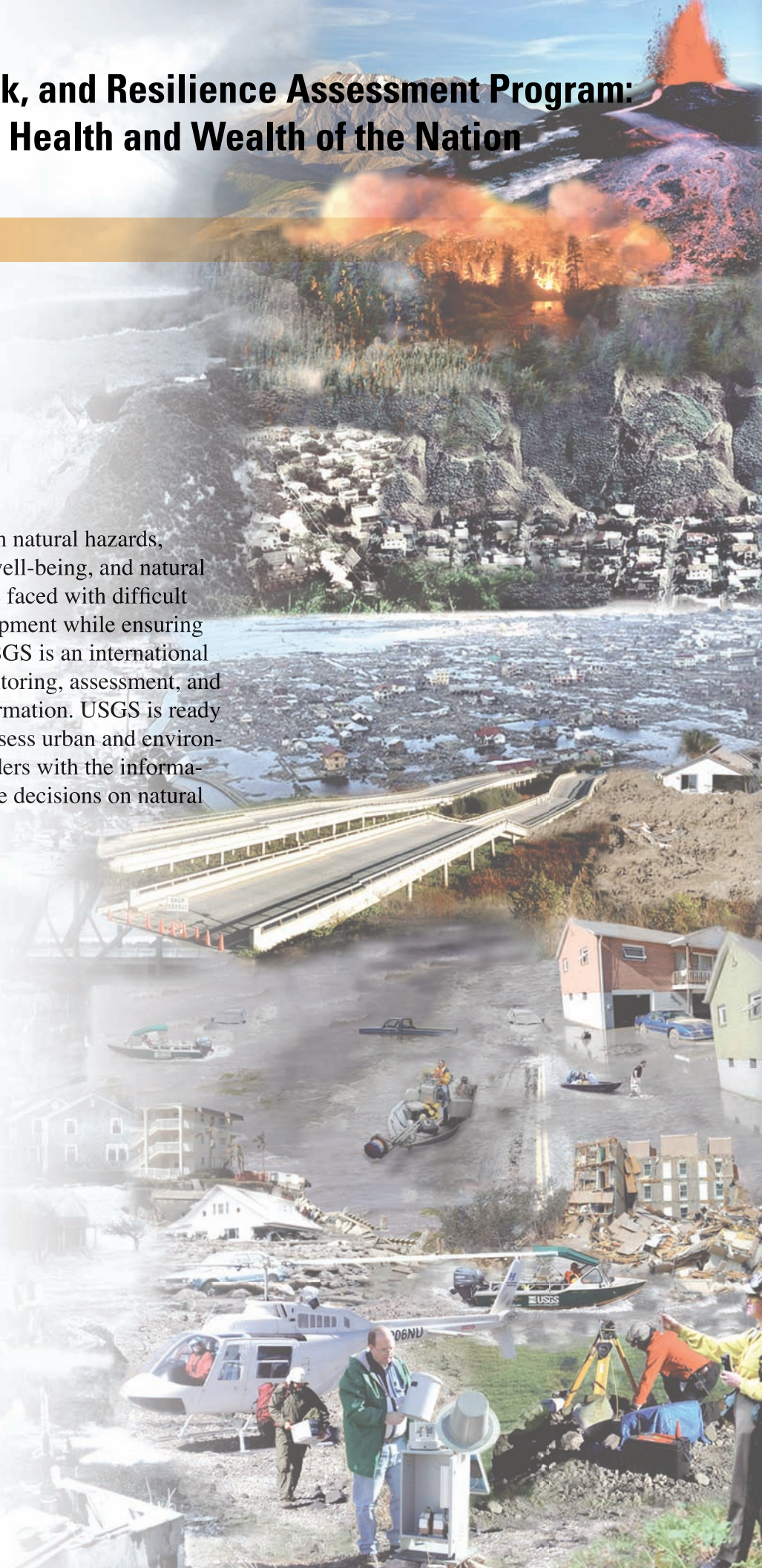
"Knowing how much water is available for use, and when water is available, are key for decision makers and the application of water law."
(National Science and Technology Council, 2004).



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, assessment, and timely communications of hazards information. USGS is ready to work with partners to monitor and assess urban and environmental vulnerability and to provide leaders with the information they need in order 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 significant and continuing threats to the Nation's safety, security, economic well-being, and natural resources. Although sudden extreme events such as hurricanes, earthquakes, flash floods, wildfires, volcanoes, and landslides capture the public's attention, equally threatening are the effects of slower, more chronic hazards such as climate change, 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 policy makers 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 our urban areas into high-hazard coastal regions of the country. With societal risk and vulnerability to natural hazards rising, governments will be faced with difficult decisions, balancing growth and development while 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 policy makers, 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 provide notification 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 NOAA's National Weather Service (NWS) for developing its forecasts and carrying out its statutory responsibility to issue flood watches and warnings. 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 post-fire recovery strategies for reducing debris flows and fire frequency, and provide firefighters with maps of current fire locations, perimeters, and potential spread. The USGS partners with the Federal Aviation Administration, NOAA, and others to help pilots avoid dangerous volcanic ash clouds. In order 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 Department of Defense, NASA, and NSF, providing real-time ground-based magnetometer data for forecasting, monitoring, and diagnosis of the changing conditions of the Earth's space environment. These accomplishments 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 our efforts to communicate how the Nation is at risk from them 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.



These images are from New Orleans in the aftermath of Hurricane Katrina in August 2005. (USGS photos)

Strategic Focus

A core element of the USGS mission is to provide scientific information in order to minimize loss of life and 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 natural hazards affecting both natural ecosystems and the built environment. The USGS leads the Nation in effectively harnessing advances in 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 decision makers at all levels. Effective risk reduction also requires the monitoring and communications tools for real-time forecasting and reporting of the locations and likely impacts of events, the national, regional, and local assessments of hazards and risk, and the fundamental research to understand the causes and effects of hazards and to predict their occurrence. The USGS must augment all of these abilities over the next 10 years.

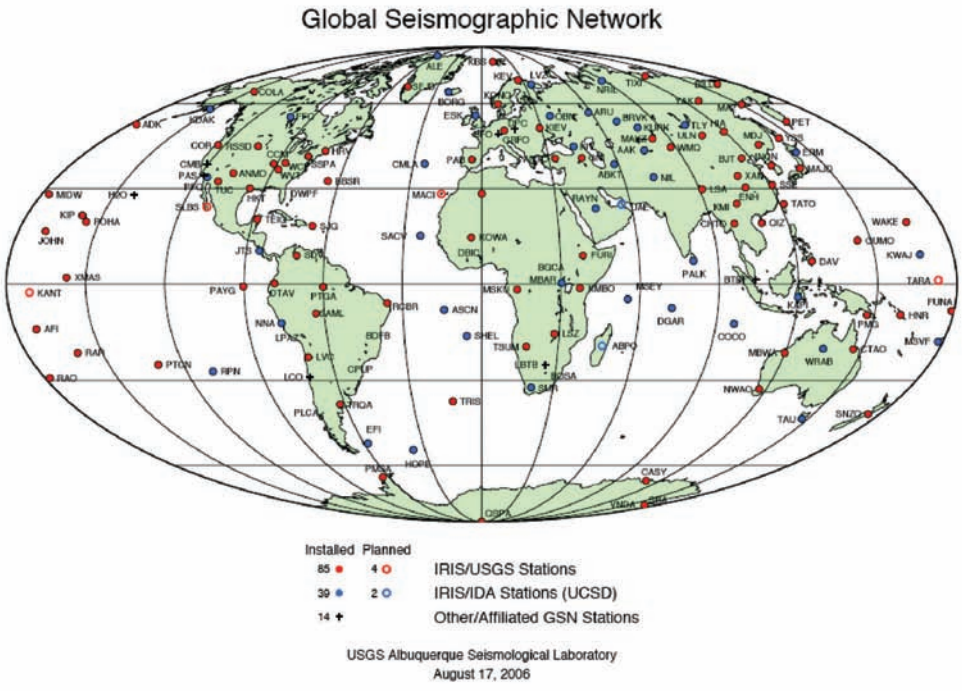
In order to reach the 10-year vision described here, major foundational investments in robust monitoring networks are necessary for accurate predictions and

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 main investments needed are:

- 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 streamgaging stations 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 LIDAR to assess and monitor hazards-related landscape changes, particularly coastal change

In addition, over 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 communications 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 via pager, mobile phone, and e-mail that will include a concise estimate of impact as well as earthquake location, magnitude, depth, an estimate of the 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 systems 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.

Characterizing hazards—assessing where they 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



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 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.

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 significantly 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.

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 our understanding even further. A few examples: Over the next decade, use of paleorecords (also called proxy records in climate and storm research) will improve our 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 short-term earthquake prediction. 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 non-contact data collection and real-time estimates of measurement uncertainty will significantly improve flood estimates.

