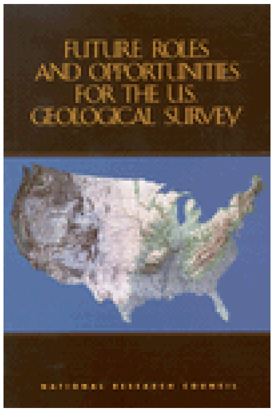

Future Roles and Opportunities for the U.S. Geological Survey

Committee on Future Roles, Challenges, and Opportunities for the U.S. Geological Survey, National Research Council

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FUTURE ROLES AND OPPORTUNITIES FOR THE U.S. GEOLOGICAL SURVEY

Committee on Future Roles, Challenges, and Opportunities for the U.S. Geological Survey
Commission on Geosciences, Environment, and Resources
National Research Council

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This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by George Hornberger, University of Virginia, appointed by the Commission on Geosciences, Environment, and Resources, and Alexander Flax, Consultant, appointed by the NRC's Report Review Committee, who were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Executive Summary

The U.S. Geological Survey (USGS) has adapted to the changing political, economic, and technical state of the nation and the world since it was established in the late nineteenth century. Over a period of more than 120 years, the USGS has evolved from a small group of scientists who collected data and provided guidance on how to parcel, manage, and use the public lands of the West to an agency comprised of thousands of scientists who conduct research and assessment activities on complex scientific issues at scales ranging from the local to the global. The USGS will no doubt continue to evolve and adapt to meet changing national needs. In fact, the recent integration of the National Biological Service and parts of the U.S. Bureau of Mines into the USGS presents an ideal opportunity to examine the agency's vision, mission, role, and scientific opportunities as the organization begins the early years of the twenty-first century.

The USGS recognized the need to adapt to changing demands when it asked the National Research Council (NRC) to undertake this study. The NRC formed a multidisciplinary committee of 16 experts (see Appendix A for biographical information on committee members) to address the following issues related to the future roles, challenges, and opportunities of the agency:

- major social needs that the USGS should address;
- significant emerging scientific and technical issues that appear especially important in terms of their relevance to the mission of the USGS;
- opportunities for improving partnerships and other cooperative arrangements with federal agencies, state agencies, universities, and the private sector;
- appropriate international functions of the USGS; and

- the balance of activities such as data acquisition and management, regional studies, and fundamental research.

This report is intended for diverse audiences. It contains advice for policy makers, managers, and scientists, as well as anyone with a broad interest in the future of the USGS. Chapter 1 is an introduction to the U.S. Geological Survey, including a discussion of its mission and vision statements. Chapter 2 provides a historical context for the chapters that follow. Chapter 3 identifies the driving forces in the early twenty-first century that stand to influence the USGS. Chapter 4 considers how the USGS might evolve to meet future national needs, and Chapter 5 discusses the administrative challenges the agency will face. The final chapter summarizes the conclusions and recommendations, most of which are given below. Throughout this summary and in Chapter 6, the committee presents its conclusions in italics and its recommendations in bold type.

A NATURAL SCIENCE[1] AND INFORMATION AGENCY

Over time, the USGS has evolved and built a solid foundation on which to plan its future. The recent integration of the Biological

[1] Throughout this report, the committee uses the term “natural science” to broadly frame the range of scientific issues that are addressed by the USGS. Natural science is defined as “any of the sciences (as physics, chemistry, or biology) that deal with matter, energy, and their interrelations and transformation or with objectively measurable phenomena” (Webster's Third New International Dictionary, 1986). The specific activities carried out by the USGS within the broad domain of “natural science” depend on the agency's mission, which in turn, is shaped by the missions and responsibilities of other federal and state agencies and a variety of societal and political forces. Examples of natural science disciplines currently within the purview of the USGS include geology, hydrology, geography, biology, and geospatial information sciences. The committee chose this terminology after considering many other alternatives because it is a relatively succinct term that is generally understood to encompass all of the major scientific issues that are addressed by the USGS. The use of a single broad term also serves to emphasize one of the committee's main points—the value of integrated, coordinated science when dealing with the types of multidisciplinary mission-relevant problems addressed by the USGS. The term also was chosen by the USGS to describe itself in its 1999 vision statement. However, it is important to clarify that the committee's use of the term “natural science” does not imply that the USGS mission should include all natural sciences. The USGS is A natural science agency—not THE natural science agency.

Resources Division (BRD) into the USGS has broadened the agency's mandate beyond its traditional focus on geological, hydrological and geographical sciences. The agency's current mission is to supply information that contributes to the effective management of a variety of natural resources and that promotes the health, safety, and well-being of the nation's citizens. This mission is fully appropriate for a federal science agency.

The USGS is a vitally important provider and coordinator of information related to critical issues in the natural sciences. As a result of changes in its external and internal environments, the USGS is evolving from an agency that was organized primarily to discover *what is out there*, to one that tries to understand *what is out there*, to one that tries to understand how *what is out there* works (i.e., process understanding). The questions posed to the agency increasingly call for multifaceted, analytical, and integrative investigations of complex processes and systems. By evolving into a natural science and information agency, the USGS will be able to play a leadership role in the elucidation of the geological, hydrological, geographical, and biological processes that are important to the nation and in the use of modern technology for the effective and efficient dissemination of this information.

In upcoming decades, many of the relevant societal needs (see Chapter 3) and emerging scientific opportunities (see Chapter 4) that the USGS should address will involve interactions among the natural environment, its biota, and people. *The USGS is well positioned, in terms of its information resources, technological capabilities, and range of professional expertise, to provide well-coordinated, comprehensive responses to priorities of society and science.* Interactions between the environment, its biota and people are highly complex and unpredictable, and solutions will require integrative, multidisciplinary approaches. **The USGS should place more emphasis on multi-scale, multidisciplinary, integrative projects that address priorities of national scale.** The committee recognizes that integration is difficult to achieve, especially in cases that require integration of natural and social sciences. However, failure to integrate inhibits the understanding of many natural science problems. Nevertheless, not all complex problems require a broad, integrative, multidisciplinary research framework; therefore, the choice of research framework must fit the specific problem. Problems that do not require a broad, integrative, multidisciplinary research framework should not be overlooked.

Effective information management will be critical to the future performance of the USGS. For the USGS, information management has two essential aspects. The first is the ability to assess the information needs of its customers and partners and to focus its resources on meeting those needs. The second is to effectively deliver and facilitate the use of reliable, high-quality data and information. **In the future, information management at the USGS should shift from a more passive role of study and analysis to one that seeks to convey information actively in ways that are responsive to social, political, and economic needs.**

MAJOR RESPONSIBILITIES

Consistent with the mission responsibilities and the technical and analytical capabilities of the participating agencies, it is desirable that the USGS provide national leadership and coordination in the specific programmatic areas for which it is responsible. In particular, **the USGS should provide national leadership and coordination in (1) monitoring, reporting, and where possible, forecasting critical phenomena, including seismicity, volcanic activity, streamflow, and ecological indicators; (2) assessing resources, including oil and natural gas (domestic and foreign), minerals, water, and biota; and (3) providing geospatial information.**

These activities include the following overlapping categories: surveys, monitoring, data analysis, research, information dissemination, and product generation. **Subject to the overriding requirement that the USGS fulfill its primary and high priority mission responsibilities, the committee believes that the USGS should continue to conduct each of these activities, but that the balance of activities should shift toward the value-added activities of data analysis, problem solving, and information dissemination.** A shift of balance does not mean that the USGS should reduce data gathering or long-term data collections, but that it should do more to interpret what the data mean and to make the data useful and accessible.

Monitoring, Reporting, and Forecasting

The value of the USGS's high-quality, long-term monitoring databases will increase as data are collected over extended periods of time and as they include a wider range of environmental variability and human influences. Long-term monitoring is expensive and time consuming, and it needs to be conducted carefully to provide the greatest amount of information return per dollar or time expended. The use of automated gauging and other remote monitoring devices, especially at remote sites, could make long-term monitoring more reliable and cost-effective, however. *Long-term databases are one of the USGS's most important contributions to the nation, and care must be taken not to disrupt them.*

For many years, the USGS has provided national leadership in communicating natural hazards information in a timely and understandable manner to multiple and diverse client groups. This information assists in protecting lives and property. The USGS is encouraged to play a stronger role in the disaster information community because the cost of natural disasters is increasing rapidly. Planning to minimize or avoid impacts is critical to reducing cost and human suffering. **It is critical that the USGS continues to exercise national leadership in natural hazards research and risk communication.**

The USGS should emphasize system modeling as a powerful tool for integrative science. The committee believes that the development of an enhanced capability in integrative system modeling can contribute to the future effectiveness of the USGS. Modeling and integration capabilities have to operate across divisions and feed into the administration of research programs.

Assessing Resources

The USGS has a national reputation for its work in the area of assessing energy, mineral, water, and more recently, biological resources. **The USGS should provide national leadership in the provision of natural resource information.** This will help the United States understand its future resource needs.

Providing Geospatial Information

The USGS is well positioned to provide the framework for a geospatial information depository and portal for the DOI and other federal departments, providing access to a range of natural science information and derivative products that can support effective decision making. In this role, the agency would be responsible for integrating and making interoperable the nation's disparate geospatial databases, for promoting and coordinating the continued development of the architecture for the National Spatial Data Infrastructure (NSDI), and for developing national mapping and product specifications. The USGS would also be responsible for making the geospatial databases available as understandable information products for public use and exchange.

NATIONAL AND INTERNATIONAL ROLES

As discussed in the previous section, the USGS is expected to address a variety of natural science issues of regional, national, and international importance. A major responsibility of the USGS is to serve as the science arm of the U.S. Department of the Interior (DOI). A number of DOI agencies (e.g., Bureau of Indian Affairs, Bureau of Land Management, Minerals Management Service, and National Park Service) rely on objective, nonadvocacy information from the USGS to inform their decision making. If this information were not available from the USGS, similar expertise would have to be developed within these agencies. **The USGS should ensure that science information is provided to DOI bureaus in an efficient and effective way. In turn, DOI leadership should ensure that USGS personnel and resources are utilized effectively in DOI decision making.**

The USGS also has significant responsibilities in support of other government agencies, states and local governments, tribes, industry, academic institutions, and the public. The USGS has to provide leadership and research on a scale appropriate to the problem being addressed.

Because many of the natural science issues within the purview of the USGS are global in nature, there is a compelling argument for the USGS to increase its international work on activities that meet mission objectives. **The USGS should develop international expertise in natural science problems relevant to the USGS mission.** Specifically, the USGS should perform a more vigorous role in pursuing foreign area and global studies that develop relevant natural science information in support of U.S. interests; increase technical assistance to foreign countries that are developing relevant natural science programs; and become more active in international activities to benefit the domestic programs and the international stature of the agency.

IMPROVING EFFECTIVENESS

In the future, the USGS likely will be asked to do more than in the past, and management of the agency will become increasingly challenging. The most fundamental challenge is one of magnitude: the size of the agency's human and financial resources relative to the demands for its information, services, and products. Yet the agency's management also has to address problems of substance, such as those associated with the need to develop an innovative, strategic, and balanced program of problem-specific and core research.

Priority Setting

The future of the USGS depends on its skill in identifying and setting rational and realistic priorities and its ability to reduce commitments of time and money that do not contribute to these priorities. Priority setting is not unknown at the USGS. In recent years, the USGS has prepared several strategic plans that establish broad priorities for the agency. However, there are three areas of concern in the USGS planning process that should be addressed. First, priorities stated in the strategic plans seem to have been developed internally with few mechanisms for refining them in response to input from customers. Second, in being responsive to its customers, the USGS should resist overpromising or overcommitting resources and, as a result, creating unreasonable expectations among its customers. Third, although responsiveness to customer needs should drive USGS priorities, this responsiveness should be in the context of the agency's national mission. **The USGS should develop a more effective process to assess and prioritize customer needs.**

An important aspect of priority setting for the USGS is to support and maintain a strong research program. Clearly, the USGS needs to undertake both problem-specific and core research to address current and emerging science issues. However, the USGS should give high priority to, and expand considerably, the core research agenda and commit the necessary resources to undertake the priority research. **The USGS should develop a research agenda that is balanced appropriately between problem-specific research and core research.** The research agenda should be developed through a formal and continuous strategic planning process.

External advisory committees are a potentially powerful instrument both for making a public agency responsive to public perceptions about its mission, goals, and achievements and for demonstrating its concern about being responsive to public needs. *As a major federal science agency, the USGS cannot afford to be without external advisory committees.* **The USGS should establish and make extensive use of external advisory committees**. Consideration should be given to the establishment of an agency-level external advisory committee and, where there are none now, external advisory committees at divisional and program levels as well.

Meeting Technical Needs

Without a new generation of talented scientists to replace departing staff, the ability of the USGS to answer the questions of the future will be compromised and the morale of the remaining staff will deteriorate. **The USGS should devote substantial efforts to recruiting and retaining excellent staff.** The rejuvenation of the work force should take into account the new areas of expertise that will be needed in the future.

Even if the professional staff of the USGS were to increase substantially in the future, the increase would probably be insufficient for the agency to accomplish its goals solely through in-house activities. As the problems that the USGS address become more complex and multidisciplinary, it is unlikely that the existing professional staff, even with major retraining, would be able to keep up with all of the new techniques and new knowledge required to carry out an ambitious program of integrative science. **To achieve its mission goals, the USGS will have to strengthen coordination and collaboration with other federal agencies as well as with states, academia, and industry.** At present, the USGS is insufficiently engaged with potential partners, especially related federal agencies whose work can enhance the ability of the USGS to achieve its mission objectives.

USGS cooperative programs with regional, state, and local governments as well as with other entities are stimulated by requests for scientific knowledge and data. Clearly, the reimbursable work of the USGS benefits many agencies. However, some of the reimbursable programs cause friction between the USGS and state and private entities, are viewed as conflicts of interest, and may divert the agency from its mission. The concerns, real or perceived, about competition between USGS and state surveys have to be addressed. **The agency should ensure that reimbursable contracts meet mission and strategic goals and that they do not compete unfairly with state or other organizations.**

Budget

The agency's budget, which has remained constant in real-year dollars for many years—despite a significant broadening of the agency's responsibilities—is a matter of concern. *Even with an agile, talented work force and a strong commitment to coordinated research efforts with other agencies and partners, it will be difficult for the agency to attain its future goals, especially those associated with a long-term core research program of integrative, multidisciplinary, relatively large research initiatives.* The USGS is being called upon to confront complex problems that are critical to human and ecosystem survival. The committee believes that long-term problems that pose increased risks to the nation, such as those associated with natural hazards, cannot be solved with the current level of funding. **As the agency's responsibilities continue to increase, its budget should be increased to a level commensurate with the tasks.** With an appropriate level of funding for practical research related to national needs, the USGS will be better able to fulfill its mission.

In addition, **future budget requests should contain sufficient flexibility to permit the USGS director to respond rapidly to new research challenges and opportunities.** A fraction of the agency's operating costs could be set aside for new initiatives analogous to a venture capital fund in the private sector.

CONCLUSION

Future demands placed on the USGS can be expected to exceed the capacity of its financial and human resources. To a degree, the demands can be met by strengthening coordination and collaboration with other federal agencies, universities, and private industry and by creating a more agile and flexible work force. However, unless significant actions are taken soon to address human and financial resource issues, the USGS may be unable to meet all of its mission goals, respond rapidly to new challenges and opportunities, and transition toward becoming a natural science and information agency.

The USGS has established a good foundation on which to plan and build a successful future. In the future, the USGS will be asked increasingly to deal with questions about how natural systems affect human systems and how human actions modify natural systems. If it broadens the basis of inquiry to include integrative approaches involving natural and human sciences and becomes proficient at information management, the USGS will more fully realize its potential to provide the scientific information and knowledge essential to the future well-being of society.

1

Introduction

In a time of drastic change, it is the learners that inherit the future. *Eric Hoffer*

For more than 120 years, the USGS has provided sound science information and knowledge to the federal government and other customers and stakeholders. It has adapted repeatedly to meet new challenges and changing societal needs. If the past is prologue, the agency will adapt to significant scientific, technical, economic, and political changes in the future. By striving to be at the forefront in identifying societal needs and conducting the scientific work necessary to meet these needs, the USGS will maintain or enhance its value as the nation's primary provider of, or coordinator for, information and knowledge related to critical issues in the natural sciences[1]. It is a

[1] Throughout this report, the committee uses the term “natural science” to broadly frame the range of scientific issues that are addressed by the USGS. Natural science is defined as “any of the sciences (as physics, chemistry, or biology) that deal with matter, energy, and their interrelations and transformation or with objectively measurable phenomena” (Webster's Third New International Dictionary, 1986). The specific activities carried out by the USGS within the broad domain of “natural science” depend on the agency's mission, which in turn, is shaped by the missions and responsibilities of other federal and state agencies and a variety of societal and political forces. Examples of natural science disciplines currently within the purview of the USGS include geology, hydrology, geography, biology, and geospatial information sciences. The committee chose this terminology after considering many other alternatives because it is a relatively succinct term that is generally understood to encompass all of the major scientific issues that are addressed by the USGS. The use of a single broad term also serves to emphasize one of the committee's main points—the value of integrated, coordinated science when dealing with the types of multidisciplinary mission-relevant problems addressed by the USGS. The term also was chosen by the USGS to describe itself in its 1999 vision statement. However, it is important to clarify that the committee's use of the term “natural science” does not imply that the USGS mission should include all natural sciences. The USGS is A natural science agency—not THE natural science agency.

challenge that will require energetic leadership and inspired strategic planning within the agency, significant input from the scientific community and user groups, and the strong support of elected officials.

The USGS is at a critical juncture in its history. The context for federal science and technology policy is changing in the post-Cold War years (HCS, 1998). Federal investments in science and technology are being linked closely to broader national goals as the world becomes more crowded, the physical and biological environment more threatened, natural resources more depleted, the global economy more competitive, and world events more interconnected. These trends raise concerns for the health of the planet, the quality of human life, and therefore the nation's prosperity and security.

To address these challenges, science in general and federal science in particular must become more responsive to the needs of society (HCS, 1998). After World War II and the onset of the Cold War, scientific research became focused on the threat of Soviet expansionism and global war, but the collapse of the Soviet Union and the rise of a global information economy have redefined the role of science. This involves a stronger orientation toward application to complex, integrated problems spanning local to global scales. In this new social contract with the nation, science must respond to national and global needs by providing information, explanatory theories, and decision support mechanisms to user groups.

Changes in the relationship between science and the federal government are taking place against a bureaucratic structure and talent pool that no longer apply in the post-Cold War years. Federal agencies are changing their structures to increase their sensitivity and responsiveness to demands from outside science. They are redefining their missions and reallocating resources to increase efficiency, deal with new technologies, promote integration of diverse approaches, and change their emphasis from outdated areas to newly defined ones.

The USGS is uniquely positioned to respond to the new challenges. Steeped in a long tradition of high-quality basic and applied science, the agency is evolving into an integrative organization with a clearly defined mission involving a combination of the sciences of geology, hydrology, biology, and geography. The formal objectives of the DOI and the strategic plans of the USGS include a new vision for integrated science: "The USGS will reach across organizational boundaries to take greater advantage of the most useful skills, data, and technology and apply them to a more integrated, multidisciplinary approach to scientific problem solving (USGS, 1996a)."

However, recent years have been tough for the agency. At a time when the USGS was engaged in a process of continuous strategic planning, restructuring, and selective reductions in work force, Congress considered the elimination of the agency. Former USGS Director, Gordon P. Eaton, summarized the threat to the organization as follows (USGS, 1996a):

> Political, economic, and societal forces that coalesced in 1995 threatened the very existence of the U.S. Geological Survey—an organization that we long believed to be vital and important to the well-being of the American people and to the advancement of the earth sciences. The near abolishment of the USGS was averted largely by our customers. It was their understanding of the value of our work and their demand that we continue to provide our products and services that ensured our near-term survival. One lesson learned from the threat was that the viability and prosperity of the USGS depend on our ability to demonstrate the relevance of our work to society at large.

In a remarkable turn of events, Congress decided not to eliminate the USGS but instead gave it new responsibilities. In 1996, consolidation of the National Biological Service and portions of the former U.S. Bureau of Mines with the USGS created a broader and more comprehensive organization. Thus, the USGS has a singular opportunity to increase its value to the nation by conducting integrated physical and biological research. As a more inclusive science agency, it has the capacity to take a national leadership role in conducting studies to develop information and knowledge on the web of relationships that constitute the air-water-human-land system (Bohlen et al., 1998). To respond effectively to the emerging challenges of the twenty-first century, the nation needs access to objective, dependable information about the many science issues that affect human welfare. Often global or international in nature and mostly occurring in the near-surface environment, these issues include the following:

- discovery, use, and conservation of resources—fuels, minerals, soils, plant and animal life, and water;
- characterization and mitigation of natural hazards—earthquakes, volcanic eruptions, floods, droughts, contamination by naturally occurring toxic materials, landslides, subsidence, and other ground failures;
- stewardship of the environment—ecosystem management, adaptation to environmental changes, remediation or moderation of adverse human effects;
- support of commercial and infrastructural development—agriculture, energy systems, communications and transportation, utilities, settlements and other structures; and
- terrestrial surveillance for national security—precise positioning, remote sensing, mapping (NRC, 2001).

As decision makers at all levels, from the U.S. Congress, to a business, to a local community, consider these and other needs of society, they will call extensively on the expertise available at, and data and information created by, the USGS. Consequently, the USGS must be prepared to respond to their needs in a timely and understandable manner.

VISION AND MISSION OF THE USGS[2]

The USGS's emphasis on activities that are relevant to society's needs is captured in its formal science vision and mission statements (USGS, 1999a).

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

[2] The vision and mission language changed slightly between the published 1997 and 1999 strategic plans. However, one conspicuous change involved the way the agency described itself. The USGS is an earth science agency in the 1997 plan and a natural science agency in the 1999 plan.

Mission. The USGS serves the Nation by providing reliable scientific information to:

- describe and understand the Earth;
- minimize loss of life and property from natural disasters;
- manage water, biological, energy, and mineral resources; and
- enhance and protect the quality of life.

The USGS addresses its science mission by arraying its programs under four major themes—environment, resources, hazards, and integrated data and information management—and by concentrating on two goals:

1. Hazards mission goal: Provide science for a changing world in response to present and anticipated needs, focusing efforts to predict and monitor hazardous events in near-real and real time and to conduct risk assessments to mitigate loss (USGS, 1999a).
2. Environmental and natural resources mission goal: Provide science for a changing world in response to present and anticipated needs to expand our understanding of environmental and natural resource issues on regional, national, and global scales and enhance predictive or forecast modeling capabilities (USGS, 1999a).

These mission goals support DOI's goal No. 4, “Provide Science for a Changing World.” They are consistent with the primary responsibilities of the USGS.

STRATEGIC CHANGE AT THE USGS

In its quest to accomplish its scientific mission and increase customer involvement, the USGS embarked on a major program to improve operations in 1999. The director of the USGS, Charles G. Groat, charged his Strategic Change Team (SCT) to focus on the mechanisms that would facilitate the transformation of the agency from a cluster of loosely linked organizational units to a tightly interactive community with one mission and one message. If fully implemented, the recommendations of the SCT will transform the organizational culture of the agency. The SCT's vision of the twenty-first century for the USGS follows (USGS, 1999b):

> The Strategic Change Team envisions a flexible and responsive USGS that is a recognized leader in providing natural sciences information, knowledge, and tools. Customers, partners, and USGS employees and managers will form an interactive community with a common passion to create, share, and use knowledge of the natural sciences to solve society's complex problems.

To realize this vision, the SCT made several recommendations including improvements in the efficiency of the agency's administration by streamlining bureau functions, the promotion of an agency-centered perspective, and a strong move toward regionalization to bring the agency's leadership and programs in proximity to customers.

STUDY AND REPORT

Change is difficult for any established organization such as the USGS; yet it is essential for the maintenance of relevance and vitality. At this critical juncture in USGS history, independent advice about the agency's vision, mission, role, and scientific opportunities can provide insight to help guide the organization in the early years of the twenty-first century. Recognizing the need to adapt to changing demands in the future, the USGS invited the National Research Council (NRC) in 1997 to conduct a comprehensive study on the evolution of the agency to meet future needs. Accordingly, in 1998 the NRC's Commission on Geosciences, Environment, and Resources formed a committee to conduct this study. The committee consists of a multidisciplinary group of 16 experts from academia, industry, and government. Its members have recognized expertise in the disciplinary units of the USGS and in related fields such as planning and public policy, ecology, public health, toxicology, and social sciences. (Brief biographies of committee members are provided in Appendix A.)

The committee was charged to consider the following:

- major societal needs that the USGS should address;
- significant emerging scientific and technical issues that appear especially important in terms of their relevance to the mission of the USGS;
- opportunities for improving partnerships and other cooperative arrangements with other federal agencies, state agencies, universities, and the private sector;
- appropriate international functions of the USGS; and
- the balance of activities such as data acquisition and management, regional studies, and fundamental research.

This broad charge stimulated and shaped the committee's deliberations that form the basis of this report, which is intended to provide strategic guidance to the USGS about its future.

To address the charge, the Committee on Future Roles, Challenges, and Opportunities at the U.S. Geological Survey held six meetings between June 1998 and July 1999. These meetings included presentations from the staff of the USGS, briefings from representatives of state and federal agencies, and discussions with leaders in the private sector. The committee also received input from professional organizations and many individuals (Appendix B). As background, the committee reviewed relevant USGS documents and materials through 1999, examined pertinent NRC reports, and read other technical reports and appropriate published literature.

This report is intended for multiple audiences because the USGS does not operate in isolation. It contains advice for an audience of policy makers, managers, and scientists, as well as anyone with a broad interest in the future of the USGS. Chapter 2 provides a historical context for the chapters that follow. Chapter 3 sketches the driving forces in the early twenty-first century that stand to influence the USGS. Chapter 4 considers how the USGS might evolve to meet future national needs, and Chapter 5 discusses the administrative challenges the agency will face. The final chapter summarizes the conclusions and recommendations that stem from this study.

2

The Past and Present as a Prologue

Established by Congress in 1879[1], the USGS was charged with the responsibility of classifying the public lands, and examining the geological structure, mineral resources, and products of the nation. Adaptation has been a common theme throughout USGS history, even though its general mission and responsibilities have remained remarkably unchanged. Throughout its history, the agency has adapted itself to changing conditions and needs, and has demonstrated repeatedly the value to the nation of an independent federal agency whose primary purpose is to provide reliable and unbiased science data, information, and knowledge.

The purpose of this chapter is to distill the historical threads that influenced the development of the USGS (Rabbitt, 1979, 1980, 1986, 1989). It traces events that led to the creation of the agency, discusses the evolution of the institution in relation to its external and internal environments, and describes what it is now. The chapter also shows that the agency has faced challenges and that lessons can be learned from the past to make the USGS stronger in the future.

THE PUBLIC DOMAIN AND THE USGS

A century before the establishment of the USGS, most of the nation's people and land were on the eastern seaboard and the Piedmont. Then the frontier was the Appalachians. Beyond the 13 colonies was a vast area of public lands. After the Louisiana Purchase in 1802, the federal government

[1] The USGS was formed later than 20 foreign geological surveys and many U.S. state geological surveys. For example, the British Geological Survey was created in 1835, the Geological Survey of Canada in 1842, and several state geological surveys in the 1850s (Eaton, 2000).

promoted the settlement of the public domain, and the nation's population center shifted steadily westward.

The key to settlement expansion was transportation. Before 1830, the location and spread of American settlements was influenced by sail and wagon technology. Eastern seaports and growing centers on the inland waterways were preeminent. From the 1830s to the 1870s, the steamboat and the iron-based railroad were the principal innovations, and ports with large railroad hinterlands grew to dominance. In the 1870s, the East still had most of the nation's cities and population and most of the private and cultivated land. The West, especially west of the Mississippi, which had most of the public lands, was scantily settled. However, the Mississippi had been bridged, and in 1869 the golden spikes made the final link in the transcontinental railroad connecting the East and California.

After the Civil War, pressure mounted for more knowledge about the natural resources of the West as the pace of territorial expansion, technological innovation, and burgeoning industrialization quickened. The need for an increasing and continuous flow of resources to fuel the Industrial Revolution led the federal government for the first time to spend money on scientific investigations. Four congressionally authorized and funded geographic and geologic surveys of the West were conducted from 1867 to 1879. These surveys —headed by Clarence King, George M. Wheeler, Ferdinand V. Hayden, and John Wesley Powell—often are referred to as “The Great Surveys.” Parties of scientists, surveyors, photographers, and journalists made these regional surveys. The survey reports made major contributions to our understanding of the West. King's survey, for example, explored the land along the fortieth parallel through which the first transcontinental railroad was built. Some scientists criticized the practical nature of the regional surveys.

Laws such as the Homestead Act of 1862 and the General Mining Law of 1872 (NRC, 1999a) were passed by Congress to encourage settlement of the nation's interior and to facilitate the extraction of mineral, energy, and other resources to power industrialization. The Homestead Act allowed persons to obtain 160 acres of public land free by proving residency on the land for five years. The General Mining Law allowed persons to stake claims on the federal lands of the western United States without payment of royalty to the federal government and without acquiring title to the land itself. Consequently, the development of natural resources over much of the nation proceeded in an uncoordinated and at times thoughtless fashion that led eventually to calls for more prudent management and stewardship. Despite the prevailing perception of inexhaustible natural riches, there was some support by individuals and groups for the conservation of resources. As early as 1872, the same year as the mining law, Congress passed legislation that led to the establishment of Yellowstone as a national park.

In the 1870s, the nation went into recession. By 1878, only the King survey had completed its reports, and the inexpensive completion of the remaining surveys became a significant consideration. Congress turned to the National Academy of Sciences (NAS) and asked it to prepare a plan for surveying and mapping the territories of the United States with the best results at the least cost. As suggested by the NAS study, federal geology was consolidated into a single agency, the USGS, and it was placed in the DOI in 1879 (Sidebar 2.1).

Clarence King, who became the first director of the USGS (Sidebar 2.2), made the agency one of applied geology, emphasizing mining. He organized the agency to demonstrate the utility of science at a time when an understanding of earth resources was of paramount importance to the development of the United States. King's scientists went to the major mining districts of Colorado, Nevada, and California. Their reports provided guidance to miners on where to look for new ore deposits and how to extract more ore from the deposits. They also helped investors in the mining industry to select their prospects. King wanted the work of the agency to include the whole country, but the DOI, uncertain about Congress' mandate, confined this work to the public lands. Two years later and under the direction of John Wesley Powell, the agency's purview was extended to include the eastern states as well as the West. And in 1897, the USGS did its first foreign work, in conjunction with the planning and design of the Panama Canal.

THE EVOLUTION OF THE USGS

The USGS evolved in concert with changes in its external and internal environments. It developed with changes in society, changes in the relationship between science and society, and changes within the institution itself. As a result of these changes, the USGS evolved from an agency that was organized primarily to discover what is out there (surveying and data collection), to one that tries to understand what is out there (survey and data synthesis), to one that tries to understand how what

SIDEBAR 2.1

MAJOR WORLD AND U.S. EVENTS THAT AFFECTED THE USGS

Date	Event	USGS Programs and Structure
1879		USGS established
1886	Drought in western U.S.	Stream gauging started
1891		Geologic and Topographic Branches established
1897	Forest Management Act	
1898	Planning for Panama Canal	First USGS international work
1900		Mining and Minerals Resources Division established Petroleum and Coal Program established
1905		Forest service derived from USGS
1906		Bureau of Reclamation derived from USGS
1909	Henry Ford introduces Model T	
1910		Bureau of Mines derived from USGS
1914	World War I started	
1917		Strategic Minerals Program started
1920	Federal Water Power Act passed	USGS responsible for streamflow records
1929	Depression began	
1930		Federal Power Commission derived from USGS
1934	Dust Bowl drought	Grazing Service derived from USGS
1941	Pearl Harbor attacked	
1943		Strategic Minerals Program expanded
1945	Atomic Bomb dropped	
1946		Bureau of Land Management established Atomic Energy Commission established
1950	Korean War began National Science Foundation established	
1957	Sputnik launched	
1961	NASA established	
1962		Marine Geology Program established
1963	Astrogeology Program established	
1969	Apollo Lunar landing	
1970	National Environmental Policy Act (NEPA)	Widerness Studies started

1970	Environmental Protection Agency Established	
1971		Earth Resources Observation Systems (EROS) Data Center established
1972	LANDSAT-1 launched	
1973		NOAA and USGS Earthquake Programs merged
1974	Atomic Energy Commission abolished and replaced by the Energy Research and Development Administration and the Nuclear Regulatory Commission	
1980		National Mapping Division established
1982		Minerals Management Service derived from USGS
1983	Exclusive Economic Zone	
1986	Wetlands Act passed	
1995	U.S. Bureau of Mines abolished	Minerals Information Function started
1996		Biological Resources Division established

NOTE: NASA National Aeronautics and Space Administration
NOAA National Oceanic and Atmospheric Administration

SIDEBAR 2.2

DIRECTORS OF THE USGS

Clarence King	1879-1881
John Wesley Powell	1881-1894
Charles Doolittle Walcott	1894-1907
George Otis Smith	1907-1930
Walter Curran Mendenhall	1930-1943
William Embry Wrather	1943-1956
Thomas Brennan Nolan	1956-1965
William Thomas Pecora	1965-1971
Vincent Ellis McKelvey	1971-1978
Henry William Menard	1978-1981
Dallas Lynn Peck	1981-1993
Gordon P. Eaton	1994-1997
Charles G. Groat	1998-present

is out there works (process understanding).

Changes in Society

Profound changes have taken place in American society in the years since the establishment of the USGS.

1879 to 1920

During these years, railroads replaced inland waterways as the major determinant of American settlement growth and expansion. Coal supplanted wood as the main energy source. Surfaced road development and the use of petroleum began in the late nineteenth century. Street and cable cars were introduced; steel, chemical, and electrical industries emerged; and the telephone was invented. By 1920, technological innovations had transformed the United States from a rural to an urban-industrial nation (Figure 2.1).

To meet the needs of the nation, USGS scientists provided information on mineral deposits, sources of commercial energy, and land and water resources. Of crucial importance was information on mineral and energy resources for industry and national defense. By the end of World War I, the agency was the nation's main source of data and information on critical earth materials.

1920-1975

Between 1920 and 1975, the national urban and regional system received a major jolt. People moved from cities to suburbs, from rural to urban areas, from the center of the country to both coasts, and from the Frostbelt and Rustbelt states to the Sunbelt and other amenity areas. Concerns about the environment and resources were being voiced as early as the 1960s. Inspired by sources such as Rachel Carson's (1962) *Silent Spring* and construction of the Glen Canyon Dam, more Americans than hitherto started to view earth as fragile, rather than subjugable. Resources became entities to be managed. Americans also were shocked when the Organization of Petroleum Exporting Countries (OPEC) quadrupled oil prices in 1973. They were reminded that the nation, a neighborhood in an increasingly integrated and unstable world, was highly dependent on foreign sources of oil and the many other essential materials that sustain a modern society.

