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Dallas L. Peck, Director

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Cover: The Earth from space. Africa and Arabia lie north of the Indian and Atlantic Oceans, cloud-draped from the Antarctica Ice Cap to the Equator. Photograph from Apollo 17 spacecraft at about 100,000 nautical miles from Earth.

Message from the Director

Once again we have gone through a year of change—a year of major challenges. During this past fiscal year, devastating earthquakes in Armenia, volcanic activity in Hawaii and Alaska, and Hurricane Hugo's rampage along the Atlantic coastline reminded us all too well of the destructive effects of the forces of nature. Hardly had the old fiscal year ended when the Nation faced another major natural disaster with the "World Series" earthquake in California, the most costly earthquake in the United States since 1906. The need to understand the processes of natural disasters and to find ways to mitigate their effects has never been greater. Coupled with the need to understand the forces of nature is the equally compelling need for reliable scientific information on the water, energy, and mineral and land resources of the Earth. The challenges to earth scientists these days are many and complex.

As we move into a new decade, the U.S. Geological Survey begins a renewed commitment to pursue the scientific knowledge that is needed to provide the Nation and the world with the tools to better understand, to predict, to mitigate, to manage, and to better cope with the environmental and natural resource challenges that face us.

The new decade brings with it a renewed challenge from the environment. In the world at large, there is a renewed commitment to the environment as a whole. Political and social attention is focused on: What is the state of our natural environment? How is it changing? What effects are caused by human interaction? Attention is being focused on an integrated environment in which the natural resources—renewable and nonrenewable—and the people resources are seen as aspects of a whole that must work together.

The USGS is intensely involved in research on the environment. Accurate assessments of the mineral and energy resources of the land and the offshore realm provide the Nation with more realistic expectations for the availability of needed resources. Detailed investigations of the quality of the surface- and ground-water resources—and how that quality may be changing—provide basic information for planning how water will be used and shared by multiple users. Basic geologic mapping of the structure of the Earth's surface provides a picture that can be used to pinpoint areas that are susceptible to landslides and other hazards, to target areas for likely mineral or energy exploration, to select safer sites for dams and reservoirs, and to build repositories for hazardous waste. By using sophisticated mapping and computer technology, we are able to combine land-use, geologic, hydrologic, and other information for analysis and manipulation in thousands of ways to provide answers for questions that we could not even ask a decade ago.

The year 1990 will begin the International Decade for Natural Disaster Reduction (IDNDR), a worldwide focused effort to reduce loss of life and economic impacts from earthquakes, hurricanes, floods, landslides, volcanic eruption, tsunamis, wildfires, and drought. The IDNDR has been endorsed by the United Nations and is being cosponsored by more than 150 nations. The underlying message for the decade is that it is only through international cooperation and scientific sharing that we can hope, on a global scale, to reduce the impacts of natural disasters and to live in a less hazardous world.

The global perspective is one that is becoming increasingly important in many of our scientific endeavors. The entire science of global change is forcing us to widen our horizons, scientifically and socially, and to consider on an international level the impacts of our human actions and how we conduct our science to deal with those human impacts as well as with natural processes.

In my role as Chairman of the Committee on Earth Sciences, I have become intensely involved in the work of global change research. It is an exciting—and sometimes daunting—field in which to be engaged. The challenges are many, including developing an understanding of the complexities of land, atmosphere, biosphere, and hydrosphere interactions and then modeling those complexities at scales that can be meaningful in developing policies and plans for coping with change. There can be arguments about how much global change has occurred. There can be arguments about the causes of that change, whether natural or human induced. But what cannot be argued, based on the scientific record and the research to date, is that our global environment is and will be changing. How much change and with what effects are two of the major questions that we as earth scientists are being asked to answer.

As you will see from articles in this Yearbook, the USGS is integrally involved in many aspects of global change, from land classification studies, remote sensing, and river-basin studies to studies of ancient climates, glacial advance and retreat, and coastline changes. We are, after all, scientists of the Earth.

We are excited and challenged by the tasks that lie before us in furthering our understanding of the global environment. The tasks ahead, the information that must be gathered, and the research that must be conducted will all allow the USGS to further its commitment to provide more and better "Earth Science in the Public Service." It is with great pleasure that I present to you the "U.S. Geological Survey Yearbook for Fiscal Year 1989."

Dallas L. Peck

In the coming decades, global change may well represent the most significant societal, environmental, and economic challenge facing this Nation and the world. The national goal of developing a predictive understanding of global change is, in its truest sense, science in the service of mankind.

A Unified Federal Approach to Global Change Research

By John A. Kelmelis

Introduction

The Earth is in a constant state of change. Past climates have been warmer—and colder—than today. Sea levels have risen and fallen, changing the shape of shorelines. The diversity of plant and animal life on Earth has changed over time. There have been times of drought and times of flooding. The face of the landscape has changed over millions of years, responding to forces that built, eroded, shifted, and moved the land surface. Some global change is the result of natural processes; other change is the result of human influence on or interaction with those natural processes. The important goal of global change research is to understand the natural aspects of global change, which aspects are caused by human activities, and, most critically, what are the effects of those changes on the global environment. Only with a sound scientific understanding of all the processes involved can the Nation and the world make informed decisions to deal with global change.

To be more certain that the scientific issues involved in global change are being adequately addressed, the Committee on Earth Sciences (CES) was established by a directive of the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) on March 6, 1987. The CES was initially charged with reviewing Federal research in earth science, both national and international, and with improving the planning, coordination, and communication among those Federal agencies involved in earth-science research. The CES was then assigned the responsibility of establishing the needs and priorities for a unified approach to global change research. The scientific objectives of Federal research efforts are to monitor, to understand, and, ultimately, to predict global change. The overriding goal of the U.S. Global Change Research Program is to gain a

Sand dunes in Death Valley, Calif. The USGS is expanding its arid-regions research including remote-sensing efforts to monitor changes in desert boundaries and to study surficial processes in arid and semiarid regions that are particularly sensitive to climate change. (Photograph by Richard Frear.)

The effects of Hurricane Hugo, as seen on Isle of Palms, S.C., underscore the need for studies of coastal processes to be used in developing predictions about the effects of inundation and accelerated erosion associated with both sea-level rise and changes in frequency and intensity of coastal storms. (Photograph by Asbury H. Sallenger, Jr.)

predictive understanding of the interactive physical, geological, chemical, biological, and social processes that regulate the total Earth system and, hence, establish the scientific basis for national and international policy formulation and decisions relating to natural and human-induced changes in the global environment and their regional impacts.

The CES is composed of representatives from the Departments of Agriculture, Commerce, Defense, Energy, Interior, State, Transportation, the U.S. Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation, Office of Science and Technology Policy, Office of Management and Budget, and the Council on Environmental Quality. Other Federal agencies may participate by invitation of the chairman of FCCSET or the chairman of CES. Dallas L. Peck, Director of the U.S. Geological Survey, is the current chairman of the CES.

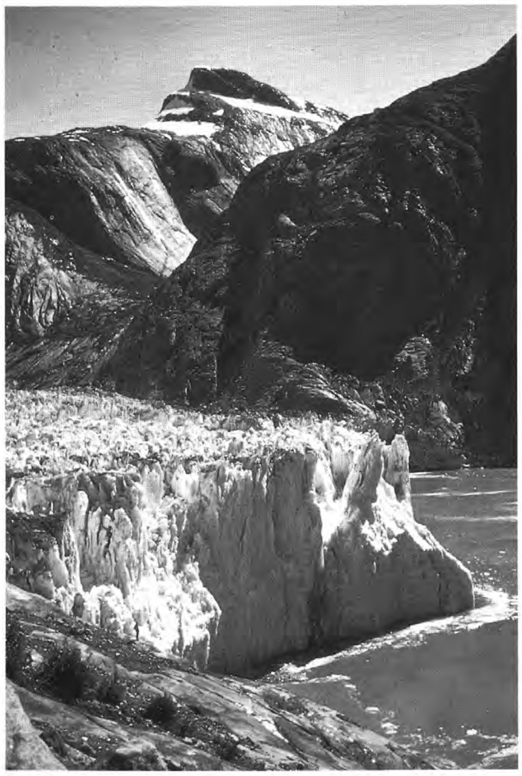
A Global Change Working Group, led by Robert Corell of the National Science Foundation, was formed as a subcommittee of the CES to identify and evaluate Federal scientific research that contributes to our knowledge of global change issues. The group identified weaknesses in the current understanding of global systems and then charged individual agencies with developing scientifically sound research projects to focus on those weaknesses.

Interdisciplinary Science Elements

Recognizing that the standard, single-disciplinary approach to scientific research would provide too narrow a focus for those global change issues which cut across two or more disciplines, the CES identified the following seven interdisciplinary science elements on which to build an integrated understanding of the Earth.

Climate and Hydrologic Systems. Understanding the characteristics of the atmosphere, oceans, and land surface that in turn influence temperature, humidity, clouds, and precipitation is a high priority of global change research. These characteristics are extremely variable and, whether natural or human-induced, can have a profound and rapid impact on the habitability of many regions of the planet. Weaknesses in current research programs include sparse data for some regions; inadequate understanding of critical atmospheric, climatic, and hydrologic factors; and poor understanding of how energy is transferred in the atmosphere, oceans, and land. Of particular concern is the lack of understanding of cloud dynamics and their contributions to the climate system.

To improve our understanding of the interrelation between the climate system and the hydrologic cycle, studies will be conducted to learn more about how clouds affect the solar energy that enters and leaves the atmosphere, how the oceans transfer and redistribute that energy, and the rates at which water and energy are transported among the atmosphere, biosphere, and land and ocean surfaces. Global ice balance—how much ice remains stored in polar ice caps

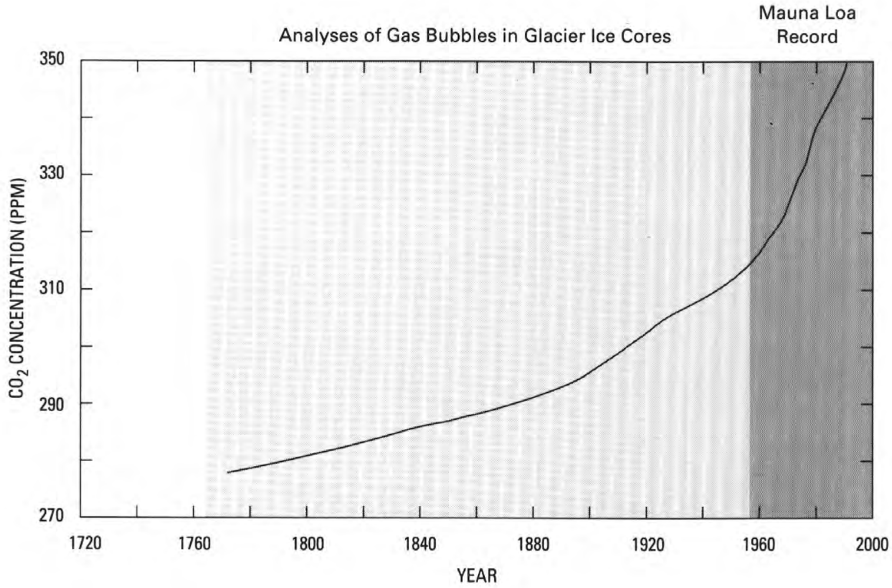


View of the calving terminus of Dawes Glacier, a tidewater glacier that empties into the upper part of Endicott Arm, 80 miles southeast of Juneau, southeastern Alaska. Glaciers are one of the best indicators of regional and global climate change, because they are extremely sensitive to variations in mean annual temperature and precipitation. Glaciers can rapidly gain mass when the climate becomes cooler and more snowy, expanding in both volume and area; conversely, glaciers can quickly shrink in area and volume under warmer and less snowy climatic conditions. As global glacier ice volume changes over time, there is a concomitant rise or fall of sea level, as glaciers lose or gain mass. (Photograph by Donald Grybeck.)

and glaciers—will play an important part in these studies, as will studies of river basins. The geographic interpretation of land-surface characteristics, particularly from remote-sensing data, will be a significant aspect of these studies.

Biogeochemical Dynamics. Many constituents of the atmosphere have the potential to influence climate, alter the amount and type of radiation that reaches the Earth's surface, and affect the use of nutrients by the biological community. In addition, chemical alteration of the hydrosphere and soils can affect local, regional, and global distributions of biological communities. Carbon dioxide in the atmosphere can enhance "greenhouse" effects, but it can also stimulate plant growth. Such complex interactions must be studied over time to better understand their relative importance.

Chlorofluorocarbons (CFC's) are greenhouse gases, but they also deplete ozone over the Antarctic and to a lesser extent over the Arctic. Ozone in the upper atmosphere filters harmful ultraviolet rays, thus protecting the Earth's biosphere. Ozone, however, is a corrosive gas when breathed by living creatures at the Earth's surface. The complex interactions of CFC's and other chemicals in the atmosphere, hydrosphere, and the land must be studied in detail because they



Analyses of ice cores from Greenland and Antarctica (light-gray area) show that concentrations of carbon dioxide in the atmosphere have increased about 25 percent since the beginning of the Industrial Era in about 1760. Between 1957 (when systematic annual measurements were begun at Mauna Loa, Hawaii, by C.D. Keeling) and 1989, atmospheric CO_2 has increased by about 12 percent (dark-gray area). (Modified from Siegenthaler and Oeschger, 1987, Biospheric CO_2 emissions during the past 200 years reconstructed by deconvolution of ice core data: Tellus, v. 39B(1–2), p. 140–154.)

can significantly affect the biosphere, of which mankind is a part.