The USGS will make significant progress towards understanding wetland and coastal processes and applying that knowledge to ameliorate the impacts of sea-level rise and hurricanes, like those of 2005, on coastal communities and ecosystems.



A wildfire left very little of this home near San Bernadino, Calif., in October 2003. (FEMA photo/Kevin Galvin)

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 multi-disciplinary approach, and a coordinated hazard and risk program provides a mechanism to integrate the hazard, land-cover, climate change, and risk and vulnerability ex-

pertise at the USGS. In addition to enhanced 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.

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.

- Form an intra-bureau 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, co-located 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 hazards assessments to local audiences and to targeted audiences with different needs.

"...advances in science and technology are improving the Nation's ability to prevent hazards from becoming disasters.... These advances mean that natural and technological hazard events no longer inevitably lead to catastrophic disaster for the communities they threaten."

(National Science and Technology Council, 2003)

Vision of 2017

In 2017, the Nation is safer from natural disasters, thanks to a seamless, integrated disaster prediction/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 due to socioeconomic trends, land use changes, ecosystem loss, and climate change is also 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.

Multi-hazards Demonstration Project in Southern California

The USGS has recognized the urgency of hazards issues and over the past several years has invested significant time and energy building a hazards initiative. One result of these efforts is a demonstration project for multi-hazards 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 Cali-



Losses from wildfire in southern California have increased every decade during the 20th century. During the past 30 years, 12 of the nation's 15 most destructive wildfires have occurred in California.

fornia 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 inter-connectedness 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.

National Volcano Early Warning System

To reduce community vulnerability on the ground and in the air, the USGS National Volcano Early Warning System will monitor the Nation's 169 geologically active volcanoes at levels appropriate to the threats each poses, work with communities to increase disaster resilience, and foster research in support of improved understanding of volcanic processes. Mount St. Helens is one of only a very few dangerous U.S volcanoes with a monitoring network equal to the level required by NVEWS; that is, adequate to infer processes occurring beneath the volcano and to detect subtle changes in its behavior that could portend a significant eruption. Following the reawakening of Mount St. Helens in October 2004, the USGS worked closely with Federal, State, and local responders, providing 24/7 monitoring, situational awareness, and alerts. Data collected during the current eruption are being used by scientists to improve understanding of magma transport, eruption triggering, impact of eruptive activity on stability of glaciers, and processes that produce earthquake signals during dome-building eruptions. These results can be applied to other volcanoes to help protect vulnerable communities lying in harm's way.

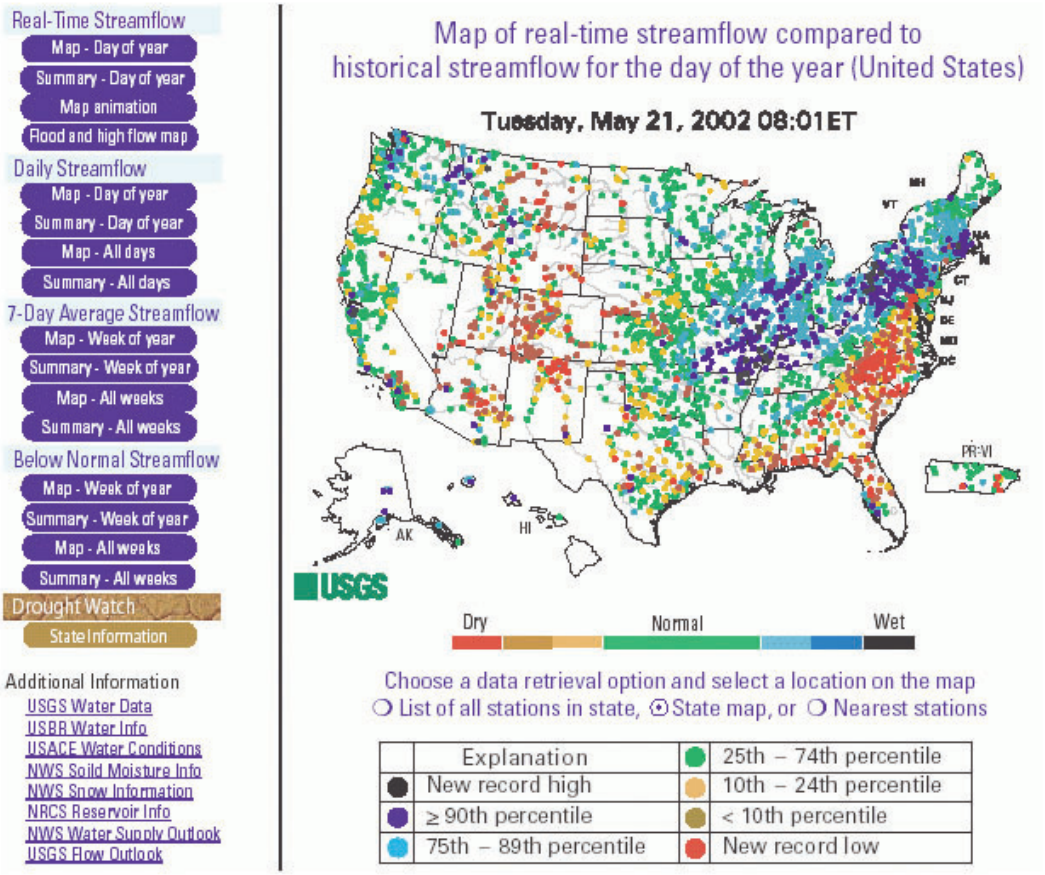


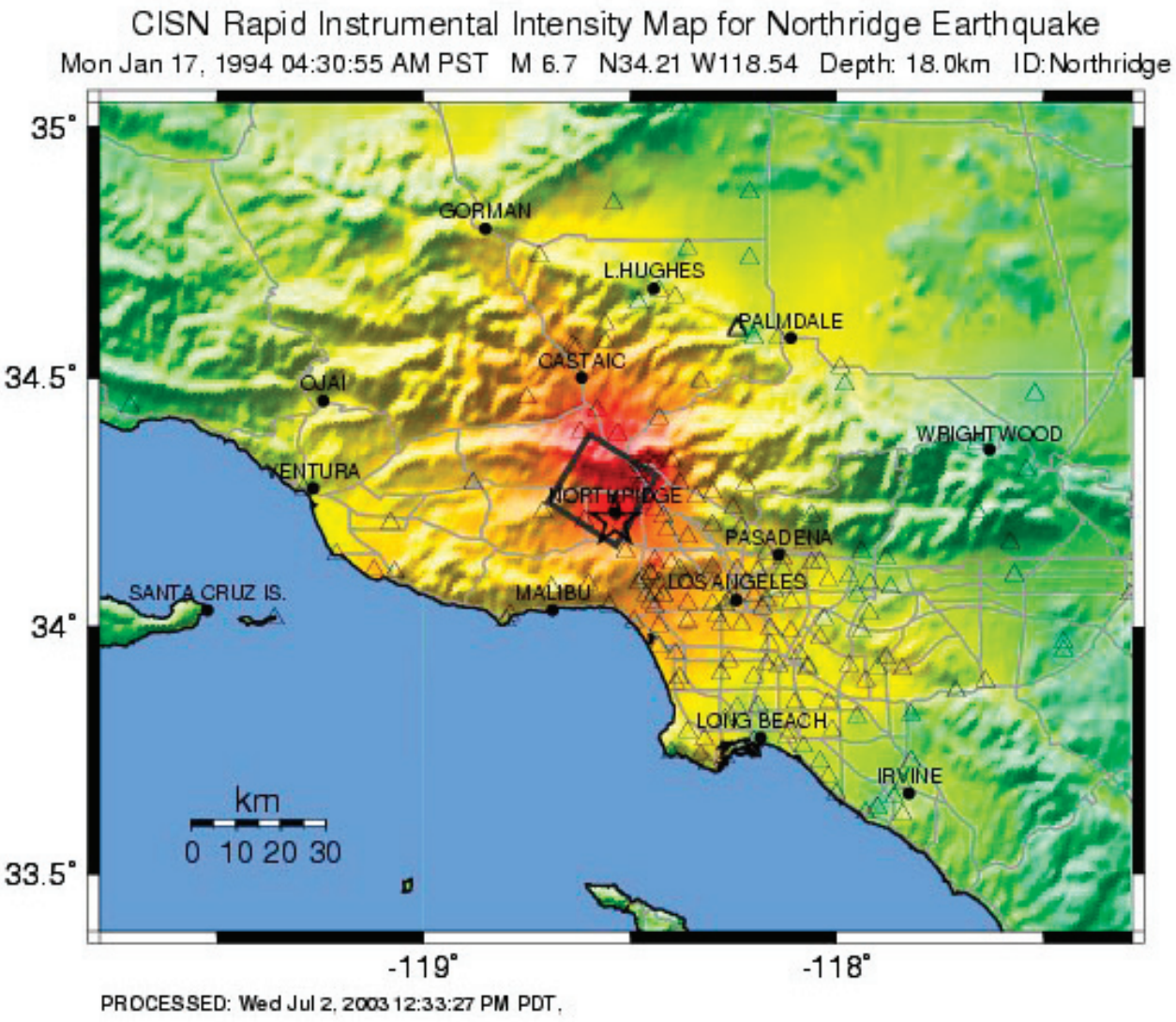
Mt St Helens USGS,Photo

Real-time Information for Safer Communities

Streamflow Information on Tap:
Since 1887, the USGS has operated a streamflow-gaging 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 NWS uses real-time data from about 4,000 of the approximately 7,000 USGS streamgaging stations to forecast flow conditions on major U.S. rivers and small streams in urban areas. In fact, the most profound change in the USGS streamflow-gaging program in recent years has been the development and widespread use of real-time streamflow data by many partners and the public. The program features a strong Cooperative Water Program in which the USGS and about 800 State and local partners share the costs of collecting, managing, and publishing streamflow information.