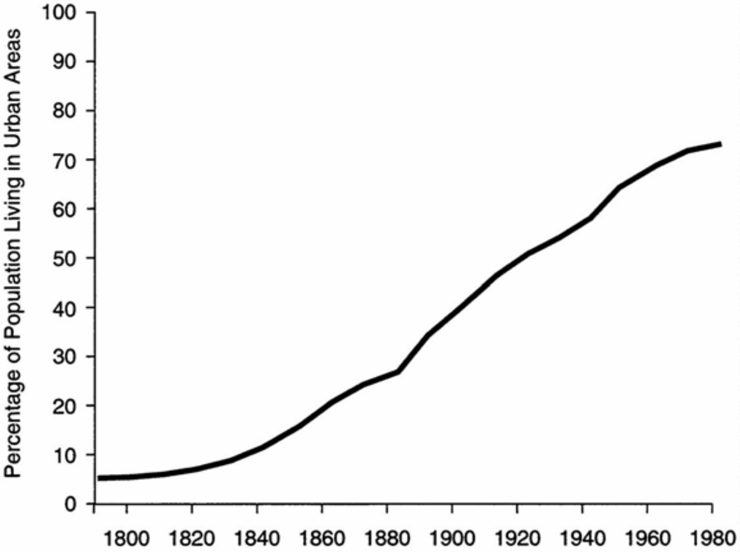


Figure 2.1 Urbanization of the United States between 1790 and 1980.
SOURCE: Berry, 1991, p. 32.

In this period, the USGS exercised leadership as the provider of critical earth science information. It produced accurate, detailed geologic and topographic maps that were needed for the appraisal and analysis of resources; for industrial development, land reclamation, utility projects, and highway construction; and for improving regional urban planning and decision making. It collected and distributed streamflow, groundwater level, water hazard (e.g., flood frequency), and water quality data to support the work of water resource managers, emergency management officials, and engineers. The agency also continued to provide basic geologic information to facilitate the growth of the built environment; inventory important materials such as building stone, sand, and gravel; and obtain information, both domestic and foreign, about essential mineral and energy resources.

In addition to surveying and data collection, management, and dissemination, USGS scientists advanced understanding through research. Initially, they applied their expertise to studies of energy and resource development. Later, they added to their portfolio other problems of human existence such as those related to conservation, environmental contamination, and natural hazards. For example, the agency developed a program of research in the 1960s on coastal areas, whose counties were becoming the most densely populated and developed in the nation. This research enhanced the public's awareness of chronic events such as beach erosion, the fragility of coastal lowlands, the intrusion of salt water into aquifers, and the problems of pollution and waste disposal in marine environments. Also in the 1960s, the USGS became a focus for research on the causes, mechanics, and effects of earthquakes and on the development of methods to determine where and when earthquakes will occur and predict their potential severity to reduce the loss of life and property. This research was initiated at a time when metropolitan areas of the earthquake-prone western United States were growing rapidly.

1975-Present

During the last 25 years, American society confronted dramatic economic, political, and environmental changes. The United States became more dependent on imported mineral and energy raw materials, as well as many other commodities and industrial products. Satellite and electronic technologies produced a major information explosion and brought an unprecedented acceleration of global interaction. The jet age increased sharply the frequency of personal contact. The communications revolution accelerated the migration of the U.S. population to the suburbs, the South, and California. Political and economic reforms in the former Soviet Union and Central Europe ended the Cold War, and market reform and democratization in many areas resulted in generally open trade. Evidence of ozone depletion increased awareness of global environmental change, and signs of rapid changes in the world's physical environment (e.g., land and water pollution, deforestation, soil erosion) spawned widespread concern about the achievement of economic and environmental sustainability (NRC, 1999b).

The momentous changes of this period had a major impact on the USGS. The agency continued with traditional pursuits such as monitoring streamflow and water quality, and conducting energy, volcano hazard, and earthquake hazard assessments. However, new techniques and technologies aided this work. For example, technological change produced a revolution in the agency's capability to monitor and analyze some of earth's resources and aspects of its physical and biological condition from air-borne and orbital platforms. The remotely sensed data are stored, processed, and distributed by the USGS's Earth Resources Observation Systems (EROS) Data Center. Computerized cartography enabled the agency to synthesize EROS Data Center data and other data into informative, easily interpreted maps that can be used for studying a wide range of problems such as volcanic eruptions, oil spills, floods, coastal storms, and nuclear reactor accidents. Moreover, geographic information systems (GISs) provided the opportunity for the USGS to store, retrieve, display, and process spatial data in ways not previously imagined.

Increasingly, USGS scientists were called upon to deal in innovative ways with difficult ecological and environmental problems at scales ranging from the local to the global on issues such as livable and safer communities and the sustainability of resources. The USGS recognized that interdisciplinary work is required to understand complex processes relating to the air-water-human-land system. It also recognized that this work requires the collaboration of scientists from many disciplines both within the agency and from other agencies.

Changes in Relationships Between Society and Science

The nation needs an independent agency that is separate from regulatory agencies to develop and provide data, information, and knowledge about critical issues in the geological, hydrological, geographical, and biological sciences. However, support for USGS activities has waxed and waned depending on societal needs and circumstances.

Invariably, Congress has been a strong supporter of the work of the agency during geopolitical crises. Two world wars in the twentieth century convinced society of the contributions of science to the security and prosperity of the nation. USGS topographic maps yielded indispensable information. The agency's investigations and assessments of critical earth materials to meet national needs were deemed essential. During the early Cold War years, when the United States felt threatened by Soviet expansionism, there was considerable support for the agency's uranium program. When national economic security or defense was not a critical issue, Congress has been more likely to question the relevance of the agency's work.

The debate on the relevance of USGS activities has often come down to the nettlesome issue of basic versus applied research. In the early years of the USGS, Congress appreciated King's emphasis on the applied approach but disliked Powell's emphasis on basic inquiry. Consequently, the USGS's operating budget was greater under King than it was under Powell. The third director of the USGS, Charles Walcott, argued for a reasonable balance between basic and applied research. Although he agreed that the USGS existed to bring earth science to the service of society, Walcott argued that fundamental research is one of the most important tools that makes this possible. During the term of the fourth director, George Smith, the pendulum swung in favor of applied research. Smith transferred scientists from positions of basic science to the well-funded land classification program. Smith's action prompted some scientists to leave the organization. The alternating emphases on basic science and applied research in the first half-century of the agency's existence continued after World War II.

From the end of World War II to the end of the Cold War, federal funds were generously available to support science. The USGS responded by setting its own research agenda with relatively little intervention from government. A culture of entitlement arose among some USGS scientists, who adopted the academic philosophy that what matters is the quality of scientific achievements and not the choice of scientific problems to be solved. Although the USGS remained broadly focused on shifting national needs, this postwar period was, in general, a time of passive introspection at the USGS.

Until the National Science Foundation (NSF) was established in 1950, federal funds to support earth science research went to the USGS almost exclusively. With the addition of NSF funding, university scientists became even more active in basic earth science research. The rise of the NSF diluted the preeminence of the USGS in earth science research.

Subsequently, other federal agencies added earth science to their portfolios. In the early 1960s, NASA became engaged in earth science research and technology. The Department of Energy (DOE) developed earth science expertise in the 1970s to address geothermal power, nuclear weapons testing (containment), and the need to dispose of nuclear waste. The USGS became challenged to define and articulate its role and capabilities with respect to other federal agencies.

With the end of the Cold War, American society became increasingly skeptical about the value of science unless it demonstrably led to improvements in the human condition. Thus, science was being held accountable for its payoffs during a period of scarce public funds for scientific work. In the early 1990s, Congress began to exert its influence on the USGS "through limited funding growth and directed funding" (Eaton, 2000). Societal forces nearly succeeded in abolishing the USGS in 1995, when lawmakers wanted to reduce the size and scope of government. According to Gordon Eaton (2000):

> As a long-standing institution that had grown to look inward as it planned its future, the USGS occupied a conspicuous place on a hit list of allegedly unresponsive or irrelevant agencies that some in Congress wanted to eliminate. Absent concern for or understanding of the potential effect of such a move, these policymakers argued that work of the USGS was basically finished and that elimination of the agency would free federal funds, help lower the federal deficit, and facilitate tax cuts.

Instead of being eliminated, the USGS was given added responsibilities; it absorbed the National Biological Service and part of the Bureau of Mines. The agency survived because its customers recognized "the practical and meaningful value of its work. These constituents asked Congress to allow the USGS to continue its work to provide the knowledge, services, and products that they and the general public required" (Eaton, 2000).

The challenges that the USGS faced in the recent past ought to make it a more outward-looking and dynamic agency in the future. It has learned at least two sobering lessons from its close encounter with extinction. First, the federal government controls the role of federal science; it assigns the funds. Second, USGS scientists must define and explain science's societal payoffs if they are to continue to be funded.

Fortunately, the agency has a long history of close links between research and social issues. This experience can serve the agency well under the new conditions for the federal support of science.

Changes Within the USGS

The USGS has experienced a number of organizational changes in its history. These changes reflect the needs of the times, politics, and the interests of the directors themselves. For example, under King's watch, the USGS had two divisions: Mining Geology and General Geology. To meet the needs of a rapidly industrializing nation, his emphasis was on mineral exploration. Other subjects, including topographic mapping, provided support for his primary mission. Powell emphasized General Geology and organized it into 10 subdivisions. He devoted attention to topographic surveys, land classification, and irrigation studies. The irrigation studies were prompted by the settlement of the Great Plains following the spread of the railroad network. The next director, Walcott, was also interested in water problems, and he established a Hydrologic Division in 1902. When the United States entered World War I, Smith established a division of Military Surveys. By World War II, a new round of reorganization resulted in an agency consisting of four branches: Geologic, Water Resources, Topographic, and Conservation. In the early 1980s, the name of the Topographic Division was changed to the National Mapping Division, reflecting the expanded responsibilities in geography and GIS, and the Conservation Division became a separate agency, the Minerals Management Agency.

In 1996, Congress mandated that the National Biological Service be merged into the USGS as the BRD. The BRD is composed of scientists and staff who were originally part of other bureaus within DOI, namely the Fish and Wildlife Service, the National Park Service, and the Bureau of Land Management. Addition of the BRD may have been a more radical change for the USGS than any change in its 120-year history. There are growing threats to the integrity of ecosystems from habitat loss and fragmentation, land use change, environmental contaminants, and the invasion of nonindigenous species. To minimize threats to the nation's biological resources, the BRD provides accurate, comprehensive, and timely information on populations, communities, and ecosystems.

The current director, Charles G. Groat, also is reorganizing the agency. This round of structural change involves bringing the institution in closer contact with its customers and partners. It also focuses on fostering interaction across administrative units of the agency. In the past, there was a lack of communication across divisions of the agency. "Over time, the scientific and technical programs of the USGS evolved so that they were not integrated across divisions and were conducted solely within divisional units" (Eaton, 2000). Moreover, scientists "in different fields of specialization examined problems from within the restrictive domains of their disciplines ... In this milieu, large investigative problems and contexts were necessarily reduced to isolated parts, the remaining elements of the whole left to others" (Eaton, 2000).

THE USGS TODAY

Currently, the USGS is organized into four areas of responsibility: geology, water resources, mapping, and biology. Until 1999, these areas were organized as the Geologic Division (GD), Water Resources Division (WRD), National Mapping Division (NMD), and Biological Resources Division.

Together, these four units form an organization of some 10,000 employees housed in about 200 offices throughout the nation (Figure 2.2), and in a few foreign countries (e.g., Saudi Arabia, Guatemala). Over the past 15 years, the number of full-time equivalent (FTE) personnel remained more or less unchanged (Figure 2.3a). However, the number of employees in the GD and NMD dropped by 32 percent (Figure 2.3b) but was compensated by a modest increase in the size of the WRD and by the 1996 addition of the BRD's 1,600 employees.

The USGS operated in 1999 with appropriated funding of about $800 million (Figure 2.4), which was supplemented with about $300 million under reimbursable contracts with other federal, state, and local agencies. During the years 1974-1999, the agency's budget remained roughly constant (Figure 2.5a and Figure 2.5b) but declined slowly as a percentage of the U.S. Gross Domestic Product (GDP) (Figure 2.6); even though the required tasks of the agency increased.

After the agency's close encounter with elimination, the USGS (1996a) prepared its first comprehensive strategic plan to guide the organization into the twenty-first century. It was viewed as an umbrella

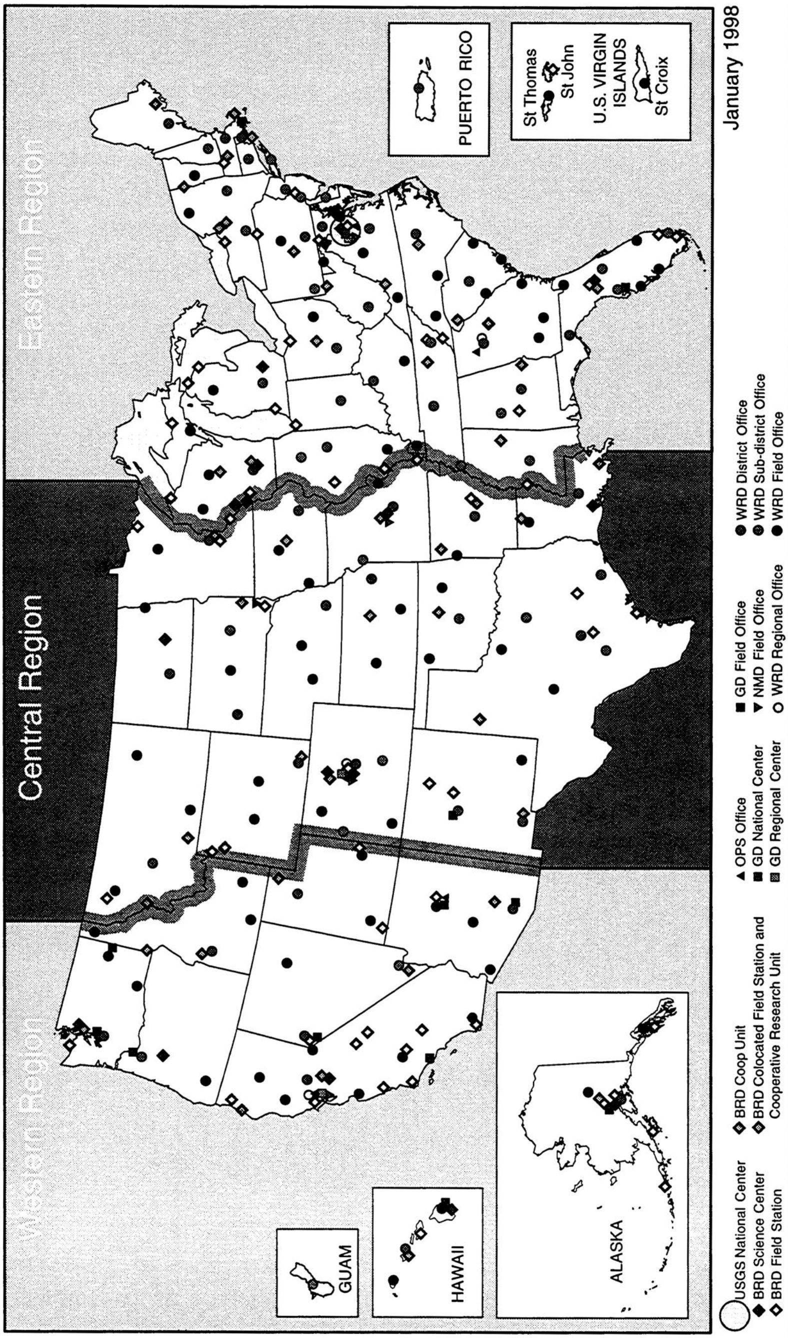


Figure 2.2 USGS office locations. SOURCE: USGS, 1998. http://www.usgs.gov/images/usgs_regions.gif

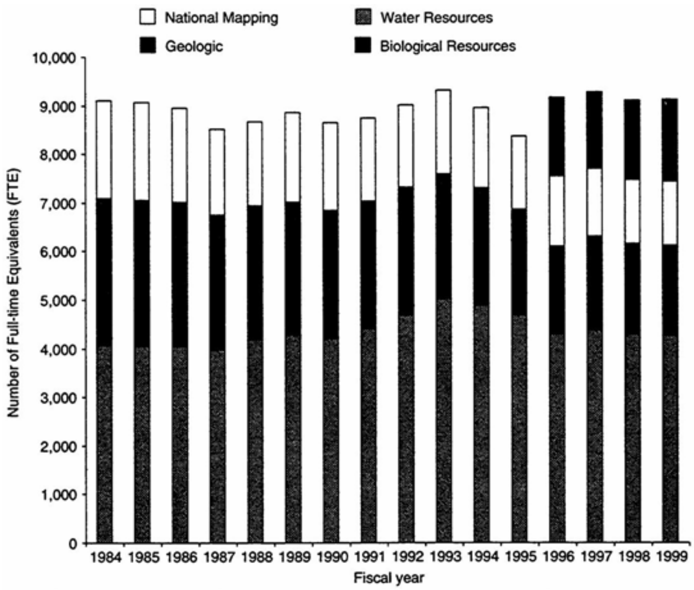


Figure 2.3 (a) Number of full-time equivalent personnel for the period 1984 to 1999. SOURCE: Data supplied by the USGS.

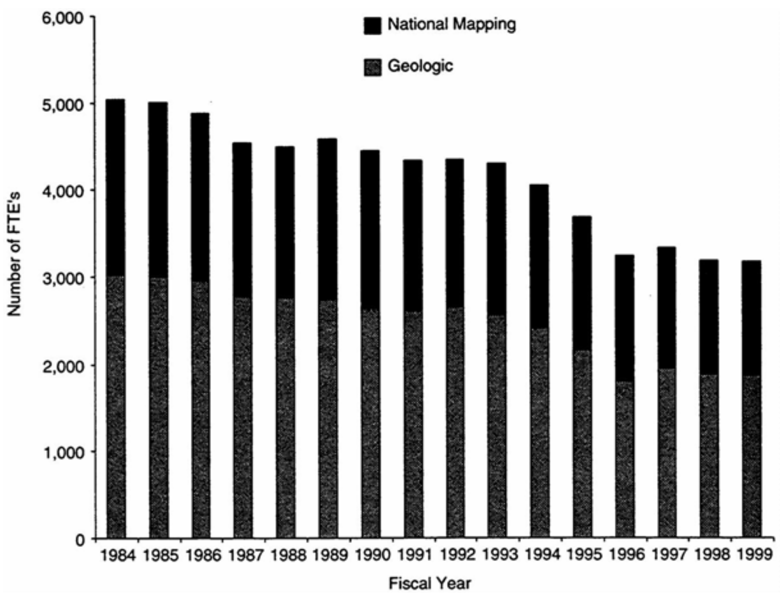


Figure 2.3 (b) Number of full-time equivalent personnel in the Geologic and National Mapping Divisions for the period 1984 to 1999. SOURCE: Data supplied by the USGS.

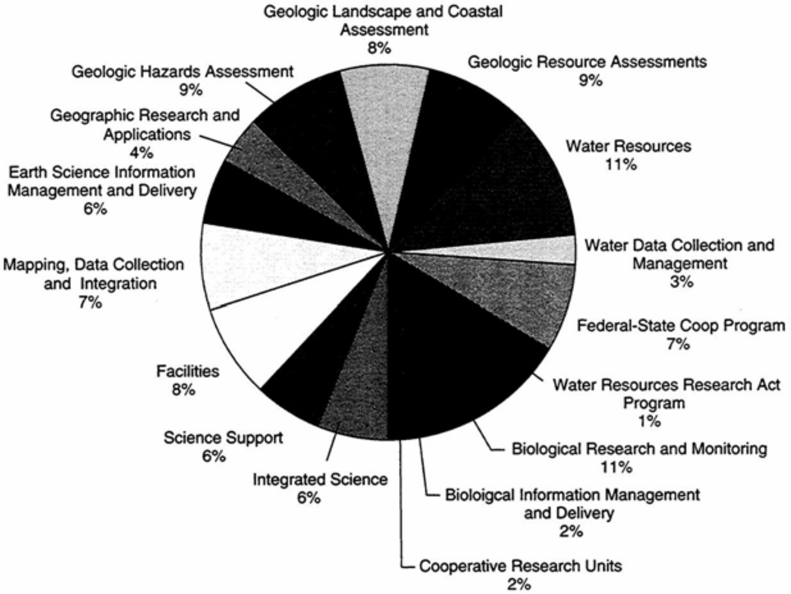


Figure 2.4 USGS funding in institutional context, FY 1999 appropriations. SOURCE: Data supplied by the USGS.

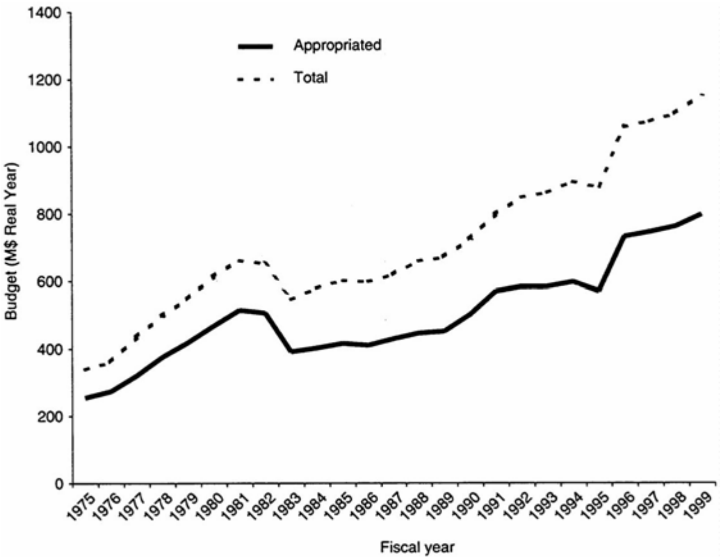


Figure 2.5 (a) USGS budget in real-year dollars, 1975-1999. Source: Data supplied by the USGS.

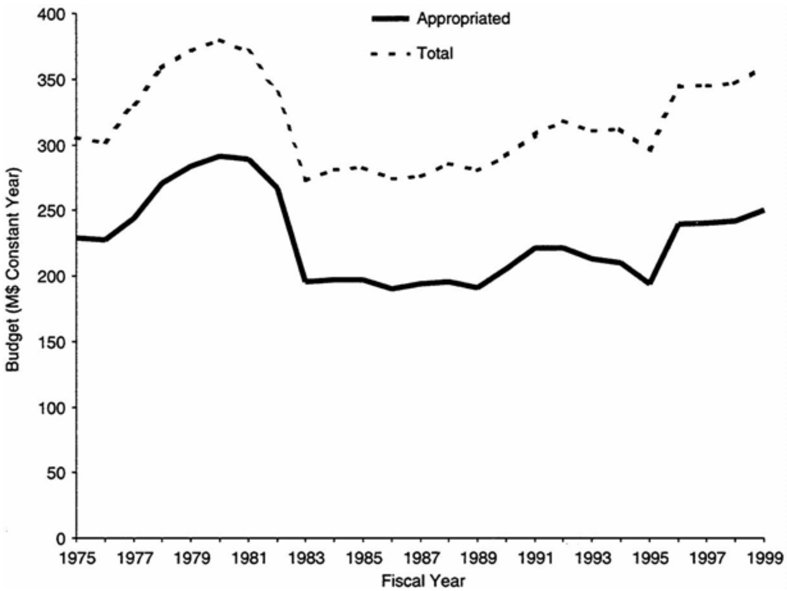


Figure 2.5 (b) USGS budget in constant-year dollars, 1975-1999 SOURCE: Data supplied by the USGS.

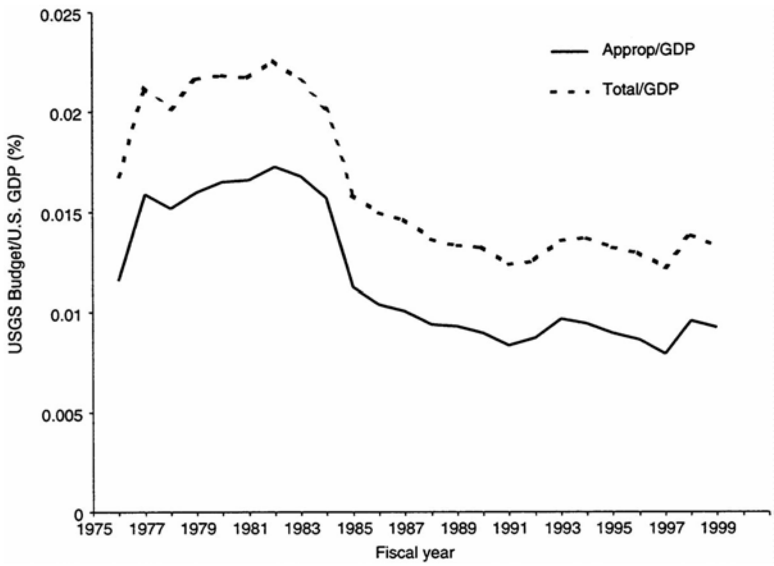


Figure 2.6 USGS budget as a percent of gross national product, 1975-1999. SOURCE: Data supplied by the USGS.

under which all organizational units of the USGS would create their own strategic plans (USGS, 1996a). The plan outlines a road map by which the agency is to address key societal issues. It recognizes that in a global economy and environment the USGS must extend its activities beyond the borders of the United States. It emphasizes that the USGS must develop more extensive partnerships with other federal agencies, academia, state and local governments, nongovernmental organizations, and private industry to supplement the agency's skills and resources. Finally, it underscores the importance of scientists, from different units and disciplines working together to address public needs. Three years later, the USGS (1999a) revised its plan to clarify its strategic direction, and the agency anticipates the release of updated plans on a regular basis.

What work will the USGS be doing in the future? According to the 1997 plan, the agency will be engaged in a well-defined group of activities: (1) water availability and quality, (2) natural hazards, (3) geographic and cartographic information, (4) contaminated environments, (5) land and water use, (6) nonrenewable resources, (7) environmental effects on health, and (8) biological resources. In the revised 1999 plan, the eight activities were collapsed into two mission goals: (1) hazards and (2) environment and natural resources. By 2005, the level of effort applied to these goals will be different from the 1997 level.

To achieve its scientific mission in the new millennium, the USGS will have to anticipate and respond in a timely manner to a broad array of complex and intellectually demanding national, international, and global science problems, many of which involve whole systems. Success will depend on several factors including the outcome of the strategic change process presently under way and the ability of the USGS to attract and support an agile and diverse world-class staff. History will determine how well the USGS meets its mission in the early years of the twenty-first century.

3

Future Societal Trends

This chapter looks to the future and strives to highlight several important trends that can be expected to influence the work of the USGS.

Although people in many countries are learning to use natural resources more wisely and efficiently, their global per capita use continues to increase. Current world population is more than 6 billion and growing at a rate of 1.3 percent a year. This rate of growth is slower than the peak global growth rate from 1965 to 1970 of about 2.1 percent per year. However, the declining growth rate involves a larger population base, and according to one scenario, the world population is expected to increase and is to reach 8.9 billion in 2050 (Figure 3.1) (United Nations, 1999). Most of the additional people will reside in the developing world.

Currently, urban populations are growing faster than the world population. Between 1970 and 1994, the level of world urbanization increased from 37 to 45 percent, and it is projected to reach 60 percent by 2025. Along with the transformation from a rural to predominantly urban world has come a swift increase in the number of large cities (United Nations, 1995). The rise in the number of megacities—that is, cities with a population of 8 million inhabitants or more—also is a striking feature of the last half-century. Projections indicate that by 2015 there will be 33 megacities, with 23 of them in developing countries (United Nations, 1995). In the last 300 years or so, rising population and consumption have significantly altered the environment on a global scale. Many of the human-induced changes have taken place since 1950 (Turner et al., 1990). Humans have contributed to the disruption of the biotic function[1] of 2.95×10^6 km^2 of soils. Deforestation and grazing account for 1.88×10^6 km^2 of this disruption (NRC, 2000c). Each year, freshwater in an amount that exceeds the contents of Lake Huron is

[1] Biotic function refers to the actions of living organisms on the soils.

withdrawn for human use (NRC, 1999b). Of this amount, agriculture consumes 70 percent, much of which is accounted for by irrigation. Pollutants from industrial, agricultural, and urban areas contaminate water, making it less potable and posing health hazards (Steingraber, 1998).

Many of the large cities of the world are near or along coastlines. In the United States, 8 of the 10 largest metropolitan areas are situated along the oceans or the Great Lakes. The development of coastal zones, which puts more people and property at risk from natural hazards, produces extensive land-cover changes and disturbs fragile marine environments. These and other human-induced environmental changes contribute to climate change, loss of biotic diversity, and the reduced functioning of ecosystems (NRC, 2000c).

The USGS has the capability and range of expertise to view much of the biosphere and to appreciate the extent of human alteration of the planet. An important role for the USGS is to use its range of expertise to

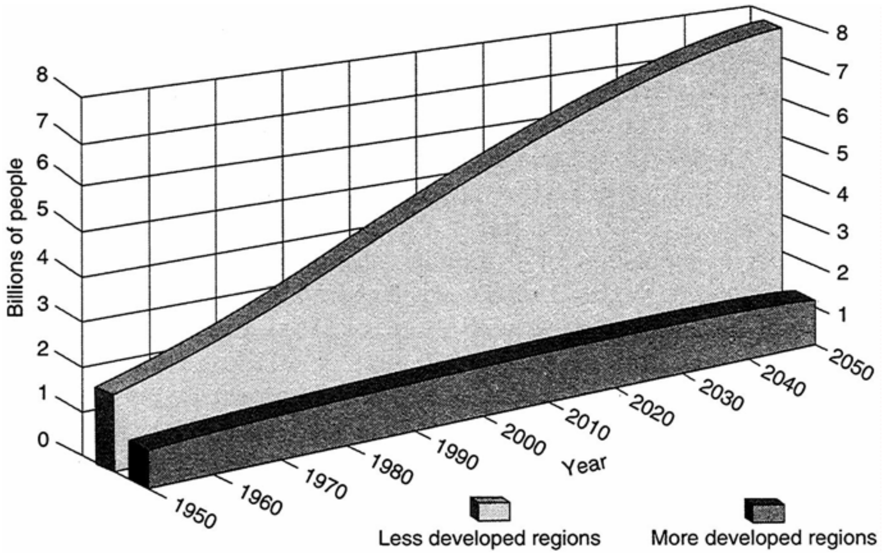


Figure 3.1 Historical and projected human population growth (in billions) for less developed and more developed regions, 1950-2050. SOURCE: United Nations, 1999.

understand land, water, and biological processes and how people affect them.

In light of the pressures of population and consumption, the committee agreed that the key trends likely to shape the future challenges and opportunities facing the USGS would be driven by:

- changes in the demand for and use of natural resources,
- emerging environmental issues,
- issues related to globalization, and
- issues related to societal expectations for information.

For each of the trends identified, there is a need for science, a significant part of which can be provided by the USGS, to document change and support policy development and implementation.

NATURAL RESOURCES

Natural resources are a major focus of USGS activities. Since its inception, the USGS has been the nation's primary supplier of reliable information on energy and mineral resources (NRC, 1996a, 1999d). For many years, the USGS also has been engaged in analyses of water resources. It is the lead federal science agency responsible for addressing a host of water issues such as water quality, water availability and conservation, and hydrologic hazards (NRC, 1997b, 1999c). When the USGS absorbed the National Biological Service in 1996, the agency augmented its portfolio of natural resources to include biological resources.

In the future, the USGS probably will be called on frequently to provide information on natural resources because pressures on these resources worldwide are likely to increase two- to fourfold by 2050 (NRC, 2000c). Because the world's population will continue to grow, demands for these resources will increase notwithstanding the reuse and recycling of materials, as well as the substitution of information for materials. Even in the United States with its slowly growing population, the patterns of resource consumption are unlikely to change significantly enough to have much effect on reducing demands for minerals, commercial energy, freshwater, and biological resources in the foreseeable future.

Mineral Resources

Americans depend on minerals for their economic well-being. More than 40,000 pounds of new minerals are mined every year for every person in the United States (National Mining Association, 1998). The average new home contains approximately 240,000 pounds of mineral products. Although the United States has less than 5 percent of the world's population and approximately 7 percent of the world's land area, it uses about 30 percent of the world's mineral resources (National Mining Association, 1998). The trend of modern manufacturing is to create products that are lighter and use less raw material, but at the same time, many of the new supermaterials require a greater number of minerals in their fabrication. For example, it takes more than 42 minerals to make a typical telephone (National Mining Association, 1998).

Minerals are also critical in food production. The bounty of American farms depends on mineral resources for fertilizer and soil amendments such as potash, phosphate rock, sulfur, and nitrogen. In addition, farming relies on machinery built from mineral resources, as do food processing and packaging.

By definition, “minerals” are inorganic substances that occur naturally in the earth's crust. Although minerals abound in nature, many of them are insufficiently concentrated to be economically recoverable. Moreover, the richest deposits are distributed unevenly and are being depleted.

The United States is not concerned about the supply of most nonmetallic minerals, which are plentiful and often widespread. In the United States, of the 12 most valuable mineral commodities, all but copper and gold are abundant (Rodenburg, 2000). There is no foreseeable world shortage of sand, gravel, clay, or dimension stone for building purposes (Rodenburg, 2000).

Commodities about which the United States is concerned are the metals—the essential materials for national military and economic security. Of the essential metals, the United States is substantially self-reliant in some, including gold and molybdenum. However, it appears to be running short of domestic sources of most essential materials (e.g., chromium, cobalt, zinc, tin, tungsten, bauxite, manganese) and is increasingly reliant on the good will of source nations. If measured in terms of percentage imported, U.S. dependence on these materials increased from an average of more than 50 percent in 1960 to more than

80 percent in 1995 (Stutz and de Souza, 1998). Thus, there is substantial national benefit to be derived from USGS world assessments of essential minerals and global databases of mineral resources.

The United States could reduce dependence on foreign ores by changing consumption habits, keeping minerals in circulation, and using substitutes. It could also apply emerging technologies to develop domestic sources more intensively. However, mineral extraction in the United States is a contentious issue (NRC, 1999a). Mining activity disturbs the land and can leave degraded environmental conditions.

As a major producer and consumer of minerals, the United States faces important societal decisions about the supply and development of essential minerals. Making informed decisions about the development of mineral deposits depends on having current, reliable, and unbiased information on mineral resources and the environmental implications of their development. The USGS has carried out this function in the past and is respected for the quality and integrity of its information. It has the expertise and experience to provide unbiased information on domestic and foreign mineral resources in the future.

Energy Resources

The services that energy provides include heating and cooling, transporting people and goods, driving industrial processes, and powering the electronic information explosion. In addition, energy is a major driver shaping the environment.

The USGS plays a prominent role in understanding the extent of the nation's energy supplies. Its focus is on onshore energy resources and the geologic controls of resource abundance, quality, and location. In contrast to the work of other federal agencies, the USGS emphasis is primarily on the initial stages in the supply process: the development of resource information that can then be used to make estimates of reserves. (By definition, “resources” are naturally occurring substances of potential profit that may someday be economically viable, whereas “reserves” are known and identified quantities of resources that can be exploited profitably with existing technology under prevailing economic and legal conditions [de Souza, 1990]). Currently, the agency concentrates on domestic and foreign coal, oil, and gas investigations, assessments, and related research.