Ecological Systems and Dynamics. The biosphere is the aggregate of all living creatures that inhabit the numerous individual ecological niches in the Earth system. The response to change of individual species and complex ecological communities must be better understood in both natural and managed environments for us to be able to explain and predict reactions to biogeochemical changes, climatic variation, and other physical and chemical stresses. Ecological systems do not merely react to their environment, they alter it as well. What these alterations are and how fast they take place must be understood to ensure sound policies that can be used to manage the land and all that lives on it.

Earth System History. The Earth's past environments can be deciphered by careful analysis of the geologic record—including fossils, ice cores, tree rings, terrestrial and marine sediments, and other natural archives of earth-history data. Reconstructions of past climates and atmospheric chemical compositions, when compared with the ecological communities that existed during those times, provide an opportunity for estimating how future changes in the Earth's system will affect modern ecological systems, both terrestrial and marine. Studies of the Earth's history also provide an opportunity to determine whether General Circulation Models (GCM's) of the climate provide realistic forecasts of the future. By running GCM's in a hindcasting mode, using actual data derived from the geologic record, rather than in a forecasting mode, we can validate their usefulness in making public-policy decisions. Earth system history information also lets us see how the earth system responded to past changes in climate; thus, we will better understand, for example, the historic distribution of surface- and ground-water resources, biological communities, and how the current distribution may be affected by future changes in the earth system.

Human Interactions. The rapidly growing human population is one of the strongest forces affecting the earth system. In the past, when populations were much smaller and technological sophistication was not at its present level, human impacts were highly localized, but people still caused lasting changes to the Earth's surface and the reduction of some living species to the point of extinction. Modern man has invented chemicals not known to nature and introduced them into the atmosphere, hydrosphere, cryosphere, biosphere, and the solid earth. Man also produces many chemicals found in nature. Modern technology can rapidly alter the Earth's surface morphology, vegetal cover, atmospheric constituents, and virtually all other facets of the environment. Determining which activities have positive and which have negative impacts is important. Studies of land-use practices, energy transformation, legal and regulatory requirements, and economic behavior must be conducted in order to understand the human impact on nature and what appropriate policy directions would be. Computer models that link growth and distribution of population, energy demands, changes in land use, and industrial productivity must then be developed to help decisionmakers better understand the implications of their policy decisions.

Solid Earth Processes. Tectonic activity, in which continents are being formed, moved, combined, and broken up, is the most extreme form of solid earth change. This process, slow as it is in human terms, alters coastlines, puts gases, aerosols, heat, and fluids into the atmosphere and oceans, and changes the elevation of the Earth's crust. Erosional, transport, and depositional processes, which are occurring constantly, move vast amounts of materials from all parts of the Earth's surface. Changes in the distribution of permafrost alter the amount of gases trapped in that frozen soil and can affect greenhouse gas concentrations in the atmosphere. This is important for our understanding of climate change and biogeochemical dynamics. Determining what part of alterations in coastlines is due to changes in sea level caused by climate variability—as compared to what part is caused by tectonic, erosional, or human-induced actions—has tremendous implications for coastal communities. The role of the midocean ridge system and volcanoes must also be better understood because they affect chemical contents of the atmosphere and the hydrosphere. In addition, surficial processes are, in themselves, a feedback mechanism for global change because they affect the dynamics of the atmosphere boundary layer.

Solar Influences. The primary source of the Earth's energy is the Sun. It is now known that the Sun is a variable star; that is, the amount of energy it emits varies over time. Scientists believe that variations in solar energy reaching the atmosphere due to solar variation and the Earth's orbital dynamics played a major role in the largest climatic variation known—the waxing and waning of the Ice Ages. However, much more knowledge is needed to be able to identify what part of global climate change is due to "greenhouse gases" and what part is due to variations in the influx of solar energy. Models that couple the solar winds to the Earth's atmosphere energy balance must be developed. The interaction of various levels of the Earth's magnetosphere, ionosphere, and thermosphere must be defined and modeled. Various scales of interactions from molecular through global must be understood as they relate to the influx of solar radiation in various spectral bands. Also, how the varying spectral output of the Sun affects the atmospheric composition and the Earth's biosphere must be determined.

Data Management Challenges

Although data management is not a science element, its importance cannot be overstated. The interdisciplinary, interagency, and international aspects of the science elements pose unprecedented challenges for data management and information exchange. Vast amounts of data already exist, and much more data are being created as each new program gets underway. Effective management of all this data will provide a needed bridge between observations of global change and scientific understanding of those changes.

Some scientists have difficulty finding out who has what data and how good the data are. Working among their various CES-member agencies and through the helpful assistance of the Interagency Working Group on Data Management for Global Change, scientists are improving access to data and devising better means to handle the massive computerized banks of information. By using existing facilities, NASA, NOAA, NSF, DOE, and DOI will continue to develop and expand a Master Directory for Global Change Data. Hundreds of global change data sets already have been documented and entered. Bilateral agreements have been signed between NASA and NOAA and between NASA and the USGS for the development of data systems to manage satellite data.

An essential component of the overall approach to global change research is the careful blend of ground- and space-based efforts that are an integral part of research, data gathering, and modeling activities. Of particular future importance is the agreement between the USGS and NASA to archive, process, and distribute all land-related data acquired by NASA's Earth Observing System (EOS), part of NASA's Mission to Planet Earth Program.

Clearly, the challenges of global change research are many. Through the unified federal approach outlined by the CES, those challenges can and will be met in the coming years. In characterizing its fundamental rationale for developing that unified approach, the CES said in its first report ("Our Changing Planet: A U.S. Strategy for Global Change Research," 1989, p. 27), "In the coming decades, global change may well represent the most significant societal, environmental, and economic challenge facing this Nation and the world. The national goal of developing a predictive understanding of global change, is, in its truest sense, science in the service of mankind."

Role of the U.S. Geological Survey in Global Change Research

By John A. Kelmelis

The U.S. Geological Survey has been conducting earth-science research for more than 110 years. Throughout that time the needs for earth-science information have grown. While early activities supported the expansion, exploration, and settlement of vast sections of the country and subsequent research was basic to development of the water, mineral, and land resources of those areas, emphasis has gradually shifted. The traditional needs still exist. It is still important to understand the details of the wide variety of natural resources held and needed by the country, but it is also important to ensure that the information gathered and the research conducted is useful to policy makers and the public in their responsibilities for making wise use of our finite resources. To this end, greater emphasis has been placed on natural hazards, environmental issues, and production of scientific data and research for the increasingly sophisticated needs of the Nation that the USGS serves.

This long history and evolutionary trend in earth-science research and information gathering has placed the USGS in a critical position as a member of the global change research community. Like each of the other Federal agencies doing focused global change research, the USGS fills a particular niche by conducting specialized research that reflects its own unique expertise. This research is linked to that of other organizations to form a network of integrated scientific programs and projects designed to observe, understand, and, ultimately, predict changes in the global environment. In addition, since much of what occurs on the global scale is caused by local and regional changes and will affect local and regional areas, much of the research must be conducted on those scales as well.

The strategy of the USGS Global Change Research Program is (1) to learn the basic scientific principles underlying various earth processes, (2) to determine how processes based on those scientific principles act in the environment, and (3) to use that knowledge to develop information and methods to help people manage resources wisely and fulfill their role as informed stewards of their environment.

USGS Global Change Research Program

Building upon its strengths, the USGS has fashioned a research program that primarily emphasizes activities in the Committee on Earth Sciences' (CES) priority integrated science elements: *Climate and Hydrologic Systems, Earth System History*, and *Solid Earth Processes.* In addition, the USGS is conducting focused research in *Biogeochemical Dynamics, Ecological Systems and Dynamics*, and *Human Interactions.* Other USGS research programs and projects that are focused primarily on other issues also contribute to our overall understanding of global change in all of the science elements including *Solar Influences.*

In addition, because of specialized experience in geographic analysis and spatial data management, the USGS has taken a leadership role in integrating information in many science elements to characterize the land processes involved with global change and to develop methods to save, manage, and distribute global change land data.

Important Questions

The USGS program is attempting to answer a number of important questions in ways that will help our Nation and the world make better decisions for the future. Some of these questions are—What were climates like in the past, and will climates on a regional and global scale be similar in the future? How is the hydrologic cycle affected by climate, and what are the appropriate scientific and societal responses to variations that might occur in the climate? What is the natural contribution of earth processes to short-

USGS global change research related to the Committee on Earth Sciences science elements

	Projects	Science elements
Geologic Division	Coastal Erosion & Inundation	Human Interactions Solid Earth Processes
	Climate of Arid Regions	Earth System History Solid Earth Processes
	Permafrost Research	Earth System History Solid Earth Processes
	Paleoclimates Research	Earth System History
	Biogeochemistry Research	Biogeochemical Dynamics Earth System History
	Interaction of Climate & Hydrologic Systems	Climate and Hydrologic Systems
	Volcano Hazards	Solid Earth Processes
Water Resources Division	Paleoclimates Research (Paleohydrology)	Earth System History
	Interaction of Climate & Hydrologic Systems	Climate and Hydrologic Systems
	Sensitivity of Hydrologic Systems	Climate and Hydrologic Systems
	Biogeochemistry of Greenhouse Gases	Biogeochemical Dynamics
National Mapping Division	Land Data	Climate and Hydrologic Systems Biogeochemical Dynamics Ecological Systems and Dynamics Human Interactions Solid Earth Processes
	Land Characterization	Climate and Hydrologic Systems Biogeochemical Dynamics Ecological Systems and Dynamics Human Interactions Solid Earth Processes
Contributing (All divisions)	Each Division has ongoing projects that contribute to, but are not specifically focused on, global change research	Climate and Hydrologic Systems Biogeochemical Dynamics Ecological Systems and Dynamics Earth System History Human Interactions Solid Earth Processes Solar Influences

and long-term climate changes? How are our coastlines changing? What portion of the change is caused by human activities, and what portion is caused by natural processes? How does the land surface respond to changes—human induced and natural—on local, regional, national, and global scales? Where will the data necessary to study global change come from, how will it be archived, and how will it be distributed? USGS global change efforts have been focused on conducting the research necessary to answer these questions.

What were climates like in the past, and will climates on a regional and global scale be similar in the future?

To answer this question, the USGS has expanded major existing programs in **Paleoclimates Research**, **Paleohydrology Research**, and studies in **Permafrost**, **Climates of Arid Regions**, and **Biogeochemistry**. The research is directed at establishing the rate, frequencies, and magnitudes of climate change through analyses of the geologic record (including terrestrial and marine cores and related botanical and geochemical records). This research provides information on the prehistoric natural variability of climate during the last thousands to millions of years. Emphasis is placed on creating a synoptic reconstruction of the Pliocene, about 5.2–1.6 million years ago, the last period when climates were significantly warmer than today. (See article, p. 43.) High resolution studies that can provide information on annual variability in climate are also being done of the recent past, and methods are being examined to extend these high resolution studies into the distant past. Some of the other topics to be studied include terrestrial coring, ice-core glaciology, paleoecology, isotopic analysis, desertification, marine paleoclimates, permafrost studies, and glacial history.

How is the hydrologic cycle affected by climate, and what are the appropriate scientific and societal responses to variations that might occur in the climate?

The USGS program in **Interaction of Climate and Hydrologic Systems** is devoted to process-oriented studies based on intensive field investigations. Its purpose is to improve understanding and prediction of how the hydrologic system

A scanning electron photomicrograph (magnified about 160 times) showing the climatically sensitive species *Palmenella limicola*, a small crustacean in the ostracodes group, which existed in the Pliocene and exists today in high latitudes of the Northern Hemisphere. This species, other ostracodes, and other microfossil groups are being used to reconstruct Pliocene paleoclimates.

responds to changes in atmospheric conditions and to provide a scientific basis for improving how those land-based responses can be represented in computer models that couple those land-atmosphere interactions. The work focuses on showing how changes in the atmosphere result in changes in the water budget, energy outputs from land surface, gas transfers with the atmosphere, and nutrient fluxes through water bodies. This information in turn provides needed data for studies in the **Sensitivity of Hydrologic Systems**. These studies develop and apply mathematical models to assess the response of hydrologic systems to climatic variability and change. Specific river basins in different hydroclimatic zones are studied to evaluate the sensitivity of water resource systems to changes in atmospheric conditions. The results of these studies will provide improved and transferable methods for evaluating sensitivities of water resource systems to varying climatic conditions. River basins that are the sites of current and planned studies include the Delaware (see article, p. 31), American and Stanislaus in California, Carson and Truckee in California and Nevada, and Gunnison in Colorado.

What is the natural contribution of earth processes to short- and long-term climate changes?

Knowing that global climate changed in the past and how those changes affected regional and local climates, water resource distribution, and ecological systems is not enough. In order to make sound resource-management plans and policies, we must also understand why those changes took place. Analyzing the geologic record will help in determining this, but more specific process-oriented studies must be conducted as well. Programs in **Volcano Hazards** and **Biogeochemistry of Greenhouse Gases** are also needed to examine the natural earth processes that contribute to such changes. These programs will provide the baseline from which to determine what changes are caused by man and what changes are natural.