ShakeMaps in Minutes:
The USGS is the only agency in the United States responsible for the routine monitoring and notification of earthquake occurrences. The USGS fulfills this role through research and monitoring and through support of 14 regional networks in areas of moderate to high seismic activity. All of these efforts are being integrated into the Advanced National Seismic System (ANSS). ANSS capitalizes on the revolution in information technology to achieve dramatic advances in real-time seismic data analysis and rapid earthquake notification. Data from earthquake sensors in urban areas can be used to produce, within a few minutes of earthquake occurrence, 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 ShakeMap depends on adequate ANSS instrumentation and effective USGS partnerships with the user community.





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 4.4 earthquake near Santa Rosa, California, August 2, 2006. Simplified versions are quickly available for the news media.

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 impacts.

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 25-30 ft, 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 Figure), 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 impacts 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. USGS data collection and interpretation efforts are done in collaboration with NASA, the U.S. Army Corps of Engineers, and the University of New Orleans and are being made available to local, State, and Federal agencies for purposes of disaster recovery and erosion mitigation.

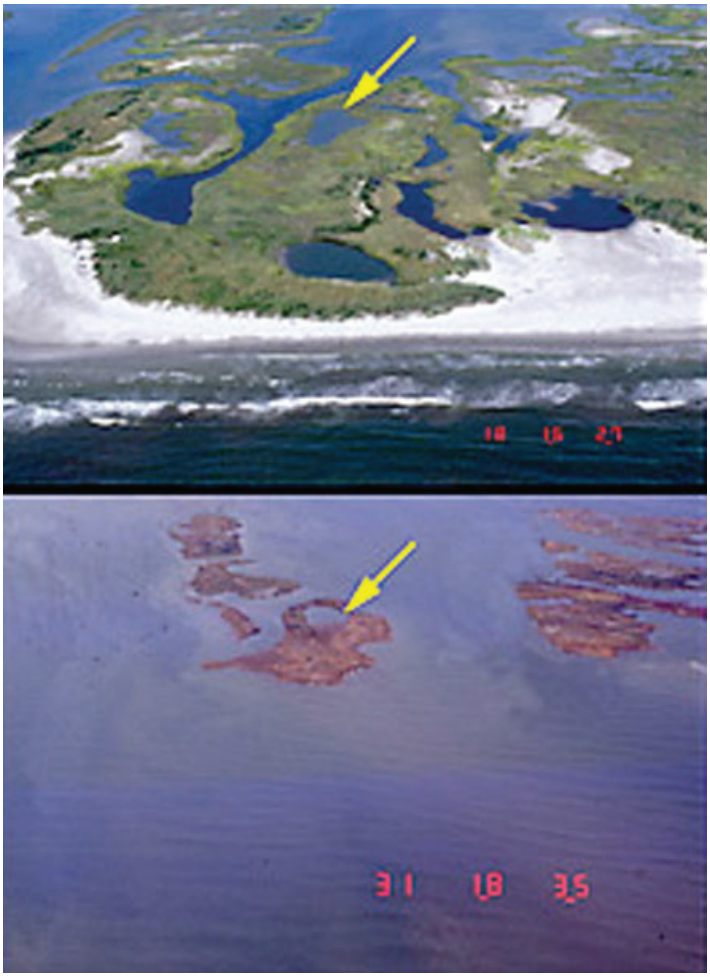


Figure: The upper image taken in July 2001 shows narrow sandy beaches and adjacent overwash sandflats, low vegetated dunes, and back barrier marshes broken by ponds and channels. The lower image shows the same location two days after Hurricane Katrina made landfall. As a result of the storm, sand was stripped from the beaches and large sections of the marsh were eroded. Today, few recognizable landforms are left on the Chandeleur Island chain.

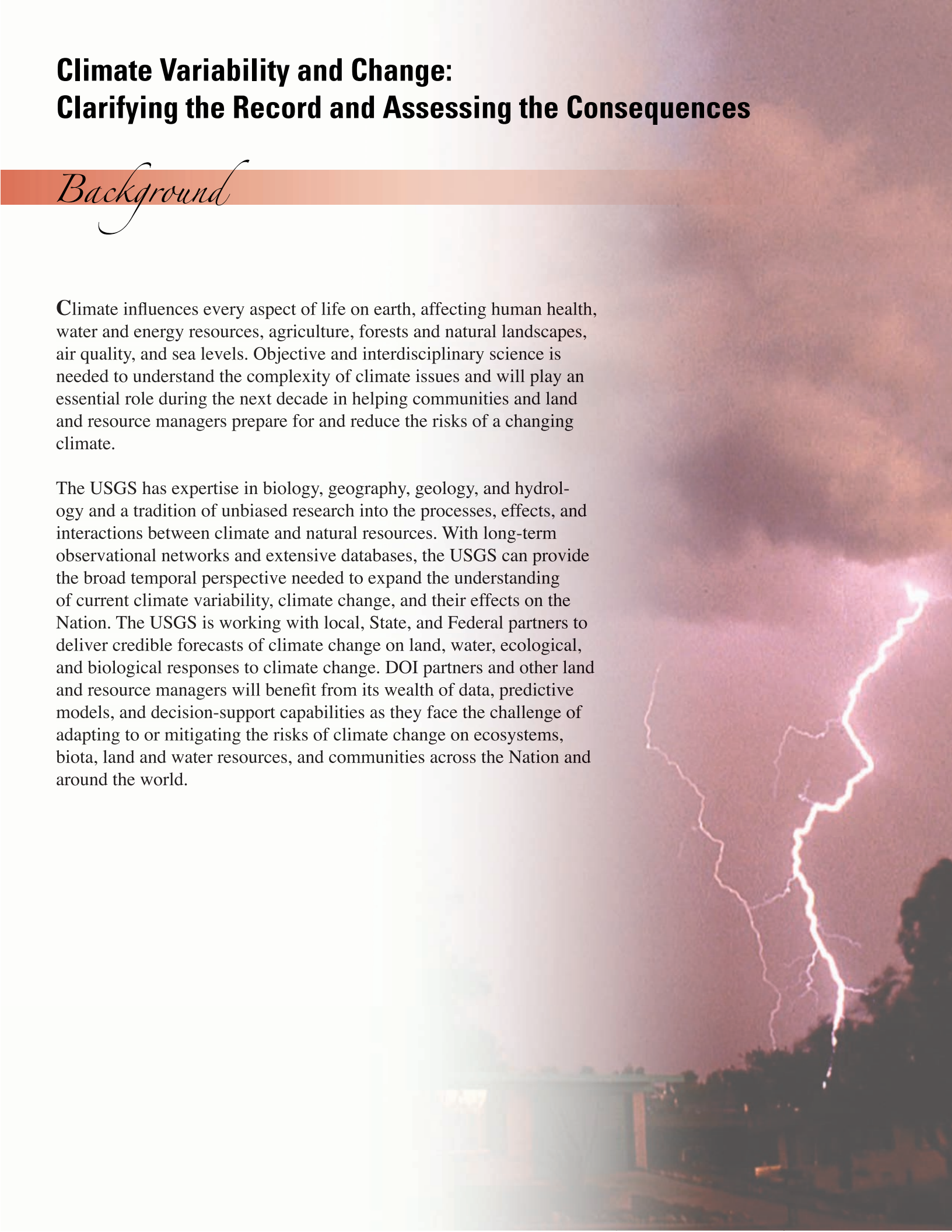
"Reducing disaster vulnerabilty requires increasing knowledge about the likelihood and consequences of natural and technological hazards, and empowering individual, communities, and public agencies with that knowledge to lower risk before, and respond effectively after, hazard events." (National Science and Technology Council, 2003)

Climate Variability and Change: Clarifying the Record and Assessing the Consequences

Background

Climate influences every aspect of life on earth, affecting human health, water and energy resources, agriculture, forests and natural landscapes, air quality, and sea levels. Objective and interdisciplinary science is needed to understand the complexity of climate issues and will play an essential role during the next decade in helping communities and land and resource managers prepare for and reduce the risks of a changing climate.