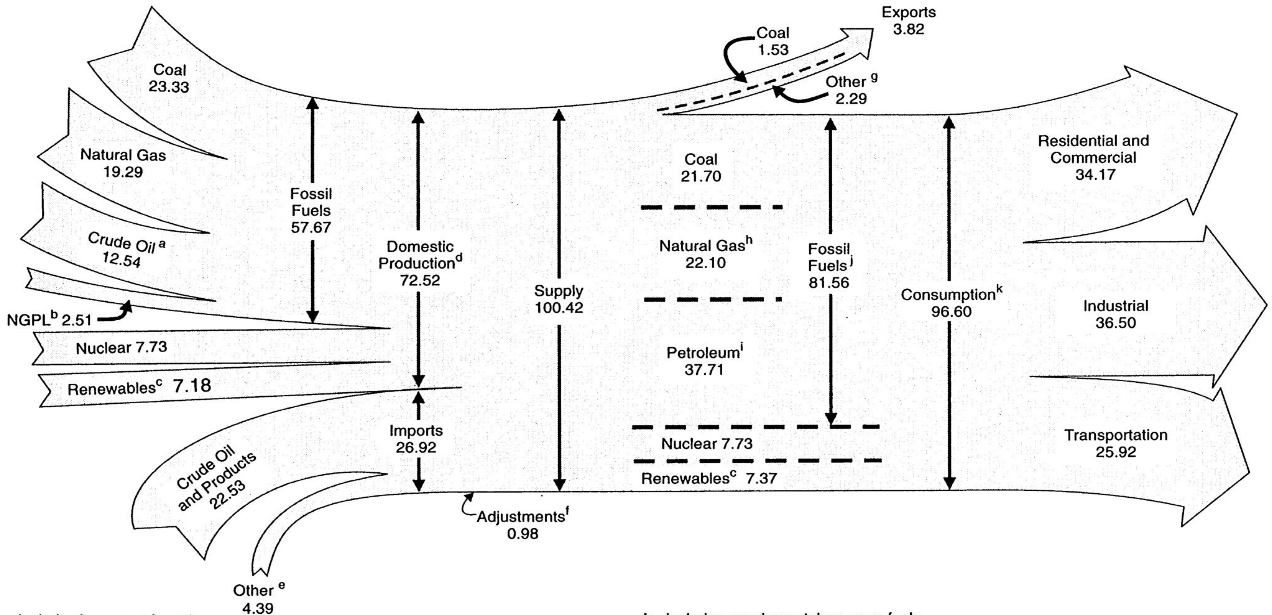
Coal, oil, and gas are the most important fuels for the present, supplying more than 80 percent of the nation's primary energy needs (Energy Information Administration, 1998) (Figure 3.2), and they will remain important fuels for decades to come (PCAST, 1997). Coal constitutes nearly 70 percent of the nation's fossil fuel resources and 57 percent of the electricity generated for public utilities (PCAST, 1997). Coal releases more pollution than oil or gas, is not as easily exploited as oil or gas, is bulky and expensive to transport, is not a good fuel for mobile energy units, and is not an efficient source of hydrocarbons for non-fuel use. Thus, energy use in the United States will remain heavily oriented toward oil and natural gas. During the course of the next few decades, if less carbon-intensive fuels become more important components of the fuel supply, natural gas may become the transition fuel to a less fossil fuel-based economy.

The United States has a substantial remaining resource base of natural gas, sufficient with a continuing pace of technology and resource accessibility to move the nation into a methane economy. Although the remaining oil resource base is significant, converting it into producible reserves in the face of lower-cost global resources is increasingly difficult. For oil as well as for natural gas where it may be converted to a liquid fuel, the United States will increasingly have an international frame of reference.

Currently, more than 50 percent of oil consumed in the United States is imported, and if predictions are fulfilled, this amount may increase to 60 percent by 2010 (PCAST, 1997). Production from domestic oil fields peaked in 1970 and has declined slowly since then (Figure 3.3). Geopolitical events such as the 1973 oil embargo left an indelible mark on the United States. Energy is no longer an invisible part of American lives. Energy prices are watched closely by industrial and agricultural users. Thus, it is appropriate for the USGS, working with other government agencies, to obtain a clear understanding of world energy resources to enhance U.S. and global energy security. In the background, however, the challenge thus far unmet has been to reduce U.S. dependence on imported oil supplies through energy efficiency options and energy supply options.

Water Resources

Water covers more than 70 percent of the earth's surface. Most of it



a Includes lease condensate.
b Natural gas plant liquids.
c Biofuels, conventional hydorelectric power, geothermal energy, solar energy, and wind energy.
d Includes -0.4 quadrillion Btu hydroelectric pumped storage.
e Natural gas, coal, coal coke, and electricity.
f Stock changes, losses, gains, miscellaneous blending components, and unaccounted for supply.
g Crude oil, petroleum products, natural gas, electricity, and coal coke.
h Includes supplemental gaseous fuels.
i Petroleum products, including natural gas plant liquids and crude oil consumed directly as fuel.
j Includes 0.02 quadrillion Btu coal coke imports.
k Includes, in quadrillion Btu, 0.16 net imported electricity from nonrenewable sources; -0.04 hydroelectric pumped storage; and ñ0.10 ethanol blended into motor gasoline, which is accounted for on both fossil fuels and renewables.

Notes: Data are preliminary. Totals may not equal sum of components due to independent rounding.

Figure 3.2 U.S. energy flow (quadrillion British thermal units), 1997. SOURCE: Energy Information Administration, 1998.

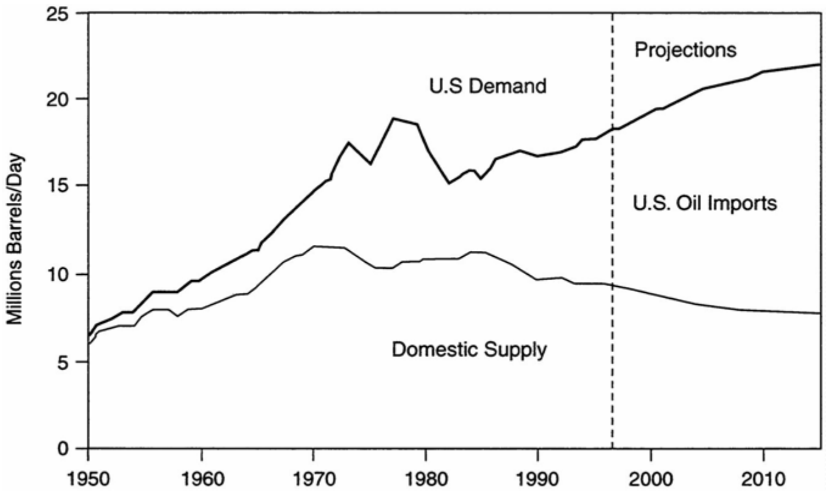


Figure 3.3 Past and projected U.S. oil imports in millions of barrels per day, 1950-2015. SOURCE: PCAST, 1997, pp. 1-8.

(97 percent) consists of the salt water of the oceans. Less than 1 percent is available for the world's biota, animals, and humans because 80 percent of freshwater is locked up in ice caps and glaciers. Nonetheless, the total amount of freshwater is more than enough to meet the world's needs now and in the future. The problem is that this global abundance is unevenly distributed among countries and regions, and local stocks or supplies are finite.

Water is a key determinant of population growth and distribution, economic development, social and political organization, and the quality of life. It is also a cause of war and a catalyst for peace. Thus, information and knowledge about this renewable resource are essential to human welfare everywhere. Because water resource issues in the United States and elsewhere are unlikely to diminish in upcoming decades, it appears probable that USGS information on streamflows and water use, regional water resource studies, and hydrologic research will be more important in the future than in the present.

Although per capita use of water in the United States and worldwide has declined since the mid-1980s (Gaelic, 1998), there is no reason to be complacent about water resources because of changes in population and consumption. Challenges to be met are numerous and include issues of water availability and accessibility, water quality, and hydrologic hazards. These issues are not new to the USGS. For example, the USGS has collected and analyzed data on water quality for more than 100 years (NRC, 1990).

Nations vulnerable to water scarcity are primarily in the arid or semiarid regions of Africa, Asia, and the Middle East. Altogether about 232 million people in 26 countries are living in regions considered “water scarce” (NRC, 1999b). Yet water availability is also an issue in some regions of the United States, which is a water-rich nation. In recent decades, the arid Southwest and West have begun to face the limits of water availability as a result of burgeoning population and development. Continued growth and development will require some combination of importing water and using and managing it more efficiently. They will also require that a balance be struck between competing uses. As in the case of other water-scarce regions of the world, conflicts among water users (e.g., agriculture, industry, households) and between ecosystems and regions (e.g., uplands, floodplains, cities) may become an increasing problem. In parts of the world, the scarcity of water also could be a source of conflict between nations (e.g., South Asia, Middle East).

Water quality is declining in developing countries, especially in urban areas. Although the degradation of water quality can be arrested and sometimes reversed, the process is slow and costly, as exemplified by the experience of developed countries over the past 30 years. In the United States, passage of the Clean Water Act in 1972 resulted in marked improvement in water quality of streams and rivers that receive discharges from municipal waste treatment plants and industrial facilities (point source pollution). Further efforts to improve the quality of the nation's water will require a reduction of pollution from diffuse (nonpoint) sources that include storm water runoff and runoff from agricultural fields and livestock wastes (NRC, 2000a) (Sidebar 3.1). In most cases, nonpoint sources of pollution are difficult to treat and identify.

Hazardous materials in the hydrologic environment are a problem of substantial national significance (NRC, 1996b) and call for the expertise of scientists. The role of the USGS in this arena is to expand scientific knowledge relevant to the behavior of hazardous materials. The generation and storage of toxic chemical and radioactive wastes will be of increasing concern over the next two decades, particularly as aging stockpiles begin to deteriorate. Modeling and monitoring the surface and subsurface movement of wastes at existing sites will be of particular importance. This modeling is vital when contamination poses threats to human

SIDEBAR 3.1

WATER CONTAMINATION

On the southeast coast of the United States where tobacco farming is on the decline, a new business, swine production, is flourishing. In the past nine years, North Carolina's small independent pig farms were taken over by large industrial operations, and North Carolina has become the nation's second leading producer of pork. The industry expanded so rapidly that regulations lagged (Pressley, 1999). The first major concern arose from the process of waste management that included land application as fertilizer. The application rates were in excess of crop uptake and consequently increased the levels of nitrogen, phosphorus, and ammonia in soils and surface organic debris, from where they could be leached or eroded into waterways. The second major concern stemmed directly from the waste lagoons. During Hurricanes Bonnie (1998), Dennis (1999), and Floyd (1999), the waste lagoons overflowed or were submerged in flooded rivers.

Contaminated water is one of the primary concerns of residents of the southeastern coast of the United States. As animal-waste lagoons flooded, so did wastewater treatment plants and septic systems. Along with the threat of increased nitrates in the water, there were rotting animal carcasses, estimates of 100,000 dead hogs, 500,000 dead turkeys, and 2 million dead chickens, threatening the water supply (USGS, 1999c). Scientists will continue to collect water samples to analyze for nutrients, bacteria, pesticides, and metals before drawing any conclusions about the extent of the damage, possible long-term effects, restoration, and future prevention methods (USGS, 1999c). In all cases, the success of these efforts depends on an understanding of the watershed and groundwater aquifer and on the ability to design workable remediation and operational programs to protect water resources. In the wake of these disasters, as part of the recovery process, an emphasis is being placed on regulations and effective environmental protection.

health, for example, when radioactive and nonradioactive wastes migrate toward surface or groundwater supplies.

Losses of life and property in the United States and worldwide to hydrologic hazards—floods, droughts, and related events (e.g., landslides)—are significant and increasing. Annually, floods in the United States result in 100 fatalities and $2.5 billion in direct damage (NRC, 1996b). The Midwest floods of 1993, which caused extensive damage and interrupted road and rail transportation, enhanced interest in the management of land use in river basins throughout the nation (NRC, 1997b). Droughts can occur anywhere in the country, can last for several years, and may have greater economic consequences than floods. However, floods are often localized events of short duration.

Biological Resources

An important mission of the USGS is to provide the scientific understanding to support the sound conservation of the nation's biological resources. Land use, water use, and nonindigenous species are the three factors that have had the greatest broad-scale effects on biological resources (USGS, 1999d). Urbanization, conversion of lands to agriculture, draining of wetlands, and fragmentation of forests are some of the most important land use changes. Changes in our waterways, due to navigation, irrigation, and hydroelectric power, have altered the biological integrity of aquatic environments. Changes in land and water use have altered habitats so that they are more favorable to nonindigenous species. Environmental contaminants and climate change also have impacts on our biological resources (USGS, 1999d).

Because resource management issues are complex, many of the questions pertaining to biological resources are considered by the USGS in a comprehensive ecological context. The need for USGS information on biological resources and ecosystems may become more important in upcoming decades in light of concerns about the loss of biological diversity and ecosystem services due to increased urban and infrastructure systems, rapidly changing land use patterns, and rising consumption.

We are increasingly aware of how much our well-being depends on biological diversity and the integrity of ecological communities. There is growing realization that the loss of biological diversity would be a great social loss and that a major loss of biological diversity might threaten the ability of the earth to support human societies. This appreciation has given rise to conservation biology, which makes it clear that people depend on ecosystem services. These services include food, construction materials, medicinal plants, wild genes for domestic plants and animals, crop and plant pollination, absorption and detoxification of pollutants, generation and maintenance of soils, and the regulation of air and water quality as well as climate (Ehrlich and Ehrlich, 1991). In addition, biodiversity is the foundation of biotechnology.

Recognizing the value of its biological resources, the United States has enacted laws and policies to protect plants and animals from extinction. The United States has also demonstrated a strong commitment to the wise, responsible, scientifically based stewardship of its biological resources through regulatory programs, acquisition of public lands, and various preservation efforts (NRC, 1993b). Despite these efforts, the nation's biological diversity is in decline and there are questions about how it should be sustainably managed.

The leading cause of species extinction is habitat destruction (Pimm and Raven, 2000). In assessing the condition of approximately 20,500 species of U.S. plants and animals, the Nature Conservancy found that about one-third were of conservation concern (Stein et al., 2000). Animals that depend on freshwater habitats and flowering plants are in the worst condition. More than 500 U.S. species may have already disappeared. These losses have affected virtually every state, but Hawaii, Alabama, and California have been especially hard hit.

Surveys of many groups of plants and animals indicate global extinction rates at least several hundred times the rate expected based on the geologic record (Pimm and Brooks, 2000). Ten percent of the world's 10,000 bird species are threatened with extinction (Collar et al., 1994). About 500 of these birds are likely to go extinct in the next 50 years, producing an extinction rate of 1,000 extinctions per million species per year (Pimm and Brooks, 2000).

With the loss of biological diversity and the alteration of ecosystems that support it, many social and economic consequences follow. The decimation of pollinating insects decreases crop yields (Nabhan and Buchanann, 1997). Degradation of wetlands exposes communities to increased flood damage. Land use changes in watersheds impoverish water purification processes at substantial cost to urban communities (e.g., the cost of installing and maintaining water treatment plants) (Chichilnisky and Heal, 1998).

The challenge for the future is sound management of the earth's ecosystems to maintain biodiversity and ecosystem function. Keys to meeting this objective include the following: the reduction of wasteful consumption; the remediation and restoration of damaged or degraded ecological systems (e.g., forests, grasslands, agricultural lands, urban and coastal environments); and the setting aside of protected areas, in which human use is excluded or altered to ensure the survival of biotic communities and wild species. Meeting this objective calls for a greater understanding of how biological systems work, how to stem the continued loss of habitats, and how to restore and manage ecosystems.

ENVIRONMENTAL ISSUES

The USGS supplies scientific information and advice about current environmental issues. This information is used by federal, state, and local agencies in carrying out their regulatory and administrative functions. The USGS is also expected to anticipate emerging environmental issues.

Environmental issues are those that affect human health, natural resources, ecosystems, or the global environment. When Americans perceive that degraded environmental conditions constitute a serious threat to their quality of life, the passage of legislation designed to reduce this threat often follows. Examples include the Clean Air Act and the Clean Water Act. Although most Americans are committed to a clean, healthful environment combined with economic growth, the depth of their commitment changes over time. Recent polls indicate that Americans are less concerned about environmental issues today than they were a decade ago (NRC, 1996c). This view could change suddenly with significant environmental surprises in the future.

Experts have identified an extensive list of environmental issues. (Table 3.1) The list includes narrowly focused, near-term environmental problems (e.g., oil spills) and broad-based ones (e.g., climate change). Historically, much environmental research has been directed at solving immediate problems. However, this problem-specific approach is limited; it misses the opportunity to “use research to create scientific and technological building blocks or core research, which can enhance our future ability to address a wide range of environmental problems” (NRC, 1996a).

Table 3.1 Identified Environmental Issues

Clean Air
- Automotive emissions
- Photochemical air pollution
- Acid deposition
- Airborne toxic substances
- Particulate matter
- Long-range pollutant transport
- Sudden, accidental releases of hazardous air pollutants
- Urban and regional-scale tropospheric ozone

Clean Streams, Rivers, Lakes, and Estuaries
- Industrial discharges
- Municipal waste discharges
- Acid mine drainage
- Agricultural runoff
- Urban runoff
- Atmospheric deposition
- Oil spills
- Thermal pollution
- Eutrophication
- Human-accelerated erosion and turbidity
- Biochemical oxygen demand
- Alternations due to floods
- Storm overflows
- Stream channelization consequences
- Effects of dams
- Introduced species
- Competition for water resources

Clean Coasts and Oceans
- Eutrophication
- Input from rivers and streams
- Chemical contamination of estuaries, coastal areas, and oceans
- Effects of recreational and
- Commercial uses
- Changes in biodiversity
- Contaminated sediments

Clean Aquifers and Soils
- Superfund and other industrial waste sites
- Disinfection byproducts
- Inadequate water delivery systems
- Point-of-use treatment (home filters, etc.)
- Old lead and lead-soldered waterpipes
- Regional scarcity of potable water

Clean Dwellings and Workplaces
- Indoor air contaminants (including radon)
- Old lead-based paint
- Asbestos
- Outgassing from construction and finishing materials
- Toxic substances used in homes and workplaces

Safe Food Supply
- Pesticide residues
- Plant uptake of contaminants
- Effect of pollution on crops

Safe Disposal of Human Waste
- Effective waste isolation/collection
- Sanitary waste disinfection

Safe Disposal of Household and Industrial Waste
- Waste reduction and recycling
- Landfill technology and use
- Radioactive waste storage, treatment, and disposal
- Incineration emissions and ash
- Offshore disposal
- Industrial wastewater treatment
- Infrastructure needs

Habitat and Species Conservation
- Riparian degradation
- Tropical ecosystem degradation
- Temperate ecosystem degradation
- Polar ecosystem degradation
- Marine ecosystem degradation
- Wetlands degradation
- Endangered species
- Species extinction

- Leaking fuel tanks
- Diffuse-source contamination
- Salt and heavy metal contamination
- Salt water inflow

Clean Drinking Water

- Drinking water pollutants
- Biological contamination
- Herbicide and pesticide effects
- Land use changes

Environmental Restoration

- Mining and extractive industry reclamation
- Military base reclamation
- Industrial site reclamation
- Effects of engineered watersheds and modified hydrologic flow patterns
- Ecological function impairment
- Assessment of "restored" sites, including wetlands

Environmental Impacts on Human Health

- Cancer
- Birth defects
- Genetic susceptibility
- Endocrine modulators
- Neurotoxicity
- Immune dysfunction
- Asthma and other respiratory dysfunction
- Cardiovascular disease
- Effects of multiple exposures

- Overfishing
- Pollutant bioaccumulation/bioconcentration
- Habitat alteration, fragmentation, and Destruction

Overarching Issues

Long-Term Sustainability

- Climate change
- Human population growth
- Ozone depletion
- Land-use patterns
- Natural resource allocation
- Conservation of non-renewable resources
- Long-term environmental monitoring
- Economic mechanisms for environmental improvement
- Industrial ecology

Assessment and Management of Risks

- Risk assessment methodologies
- Human exposure pathways
- Ecosystem exposure pathways
- Assessment of ecological risk
- Toxicity and measures of effects
- Effects of multiple exposures and stressors
- Psychology and perception of risk

Undoubtedly, the USGS will be asked to address overarching environmental problems in the future. Solutions of these social problems requires a broad research program that is capable of developing complex system models and using advanced technology.

GLOBALIZATION AND NATIONAL SECURITY

The USGS of the future will operate in a world that is more closely interconnected through markets, transportation, communications, interlinked technologies, and migration. The increasing connectedness of people and their activities, together with market reform and democratization in many areas, is popularly described as "globalization." Since the nation's well-being in coming years will be more tied to global markets and developments than in the past, it is appropriate for the USGS to become more active at international and global levels as well. By playing a strong role on behalf of the United States in promoting, facilitating, and conducting international and global studies to develop critical science information, the USGS lends support to national security as well as foreign policy and private sector interests as the following examples illustrate:

1. The larger world population of the future will be concentrated in developing countries. Many of these people will be living in low-latitude coastal regions where urban and economic growth is most intense and where the incidence of severe natural disasters—earthquakes, volcanic eruptions, tsunamis, and hurricanes—is more common. Moreover, the interconnectedness that is implicit in globalization means that natural hazards in almost any part of the world will increasingly have profound effects on the well-being of the citizens of the United States. Through precise observations and good understanding of the phenomena involved, the impact of natural hazards on people and property can be mitigated.
2. Environmental threats emerge from the increasing connectedness of world population. The rapid movement of people and goods makes possible biological invasions that destroy native species and crops. For example, the zebra mussels that were first discovered in North America in 1988 can now be found in the waterways of 19 states. It is likely that zebra mussels were introduced into the Great Lakes through ballast water. They block water supply pipes. Densities as high as $700,000/m^2$ have been observed at one power plant in Michigan, and the diameter of the pipes has been reduced by two-thirds at water treatment facilities (USGS, 2000c). Most of the biological impacts of zebra mussels are not yet known. However, they are having an impact on the population of native mussels in Europe.

3. Beyond the introduction of plants and animals that may be damaging to the environment, the rise of the global transportation network provides an avenue for the spread of pathogens that may pose threats to human health. For example, in the fall of 1999, the virus responsible for West Nile fever was found to be infecting people in and around New York City, the first known occurrence of this pathogen in the Western Hemisphere. Early indication of this mosquito-borne disease, and its actual identification, came from work on wild birds, which are an intermediate host. The potential for the spread of this disease to a much wider area through infection of migrating birds illustrates the complex ecological interactions involved in such outbreaks. As a major federal science agency, the USGS has an important role to play in conducting studies to reduce the spread and impact of nonnative invasive plants, animals, and pathogens that have been intentionally or accidentally introduced from foreign countries into the United States.
4. Increasing connectedness led to the export of environmental problems associated with manufacturing from developed to some developing countries. These developing countries have weaker or inadequately enforced environmental regulations, employ less expensive labor, and use older technologies that do not incorporate modern advances in energy efficiency or industrial ecology. In the future, the USGS may be called upon to provide geological and biological expertise or advice to assist developing countries with environmental restoration efforts and waste disposal issues.
5. The global transport network has diminished the friction of distance, but has not eliminated access issues. Globalization of the marketplace does mitigate access problems in times of geopolitical stability. A major national security issue for the United States is access to essential minerals and commercial energy that sustain the national economy. The United States depends heavily on imported oil and minerals. In addition, more favorable mineral exploration and mining statutes, as well as better mineral prospects and lower operating and labor costs in foreign countries, have encouraged many mineral companies to increase operations abroad. In upcoming years, the USGS can serve the national interest as well as the aspirations of American companies in the global economy by releasing U.S.-produced maps and information from foreign projects

and encouraging foreign governments to release information on energy and mineral deposits.

It is probable that the United States will require more information in the future than in the past on international and global science issues. This information can be obtained through some combination of efforts involving universities, federal agencies, and the private sector. However, independent and reliable science information in the service of national security and foreign policy interests is obtained most appropriately through a federal science agency.

SOCIETAL EXPECTATIONS AND THE DEMAND FOR INFORMATION

The human desire to seek and explore new frontiers is exemplified by a seemingly insatiable appetite for information. Consumers seem compelled to access, visualize, and apply new products that are thought to improve the quality of life. Scientists are driven by intellectual curiosity and societal pressures to develop understandings of problems for the benefit of humanity. These needs, plus such technological miracles as microelectronics, computer software, and technical advances in satellites, sensors, and fiber-optic and wireless telecommunications, promoted the rapid evolution of new tools for human progress— information technologies.

The new information technologies represent the merger of computer technology and communications technology in the 1960s. A major technologic innovation has been global positioning systems such as GPS, Global Navigation Satellite System (GLONASS), etc. The evolution of these new information technologies can be only dimly discerned, but the effect of technologies on human society has already been profound. These remarkable technologies have changed the way knowledge diffuses, making it easier for organizations to coordinate among widely separate units and enterprises. They have also fundamentally changed the way in which individuals live, work, and think about the world.

A computer linked to networks of information is the key to the information technology revolution. Communication networks, such as the Internet, allow people to communicate almost instantaneously with others on the network. Communications linkages can include vicarious living through petabyte storage systems and highly sophisticated sensor and image presentation systems, to enable scientists to create and simulate models of earth physics, land cover dynamics, and habitation analysis systems to support environmental, demographic and socioeconomic decisions, as well as to provide spectacular public entertainment modes. Twenty years ago, mapping applications of GISs were simply digitized versions of traditional maps. The present phase of GIS development involves the use of aerial and terrestrial data to create real-time three-dimensional virtual models. The new three-dimensional information not only helps scientists to better understand environmental, physical, and social processes, but also helps professionals to solve practical problems quickly (Sidebar 3.2). Advances in spatial data technologies are also influencing how scientists communicate with students and the public; for example, geologists are using animation and simulation to illustrate the evolution of landscapes through geologic time.

These new technologies provide new ways for the USGS to conduct research and reach its customers. The future holds exciting opportunities to use information machines to develop process models, build scenarios, and make projections about resources and complex earth and life systems. The widespread diffusion of the Internet and World Wide Web provides opportunities for the USGS to reach a broader and more diverse customer base with information about earth system processes and resources in the future. However, new technologies and commercial capabilities present challenges to the USGS in terms of the scope of what the agency is able to do and what is appropriate for it to do. For example, the agency's topographic mapping role is being supplanted by private enterprise. The rapidly advancing state of technology may result in substantial changes in the way the USGS conducts its business in the future.

SERVING THE UNDERSERVED POPULATION

The USGS should confront equity issues in providing information and services to the underserved population as well as in hiring its work backgrounds. Based on data provided to the committee by the USGS, as of September 2000, the USGS would have had to hire 621 people from under-represented groups (Figure 3.4 and Figure 3.5) to reach parity with the civilian labor force. Significant demographic shifts in the nation's

SIDEBAR 3.2
FUTURE APPLICATIONS OF SPATIAL DATA TECHNOLOGIES

Advances already under way in information technology, communications infrastructure, microelectronics, and related technologies will provide unprecedented opportunities for information discovery and management and new ways to conduct research. Following are two examples of how spatial information might be used by professionals in the early decades of the twenty-first century.

1. Recent rains have caused a small landslide on a new earthfill. A geotechnical engineer working for the New Mexico Department of Transportation dons a headset as she leaves the site office. The headset provides an enhanced-reality system that combines glasses, earphones, and a tiny microphone, yet weighs little more than a pair of sunglasses. When the engineer reaches the site, she issues a simple voice command, and the microtopography of the earthfill slope is superimposed as a red wire-frame display on the landscape before her. Where there has been significant erosion, the designed surface appears like a net stretched above the ground. In areas where deposition has occurred, the original surface lies below the current one, so the planned surface is obscured. The engineer takes out a hand-held device and begins to point at the current surface in various places while clicking the pointing device. A green mesh appears as she quickly collects sufficient points to make the digitized data fit the current microtopography. Her new slope data appear simultaneously in the division office, allowing a colleague to undertake slope stability calculations. Using these results, the engineer is able to discuss with the earthfill contractor the steps necessary to repair the slope erosion damage and prevent a recurrence.
2. In the Denver suburb of Lakewood, a public hearing on a new transit stop on the proposed western light rail corridor is under way. The planners display photorealistic three-dimensional simulations of existing and proposed conditions on a large screen. Citizens protest the style and scope of the proposed parking structures. Several small group discussions are organized around graphical workstations operated by facilitators. Alternatives are suggested and incorporated in rough form into the displays as the discussions progress. At the end of the meeting, two new alternatives are selected for further detailed analysis and presentation on the local Jefferson County Web site at the end of the following week.

These alternatives will be the subject of an additional public hearing at the County Planning Commission in a month.

These scenarios may sound like science fiction. Yet much of the technology needed to support them (e.g., high-speed wireless information links, near real-time remote sensing imagery, high-performance computing, and GPS chips) is already under development or available in prototype form (Turner and Bespalko, 1999).

population are expected and will change the labor pool from which the USGS work force is drawn. The USGS (1998c) recognizes the value of a diverse work force:

> Demographic changes among our customers and stakeholder base, including Congress, may also affect their expectations of us and our programs. Different cultures may have different perspectives concerning the value of goods and services provided from our national resources. A representative workforce will help the USGS to interact more effectively with customers and cooperators. To survive and prosper during the coming century, we need the diverse talent of many people— their different ways of thinking, wide-ranging knowledge and experience, unique skills and talents, and varied ethnic and cultural perspective.

As technological disparities increase between communities across the United States, science service providers need to rethink how best to address these disparities. Being responsive to equity concerns should be a part of innovative management approaches designed to communicate and to bringing socially just science to poor and minority communities. Data provided by the USGS do affect land use planning, mineral resource development, and evaluation of sites for major urban and industrial development. A number of studies (Soliman et al., 1993; Anderson et al., 1994; Been, 1994) have shown that a disproportionate number of hazardous waste sites are located in minority and low-income neighborhoods. It is important that USGS employees be perceived as socially growing conscious, preeminent experts especially when collecting and providing data that bear on major urban and industrial development. There is resentment and lack of trust in many African-American and Native

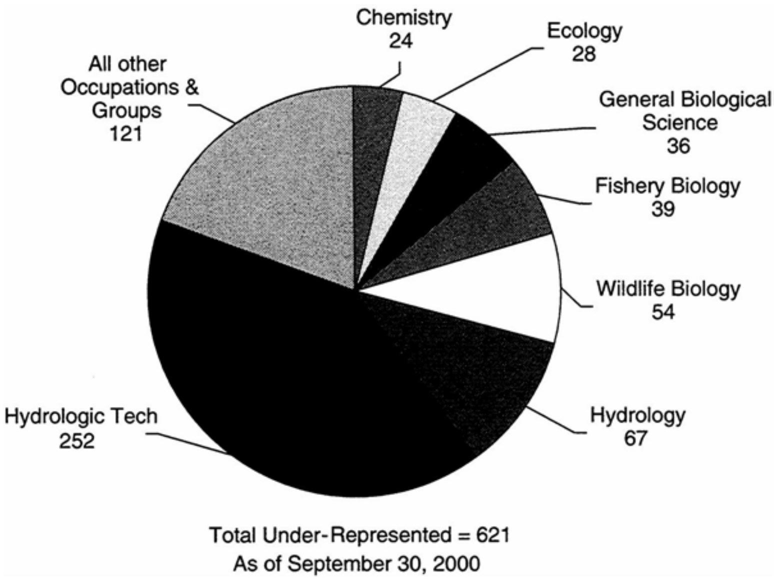


Figure 3.4 Number of hires needed to reach parity with the civilian labor force, categorized by discipline. SOURCE: Data supplied by USGS.

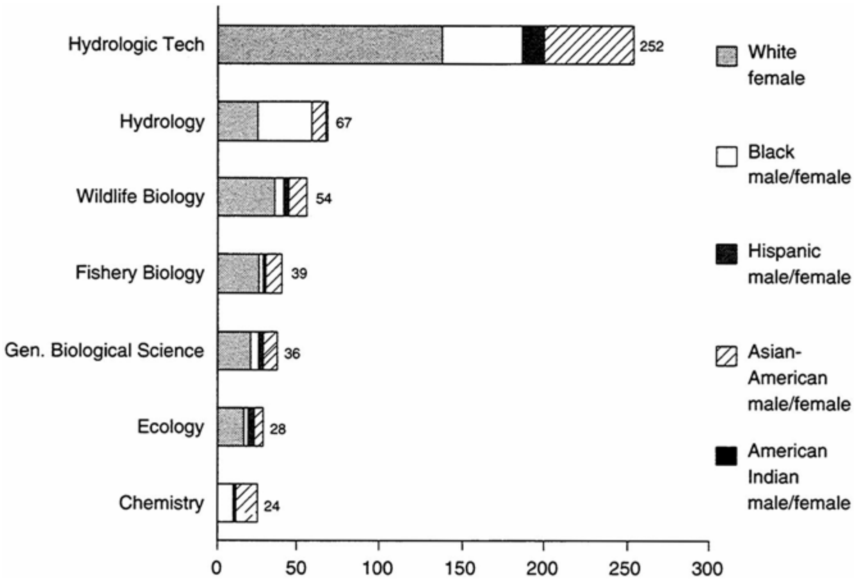


Figure 3.5 Same data shown in Figure 3.4 broken down by race and gender.

American communities for government agencies and researchers who disregard community input and participation in targeting programs at low-income neighborhoods (Bullard and Wright, 1993). With evidence to show that the distributional effects of residual pollution are often borne disproportionately by economically and racially disadvantaged communities (Rios et al., 1993; Perlin et al., 1995; Sheppard et al., 1999), it is important that the USGS be perceived as socially just and operate in a way that meets the needs and wants of all segments of the American population (the clients).

SUMMARY

In coming decades, growth in population and consumption will place greater stress on natural resources and the environment. Consequently, society will face major natural resource and environmental challenges. It will have to make decisions about sources of essential minerals and fossil fuels and will have to plan for mineral and energy transitions. The nation will continue to address issues of water availability and quality, as well as the need to reduce the impacts of floods and droughts. During the early years of this century, it will be necessary for scientists to reach understandings of sustainability, the resilience of natural systems, and environmental change and for policy makers to make wise decisions about resource use and the conservation and preservation of the environment. Finding durable solutions to emerging environmental problems will oblige scientists to work within a broad research program whose results will be applicable to a range of environmental issues. In the more connected world of the twenty-first century, many natural science issues within the purview of the USGS will have an international and global focus, and understanding them will be valuable for national security and public policy reasons. New information technologies are bringing to the fore many new, exciting research opportunities such as the application of real-time three-dimensional geospatial models to help solve complex natural science and resource problems. Societal trends suggest that the demands placed on the USGS in the future will be greater and more varied than in the past. How the USGS might address its mission in the future is considered in Chapter 4.

4

Evolving to Meet National Needs

To help the USGS think about its future science directions and information management function, this chapter considers how the USGS might evolve to meet national needs. After discussing the role of the USGS, attention turns to the agency's customers and programmatic activities. The international role of the USGS is treated in a separate section to highlight the increasing importance of activities in this arena in the new century. The succeeding section provides examples of research opportunities the USGS can embrace to solve relevant natural science problems. The concluding section presents the committee's recommended transition of the USGS toward a natural science and information agency.

ROLE OF THE USGS

The USGS in the twenty-first century will be expected to exercise strong national leadership in its areas of primary responsibility. Its principal duties are to serve as the DOI's primary source of science expertise and information and as the principal federal agency for science information and research related to conservation and management of natural resources and to natural hazard mitigation. The USGS also has obligations to conduct international activities as part of its mission.

A major responsibility of the USGS is to serve as the science agency for the DOI. The DOI's mission is to “restore and maintain the health of federally managed lands, waters, and renewable resources,” to “encourage the preservation of diverse plant and animal species and protect habitat critical to their survival,” to “reduce the impacts of hazards caused by natural processes and human actions,” and to “contribute to sound resource decision-making” (DOI, 1997). This mission can be accomplished only with the continual input of relevant scientific information from the USGS. To meet this obligation, in coming years, the USGS should ensure that science information is provided in an efficient and effective way and that its personnel and resources are utilized on important DOI issues.