Plume of sulfur-rich gas from Redoubt Volcano, Alaska, as seen between explosive phases of this ongoing eruption. Sulfur aerosols, especially when they rise into the stratosphere, cause temporary global cooling and may complicate analysis of global warming. (Photograph by Chris Newhall.)

How are our coastlines changing? What portion of the change is caused by human activities, and what portion is caused by natural processes?

The majority of the Earth's population lives in urban areas, and most urban areas are near the coast. Coastal communities represent an enormous investment in culture and commerce by humankind. Changes in coastal characteristics, both coastline and wetlands, can take place due to climate change or they can be caused by tectonic, erosional, or human processes. Some human activities designed to protect coastal areas may actually be harmful in the long run to the area being protected and to other areas as well. To determine what those effects might be, the **Coastal Erosion and Inundation Program** is examining selected coastal, barrier island, and lake shore areas.

How does the land surface respond to changes—human induced and natural—on local, regional, national, and global scales?

Land Surface and Geographic Characterization is a research program that cuts across five of the seven CES priority science elements. By using remote sensing, geographic information system, digital mapping, computer modeling, and other technologies, researchers in this program will develop techniques to analyze changes in numerous aspects of the Earth's surface and to provide the means to detect change and monitor the processes of activities that take place on the terrestrial component of the Earth's surface. Special attention is being given to the relation between processes at varying time and spatial scales, how they interrelate, and what is the best strategy for observation.

Where will the data necessary to study global change come from, how will it be archived, and how will it be distributed?

Global change research is an information-hungry and information-producing scientific effort. Data will not only be needed by the research program, each project will also generate data. The data will take many forms, including field notes; ice, rock, sediment, and other cores; digital cartographic and geographic data; geophysical readings; aerial photographs; satellite images; biological samples; and others. To support this data explosion and to ensure the availability of data to other scientists, each research project must develop a data-management plan that links with systems that have been developed or are being developed. However, for data that are considered more general in nature, such as land-surface data sets for large areas and satellite images, a **Land Surface Data System** is needed. This system, housed at the Earth Resources Observation System (EROS) Data Center of the USGS, will provide a means to archive, inventory, and distribute data sets that are responsive to research needs.

Accomplishments

Although the USGS global change research program is relatively young, there have been a number of accomplishments to date. Among these are the following:

- A model has been developed for water resource managers to use in the Delaware River basin to help determine the appropriate water allocation strategy during varying conditions of water availability. Under current circumstances, drought conditions exist in the Delaware basin 10 percent of the time. This could vary substantially if a significant change in climate were to take place. The Delaware River basin, which supplies water for an estimated 20 million people, is subject to changes in water salinity, water quality and quantity, water distribution, and water demand due to changes in the climate. These physical parameters have been incorporated into the model along with certain socioeconomic variables to give water managers a comprehensive and usable model. Refinements to this model will be made through FY 1991. Other areas are being considered for similar studies.
- An initial estimate has been made of what global climate conditions were during the Pliocene. A plan has been developed to determine an understanding of that climate on a broad regional level. Once the regional studies are complete, there will be sufficient data to help validate atmospheric general circulation models, which are used to predict future climates. In addition, techniques have been developed for accurate high-resolution studies of past climates.
- As part of the Louisiana Barrier Erosion Study, a careful analysis of tide gage records and geologic framework investigations shows that the sea level has risen relative to the land approximately 3 to 4 feet during the past 100 years. The majority of the rise is due to land subsidence and sediment compaction of the recently deposited sediments in the delta. Because these rates of sea-level rise are close to the maximum rates being forecast for the future due to "greenhouse effect," the results from the barrier islands and wetlands studies can be used in predicting possible future coastal conditions for other similar regions around the United States.
- A technique has been developed to identify and to measure changes in the historic temperature of climates in permafrost areas. This will help in modeling the potential release of methane, a greenhouse gas, trapped in the permafrost.
- A baseline of Antarctic glacial extent has been established by using satellite data obtained during the mid-1970's. This can be compared to additional synoptic views of Antarctica to help determine if the ice edge is advancing or retreating in response to changes in temperature and other variables in the Southern Hemisphere.
- More than 400,000 deteriorating satellite images have been identified. A system is being developed at EROS Data Center to save these data by transferring them onto stable media. Also, the requirements for the Global Land Data System have been identified, and the design of the system is proceeding.
- A plan has been completed for the long-term management of the land portion of the Earth Observing System data.

People and Programs of the U.S. Geological Survey

Mission

Our Nation faces some serious questions concerning changes in our global environment and the availability and use of land, water, energy, and mineral resources of the Earth. How can we ensure an adequate supply of critical resources in the future? In what ways are we irreversibly altering our natural environment when we use these resources? How has the global environment changed over geologic time, and what can the past tell us about the future? Will we have adequate supplies of water of good quality available for our national needs? How can we predict, prevent, or mitigate the effects of natural hazards? Responses to these and similar questions depend on continually increasing the knowledge about the structure, resources, and dynamics of the Earth. The effort to collect, analyze, and disseminate the scientific information necessary to answer these questions is the primary mission of the U.S. Geological Survey.

The U.S. Geological Survey was established by an Act of Congress on March 3, 1879, to provide a permanent Federal agency to conduct the systematic and scientific "classification of the public lands, and examination of the geological structure, mineral resources, and products of the national domain."

Since 1879, the research and fact-finding role of the USGS has grown and has been modified to meet the changing needs of the Nation it serves. The USGS, however, has remained an impartial scientific and technical agency without developmental or regulatory responsibilities.

Today's programs serve a diversity of needs and users. The current mission of the USGS is to provide geologic, topographic, and hydrologic information that contributes to the wise management of the Nation's natural resources and that promotes the safety and well-being of the public. This information is provided to the public in many forms—including reports, maps, and data bases that provide descriptions and analyses of the water, energy, and mineral resources, the land surface, the underlying geologic structure, and the dynamic processes of the Earth.

As the Nation's largest earth-science research agency, the USGS maintains a long tradition of providing accurate and impartial information to all, which underscores its continued dedication to "Earth Science in the Public Service."

Organization and Budget

The USGS is headquartered in Reston, Va., near Washington, D.C. Its scientific programs are administered through the Geologic, Water Resources, and National Mapping Divisions, supported by the Administrative and Information Systems Divisions. The USGS conducts its research and investigations through an extensive organization of regional and field offices located throughout the 50 States, Puerto Rico, and the Territory of Guam. The USGS conducts a large share of its research and investigations through cooperative agreements with more than 1,000 other Federal, State, and local agencies and the academic community.

In fiscal year 1989, the USGS had obligational authority for $670.9 million, $452 million of which came from direct appropriations; $7.9 million from estimated receipts from map sales, and $210.9 million from reimbursements. The USGS was reimbursed for work performed for other Federal, State, and local agencies whose needs for earth-science expertise complement USGS program objectives. Work for State, county, and municipal agencies is most often conducted on a cost-sharing basis.

Most of the appropriations and reimbursements received by the USGS in fiscal year 1989 were distributed to geologic, hydrologic, mapping, and administrative areas of responsibility. Budget tables appear near the back of this book.

Personnel

At the end of fiscal year 1989, the USGS had 8,589 permanent full-time employees. The USGS's diversified earth-science research programs and services are reflected in its workforce, more than half of which possesses a bachelor's or higher level degree. Almost half of the USGS employees are professional scientists.

Permanent employees are supported by other-than-full-time permanent employees, including many university students and faculty members. This relation with the academic community has made the expertise of many eminent scientists available to the USGS. Students have also proved valuable during times of increased workload, especially during the field season. Academic institutions have also provided a means of recruiting qualified young professionals for permanent full-time positions upon completion of their studies. The USGS has several innovative programs that provide opportunities for graduate students. Other programs promote interest in the earth sciences at historically black colleges and universities. (See article, p. 21.)

Awards and Honors

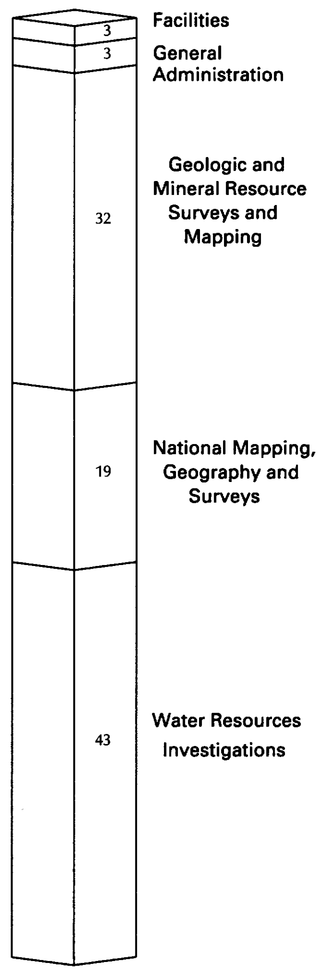
Each year, USGS employees receive awards and honors that range from certificates of excellence and monetary awards to recognition of their achievements by election to membership or office in professional societies. The large number of these awards attests to the high caliber of USGS personnel. Of the many who received awards, the USGS is pleased to acknowledge here those individuals who became members or officers in professional societies or who received awards from those organizations. Also acknowledged are those who received the Presidential Rank Award from the Office of Personnel Management and other special USGS awards.

Service in professional societies is an important contribution by USGS scientists to the USGS. These societies play a fundamental role in disseminating knowledge as well as providing a forum in which to test new ideas. The USGS is proud of those individuals who have been honored by election to society presidencies or chairmanships of society committees by their professional peers.

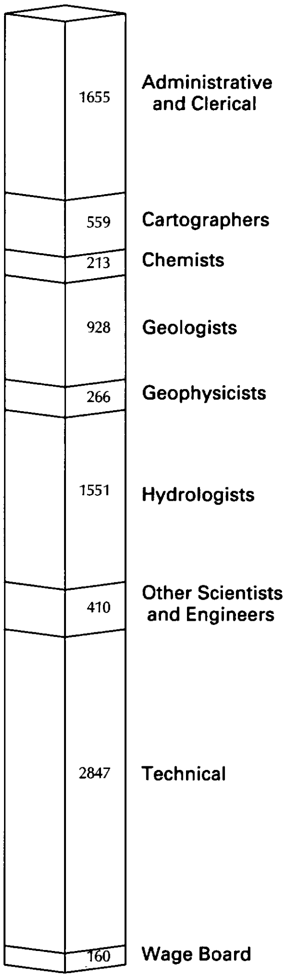
Awards and Honors Received by USGS Employees During 1989

S.T. Algermissen, Geophysicist, Geologic Division, was awarded the 1989 Prize of the Center for Seismology in South America (CERESIS) for his outstanding contribution to seismology in South America over a period of years.
Charles E. Barker, Geologist, Geologic Division, was elected Vice President, Society of Luminescence Microscopy and Spectroscopy for 1989–90.
Raymond M. Batson, Cartographer, Geologic Division, became the first recipient of a prestigious NASA award in 1989 for significant contributions to planetary cartographic science. The award was in recognition of his leadership in fostering a sustained high level of production of planimetric maps covering all major solid bodies of the solar system.
Earl E. Brabb, Geologist, Geologic Division, was presented with the Distinguished Practice Award of the Engineering Geology Division of the Geological Society of America for distinguished public service, research, consulting, and administration.
P. Robin Brett, Geologist, Geologic Division, was elected Secretary General of the International Union of Geological Sciences for the period 1989–92.
William J. Campbell, Meteorologist, Water Resources Division, received the William T. Pecora Award of the Department of the Interior and NASA for his

Percentage of Total Funds by Activity



Personnel, by Occupation



outstanding scientific contributions and leadership in international experiments that have applied remote sensing methods to the study of the cryosphere (the cold regions of the planet).

Alden P. Colvocoresses, Research Cartographer, National Mapping Division, was awarded the Alan Gordon Memorial Award by the American Society for Photogrammetry and Remote Sensing for his contributions to the application of satellite remote sensing to cartography and in fostering the development and refinement of satellite image mapping worldwide.

Charles G. Cunningham, Geologist, Geologic Division, was presented with the Japanese Government Research Award for Foreign Specialists. The award includes fieldwork for ore deposit research at the Osorezan geothermal system in Japan.

G. Brent Dalrymple, Geologist, Geologic Division, was elected President of the American Geophysical Union for the period 1990–92.

Frederick J. Doyle, Scientific Advisor for Cartography, National Mapping Division, was elected to the National Academy of Engineering. He is the first USGS employee to be selected for membership in this organization.

Robert L. Earhart, Geologist, was awarded the Exemplary Act award of the Department of the Interior for life-saving emergency medical care he rendered to a Venezuelan geochemist.

George E. Ericksen, Geologist, Geologic Division, was presented with the 1988–89 Richard Owen Award of the University of Indiana as a distinguished alumnus for his outstanding contributions to the geological sciences and meritorious service to the profession.

Kathie R. Fraser, Technical Publications Editor, Geologic Division, was presented with a 1989 Blue Pencil Award—in the book for technical audience category—by the National Association of Government Communicators.

Virgil A. Frizzell, Jr., Geologist, Geologic Division, was selected as the Congressional Science Fellow for 1989–90 by the American Geophysical Union. He served as a consultant to Congressman Norman Y. Mineta who represents California's 13th district.

Warren B. Hamilton, Geologist, Geologic Division, was elected to the National Academy of Sciences in recognition of his outstanding contributions in advancing the science of geology. He also was awarded the Penrose Medal, the highest award given by the Geological Society of America in honor of his eminent research in geology.