The USGS has expertise in biology, geography, geology, and hydrology and a tradition of unbiased research into the processes, effects, and interactions between climate and natural resources. With long-term observational networks and extensive databases, the USGS can provide the broad temporal perspective needed to expand the understanding of current climate variability, climate change, and their effects on the Nation. The USGS is working with local, State, and Federal partners to deliver credible forecasts of climate change on land, water, ecological, and biological responses to climate change. 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

***USGS** scientists will meet the pressing needs of the Department of the Interior, policy makers, and resource managers for scientifically sound state-of-the-science information on climate change and its effects. The USGS will provide predictive and adaptive tools and strategies for managers to use to reduce the risk of hazards as well as increase the potential for hydrologic and ecological systems to be self-sustaining and resilient to climate change and related disturbances. The USGS will expand its research and monitoring, which are essential to identifying and understanding critical interdependencies between climate and management decisions in the response of natural resources, including water, energy, and ecosystems*

Climate change is a natural, continuous Earth process that is influenced by many forces, but natural climate cycles are now clearly being perturbed by increasing greenhouse gas emissions from human activities (U.S. Climate Change Science Program, 2006). 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, and outbreaks of disease and insect damage. Climate change challenges our 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 and economies. Changes in temperature and precipitation patterns are projected to intensify in response to increasing greenhouse gas emissions throughout the twenty-first century (IPCC, 2001).

The consequences of global climate change to society, land, water and ecosystems are of increasing public concern. Scientific insight into the direct and indirect effects of climate change on local and regional resources will likely lead to significant changes in management of land, water and other natural resources in the United States and elsewhere. During the next decade, the United States and other nations must develop scientifically rigorous response strategies that are both effective and adaptable. Scientists must increase their efforts to collect and convey scientific information needed for developing these strategies and adapting them to changing knowledge and conditions.

Effective management of the Nation's land, water, and ecosystem resources requires weighing tradeoffs among multiple criteria concerning multiple resources and understanding the complex interdependencies that are inherent in environmental processes and human affairs. Identifying and understanding critical interdependencies is especially important in decisions that require anticipating the interactive effects of changes in climate and changes in resource management.

The USGS occupies a strong and unique role in the U.S. climate change science community. Our observation and research networks allow us to monitor and interpret the complex interactions of climate change with ongoing changes in land, water, and biological resources. Our studies of the global carbon cycle, particularly sedimentation rates and terrestrial and geologic sequestration potential, contribute to the management of carbon dioxide, an important greenhouse gas. Our breadth of multidisciplinary scientific expertise—spanning geology, biology, hydrology, and geography—enables us to deliver uniquely integrated information, predictive scenarios, and technological tools for response to climate change by the managers of the Nation's lands, waters, and ecosystems. Our capabilities will become a major component in the emerging government response to the need for information about interdependent resource effects of climate change. The following list lays out some of the key questions for which USGS strengths in research and monitoring are needed:

- *What natural processes directly drive and respond to climate change and variability over time, and how do changes in land cover, land use, and water use interact with climate?* Ice cores, tree rings, sediments, and other unique data collections are windows into the geologic past for exploring the long-term variability of climate and associated changes. The effects of human alteration of erosion and sedimentation rates on the global carbon cycle will be studied and interpreted. We will employ our extensive archives of remotely sensed data and ground-based monitoring, in combination with data available from other sources, to quantify and interpret changes through the historic period.

- *What links between climate, land use, and hydrology influence the temporal and spatial characteristics of water resources?* We will couple the extensive USGS hydrologic monitoring networks with modeling and other scientific tools to evaluate and forecast trends and anticipate and communicate thresholds in climatic variables that will affect society and the environment.

- *What places and resources in the United States are the most vulnerable to climate-influenced changes, and what characteristics increase the risk of adverse change?* We will combine geospatial and visualization tools with other research approaches to determine climate- and land use-caused risks and to identify the regions and resources most vulnerable to change at a variety of landscape scales.

- *How can regions and resources be managed to increase their resilience to climate variability and change?* Managers need scientifically sound predictive and adaptive tools and strategies to reduce the risk of natural hazards and to increase the potential for hydrologic and ecological systems to be self-sustaining and resilient to climate change and related disturbances. The USGS will conduct research into adaptation and restorative techniques, including geologic carbon sequestration, and refine the monitoring strategies for evaluating responses.

- *How will climate change, in concert with land-use and land-cover change, affect ecosystems, soil and sediment systems, and the storage and mobility of carbon, nitrogen, and other natural and manmade chemicals?* Remote and ground-based monitoring, experiments, models, and synthesis efforts will be used to understand processes and interpret trends, tipping points, other resource responses, and their causes. We will continue to build capacity to assess the influence of climate change (and related factors such as runoff and sea level rise) on sediment dynamics and geomorphology.

DOI is directly responsible for managing one out of every five acres of land in the United States, including vast water, ecosystem, and other trust resources. DOI is on the front line of response to climate change and its complex implications for management of multiple resources. The USGS and DOI are pioneering the application of joint fact finding, adaptive management, and other collaborative approaches that complement our experience in applying scientific information to resource management. The USGS can contribute information and understanding that will be essential to decision makers in DOI bureaus with resource management responsibilities.



Snow near the Granite Mountains in the Mojave National Preserve.
USGS Photo

U.S. research on climate change is planned with extensive interagency consultation. This is not merely a mandated consequence of Federal climate science programs; it is a reflection of the integrated nature of the scientific problems. Thus USGS will work in close collaboration with other Federal agencies. In particular, many USGS activities will require strategic agreements to use existing datasets that are collected and maintained by other agencies. USGS datasets, and USGS capabilities to integrate and convey information, can add considerable value to other agencies' climate change programs.

Observations are the foundation of USGS science. Field-based earth-system monitoring and research from the USGS are essential for identifying and understanding critical interdependencies in the sensitivities of natural resources to changing climate and management. Interdisciplinary collaboration fosters insights, understanding, and solutions to social and environmental problems, and the clear and timely communication of unbiased and interdisciplinary scientific information is essential for developing effective, adaptable strategies for the United States and other nations facing the challenges of changing climate.

Strategic Actions

- Expand understanding of current climate variability, climate change, and their effects on land ecosystems by placing them in the context of climate variability and change in the past.

- Improve and expand USGS observing networks for long-term observations of the physical and biological resources that directly and indirectly respond to climate to influence land and water ecosystems and their biota, using state-of-the-art satellite, smart technology, sensor nets and telemetry techniques, volunteer networks, and field technicians.

- Using indicators of ecosystem condition, report regularly on the Nation's environmental and natural resource condition. Evaluate and interpret regional and national trends, potential thresholds, and consequences of climate change to decision makers, emphasizing what is known and what is uncertain about effects on the Nation's lands, waters, and ecosystems and their biota.

- Conduct research into the interactions among climate, land-use change, and other human-caused disturbances on ecosystems and their biota, natural hazards and their impacts, water quality and quantity, and exposure of humans and biota to disease. Identify thresholds of environmental change, addressing the social and ecological risk associated with crossing these thresholds.

- Work with DOI partners to develop and test methodologies for adapting to or mitigating the risks from climate change on ecosystems, their biota, and land and water resources.

- Develop predictive models and decision-support tools for managers of the Nation's lands and waters that can deliver credible forecasts of climate-change effects on land, water, and ecological and biological responses.

- Conduct basic climate-change science that quantifies carbon stocks in soils and terrestrial sediments, and measure rates of carbon movement due to wind- and water-caused erosion, hydrologic processes, and land-use change.

Vision of 2017

USGS scientists use decades of observational data and long-term records to interpret the consequences of climate variability and change to the Nation's 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 policy makers, natural resource managers, and the public to make decisions on a daily basis.



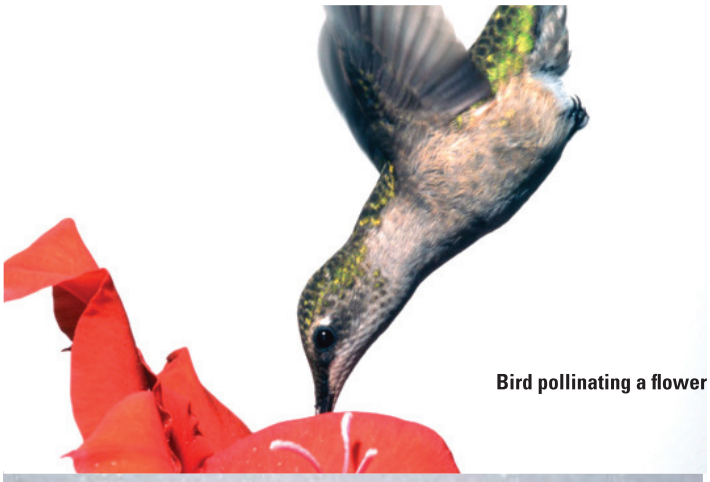
Dust devil near Saratoga Springs, Death Valley.
USGS Photo



Snow near Granite Mountains in the Mojave National Preserve.
USGS Photo

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, NGOs, and universities to implement a national phenology network and develop the tools to analyze the data at multiple scales.