The USGS has the responsibility to provide other federal agencies, states and local governments, tribes, and private and nonprofit organizations with the scientific understanding needed to support the sound management and conservation of the nation's natural resources. It is also charged to furnish accurate and timely geospatial data and information in a form related to geology, hydrology, biology, and topography. To accomplish this role, the USGS:

- conducts and sponsors research on relevant national issues;
- assesses resources, including oil and gas (domestic and foreign), minerals, water, and biological resources;
- monitors, reports, and where possible, provides forecasts of phenomena such as seismicity, volcanic activity, and streamflow;
- establishes formats and data standards (e.g., geospatial data) and maintains science databases and infrastructures (e.g., National Spatial Data Infrastructure [NSDI], National Biological Information Infrastructure [NBII]);
- promotes utilization of data and information through a variety of communication channels ranging from published studies to Web sites;
- provides scientific and technical assistance in the effective use of techniques, products, and information;
- develops new technologies for the collection, coordination, and interpretation of data;
- coordinates topographic, geologic, and land use mapping, digital cartography, and water data activities in support of national needs and priorities;
- provides scientific support and technical advice for legislative, regulatory, and management decisions; and
- maintains liaison and coordination with scientists and users of relevant natural science information at federal, state, and local levels; with nongovernmental organizations; and with academia and industry.

These activities of the USGS are aimed at providing accessible, credible, independent science information that is used to “minimize loss of life and property ... manage ... resources, enhance and protect the quality of life, and contribute to wise economic and physical development" (USGS, 1996a). The data, information, and knowledge supplied by the USGS are essential to the federal government. As population and consumption pressures grow and environmental concerns increase in the twenty-first century, the technical advice provided by the USGS should become more valuable to the federal government. To enhance the USGS's role in the twenty-first century, the committee recommends that high priority be placed on efforts to:

- investigate mission-relevant complex science problems of regional, national, and international importance (e.g., global change, ecosystem protection and management, environmental restoration, coastal erosion);
- strengthen liaison and coordination mechanisms with related federal agencies and ties with universities and other partners to identify a research agenda that results in an increase in collaborative, multidisciplinary research on critical natural science problems;
- maintain and improve relations with state and regional government organizations that are users of natural science information; and
- facilitate the use of science information by the general public and by stakeholders.

The USGS engages in international activities that augment and benefit domestic programs and that promote, support, and implement U.S. foreign and domestic policy. These activities include conducting collaborative research and providing technical assistance and training. Because many science issues today are global and international in nature, the USGS in the twenty-first century should place high priority on the following:

- performing a more vigorous role in pursuing foreign area and global studies that develop critical science information on mission-relevant areas in support of U.S. interests;
- providing increased technical assistance to foreign countries that are developing relevant natural science programs, through financial support from appropriate sources; and
- becoming more active internationally to benefit the domestic programs and the international reputation of the agency;

The USGS of the twenty-first century will be called upon to play critical roles in solving complex science problems. Many of these problems, as indicated in Chapter 3, are long-term national and international issues (e.g., access to adequate water resources). Solutions to these problems will necessitate innovative scientific approaches, including the application of integrative science that will require the collaboration of scientists from many disciplines both within and outside the agency. It is unlikely that complex, multidisciplinary problems related to natural hazards, environment, and natural resources can be solved with current levels of investment. As the agency's responsibilities continue to increase, its budget should be increased to a level commensurate with the tasks. With an appropriate level of funding for practical research related to national needs, the USGS will be better able to fulfill its role as a provider of, and coordinator for, information resources related to critical issues in the natural sciences.

SERVING CUSTOMERS

In the twenty-first century, the activities of the USGS will continue to be shaped to an important extent by a broad-ranging group of users that include:

- other agencies within the DOI, such as the Bureau of Land Management (BLM), National Park Service (NPS), Minerals Management Service (MMS), Bureau of Indian Affairs (BIA), U.S. Bureau of Reclamation (USBR), Office of Surface Mining Reclamation and Enforcement, and U.S. Fish and Wildlife Service (USFWS);
- other federal agencies, such as National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), DOE, Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), U.S. Army Corps of Engineers (USACE), Department of Defence (DOD), and U.S. Forest Service (USFS);
- Congress;
- local and state government agencies, particularly state geological surveys water resource agencies, fish and game agencies, and geographic agencies.

- tribal organizations;
- the education community, including faculty and students at universities, colleges, and K-12 schools;
- professional societies, such as the Association of American Geographers, American Geophysical Union, Ecological Society of America, Geological Society of America, and American Society for Photogrammetry and Remote Sensing;
- the private sector;
- nonprofit organizations, such as the World Resources Institute, Resources for the Future, and the Nature Conservancy;
- foreign governments and international organizations; and
- the general public.

As the science agency of the DOI, the USGS must serve the science requirements of other DOI bureaus while also serving as DOI's instrument for providing science information and advice to the nation. The balance between service to other bureaus within the DOI and service to other clients and customers on behalf of the DOI undoubtedly is and will continue to be a challenge to strategic planning in the USGS and DOI. The committee urges the USGS and DOI to place the highest priority on the identification and assessment of the needs of USGS clients and customers both inside and outside the DOI, in order to ensure that the appropriate balance of service is maintained to all clients and customers.

Recently, the USGS has been responding to this challenge by increasing communication with its customers. For example, in the spring of 2000, the USGS convened a series of "listening sessions" at which customers and partners spoke with members of the agency's Executive Leadership Team about their interactions with the USGS and what they need from the USGS. The information will be used by the USGS in planning its future science directions. Another challenge for the USGS is to expand its cooperative research efforts with outside experts. Indeed, the success of USGS programs in the future will depend in part on how effectively the USGS cooperates with other agencies, state and local governments, universities, and organizations that are conducting similar work. Cultivating, maintaining, and strengthening links with all USGS clients and customers place heavy demands on the staff of the agency, but the effort will be justified by the resulting expansion of the utility of USGS products and services.

The USGS can point to a number of successes in interacting with customers and partners, including the following:

- provision of information to DOI's NPS resource managers to improve the effectiveness of park management, including the protection and restoration of biological communities, management of water resources, and enhancement of the visitor experience;
- assistance to establish the scientific basis for water management, environmental remediation, and water quality regulation for the EPA;
- cooperation with the Department of Agriculture to research the fate and transport of agricultural chemicals in midwestern water supplies;
- science policy outreach activities, as exemplified by rapid-response analyses for Congress;
- provision of hydrologic data and interpretation to state, county, municipal, and tribal customers of the Federal-State Cooperative Water Program;
- cooperation with state and university partners to collect, process, analyze, translate, and disseminate science information through digital geologic maps under the National Cooperative Geologic Mapping Program (NCGMP);
- assistance to state and local governments through the provision of geospatial data for land management, resource monitoring and management, scientific analysis, and information support;
- collaboration with the private sector, primarily through the use of contract agreements and cooperative research and development agreements (CRADAs), as exemplified by contracts for the acquisition and production of geospatial data, data management and dissemination, support services, equipment and supplies, and technology and maintenance;
- an e-mail list for notification of new publications; and
- publication of reports on CD-ROM, which incorporate and augment an activity formerly dominated by open-file reports and speed up the publication and distribution process.

Opportunities exist for the USGS to improve interactions. To enhance the USGS's role in the twenty-first century, the committee endorses efforts that:

- strengthen liaison and coordination with related federal agencies (e.g., NASA, NOAA, the National Weather Service [NWS], EPA, DOE, and NSF);
- maintain and improve relations with state and regional government organizations and with nongovernmental organizations that are users of natural science information;
- facilitate the use of natural science information by the general public and by stakeholders for critical issues;
- increase interactions with the private sector, foreign customers, and partners;
- encourage USGS scientists to publish their research results promptly in journals, present papers at conferences, and convene workshops and seminars; and
- nurture student interest in the natural sciences at a time of a looming national shortage of technical personnel.

In addition, the committee urges the USGS to assess on a regular basis its services to customers at regional, state, and local levels. Currently, the USGS focuses much attention on state surveys and WRD cooperators. Efforts should be made to diversify the agency's customer base at regional, state, and local levels. The committee is also concerned that, in some instances, the USGS acts as a consultant to local governments. As stated in the NRC report *Preparing for the Twenty-first Century: A Report to the USGS Water Resources Division* (NRC, 1991), "this situation should be avoided unless some broader purpose is served." Exceptions to this recommendation are cooperative programs such as the NCGMP, National Earthquake Hazard and Reduction Program (NEHRP), and National Water Quality Assessment Program (NAWQA); regional groundwater assessment activities, and the national stream gauging program that have national interest implications. "Other exceptions occur at sites where cutting edge science is being applied or where the results of the activity may be expected to contribute to a more generalized understanding" of science problems (NRC, 1991). Examples of local work that has national impact are USGS contributions to aquatic ecosystem studies of San Francisco Bay and Chesapeake Bay (Sidebar 4.1). Although cooperative programs at local levels will continue to be important to the mission of the USGS, the agency should "continually evaluate the merits of its local ... activities to ensure that its limited personnel are engaged in projects with

SIDEBAR 4.1

CHESAPEAKE BAY AND SAN FRANCISCO BAY: EXAMPLES OF ECOSYSTEM CONSERVATION AND RESTORATION

In 1983, the Chesapeake Bay Agreement was signed, beginning the regional partnership aimed at directing and conducting the restoration of the nation's largest estuary, the Chesapeake Bay. The Chesapeake Bay Program's (CBP's) highest priorities include:

- restoration of living resources—finfish, shellfish, bay grass, and other aquatic species and wildlife,
- improvements that include the fisheries and habitats,
- nutrient and toxic reduction, and
- advances in estuarine sciences.

The USGS is one of several partners in this effort to restore the bay. The USGS contributes by conducting studies, serving on committees, and work groups, and providing data. Specifically, the USGS has implemented a River Input Monitoring Program that quantifies loads and long-term trends in concentrations of sediments entering the Chesapeake Bay. Other scientific contributions include construction of mapping information that is used for watershed delineation and surface-water modeling; conducting health assessments to monitor outbreaks of Pfiesteria; and several joint projects to increase understanding of nutrient reduction, delivery, and movement into the bay. USGS employees serve on several CBP committees some of which include the Federal Agencies Committee, the Water Quality Technical Workgroup, and the Scientific and Technical Advisory Committee. These committees provided information to resource managers, scientists in the Chesapeake Bay Program, Congress, DOI, and the media by publishing reports, fact sheets, press releases, and congressional briefings. The USGS is also a major participant in the Chesapeake Information Management System, which is a library of information and tools specifically developed to increase public access to Chesapeake Bay information (CBP, 2000).

Similar to the Chesapeake Bay Program, the CalFed Bay-Delta Program's mission is to develop a long-term plan that will restore ecological health and improve water management for beneficial uses of another major U.S. estuary the San Francisco Bay, and the Sacramento-San Joaquin Delta. It represents one aspect of CalFed, an association of state and federal agencies that manage and regulate the estuary (CalFed Bay-Delta Program, 1999). The USGS established its Ecosystem Program to provide managers with adequate information to address current problems or prevent future problems in ecosystem sites. The USGS, which is a participating agency in the CalFed Policy group, is helping to clean, protect, and improve the bay-delta ecosystem. As with the CBP, the USGS has made numerous scientific contributions to the bay-delta program. Recently, the USGS studied long-term trends of metals in the bay and their effects on aquatic life, and it is measuring sedimentation in the delta to describe the transport of sediment needed for habitat restoration.

a ... national purpose" (NRC, 1991). Moreover, in its current move toward regionalization, the USGS should be careful not to usurp the role of regional organizations and state and local governments by engaging in activities that are their responsibilities.

FUTURE PROGRAM EMPHASIS

Programmatic activities of the USGS comprise the following overlapping categories: surveys, monitoring, data analysis, research, information dissemination, and product generation.[1] The USGS should continue to conduct all of these activities. However, in the first decades of the twenty-first century, the USGS should give more attention than it has in the past to integrative data analysis, problem solving, and information dissemination. A shift in balance does not mean that the USGS should reduce data gathering and monitoring activities. Rather, it means that in addition to these activities, the USGS should do more to interpret what the data mean and to make the data useful and accessible. The USGS should determine which high-quality, long-term monitoring databases are in the national interest and should seek federal funds for them.

[1] Surveying and monitoring are techniques for gathering data, where "data" is defined as raw facts about the world. Data products are methods to make the data available to users. After data analysis and interpretation, information products are generated.

The value of the USGS's high-quality, longitudinal databases (e.g., streamflow, groundwater levels, water quality, and natural hazard databases as well as biological-geological-topographic surveys) will increase as they become longer and include a wider range of environmental variability and human influences. When surveys are repeated, they constitute a form of monitoring that can be used to detect or quantify natural change or human influence. Invariably, the remapping of static features with new technology (e.g., radar altimeters, seismic tomography, hyperspectral imaging) reveals previously unsuspected characteristics. The use of automated gauging and other remote monitoring devices, especially at remote sites, makes long-term monitoring more reliable and cost-effective. The development and availability of long-term monitoring data are especially important in the biological sciences, since USGS is one of the few entities that has the capacity to carry out this work over long periods. There is a particular dearth of trend data for species groups or ecosystems, and certain USGS datasets, such as the Breeding Bird Survey and the more recent amphibian work, are flagship datasets. These long-term databases are one of the USGS's most important contributions to the nation, and care must be taken not to disrupt them.

When the USGS was established, it was charged with the classification of public lands and the examination of the geology, resources, and products of the nation's domain. Scientists of the USGS met this challenge, but the need for such information remains as vital to the national interest today as it was more than a century ago. Arguably, the most important of all geological records are geologic maps. Geologic maps are the primary foundation for a broad range of science investigations, from mineral exploration to hydrogeologic investigations to land use planning. They are the fundamental source for creating many other kinds of map data, such as landslide hazard maps, earthquake hazard maps, aquifer maps, groundwater vulnerability maps, mineral resource maps, and in combination with other data sources, soil maps.

The National Geologic Mapping Act of 1992 established the National Cooperative Geologic Mapping Program to implement and coordinate an expanded geologic mapping effort by the USGS, the state geological surveys, and universities. The primary goal of the program is to collect, process, analyze, translate, and disseminate earth science information through geologic maps (Sidebar 4.2). This information contributes to maintaining and improving the quality of life and economic vitality of the

SIDEBAR 4.2
NATIONAL COOPERATIVE GEOLOGIC MAPPING PROGRAM

The National Cooperative Geologic Mapping Program has three primary components: (1) FEDMAP, which funds federal mapping projects; (2) STATEMAP, a matching-funds grants program with state geological surveys; and (3) EDMAP; a geologic mapping education matching-funds program with universities. This information contributes to maintaining and improving the quality of life and economic vitality of the nation and to mitigating the effects of hazardous events and conditions. Technological advances in computing and spatial data analysis in the past decade provide geologic map data in digital formats that can be used by the public at all levels to assist in analysis and decision making. Priorities for the program are cooperatively developed through review councils and forums representing the broadest range of stakeholders.

A new program direction began in 1999, with new FEDMAP geologic mapping projects being organized into regional partnership projects with long-term plans and strategies to address distinct issues throughout geologically similar regions of the nation. The objective of the state geologic mapping (STATEMAP) component of the NCGMP is to produce geologic maps of areas in which knowledge of geology is important to the economic, social, or scientific welfare of individual states. Two types of activities are supported by the STATEMAP program: (1) those that produce new geologic maps and (2) those that compile existing geologic data in digital form. The objectives of the educational component (EDMAP) of the NCGMP are to: (1) provide funding for students in academic research programs through cooperative agreements that involve geologic mapping and scientific data analysis as major components; (2) expand the research and educational capacity of academic programs that teach students the techniques of geologic mapping and field data analysis; and (3) facilitate the publication and distribution of geologic maps generated in field-based academic research programs. The emphasis of EDMAP is on the acquisition of new geologic map information presented as geologic maps.

nation and to mitigating the effects of hazardous events and conditions.

Much of the geology of the United States has been mapped, but the maps are not necessarily adequate to address current needs. Geologic maps, like other scientific reports, become dated as ideas change and additional knowledge of the earth is acquired. Although most existing maps document bedrock geology, they fail to capture geomorphology, soils, and hydrologic features that are increasingly important to society. Few geologic maps are designed to integrate geologic information with associated geophysical and biological information.

With new tools for mapping (e.g., satellite sensors) and new needs for map products, the importance of fundamental field research as documented on geologic maps should remain an important component of USGS programs. For areas of critical national interest, these new products should be created from interoperable three-dimensional digital databases representing integrative, multidisciplinary studies encompassing topography, geology, hydrology, biology, hazards, resources, and human use.

Long-term monitoring is expensive and time consuming, and it has to be conducted carefully to provide the greatest amount of information return per dollar or time expended. In order to provide the maximum value to society, monitoring programs must be maintained indefinitely into the future so as to obtain the data necessary for understanding the natural cycles and fluctuations of earth systems as well as the impact of human activity on them.

The use of adaptive approaches to ecosystem management and restoration will also demand an increased focus on monitoring. Adaptive approaches arose because of concerns that conventional resource management approaches inadequately incorporate principles of ecosystem science and the needs of decision makers and other stakeholders (Lee, 1993; Gunderson et al., 1995). Traditional approaches tend to increase ecological “surprises” (e.g., exotic species invasions) and decrease ecosystem resilience (i.e., rate of recovery from disturbance). Adherents of the emerging field of adaptive management argue that some problems and processes in large-scale ecosystems and complex resource management regimes can be understood only through management experiments. An important component of these experiments is the careful monitoring of ecological and social effects and of responses to management operations (Walters and Holling, 1990).

If the balance of activities of the USGS shifts toward data analysis, problem solving, and information dissemination, it should not occur at the expense of the agency's long-term data collections. Data networks may have to expand in some functional areas and contract in others. Any decision to change data networks should be made only after careful consideration. After review, it may be prudent, for example, to discontinue data collection at stream gauging stations that serve individual users and fail to contribute to the national network or to further scientific knowledge (NRC, 1991).

The committee believes that in the future, the USGS could realize efficiencies in functional areas in which the agency invested heavily in the past. It urges the USGS to review national resource surveys for their relevance to the agency's mission. It encourages the agency to make greater use of remote sensing, in national resource surveys. The USGS could also enhance monitoring in many instances through greater attention to the use of conceptual and mathematical modeling. Monitoring critical phenomena such as seismicity, volcanic activity, streamflow, and biological indicators might become more cost-effective by (1) assessing sampling protocols, remote sensing tools, and new technological opportunities; (2) focusing on specific environmental indicators; and (3) encouraging collaborative cost-sharing programs with states. Improvements in data analysis could be achieved with the broader use of conceptual and mathematical modeling. Research into processes and relationships could be enhanced by regular internal and external reviews and articulation of the kinds of research that are considered necessary and useful for public policy. The committee believes that there should be less emphasis on the design and development of new products and more emphasis on the development of new data products and more emphasis on the development of new and relevant information and on archiving, update, maintenance, ease of availability, and security of added products. This emphasis could leverage the capability of value-added industry to produce tailored products on demand for USGS investigations and studies, using the most current and reliable software and hardware.

Integrative System Models

In the twenty-first century, the USGS should emphasize that system modeling is a powerful tool for integrative science. System modeling would enable the USGS, in coordination with other agencies and partners, to develop a greater understanding of complex science problems that involve natural and human systems.

The USGS has the capability, within one agency, to gather geographic, geologic, hydrologic, and biological information about land use issues. By using the NMD appropriately, it can represent the information geographically. The challenges are (1) to recognize the types of information needed to solve a particular problem and (2) to integrate different types of information in meaningful ways. Integration is critical to understanding complex natural and human systems. For example, in a natural system problem, there may be geologic influences on hydrology, hydrologic influences on biota, and biological feedbacks influencing both geology and hydrology. On the other hand, the information requirements for another problem may be less broad. Thus, it is important to recognize problem dimensions and defend decisions to limit investigations, rather than to expend resources needlessly on the collection of data that are unlikely to contribute significantly to the solution of problems.

Understanding complex systems cannot be achieved without integrative system models, whether they are formulated qualitatively or quantitatively. This idea can be illustrated by considering the example of anticipating the potential effects of a particular land use decision on the future state of an ecosystem. In this case, the components of the system model are the concepts that describe interrelationships between the hydrology, geology, and biology of the system. Often, the conceptual model can be transformed into a numerical simulation. Numerical simulations can then be employed to conduct sensitivity tests to quantify the influence of each factor or process in the conceptual model on the future state of the system. Results of numerical simulations are only as reliable as the input data and the degree to which the conceptual model approximates reality. However, a first-generation model can be utilized to assess what input data are most useful for improving the model and, hence, to prioritize data gathering. Subsequently, newly acquired data generate modifications to the model. These adjustments may lead to shifts in data gathering priorities. The model evolves as data gathering proceeds. As the model improves, the understanding of the system may improve.

The value of using models to manage and predict the behavior of natural systems differs to some extent with the time scale of the system being modeled, however. A recent report *A Vision for the National Weather System: Road Map for the Future* (NRC, 1999e) provides an example of how weather prediction models have improved over a span of 50 years. The improvements in weather predictions may not offer a good analogue for modeling systems that operate over much longer time scales, however. Weather predictions are concerned with phenomena at most several days to a week in the future (indeed, accuracy falls off rapidly when the predictive horizon recedes beyond this time scale), and it is possible to make—and verify—millions of weather predictions each year. Accuracy can therefore be rigorously and repeatedly tested against reality—unlike predictions of phenomena that unfold on geological time scales. This capacity for feedback also means that scientists who model weather can continually improve the models on the basis of comparisons between their models and real weather (Roebber and Bosart, 1996). Some branches of science that are concerned with slowly acting or rare processes do not have this luxury for most of the systems that they model.

The USGS's traditional emphasis and strength is empirical science. Of course, individual scientists or small groups of scientists develop conceptual models, but these are often implicit and abstract, rather than explicit and testable. It is rare for USGS scientists in the GD and BRD to carry conceptual models to the stage of numerical simulation and then go on to reevaluate data needs. On the other hand, the hydrogeologists in WRD were largely responsible for the development, testing, and widespread application of numerical models of groundwater flow and contamination in the 1970-1980s. Their work has disseminated into the private sector and provides one of the best examples of the USGS's innovations bearing fruit in the private sector. For systems with multidisciplinary characteristics, the conceptual models developed by individual scientists are likely to be inadequate, because individual scientists tend to de-emphasize or omit model components from outside their own disciplines. The USGS is in an excellent position to manage true integration in the application of environmental models.

The need for integrative models, or performance assessment models, has been recognized in other contexts. However, there is no tried and true recipe for constructing or using them in the design and execution of research programs or in public policy. Integrative models are being developed in studies of land use or cover change (Frederick and Rosenberg, 1994; NRC, 1998c). Better-known examples are general circulation models (GCMs) used to predict the effects of greenhouse gas emissions on future global climate (NRC, 1998a), and meteorological models used by the National Weather Service (NWS) to generate weather predictions (NRC, 1999e). Model shortcomings drive scientific inquiry—both for additional data and for improvements in model formulation. In all cases, the environmental models are inadequate to fully represent natural and human systems, and therefore they must be applied with great care and with continual interaction between scientists and those who are applying model results to real-world problems (Sarewitz et al., 2000). The USGS is well placed through its role as a natural, science agency, its connections with various agencies and interest groups concerned with altering natural systems, and its respect within the academic community to act as a balanced and well-informed adviser about the development and appropriate application of environmental modeling to issues of great and widespread social concern.

The USGS as a Scientific Information Portal

The committee envisages the USGS of the twenty-first century as the key natural science and information agency for the DOI. The USGS is well positioned to develop and maintain the framework for a geospatial information depository and portal for the DOI, providing access to a wide range of science information and derivative products that can support effective decision making. In this role, the agency would:

- be responsible for integrating the nation's topographic, geologic, hydrologic, biologic, soils, land-cover, and demographic geospatial databases, among others, to make them interoperable for the scientific and public good;
- be responsible, as the lead agency of the Federal Geographic Data Committee (FGDC), for promoting and coordinating the continued development of the architecture for the NSDI, where database content would not be limited to scale, but populated, archived, and accessed in ways that maintain the integrity of the data at a wide range of positional and content accuracy (NRC, 1993a, 1994, 1995a); and

- be responsible for developing national mapping and product specifications, with an increasing focus on derivative and value-added products and quality assurance standards.

Historically, the USGS focused its scientific and data collection efforts on the survey and classification of public and undeveloped lands in support of natural resource exploitation. It served as one of the nation's primary sources of natural resource information. Since its inception, the USGS has been the federal government's primary mapping agency of the nations' surface and subsurface features (Sidebar 4.3).

More recently, the USGS developed programs that reflect the federal government's need to respond to emerging issues. Examples range from local to national scales and address issues such as emergency response to natural disasters, urban expansion and open space, the increasing concentration of population and infrastructure in the coastal zone, the interface between cities and agricultural and wild lands, place-based planning, and the environmental geology of development activities. These and other issues require databases that are more accurate, more current, and at higher levels of detail than those of the basic topographic quadrangle maps provided traditionally by the USGS (Sidebar 4.4).

To fulfill this requirement, it is necessary to ensure that heterogeneous geospatial data, collected by scientists from multiple disciplines, can be integrated into a comprehensive and compatible data architecture upon which the user community may rely. In order to meet this challenge, the USGS should play a leading and facilitating role in shaping national policy on geospatial data and developing an interoperable capability that will make it the portal (i.e. a primary access point) for both digital and analog forms of integrated science data in the DOI and other federal agencies that maintain geospatial databases. The committee believes that it is in the public interest and a federal responsibility for the research, identification, implementation, and development of an interdisciplinary, multidatabase architecture that will allow disparate databases to become nondestructively interoperable in a common geospatial context and sustainable. The interoperability of databases requires interdisciplinary semantics research for development of a scientific *lingua franca.* This research and development is important because it enables sharing of data from interdisciplinary sources, it avoids duplication of expenses, and it facilitates scientific discovery and advancements.

SIDEBAR 4.3

NATIONAL MAPPING DIVISION: FROM TRANSITION TO TRANSFORMATION

The traditional role of USGS as a mapmaker needs to be redefined for a variety of reasons. First, the role of traditional cartographers has changed dramatically and will continue to change. The mapping sciences are rapidly converging into the spatial information sciences because of the advent of advanced technologies including automated cartography, GISs, GPS, and digital data from terrestrial, airborne, and satellite sensors. Essentially, the role and form of a map have changed. Maps were at one time the products of a cartographer who selected what features to portray at specific scales; today, the map user is empowered to construct a map from a series of data elements drawn from geospatial databases. Once a matter of symbols and line work representing natural and human-made features, the “modern” map can be a dynamic and multidimensional ensemble of symbolized data and imagery. Mapping is now primarily the integration and portrayal of multiscalar, multimedia, and multisource geospatial data, created by retrieval of data from databases and manipulated by GIS tools to create tailored information products.

The USGS is now in a position to become the lead civil agency for undertaking both basic and applied research leading to the development of methodologies and the promulgation of standards for the development of geospatial databases. Because many USGS data collection and mapping activities can now be privatized (e.g., the production of basic topographic quadrangle maps), the traditional role of the USGS as a primary production facility is dated. In the future, the USGS can maximize its influence and stature as a standard-setting and quality assurance body and as the primary conservator of the nation's geospatial science data.

Like the USGS, other DOI bureaus and federal science and management agencies that rely on geospatial data are developing databases from their data collection and monitoring activities. The underlying problem is a lack of interoperability among these geospatial databases. Databases that reflect the needs of their designers are disparate in character and not readily shared. The heterogeneity of geospatial

SIDEBAR 4.4
NATIONAL BIOLOGICAL INFORMATION INFRASTRUCTURE

An emerging area of potential international leadership for the USGS is the field of biodiversity informatics, including the design of systems for compiling and disseminating biological and ecological information and for documenting the provenance and quality of these data. As the importance of biodiversity conservation and sustainable use has grown around the world, the need for credible and readily accessible information is one theme that is bringing together the community of nations. By developing a national approach for using the Internet to distribute biological information —the National Biological Information Infrastructure—the USGS has been at the forefront of these efforts and is playing a key role in encouraging other nations to develop similar, linked capabilities. The USGS has developed a clear leadership role within the U.S. government. Its efforts can be regarded as meeting national interests both directly and by influencing the conservation of biodiversity outside the United States, an issue that has been clearly identified by the U.S. government as one of national interest. This work has involved participation in a series of international biodiversity information initiatives including the trinational (Canada, United States, Mexico) North American Biodiversity Information Network (NABIN), the Western Hemisphere-wide Inter-American Biodiversity Information Network (IABIN), and the global biodiversity clearinghouse developing under the auspices of the Convention on Biological Diversity.

A recent report by the President's Committee of Advisors on Science and Technology (PCAST, 1998) has recommended that the funding for NBII be increased fivefold to develop standards and construction of the next-generation NBII. The new system would include “regional nodes at which computer scientists, information scientists, biodiversity and ecosystem scientists, and sociologists, using leading-edge tools and technologies, will work together to develop true interoperability among multiple database types, new software tools for gathering, analyzing and synthesizing data, new means of scientific collaboration, new means of presenting computational results so that biodiversity and ecosystems research findings can be more readily applied in management and policy” (PCAST, 1998).

databases is an obstacle to the development of integrated science at the USGS. The committee recommends that the USGS address this problem through research, standards, and application of integration methodologies. Implementation of this recommendation is contingent on the federal government is (1) recognizing the importance of this role and (2) making available the resources that are commensurate with the magnitude of the task.

The USGS is ideally situated to identify, develop, and implement an optimal multidatabase architecture. This architecture would allow disparate USGS databases to become interoperable and sustainable and would enable data sharing with other federal science agencies. In partnership with its federal, state, local, and private clients, the USGS needs to identify, promote, and set specifications and procedures for database architecture. Products and standards reflecting the availability of high-resolution satellite imagery from commercial satellites should be adopted as the primary data source for topographic mapping and related thematic geospatial databases, with the National Technical Means Program[2] and aircraft imagery as supplemental sources.

The USGS no longer enjoys a comparative advantage over the private sector in the production and dissemination of all of its traditional data collection and mapping products. Consequently, the committee believes that it is appropriate for the USGS to give consideration to (1) outsourcing production and dissemination (sales) of nonspecial data collection and mapping products and (2) placing emphasis on geospatial information integration; GIS database content; and database quality, maintenance, and interoperability. Already, the USGS has begun to outsource activities, such as the production of its digital orthophoto-based quarter quads, that lend themselves to specification, outside production, and quality control. The emergence of commercial production capabilities and new technologies—particularly in data collection, information handling, and dissemination—provides an opportunity to transform the NMD into a robust data integration facility for the USGS and its multiple audiences.

[2] The National Technical Means Program performs applications development and transfer of classified data and technology to civilian agencies.

Other Program Areas

As part of its role as a scientific information portal, the USGS should exercise leadership in other areas that fall within the agency's responsibilities. Two important functional areas are (1) monitoring, reporting, and where possible, forecasting critical phenomena (e.g., seismicity, volcanic activity, streamflow) and (2) assessing natural resources.

An example of the first area is the USGS effort in earthquake monitoring, assessment, and research. The U.S. earthquake monitoring and basic research system is supported and operated by the USGS and the NSF-funded Incorporated Research Institutions for Seismology (IRIS) in collaboration with university and other partners. This system includes a large number of stations, including the USGS's National Seismic Network (NSN) broadband stations, that are used to monitor earthquakes in the seismogenic regions of the United States and typically involve digital recording, continuous telemetry to central processing sites, and automated arrival detection and earthquake location procedures (Figure 4.1). This national effort is part of a larger international effort that includes thousands of seismic stations that contribute data to the International Seismic Center (ISC) (Figure 4.2). A major objective of the national and international monitoring systems is the rapid location and analysis of earthquakes for emergency response and hazard mitigation. As an earthquake monitoring agency, the USGS's National Earthquake Information Center needs to acquire data in near real time to provide rapid assessment of international earthquake disasters to the State Department, which must deal with U.S. interests regarding disasters around the world. The USGS interest in global earthquake monitoring is also stimulated by the fact that the worldwide study of earthquakes is an effective way to understand the nature of these phenomena and the natural hazards within the United States (NRC, 1995b).

Natural disasters are a growing concern nationally and internationally (GDIN, 1997). In the United States, natural disasters occur nearly everywhere and include earthquakes, volcanic eruptions, landslides, floods, tornadoes, and hurricanes (Figure 4.3). The provision of accurate, timely, integrated information from the USGS and other sources can be used to reduce losses from natural disasters. The USGS is encouraged to play a stronger role in the disaster information community in the future than it has in the past. The USGS has the responsibility to monitor

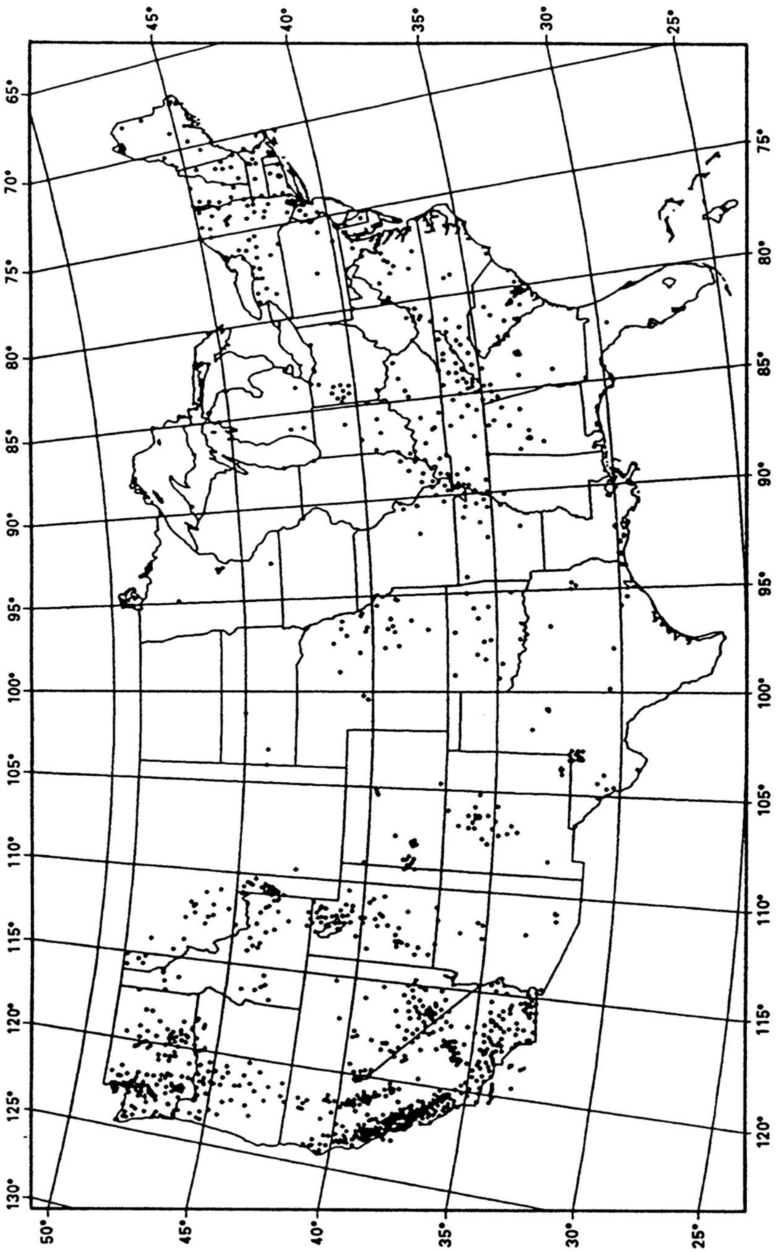


Figure 4.1 Stations operated by the USGS for routine earthquake monitoring. SOURCE: NRC, 1995b.