Thomas L. Holzer, Geologist, Geologic Division, was elected Chairman of the Engineering Geology Division of the Geological Society of America for 1988–89.

Carolyn S. Hulett, Publications Graphic Specialist, Geologic Division, was presented with a 1989 Blue Pencil Award—in the book for technical audience category—by the National Association of Government Communicators.

Marshall E. Jennings, Hydrologist, Water Resources Division, was named 1989 Engineer of the Year for the U.S. Geological Survey, Department of the Interior, by the National Society of Professional Engineers.

Jean S. Kane, Chemist, Geologic Division, received the 1989 Outstanding Member award of the Baltimore-Washington Section of the Society for Applied Spectroscopy.

Susan Werner Kieffer, Geologist, Geologic Division, was awarded the Spendiarov Prize by the U.S.S.R. Academy of Sciences at the 28th International Geological Congress (IGC). This was the most prestigious award given at the IGC in Washington, D.C., July, 1989, and saluted her contributions to our knowledge of the Earth and the planets and her prolific research in fields ranging from volcanology and planetology to thermodynamics and river hydraulics.

Baerbel K. Lucchitta, Geologist, Geologic Division, was elected Second Vice Chairman for 1989–90 of the Planetary Geology Division of the Geological Society of America.

Richard F. Madole, Geologist, Geologic Division, was elected Second Vice Chairman for 1988–89 of the Quaternary Geology and Geomorphology Division of the Geological Society of America.

Harold Masursky, Geologist, Geologic Division, received the National Air and Space Museum Trophy from the Smithsonian Institution, presented for outstanding achievements in air and space technology and for his exceptional personal contributions in lunar and planetary science.

Gerald Meyer and C.L. McGuinness (posthumously), Hydrologists, Water Resources Division, each received the Distinguished Service in Hydrogeology Award from the Hydrogeology Division of the Geological Society of America.

Douglas J. Nichols, Geologist, Geologic Division, was presented the 1989 Unocal Best Geological Applications award by the American Association of Stratigraphic Palynologists for his paper on the Cretaceous-Tertiary boundary in the Powder River Basin, Wyoming and Montana.

William H. Orem, Chemist, Geologic Division, was elected Secretary of the Geochemistry Division of the American Chemical Society for the period 1988–91.

Roger L. Payne, Geographer, National Mapping Division, was elected President of the American Name Society for 1989–90.

Joseph S. Rosenshein, Hydrologist, Water Resources Division, was elected Chairman of the Hydrogeology Division of the Geological Society of America.

James C. Savage, Geophysicist, Geologic Division, was awarded the Charles A. Whitten Medal by the American Geophysical Union for his outstanding research in the form and dynamics of the Earth and planets.

Christopher J. Schenk, Geologist, Geologic Division, was elected President, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists for 1989–90.

Wayne C. Shanks, Geologist, Geologic Division, was named the Thayer Lindsley Visiting Lecturer for the period 1989–90 by the Society of Economic Geologists, in recognition of his major contributions on the genesis and character of sea-floor minerals.

Eugene M. Shoemaker, Geologist, Geologic Division, and his wife Carolyn, a USGS volunteer, were awarded the Rittenhouse Medal by the Rittenhouse Astronomical Society in recognition of their outstanding contributions to the science of astronomy.

Charles W. Spencer, Geologist, Geologic Division, was elected to a 4-year term (1989–93) as a member of the Rocky Mountain Association of Geologists Foundation. This three-person Board of Directors awards scholarships, funds selected publications, and provides awards for outstanding students.

Nancy K. Tubbs, Cartographer, National Mapping Division, was elected President, Rocky Mountain Region, American Society for Photogrammetry and Remote Sensing for 1989.

David J. Varnes, Geologist, Geologic Division, was presented the Hans Cloos Medal, the highest award of the International Association of Engineering Geology (IAEG), at the 28th IGC, in honor of his contributions to the science of engineering geology and for his service to the profession and IAEG.

Robert E. Wallace, Geologist, Geologic Division, was awarded the Medal of the Seismological Society of America in recognition of his outstanding contributions to the fields of seismology and earthquake engineering.

Donald E. Wilhelms, retired Geologist and USGS volunteer, Geologic Division, was presented the 1989 G.K. Gilbert Award of the Planetary Geology Division of the Geological Society of America, in recognition of outstanding contributions to the solution of fundamental problems in planetary research.

Presidential Rank Awards

Presidential Rank Awards are presented annually by the Office of Personnel Management to career members of the prestigious Senior Executive Service for exceptional service at an executive level over an extended period of time. Presidential Rank Awards, the highest civilian honor awarded to Federal executives, are given at two levels: Distinguished ($20,000 award) and Meritorious ($10,000 award). In 1989, President George Bush recognized the following USGS executives with the rank of Meritorious Executive:

Benjamin A. Morgan III, Chief Geologist, Geologic Division, for his leadership in guiding the scientific programs of the Geologic Division through a period of transition and essentially level funding, while providing a framework for a vigorous earth science research program for the next decade.

Roy R. Mullen, Associate Chief, National Mapping Division, for his work as principal architect of the Mark II program, which is designed to carry the national mapping program into the next century by implementing automated procedures and the science of digital cartography within the USGS and the Department of the Interior.

Merle E. Southern, Chief, Rocky Mountain Mapping Center of the National Mapping Division, for his successful integration of research activities into the production process and for his accomplishments in establishing a central distribution center for the storage and dissemination of the thousands of USGS book, map, and digital cartographic products.

John Wesley Powell Awards

Each year the USGS presents the John Wesley Powell Award to persons or groups outside the Federal Government for voluntary actions that result in significant gains or improvements in the efforts of the USGS to provide earth science in the public service.

Interior Secretary Manuel Lujan presented the 1989 John Wesley Powell Awards at the USGS National Center in Reston, Va., on the 110th anniversary of the USGS, March 3, 1989. Recipients of these awards, named for the second director of the USGS, were **Duane M. Hamann** and **M. Gordon Wolman**.

Duane M. Hamann, a teacher at the Parkfield, Calif., elementary school, provided invaluable assistance to the USGS in describing and explaining to the local community the Parkfield Earthquake Prediction experiment being conducted there. In addition, his willingness to integrate USGS research activities into the school curriculum resulted in national and international media coverage that provided public education about USGS activities.

M. Gordon (Reds) Wolman, Chairman of the Department of Geography and Environmental Engineering of Johns Hopkins University, has served as a trusted and valued advisor to the Directors and division chiefs of the USGS for over two decades and has helped to strengthen the technical content of many USGS programs. In addition, he has trained an impressive list of young scientists, a number of whom now serve in significant positions within the USGS.

Outstanding Federal Employees with Disabilities—1989

William L. Rambo, Geologist with the Geologic Division in Menlo Park, Calif., was one of 12 Federal employees Governmentwide honored at the Twenty-first Annual Presidential Awards Ceremony for Outstanding Federal Employees with Disabilities. This ceremony focuses attention on the job capabilities of federal employees with disabilities, highlighting their accomplishments and increasing public awareness of their valuable contributions.

Mr. Rambo, whose career as a field geologist was cut short by an on-the-job accident which left him confined to a wheelchair, was cited for his major impact on the USGS public outreach program in California, where he has been active in fielding questions from the public; in organizing and chairing the local Earth Science Information Committee; and his instrumental role in public outreach activities at the Menlo Park regional center.

Mr. Rambo joined **Amy W. Meade** and **R. Michael Hathaway** at special ceremonies at the USGS National Center recognizing Ms. Meade and Mr. Hathaway as USGS Outstanding Federal Employees with Disabilities for 1989. Ms. Meade, who had planned a career in architectural design, lost her sight and subsequently came to work for the USGS, where, with the help of an Artic Vision Speech Synthesizer, she has begun a promising new career as a computer assistant. Mr. Hathaway, confined to a wheelchair, was cited for his exceptional contributions to the development of computer technology within the USGS.

Program Descriptions

Geologic Division

Organization

The headquarters office of the Geologic Division is located in Reston, Va., and consists of the Office of the Chief Geologist and six subordinate offices: Earthquakes, Volcanoes, and Engineering; Regional Geology; Mineral Resources; Energy and Marine Geology; International Geology; and Scientific Publications. Assistant Chief Geologists in the Eastern, Central, and Western Regions act for the Chief Geologist in carrying out general objectives, policies, and procedures for the Division. Project operations are conducted by personnel located principally in regional centers at Reston, Va.; Denver, Colo.; and Menlo Park, Calif.; and at field centers in Flagstaff, Ariz.; Anchorage, Alaska; Woods Hole, Mass.; Tucson, Ariz.; Reno, Nev.; and Spokane, Wash.

Geologic Hazards Surveys

The Earthquake Hazards Reduction Program conducts a national research effort to reduce hazards and risks from future earthquakes in the United States. Specific tasks include evaluation of earthquake potential for seismically active areas of the United States and operation of global seismic networks.

The Volcano Hazards Program conducts research on volcanic processes to help reduce the loss of life, property, and natural resources that can result from volcanic eruptions and related hydrologic events. The Hawaiian Volcano Observatory on the Island of Hawaii and the Cascades Volcano Observatory in Vancouver, Wash., are the principal field research centers for this program. The Alaska Volcano Observatory, a cooperative effort with State and academic organizations, is located in Anchorage.

The Landslide Hazards Program emphasizes field and laboratory research into the active earth processes that result in ground failures such as landslides, mudflows, and debris flows.

Geologic Framework and Processes

The National Geologic Mapping Program conducts basic geologic research to acquire fundamental data on the Nation's geologic structure and the environmental and dynamic processes that have shaped it. Geologic mapping, geophysical research on the properties of Earth materials, age determinations of rocks, and modernization of mapping techniques are the main components of the program.

The Deep Continental Studies Program conducts research to obtain information on the composition, structure, formation, and evolution of the middle and lower crust and upper mantle of the Earth.

The Geomagnetism Program measures and interprets changes in the strength and direction of the Earth's magnetic field. Eleven geomagnetic observatories provide data for continually updating global navigational charts and maps produced by various Federal agencies.

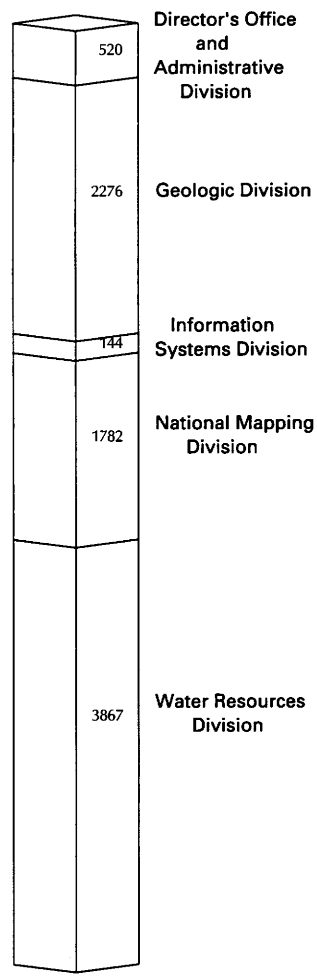
The Climate Change Program conducts research on the natural variability of past climate, on the extent of human influence on natural patterns of change, and on the magnitude of climate change demonstrated in the geologic record in support of Federal global change research efforts.

The Coastal Erosion Program provides geologic information on the nature, extent, and cause of coastal erosion, which is used by various Federal and State agencies to mitigate coastal retreat and land loss.

Offshore Geologic Surveys

The Offshore Geologic Framework Program conducts scientific investigations to acquire an understanding of basic geologic and geophysical characteristics of the continental margins, adjacent slope and deep-ocean areas, and the U.S.

Personnel, by Division



Exclusive Economic Zone. Results of these studies and analysis of new information are essential for energy and mineral resource evaluation and assessment of these areas.

Mineral Resource Surveys

The National Mineral Resource Assessment Program provides comprehensive scientific surveys to identify significant new targets for industry exploration in the conterminous United States and Alaska and also provides mineral resource information for planning the use of public lands.

The Strategic and Critical Minerals Program provides comprehensive information on domestic and world resources of nonfuel minerals that are essential to a strong national economy and defense.

The Development of Assessment Techniques Program carries out basic and applied research on the origin and the geologic, geochemical, and geophysical characteristics of mineral deposit systems in order to develop concepts and techniques to improve the capability to identify and evaluate mineral resources.

Energy Geologic Surveys

The Evolution of Sedimentary Basins Program studies the tectonic framework and depositional, thermal, and diagenetic processes of sedimentary basins in the United States to develop data essential to the successful exploration for and evaluation of mineral and energy resources.

The Coal Investigations Program conducts geologic, geophysical, and geochemical research to develop scientifically based assessments of the quality, quantity, and availability of the Nation's coal resources.

The Oil and Gas Investigations Program supports basic and applied research on the generation, migration, and entrapment of petroleum and natural gas.

The Oil Shale Investigations Program conducts research to assess the Nation's oil shale resources, including investigation of the structure and chemistry of oil shale deposits and identification of oil shale deposits suitable for exploitation under current environmental and technological constraints.

The Uranium/Thorium Investigations Program conducts basic research to determine the nature and distribution of uranium and thorium resources, including newly forming uranium deposits and daughter products, such as radon, that may be health hazards.