Bird pollinating a flower



Flower Growing in the snow



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 rain storms 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 (ACIA, 2004).

The ability to monitor, and thus understand, the responses of vegetation, animals, and ecosystem processes to these physical changes is also 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. 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 may also 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.

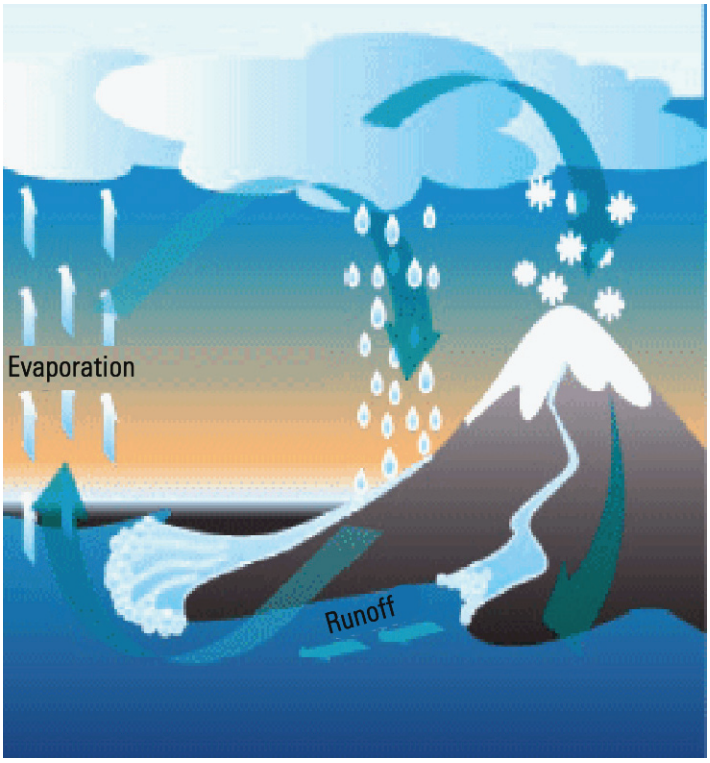
The challenge is to understand which landscapes are more or less responsive to climate change and how such landscapes will change over the coming decades (ACIA, 2004).

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 (ACIA, 2004).

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



NBS Photo



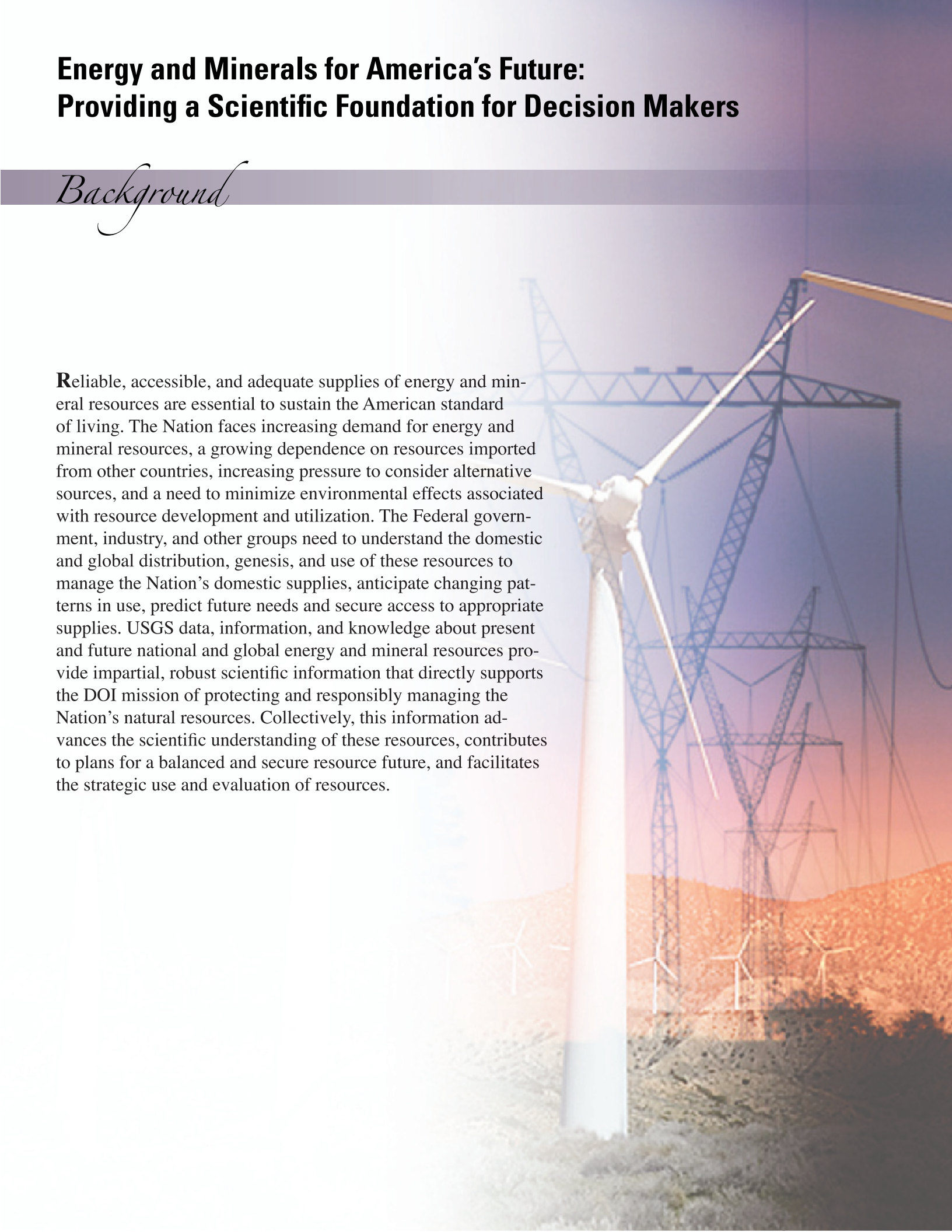
Hydroclimatology

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, in press), earlier spring snowmelt (Stewart and others, 2005), less spring snowpack (Mote, 2003), and earlier greenup of vegetation (Cayan and others, 2001). Similar hydroclimatic changes have also been observed in the Northeastern United States, where snowmelt occurrs 1-2 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 decision makers 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 Decision Makers

Background

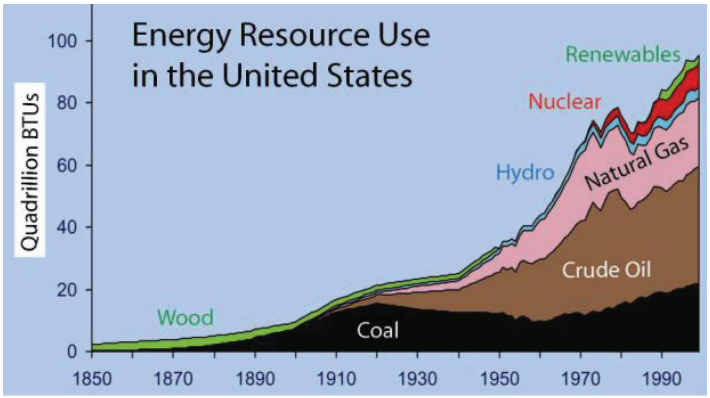
Reliable, accessible, and adequate supplies of energy and mineral resources are essential to sustain the American standard of living. The Nation faces increasing demand for energy and mineral resources, a growing dependence on resources imported from other countries, increasing pressure to consider alternative sources, and a need to minimize environmental effects associated with resource development and utilization. The Federal government, industry, and other groups need to understand the domestic and global distribution, 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. USGS data, information, and knowledge about present and future national and global energy and mineral resources provide impartial, robust scientific information that directly supports the DOI mission of protecting and responsibly managing the Nation's natural resources. Collectively, this information advances the scientific understanding of these resources, contributes to plans for a balanced and secure resource future, and facilitates the strategic use and evaluation of resources.