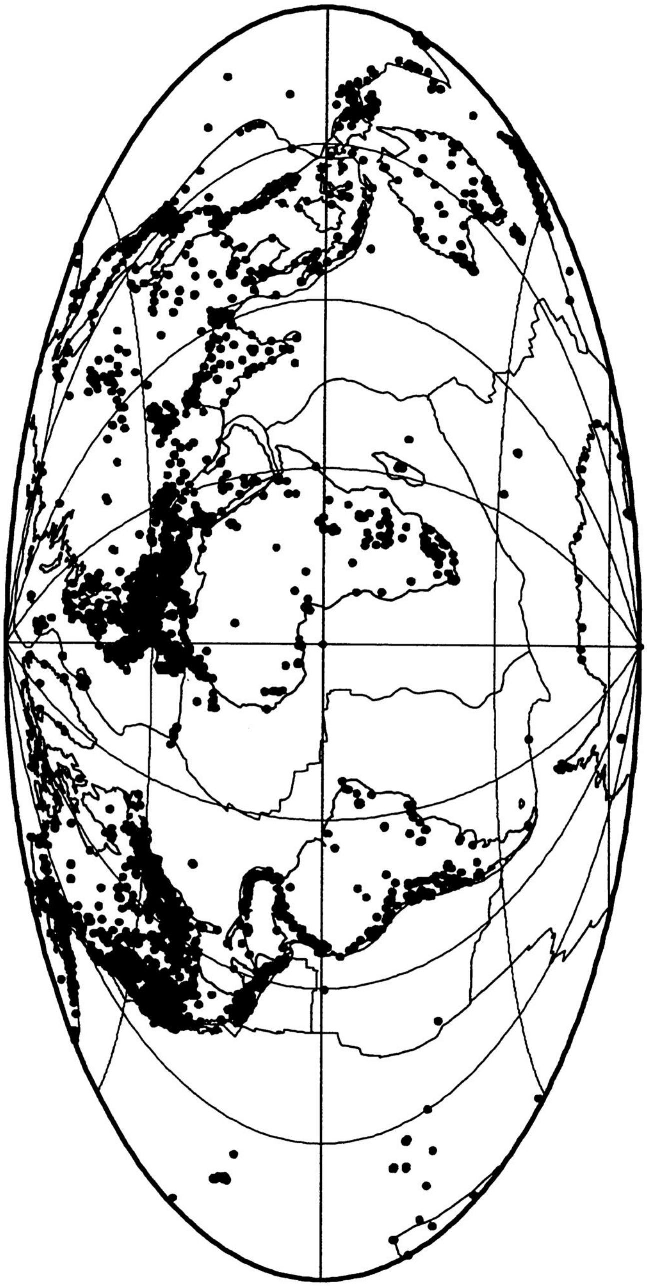


Figure 4.2 Seismic stations that contribute data to the International Seismic Center. SOURCE: NRC, 1995b.

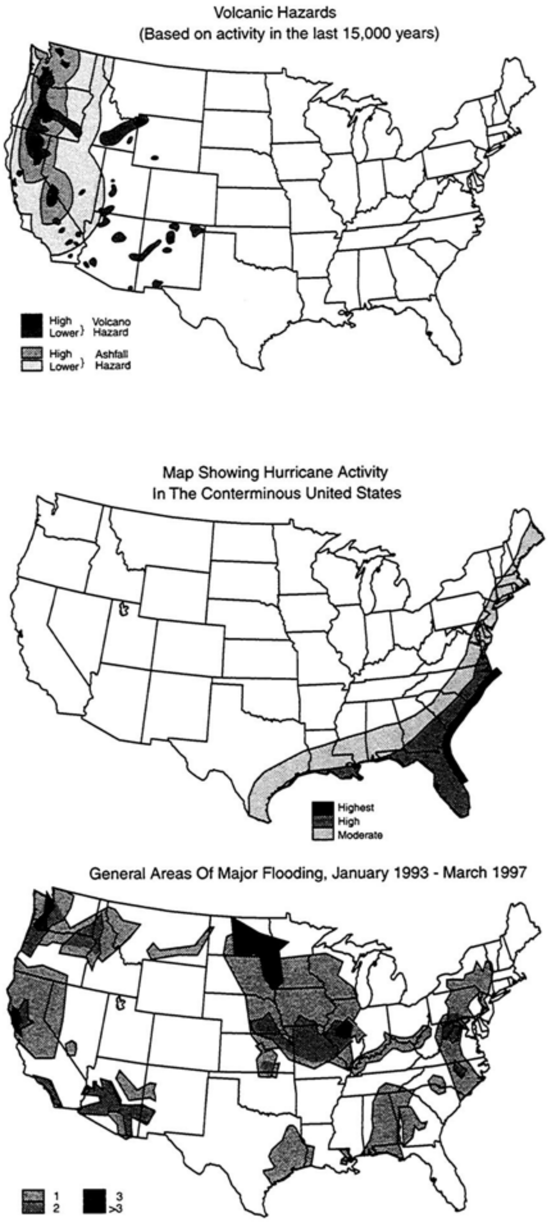


Figure 4.3 Primary extent of potential natural disasters in the United States. SOURCE: GDIN, 1997, p. 10.

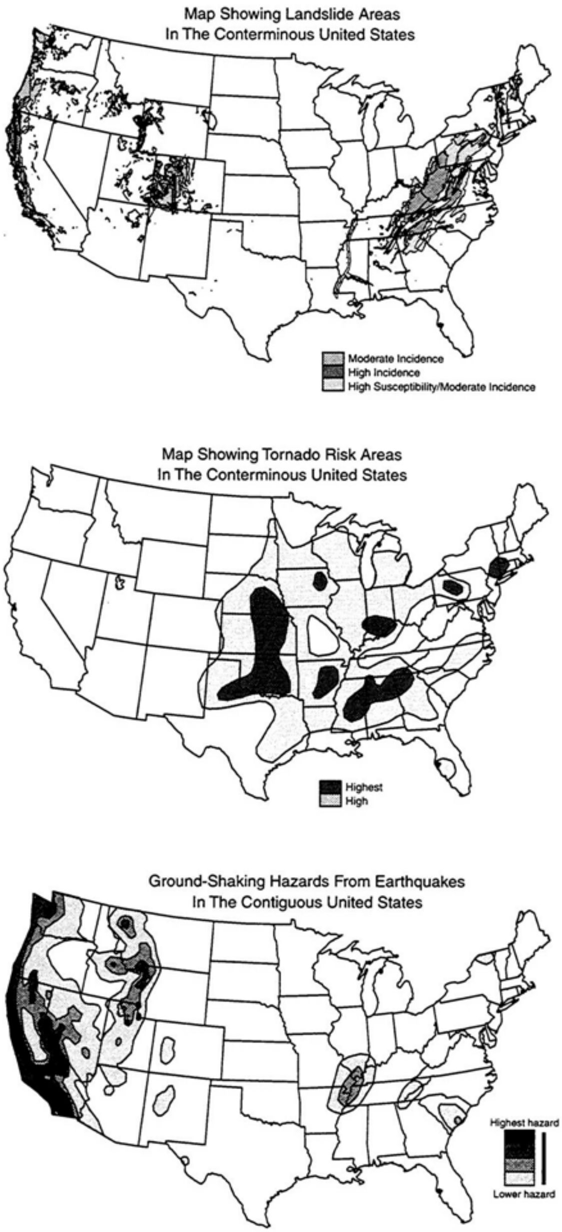


Figure 4.3 Primary extent of potential natural disasters in the United States. SOURCE: GDIN, 1997, p. 10.

and issue warnings for earthquakes, volcanic eruptions, and landslides, as well as to monitor floods. It also has the responsibility to make disaster-related information available to disaster managers. Although disaster managers are finding it easier to obtain and share relevant information than in the past because of the Internet, data formats and reliability as well as accessibility remain problematic. The USGS, as the recommended portal for integrated digital natural science data, is urged to provide national leadership in this area. For example, the agency already has Global Disaster Information Network (GDIN)-type prototype networks and could easily become the lead player.

The USGS should maintain and enhance its leadership in the area of assessing resources. For many years, the USGS has provided assessments of energy, mineral, and water resources and, more recently, of biological resources as well. Previous NRC reports have praised the USGS for the comprehensiveness and relevance of its energy, mineral, and water resource investigations and provided strategic guidance for the future of these activities (NRC, 1991, 1996a, 1999d). For example, the 1999 review of the USGS Energy Resources Program "found the 1995 domestic oil and gas assessments to be effective, of high quality, and a substantial improvement over previous assessments" and commended the Energy Resources Program "for its productive consultations with states and industry and for the innovative methods to disseminate the results (NRC, 1999d). The same report observed that the data compiled in the USGS's world oil and gas assessments "are much in demand. Both federal agencies and energy companies have found its products to have significant value" (NRC, 1999d). It also encouraged "the Energy Resources Program to evaluate whether the effort on world energy resource assessment and supporting research should be increased above present levels" (NRC, 1999d). Since the publication of the report, the USGS has released its world oil and gas assessment for 2000, which is based on geology and statistical analysis. Resource assessments— energy, minerals, water, and biological resources—comprise critical information that should be provided by a federal science agency. As the United States progresses into the twenty-first century, natural resources essential to the economic and strategic security of the nation will be subject to much greater pressures than in the past. By providing national leadership in offering natural resource information, the USGS will help the United States understand its future natural resource needs.

INTERNATIONAL ACTIVITIES

Many of the current and emerging science challenges discussed in Chapter 3 are not the province of any one nation. They are global and international in nature. To address these challenges in the twenty-first century, the USGS is encouraged to play a stronger international role, on behalf of the United States, in order to accomplish its mission. The committee believes that the importance to the United States of USGS international activities and collaboration cannot be overstated.

The USGS, which has been operating internationally for more than 100 years, defines its role in the international arena in terms of promoting U.S. national security and policy interests, furthering U.S. private aspirations in the global economy, addressing global environmental interests, and improving the utility or effectiveness with which the USGS carries out its fundamental domestic mission. Specific examples of USGS activities for each of these four categories follow.

Role in U.S. national security and foreign policy interests:

- Providing information and technical assistance in responding to catastrophic earthquakes, landslides, volcanic eruptions, floods, and droughts in foreign countries.
- Providing technical assistance in the assessment of biological, water, energy, and mineral resources; and the development of data and information standards and regional data-sharing networks—recent examples include water resource assessment in Abu Dhabi; coal exploration in Pakistan and Armenia; petroleum geology in Russia and Ukraine; mineral assessments in Bolivia, Venezuela, and Costa Rica; a famine early-warning system for Africa; and the Inter-American Biodiversity network.
- Using scientific cooperation to create nonthreatening environments to facilitate communication and negotiation between hostile parties—examples of facilitation include the Regional Water Data Banks Project (Israeli-Palestinian-Jordanian water agencies) in the Middle East peace process (Sidebar 4.5) and communal activities between Turkish and Greek Cypriot water managers.
- Conducting studies to control the spread and reduce the impacts of nonnative invasive plants, animals, and pathogens that have been

intentionally or accidentally introduced from foreign countries into the United States.

- Providing technical assistance to international organizations in documenting, managing, and integrating biological data and information.
- Coordinating multilateral data sharing projects to ameliorate regional conflicts through the sharing of data and scientific expertise—examples include support provided to the U.S. State Department's Nile River Basin working group, and the Peace Through Seismology project, which coordinates seismology data sharing among countries in the eastern Mediterranean region.
- Providing expertise in the application of National Technical Means to address relevant national security issues.
- Conducting global assessments of energy and mineral resources.
- Maintaining and providing information and data from the Global Seismographic Network, a critical element in the Comprehensive Test Ban Treaty strategy (NRC, 1995b).

Role in furthering U.S. private sector aspirations in the global economy:

- Introducing and encouraging the use of U.S. equipment, methodologies, and software.
- Building regional and global databases of energy and mineral resources.
- Encouraging the release of data on energy and mineral deposits, geologic and topographic maps, and hydrologic data by foreign governments.
- Facilitating contacts between U.S. companies and foreign counterparts.
- Developing and disseminating standards and procedures for data and information processing and distribution, mapping, and hydrologic and geologic data collection and processing.
- Releasing U.S.-produced maps and data from foreign projects for potential use by the U.S. private sector.

Role in addressing global environmental issues:

- Developing global reference databases for use by climate modelers and other researchers investigating regional and global environmental trends. These include global digital elevation models (DEMs), as well as global databases for landcover, geology, drainage basin boundaries, ecosystems, soils, glaciers, and vegetation.
- Conducting studies of historic climatic and ecological changes in the geologic record to help understand the possible consequences of future climate change in ecosystems at different latitudes.
- Representing the U.S. government in organizations such as the International Hydrologic Program and Mineral Deposit Modeling Program of UNESCO (United Nationals Educational, Scientific, and Cultural Organization), Inter-American Dialogue on Water Management, International Union of Geological Sciences, International Geographical Union, International Union of Biological Sciences, the International Union of Geodesy and Geophysics, International Society for Photogrammetry and Remote Sensing, the International Cartographic Association, and the International Quaternary Association.

Role in improving the utility or effectiveness of the USGS's domestic mission:

- Obtaining scientific knowledge, insights, and data needed by domestic programs, such as knowledge of hydrologic, geologic, and biologic systems and phenomena, as well as mapping, remote sensing, and GIS technologies.
- Developing a better understanding of hazards (e.g., earthquakes, volcanic eruptions, landslides, floods).
- Coordinating studies to support increased cooperation in managing migratory species (e.g., migratory birds, anadromous fish, Arctic mammals, sea turtles), nonnative invasive species, and shared (transborder) ecosystems.
- Participating in international scientific professional societies.
- Adding to the knowledge and skills base of USGS scientists.
- Allowing comparisons of sites and situations within the United States to those in other parts of the world.

- Adding to the international and domestic stature of the USGS.

As the above examples illustrate, international activities of the USGS are designed to enhance domestic USGS programs and contribute to global knowledge and understanding of natural science problems. They also contribute technical assistance, technology transfer, and education. Given the increasing international and global nature of many natural science problems, there will be more opportunities in the future than in the past for the USGS to pursue international collaborative initiatives. Also, given the increasing international and global importance of natural science problems, the committee believes that the USGS should devote more resources to international efforts in the future than it did in the past.

FUTURE RESEARCH OPPORTUNITIES

The major societal trends outlined in Chapter 3 present many opportunities for the USGS to help the nation solve complex problems. Several recent NRC studies address research opportunities in

SIDEBAR 4.5
THE WATER RESOURCES DIVISION AND INTERNATIONAL HYDROLOGIC ISSUES

Activities addressing hydrologic issues are currently under way in 20 countries in the Middle East, Central America, South America, northern Africa, Asia, and the western Pacific. The WRD's expertise and high level of credibility are principal reasons for requests for help from the international community. For example, the WRD was asked to work with Israeli, Jordanian, and Palestinian water agencies in resolving difficult water allocation issues (NRC, 1999f). Through its expertise in hydrologic data network design and data management, the USGS has become a trusted facilitator in openly exchanging previously sensitive water data among all contentious parties. The project has been one of the few lasting successes of the Middle East peace process and shows how science can promote common understanding and reduce international tensions.

the environmental, hydrological, and earth sciences that may be of interest to the USGS as it plans its future science directions. These studies include *Our Common Journey: A Transition Toward Sustainability* (NRC, 1999b), *Global Environmental Change: Research Pathways for the Next Decade* (NRC, 1999j), and *Grand Challenges in Environmental Sciences* (NRC, 2000c). More specialized studies include *Hydrologic Science Priorities for the U.S. Global Change Research Program: An Initial Assessment* (NRC, 1999c), *Basic Research Opportunities in Earth Science* (NRC, 2001), and *Envisioning the Agenda for Water Resources Research in the Twenty-First Century* (NRC, in preparation).

Instead of developing a long list of research opportunities, the committee identifies the following topics, grouped around the USGS's three major themes, which are regional to national in scale and coincide with the scientific mission and capabilities of the USGS. The committee intentionally has not prioritized these topics.

Hazards:

- Effective hazard information for communities in high-risk environments
- Hydrologic processes and hazards
- Wildfires and public policy

Environment:

- Global climate change
- Climate variability and water resources
- Links between geologic processes and human health
- State of the nation's ecosystems
- Restoration of aquatic ecosystems
- Investigations to support wise urban development in the West

Natural resources:

- Life cycles of ore materials
- Geologic frameworks for transition to a methane fuel economy

Short discussions of how the USGS can contribute to each broad topic follow. Because the USGS must plan its own research agenda, these suggestions are intended to be illustrative of the sorts of issues that a future research agenda might embrace.

Hazards

Effective Hazard Information for Communities in High-Risk Environments

Because of lack of knowledge, convenience, or economic benefit, a large number of people in the United States and in foreign countries live in dangerous environments. People live on floodplains, in places prone to earthquakes and landslides, and in areas close to active volcanoes. The USGS has programs of high technical quality that define the risks from, and provide disaster information and warnings about, each of these natural hazards. These programs could be strengthened, in budget and personnel, which would provide increased opportunities for enhanced monitoring, for process studies, and for incorporating more social science for risk analysis, economic valuation, and effective education. The disaster management community in the United States and foreign countries would benefit substantially from the results of more comprehensive hazard mitigation studies by USGS scientists.

An example of a USGS program that provides valuable hazard information is the Volcano Hazards Program (VHP), (NRC, 2000b). The VHP has developed investigations of exceptional scientific quality and has maintained enduring, informal links between scientists and decision makers in communities facing imminent risk from volcanic eruptions (Sidebar 4.6). The Volcano Disaster Assistance Program (VDAP) is a cooperative effort of the USGS and the U.S. Agency for International Development (USAID)/Office of Foreign Disaster Assistance to assess and monitor volcano hazards. An outstanding example of the success of VDAP occurred in the Philippines during the Mt. Pinatubo eruption of 1991. A prompt effective response on the part of the VDAP team placed scientists with expertise in monitoring and interpretation at the disposal of the Philippine government. Working side-by-side with Filipino volcanologists, USGS scientists provided accurate and effective warnings that saved thousands of Filipino lives and millions of dollars of U.S. military equipment.

In the United States, natural events such as hurricanes and earthquakes have cost numerous lives and billions of dollars in property damage during the last decade. Disaster losses are reduced when people at risk take appropriate action based on the best information available. As more people, infrastructure, and investment continue to concentrate in high-risk areas (e.g., the coastal zone), it is important for the USGS, as one player in the broad disaster community, to develop detailed hazard maps for every town and city in the United States. Strong coordination with other players such as other federal agencies (e.g., NOAA), state and local agencies, universities, and many private organizations is encouraged. The hazard maps will be helpful to the Federal Emergency Management Agency (FEMA), which leads the federal response to major disasters, as well as to other disaster managers and planners.

SIDEBAR 4.6

COMMUNICATING HAZARD INFORMATION EFFECTIVELY: VOLCANIC UNREST IN LONG VALLEY, CALIFORNIA

The eastern Sierra Nevada town of Mammoth Lakes lies inside the 15-by 30-km Long Valley caldera, one of the largest in the United States. The caldera is crossed by young rhyolite lava domes, craters, and open fissures. The most recent eruption occurred 250 years ago.

In May 1980, earthquake swarms associated with a 25-cm uplift of the caldera floor aroused concern in the area. Establishment of leveling lines and a larger seismic network affirmed that the uplift and earthquakes could possibly be associated with magma ascent. Geoscientists debated the possibility of an eruption. Meanwhile, angry residents, worried about losing business and declining real estate values, began to threaten the scientists. The poor communication skills of the scientists and poor understanding of geologic processes by the residents caused the confrontation.

From the early 1980s to the late 1990s, during another period of geologic unrest, communications improved between USGS scientists and the public. During this period of personal contact, geologists became well known in the community, and they increased public understanding of the potential risks of an eruption. A color code was established for ranking activity levels, ranging from “green” for no immediate risk to “red” for an eruption in progress. In addition, a Web site provided real-time geophysical data, explanations of volcanic activity, and a history of volcanic activity in the area. Years of constant contact built trust between USGS scientists and members of the public.

Hydrologic Processes and Hazards

The nation's inhabited river floodplains are susceptible to large monetary losses through flood damage to land and infrastructure. They are also vulnerable to losses of ecosystem functions and other environmental values that are either destroyed or withheld as a result of society's attempts to reduce economic losses. Presently, most USGS investigations of flood-prone valley floors are focused on the refinement of the definition of the flooding hazard. This role is valuable, enabling the agency to serve the nation with assessments and information. Because of the refractory nature of the conflict between flood hazards, society's determination to maximize the use of floodplains, and the increasing value placed on floodplain ecosystem functions, there is an urgent need to broaden the nature of investigations of inhabited floodplains.

Therefore, a good opportunity exists for the USGS to link its hazards and environment research themes. Typically, hazards are viewed as “unpreventable natural events that ... expose our Nation's population to risk of death or injury and may damage or destroy private property, societal infrastructure, and agricultural or other developed land” (USGS, 2000a). However, hazards are also natural occurrences that play a role in preserving environmental health. Trying to understand and manage the human impacts of hazards without a holistic understanding of the environmental role of hazardous landscape shaping processes can be counterproductive (NRC, 1999g). Floods “can be extremely dangerous natural events, leading frequently to loss of life and property,” yet they also help “to maintain the high levels of biodiversity that are characteristic of riparian ecosystems, replenish fertile agricultural soils ... and transport sediment necessary to maintain downstream delta and coastal areas” (Haeuber and Michener, 1998). Thus, policies and practices aimed at limiting flood losses can have adverse effects on riparian ecosystems that are costly over the long term from economic and environmental standpoints.

If policy decisions about natural hazards are to be beneficial over the long term, hazards must be treated as processes that occur within natural systems that include society, not as discrete events that act on human society. In this view, the scientific approach to hazards must be unified. The diversity of scientific expertise at the USGS presents an opportunity to achieve this unification. For example, flood management practices on alluvial valley floors are often inadequate because research and application of knowledge have been fragmented among disciplines and agencies. The USGS has the capability to conduct an integrative study of the hydrology, biology, and engineering that affect the conditions of valley floors as a basis for developing analytical and planning tools for decision making about land use, habitat preservation, and water quality (Sidebar 4.7). A comprehensive, multidisciplinary analysis of an appropriate floodplain could lead to the recognition of general principles applicable to both hazard and water resource management. Integrating studies of hazards and environmental processes is beneficial because it can provide valuable information. This information can lead to improved emergency response, preventive planning and zoning, reduction of and limits to financial impacts and liability, education and protection of the public, and rehabilitation of many valued landscape functions.

SIDEBAR 4.7

GRAND CANYON CONTROLLED FLOOD

When Glen Canyon Dam was closed in 1963, the Colorado River through the Grand Canyon began to change (NRC, 1987). There was an increase in riparian vegetation, especially the nonnative riparian tree tamarisk. Water temperatures no longer exhibited strong seasonal variations and became nearly constant at 8°C. Nonnative fish became more abundant, especially rainbow trout. An endangered native fish, the humpback chub, was in jeopardy. The river water became autotrophic instead of heterotrophic. A change also occurred in the geomorphology of the canyon shores and debris flow deposits that localize the major rapids (Webb et al., 1999).

At 6:15 MST on March 26, 1996, the U.S. Secretary of the Interior initiated the first experimental controlled flood in the Grand Canyon of the Colorado River. The controlled flood was meant to recreate the Colorado River's seasonal floodwaters that in the past prevented growth of vegetation on the channel banks, deposited sandbars, and eroded boulder deposits in the main channel left by flash floods in tributaries. Over the next seven days, Glen Canyon Dam released 45,000 cubic feet of water per second (USGS, 2000b). The event was a scientific experiment to determine the possible use of floods as a river restoration technique.

The March 26 experiment was made possible through a partnership of three divisions of the USGS and the BIA, USFWS, USBR, NPS, several academic institutions and Native American tribes, and the Arizona Game and Fish Department (Schmidt et al., 1998). USGS scientists created models of experimental flood discharge that convinced opponents that the experiment would work. In other words, the discharge would cause little harm to archaeological sites and existing protected species of animals and plants, would have beneficial effects on river recreational use, and would help control the invasion of some nonnative species.

The important role of USGS scientists cannot be overstated. They developed simulations of potential flood effects, conducted experiments based on well-crafted hypotheses, collected data, and formulated management questions before the experiment began. Their activities were closely coordinated with interested parties. The level of water release was not as high as the natural floods of the Grand Canyon in the past. As a result, the restructuring of the geomorphic surfaces was not overly dramatic. However, most of the predictions made by the scientists before the release turned out to be accurate, and virtually none of the consequences feared by some stakeholders occurred. In the end, as one scientist said, “The most important aspect of this project was that it happened at all” (Webb et al., 1999). This example illustrates the ability of the USGS to provide integrative science information and to cooperate constructively with stakeholders. It also shows how single projects involving multiple disciplines can deal with a variety of topics of general interest to the public such as endangered species, unwanted domination by nonnative species, habitat restoration, and water chemistry. In the future, the USGS will be called upon more often than in the past to conduct such complicated integrative studies.

Wildfires and Public Policy

Fire is an essential element of forests, shrublands, grasslands, and riparian systems and exerts a significant influence on numerous ecosystem functions (Pyne, 1982). Fire recycles nutrients, reduces biomass, influences insect and disease populations, and is the principal change agent affecting vegetative structure, composition, and biological diversity. Fires naturally reduce the amount of undergrowth and debris, allowing trees to grow taller and healthier. Smaller periodic fires reduce the intensity and magnitude of wildfires by reducing the accumulation of flammable fuels on the forest floor.

Wildfire suppression has changed historic ecological conditions. As humans alter fire frequency and intensity, many plant and animal communities are experiencing a loss of species diversity, site degradation, and increases in the size and severity of wildfires (Ferry et al., 1995). Fire exclusion from suppression efforts has resulted in a lack of periodic, natural fire in America's forests and grasslands. The absence of periodic, low-intensity fires has increased the risk of large, catastrophic fires and has negatively impacted the health of forests and grasslands in the United States.

In 1999, more than 93,000 fires burned almost 5.7 million acres in the United States. Although the number of fires has remained relatively constant over the past several decades, the number of acres burned has over the same period. The 1999 acreage represents a 55 percent increase over the 10-year average. In addition to firefighter fatalities and structures burned, air and water quality was degraded in some areas. The year 2000 has proved to be more devastating. As of September, there had been almost 78,000 fires that burned 6.7 million acres. Federal and state agencies, scientists, local fire chiefs, and others have indicated that the reduction of wildland fuel loadings is essential for reducing threats to property and resources and for restoring and maintaining ecosystem health and productivity. In order to minimize the threat of loss from fires, managers must be able to plan protection strategies that are appropriate for individual areas. A prerequisite for this planning is the ability to assess and map the potential for a major fire to occur.

Fire issues have led to the development of the Joint Fire Science Program, which is a partnership involving six land management and research agencies (USFS, BIA, BLM, NPS, USFWS, and USGS). The program was established by Congress and has a budget of about $8 million. The purpose of the program is to obtain information and tools for managers and specialists making decisions and conducting activities related to wildland fires.

In addition to its involvement in the Joint Fire Science Program, the USGS has several activities related to fire suppression and ecosystem health. For example, as part of the International Program at the EDC, the USGS initiated a fire potential index project to develop a model to assess fire hazard potential. The fire potential index model, which was developed jointly with the USFS Fire Laboratory, is based on national Fire Danger Rating Systems fuel models, relative greenness of Normalized Difference Vegetation Index from NOAA's Advanced Very High Resolution Radiometer, and 10-hour time lags in fuel moisture. Results suggest that the model is a potentially valuable fire management tool for land managers. The fire potential index is being calibrated for the conterminous United States on a daily basis, and this information is being displayed from the National Interagency Fire Center.

The USGS should play a more prominent role in scientific activities related to fires. Because many fire questions relate to hazards and environmental issues, the USGS should coordinate and lead more of the research needed. For example, the agency could conduct field experiments on the effects of fire on runoff and erosion and could model fire's effects on biota and on the chemical and physical characteristics of soil and water. The USGS could lead the mapping of fuel loads, erosion potentials, and effects on stream water quality and could motivate the exploration of options for management of the hazard through prescription burning.

There will be effects of any fire management strategy, or no strategy, on the condition of forests, as well as on rates of erosion and sedimentation and on water quality. This national-scale issue has components of hydrology, forest and rangeland ecology, soil science, aquatic biogeochemistry, and geomorphology. Addressing the problem also requires palynology, stratigraphy, and geochronology to define spatial and temporal patterns of precolonial forest conditions, and skills in spatial data handling for archiving and modeling. The USGS has all of these capabilities, together with the standing among agencies and Congress, to lead the effort. It could take the initiative to coordinate other agencies and academics to provide policy-relevant information on fires, an environmental management topic of national significance.

Environment

Global Climate Change

Involvement by the USGS in the nation's global climate change research enterprise is marginal, yet global climate change offers an array of scientific and societal challenges that fall within the expertise and mandate of the agency. Global change is a fundamental tenet of historical geology. The earth is an evolving dynamic planet. The history of global change is preserved in the geological record. As landmasses and oceans of the planet have changed, so too have the climate and character of life on earth. Only by fully understanding the natural changes of the past, can scientists begin to understand the role of humans as an agent of change. For example, the USGS should play a more prominent role in efforts to document anthropogenic influences on climate. The question of the effects of human-caused climate change, especially anthropogenic forcings that are expected to modify the earth's climate (Figure 4.4) (Mahlman, 1997), dominates political and diplomatic agendas, and lies at the forefront of scientific research as well. Detailed climate records covering the last several hundred years are needed to provide a base-line with which to evaluate the effects of anthropogenic emissions on climate. On centennial and millennial time scales, sea surface temperatures in the Sargasso Sea, calculated from oxygen isotopic data and corrected for salinity variations, indicate that variability has been greater than measured over the past four decades (Figure 4.5) (Keigwin, 1996).

Anthropogenic effects on climate can be understood only in the context of knowledge about the undisturbed climate regime; and such knowledge is derived from research in paleoclimatology; paleooceanography; and quaternary geology, including historical geology, geomorphology, and paleontology. The USGS can offer a strong observational and theoretical foundation in these and related fields in order to augment and test the results of coupled GCMs that dominate climate change science. The USGS can also contribute significantly to understanding the multiple causes of climate change, including human contributions from changing land use patterns and natural contributions from volcanism.

The implications of climate change for natural hazards fall squarely in the realm of the USGSs history of work on understanding, monitoring, and mitigating hazards. For example, catastrophic landslides in Nicaragua caused many of the deaths from Hurricane Mitch in 1998. These landslides, in turn, reflect surficial geology and land use patterns that are integral elements of any strategy to protect society against the impacts of climate, whether caused by humans or not. In other words, climate change is much more than a problem of atmospheric dynamics. Yet most research has been focused on understanding how the atmosphere behaves and how it will evolve. Greater USGS involvement

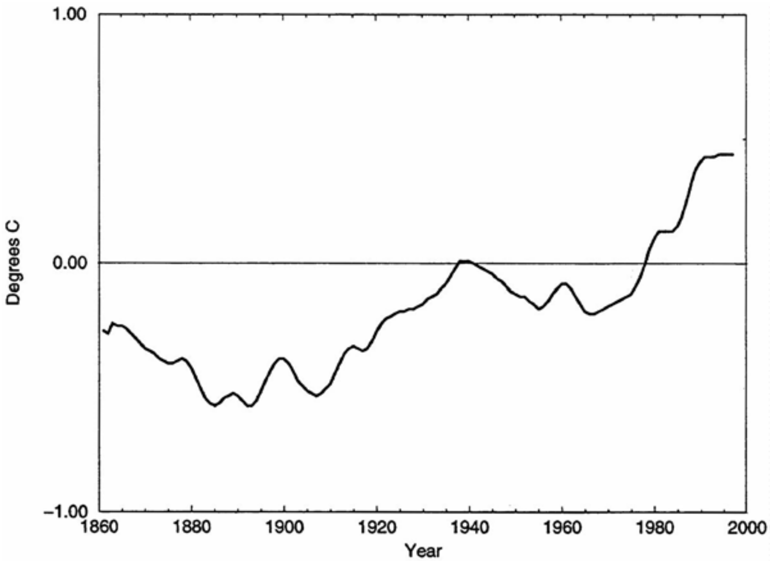


Figure 4.4 Annual global mean temperature for land areas from 1861 to 1997. The curve shows anomalies with respect to the mean temperature for the 30 years 1961-1990. SOURCE: NRC, 1999b, p. 85.

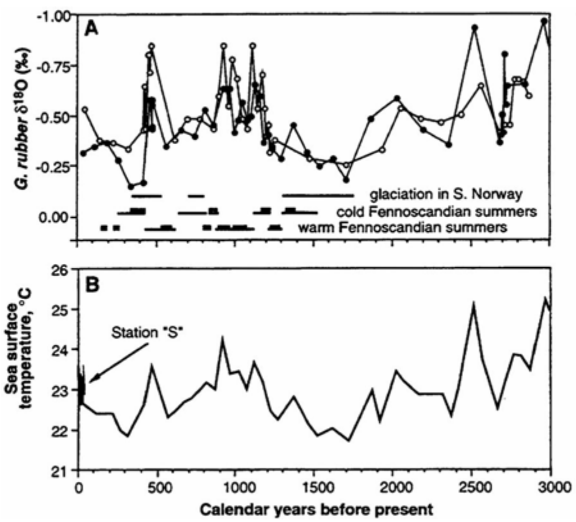


Figure 4.5 Sea surface temperatures in the Sargasso Sea, calculated from oxygen isotope data, indicate greater variability than has been measured over the past for decades. Reprinted (figure) with permission from Keigwin, LD., The Little Ice Age and Medieval Warm Period in the Sargasso Sea. *Science* 254:1504-1508, 29 November 1996. American Association for the Advancement of Science.

in the nation's climate research program could enhance understanding of the human consequences of climate variability and sensitivity and of the vulnerability of humans to climate variability (NRC, 1999h).

On a larger scale, the combined biological and hydrological expertise at the USGS offers the opportunity to make significant contributions to our understanding of the global carbon, phosphorus, sulfur, and nitrogen cycles. These four elements, along with others, are required for the existence of life. An improved understanding of these cycles is critical if we are to understand how human activities may be modifying the climate system. Today, humans use nearly half of the earth's terrestrial primary productivity, yet scientists do not completely understand the relative roles of biotic and abiotic processes in cycling these elements so that they remain available to living systems (Schlesinger, 1997). The USGS could play a significant role in studies of the cycling of elements critical to life. For a particular example, the USGS is unique among federal agencies in having the personnel and data resources to construct the carbon budget of the nation (including soil, vegetation, and fossil fuel consumption) under current, historical, prehistoric, and projected future land use scenarios.

Greater USGS participation in global climate change research would help to broaden the definition of the problem beyond the current focus on temperature change and atmospheric warming. The focus should be expanded to encompass a range of important issues such as social sensitivity and vulnerability to climate impacts, the influence of land use change on climate, and the value of ecosystem services for societal well-being.