The Geothermal Investigations Program conducts basic research to determine the nature, distribution, and magnitude of the Nation's geothermal resources. These studies define the geologic and hydrothermal regimes of the various classes of geothermal resources and identify the crustal, geochemical, and hydrothermal processes that produce geothermal systems.

The World Energy Resources Assessment Program provides information on worldwide energy resources for use by other agencies in the development of national-energy, international-trade, and foreign policies.

Water Resources Division

Organization

The headquarters office of the Water Resources Division is located in Reston, Va. The Chief Hydrologist, the Associate Chief Hydrologist, and five Assistant Chief Hydrologists are responsible for the overall direction of the Division. National water-research programs are developed at Division headquarters under the direction of the Assistant Chief Hydrologist for Research and External Coordination.

General direction of the Division's field programs is conducted through four Regional Hydrologists, located in Reston, Va.; Atlanta, Ga.; Denver, Colo.; and Menlo Park, Calif. Forty-two District Offices conduct the water-resources investigations and data-collection programs of the Division in all 50 States, Puerto Rico, the Virgin Islands, and the Territory of Guam.

National Water-Quality Assessment Program

The National Water-Quality Assessment Program seeks to provide nationally consistent descriptions of the quality of the Nation's water resources over a large, diverse, and geographically distributed portion of the country; provide a baseline for evaluating future trends in water quality and, where possible, define trends in water quality over recent decades; and provide an understanding of the factors influencing water quality. This information provides the basis to forecast change and evaluate the likely effect on water quality of various proposed remedial actions. Initial efforts involve four surface-water and three ground-water pilot studies, with plans to have 20 study units in operation by the beginning of FY 1991.

National Water Summary Program

The National Water Summary Program provides water information on a State-by-State and national basis to aid policymakers in the analysis and development of water policies, legislation, and management actions. Changing patterns in availability, quantity, quality, and use of water resources are summarized for use by Government officials, natural resources managers, and the general public.

The principal products of the program are National Water Summary reports that describe hydrologic events and water conditions for a water year and provide a State-by-State overview of specific water-related issues.

Hazardous Waste Hydrology Programs

The USGS conducts research and investigations into the disposal of hazardous chemical and radioactive wastes, which provides information to help in alleviating their effects on the Nation's water resources. The USGS evaluates the existing and potential effects on water resources of the earth-science aspects in hazardous-waste disposal and provides baseline data on the chemical contamination of surface and ground water to assist the Department of Energy in developing procedures and guidelines for identifying suitable waste-disposal sites. Radioactive-waste studies are conducted in the Nuclear Waste Hydrology Program, the principal emphasis of which is a better understanding of radionuclide transport in ground-water systems. Nonradioactive wastes are the focus of the Toxic Substances Hydrology Program, which provides data to mitigate existing and potential contamination problems.

Regional Aquifer Systems Analysis Program

The Regional Aquifer Systems Analysis Program is a systematic study of a number of regional ground-water systems that represent a significant part of the Nation's water supply. The program includes assessment of discharge-recharge dynamics, hydrogeologic and chemical controls governing response of aquifer systems to stress, and development of computer simulation models.

Acid Rain Program

The USGS provides information needed to improve the scientific understanding of the occurrence and effects of acid rain, so that judgments can be made about effective measures for controlling or alleviating the problem. Components of the acid rain research and monitoring program include determination of the effects of acid deposition on lakes, streams, and aquifers; operation of the National Trends Network; and research into more precise methods of measurement. The program is coordinated through the Interagency Task Force on Acid Precipitation.

Hydrologic Data Collection Program

The Hydrologic Data Collection Program provides information on the quantity, quality, location, and use of the Nation's surface and ground water to support the needs of Federal, State, and local governments. Data collection stations are maintained at selected locations to provide records on streamflow, reservoir and lake storage, ground-water levels, and the quality of surface and ground water. These data form an information base that supports national and regional assessments of water resources.

Federal-State Cooperative Program

The Federal-State Cooperative Program, which constitutes more than 40 percent of overall Division activity, is a partnership for water-resources investigations involving 50–50 cost sharing between the USGS and more than 1,000 cooperating State or local government agencies. One of the program's unique characteristics is that the USGS performs most of the work on behalf of the cooperators. A variety of hydrologic data collection activities and water-resources investigations are included in the program.

National Research Program

Basic research in the Water Resources Division focuses on increasing understanding of the fundamental hydrologic processes of the Nation's ground- and surface-water systems. Knowledge and techniques derived from these efforts are directed at solving current problems and anticipating future problems. Research studies are concentrated in surface-water hydrology, geochemistry, ground-water hydrology, sediment transport and geomorphology, water chemistry, and ecology.

State Water Resources Research Institutes Program

The State Water Resources Research Institutes Program, the costs for which are shared by Federal and State governments, supports 54 Water Research Institutes at land-grant colleges or universities in the 50 States, the District of Columbia, Puerto Rico, the Virgin Islands, and Guam. Research projects at the institutes are carried out in all water-related fields including engineering and the physical, biological, and social sciences.

Water Resources Research Grants Program

The Water Resources Research Grants program supports research as defined in the Water Resources Research Act of 1964. Competitive grants are awarded on a dollar-for-dollar matching basis to qualified educational institutions, foundations, private firms, individuals, or agencies of local or State governments. Research is supported on water-resources-related problems of national interest.

National Water Data Activities Coordination Program

The Office of Water Data Coordination (OWDC) is responsible for providing leadership to coordinate the water-data acquisition and information sharing activities of all agencies of the Federal Government. The office was created as part of the Department of the Interior's implementation of Office of Management and Budget Circular A–67. The scope of the activities includes the quality, quantity and use of streams, lakes, reservoirs, estuaries, and ground water.

Much of the program is accomplished through two major committees that advise the Secretary of the Interior on programs and plans related to the implementation of Circular A–67. Thirty Federal organizations are represented on the Interagency Advisory Committee on Water Data, and over 100 representatives of those organizations conduct the activities of the Committee. The second group is the Advisory Committee on Water Data for Public Use, which is composed of 16 major national organizations involved in water-related issues. This committee operates under the Federal Advisory Committee Act.

National Mapping Division

Organization

The headquarters office of the National Mapping Division is located in Reston, Va., and is composed of five primary organizational units: Program, Budget and Administration; Coordination and Requirements; Production Management; Research; and Information and Data Services. Four mapping centers (Reston, Va.; Rolla, Mo.; Denver, Colo.; and Menlo Park, Calif.) and the Earth Resources Observation Systems (EROS) Data Center (Sioux Falls, S. Dak.) perform the operational mapping, remote sensing, printing, product distribution, and data dissemination activities.

To serve a diversity of needs and users, the Division concentrates its activities in four major program areas as follows:

Mapping Coordination

The USGS annually coordinates requirements for maps and digital cartographic data of Federal agencies under authority of Office of Management and Budget Circular A–16. The USGS also coordinates requirements of State and local agencies for maps and map-related products. In the area of digital cartography, the USGS chairs both the Interior Digital Cartography Coordinating Committee (a departmental committee) and the Federal Interagency Coordinating Committee on Digital Cartography (a multiagency committee) and provides leadership in the use of digital spatial data and in the development of digital data exchange standards. The USGS also provides staff support to the U.S. Board on Geographic Names, an interdepartmental board that determines the choice, form, spelling, and application of official geographic place names for Federal use.

National Map and Digital Data Production

The USGS prepares various base maps, image map products, digital cartographic data, and selected thematic maps of the Nation that are used extensively for land planning, land and resource management, and recreation purposes. These maps and data are made available in conventional printed form in various scales, in digital form, and as reproductions of aerial photographs and satellite images. Digital data are available from the National Digital Cartographic Data Base as digital line graphs or digital elevation models.

Primary topographic maps, including 7.5-minute maps mostly at 1:24,000 scale for almost all areas of the lower 49 States and 15-minute maps of Alaska at 1:63,360 scale, are especially useful where detailed information is needed for all types of land and resource management. The program involves the periodic inspection for data currentness and appropriate revision of these detailed maps. Other series of topographic maps at smaller scales are also available, such as the intermediate-scale maps prepared at 1:100,000 scale and the 1:250,000-scale map series, which provide complete topographic coverage of the United States. These map series are widely used by Federal and State agencies and the private sector for preparing their own special-purpose maps and depicting their unique data. Other base maps are available, including 1:500,000-scale State base maps and smaller scale U.S. base maps.

The land use and land cover maps, primarily at 1:250,000 scale and at 1:100,000 scale in selected areas, provide the only systematic nationwide inventory of land use and land cover data. The USGS also prepares various special-purpose map products, such as orthophoto quadrangle maps, image maps, U.S. National Park maps, and a variety of thematic maps.

National Mapping Research and Technology

The USGS has pioneered investigations that have led to major developments and significant changes in surveying and mapping. Mapping research activities, which are centered primarily on the geographic and cartographic disciplines, currently emphasize spatial data analysis, applications of remote sensing and geographic information systems, and advanced techniques for producing digital cartographic data.

The Division has embarked on a major research and development plan (known as Mark II) to move from manual to digital production and revision of map products. The goals of Mark II are to implement the advanced cartographic systems and procedures required to automate map production and to provide data for the National Digital Cartographic Data Base.

Information Services

The USGS disseminates much of the Nation's earth-science information through its Earth Science Information Centers (ESIC), 60 ESIC/State affiliated offices, and the Earth Resources Observation Systems Data Center. The information is provided in many forms, from maps and books to computer-readable magnetic tapes and compact disks. About 140,000 different maps and books and about 9.1 million aerial and space images are available for purchase. USGS maps are also available from more than 3,500 authorized commercial map dealers nationwide.

International Activities

The U.S. Geological Survey has been involved with earth-science studies in foreign countries for nearly 50 years. Authorization is provided under the Organic Act, as revised, and the Foreign Assistance Act and related legislation when such studies are deemed by the Departments of the Interior and of State to be in the interests of the U.S. Government.

Current international program efforts focus on technical assistance programs in developing countries and scientific cooperation and research through agreements with other countries as an extension and enhancement of the USGS's domestic programs. Cooperative research activities range from informal communications between scientists, through formal, jointly staffed projects, to multi-nationally staffed coordinated programs focused on particular problems or topics.

Related activities that are integral to the international programs include institutional development, exchange of scientists, training of foreign nationals, and representation of the USGS or the U.S. Government in international organizations and at international conferences and meetings.

Administrative Division

Organization

The headquarters office of the Administrative Division is located in Reston, Va. The Division is composed of five headquarters offices. Financial Management and Systems Management are centralized headquarters functions; Facilities and Management Services, Personnel, and Procurement and Contracts provide operational support at headquarters and at USGS field units through Regional Management Offices in Denver, Colo., and Menlo Park, Calif. The Division also manages the development, maintenance, and operation of the financial management system for the entire Department of the Interior through a sixth component, the Washington Administrative Service Center.

The Assistant Director for Administration is the Division Chief. Under his leadership, the Division provides administrative direction and coordination to support the scientific and technical programs of the USGS.

Information Systems Division

Organization

The Information Systems Division's headquarters office is in Reston, Va. The Division is composed of five Offices: Assistant Director, Computer and Communications Services, Customer Services, Field Services, and Management Services. Service centers in Reston, Menlo Park, Calif., Denver, Colo., and Flagstaff, Ariz., provide a complete range of services to users.

The Assistant Director for Information Systems is the Division Chief. He chairs the USGS Information Systems Council, which is composed of the top automated data processing manager in each Division and in the Central and Western Regions. The council recommends technology-related policies to the Director, coordinates computer science research and technology, and provides guidelines for the sharing, acquisition, and use of major computer systems and information management programs for the USGS.

Outreach

Information Dissemination

Along with its continuing commitment to meet the earth-science needs of the Nation, the USGS remains dedicated to its original mission to collect, analyze, interpret, publish, and disseminate earth-science information. The results of USGS investigations are published in its scientific reports and in its topographic, geologic, and hydrologic maps. About 140,000 different maps and books are available for purchase. A series of general-interest publications is available to inform the public about USGS activities. Research results and investigations are also published in journals of technical and scientific organizations and in publications of cooperating Federal and State agencies. News releases, real-time information on earthquakes in the United States and around the world, and news conferences on reports and events of current interest are other important means by which the USGS provides earth-science information to the public.

About 140,000 different maps and books are available for purchase.

During fiscal year 1989, the USGS produced 4,451 new or revised topographic, geologic, and hydrologic maps, bringing the total number of maps available to 83,000. Of these, over 8 million copies were distributed. The number of reports approved for publication by the USGS in fiscal year 1989 was 4,649, with 72 percent designated for publication in professional journals and monographs outside the USGS and the remainder scheduled for publication by the USGS. In addition, over 170,000 copies of technical reports of various classifications were distributed. Also, 1,002 new reports were released to the USGS's open files making the total more than 28,000 open-file reports available. Over 642,000 copies of the USGS general-interest publications were distributed to meet inquiries from the general public. Additionally, of the approximately 9.1 million different aerial and space images available for sale, about 195,000 copies are sold annually. USGS maps are also available from more than 3,500 authorized commercial map dealers nationwide.