Statement of Strategic Science Direction

USGS *national and global assessments of the quantity, quality, occurrence, and availability of energy and mineral resources are conducted and updated in a comprehensive national, global, societal, and environmental context. Cumulative knowledge, long-term data, and new understandings of resource origin and assessment methodologies have improved the reliability and accuracy of assessments, even as the energy mix evolves and new requirements for rare and scarce materials used by the Nation emerge. USGS research and assessment methodologies provide the information necessary for understanding and evaluating how the occurrence, formation processes, extraction methods and use of priority energy and mineral resources influence landscape, water, climate, ecosystems, and human health*

Energy and mineral resources are the backbone of human food supplies, shelter, and economies. 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 lbs. of new non-fuel 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 about both domestic and international energy and mineral resources is therefore 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 must consider energy and mineral resource development in the context of multiple land-use options. State and local agencies and geological surveys, foreign governments, non-governmental organizations, and industry use energy and mineral resource information and research for their individual needs.



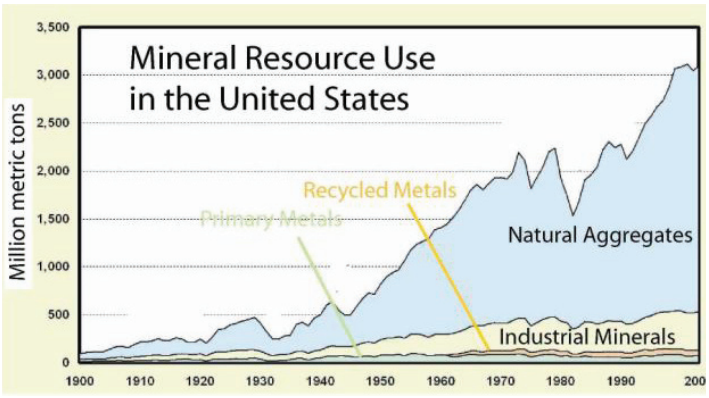


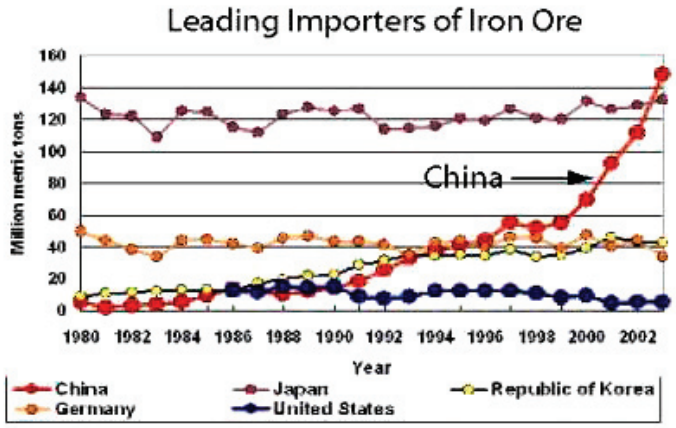
Figure: The use of energy (Left) and mineral (Right) resources in the United States has grown rapidly since 1940.
Source: National Renewable Energy Lab (Left); USGS Mineral Resources Program (Right).

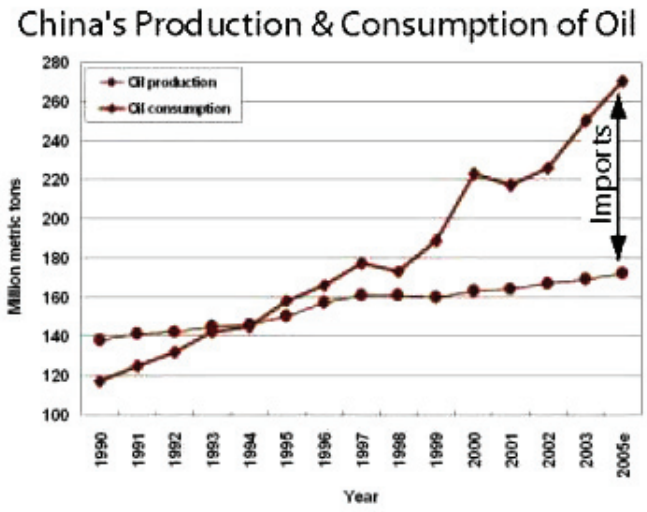
Two issues will dominate the availability of energy and minerals resources in the future: the impacts of globalization and the likelihood that environmental impacts from energy and mineral extraction and consumption will factor more strongly into how societies use resources. Modernization and international commerce have spurred the transport of goods among nations, resulting in a global economy. This globalization is increasing the competition for vital resources, many which are only available in foreign countries because of unique geological circumstances. Developing countries such as China 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 can also 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 coal-bed methane, gas hydrates, oil shale, 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 picture 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 impacts, 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, and increasing levels of atmospheric carbon dioxide. The Nation will have to balance the environmental impacts of development with 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.



Photo of tanker oil spill in Prince William Sound, Alaska.
USGS,Photo





Rapid economic growth in China has resulted in a rapid increase in net imports of iron ore and oil since the mid-1990s. China now also consumes more copper than the United States (Menzie et al., 2004).

In advancing this energy and minerals resource strategic science direction, the USGS builds on its strengths. USGS national and global energy and mineral resource assessments and baseline data are internationally recognized as authoritative. These geologic baselines and assessments are backed by continually updated earth-science research and explicitly account for uncertainty in characterizing resource endowment and quantifying undiscovered resources. In addition to geologic expertise, the USGS provides critical data on the supply, demand, and flow of mineral commodities on a global scale that are used throughout government and the private sector. This interdisciplinary expertise is essential for conducting needed research and assessments in existing and emerging natural-resource issues.

Strategic Focus

The continuing importance of USGS assessments of the quantity, quality, occurrence, and availability of energy and mineral resources, both nationally and globally, is heightened by growing globalization and concerns about environmental impacts of extraction and use of energy and mineral resources. Research that builds understanding of the Earth system in which resources occur is essential for improving the accuracy of assessments, particularly the potential for undiscovered resources. Equally important is building upon and maintaining long-term data sets for understanding trends in resource provenance, occurrence, and use. As the Nation's energy mix evolves, the USGS needs to continue to expand its research and assessment portfolio to include a larger suite of potential energy sources, including unconventional gas from coal and shale, gas hydrates, oil shale, geothermal resources, and uranium. As the energy mix diversifies, the research portfolio will change to reflect national and international trends. Research on sequestration of carbon in the subsurface will draw on our comprehensive expertise in the Nation's geologic underpinnings and understanding of fluid migration in geologic environments. Mineral-resources research needs to continue to anticipate evolving requirements for rare and scarce materials used in industry and defense. As new requirements emerge, USGS undertakes new research in order to provide geologic understandings, baselines, and assessments for these materials.

The USGS should take advantage of its multidisciplinary expertise to produce energy and mineral resource assessments that add environmental and societal perspectives to the national and international geological perspectives already provided. Energy and mineral resources must be understood in a broader context of the longer-term flow of materials through our economy and environment. Assessments should include how the occurrence, formation processes, and extraction methods for priority energy and mineral resources influence landscape, water, climate, ecosystems, and human health. For example, as the use of biofuels expands, the United States will require an assessment of the impacts to our Nation's biota, water, and lands, including the potential ecological effects of genetically modified plant species, current and expect-

ed future changes in water quality and quantity from biofuels production, and impacts on native plants, migratory birds, and wildlife from returning currently fallow lands to agriculture production.

The USGS will also need to analyze the complex environmental consequences of resource production and use and offer scientific strategies to understand the processes that result in adverse environmental impacts, including providing quantitative, scientifically sound data, models and information for informing ecosystem-based management practices. Developing this capability is particularly urgent for U.S. Federal lands, many which are managed within DOI, where competing demands for recreation, transport, leasing, conservation, and economic growth require decisions informed by science. The impacts of the most common waste product of carbon-based energy utilization, carbon dioxide, should also be included in considering the costs and benefits of resource utilization. Determining the feasibility of sequestering carbon dioxide in geologic and biologic repositories will require evaluation of the geologic, hydrologic, and ecologic characteristics of storage sites, along with economic considerations.



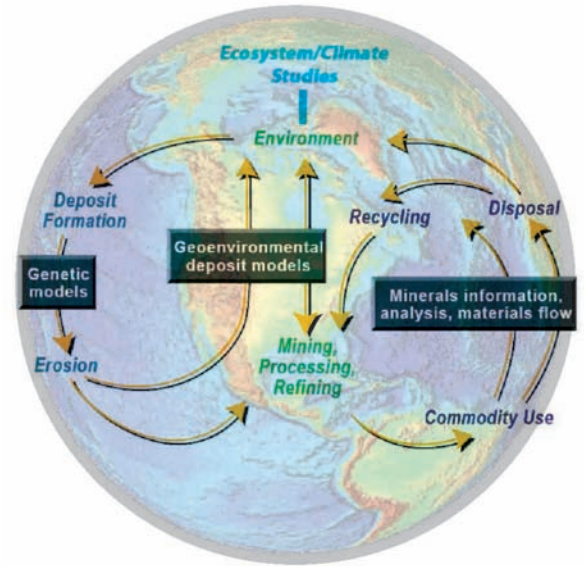
Rapid economic growth in China has resulted in a rapid increase in net imports of iron ore and oil since the mid-1990s. China now also consumes more copper than the United States (Menzie et al., 2004).