Climate Variability and Water Resources

A central issue about natural and human factors in climate change is its effect on the availability of water in the form of streamflow, lake and reservoir storage, groundwater recharge, and soil moisture in the root zones of croplands and other ecosystems (NRC, 1999c). The nation needs a significant increase in assessments skill for water resource projections, including anticipating the role of interannual and interdecadal climate variations and defining policy-related uncertainties about the influence of climatic variability and secular changes.

A model for this role is the systematic attempt by NOAA to increase proficiency in the economically and socially vital activity of weather prediction, through improvements in monitoring and computing systems, and in collaboration with investigations and model development by agency and academic researchers. By contrast, the terrestrial phase of the hydrologic cycle has never received systematic investigation, and there is potential for updating modeling concepts and methods for predicting various components of the hydrologic cycle (such as soil-moisture patterns, the extent and duration of inundation, and the role of land-atmosphere feedbacks) at the national or major river basin scale. The atmospheric component of the problem is monitored and analyzed by NOAA, and large-scale aspects of the terrestrial phase of the hydrologic cycle are analyzed by academics collaborating with NOAA, NASA, and the USGS. However, there is potential for much larger and more articulated investigations of terrestrial hydrologic processes, including regional droughts and major floods in large river basins. This initiative could involve not only the maintenance of monitoring networks but also organizing field campaigns, assimilating information from earth and atmospheric monitoring satellites and weather forecasts, and development of large-scale mathematical models for assessment of the vulnerability of flood potential, drought, and related regional-scale phenomena. The role of the atmosphere, vegetation cover, and the hydrogeologic properties of landscapes could be integrated by such an effort led by the USGS. This effort could be combined with detailed mapping of topography, ecosystems, land use, and other infrastructure in valley floors to anticipate and monitor the effects of various hydrologic regimes.

The USGS could take on leadership of the broader U.S. water resources community to assess and report as appropriate on the role of hydrology in large efforts such as the Global Energy and Water Cycle Experiment (GEWEX) Continental-Scale International Project (GCIP) (NRC, 1998b) (Sidebar 4.8). This initiative is aimed at improving our understanding of the atmospheric and terrestrial phases of the hydrologic cycle within the Mississippi River Basin and then forging a strong hydrologic component of such national campaigns. The time is appropriate for the USGS to play a stronger collaborative role with NASA, NOAA, USACE, other federal agencies, and the academic community to provide the nation with studies and investigations that improve understanding and predictions of climate-related effects on water resources.

SIDEBAR 4.8

GLOBAL ENERGY AND WATER CYCLE EXPERIMENT CONTINENTAL-SCALE INTERNATIONAL PROJECT

The GEWEX Continental-Scale International Project is a multifaceted group of NOAA-sponsored activities designed to improve scientific understanding and the ability to model, for climate prediction purposes, the coupling between the atmosphere and the land surface on a continental scale. GCIP activities are focused on the Mississippi River basin to take advantage of the existing meteorological and hydrological networks that are being upgraded with new Doppler radar, wind profilers, and automatic weather stations. GCIP research involves a systematic multiscale approach to accommodate physical process studies, model development, data assimilation, diagnostics, and validation topics.

The GCIP Science Plan (World Meteorological Organization, 1992) defines the following objectives:

- to determine the time and space variabilities of the hydrologic and energy budgets over a continental scale;
- to develop and validate macroscale hydrological models, related high-resolution atmospheric models, and coupled hydrologic-atmospheric models;
- to develop and validate information retrieval schemes incorporating existing and future satellite observations coupled with enhanced ground-based observations; and
- to provide a capability to translate the effects of future climate change into impacts on water resources on a regional basis.

Links Between Geologic Processes and Human Health

Study of the interface between natural sciences and medicine is a nontraditional discipline that has been described by such terms as medical geology and geomedicine (Lag, 1983). A causal relationship between geochemistry and human health is highly plausible because many elements in the earth's crust are essential to our biochemical and physiological function. It is a potentially exciting field of inquiry because proper amounts and balances of several elements may help prevent disorders now of intense interest, such as some cancers and cardiovascular diseases, developmental defects, and a host of long-term, and therefore age-related, human ills. Critical studies are required to ascertain if particular illnesses such as multiple sclerosis, certain cases of anemia, and Kaschin-Bek disease[3] are geomedical problems. The intersection between natural sciences and allied health sciences remains an underexplored field. This intersection should be explored by the USGS in coordination with other agencies such as the National Institutes of Health (NIH).

Marked improvement in human health related to clean drinking water and adequate water for sanitation is a major achievement of public health in developed countries. More recently, increasing attention is being given to the full consequences for human health of large-scale alterations in the biogeochemical cycles of both major elements and trace metals. In addition to health outcomes that may stem directly from polluting substances, there is growing evidence of indirect effects of human-induced changes in the environment on the emergence and spread of disease vectors for Lyme disease, malaria, dengue fever, cholera, yellow fever, and hantavirus. Scientists in the USGS, for instance, have in-depth knowledge of biogeochemical cycles, food chain contamination, and factors that affect water quality and quantity. In addition, they have the expertise that should enable them to investigate complex, interdisciplinary problems that span multiple spatial and temporal scales. They have the capability for spatial data analysis (risk factor mapping) that can be applied in environmental epidemiology for disease cluster analysis. In disaster epidemiology, geological information is needed to understand the proliferation of waterborne pathogens following floods, earthquakes, and disruption of the water supply. Clearly, the USGS has the ability to make important contributions to the study of the health of human communities using established tools in biogeochemistry.

The effects of climate change on human health can be profound— from changes in the quantity and quality of potable water supplies to the spread of vector-borne diseases such as malaria. Changes in the temperature of the atmosphere and earth's surface, as well as the amounts and areal or seasonal patterns of precipitation, probably will result in some regions becoming drier and others wetter (NRC, 1999b). The incidence of floods, storms, landslides, and droughts will change.

[3]A disease of the musculoskeletal and connective tissue that results from consumption of water contaminated with fluoride.

Many physical processes that can impact the partitioning, distribution, and effects of toxic contaminants and the risk to humans are also susceptible to change in climate. Climate-related changes in the hydrological cycle can, in turn, affect biological systems by changing their productivity, composition, and diversity and food web relationships. The relationships between climate change, geological processes, and human health provide opportunities for holistic scientific investigation.

State of the Nation's Ecosystems

When the BRD was added to the USGS, it expanded the agency's potential to deal with biological issues of importance to the nation. These issues include the assessment of the nation's ecosystems and the scientific basis for ecosystem management. Several critical questions have been posed (Lubchenco et al., 1991):

- What are the patterns of the diversity of nature and what are their critical ecological and evolutionary determinants?
- What factors control the sizes of populations?
- How are changes in population size related to processes mediated at the level of the individual?
- How does fragmentation of the landscape affect the spread and persistence of populations?
- How do patterns and processes at one spatial or temporal scale affect those at other scales?
- What are the feedbacks between the biotic and abiotic portions of ecosystems and landscapes?
- How do climatic, anthropogenic, and biotic processes regulate geochemical processes?

Interactions among life scientists, geologists, geographers, and experts in surface and groundwater hydrology are required to address these broad questions, as exemplified in a recent NRC report *Grand Challenges in Environmental Sciences* (NRC, 2000c). Consider the significant ecological consequences of land and water use changes, for example (Sidebar 4.9). Documenting these changes and studying the mechanisms by which such changes influence existing systems are important to the nation's economy and to the protection of a suite of natural ecosystems. The USGS has the capability to play a strong role as a source of information on ecosystems in the future and to capitalize on society's interest in the conservation of biodiversity, the potential effects of climate change, the cause of the invasion and spread of non-native species, and the sustainability of the biosphere.

SIDEBAR 4.9
GREAT LAKES ECOSYSTEM

The Great Lakes, with a shoreline of more than 10,000 miles, are a major geological feature in North America and an important natural resource. These lakes contain approximately 20 percent of the surface freshwater available on earth and about 80 percent of surface freshwater in North America. Nearly 40 million people live in the Great Lakes watershed, which is one of the more industrialized regions of the country. The demand for high-quality relevant data concerning the health of various components of the Great Lakes ecosystems has risen rapidly in recent years. Billions of dollars and huge resources have been expended in the United States and Canada in an effort to reverse the effects of culturally-induced eutrophication, toxic chemical pollution, overfishing, habitat destruction, and the invasion of nonindigenous species. Environmental managers are being required to demonstrate that past programs have been successful and that a commitment of additional resources Would yield significant benefits. One way to measure the health status of the Great Lakes is to develop a suite of diagnostic indicators that quantify the condition of the ecosystem and identify its primary stressors at local to regional scales. The diagnostic measures can be used to characterize landscape and lake attributes and to derive a range of environmental end points such as watershed quality, nearshore/offshore biological conditions, habitat suitability, and water quality.

The USGS operates a regional BRD office with biological stations and research facilities on each of the Great Lakes. This regional laboratory has unique capability for research on fish communities (e.g., community dynamics, life history, trophic level), aquatic habitat (e.g., biodiversity, species biology, ecosystem health assessment), watershed characterization (e.g., fire ecology, species biology, wetland ecology, stream contaminants), and ecosystem modeling. In addition, the USGS's WRD, which has offices in all Great Lakes states, conducts research on local hydrogeologic problems including contaminant hydrology. Although the BRD and WRD make important contributions to solving site-specific problems, little effort has been made to coordinate monitoring and research efforts to provide a basin-wide perspective on the conditions of Great Lakes' ecosystems. A comprehensive ecosystem approach to managing the resource capital of the Great Lake is needed.

In terms of the available expertise and research facilities, the USGS is well positioned to play a key role in multidisciplinary investigations to characterize the Great Lakes as a whole and assess their health conditions. The agency has the tools and expertise to undertake a systematic evaluation of the biological, chemical, and physical processes at multiple scales, ranging from individual communities to the entire watershed. Such a multidisciplinary research program, using integrative indicators, could provide environmental managers and the general public with information about changes to the ecosystems of the Great Lakes as well as probable consequences of changes in environmental end points and likely results of various risk management scenarios. An analysis of trends in environmental measures could provide a perspective on whether conditions are improving or deteriorating, as well as how the lakes are responding to present controls and remedial measures. Integrative, multidisciplinary projects that address the health of Great Lakes ecosystems offer an opportunity for the USGS to play a leading role in the provision of technical advice for the management and protection of this precious natural resource.

natural ecosystems. The USGS has the capability to play a strong role as a source of information on ecosystems in the future and to capitalize on society's interest in the conservation of biodiversity, the potential effects of climate change, the cause of the invasion and spread of non-native species, and the sustainability of the biosphere.

The national Gap Analysis Program (GAP) provides broad geographic information on the status of species and their habitat in order to provide land managers, planners, scientist, and policy makers with the information they need. Gap analysis is a method for identifying the degree to which native animal species and communities are represented in our conservation lands. This program is sponsored and coordinated by the USGS and is its principal program to assess and map ecosystems across the United States. Presently, GAP is made up of more than 445 contributing organizations in 44 states (USGS, 1997b). These partners include businesses, universities, state and federal agencies, tribes, and nongovernment organizations.

Currently, EPA, USFS, NPS, USBR, BLM, several agencies charged with fisheries and aquatic mammal management, and other agencies deal with issues of ecosystem management. Many scientists of the BRD were involved with ecosystem management before they joined the USGS. Ecosystem management requires not only biological data, but also geologic and hydrologic data on patterns of physical and biological features, much of which can be obtained using remotely sensed imagery. Clearly, the USGS, through coordinated research, is well suited to assist and, in many cases, to lead such studies.

Restoration of Aquatic Ecosystems

Since the 1970s, the functions of aquatic ecosystems and the value of aquatic systems to society have become better understood and interest in the holistic process of the restoration of aquatic ecosystems has increased (NRC, 1992a, 1995c). Restoration efforts in a part of the Florida Everglades hydrologic-biologic system (Sidebar 4.10) are perhaps the most visible current expression of this national interest, but there are other important restoration efforts under way. Progress is being made to restore the Chesapeake Bay, an economically and ecologically important estuary (CBP, 2000). The CalFed Bay-Delta Program is attempting to improve ecosystem functioning, water quality, water supply, and levee integrity in the Central Valley of California (CalFed Bay-Delta Program, 1999). There is interest in the removal of obsolete dams in the Pacific Northwest that block fish runs and affect the quantity and timing of water flow in rivers as well as flow velocities, water chemistry, and water temperatures (NRC, 1996d). Both of these projects are collaborations of federal, state, and local partners.

Adequate technical information is needed to help guide and assess appropriate responses to these initiatives. A coordinated program of process investigations, monitoring, historical reconstruction, modeling, large-scale experimentation and performance assessment is needed. A federal science agency is necessary for the development of unbiased transferable data, information, and knowledge about aquatic systems. The USGS has the nationwide science infrastructure for this task; the range of technical expertise in terrestrial and aquatic biology, hydrology, sedimentation, and geomorphology; and the capabilities for monitoring, mapping, data analysis, problem solving, and information dissemination, as exemplified by the long-term estuarine study of the San Francisco Bay. Since 1968, the San Francisco Bay has served as an estuarine laboratory for the USGS.

SIDEBAR 4.10
SOUTH FLORIDA RESTORATION PROJECT

The Florida Everglades is the largest single wetland in the contiguous United States, covering an area of 1.5 million acres and extending from near Orlando in the north to Florida Bay in the south (Davis and Ogden, 1994). Since the mid-1800s, fully half of the Everglades has been drained and converted to agriculture and urban uses, and intense human activity has altered the remaining wetland. These alterations have been caused chiefly by diversion of water for human uses, reduction of water flows to protect against floods, increase to the nutrient supply of wetlands by runoff from agricultural fields and urban areas, and invasion of nonnative or otherwise uncommon plants and animals that outcompete native species. Populations of wading birds, including some endangered species, have declined by 85-90 percent in the past half-century, and many species of South Florida's mammals, birds, reptiles, amphibians, and plants are either threatened or endangered. The present management system of canals, pumps, and levees will be unable to provide adequate water supplies to agricultural and urban areas, or sufficient flood protection, let alone to support the natural, but severely damaged, ecosystems remaining as wetlands. The present system is unsustainable.

To meet the needs of increasing population and agricultural demands for water, and to begin the restoration of Everglades aquatic ecosystem to a more natural regime, an ambitious plan called the Central and South Florida Project has been developed by the U.S. Army Corps of Engineers and its local sponsor, the South Florida Water Management District. It was assisted by the South Florida Ecosystem Restoration Task Force, a team of several federal agencies (including the USGS), state and local agencies, and Indian tribes. The USGS has been a catalyst and a major contributor to the science underlying the restorative actions to be taken.

The plan to restore the Everglades is ambitious and comprehensive. It entails changing the current hydrologic regime in the remnant Everglades to one that resembles a more natural one, reestablishment of marshes and wetlands, implementation of agricultural best-management practices, enhancements for wildlife and recreation, and provisions for water supply and flood control. It will involve the creation of several large surface and subsurface storage areas to capture much of the water now drained by ditches and canals directly to the Atlantic Ocean or the Gulf of Mexico, the creation of new wetlands to trap agricultural and urban pollutants before their discharge to the natural wetlands, the supplementation of flows with highly treated wastewater, and an increase and change in the pattern of water releases to the natural wetlands and estuaries, partly by removing artificial barriers to the formerly dominant process of overland sheet flow.

Planning for and implementation of the restoration effort requires application of state-of-the-art large systems analysis concepts, hydrological and hydroecological modeling, hydrological and ecological data, sophisticated decision support systems, integration of social sciences, and monitoring for planning and evaluation of performance in an adaptive management context. These large, complex challenges of the greater Everglades restoration effort demand the most advanced, interdisciplinary, and scientifically sound capabilities the nation has to offer.

It is likely that this multiple-agency integrated approach to projects of regional and national concern will be a dominant way of doing business in the future (Harwell, 1997; Harwell et al., 1999). The USGS divisions have to develop working relations that foster the continuation of this type of collaboration. The USGS as an entity must be prepared to respond to the complex environmental problems the nation faces now and in the future.

Investigations to Support Wise Urban Development in the West

For several decades the population in the more arid parts of the western United States has increased faster than the national population growth rate. Rapid population growth is expected to continue and will be accompanied by rising resource consumption and rising requirements for environmental quality and outdoor recreation. This development raises management problems for governments at all levels. Nettlesome problems include the trend of transfers of water from agricultural to urban and industrial uses (NRC, 1992b) and the need to provide clean water supplies in a region that has already begun to face the physical limits of water resources. Alternative plausible scenarios of availability and timing will be necessary, along with innovative investigations of water use and substitution. Not only river flows, but groundwater recharge and snow-pack distributions will have to be investigated, and the ecological effects of further altering water supplies will have to be addressed. Another development is settlement of alluvial fans and debris-flow fans (NRC, 1996e) that results in flood hazard management problems. Urban expansion into fire-prone chaparral and woodland ecosystems threatens to intensify fire management problems, including both ecological damage and postfire erosion hazards to settled areas (Keeley et al., 1999). Low-density settlement patterns, typical of the West, threaten to eradicate or impoverish large areas of both terrestrial and aquatic habitat.

In addition to water and flooding issues, the USGS should continue its work with state and municipal agencies to evaluate the basic geologic framework of cities. Having a detailed geologic map and a three-dimensional view of a city's geology is crucial for geotechnical evaluations and land use and an idea of the distribution and character of construction materials. Integrated work on urban geology in several southwestern cities is beginning with the STATEMAP program, in which the USGS cooperates with municipalities and states.

The nation needs an integrated research agenda on the sustainable development of lands in the West. These lands will be the focus of conflict because of the environmental constraints on available resources and the changing environmental values of society. The USGS would be shrinking from its responsibilities to “provide science for a changing world in response to present and anticipated needs” if it does not embrace this topic in much the same way that John Wesley Powell sought to provide scientific information for wise development of the West more than a century ago.

Natural Resources

Life Cycles of Ore Materials

One of the great challenges of the coming decades will be to better understand the cycles of material and energy flow and use within the dynamic earth environment. Earth systems are inherently complex (NRC, 1993c) and human activity adds to this complexity. Understanding these systems will require integration across many natural and social science disciplines. Breakthroughs in understanding will often come at the interfaces of disciplines. As a multidisciplinary science agency, the USGS is suited to play a role in advancing functional models of material and energy cycling within the earth's environment.

Investigations of mineral, energy, and water resources have been at the center of USGS activities for more than a century, but these investigations will undergo major changes in coming decades. There will be decreased emphasis on identifying domestic resources for development and increased emphasis on gathering and interpreting information needed to support the sustainable use of resources. Essential to this changing emphasis will be the development of reliable models, known generally as life-cycle models, that trace the fate of elements and minerals in the environment. Life cycle models of mineral resources document the physical and chemical processes involved in deposit formation, weathering and erosion, mining and processing, commodity use, recycling, and ultimate disposition of mineral commodities.

Mineral deposits are physical and chemical anomalies in the crust of the earth. Whether or not a mineral deposit is developed, it may have an impact on the local environment and ecosystem of an area. Thus, the life cycle of a mineral commodity starts with the formation of a mineral deposit. Genetic mineral deposit models provide an understanding of the character, location, and abundance of the nation's mineral resources. Geoenvironmental models build on these genetic ore deposit models with information that can be used to understand and predict the effects of natural exposure or human development. Mining, processing, and refining provide the interface between the natural mineral cycle and the human use cycle in which mineral products are used, recycled, and ultimately disposed. For many elements, these geochemical cycle models link directly to models relating environmental geochemistry to animal and human health.

The impacts of resource development and use can be diverse, affecting air quality, water quality, stream sedimentation, and soil erosion or contamination. Useful geoenvironmental models must be based on rigorous models of the geochemical, geological, and biological processes involved, as well as on adequate documentation of the natural background character of the nation's lands and waters. Documented national geochemical baselines and backgrounds provide a standard or measure against which future environmental perturbations, natural or anthropogenic, can be compared. Determining geochemical baselines and backgrounds must also be a multidisciplinary endeavor involving geochemists, geologists, hydrologists, and biologists. The USGS, with integrated expertise in the earth and biological sciences, is capable of meeting this challenge.

Geologic Frameworks for Transition to a Methane Fuel Economy

Historical market forces promoting efficiencies, along with current and future concerns of atmospheric quality, are likely to drive the world and particularly the United States to a methane-based economy and eventually to an energy economy based on hydrogen (Williams, 1996; PCAST, 1997; Serchuk and Means, 1997). Several recent estimates of the remaining natural gas resource base in North America, and especially the United States, indicate a volume sufficient to meet the large demands of the methane economy (NRC, 1999d). However, no more than one-third of the expected demand can be met by current reserves, currently projected reserve growth from existing fields, and ready discovery. Adding a sufficient volume of resources to producible reserves will involve discovery in the deeper parts of basins where the geology is known only marginally or in hostile environments, such as ultradeep waters and arctic frontiers. Other sources must come from low-permeability formations where basic understanding of formation variation and fracturing will be required. Increasingly, reserves must be developed from a whole series of emerging resources such as basin center formations, deep deposits of coal bed methane, methane hydrates, and methane in geopressured geothermal waters, all insufficiently known (Collett, 1993; Kvenvolden, 1993; Socolow, 1997). As the natural gas resource base moves from higher- to lower-quality resources, demands for technology and the geologic framework to efficiently deploy new and advancing technology become essential if natural gas supplies are to be available as needed and at affordable prices.

The United States has a substantial geological work force to meet the demands of the methane energy economy—in industry, universities, states, and private research concerns. However, the paramount public interest that will be served by a clean-burning and efficient energy source defines a role for the USGS in collaboration with other partners particularly DOE, MMS, EPA, and the Department of the Navy.

TRANSITION TOWARD AN INTEGRATED NATURAL SCIENCE AND INFORMATION AGENCY

The research opportunities discussed in the previous section all concern complex systems and illustrate a need for the USGS to develop a strong agency-wide commitment to, and capacity in, integrative science. Because of its information resources, technological capabilities, and range of professional expertise, the USGS is well positioned to pursue integrative science. By evolving into a natural science and information agency, the USGS can meet society's expectations for analytical and integrative science focused on problem solving, rather than on monitoring or knowledge advancement alone (Pielke et al., 1999).

Integrative science focuses on the major issues that cross the narrow boundaries of conventional scientific disciplines and is more than simply an interdisciplinary collaboration, although it may begin there. Rather, integrative science entails individuals sharing different perspectives, methodologies, and conceptual models in a manner that changes each person's approach to the problem at hand. Integrative science is the construction of conceptual models that link causal processes to illuminate the complex interrelationships among physical and biological phenomena (Turner, 1991). Data are a starting point in the refinement, testing, and elaboration of successively more realistic models of natural-and human-driven processes, but the overall goal is to derive and apply a conceptual understanding of these systems to the betterment of human life. Thus, data on streamflows should lead to a holistic understanding of flood dynamics, but may also lead to a better understanding of agricultural productivity, avoidance or mitigation of contamination, and ecosystem dynamics. In other words, the output should be multidimensional and utilitarian.

An integrative approach implies focusing on the nature of the problems in all of their complexity and creating teams with the skills and resources necessary to provide the entire suite of knowledge required for well-informed responses. Developing interdisciplinary teams requires more of management than drawing a committee of scientists from each of the existing USGS divisions to attack a problem. It requires management of the development of the integrative habit of inquiry by knowledgeable individuals. The development of true interdisciplinary teams requires changes in group dynamics, analytical approaches, and types of synthesis activities (Metzger and Zare, 1999). A determination to commit the agency to integrative scientific investigations is not an easy step to undertake. Not only are the objects of study (e.g., fish, trace-element geochemistry, tectonics), and therefore the vocabularies, different among disciplines, but the traditional spatial and temporal scales of phenomena to be studied and the nature of acceptable explanations are different too, as are scientific methods, criteria of evaluation, and professional culture in general. Thus, integrative work relevant to policy often requires that new perspectives are forged, new applications of methods are developed (perhaps involving unprecedented measurement precision), and greater emphasis is given to the definition of conceptual system models. Despite the difficulties of achieving integrative science even for rather narrowly defined problems, the results can be analyses of unprecedented power and utility and more effective reports and data products. Both the difficulties and the rewards imply that in a large, multifaceted agency such as the USGS, senior management has to take the lead in promoting such integration because they are the only personnel with knowledge of all the agency's resources and they alone are charged with the strategic application of these resources in the overall national interest.

USGS managers should also recognize the opportunity inherent in multiagency (federal, state, tribal, and local) teams. Several recent multiagency studies, such as the ecosystem evaluations of San Francisco Bay and Chesapeake Bay, offer illustrations of both the potential, for integrated science investigation and the commitment to integrated implementation of recommendations.

The committee believes that comprehensive understanding of the types of complex natural science issues described in earlier sections of the report will be difficult to achieve without some substantial degree of disciplinary integration. Thus, the committee recommends that the USGS evolve from an agency organized primarily around disciplines to discover and understand *what is out there* (surveys, data collection, and data synthesis) to one that is organized to a greater degree around interdisciplinary teams to understand how *what is out there* works (process understanding). Understanding how the complex air-water-human-land system works calls for scientists to cooperate on studies that encompass a combination of physical, chemical, biological, and social processes.

The USGS was founded around disciplinary skills and experience, and it continues to embrace a discipline-specific organizational structure. Despite this constraint, the agency recognizes the value of interdisciplinary teams and studies, and has demonstrated the importance of these efforts many times. However, it has not yet created an interdisciplinary environment to confront the complexity of the issues at hand. One of the important benefits of USGS ecosystem studies has been to increase the appreciation by earth system scientists of the interdependence of natural processes with the lithosphere, hydrosphere, biosphere, and atmosphere. Animal life depends upon plant life, which depends upon water and soil, which are controlled by geology and climate. It is impossible to understand any single part of the environment without an understanding of the whole. The USGS has the capability and the opportunity to advance understanding of such interconnected processes, with integrated research teams crossing traditional disciplinary boundaries.

The failure to integrate will inhibit understanding of natural science problems. However, the committee recognizes that integration is difficult to achieve, especially in cases that require integration of physical and social sciences. Because of the gulf between disciplines, efforts to achieve integration are more likely to advance incrementally through the cooperative study of particular problems than through the top-down imposition of a comprehensive framework. All the same, senior USGS management should help to instill an agency-wide commitment to integrative science. Senior USGS management should ensure that appropriate disciplines are brought to bear on problems that require cooperative study for their solution.

SUMMARY

In the twenty-first century, the USGS will be called upon to play critical roles in solving complex problems. To confront these issues, the committee recommends that the USGS evolve into a natural science and information agency. The USGS should exercise national leadership in its areas of primary responsibility and, in view of the international and global nature of many science problems, should increase its international activities above present levels.

Opportunities exist for the USGS to improve service to its multiple audiences particularly by (1) ensuring that science information is provided to DOI departments efficiently and effectively; (2) strengthening liaison and coordination with related federal agencies; (3) maintaining and improving relations with state and regional government organizations and with nongovernmental organizations that are users of science information; (4) facilitating the use of science information by the general public and by stakeholders for critical issues; and (5) increasing interactions with foreign customers and partners. In light of its strong move toward regionalization to bring the agency's leadership closer to its customers, the USGS should be careful not to assume the role of state or regional organizations.

In the realm of future program emphasis, the USGS should provide national leadership and coordination in such areas as establishing data standards; assessing resources; and monitoring, reporting, and where possible, forecasting critical natural science phenomena. It should give high priority to (1) maintaining and enhancing high-quality, long-term databases; (2) emphasizing the value-added activities of data analysis, information dissemination, and problem solving; (3) establishing an interdivisional program in system modeling and integration; (4) advancing toward a natural science and information integration organization that involves the development of a framework for a geospatial information depository and portal; and (5) conducting monitoring activities more efficiently through the use of advanced technology.

The committee believes that the USGS should, because of its mission, study problems of regional, national, and international importance. It encourages studies that encompass a combination of physical, chemical, biological, and social processes and are thus multidisciplinary and provide opportunities for integrative science. Senior USGS management should ensure that appropriate disciplines are brought to bear on studies that must integrate across disciplines.

The USGS will face administrative challenges as it transitions toward a natural science and information agency. These challenges are the subject of Chapter 5.

5

Future Challenges

The principal function of the USGS is to bring science to the service of society in a changing world. Demands placed on the USGS for this information likely will be greater in the future than in the past, and management of the agency will become increasingly challenging. This chapter discusses some of the administrative challenges that the USGS will face: priority setting, research program, external guidance, human resources, coordination and collaboration, reimbursable programs, and budget and funding.

PRIORITY SETTING

The mission of the USGS is to provide "the Nation with reliable, impartial information to describe and understand the earth" (USGS, 1996a). To fulfill this mission, it is imperative that the agency's work is designed to meet the changing needs of a broad-ranging group of customers. Consequently, communicating with customers about the kinds of science information they need is essential. For such communication to be effective, a workable process of priority setting should accompany it. Indeed, the future of the USGS depends on its skill in identifying and setting rational and realistic priorities and its ability to reduce commitments of time, money, and people that do not contribute to them.

Information provided to the committee indicates that there is a tension caused by a mismatch between the demands placed on the USGS and the way in which its resources are allocated, and by the conflicting requirements of solving specific problems and addressing broader national needs. Three areas of tension in the planning process warrant immediate and continuous attention. First, although a priority-setting process is essential for the efficient deployment of USGS resources in fulfillment of the basic mission of the USGS, this process must be responsive to the needs of its customers. In recent years, the USGS has produced six strategic plans [1] (USGS, 1996a, 1996b, 1997a, 1998a, 1998b, 1999a) that establish broad priorities linked to the agency's mission; however, in some cases, the priorities defined in these plans appear to have been developed without adequate dialogue with USGS customers.

Second, some USGS planning goals have been unrealistically optimistic and have created unreasonable expectations among its customers. As one example of this problem, the BRD's Bureau Information Needs process, which helps set priorities for serving DOI land management bureaus, seems to have led to unreasonably high expectations by promising more than could be done and, in some instances, leading to customer disappointment and disaffection.

Third, although USGS priority setting must be responsive to customer needs, the scope of the response must be restricted to the agency's basic mission. As stated in Chapter 4, the USGS should avoid becoming a job shop for local constituencies or a competitor with private sector or state and local sources of scientific information. For example, some USGS work on natural hazards appears to have arisen out of local issues. In such cases, a local jurisdiction has a problem with a hazard such as flooding and channel erosion, and the district office becomes involved on a cooperating, partially funded basis. A member of the WRD's National Research Program also may be recruited to lend expertise. In the end, the result may solve a local problem, and a USGS scientist may craft an internal report or a journal article describing a methodological advance. This is a useful transfer of technology, a case of the USGS serving clients, but it is also ad hoc and a case of the agency supporting itself financially by providing services that could be provided by other organizations. Although in this type of activity the USGS delivers high-quality technical service to society, there is nothing strategic about such a use of the agency's expertise, instead, it is a diversion of the USGS's limited human resources. Meanwhile, national issues that require large-scale and long-term application of the agency's resources remain unstudied and unresolved.

[1] The Geologic Division, Water Resources Division, National Mapping Division, and the Biological Resources Division have written strategic plans (USGS, 1996b, 1997a, 1998a, 1998b), and two USGS-wide strategic plans have been written in the past five years (USGS, 1996a, 1999a).

The committee concludes that USGS priority setting in the past has been too ad hoc and insular. It notes that a significant step toward an enhanced priority-setting process is the DOI "Agreement on USGS Research Support for DOI Resources Management Bureau Needs" (Sidebar 5.1), which attempts to establish a process for determining USGS science priorities in support of the management and regulatory missions of other DOI bureaus. The USGS should work to ensure that the spirit and substance of this agreement are met. Similar, formalized approaches should be pursued with other customer groups, such as state geological surveys, environmental protection agencies, and resource management agencies. Thus, the committee recommends that the USGS consider consultative mechanisms for prioritizing its activities and seeing that they are responsive to customer needs and consistent with stated mission goals. This process should be designed to identify short-term, problem-specific needs, problems, and priorities; and, more importantly, to identify and garner support for longer-term core research priorities.

RESEARCH PROGRAM

An important aspect of priority setting for the USGS is the development of an innovative research program. Information supplied to the committee indicates that discussions about future science directions at the USGS tend to focus on well-known issues and their incremental advancement, not on the kinds of integrative research and process elucidation in which the USGS must excel to successfully address complex science problems in the future. The committee believes that the USGS must develop objectives for a long-term core research program that is supported programmatically by the Executive Leadership Team. One important objective of such a program should be to generate new knowledge on a set of inadequately studied phenomena that are central to a deeper understanding of interactions among natural systems and between nature and society.

By "long-term" research is meant a period that is long enough to significantly enhance the understanding of specific, understudied science problems. This period should be on the order of 5 to 10 years. Such a time horizon would provide the opportunity for multidisciplinary teams of researchers to collaborate, apply novel approaches, and produce significant results on critical problems (NRC, 1997d).

SIDEBAR 5.1

THE USGS BUDGET DEVELOPMENT PROCESS

An agreement is in place to facilitate sound and effective USGS science support for the DOI's bureaus. It outlines the type and degree of support offered and gives input to the USGS for defining Government Performance Results Act metrics and outcomes. Steps in the new USGS Budget Development Process include the following:

Step 1. Input from field managers: USGS regional directors hold regional science forums with DOI bureaus to review and synthesize priorities.

Step 2. Individual bureau meetings: The director of the USGS meets with each DOI bureau director.

Step 3. Identification of priorities, topics, and projects: The DOI Science Board, or a committee of the board, evaluates Steps 1 and 2 for information needs and overlaps.

Step 4. Initial science support proposal: The USGS creates an initial proposal for applying USGS science abilities to DOI's bureau science needs.

Step 5. Meeting to review science support proposal: The DOI Science Board, or a committee of the Board, reviews the initial science support proposal, assesses current research and its applicability, and evaluates pending budget proposals.

Step 6. Final science support proposal: The USGS creates a final proposal outlining planned activities and funding for their enactment. The USGS submits this proposal for approval by DOI bureau directors.

Step 7. Cooperation on budget support: DOI bureau directors and the USGS director take appropriate actions to support the proposal during the approval and appropriations process.

Step 8. Project selection: The USGS director meets with DOI bureau directors to discuss specific projects, their schedules, budgets, and implementation procedures.

In the past, much USGS research and development was focused reactively on short-term, narrowly defined problems and often failed to anticipate the emergence of critical long-term, problems. This approach is unsuitable for dealing with complex natural science problems. The solution to many of these problems requires a research framework based on integrative science—science committed to bridging barriers that separate traditional modes of inquiry (Gunderson et al., 1995; Houghton et al., 1996d, 1999j; Houghton et al., 1996; Johnson, et al, 1998). Nevertheless, not all complex science problems require a broad, integrative multidisciplinary research framework; therefore, the choice of research framework must fit the specific research problem. Problems that do not require a broad, integrative, multidisciplinary research framework should not be overlooked.

The USGS should review the balance between problem-specific research and core research efforts that incorporate integrative science, in order to achieve an appropriate mix of core and problem-specific research efforts. In the committee's view, the USGS should give high priority to and expand considerably the core research agenda and should commit the necessary resources to undertake priority research. The research agenda should be developed through a formal and continuous strategic science planning process. Periodic review of the implemented research agenda should be undertaken to ensure a sustainable effort.

To focus its efforts, the USGS should consider mechanisms to set its research agenda based on the following principles (NRC, in preparation):

- An agenda of both core and problem-specific research priorities should be set.
- The core research agenda should develop (1) greater understanding of the basic processes – physical, chemical, biological, and social – that underlie earth systems at different scales, (2) appropriate monitoring programs, and (3) research tools to identify and measure the attributes of whole systems (NRC, 1997e).
- The research effort should be coordinated with federal agencies such as the DOE, NSF, NASA, and NOAA to reduce needless duplication, ensure that gaps do not occur, and develop efforts that are complementary and compatible.
- The research effort should make extensive use of government (federal, state, and local), industry, and university partnerships and should involve foreign countries as necessary.