Outreach—Earth Science for Today and Tomorrow

By Maxine C. Jefferson

The USGS has always placed great emphasis on promoting geoscience education, on the employment of women, minorities, persons having disabilities, and on promoting volunteer opportunities. During 1989, the emphasis on the earth sciences and education took on a particularly significant focus in view of national education reports that showed a continuing decline in general public awareness of science issues of national importance and a reduction in the number of students who are preparing for careers in engineering and science. Demographic studies also indicate that women and minorities will make up a larger percentage of the available workforce of the future. Women and minorities traditionally have been underrepresented in engineering and science. For this reason, the USGS sees a special challenge in encouraging these people to pursue an interest in the earth sciences. USGS efforts to increase the interest of minorities and women in engineering and science, to recruit persons having disabilities, and to involve the public and academic communities in volunteerism all have a positive impact on employment opportunities for these special emphasis groups.

As one of the largest employers of earth scientists in the United States, the USGS sees itself as having a special responsibility as well as a well-grounded framework on which to build support for science educators and students. Educational initiatives and outreach efforts increased during fiscal year 1989 because of participation in career fairs, classroom presentations, teacher workshops, open houses, field courses and field trips, judging science fairs, visits and tours at USGS facilities, and distribution of information.

Formally organized programs and ongoing activities in 1989 included student and faculty hiring programs, the Minority Participation in Earth Sciences Program, the Historically Black Colleges and Universities Program, a cooperative program with the American Geological Institute, and research grants, cooperative agreements, and contracts with universities in support of USGS research mission objectives. Personnel specialists and Division subject matter specialists attended numerous career fairs at colleges and universities nationwide to expose students and faculty to the nature and extent of scientific work at the USGS. The fact that more than 500 students and faculty were appointed to positions in the USGS this year clearly indicates the success of such efforts.

Outreach to colleges and universities is a critical element in the effort to increase the employment of women and minorities in the field of earth science. However, the USGS also is devoting increased resources for outreach to elementary and secondary schools to develop an interest in earth science at younger ages. In fact, this year's involvement with elementary and secondary schools was increased, and special efforts at these grade levels will continue.

In August 1989, the USGS hosted 75 secondary science teachers at the USGS National Center and presented a series of talks and demonstrations on current research and operations. At the USGS Western Region Headquarters, the bureau hosted a special 2-day seminar for earth-science teachers in the San Francisco area. The seminar was attended by more than 110 teachers, and 20 USGS scientists shared their expertise and the results of their current research. In September 1989, as part of the Department of the Interior's emphasis on Hispanic Heritage Month, the USGS served as host to the Departmentwide Hispanic Youth Conference, "Conferencia Juventud," that was attended by over 450 Hispanic high school students from the Washington, D.C., metropolitan area. Additionally, the USGS is actively involved in the Partnerships in Education Initiative and has adopted many schools nationwide.

Continuing interchange with elementary and secondary science teachers is planned in an effort to assist in the development of new educational materials, publications, and lesson plans that are based on the curricula needs of teachers and students in grades kindergarten through 12 and to determine ways in which USGS scientists and teachers can assist one another in promoting earth-science education. The USGS is placing special emphasis on the interaction of the earth-science disciplines in which they are involved. This emphasis illustrates to the educational community how the scientific fields of geology, hydrology, cartography, geography, and computer science interrelate in the earth-science curricula and in the physical world in which we live.

USGS emphasis on outreach to persons having disabilities has rendered successful employment results. In any given year, over 1 percent of the appointees to the USGS workforce have disabilities. Also, over 1 percent of the disabled persons appointed have disabilities that were targeted for special recruitment efforts. With a current total workforce of 10,534 persons, 6 percent of whom are persons having disabilities, the USGS continues to be among the highest in the Department of the Interior in the employment of persons having disabilities.

One major outreach effort to both the public community and to the academic community in particular is the Volunteer for Science Program that was established in 1986. At the end of FY 1987, 397 volunteers had donated over 76,754 hours that resulted in an estimated savings of $790,380 to the USGS. By the end of FY 1989, a total of 1,298 volunteers had donated 294,145.50 hours that resulted in an estimated savings of more than $3,000,000. In the 2-year period from October 1987 to September 1989, the number of volunteers, the number of hours donated, and the estimated savings have more than tripled.

Most USGS volunteers are recruited through the efforts of a nationwide network of coordinators. USGS volunteers are from varied backgrounds and ages that range from senior citizens who are interested in providing useful services and being involved, to college students who are eager for exposure to scientific research and advanced technology, to elementary school students who are anxious to learn more about fossils and rocks. USGS volunteers come from all walks of life: the community, elementary and high schools, colleges and universities, professional associations, and retiree associations. The USGS takes special pride in the 44 Scientists Emeriti and in the 93 USGS retirees who serve as volunteers on various projects and provide assistance in the Visitors Center at the National Center. The fact that students and faculty from over 135 colleges and universities, including historically black colleges and universities, also participate in the program is another pleasing result of this effort. The retirees who volunteer in the USGS Visitors Center serve as docents, conducting tours, developing tour programs, and scheduling tour groups for visits. The results of this docent program will be used to assist in the development of similar programs at other USGS regional Centers.

The Volunteer for Science Program is promoted extensively through recruitment flyers and posters, news releases, visits to high schools and colleges, participation in volunteer fairs, awards ceremonies, certificates of appreciation, volunteer pins, USGS retirees associations, and the distribution of volunteer information with map sales. The volunteer program is conducted in cooperation with Take Pride in America sponsored by the Department of the Interior.

Particularly noteworthy in 1989 was outreach to over 900 colleges and universities having earth science, geography, and computer-science departments. The USGS provided these academic institutions with a booklet listing nationwide USGS volunteer/intern opportunities in the field of geology. Another recruitment and outreach tool is the Volunteer Yearbook that contains descriptions of specific volunteer assignments and lists the names of volunteers. Through these outreach efforts, the program has continued to attract persons interested in science and public service. Because the Volunteer for Science Program is of mutual benefit to both the USGS and the volunteer, it is not only a successful program but also a rapidly growing program.

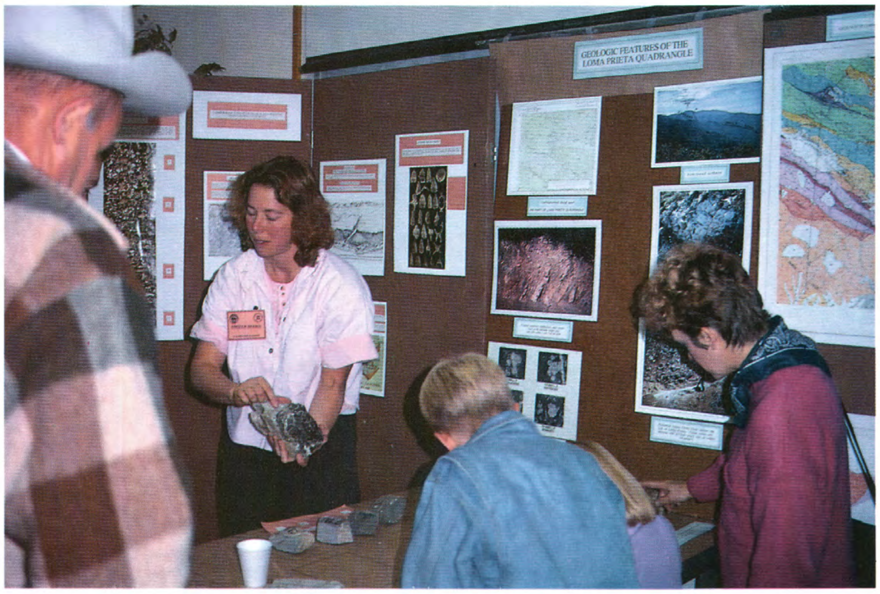
Reaching Out in a Big Way

By Gail A. Wendt

Menlo Park Symposium and Open House

Breaking new ground in its efforts to reach out to a wider audience for its scientific information, the USGS hosted a combined symposium and open house at its regional headquarters in Menlo Park, Calif. Titled "Geohazards '88," the two-day symposium on November 17 and 18 was followed by a day-long open house for the general public on Saturday, November 19.

Aimed at local planners and managers who benefit from the information available from the USGS, the symposium



Angela Jayko explaining local geology. (Photograph by Leslie Gordon.)

Mark Wilcox giving tour of Mineral Separation Lab, building 4. (Photograph by Leslie Gordon.)

highlighted research on the causes, effects, and prediction of geologic and hydrologic hazards.

Speakers at the symposium represented the many scientific disciplines of the USGS and the numerous outside agencies with whom the USGS conducts cooperative research. More than 200 public officials attended the symposium and heard presentations on probabilities for large California earthquakes, what happens to hillsides from landslides caused by earthquakes, the fate and effects of toxic substances in San Francisco Bay, and volcanic hazards at Mount Lassen. This symposium represented the first such concerted effort by the USGS to reach out to a specific audience—local and regional land-use and resource managers and planners—and to help them better understand what information and products were available from the USGS and how they could best use these earth-science tools.

At the Saturday open house, some 8,000 citizens, including many family groups, came out to see what the USGS is all about in Menlo Park. The Menlo Park facility had previously hosted an open house in 1985 and used that experience to bring even more exciting exhibits and presentations to the public at the 1989 open house.

Exhibits and presentations covered the full gamut of USGS research and investigations from satellite image mapping and geographic information systems to ground-water contamination and water use. Other research efforts including mineral resources, planetary geology, and marine geology were highlighted. Computer applications, publications, the USGS library, and the Menlo Park Earth Science Information Center—one of the 11 public outlets for USGS information and map and book sales—rounded out the extensive program.

In direct response to visitors at the open house who said that they would like to visit the USGS more often, the Earth Science Information Center (ESIC) at the Menlo Park office has become the first ESIC in the Nation to extend its hours to 7 p.m., each Thursday, beginning January 1990.

Reston Open House

In the spring of 1989, in conjunction with National Science and Technology Week, sponsored by the National Science Foundation, the USGS hosted an open house at its National Center in Reston, Va. The 1-day event on Saturday, April 29, 1989, was attended by some 5,000 residents in the Washington, D.C., area.

The theme of National Science and Technology Week, "Everyone is a Scientist," was used. Displays, exhibits, and activities for the open house focused on getting across the message that science is an important and intrinsic part of everyone's daily life. One of the most popular events was "Ask the Scientist," which gave visitors an opportunity to bring in rocks and fossils to be identified by USGS geologists or to ask questions about local geology. At times, the crowds were so large that it was hard to hear—or see—the scientists.

Another highlight that received great popular acclaim was the premiere showing of the new USGS/Smithsonian film, "Inside Hawaiian Volcanoes."

The newly refurbished "Maps and Minds" exhibit—sponsored by the USGS and the National Geographic Society, and recently back from a 5-year tour around the Nation—provided a pleasant and educational walk through the history of mapmaking. "Maps and Minds" remained at the USGS through the 28th International Geological Congress in July in Washington, D.C., when hundreds more visitors from around the world came out to Reston to visit the National Center. The exhibit then began another 5-year tour around the country through the Smithsonian Institution Traveling Exhibit Service.

Other exhibits and displays at the open house featured coastal erosion, the Parkfield earthquake prediction experiment, scientific visualization—an exciting new world of computerized imagery, acid rain, and mineral resources. Special activities were set up for Girl Scout and Boy Scout groups at which information was available on which specific exhibits and presentations would satisfy badge requirements.

Special tours took visitors to the tree-ring laboratory, the extensive map and book collections of the USGS library, the Technology Information Center, the mainframe computer room, and the carbon-14 age-dating laboratory. Many intrepid visitors braved the pouring rain and enthusiastically ventured out to see the ground-water well on the USGS grounds.

Visitors were able to purchase a special poster commemorating the 110th anniversary of the USGS, which featured an aerial view of the Reston area around the National Center. The Earth Science Information Center was open throughout the event, and waiting lines of visitors usually extended out of the door.

Visitors were asked to fill out a brief questionnaire before they left. Comments were extremely positive, with "Excellent" often repeated. Many visitors said they would like to see more events like the open house in the future. Perhaps most rewarding were the comments about the enthusiasm and helpfulness of the USGS scientists and other personnel who were there to answer questions and to help the visitors.

Visitors—children and adults alike—enthusiastically looked at, handled, and identified major rock-forming minerals with the assistance of geologists and physical science technicians. Harvey Belkin and Jane Hammerstrom explained a common method of identifying minerals by using fingernails, copper pennies, glass, and stainless steel knife blades as a way to rank the hardness of minerals.

Looking for flakes of gold was an activity in great demand at the April open house. Geologist John D'Agostino demonstrated how to shake the mineral pan so that the heavy minerals remain in the crease of the pan. Many young people enjoyed finding garnets, pyroxenes, and amphiboles among the gravels.

Water Resources Investigations

Mission

The U.S. Geological Survey has the principal responsibility within the Federal Government to provide the hydrologic information and understanding needed by others to achieve the best use and management of the Nation's water resources. To accomplish this mission, the Water Resources Division, in cooperation with State, local, and other Federal agencies,

- Systematically collects and analyzes data to evaluate the quantity, quality, and use of the Nation's water resources and provides results of these investigations to the public.
- Conducts water-resources appraisals describing the occurrence, availability, and physical, chemical, and biological characteristics of surface and ground water.
- Conducts basic and problem-oriented hydrologic and related research that aids in alleviating water-resources problems and provides an understanding of hydrologic systems sufficient to predict their response to natural or human-caused stress.
- Coordinates the activities of Federal agencies in the acquisition of water-resources data for streams, lakes, reservoirs, estuaries, and ground water.
- Provides scientific and technical assistance in hydrologic fields to other Federal, State, and local agencies, to licensees of the Federal Energy Regulatory Commission, and to international agencies on behalf of the Department of State.
- Administers the State Water Resources Research Institutes Program and the National Water Resources Research Grants Program.