Strategic Actions

- 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.
- Develop a multidisciplinary approach to energy and mineral assessments that includes comprehensive accounting of the life cycle (materials flow) and environmental impacts of energy and mineral exploration, extraction, and use. Refine methodologies for doing this quantitatively.
- 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 utilizing 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.
- Develop procedures to evaluate and understand impacts 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.

As minerals have been the basis of breakthroughs in civilization, they are now essential for the present and future technological revolution. NRC, 2003.

USGS energy and mineral information and USGS national and global assessments of energy and mineral resources 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 incorporate environmental and materials flow expertise into studies and assessments. The quantified impacts of resource development, use, and recycling on ecosystems, landscapes, water, climate, and human health are an essential part of USGS studies and assessments. Working across disciplines, USGS science provides the knowledge base that facilitates integration of adaptive ecosystem management with energy- and mineral-resource policies on Federal lands as well as providing this information for a larger audience domestically and internationally. Assessments of previously unexploited mineral and energy resources, including renewable resources such as biofuels, are required to keep pace with evolving geologic understanding and technological developments. Thus, the energy and mineral strategic science of the USGS includes ecologic, hydrologic, and climate studies in addition to traditional geologic research and assessment.



Idealized minerals flow showing the life cycle of mineral-resource systems. The black boxes indicate some of the USGS roles in understanding the life cycle. Modified from USGS (2006).

Sequestration

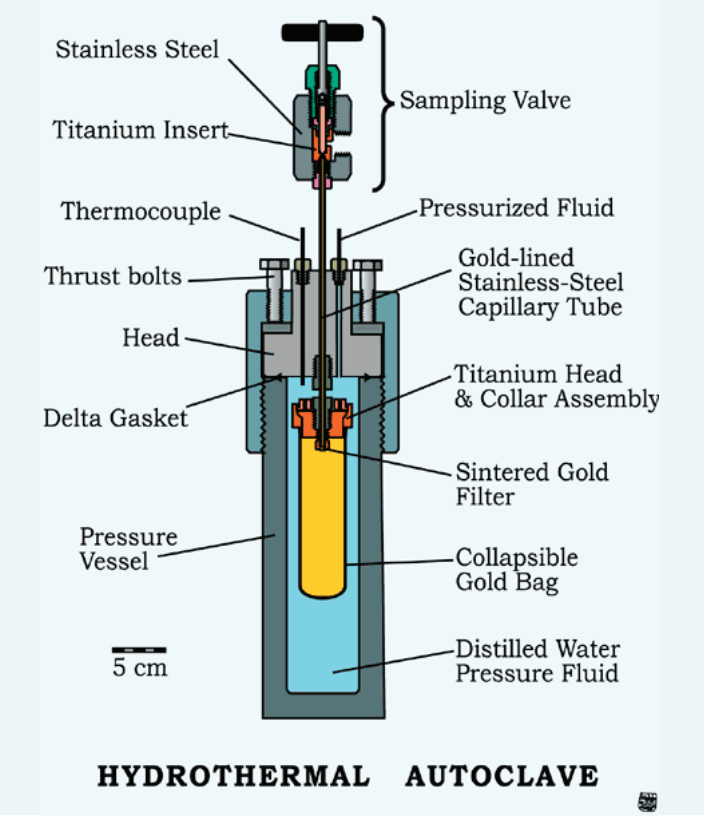
Sequestration of carbon dioxide, either geological or in ecosystem soil and biomass, is one strategy for limiting atmospheric accumulation of carbon dioxide from fossil fuel combustion. Globally, the amount of carbon dioxide that must be stored (billions of tons per year) in order to impact global climate is very large, raising fundamental questions that must be addressed so that stakeholders in Federal and State agencies, Congress, the public, and NGOs 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 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 verification of 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 waterways 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.

Carbon Dioxide Sequestration in Saline Aquifers



Experimental scheme (drafted by Bruce Rogers, WRCMG) for determining the solubility of carbon dioxide in water and brines, using a fixed-volume reaction cell (labeled "Pressure Vessel" in diagram) and rotating furnace to simulate the pressures and temperatures of deep aquifers. Fluid or gas samples are withdrawn with a high-pressure syringe and transferred to a coulometer for carbon dioxide analysis.

Potential Future 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 two decades, 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 hydrate 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 being used, as well as ones that may be used in the future.



Photograph of methane hydrate ignited.

Gas hydrate occurs 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).

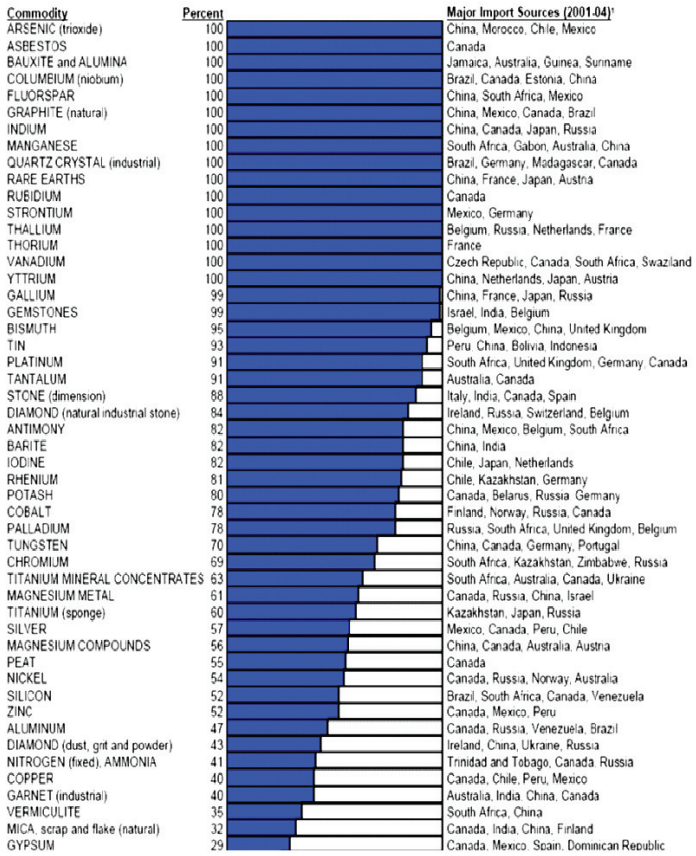
Materials and Mineral Resources for the Future

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, 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 will generate 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.

2005 U.S. Net Import Reliance For Selected Nonfuel Mineral Materials



Commodity	Percent	Major Import Sources (2001-04)[1]
ARSENIC (trioxide)	100	China, Morocco, Chile, Mexico
ASBESTOS	100	Canada
BAUXITE and ALUMINA	100	Jamaica, Australia, Guinea, Suriname
COLUMBIUM (niobium)	100	Brazil, Canada, Estonia, China
FLUORSPAR	100	China, South Africa, Mexico
GRAPHITE (natural)	100	China, Mexico, Canada, Brazil
INDIUM	100	China, Canada, Japan, Russia
MANGANESE	100	South Africa, Gabon, Australia, China
QUARTZ CRYSTAL (industrial)	100	Brazil, Germany, Madagascar, Canada
RARE EARTHS	100	China, France, Japan, Austria
RUBIDIUM	100	Canada
STRONTIUM	100	Mexico, Germany
THALLIUM	100	Belgium, Russia, Netherlands, France
THORIUM	100	France
VANADIUM	100	Czech Republic, Canada, South Africa, Swaziland
YTTRIUM	100	China, Netherlands, Japan, Austria
GALLIUM	99	China, France, Japan, Russia
GEMSTONES	99	Israel, India, Belgium
BISMUTH	95	Belgium, Mexico, China, United Kingdom
TIN	93	Peru, China, Bolivia, Indonesia
PLATINUM	91	South Africa, United Kingdom, Germany, Canada
TANTALUM	91	Australia, Canada
STONE (dimension)	88	Italy, India, Canada, Spain
DIAMOND (natural industrial stone)	84	Ireland, Russia, Switzerland, Belgium
ANTIMONY	82	China, Mexico, Belgium, South Africa
BARITE	82	China, India
IODINE	82	Chile, Japan, Netherlands
RHENIUM	81	Chile, Kazakhstan, Germany
POTASH	80	Canada, Belarus, Russia, Germany
COBALT	78	Finland, Norway, Russia, Canada
PALLADIUM	78	Russia, South Africa, United Kingdom, Belgium
TUNGSTEN	70	China, Canada, Germany, Portugal
CHROMIUM	69	South Africa, Kazakhstan, Zimbabwe, Russia
TITANIUM MINERAL CONCENTRATES	63	South Africa, Australia, Canada, Ukraine
MAGNESIUM METAL	61	Canada, Russia, China, Israel
TITANIUM (sponge)	60	Kazakhstan, Japan, Russia
SILVER	57	Mexico, Canada, Peru, Chile
MAGNESIUM COMPOUNDS	56	China, Canada, Australia, Austria
PEAT	55	Canada
NICKEL	54	Canada, Russia, Norway, Australia
SILICON	52	Brazil, South Africa, Canada, Venezuela
ZINC	52	Canada, Mexico, Peru
ALUMINUM	47	Canada, Russia, Venezuela, Brazil
DIAMOND (dust, grit and powder)	43	Ireland, China, Ukraine, Russia
NITROGEN (fixed), AMMONIA	41	Trinidad and Tobago, Canada, Russia
COPPER	40	Canada, Chile, Peru, Mexico
GARNET (industrial)	40	Australia, India, China, Canada
VERMICULITE	35	South Africa, China
MICA, scrap and flake (natural)	32	Canada, India, China, Finland
GYPSUM	29	Canada, Mexico, Spain, Dominican Republic

The Earth is not running out of critical mineral resources – at least for the near future – but the ability to explore for, and produce, those resources is being restricted in many regions by competing land use, as well as political, and environmental issues. Planet Earth, 2006,

Achieving the Vision:
New Methods of Investigation and Discovery

Background



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.