- The USGS should place more emphasis on multidisciplinary, integrative projects that address priorities of a national scale.
- The research effort should be proactive and should anticipate emerging science problems.
- The research effort should be accountable to the public to ensure that the research investment has been appropriately used to meet national needs.

This system of setting the research agenda will require substantive communication within the USGS and, as the previous section notes, beyond its borders as well. Thus, the evolution of science priorities should be developed through continuing consultation with other parts of the DOI, federal and state agencies, the White House Office of Science and Technology Policy, congressional staff, research universities, relevant private sector groups, nonprofit organizations, and public interest groups. The result should be a portfolio of planned and coordinated core and problem-specific research activities appropriate to USGS expertise, with broad support inside and outside the agency.

EXTERNAL GUIDANCE

Organizations frequently use external advice to help guide program design and development. Many federal agencies have strengthened their programs through the use of external advisory committees. Examples of standing advisory bodies that are productive contributors to federal science planning and implementation include the NSF's National Science Board, National Institute of Standards and Technology Programs (administered by the National Research Council), the EPA's Science Advisory Board (administered by EPA), and the NASA Space Science Advisory Committee (administered by NASA).

External advisory committees are stakeholder oriented and come in various sizes and shapes that fit various components and subdivision of the organization. No good public agency can afford to be without external advisory committees.

The USGS has been relatively insular, which is counterproductive to its long-term scientific and political interests. The USGS could benefit from external advice at the agency level. Thus, the committee recommends that the USGS establish and make extensive use of an agency-level external advisory committee. This advisory committee should not parallel the divisional structure of the USGS. Instead, it should be organized to reflect the breadth of the agency's mission-related themes.

The advisory committee should consist of non-USGS members who have broad expertise and should include representation from federal and state agencies, industry, universities, nongovernmental organizations, consultants, and other users of USGS information, products, and services. Members should comprise “experts who not only display an informed sensitivity to the agency's mission but also enjoy unquestioned standing among their peers” (Jasanoff, 1990).

The establishment of an advisory committee should ensure that customers and partners are adequately consulted in program planning and development. An advisory committee could identify issues that might impede the agency from accomplishing its scientific goals. External input could help significantly to strengthen interactions with government organizations. The advisory committee could make recommendations for organizational changes where program leadership is ineffective. In addition, the advisory committee could provide guidance if the agency's current move toward regionalization is considered to have adverse effects on the USGS.

The establishment of an agency-level advisory committee would create new administrative burdens for USGS management. However, closer cooperation with customers and partners, less insularity, and a disinterested advice and assessment process could result in greater efficiency and effectiveness at every level of the agency. This advisory committee would also build strong customer support for the agency's programs.

The committee also recommends that the USGS consider mechanisms to improve external guidance at divisional and program levels. The committee suggests advisory committees and specially constituted review panels. Charges for these advisory committees, as suggested by the NRC Committee to Review the USGS Coastal and Marine Geology Program (NRC, 1999k), include the following:

- maintaining focus and direction through oversight of strategic plan implementation;
- providing advice to divisional and program directors on budget and staff allocations;

- evaluating products and providing feedback to the strategic planning process; and
- ensuring good peer review (quality assurance).

A major advantage of standing advisory committees is that they have organizational memory, but because they need to have broad expertise, they may not be as well suited to reviewing specific aspects of a program as specially constituted review panels. Therefore, the USGS should continue to request specially constituted review panels to conduct independent reviews and provide answers to specific questions.

HUMAN RESOURCES

The underpinning of the scientific credibility and respect of the USGS has been its talented staff. Maintaining a talented staff is a major challenge for the USGS. Currently, the USGS has a large number of experienced and highly skilled scientists and technicians. However, the inability of the USGS to make more than a few new appointments in recent years is a matter of concern. The deep reservoir of accumulated knowledge that has been developed through decades of research is in danger of being lost through attrition because of forthcoming retirements unless existing staff and new staff overlap. Without new full-time hires to replace departing staff, the ability of the USGS to fulfill its mission in the future will be compromised and the morale of the remaining staff will deteriorate.

High-quality personnel are essential for developing high-quality science information; therefore, the committee urges the USGS to devote substantial efforts to recruiting and retaining excellent staff. This initiative should be undertaken as part of the agency's strategic science planning and should take into account the new areas of expertise that will be necessary in the future. In identifying new hiring priorities, the USGS needs to pay special attention to its long-term core research agenda. Thus, opportunities should be made available to recruit scientists who can work effectively across program boundaries and who can be expected to provide leadership on the integration of science information. For example, it would be desirable for the USGS to recruit first-class scientists who could develop a broad and comprehensive understanding of aquatic habitats, conduct integrated hazards and environmental studies, or contribute to such burgeoning multidisciplinary areas as industrial ecology and place-based science.

The retention of skilled employees is critical to maintaining scientific excellence. A recent NRC review of the USGS Coastal and Marine Geology Program (CMGP) (NRC, 1999k) suggested that the agency has to identify ways to reward creative and resourceful staff. The report indicated that a number of "CMGP staff voiced concerns that the current reward system does not adequately recognize efforts that enhance overall CMGP stature but do not result in classic peer-reviewed publications" (NRC, 1999k). The evaluation tool used to evaluate research staff at the USGS (as well as other federal agencies) is the Research Grade Evaluation Guide (RGEG). As recommended by the Office of Personnel Management (OPM), the USGS "applies the RGEG using a peer panel to assess the research assignment and the researcher's scientific contribution and stature" (NRC, 1999k). The Committee to Review the USGS Coastal and Marine Geology Program encouraged senior management of the USGS to explore the impacts of the current RGEG on programs and staff and to voice adverse impacts to OPM.

In an environment of short-term justification and fiscal pressures, the USGS may be unable to expand its permanent work force even though the agency is increasingly being called on to play critical roles in complex science problems. If the size of workforce remains the same as today or continues to decrease, the modes by which the USGS employs people in the future will have to be increasingly flexible. To respond quickly to new business opportunities, emerging science issues, changing congressional mandates, or important new initiatives, the USGS will need a flexible workforce whose members have broad perspectives, adapt quickly to changes in program directions, and have the skills and knowledge to work in multidisciplinary, integrated teams. Consequently, the committee recommends that the USGS develop an organizational culture that encourages, values, and rewards flexibility and teamwork because these skills are critical if the agency is to become a natural science and information agency.

As noted in the USGS strategic plan (USGS, 1996a), the agency must recruit and retain an agile, diverse workforce to achieve its mission in the twenty-first century. Improving workforce diversity is one of the specific objectives of the agency. As enunciated in the USGS strategic plan, by 2002 the agency will "achieve levels of diversity that are reflective of the Nation's citizenry" (USGS, 1996a). Moreover, as the "clientele served by the Survey continues to grow more diverse culturally, economically and socially, the USGS must be sensitive to that diversity. In addition to traditional customers and constituents, the USGS must reach out to these new customers and stakeholders through targeted recruitment and other techniques which inspire mutual trust and confidence" (USGS, 1996a).

To facilitate integrated science, the issue of personnel location should be addressed. In the future, USGS professional staff members will be expected to increase the effectiveness of their multidisciplinary investigations, which can be facilitated by concentrating scientists from different disciplines in centralized facilities. The GD and NMD are centralized in the same three regional centers, but the BRD is housed in different regional centers and the WRD is state based. Although it is likely that the USGS will continue to have large regional centers with a few smaller offices, the committee believes that consideration should be given to the colocation of scientists from different disciplines in order for them to conduct integrative science projects more efficiently.

COORDINATION AND COLLABORATION

Even if the professional staff of the USGS were to increase substantially in the future, the increase would probably be insufficient for the agency to accomplish its goals solely through in-house activities. As the problems that the USGS has to address become more complex and multidisciplinary, it is unlikely that the existing professional staff, even with major retraining, would be able keep up with all of the new techniques and new knowledge, let alone cover all of the areas of expertise necessary to carry out an ambitious program of integrative science. To achieve its goals, the USGS will have to strengthen coordination and collaboration with other federal agencies and with academia and industry as well. Coordination and collaboration increase institutional flexibility in meeting mission goals. They permit the sharing of resources (personnel, equipment, and ideas), enhance the prospects for new project funding, and can lead to high-quality science. The committee views a commitment by the USGS to partnerships as well as to external grant programs and employee exchanges as critical to the ability of the agency to exercise national leadership in its areas of primary responsibility.

A Biological Survey for the Nation (NRC, 1993b) outlines five specific mechanisms that the National Partnership for Biological Survey should establish for national coordination: (1) provide for high-level, balanced input from diverse participants and users into the development and implementation of the partnership; (2) take full advantage of the federated structure of U.S government, in particular the states; (3) have a clear lead organization with primary responsibility and authority for fostering coordination; (4) provide continuity of involvement by participants and users; and (5) be designed to encourage active, voluntary participation.

Federal Partnerships

The USGS should make extensive use of federal partnerships. Although the USGS works with virtually every federal government department, including Agriculture, State, Commerce, DOD, NSF, EPA, FEMA, DOE, NOAA, and NASA, communication tends to be more ad hoc than systematic, and there appears to be little coordination between the USGS and other federal agencies. In the 1970s, there was a successful coordinating committee between the USGS and NOAA, but for reasons rooted in history, there is now an absence of strong coordinating committees between the USGS and other agencies with conspicuous natural science components in their missions. The committee notes that the USGS is insufficiently engaged with related federal agencies whose work can enhance its ability to achieve mission objectives. In addition, the USGS can contribute to the work of these other agencies.

Improved coordinating mechanisms could facilitate collaborative activities between the USGS and other agencies. The USGS and EPA could work more closely to assess the quality of the nation's water resources. The USGS and the USFS could cooperate on studies of biotic and water resources or on the cumulative effects of watershed management in the forested and mountainous regions of the country. The USGS and NASA could coordinate and design studies on geologic hazards and the hydrologic cycle. The USGS and the U.S. Army Corps of Engineers could work more closely in studying the major rivers and floodplains of the nation. For the study of climate changes and their relation to water and biological resources, the USGS could potentially benefit from cooperative programs with NOAA and NASA, including the near-surface atmospheric lands and water interface. In the areas of groundwater hydrology, geochemistry, shallow subsurface geophysics, and health risk analysis, collaborations with DOE's national laboratories may be beneficial.

Several NRC reports have urged the USGS to seek partnerships and improve coordination with federal agencies. For example, its *Review of the USGS Volcano Hazard Program* (NRC, 2000b), the committee observed that there is insufficient integration and communication between the Volcano Hazards Program (VHP) and other federal agencies engaged in volcano hazards research. “This ‘balkanization' of U.S. volcanology results in inefficiencies and duplication of effort in the federal establishment” (NRC, 2000b). The report urges the VHP to improve coordinating mechanisms and, at the very least, to convene “regular meetings of volcano-related policy makers within the Washington, D.C. area, including the VHP, NASA, NSF, NOAA, Federal Aviation Administration (FAA), FEMA, the Smithsonian Institution, and relevant offices of the Departments of Interior, Energy, State, and Defense” (NRC, 2000b). It emphasizes that the overall goals of the VHP would be improved considerably by strengthening coordination.

For federal coordination, the Committee on the Formation of the National Biological Survey recommended an interdepartmental committee, which would include the heads of the essential federal agencies and departments (NRC, 1993b). The mechanism should provide coordination of federal policies and identify federal agency priorities for the conduct of research and assessments. The interagency committee would serve as a forum for policy discussion and coordination and as a framework for increased day-to-day interactions.

Collaborations are a two-way street, and the responsibility for the current lack of coordination does not fall entirely on the USGS. It is possible to find local and recent successful attempts to increase communication among agencies, but these are typically arrangements among individuals or small groups. Commitments among agency leaders and incentives are needed to bring about integration. The USGS should consider the cofunding and comanagement of research projects as an option for better coordination with federal agencies.

The committee believes that many future research opportunities for the USGS may be missed in the absence of a strong commitment to coordination and collaboration with other federal agencies. Therefore, the USGS should place greater emphasis in the future than it has in the past on strengthening coordination and liaison with federal agencies.

Industry and University Partnerships

The USGS can also cooperate with academic and industrial sectors in addressing common objectives. Each sector has its strengths and weaknesses. Because of market forces, the private sector tends to focus on near-term research. By contrast, universities lean toward long-term research. It would be to the benefit of the overall USGS research program to increase interactions with both academe and industry. For example, the USGS could seek collaborative projects with industry (e.g., on issues related to natural resources, industrial ecology, and digital data information systems) where such projects are consistent with the goals and objectives of the agency. The USGS could also better accomplish its goals by enhancing collaboration with researchers at academic institutions. A good example of collaboration is between the scientists of the agency's Menlo Park office and scientists and students of Stanford University and the University of California, Berkeley. An additional example of the relationships between the USGS and academic institutions involves the water resources research institutions in all 50 states, territories, and the District of Columbia. Another appealing option is the colocation of staff and facilities at universities. Colocation has been successful at several universities such as the University of Arizona.

External Grants Program

In an era when the USGS can no longer be expected to conduct its basic research function in-house, the agency will benefit more than ever from the extramural grants program. Such grants buy the talents of university, government, and industry researchers. They would help programs to continue to produce high-quality research, allow flexibility for redirection of programs as needed, and provide opportunities to collaborate with research scientists at other institutions.

Employee Exchanges

Another way to promote collaborations with other institutions is the exchange of employees with other government agencies and universities (on personal details through the Intergovernmental Personnel Act). In exchange, visiting scientists would bring fresh perspectives and keep staff aware of emerging research opportunities. Similar exchanges should occur within the USGS more frequently in the future. Intra-agency transfers foster cooperation, lessen the “stovepiping” of programs, and could accelerate the development of new integrated entities.

REIMBURSABLE PROGRAMS

The USGS commonly enters into cooperative programs with regional, state, and local agencies, Native American tribes, and other organizations. Usually, cooperative programs are stimulated by requests from other entities for scientific knowledge and data. Roughly $300 million, or approximately 25 percent of the USGS budget, is derived from reimbursable contracts, which is not exceptional by historical standards. During the years of the Great Depression, reimbursable work represented as much as 80 percent of the USGS budget. Reimbursable programs can have considerable value: they allow the USGS to exchange employees between programs, they allow the agency to leverage its funds and thereby expand its range of operations, and they provide a measure of the worth of certain agency products.

The policy of the USGS is not to duplicate programs or projects carried on by others. Efforts are applied to investigations or activities that augment or complement those of other agencies or are needed to meet federal requirements, including those of other federal agencies (USGS, 2000e). The USGS also does work for nonfederal agencies. When it engages in such work, the USGS is required by policy to determine that the service is not available elsewhere, there is no conflict of interest or apparent conflict of interest, the service promotes the objectives of the USGS, and there is a benefit to the USGS in providing the service. (USGS, 2000e).

The efficacy of engaging in reimbursable work has been a source of debate both within and outside the USGS for many years. Proponents emphasize that reimbursable work enhances USGS programs, expands the workforce, and keeps the agency in close contact with customers. Opponents argue that reimbursable programs distort the priorities of the USGS and inevitably lead to problems of conflict of interest or perceived conflict of interest that act against the best long-term interests of the agency. Since the bulk of reimbursable funds to the USGS come through the WRD, the debate applies mainly to the WRD at this time.

The USGS has a long-standing partnership with state geological surveys and water resources agencies. The committee learned that this partnership is strained because of concerns by state surveys that the USGS inappropriately competes with them for local project funds. The concerns, real or perceived, about competition between the USGS and state surveys need to be addressed. The committee believes that USGS leadership and the directors of state surveys should establish a process of collaboration, where technical staff and financial resources are contributed by both to specific, integrated programs. This type of collaboration has worked well between the USGS and state environmental quality programs. Although this collaboration may not provide external funding for the USGS, it does provide an opportunity for it to acquire additional water quality data beyond what its staff alone could collect, thus supplementing a key component of the agency's strategic plan without expending additional resources. From the state perspective, USGS databases and staff expertise are key components of partnerships. Many environmental problems addressed at the state level require an understanding of geologic systems.

Clearly, the reimbursable work of the USGS benefits many agencies. However, some of the reimbursable programs cause friction between the USGS and state and private entities, are viewed as conflicts of interest, and may divert the agency from its mission. Existing guidelines for reimbursable programs appear to be insufficiently clear or inconsistently applied (USGS, 2000e). The USGS, specifically the WRD, is aware of the issue and has taken steps to avoid unfair competition with the private sector. However, the issue of USGS funding through reimbursable work deserves review with regard to its effects on customer relations and with regard to the USGS mission and strategic plan.

The committee believes that the USGS should place more emphasis on whether potential cooperative projects meet mission and strategic plan objectives. Careful selection of outside funding opportunities can nurture research priorities. This effort requires focused and coordinated leadership and program management. In the committee's view, appropriate reimbursable programs are partnerships in which the USGS performs a function that is consistent with its basic mission and that contributes to its strategic objectives without competing unfairly with organizations that can provide a similar service.

BUDGET AND FUNDING

The agency's budget remained roughly constant between 1974 and 1999 even though the tasks of the agency increased. The diminished buying power is a matter of concern. It increases the burden on an already overworked professional staff and decreases the ability of the agency to accomplish its program goals. To be sure, the agency should seek opportunities for cost-sharing collaborative efforts that are relevant to program goals. Yet even with a strong commitment to coordinated research efforts with government, industry, and academia, it will be difficult for the agency to attain its goals in the future, especially those associated with a long-term core research program. Increasingly, the USGS is being called upon to solve complex science problems that are critical to human and ecosystem survival. Long-term problems such as those associated with natural hazards that pose increased risks to the nation cannot be solved with the current level of program funding. As the agency's responsibilities continue to increase, its budget should be increased to a level commensurate with the tasks. With an appropriate level of funding for practical research related to national needs, the USGS will be better able to fulfill its mission.

Although the committee has no basis on which to recommend a specific funding level, it urges the USGS Executive Leadership Team to estimate the amount of funding required to develop long-term, innovative, high-priority projects. These estimates, which could be validated by an agency-level external advisory committee, could be used to justify future budget requests. The Executive Leadership Team and advisory committee(s) could identify places where cuts in funding might be made to help balance necessary funding increases.

The committee also believes that future budgets should contain sufficient flexibility to permit the USGS to respond rapidly to new challenges and emerging opportunities. Owing to the complex congressional appropriations process, the linkage between the USGS budget and its strategic plan may be imperfect. Thus, it is imperative for the leadership of the USGS to have open and effective communication with Congress, to articulate broad goals for the organization that are aligned with national interests, and to ensure that the USGS director is an effective spokesperson and visionary leader. Some budget flexibility is essential for the agency to respond adaptively to new opportunities. The committee suggests that a fraction of the agency's operating costs be set aside for new initiatives analogous to a venture capital fund in the private sector. The committee recommends that discretionary funds be made available to the director for the mobilization of new integrated science initiatives as needs and opportunities arise.

SUMMARY

Demands placed on the USGS will be greater in the future, and management of the agency will become increasingly challenging. To accomplish its mission, the USGS will have to address a number of administrative issues.

An important task for the USGS is to put in place a formal mechanism for assessing customer needs and prioritizing activities that are consistent with program goals. The development of a research program involving problem-oriented and core research is an important aspect of the priority-setting process. The core research program should emphasize long-term research on problems of importance to the nation. External guidance would assist the USGS in program design and development. Therefore, the USGS should give high priority to the establishment of an agency-level external advisory committee and, where there are none now, external advisory committees at divisional and program levels as well.

The USGS is fortunate to have a highly talented and experienced work force to develop and provide science information. In view of many upcoming retirements, the USGS should devote substantial efforts to recruiting and maintaining excellent staff. Rejuvenation of the work force should take into account the new areas of expertise that will be needed in the future. In an environment of fiscal pressures, the agency may not be able to make as many new appointments as it might wish. As a result, a premium will be placed on a flexible workforce.

Even with a flexible work force the USGS will be unable to accomplish all of its goals in-house. Therefore, the agency should make a strong commitment to increasing its coordination and collaboration with federal agencies and with academia and industry as well. Cooperative programs with regional, state, and local governments and with other entities can be helpful too. However, great care should be taken to ensure that reimbursable contracts meet mission and strategic plan objectives and that they do not compete unfairly with state or other organizations.

An overarching management issue is the agency's budget. Since 1974, the agency's budget has remained roughly constant even though the tasks of the agency have increased. At a time when the agency is being ask to provide effective solutions to complex problems, the USGS must be effective in requesting increased funding, especially for a long-term core research program. Without adequate funding to support the research emphases outlined in this report, problems associated with such issues as natural hazards and water scarcity will remain understudied, with profound affects on the welfare of the citizens of the United States. The committee also recommends that discretionary funds be available to the director of the USGS as a way to mobilize new integrative science initiatives as needed.

6

Preparing for the Future: Conclusions and Recommendations

Over a period of more than 120 years the role of the USGS has evolved from a few scientists who collected data and provided guidance on how to parcel, manage, and use the public lands of the West to thousands of scientists who conduct research and assessment activities on complex scientific issues at scales ranging from the local to the global. If the past and present are guides, the USGS will continue to evolve and adapt to meet national needs. Change is a constant, but it is also difficult for any established organization like the USGS. Recognizing the need to adapt to changing demands in the future, the USGS invited the NRC in 1997 to conduct an independent review to help guide the organization in the early years of the twenty-first century. The Committee on Future Roles, Challenges, and Opportunities at the U.S. Geological Survey was charged to undertake a comprehensive study on the evolution of the agency to meet future needs. Specifically, the committee was charged to consider the following:

- major societal needs that the USGS should address;
- significant emerging scientific and technical issues that appear especially important in terms of their relevance to the mission of the USGS;
- opportunities for improving partnerships and other cooperative arrangements with other federal agencies, state agencies, universities, and the private sector;
- appropriate international functions of the USGS; and
- the balance of activities such as data acquisition and management, regional studies, and fundamental research.

The preceding chapters address the components of the charge. In this final chapter, the committee presents its conclusions and recommendations, which are intended to provide strategic guidance on how the agency can prepare for its future. The conclusions appear in italics and the recommendations in bold type.

A NATURAL SCIENCE[1] AND INFORMATION AGENCY

Over time, the USGS has evolved and built a solid foundation on which to plan its future. At present, senior management is attempting to modify the agency's culture from a cluster of loosely linked organizational units to a tightly interactive community. The recent integration of the BRD into the USGS is an organizational change that provides an opportunity for the agency to respond to questions beyond the geological, hydrological, and geographical sciences. When the BRD merged with the USGS, it prompted slight changes in wording, but no fundamental changes to the formal mission statement of the agency. The mission of the agency is to supply information that contributes to the wise management of natural resources and that promotes the health,

[1] Throughout this report, the committee uses the term "natural science" to broadly frame the range of scientific issues that are addressed by the USGS. Natural science is defined as "any of the sciences (as physics, chemistry, or biology) that deal with matter, energy, and their interrelations and transformation or with objectively measurable phenomena." (Webster's Third New International Dictionary, 1986) The specific activities carried out by the USGS within the broad domain of "natural sciences" depend on the agency's mission, which in turn, is shaped by the missions and responsibilities of other federal and state agencies and a variety of societal and political forces. Examples of natural science disciplines currently within the purview of the USGS include geology, hydrology, geography, biology, and geospatial information sciences. The committee chose this terminology after considering many other alternatives because it is a relatively succinct term that is generally understood to encompass all of the major scientific issues that are addressed by the USGS. The use of a single broad term also serves to emphasize one of the committee's main points—the value of integrated, coordinated science when dealing with the types of multidisciplinary mission-relevant problems addressed by the USGS. The term also was chosen by the USGS to describe itself in its 1999 vision statement. However, it is important to clarify that the committee's use of the term "natural science" does not imply that the USGS mission should include all natural sciences. The USGS is A natural science agency—not THE natural science agency.

safety, and well-being of the nation's citizens. The information in the form of maps, databases, and analyses provides managers and policy makers with timely, unbiased, and reliable information on water, energy and minerals, biota, and land resources. This mission is fully appropriate for a federal science agency. Furthermore, the role of the USGS is well defined with respect to other federal agencies. The USGS provides technical expertise and information not available elsewhere to a variety of federal agencies and other customers.

The USGS is a vitally important provider and coordinator of information related to critical issues in the natural sciences. As a result of changes in its external and internal environments, the USGS is evolving from an agency that was organized primarily to discover *what is out there,* to one that tries to understand *what is out there,* to one that tries to understand how *what is out there* works (i.e., process understanding). Although all three approaches are present in the work of the USGS today, the questions posed to the agency by society increasingly call for multifaceted, analytical, and integrative investigations of complex processes and systems. By evolving into a natural science and information agency, the USGS will be able to play a leadership role in the elucidation of the geological, hydrological, geographical, and biological processes that are important to the nation and in the use of modern technology for the effective and efficient dissemination of this information.

In upcoming decades, many of the relevant social needs (Chapter 3) and emerging scientific opportunities (Chapter 4) that the USGS should address will involve interactions among the natural environment, its biota, and people. *The USGS is well positioned, in terms of its information resources, technological capabilities, and range of professional expertise, to provide well-coordinated, comprehensive responses to priorities of society and science.* Interactions between the environment, its biota and people are highly complex and unpredictable, and in many cases, the solutions require integrative approaches.

Integrative science focuses on issues that cross disciplinary boundaries and is more than multidisciplinary collaboration. It involves individuals sharing different perspectives, methodologies, and conceptual models in a manner that changes each person's approach to the problem at hand. An integrative approach to science entails a focus on problems in all of their complexity, and the creation of teams with the skills and resources necessary to provide the entire suite of knowledge required for solutions or at least for well-informed responses. Developing interdisciplinary teams requires more of management than drawing a committee of scientists from each of the existing USGS divisions to attack a problem. It requires management to foster the integrative habit of inquiry by knowledgeable individuals.

A determination to commit the USGS to integrative scientific investigations is not an easy step to undertake. Not only are the objects of study—and therefore the vocabularies—different among disciplines, but the traditional spatial and temporal scales of phenomena to be studied and the nature of acceptable explanations are different too. Integrative work relevant to policy often requires that new perspectives are forged, new applications of methods are developed, and greater emphasis is given to the definition of conceptual system models. Both the difficulties and the rewards imply that in a large, multifaceted agency such as the USGS, senior management has to take the lead in promoting such integration because they are the only personnel with knowledge of all the agency's resources and they alone are charged with the strategic application of these resources in the overall national interest.

The USGS was founded around disciplinary skills and experience, and it continues to embrace a discipline-specific organizational structure. Despite this constraint, the agency recognizes the value of interdisciplinary teams and studies and has demonstrated the importance of those efforts many times. However, the agency has not yet created an interdisciplinary environment to confront the complexity of the issues at hand. The USGS has the capability and the opportunity to advance understanding of how the complex air-water-human-land system works with integrated research teams crossing traditional disciplinary boundaries.

The USGS should place more emphasis on multiscale, multidisciplinary, integrative projects that address priorities of national scale. The committee recognizes that integration is difficult to achieve, especially in cases that require integration of natural and social sciences. However, the failure to integrate will inhibit understanding of many natural science problems. Nevertheless, not all complex science problems require a broad integrative multidisciplinary research framework; therefore, the choice of research framework must fit the specific research problem. Problems that do not require a broad integrative multidisciplinary research framework should not be overlooked.

In the future, the USGS must continue to be first and foremost a scientific agency capable of high-quality assessments and research on relevant natural science issues. However, the nation and the world are entering a new era where economies are global, and information and its management are now a major source of wealth. How effectively the USGS can manage information will be critical to its future performance. For the USGS, information management has two essential aspects. The first is the ability of the USGS to assess the information needs of its customers and partners and to focus its resources on meeting those needs. The second is to deliver and facilitate the use of reliable, high-quality data and information effectively. The revolution in information technologies provides new opportunities for the way in which the USGS collects and disseminates information. **In the future, information management at the USGS should shift from a more passive role of study and analysis to one that seeks to convey information actively in ways that are responsive to the social, political, and economic needs.**

MAJOR RESPONSIBILITIES

Consistent with the mission responsibilities and the technical and analytical capabilities of the participating agencies, it is desirable that the USGS provide national leadership and coordination in the specific programmatic areas for which it is responsible. **The USGS should provide national leadership and coordination in (1) monitoring, reporting, and where possible, forecasting critical phenomena, including seismicity, volcanic activity, streamflow, and ecological indicators; (2) assessing resources, including oil and natural gas (domestic and foreign), minerals, water, and biota; and (3) providing geospatial information.**

These activities include the following overlapping categories: surveys, monitoring, data analysis, research, information dissemination, and product generation. **Subject to the overriding requirement that the USGS fulfill its primary and high priority mission responsibilities, the committee believes that the USGS should continue to conduct each of these activities, but that the balance of activities should shift toward the value-added activities of data analysis, problem solving, and information dissemination.** A shift of balance does not mean that the USGS should reduce data gathering or long-term data collections, but that it should do more to interpret what the data mean and to make the data useful and accessible.

Monitoring, Reporting, and Forecasting

The value of the USGS's high-quality, longitudinal databases will increase as they become longer and include a wider range of environmental variability and human influences. When surveys are repeated, they constitute a form of monitoring that can be used to detect or quantify natural change or human influence. The use of automated gauging and other remote monitoring devices, especially at remote sites, makes long-term monitoring more reliable and cost-effective. *Long-term databases are one of the USGS's most important contributions to the nation, and care must be taken not to disrupt them.*

Long-term monitoring is expensive and time consuming, and it has to be conducted carefully to provide the greatest amount of information return per dollar or time expended. In order to provide the maximum value to society, monitoring programs must be maintained indefinitely into the future so as to obtain the data necessary for understanding the natural cycles and fluctuations of earth systems as well as the impact of human activity on them.

The USGS can realize efficiencies in program areas in which the agency invested heavily in the past. Efficiencies can be realized by employing methods, such as remote sensing, in national resource surveys and reviewing national resource surveys for their relevance to the agency's mission. The USGS could also enhance monitoring and data analysis with the use of conceptual and mathematical modeling. Research into processes and relationships could be enhanced by regular internal and external reviews and articulation of the kinds of research that are considered necessary and useful for public policy. Finally, the USGS should place less emphasis on the design and development of new products and more emphasis on the update, maintenance, ease of availability, and security of quality data stores that are amenable to the rapid generation of value-added products. This emphasis could leverage the capability of value-added industry to produce tailored products on demand for USGS investigations and studies, using the most current and reliable software and hardware.

For many years the USGS has provided national leadership in communicating natural hazards information in a timely and understandable manner to multiple and diverse client groups. This information assists in protecting lives and property. The USGS is encouraged to play a stronger role in the disaster information community because the cost of natural disasters is increasing rapidly. Planning to minimize or avoid impacts is critical to reducing cost and human suffering. The USGS has responsibility to monitor and issue warnings for earthquakes, volcanic eruptions, and landslides, as well as to monitor floods and water quality. It also has responsibility to make disaster-related information available to disaster managers. Although disaster managers are finding it easier to obtain and share relevant information than in the past because of the Internet, data formats and reliability as well as accessibility remain problematic. **It is critical that the USGS continue to exercise national leadership in hazards research and risk communication.**

The USGS should emphasize system modeling as a powerful tool for integrative science. System modeling would enable the USGS, in coordination with other agencies and partners, to develop a greater understanding of complex science problems that involve natural and human systems. The USGS has the capability, within one agency, to gather geologic, hydrologic, and biological information about land use issues. By using the NMD appropriately, it can represent the information geographically. The challenges are (1) to recognize the types of information to solve a particular problem, and (2) to integrate different types of information in meaningful ways. Understanding of large, complex systems can be improved through the use of integrative system models. Moreover, effective application of such models to real-world problems requires a comprehensive understanding of social, as well as geological, contexts.

The committee believes that the development of an enhanced capability in integrative system modeling can contribute to the future effectiveness of the USGS. Modeling and integration capabilities need to operate across divisions and feed into the administration of research programs, especially for helping to establish research priorities and identifying where multidisciplinary or interdisciplinary research is needed. Modeling and integration efforts would also benefit from the establishment of a coordination committee involving related federal agencies and from the development of strong ties with other partners. Developing this modeling and integration capability would require hiring new scientists with appropriate background skills and developing new partnerships.

Assessing Resources

The USGS has a national reputation for its work in the area of assessing energy, mineral, water, and more recently, biological resources. These assessments are critical for the well-being of the United States. As the United States progresses into the twenty-first century, natural resources essential to the economic and strategic security of the nation will be subject to much greater pressures than in the past. **The USGS should provide national leadership in the provision of natural resource information**. By doing this the USGS will help the United States understand its future natural resource needs.

Providing Geospatial Information

The USGS is well positioned to provide the framework for a geospatial information depository and portal for the DOI and other federal departments, providing access to a wide range of natural resource information and derivative products that can support effective decision making. In this role, the agency would be responsible for integrating and making interoperable the nation's disparate geospatial databases, for promoting and coordinating the continued development of the architecture for the NSDI, and for developing national mapping and product specifications. The USGS would also be responsible for making the geospatial databases available as understandable information products for public use and exchange. Sharing geospatial data is important, because it avoids duplication of expenses associated with generation and maintenance of data.

NATIONAL AND INTERNATIONAL ROLES

As discussed in the previous section, the USGS is expected to address a variety of natural science issues of regional, national, and international importance. A major responsibility of the USGS is to serve as the science arm of the Department of the Interior (DOI). For informed decision making, DOI's agencies make use of objective, non-advocacy information from the USGS. If this information were not available—for example, to the BIA, BLM, MMS, and NPS—similar expertise would have to be developed within these agencies. **The USGS should ensure that science information is provided to DOI bureaus in an efficient and effective way. In turn, DOI leadership should ensure that USGS personnel and resources are utilized in DOI decision making.**

The USGS also has significant responsibilities that support other government agencies, states and local governments, tribes, industry, academic institutions, and the public. The oil and gas assessments and natural hazard maps are examples of USGS products that are of interest to a wide range of audiences. Interest in and concern about natural processes, resources, and environments are now affecting more segments of the population, and the USGS should encourage this interest. The USGS needs to provide leadership and research on a scale appropriate to the problem. Such a focus will require regional directors to understand the broader national and international context of a problem, and headquarters to appreciate the diversity of regional problems.

The USGS engages in international activities. For many years, the agency has worked internationally to provide the nation with much needed information about sources of essential minerals and fuels. More recently, research in foreign countries has helped USGS scientists to understand and prevent or mitigate environmental threats, and this work has proven to be a wise and necessary investment. Foreign area studies are worthwhile because environmental threats in one place can have significant influences in other places. For example, globalization means that U.S. companies and financial markets are increasingly vulnerable to disruptions caused by natural disasters anywhere on earth. The Kyoto earthquake provided an indication of how a much larger and more devastating earthquake in Tokyo might affect the economic and social fabric of the world.

Because many of the natural science issues within the purview of the USGS are global in nature, there is a compelling argument for the USGS to increase its international work on activities that meet mission objectives. **The USGS should develop international expertise in natural science problems relevant to the USGS mission.** Specifically, the USGS should perform a more vigorous role in pursuing foreign area and global studies that develop relevant natural science information in support of U.S. interests; increase technical assistance to foreign countries that are developing relevant natural science programs; and become more active in international activities to benefit the domestic programs and the international stature of the agency.