Highlights

Embudo: 100 Years of Influence on Water-Data Collection

By Charles W. Boning

The U.S. Geological Survey began its stream-gaging program 100 years ago on the Rio Grande near the village of Embudo in northern New Mexico. The site was selected by Major John Wesley Powell, the USGS's second Director, who recognized the need to develop techniques and procedures that would meet the requirements of legislation passed in October 1888 authorizing surveys of water resources for irrigation and flood prevention.

Few people were knowledgeable about stream gaging in 1888; therefore, Powell envisioned a camp for training a cadre of young engineers who in turn could train others to carry out this aspect of the USGS's mission. Embudo was chosen for this training camp chiefly because it was accessible by railroad, and because gaging rivers in areas farther north was complicated by ice during winter. A western site was needed because the legislation specifically authorized such work only for arid lands, which excluded eastern streams. Also, the Rio Grande was an ideally sized river on which to conduct a training program. Also, data on flows of the Rio Grande were needed to help resolve issues of water rights with Mexico.

The training camp was established in December 1888 with a select group of engineers who had recently graduated from eastern colleges. The trainees were led by Frederick Haynes Newell, who was later recognized as the father of systematic stream gaging. Because there was little available precedent for gaging streams, the group relied on their own innovations for developing stream-gaging procedures and for redesigning and refining equipment suitable for this purpose. Their first rudimentary efforts in December 1888 included measuring velocity by timing floats that were placed in the river and by measuring stream depths from a raft made from logs and barrels that was tied to a rope stretched across the river. Other data collected were water temperature, barometric pressure, and evaporation. The ingenuity of those first streamgagers was evident in how they measured evaporation. They borrowed a bread pan from the camp cook and measured evaporation by recording the loss of water from the pan.

In January 1889, when more supplies and appropriate equipment arrived, the first USGS gaging station was constructed. The gage consisted of a stilling well that was dug into the gravel bank of the Rio Grande. By extending intake pipes from the well into the river, the engineers were ensured that the water level in the well was consistent with the level in the river. Although extremely rudimentary in construction, the basic design of this first gage is similar to gages still in use today.

A makeshift shelter was built over the well to house an instrument that was provided by the U.S. Coast and Geodetic Survey to record water levels in the well. This recorder had a horizontal chart drum that turned with time. The water level in the well was sensed by a float that was attached to a wire suspended from a wheel on the recorder that turned as the river stage changed. Here again, although bulky and relatively crude, the recorder operated on the same principle as many recorders still in operation today.

To measure stream velocity, several types of meters were tested and modified as appropriate for the flow characteristics of the Rio Grande. Meters were redesigned to accommodate the shallow depths of the river, and the counting mechanisms were refined to avoid interference from weeds and grasses that were suspended or floating in the water. The engineers experimented with various procedures for making discharge measurements: they traversed the stream at a constant rate while the meter was suspended in the flow to integrate velocity across the stream; they raised and lowered the meter at a constant rate at points in the stream to integrate velocity from the water surface to the streambed, and they measured velocity using the meter that was held stationary at various points in the stream and at various depths. The procedures developed at Embudo by this pioneering group of engineers provided the framework for modern stream-gaging technology.

The stream-gaging program grew in response to the need for data for irrigation, navigation, and flood prevention purposes. By 1900, about 160 gages had been established. In the following decades, growth in the stream-gaging program was more dramatic. Data were needed not only for large flood-control and irrigation projects but also for the expansion of hydroelectric power generation from the 1920's to the 1950's. The

The men in the cable car are measuring the flow in the Arkansas River near Canyon, Colo., circa 1890 by using procedures developed at Embudo, N. Mex. (Photograph from U.S. Geological Survey Water-Supply Paper 56, 1901.)

The present-day gaging station on the Rio Grande at Embudo, N. Mex. (Photograph from U.S. Geological Survey Professional Paper 778, 1971.)

passage of legislation in 1929 that authorized the USGS cooperative program with State and local agencies was a major factor in the growth of the stream-gaging network as State officials recognized the need for data to effectively manage their water resources. Severe floods and droughts, such as those of the 1930's, recent energy crises, and water-quality legislation all have given impetus to the need for more streamflow data.

The USGS maintains a national archive for water data and makes the information available to all.

From the meager beginning at Embudo, the USGS data-collection networks have grown to more than 50,000 sites where water-quantity, water-quality, or ground-water-level data are obtained, including a network of over 7,000 continuously recording stream-gaging stations and about 3,600 sites where streamflow data are gathered periodically each year. The USGS maintains a national archive for water data and makes the information available to Federal, State, and local agencies, to academia, and to thousands of people involved in the development and management of the surface-water resources of the country. The data also satisfy many needs of the research community in defining and understanding biological, chemical, hydraulic, and morphological processes in hydrologic systems.

The USGS continues to exercise the same innovative spirit that was shown by those early scientists who established the first gaging station at Embudo. USGS scientists and technicians have made significant advances in designing instruments used to measure hydrologic parameters and record water-resources data. The USGS has established a modernized data storage, retrieval, and archival system, and developed and refined complex procedures used to study and simulate hydrologic processes. As the USGS faces such new and expanding challenges as intensifying water-quality research and emerging concerns of global change, the need for timely, accurate, and pertinent information remains as paramount today as it did for those early scientists at Embudo 100 years ago.

Hydrologic Function of Wetlands

By Thomas C. Winter

Scientists have long known that wetlands serve many important physical, chemical, and biological functions. In recent years, this awareness has become more widespread, and there is a public demand that wetlands be managed and preserved as essential parts of landscapes and ecosystems. Wetlands have not yet been extensively studied, however, and their functions are not well understood by the public. Because much remains unknown about wetlands, it is difficult to place a value on them. In order to manage wetlands effectively or to defend their preservation, it is critical that their essential function as part of the global ecosystem be understood. That understanding begins with their fundamental hydrology.

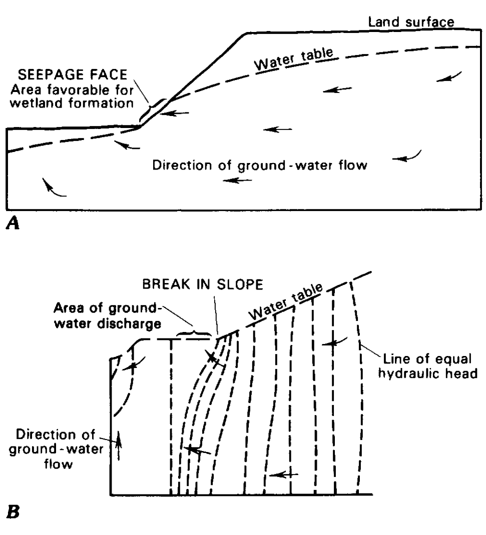
Wetlands occur in virtually all physiographic regions. Wetlands can be a dominant part of the landscape, such as the vast tracts of wetland terrane in the arctic and subarctic, or a minor part, such as an oasis in a vast desert. In the temperate, subtropical, and tropical zones, wetlands differ greatly in size and are common features of the landscape. No matter what their size is relative to other parts of the landscape, wetlands are highly visible and significant in most areas because they commonly occur where the focus is on development and agriculture.

The most common man-induced disturbances that affect wetlands are direct filling or drainage and modification of the uplands within the watershed. Wetlands are filled or drained to provide land for development, such as buildings, parking lots, roads, and airports, for agriculture, and for many other uses. Modification to upland watersheds adversely affects down-gradient wetlands because the water, chemical, and biological regimes are changed.

Wetlands occur where a combination of physiographic and hydrologic conditions favor the accumulation and (or) retention of water. Physiographic conditions that tend to enhance the formation of wetlands include flat to minimal land slope, areas where steep land slopes abut low land slopes, and hummocky topography; hydrologic conditions include soils of low permeability and areas where ground water discharges at the land surface.

Flat and (or) hummocky terrane and soils of low permeability are especially effective in the formation and maintenance of wetlands where surface water or precipitation is the source of water. In such settings, runoff is greatly retarded either by the low gradient or storage in depressions in the topography, and infiltration is also slow because of the low permeability of the soils. Examples of large regions that are characterized by low gradients and shallow depressions include glacial lake plains, such as the Glacial Lake Agassiz plain now occupied by the Red River of the North and the Red Lake peatlands in Minnesota; coastal lowlands along the Atlantic Ocean and Gulf of Mexico; and flood plains of major rivers. An example of a large region that is characterized by numerous depressions in a wide variety of sizes is the glaciated Northeastern and North-Central United States. Here, because the landscape is geologically young, an integrated drainage network has not been established, and storage of runoff water in depressions is extensive.

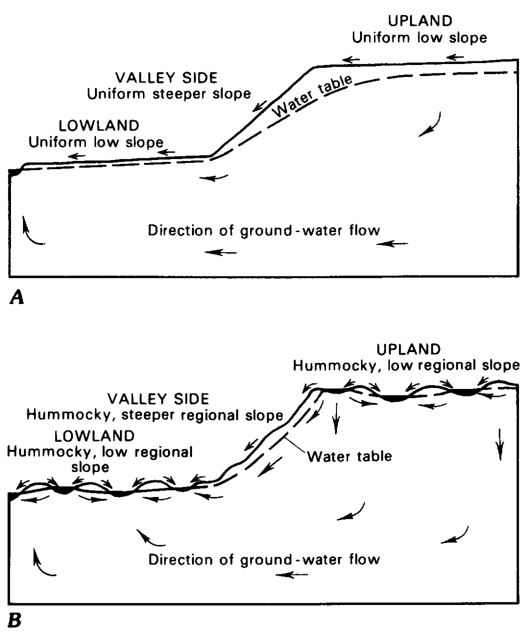
The same landscape features that enhance formation of wetlands from surface-water sources also are important to ground-water-flow systems. Regional slope and local relief of the water table and permeability of the land surface are primary controls on ground-water-flow



Geologic boundaries associated with the formation of some types of wetlands. *A*, Development of a seepage face, caused by ground-water flow intersecting the land surface. *B*, Upward movement of ground water associated with a break in slope of the water table. The upward movement occurs in the lower slope segment near the break in slope.

systems. An additional feature, a break in slope of both land surface and the water table, also commonly results in the formation of wetlands.

Considering wetlands in the framework of ground-water-flow systems is appropriate because, as is the case with most surface water, wetlands are hydrologic features where considerable interaction takes place between ground water and surface water. In a generalized landscape that has uniform, low-gradient land slopes, for example, precipitation falling on an upland will run off slowly because of the low hydraulic gradient. If the soil has low permeability, infiltration is slow, thus enhancing the potential for evapotranspiration because of the long residence time of the water on the land surface. If the upland consists of highly permeable material, infiltration and therefore ground-water recharge is enhanced, the potential for evapotranspiration is less, and little precipitation will run off. Regardless of permeability, regional flow systems predominate: ground water recharges beneath the upland and ground water discharges in the lowland. The lowland is the most favorable location for wetland formation because surface runoff from the upland is coupled with the regional ground-water discharge. Furthermore, the potential for water loss by evapotranspiration is great because of the abundant supply of water from both sources.



Schematic of the hydrologic function of wetlands; that is, the interaction between atmospheric water, surface water, and ground water, in the context of a generalized landscape. The generalized landscape consists of a relatively flat upland and lowland separated by a steeper slope. Furthermore, the land surfaces can be smooth and uniform (*A*) or hummocky (*B*). The landscape is generalized because it is characteristic of many physiographic settings and scales, such as high moraines adjacent to lower moraines or glacial lake plains, uplands adjacent to river valleys, high terraces adjacent to lower terraces, and coastal scarps adjacent to coastal lowlands.

In a generalized landscape that has hummocky topography, ground-water-flow systems are more complex. Here, numerous small, local flow systems form at shallow depths and are underlain by more extensive regional flow systems. Part of the precipitation that falls on any part of a hummocky landscape runs into depressions where much of the water is returned to the atmosphere by evapotranspiration. With respect to local ground-water-flow systems throughout the landscape, however, some depressions are areas of recharge, some are areas of discharge, and others serve both functions. In upland areas, for example, some of the recharge from the depressions is to regional flow systems, and, in lowland areas, some of the ground-water discharge to depressions is from regional flow systems. Additional complexities include seasonal flow reversals caused by recharge near wetland edges, bank storage during periods of high water levels in the wetlands, and the presence of phreatophytic plants.

The complex and dynamic interactions . . . in wetland ecosystems are a challenge to . . . effective management.

The complex and dynamic interactions between precipitation, surface water, and ground water in wetland ecosystems are a challenge to understanding and then developing effective management of these systems. For example, wetlands that recharge ground water commonly hold water for only part of the year. Because these are easiest to drain, they are commonly drained first. Unfortunately, drainage of wetlands that receive ground-water discharge commonly does not result in a gain of that land for other uses, because not only does drainage not stop the ground-water discharge, it also results in the deposition of salts and (or) in unstable soils. Thus, the wetland is lost and use of the land is lost as well.

It is essential also to understand the hydrologic function of wetlands from the perspective of the chemicals that wetlands can transport. For example, if contaminants are released from a wetland that recharges ground water, the contaminants will move through local ground-water-flow systems and discharge into nearby wetlands. If the wetland also recharges regional flow systems, the contaminants could affect a much larger area, eventually discharging into wetlands in the lowlands.