The nature of scientific collaboration is also changing. As the complexity of scientific questions grows, the need for 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.

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. 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 Strategic Science Direction

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 discipline, 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 science disciplines. Data integration within the USGS is a prerequisite for joining international efforts to develop a 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 they are 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 multi-dimensional data, and 3D visualization of complex problems.

Strategic Actions

- Incorporate planning for long-term data management and dissemination into fundamental science practices.
- Adopt and implement open data standards and contribute to the creation of new standards through international standards communities.
- Develop and implement a comprehensive scientific cataloging strategy that incorporates existing data sets resulting in an integrated science catalog.
- Develop a sustainable data-hosting infrastructure to support the retention, archive, 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.
- Foster greater cooperation among USGS programs to reduce data duplication 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.



USGS, Photo

Vision of 2017

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. 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 of significance to their own work.

"… a new age has dawned in scientific and engineering research, pushed by continuing progress in computing, information, and communication technology; and pulled by the expanding complexity, scope, and scale of today's research challenges…organizations, enabled by cyberinfrastructure, are increasingly required to address national and global priorities such as understanding global climate change, protecting our natural environment, applying genomics-proteomics to human health, maintaining national security, mastering the world of nanotechnology, and predicting and protecting against natural and human disasters, as well as to address some of our most fundamental intellectual questions such as the early formation of the universe and the fundamental character of matter." (Atkins and others, 2003).

Statement of Strategic Science Direction

The USGS will foster a culture and resource base that encourage 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. Three new and evolving technologies that are particularly relevant to the earth sciences are highlighted in this section. The challenges involved in developing the new technologies needed to address complex questions offer significant opportunities for collaboration, resource sharing, and leveraging with other Federal, State and local government agencies, academic and research institutions, non-profit 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 in the 1-100 nM size range) 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. NSF has predicted that nanotechnology will contribute about $1 trillion to our 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 impacts 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. The USGS is a leader in understanding and assessing environmental change. Change that results from application of nanotechnology has serious implications for water, ecosystems, and human health. The interdisciplinary science expertise of the USGS will be needed 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.

Geomicrobiology

Geomicrobiology (sometimes the broader term "geobiology" is used) is the interdisciplinary study of the interactions of (micro)organisms and earth materials (soils, sediments, the atmosphere, the hydrosphere, minerals, rocks, and so on). Microbes play a quantitatively dominant role in many Earth-surface processes, as noted by the American Academy of Microbiology: "Geological and biological activities are integrated, and they influence each other in profound ways. This interplay has shaped the Earth and all creatures on it." Modern molecular techniques (the use of nucleic-acid base sequencing technology to identify the phylogenetic groups present within mixed microbial populations) have significantly ex-



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



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



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.

tended 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 characterize the functionality of these microorganisms, the USGS should expand its current geomicrobiology research, building upon the excellent work already underway.

Environmental Sensing

Currently, more than 12 million remotely sensed images archived and maintained by the USGS are helping land managers and scientists address critical issues such as fire fuels mapping to assess fire risk potential, mapping the spread of invasive species, documenting habitat changes that affect biodiversity, and topographic mapping at high resolution along the coasts. The list of remote sensing sensors and applications grows every year, expanding the geographical context of USGS science. As DOI's landscape monitoring activities expand over the next decade to include more regional and national studies, traditional USGS site-specific data must increasingly be integrated into the larger geographical framework provided from space. Rapid advances in wireless, lightweight sensors portend the emergence of site-specific, regional, national, and global networks of environmental sensors. Such networks would greatly expand the scope, efficiency, and accuracy of environmental monitoring efforts of the Nation's natural resources and public lands. The next generation of sensors, deployed by the hundreds or thousands, could reduce the need for labor-intensive manual sampling of water, soil, air, vegetation, and wildlife. Remotely deployed sensors could make accurate and frequent measurements of environmental conditions in inaccessible places and transmit that information to a central location. One example of a sensor network—referred 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). Because motes are wireless, small, and relatively inexpensive, closely spaced arrays can be embedded in an environment to be monitored. Their combination of sensing facilities with a modicum of computation and radio networking onboard allows the motes to 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 can be developed to monitor a vast range of data types, including real-time stream chemistry, water quality and quantity, soil moisture, fire condition, the impacts of energy and mineral development, land-cover change, climate change (especially important in northern Alaska), and natural hazards. Biosensors are being developed that can monitor wildlife pathogens, migration of invasive species, and ecosystem health.



View of the area from which uranium was extracted, looking east toward Jungfrau Peak with goethite-coated waste-rock piles in foreground. The remains of an ore chute are visible just left of center near the site of an abandoned mine shaft.

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 in which 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.

"… a new age has dawned in scientific and engineering research, pushed by continuing progress in computing, information, and communication technology; and pulled by the expanding complexity, scope, and scale of today's research challenges…organizations, enabled by cyberinfrastructure, are increasingly required to address national and global priorities such as understanding global climate change, protecting our natural environment, applying genomics-proteomics to human health, maintaining national security, mastering the world of nanotechnology, and predicting and protecting against natural and human disasters, as well as to address some of our most fundamental intellectual questions such as the early formation of the universe and the fundamental character of matter." (Atkins and others, 2003).

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 break-through research techniques leading to new discoveries.

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." – Report of the NSF Blue-Ribbon Advisory Panel on Cyberinfrastructure, Revolutionizing Science and Engineering through Cyberinfrastructure, Daniel E. Atkins, Chair, 2003 (Atkins, Droegemeier et al. 2003)

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 in order 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" appears 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. http://paces.geo.utep.edu/research/geoinformatics/geoinformatics_explained_detailed.shtml

Conclusion:



A Light-Bulb Moment

Like much of humanity, the perspective of scientists was forever changed by the image of Earth beamed back to us from Apollo 8. The picture of our lone blue planet against the black background of space enlarged the frame of thinking of many sciences 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 non-scientists, too, have experienced their own light-bulb 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. 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 significant force capable of reshaping the face of the planet (Crutzen, 2002, Clark and others, 2005). The ability of humanity to use our understanding of human impacts on Earth's environment to help guide our use of the Earth towards positive outcomes is embodied in the term 'sustainability'. This concept of sustainability embodies 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)..



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

As the only integrated natural resources research bureau in the Federal Government, the USGS has a significant 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 our 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, even immigration, form a web of linked dependencies among environment, societies, and economies. The USGS must integrate its scientific capabilities 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 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." They 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. They 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 the environmental research system."

The USGS has already made strides to realize its potential. Integration of USGS science activities in order to provide the Nation with answers to the complex questions it faces is underway. In the preceding portions 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 policy makers 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 as input to models that characterize the present state of that portion of the Nation, use high-resolution projections of future climatic states to understand how the situation will change, and provide this information to decision makers 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.■

Appendix:

Charter for the Strategic Science Team

Strategic Science Team Members

Mark A. Ayers,
Water Resources
Jill S. Baron,
Biological Resources
Paul R. Beauchemin,
Office of Communications
Kevin T. Gallagher,
Geospatial Information Office [Co-Chair]
Martin B. Goldhaber,
Geology [Co-Chair]
Deborah R. Hutchinson,
Geology
James W. LaBaugh,
Water Resources
Roger Sayre,
Geography
Steven E. Schwarzbach,
Biology
Eugene S. Schweig,
Geology
***June Thormodsgard**,
Geography
Charles Van Riper,
Biology
William Wilde,
Administrative Policy and Services

*Replacing Mark De Mulder, who served on the team from February to May.

Strategic Science Team website:
[www.usgs.gov/science_strategy/default.asp]

Glossary of Terms

Acronyms

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