IMPROVING EFFECTIVENESS

In the future, the USGS will be asked to do more than in the past, and management of the agency will become increasingly challenging. The most fundamental challenge is one of magnitude: the size of the agency's human and financial resources relative to the demands for its information, services, and products. Yet the agency's management also has to address problems of substance, such as those associated with the need to develop an innovative, strategic, and balanced program of problem-specific and core research.

Priority Setting

The future of the USGS depends on its skill in identifying and setting rational and realistic priorities and its ability to reduce commitments of time and money that do not contribute to these priorities. Priority setting is not unknown at the USGS, which has in recent years prepared several strategic plans that establish broad priorities for the agency. However, there are three areas of concern in the USGS planning process that should be addressed. First, priorities stated in the strategic plans seem to have been developed internally with few mechanisms for refining them in response to input from customers. Second, in being responsive to its customers, the USGS should resist overpromising or overcommitting resources and, as a result, creating unreasonable expectations among its customers. Third, although responsiveness to customer needs must drive USGS priorities, this responsiveness must be in the context of the agency's national mission.

The USGS should develop a more effective process to assess and prioritize customer needs. A step in the right direction is the DOI "Agreement on USGS Research Support for DOI Resources Management Bureau Needs," which attempts to establish a process for determining USGS science priorities in support of the management and regulatory missions of other DOI bureaus. The USGS should work to ensure that the spirit and substance of this agreement are met. Similar, formalized approaches should be pursued with other customer groups, such as state geological surveys, environmental protection agencies, and resource management agencies. Thus, the USGS needs to consider mechanisms for prioritizing its activities and seeing that they are consistent with stated mission goals.

An important aspect of priority setting for the USGS is to support and maintain a strong research program. This report emphasizes the need for the USGS to develop objectives for a long-term core research program. One important objective of such a program should be to generate new knowledge on a set of understudied issues of importance to society (Chapter 3) and science (Chapter 4) that are central to a deeper understanding of interactions among natural systems and between nature and society.

By "long-term" research is meant a period that is long enough to improve understanding of specific, understudied problems. This period should be of the order of 5 to 10 years. Such a time horizon would provide the opportunity for teams of multidisciplinary teams of researchers to collaborate, apply novel approaches, and produce significant results on critical problems.

In the past, much USGS research and development focused reactively on short-term and narrowly defined problems, and often failed to anticipate the emergence of critical long-term problems. This approach is unsuitable for dealing with complex natural science problems that are relevant to the USGS mission. The solution to many complex natural science problems requires a research framework based on integrative science—science committed to bridging barriers that separate traditional modes of inquiry.

The USGS should develop and set a research agenda that is balanced appropriately between problem-specific research and core research. Clearly, the USGS needs to undertake both problem-specific and core research to address current and emerging science issues. However, the USGS should give high priority to, and expand considerably, the core research agenda and commit the necessary resources to undertake the priority research. The research agenda should be developed through a formal and continuous strategic science planning process. The USGS should review continually the balance between problem-specific research and core research and determine the appropriate mix of problem-specific and core research efforts.

To focus its efforts, the USGS should consider mechanisms to set a research agenda based on a series of guiding principles. Setting the research agenda will require substantive communication within the USGS and beyond its borders as well. The result should be a portfolio of planned and coordinated core and problem-specific research activities appropriate to USGS expertise with broad support inside and outside the agency.

The principle of calling on external advisory committees to assist in program design and development is well established. Many federal agencies have strengthened their programs through the extensive use of such committees. *As a major federal science agency, the USGS cannot afford to be without external advisory committees.* **The USGS should establish and make extensive use of external advisory committees.** Consideration should be given to the establishment of an agency-level external advisory committee and, where there are none now, external advisory committees at divisional and program levels as well.

A major advantage of external advisory committees is that they have organizational memory, but because they need to have broad expertise, they may not be as well suited to reviewing specific aspects of a program as specially constituted review panels. Therefore, the USGS should continue to request specially constituted review panels to conduct independent reviews and provide answers to specific questions.

Meeting Technical Needs

The scientific credibility and respect attributed to the USGS are primarily the product of an outstanding work force. However, the reservoir of accumulated knowledge is in danger of being lost through forthcoming retirements unless existing staff overlap with new staff. *Without a new generation of talented scientists to replace departing staff, the ability of the USGS to answer the questions of the future will be compromised and the morale of the remaining staff will deteriorate.*

The USGS should devote substantial efforts to recruiting and retaining excellent staff. The rejuvenation of the work force should take into account the new areas of expertise that will be needed in the future. In identifying new hiring priorities, the USGS has to pay special attention to its long-term core research agenda. Thus, opportunities should be made available to recruit scientists who can work effectively across program boundaries and who can be expected to provide leadership in the integration of science information.

To facilitate integrative science, the issue of personnel location will have to be addressed. In the future, USGS professional staff members will be expected to increase the effectiveness of their multidisciplinary investigations, which can be facilitated by concentrating scientists from different disciplines in centralized facilities. Therefore, consideration should be given to the colocation of scientists from different disciplines in order for them to conduct integrative science projects more efficiently.

In an environment of fiscal pressures, the agency may not be able to make as many new hires as it may wish. As a result, the USGS has to develop an organizational culture that encourages, values, and rewards flexibility and teamwork. For the agency to undertake multidisciplinary, integrative initiatives, it is of paramount importance that scientists be able to transcend traditional disciplinary boundaries. To retain excellent staff, careful consideration must be given to the reward system. The present reward system favors research over assessment and service activities. Management should seek ways to resolve this nettlesome issue by altering reward structures to encourage, recognize, and reinforce categories of professional activity that are sometimes underrated.

Even if the professional staff of the USGS were to increase substantially in the future, the increase would probably be insufficient for the agency to accomplish its goals solely through in-house activities. As the problems that the USGS addresses become more complex and multidisciplinary, it is unlikely that the existing professional staff, even with major retraining, would be able keep up with all of the new techniques and new knowledge, let alone cover all of the areas of expertise necessary to carry out an ambitious program of integrative science. **To achieve its mission goals, the USGS will have to strengthen coordination and collaboration with other federal agencies, as well as with states, academia, and industry.** At present, the USGS is insufficiently engaged with potential partners, especially related federal agencies, whose work can enhance the ability of the USGS to achieve its mission objectives. Coordination and collaboration increase institutional flexibility in meeting mission goals. They permit the sharing of resources (personnel, equipment, and ideas), enhance the prospects for new project funding, and can lead to high-quality science. In addition to making a strong commitment to increase external coordination and collaboration, the USGS should strive to improve cooperation between scientists within the agency. The USGS can make greater use of intra-agency transfers that foster cooperation, lessen the "stovepiping" of programs, and could accelerate the development of new integrated entities.

USGS cooperative programs with regional, state, and local governments as well as with other entities are stimulated by requests for scientific knowledge and data. These reimbursable programs can have considerable value: they allow the USGS to exchange employees between programs, they allow the agency to leverage its funds and thereby to expand its range of operations, and they provide a measure of the worth of certain agency products.

The efficacy of engaging in reimbursable work has been a source of debate both within and outside the USGS for many years. Proponents emphasize that reimbursable work enhances USGS programs, expands the work force, and keeps the agency in close contact with customers. Opponents argue that reimbursable programs distort the priorities of the USGS and inevitably lead to problems of conflict of interest or perceived conflict of interest that act against the best long-term interests of the agency.

The USGS has a long-standing partnership with state geological surveys and water resources agencies. This partnership is strained because of concerns by state survies that the USGS inappropriately competes with them for local project funds. The concerns, real or perceived, about competition between USGS and state surveys have to be addressed. **The agency should ensure that reimbursable contracts meet mission and strategic goals and that they do not compete unfairly with state or other organizations.**

Clearly, the reimbursable work of the USGS benefits many agencies. However, some of the reimbursable programs cause friction between the USGS and state and private entities, are viewed as conflicts of interest, and may divert the agency from its mission. Existing guidelines for reimbursable programs appear to be insufficiently clear or inconsistently applied. The USGS is aware of the issues and has taken steps to avoid unfair competition with the private sector. However, the issue of USGS funding through reimbursable work deserves review with regard to its effects on customer relations and with regard to the USGS mission and strategic plan.

The USGS should place more emphasis on whether potential cooperative projects meet mission and strategic plan objectives. Appropriate reimbursable programs are partnerships in which the USGS performs a function that is consistent with its basic mission and that contributes to its strategic objectives without competing unfairly with organizations that can provide a similar service.

Budget

The agency's budget, which has remained constant for many years, is a matter of concern. *Even with an agile, talented work force and a strong commitment to coordinated research efforts with other agencies and partners, it will be difficult for the agency to attain its future goals, especially those associated with a long-term core research program of integrative, multidisciplinary, relatively large research initiatives.* In response to priorities of society and science, the USGS is being called upon to confront complex problems that are critical to human and ecosystem survival. Long-term problems such as those associated with natural hazards that pose increased risks to the nation cannot be solved with the current level of program funding. **As the agency's responsibilities continue to increase, its budget should be increased to a level commensurate with the tasks.** The USGS should justify and request additional funds to support the development of a research portfolio in the national interest. With an appropriate level of funding for practical research related to national needs, the USGS will be better able to fulfill its mission.

Future budget requests should contain sufficient flexibility to permit the USGS director to respond rapidly to new research challenges and opportunities. A fraction of the agency's operating costs could be set aside for new initiatives analogous to a research and development budget in the private sector.

SUMMARY

Underlying many of the committee's conclusions and recommendations is the inescapable observation that future demands placed on the USGS can be expected to exceed the capacity of its financial and human resources. Some of the increased demand may be met by improvements in collaboration and coordination with other federal agencies, universities, and private industry and by creating a more agile and flexible work force. However, unless significant actions are taken soon to address human and financial resource issues, the USGS may be unable to meet all of its mission goals, respond rapidly to new challenges and opportunities, and transition toward becoming a natural science and information agency.

Although the demand for information from the USGS and its supply capacity are out of line, the USGS has established a good foundation on which to plan and build a successful future. It has evolved from an organization that was called on to document the natural resources of the West to one that is now being asked to understand geological, hydrological, geographical, and biological processes of immense importance and complexity. In the future, the USGS will be asked increasingly to deal with questions about how natural systems affect human systems and how human actions modify natural systems. More specifically, it will be asked to provide information on a host of problems ranging from environmental threats and human vulnerability to sustainable resources and livable communities. If it broadens the basis of inquiry to include integrative approaches involving natural and human sciences and becomes proficient at information management, the USGS will more fully realize its potential and provide the scientific information and knowledge essential to the future well-being of society.

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Appendixes

Appendix A

Biographical Sketches of Committee Members

Donald J. DePaolo (Chair) is professor of geochemistry at the University of California, Berkeley, and a senior faculty scientist at the E.O. Lawrence Berkeley National Laboratory. His research interests include the chemical evolution of the Earth's mantle and continental crust, igneous and metamorphic petrology, and isotopic hydrology. He received the F.W. Clarke Medal of the Geochemical Society, the J.B. MacElwane Award of the American Geophysical Union, and the Mineralogical Society of America Award. His previous NRC service includes membership on the Committee Advisory to the U.S. Geological Survey, the Virtual Commission on Environmental Management Sciences, and the Board on Earth Sciences and Resources. Dr. DePaolo was elected to the National Academy of Sciences in 1993.

Hugo F. Thomas (Vice Chair) is director of the Connecticut Institute of Water Resources and adjunct member of the Department of Natural Resource Management and Engineering, College of Agriculture and Natural Resources, University of Connecticut. He previously served as chief of environmental services in the Connecticut Department of Environmental Protection and state geologist of Connecticut. His interests include the study and implementation of new techniques for integrating and using natural resources data in land and water decision making. Dr. Thomas established the Connecticut Geographic Information System Center to further data integration and use. In 1988, he was awarded the John Wesley Powell Award by the USGS, its most prestigious award for nonfederal scientists in enhancing the application of earth sciences to public needs. Dr. Thomas is a former member of the Water Science and Technology Board.

John C. Antenucci is president of PlanGraphics, Inc. He is an engineer, planner, management consultant, and author specializing in technical and institutional issues concerned with management of geographic information. He is the author of *Geographic Information Systems: A Guide to the Technology*, a leading book in the field of spatial information. Mr. Antenucci served as a member of the NRC's Mapping Science Committee from 1989 to 1992, during which time the committee prepared studies for the Defense Mapping Agency and the National Mapping Division of the U.S. Geological Survey.

Odin D. Christensen is the chief geologist for Newmont Mining Corporation. He is responsible for technical oversight of Newmont's geological activities throughout the world. Dr. Christensen has been responsible for geologic exploration at Newmont's Carlin mine during unprecedented discovery and explosive growth along the Carlin Trend of Nevada. He served as the Thayer Lindsley Distinguished Lecturer of the Society of Economic Geologists. Prior to joining Newmont, he was an assistant professor at the University of North Dakota and later, a research geochemist at the University of Utah Research Institute.

Michael T. Clegg is dean of the College of Natural and Agricultural Sciences and professor of genetics at the University of California, Riverside. He is chair of the NRC's Board on Biology and former chair of the Committee on Scientific Issues in the Endangered Species Act. His research interests are genetics, plant domestication, and plant molecular evolution. Dr. Clegg is a fellow of the American Academy of Arts and Sciences and was elected to the National Academy of Sciences.

Thomas Dunne is a professor in the Donald Bren School of Environmental Science and Management and the Department of Geological Sciences at the University of California, Santa Barbara. He conducts field and theoretical studies of drainage-basin, hillslope, and fluvial geomorphology and of the application of hydrology and geomorphology in landscape management and hazard analysis. Dr. Dunne leads the Interdisciplinary Science Team, participating in NASA's Earth Observing System, that studies hydrology, sedimentation, biogeochemistry, and environmental change in the Amazon River Basin. He also conducts field research on erosion and sedimentation in the Pacific Northwest, central California, and New Mexico. He received the Robert E. Horton Award of the American Geophysical Union and the G.K. Warren Prize in Fluviatile Geology from the National Academy of

Sciences. His previous NRC committee service includes the Committee on Opportunities in the Hydrological Sciences, Committee on Alluvial Fan Flooding, and Committee on Water Resources Research of the USGS. Dr. Dunne was elected to the National Academy of Sciences and the American Academy of Arts and Sciences.

William Fisher holds the Barrow Centennial Chair in the Department of Geological Sciences at the University of Texas at Austin. He has extensive experience in academia and in state and federal government, including service as Texas State Geologist and director of the Bureau of Economic Geology, and as Assistant Secretary of the Interior. Dr. Fisher is past president of the Association of American State Geologists, American Association of Petroleum Geologists, American Geological Institute, American Institute of Professional Geologists, and Gulf Coast Association of Geological Societies. He has received the Powers Medal from AAPG, the Campbell Medal from AGI, the Parker Medal from AIPG, and the Hedberg Medal from ISEM. His research interests include energy and mineral policy, basin analysis, energy and mineral resource evaluation, stratigraphic facies analysis, seismic stratigraphic analysis, oil and gas recovery, environmental geology, and waste disposal. Dr. Fisher is a former member of the NRC's Commission on Geosciences, Environment, and Resources, former chair of the Board on Earth Sciences and Resources, and currently a member of the Board on Energy and Environmental Systems. Dr. Fisher was elected to the National Academy of Engineering.

Lawrence W. Fritz is senior staff scientist at Lockheed Martin Corporation and is also president of the International Society for Photogrammetry and Remote Sensing. His expertise includes mapping, geodesy, remote sensing and spatial information sciences. He served as director of the NOAA Charting Research and Development Laboratory and senior policy analyst for remote sensing, space and national security at the White House Office of Science and Technology Policy. He is on the Board of Directors of the Open GIS Consortium and served as chairman of the Review Board of *the Photogrammetric Engineering & Remote Sensing Journal.* He is an honorary cosmonaut of the Russian Academy of Cosmonautics, an honorary member of the American Society for Photogrammetry and Remote Sensing, a comendador of the Brazilian

Ordem do Mérito Cartográfico, he received the Colbert Medal of the Society of American Military Engineers and the Fairchild Award of ASPRS.

Grant H. Heiken is staff member in the Earth and Environmental Science Division at Los Alamos National Laboratory. He was president of the International Association of Volcanology and Chemistry of the Earth's Interior (1995-1999). Dr. Heiken has conducted extensive research in volcanology, volcanic hazards, geothermal resources, and lunar geology. He is co-team leader of a Los Alamos initiative in “urban security,” which is an interdisciplinary, coupled approach to modeling cities, with integration of geological and atmospheric processes. His work on the interplay between natural hazards and society is demonstrated by a forthcoming book he coedited entitled Volcanic Hazards and Human Antiquity and by his role in organizing the First International Symposium on Volcanic Ash and Aviation Safety. He is a former member of the U.S. National Committee for the International Union of Geodesy and Geophysics and former chairman of the U.S. National Committee of the International Association of Volcanology and Chemistry of the Earth's Interior.

James A. MacMahon is a professor of biology and dean of the College of Arts and Sciences at Utah State University in Logan, Utah. His expertise is in ecology and vertebrate zoology. His research interests include the community ecology of deserts; biology of desert perennials; energy exchange in plant and animal populations; biology of reptiles and amphibians; and biology of arachnids. He serves on the editorial board of *Ecological Restoration* and as president of the Ecological Society of America. He is a member of the Board on Environmental Studies and Toxicology.

Dianne R. Nielson is executive director of the Utah Department of Environmental Quality, which safeguards and protects public health and quality of life by protecting and improving environmental quality. Prior to this appointment, Dr. Nielson worked as an exploration geologist and later directed the Utah Division of Oil, Gas, and Mining. She has worked closely with mining and oil and gas operators to minimize environmental impacts of resource development and to ensure viable postproduction land use. She has chaired or worked on numerous state and federal commissions and advisory committees dealing with resource development and environmental issues. She is a member of the NRC Board on Earth Sciences and Resources and its Committee on Earth Resources, and is a past member of the Panel to Review the Mineral Resource Surveys Program Plan of the U.S. Geological Survey, as well as the Committee on Onshore Oil and Gas Leasing.

Joanne M. Nigg is professor of sociology and co-director of the Disaster Research Center at the University of Delaware. She is also president of the Earthquake Engineering Research Institute. Dr. Nigg is an expert on the societal response to natural hazards and disasters. Specifically, her research has focused on the public understanding of disaster forecasts; public, organizational, and governmental responses to natural disasters; the factors that facilitate or inhibit the development of disaster preparedness and mitigation programs by local governments; and the evaluation of disaster education programs. She is a member of the Board on Natural Disasters and a past member of the Committee on Earthquake Engineering.

Jerome O. Nriagu is professor of environmental chemistry of the Environmental Health Sciences Program, School of Public Health, University of Michigan, Ann Arbor. He has authored and edited 25 books related to his research interests in environmental chemistry, biogeochemistry, aquatic toxicology, and the health effects of toxic metals, especially lead, thallium, chromium, arsenic, and cadmium. He is the editor of the international journal Science of the Total Environment (published by Elsevier), and the book series, "Advances in Environmental Science and Technology" (published by Wiley-Interscience). Dr. Nriagu is currently involved in a number of projects on environmental pollution and associated health effects in developing countries, served as chairman of the Dahlem Conference on Metal Cycles and Human Health, and was involved in organizing an International Conference on Medical Geology. He served on the NRC's Panel on Lead in the Human Environment.

Raymond A. Price is professor emeritus of geological sciences and geological engineering at Queen's University, Kingston Ontario. Previously, he was director-general of the Geological Survey of Canada and Assistant Deputy Minister of Energy Mines and Resources, Canada. A leading authority on tectonics and structural geology, Dr. Price has extensive expertise and experience in international geoscience organizations and multidisciplinary scientific problems, including global change and radioactive waste disposal. Dr. Price is a former president of the Geological Society of America and former president of the International Council of Scientific Unions Inter-Union Commission on the Lithosphere. He has served on several NRC committees, and is a former member of the Commission on Geosciences, Environment and Resources and Board on Earth Sciences and Resources' Panel to Review the U.S. Geological Survey's Energy Resources Program. He has received the Sir William Logan Medal of the Geological Association of Canada, the Leopold von Buch Medal of the Deutsche Geologische Gesellschaft, and the Major Edward D'Ewes Fitzgerald Coke Medal of the Geological Society of London, and he has been made an Officier de l'Ordre des Palmes Académiques, France. Dr. Price was elected to the National Academy of Sciences and the Royal Society of Canada.

Daniel R. Sarewitz is managing director and, senior research scholar at Columbia University's Center for Science, Policy, and Outcomes, where he works on a wide range of science and environmental policy issues. From 1995 to 1997, he was director of the Institute for Environmental Education of the Geological Society of America in Boulder, Colorado. For four years he was the science adviser to Chairman George E. Brown, Jr., with the Committee on Science, Space, and Technology of the U.S. House of Representatives. He is the author of the book *Frontiers of Illusion: Science, Technology, and the Politics of Progress (1996), and the lead editor of Prediction: Science, Decision-Making, and the Future of Nature (2000).*

Bruce A. Stein is vice president for programs for the Association for Biodiversity Information, Arlington, Virginia. Dr. Stein is a specialist in the development and application of biodiversity information for conservation purposes. From 1987 to 2000 Dr. Stein was a Senior Scientist with The Nature Conservancy, where he was involved in establishing biodiversity inventory and protection programs. His current responsibilities include working with the Network of Natural Heritage Programs, a consortium of state biodiversity information centers, and with a variety of U.S. federal agencies to encourage the use of biodiversity information in environmental management. Dr. Stein is a specialist in plant inventory, classification, and conservation, with particular expertise in the botany of tropical South America. He is a research collaborator at the National Museum of Natural History and serves on the steering committee of the Species Survival Commission of the World Conservation Union. His recent publications include the book: *Precious Heritage: The Status of Biodiversity in the United States.* Dr. Stein holds a B.A. in biology and environmental studies from the University of California, Santa Cruz, and received his Ph.D. from Washington University, St. Louis, in a joint program with the Missouri Botanical Garden.

Anthony R. de Souza (NRC) is currently director of the Board on Earth Sciences and Resources at the National Research Council in Washington, D.C. Previously, he was executive director of the National Geography Standards Project, secretary general of the 27th International Geographical Union Congress, editor of *National Geographic Research & Exploration*, and editor of the *Journal of Geography.* He has held positions as a professor and as a visiting teacher and scholar at the George Washington University, University of Wisconsin-Eau Claire, University of Minnesota, University of California-Berkeley, and University of Dar es Salaam in Tanzania. He has served as a member of NRC committees. He holds B.A. (honors) and Ph.D. degrees from the University of Reading in England, and has received numerous honors and awards, including the Medalla al Benito Juarez in 1992 and the Gilbert Grosvenor honors award from the Association of American Geographers in 1996. His research interests include the processes and mechanisms of economic development and human-environment relationships. He has published several books and more than 100 articles, reports, and reviews.

Tamara L. Dickinson (NRC) is a senior program officer for the Board on Earth Sciences and Resources of the National Research Council. She has served as program director for the Petrology and Geochemistry Program in the Division of Earth Sciences at the National Science Foundation. She has also served as discipline scientist for the Planetary Materials and Geochemistry Program at NASA Headquarters. As a postdoctoral fellow at the NASA Johnson Space Center, she conducted experiments on the origin and evolution of lunar rocks and highly reduced igneous meteorites. She holds a Ph.D. and a M.S. in geology from the University of New Mexico and a B.A. in geology from the University of Northern Iowa.

Rebecca E. Shapack (NRC) is a research assistant for the Board on Earth Sciences and Resources of the National Research Council. She holds a B.S. in mathematical sciences engineering with a concentration in biology from the Johns Hopkins University, and is currently working on her M.S. in public health at the George Washington University.

Appendix B

Oral Presentations and Written Statements Submitted to the Committee

ORAL PRESENTATIONS

The following individuals made presentations to the Committee on Future Roles, Challenges, and Opportunities of the USGS:

Allison, *Lee* Utah State Geologist, Utah Geological Survey; *Alpine*, *Andrea* Western Regional Director, USGS; *Babbitt, Bruce* Secretary of the Interior, Department of the Interior; *Baker, D. James* Administrator, National Oceanic and Atmospheric Administration, and Co-chair, Committee on Environment and Natural Resources, National Science and Technology Council; *Baron, Jill* Research Ecologist, Midcontinent Ecological Science Center; USGS; *Bartolino*, *James* Project Chief, Middle Rio Grande Project, USGS; *Bernknopf, Richard* Economist, National Mapping Division, USGS; *Betancourt*, *Julio* Paleoecologist, University of Arizona, Desert Laboratory; *Bohlen, Steve* Associate Chief Geologist, Gelogic Division, USGS; *Boyd*, *Wilbert (Rocky)* Project Manager, Natural Resources Research Center, U.S. Forest Service; *Burkardt, Nina* Social Science Analyst, Midcontinent Ecological Science Center, USGS; *Cain, Doug* Subdistrict Chief, Pueblo, Colorado; *Campbell*, *David* Research Hydrologist, Water Resource Division, USGS; *Carr*, *Michael H.* Research Geologist, Astrogeology Group, Menlo Park, USGS; *Casadevall, Thomas* Acting Director, USGS; *Cloern, James* Physical Scientist, Water Resources Division, National Research Program, Western Division, USGS; *Cluff*, *Lloyd* Manager, Geosciences Department, Pacific Gas and Electric Company; *Cole, James* Geologist, Cooperative Geologic Mapping Program, USGS; *Coplen*, *Tyler* Research Chemist, Water Resource Division, USGS; *Corell*, *Robert* Assistant Director for Geoscience, National Science Foundation; *Cowart*, *Vicki* State Geologist and Director, Colorado Geological Survey; *Daniel*, *Dick* Assistant Director for CALFED Ecosystem Restoration Branch; *Davis*, *James* California State Geologist;

Department of Conservation, Division of Mines and Geology; *Dennehy*, *Kevin* Supervisory Hydrologist, NAWQA, USGS; *Dennis*, *John* Chief, Natural Systems Management Office, National Park Service; *Dieterich*, *James* Director, Earthquake Hazards Program, USGS Western Region; *Donnelly*, *Jay* Managing Editor, National Atlas, USGS; *Dyer*, *Russ* Project Manager, Yucca Mountain Site Characterization Office, Department of Energy; *Eisner*, *Rich* Regional Administrator, Governor's Office of Emergency Services Coastal Region; *Fenn*, *Dennis* Chief, Biological Resource Division, USGS; *Fenves*, *Gregory* PEER Department of Civil Engineering, University of California, Berkeley; *Fouch*, *Thomas* Associate Chief Geologist for Central Region, USGS; *Gautier*, *Donald* Chief Scientist, Western Earth Surface Processes Team, Menlo Park, USGS; *Gaydos*, *Len* Leader, Earth Resources Observation Systems-Ames Research Group, Menlo Park, USGS; *Glauthier*, *T.J.* Associate Director for Natural Resources, Energy and Science, White House Office of Management and Budget; *Green, Kass* President, Pacific Maderian; *Groat*, *Charles G.* Director, USGS; *Gunderson*, *Linda* Associate Chief, Geologic Division, USGS; *Hampton, Monty* Geologist, Coastal and Marine Geology Team, Menlo Park, USGS; *Hazeltine*, *Susan* Deputy Chief Biologist for Science, Biological Resources Division, USGS; *Henyey*, *Thomas* Science Director, Southern California Earthquake Center; *Hester, David* Cartographer, Rocky Mountain Mapping Center, USGS; *Hill*, *David* Chief Scientist,Long Valley, Volcano Hazards Program, USGS; *Hirsch, Robert* Chief Hydrologist, Water Resource Division, USGS; *Horak*, *William* Colorado District Chief, Water Resources Division, USGS; *Houseknecht*, *David* Energy Resource Program Coordinator, USGS; *Howell*, *David* Geologist, Western Earth Surface Processes Team, Menlo Park, USGS; *Hsieh*, *Paul* Hydrologist, Water Resources Division, Menlo Park, USGS; *Hunter, Don* Ecologist; Midcontinent Ecological Science Center, USGS; *Iverson*, *Richard* Hydrologist, Cascades Volcano Observatory, USGS; *Jancaitis, Jim* Senior Program Advisor, National Mapping Division, USGS; *Karl, Herman* Geologist, Western Regional Coastal and Marine Geology Team, Menlo Park, USGS; *Kelmelis, John* Associate Chief Scientist, National Mapping Division, USGS; *Klein*, *Mary* Director, Fish and Wildlife Biology, Colorado State University; *Knopf, Fritz* Senior Scientist, Midcontinent Ecological Science Center, USGS; *Koleis*, *Marvin* Office of Energy Management, Colorado Department of Local Affairs; *Kurath*, *Gail* Senior Scientist, Western Fisheries Research

Center, USGS; *Lang*, *Larry* Chief of Flood Control and Flood Plain Management, Colorado Conservation Board; *Leahy*, *P. Patrick* Chief Geologist, Geologic Division, USGS; *Lester*, *David* Executive Director, Council on Energy Resources Tribes; *Mallard*, *Gail* Associate Chief Hydrologist, Water Resources Division, USGS; *McGregor*, *Bonnie* Associate Director for Science, USGS; *McMahon*, *Peter* Research Hydrologist, USGS; *Miller*, *William* National Hazards Information Center; *Mladinich*, *Carol* Project Member, Front Range Infrastructure Project, USGS; *Nielson*, *Dianne* Executive Director, Utah Department of Environmental Quality; *Perciasepe*, *Robert* Assistant Administrator for Water, Environmental Protection Agency, Office of Management and Budget, Executive Office of the President; *Perkins*, *Jeanne* Earthquake Program Manager, Association of Bay Area Governments; *Phillips*, *Scott* Hydrologist, Chesapeake Bay Ecosystem Program, USGS; *Pielke*, *Roger* Professor, Atmospheric Science, Colorado State University; *Plummer*, *Neil* Hydrologist and Senior Scientist, Water Resources Division, USGS; *Posey*, *Harry* Environmental Protection Specialist, Colorado Department of Natural Resources, Colorado Division of Minerals and Geology; *Posson, Doug* Director for Central Region, USGS; *Ray*, *Pulak* Chief Geologist, Minerals Management Service; *Rogers*, *John* Deputy Director, U.S. Fish and Wildlife Service; *Romanowitz*, *Barbara* Seismological Laboratory, University of California, Berkeley; *Rossmeissl*, *Hedy* Assistant Chief, National Mapping Division; *Ryan*, *Barbara* Associate Director for Operations, USGS; *Savage, William (Woody)* Pacific Gas and Electric, Geosciences Department; *Schaefer, Mark* Deputy Assistant Secretary for Water and Science, Department of the Interior; *Shea*, *Pat* Director, Bureau of Land Management; *Shevock*, *Jim* Associate Pacific West Regional Director, National Park Service; *Smith, Larry* Director, Water Resources Division, Sacramento, USGS; *Stalnaker*, *Clair* Fish and Wildlife Biologist, Midcontinent Ecological Science Center, USGS; *Stendell*, *Rey* Director, Midcontinent Ecological Science Center, USGS; *Stohlgren*, *Thomas* Ecologist, Midcontinent Ecological Science Center, USGS; *Testa*, *Steve* Chairman, Testa Environmental Corporation; *Tilling*, *Robert* Chief, Volcano Hazards Team, Menlo Park, USGS; *Tonnessen*, *Kathy* Ecologist, Air Resources Division, National Park Service; *Tosta*, *Nancy* Director, Forecasting and Growth Strategy, Puget Sound Regional Council; *Wilson*, *Clark* Program Scientist, Geodynamics and Geopotential, National Aeronautics and Space Administration; *Witherbee*, *Kermit* Group Supervisor, Branch of

Fluid Minerals, Bureau of Land Management; *Witmer, Richard* Chief Geographer, USGS; *Wondra*, *Phil* Deputy Regional Chief Biologist, Central Region, USGS; *Zavoli*, *Walt* Vice President, Research and Development, Etak Inc.

WRITTEN STATEMENTS

Blockstein, *David* Senior Scientist, Committee for National Institute for the Environment; *Bredehoeft*, *John* Consultant/Principal, The Hydrodynamics Group; *Duffy*, *Christopher J.* Group Member, Computing, Information, and Communications (CIC7), Los Alamos Laboratory; *Ferry*, *John M.* President, Mineralogical Society of America; *Hood*, *Laura* Conservation Planning Program Manager, Defenders of Wildlife; *Kesler*, *Stephen* Professor, Geological Sciences, University of Michigan; *McKee*, *Lance* Vice President, Corporate Communications, Open GIS Consortium, Inc.; *Paul*, *Ellen* Executive Director, The Ornithological Council; *Reimer, G. Michael; Rittmann*, *Bruce E.* Acting Director, Institute for Resources and Environmental Geoscientist; *Saperstein, Lee* Chair, Board on Natural Resources; *Scalet*, *Charles G.* President, National Association of University Fisheries and Wildlife Programs, Department of Wildlife and Fisheries; *Shaffer*, *Mark* Vice President for Program, Defenders of Wildlife; *Smith, James UPS* Foundation Visiting Professor, Stanford University; *Spirakis*, *Charles* Golden, Colorado; *Tubbesing*, *Susan* Executive Director, Earthquake Research Institute.

Acronyms

BIA	Bureau of Indian Affairs
BIN	Bureau Information Needs
BLM	Bureau of Land Management
BRD	Biological Resources Division
CBP	Chesapeake Bay Program
CIMS	Chesapeake Information Management System
CMGP	Coastal and Marine Geology Program
CRADA	cooperative research and development agreement
DEM	digital elevation model
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
EDC	EROS Data Center
EDMAP	educational component of NCGMP
EPA	Environmental Protection Agency
EROS	Earth Resources Observation Systems
FAA	Federal Aviation Administration
FAC	Federal Advisory Committee
FEDMAP	federal mapping component of the NCGMP
FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FTE	full-time equivalent
GAP	Gap Analysis Program
GCIP	GEWEX Continental-Scale International Project
GCM	general circulation model
GD	Geologic Division
GDIN	Global Disaster Information Network
GDP	Gross Domestic Product
GEWEX	Global Energy and Water Cycle Experiment

GIS	geographic information system
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
IABIN	Inter-American Biodiversity Information Network
IRIS	Incorporated Research Institutions for Seismology
ISC	International Seismic Centre
MMS	Minerals Management Service
NABIN	North American Biodiversity Information Network
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NAWQA	National Water Quality Assessment Program
NBII	National Biological Information Infrastructure
NBS	National Biological Service
NCGMP	National Cooperative Geologic Mapping Program
NEHRP	National Earthquake Hazard Reduction Program
NEIC	National Earthquake Information Center
NIH	National Institutes of Health
NMD	National Mapping Division
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRC	National Research Council
NSDI	National Spatial Data Infrastructure
NSF	National Science Foundation
NSN	National Seismic Network
NWS	National Weather Service
OFDA	Office of Foreign Disaster Assistance (USAID)
OPEC	Organization of Petroleum Exporting Countries
OPM	Office of Personnel Management
PCAST	President's Committee of Advisors on Science and Technology
RASA	Regional Aquifer Systems Analysis
RGEG	Research Grade Evaluation Guide
RIM	River Input Monitoring
SCT	Strategic Change Team
STAC	Scientific and Technical Advisory Committee
STATEMAP	state geologic mapping component of the NCGMP
USACE	U.S. Army Corps of Engineers
USAID	U.S. Agency for International Development
USBR	U.S. Bureau of Reclamation

USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VDAP	Volcano Disaster Assistance Program
VHP	Volcano Hazards Program
WRD	Water Resources Division