In managing wetlands, it is especially important to be aware of the seasonal reversal of flow conditions near wetland boundaries. A one-time or short-term study of a wetland can be misleading because flow directions commonly reverse near wetland edges. A condition measured at one time, and upon which a management decision is based, may not persist, thereby confounding that decision. Furthermore, the highly dynamic flow regime near wetland boundaries makes it particularly difficult to determine and map the extent of wetlands, presently one of the most highly visible problems facing the Nation today and one that is receiving considerable attention.

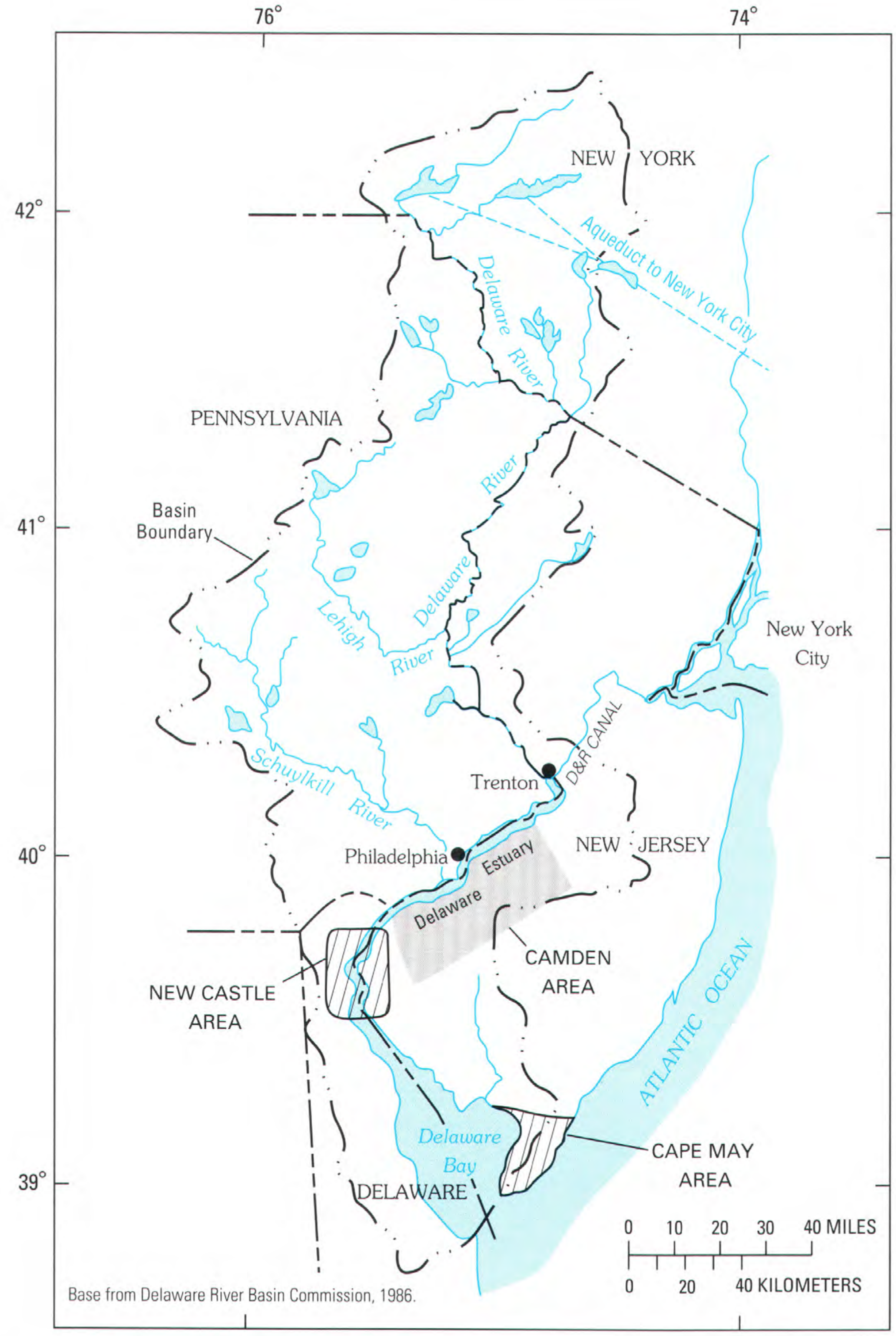
In summary, wetlands are a highly dynamic hydrologic feature throughout the landscape. Wetlands interact extensively with the atmosphere by discharging large volumes of water from both surface- and ground-water sources through evapotranspiration. Because they exist along the edges of most surface-water bodies, wetlands also have an important role in surface-water hydrology by controlling flow velocities, sediment transport, and shore erosion. Wetlands are also important areas of ground-water discharge and, in some settings, are areas of critical ground-water recharge. All of these hydrologic functions and their interactions must be considered in managing wetlands. Currently, however, the data base upon which management schemes must be derived is extremely small and only covers a few localities. Additional studies that investigate the critical role of wetlands in the local, regional, and national hydrologic scheme are needed, therefore, to better understand and quantify the interactive processes of wetlands.

Hydrologic Effects of Climatic Change in the Delaware River Basin

By Mark A. Ayers, David M. Wolock, Gregory J. McCabe, and Lauren E. Hay

The greenhouse effect is an essential component of the climatic processes that support life on Earth. Without the presence of certain gases, the Earth's atmosphere would be about 50 Fahrenheit degrees colder than it is now. Since the Industrial Revolution in the mid-1800's, concentrations of atmospheric greenhouse gases, especially carbon dioxide (CO_2) and methane, have been increasing steadily. Concentrations of atmospheric CO_2 are expected to double in the next century, reaching levels that probably have not existed on Earth in more than a million years. The current consensus among scientists is that an increase in the concentration of greenhouse gases in the atmosphere will result in global warming. Estimates indicate that the average global air temperature could increase from 2 to 7 Fahrenheit degrees as a result of a doubling of atmospheric CO_2, according to the National Academy of Sciences. Despite the general consensus concerning the inevitability of global warming, much uncertainty associated with climatic change still exists. The definition of the processes involved in global warming and their attendant effects on water resources, therefore, present a major scientific challenge for the next few decades.

In 1988, the USGS began an interdisciplinary study of the sensitivity of water resources to the potential effects of climatic change in the 12,765-square-mile Delaware River basin. In view of the uncertainty of climatic-change projections and because the effects of climatic change on basin hydrology are poorly understood, this study focuses on defining the basic relations of water-resource systems to current climate and the effects of simple assumptions of future climatic change on the sensitivity of these systems.



Delaware River basin study area.

Climate Modeling

Two regional climate models have been developed to estimate (1) current variability of daily temperature and precipitation over the basin and (2) scenarios of climatic change for the basin. The first climate model randomly predicts consecutive wet and dry periods and precipitation intensities for the wet periods. The approach replicates historical temperature and precipitation records well enough to allow hydrologists to evaluate how streamflow responds over space and time to differing temperature and amounts of precipitation. This climate model is linked directly to the watershed model that simulates daily streamflow.

The second climate model randomly predicts the daily weather pattern over the basin, such as a high-pressure system, a cold-frontal passage, or a warm-frontal passage. The model then assigns values of climate variables (temperature and precipitation) based on the observed relations between the variables and weather patterns in historical records. The approach also accurately replicates the statistics of historical climate records and provides a means of estimating climatic variability over the entire basin. Initial analyses indicate that the frequency of weather patterns for present climatic conditions simulated by global climate models is similar to the frequency of observed weather patterns for the basin. In order to check future scenarios, hydrologists used the model to simulate conditions in which the amount of CO_2 in the atmosphere doubled. Data from this scenario are being analyzed to determine the resulting change in frequencies of weather patterns, which will then be used to define temperature and precipitation changes for the basin.

Watershed Modeling

Monthly streamflow models (with and without reservoir data) and a daily streamflow model (without reservoir data) have been developed to analyze the effects of climatic change on streamflow in the basin. Reservoir operations are being added to the daily streamflow model in order to incorporate management options into the assessment of climatic change in the basin.

Several analyses of streamflow sensitivity to climate variables already have been completed. Analyses of the effects of climatic changes on monthly streamflow that were made by using a monthly water-balance model without reservoir data indicate that winter warming would cause an increase in the proportion of precipitation as rain in the northern part of the basin. This effect would reduce snow accumulation, increase winter runoff, and reduce spring and summer runoff. Estimates of total annual runoff indicate that a 5-percent increase over current precipitation amounts would be needed to counteract runoff decreases resulting from a warming of 4 Fahrenheit degrees; a 15-percent increase would be needed for a warming of 7 Fahrenheit degrees. A warming of from 4 to 7 Fahrenheit degrees, without corresponding precipitation increases, would cause a 9- to 25-percent decrease in total annual runoff. When reservoir data are factored into the model, a significantly greater risk of a drought emergency exists in which reservoir levels are too low to meet demand—for scenarios in which precipitation does not increase sufficiently to offset the CO_2-induced warming.

A topographically based hydrologic model was developed and linked with the wet/dry climate model to analyze the sensitivity of daily streamflow. Results of this model, without reservoir data, indicate that the overall effect of warming is to decrease daily streamflow. Most of this decrease would occur in the warmer seasons. In the northern part of the basin where snow accumulation currently is significant, the warming actually would result in an increase in the February average and maximum daily flow, regardless of precipitation changes, because of the increased precipitation as rain. In general, the model showed that watershed runoff was more sensitive to changes in precipitation intensity than to changes in precipitation duration or temperature.

Estuary Modeling

A sea-level rise, which is likely to accompany global warming, would alter estuarine salinity. Scientific consensus indicates a global warming of about 7 Fahrenheit degrees for conditions of double CO_2 would result in an estimated sea-level rise of from 0.5 to 4.5 feet. In the Delaware River Estuary, a rise of 2.4 feet would cause the saltwater front to move about 8 miles farther upstream. Both the rise in sea level and the saltwater movement could have serious implications for the continued availability of surface and ground water in the area of the upstream saltwater movement.

Ground-Water Modeling

Three ground-water models will be used to assess the effects of sea-level rise and the resulting changes in salinity on ground-water availability. The final calibration of these models is near completion. An available model of the aquifer system near New Castle, Del., was used for sensitivity analyses. The model results indicate that this semi-confined aquifer system is sensitive to the flooding that would result from a rise in estuary levels. Because of the presence of a confining unit under the estuary that restricts the movement of saline water into the aquifer, a sea-level rise of 5 feet alone would not result in a significant change in recharge of saline estuary water into this aquifer system. A combination of flooding and a sea-level rise of 5 feet, however, would triple the amount of saltwater recharged to the aquifer system because the flooding would extend beyond the confining unit. A second ground-water model will focus on potential changes resulting from sea-level rise on saltwater intrusion in an unconfined aquifer system near Cape May, N.J. A third model will assess the effects of the extended movement of saltwater in the estuary on saltwater intrusion and ground-water availability in a multiple-layered confined-aquifer system near Camden, N.J.

Results of simple analyses of the potential global warming on water resources in the Delaware River basin suggest serious implications for future availability of water-related resources. In this humid, temperate climate, where precipitation is distributed evenly throughout the year, decreases in snow accumulation in the northern part of the basin and increases in evapotranspiration throughout the basin could change the temporal distribution of runoff and reduce streamflow by as much as from 9 to 25 percent unless precipitation increased. Also, ground-water recharge of saline estuary water in one aquifer near New Castle, Del., could double with a sea-level rise of 5 feet. USGS scientists will continue to refine and complete the models and scenarios in order to quantify more accurately the effects and associated risks of the various potential climatic and sea-level changes on streamflow and ground water in the Delaware River basin.

Investigation of Water Quality, Bottom Sediment, and Biota Associated With Irrigation Drainage in the Western United States

By Herman R. Feltz, Richard A. Engberg, and Marc A. Sylvester

In response to concerns expressed by the U.S. Congress over contamination at the Kesterson National Wildlife Refuge in California, the Department of the Interior (DOI) started a program in 1985 to identify the nature and extent of irrigation-induced water-quality problems that might exist in other western areas where the DOI has responsibility. The DOI formed a Task Group on Irrigation Drainage, an interbureau group chaired by the USGS. Initially, the Task Group identified 19 locations in 13 States that warranted reconnaissance-level investigations (fig. 1). These locations relate to three specific areas of DOI responsibility: irrigation or drainage facilities constructed or managed by the DOI, national wildlife refuges managed by the DOI, and other migratory-bird or endangered-species management areas that receive water from DOI projects.

Nine of the 19 locations were selected for reconnaissance-level investigations during fiscal years 1986–87. Study teams composed of three scientists, one each from the USGS (team leader), the U.S. Fish and Wildlife Service, and the Bureau of Reclamation, were formed to conduct the investigations at each location. Surface and ground water, bottom sediment, and biota were investigated at each location. Reports for completed studies are shown in table 1. Reconnaissance-level investigations were started in fiscal year 1988 at the remaining 10 sites identified by the Task Group. Reports for these studies will be published in fiscal year 1990. A 20th study for the Pine River area in southwestern Colorado was added in fiscal year 1989 (fig. 1).

In the first nine study areas, analyses of water, bottom sediment, and biota sampled were evaluated against Federal and State water-quality regulations and criteria, baseline data for adjacent areas, and other guidelines that might be helpful in making assessments of adverse

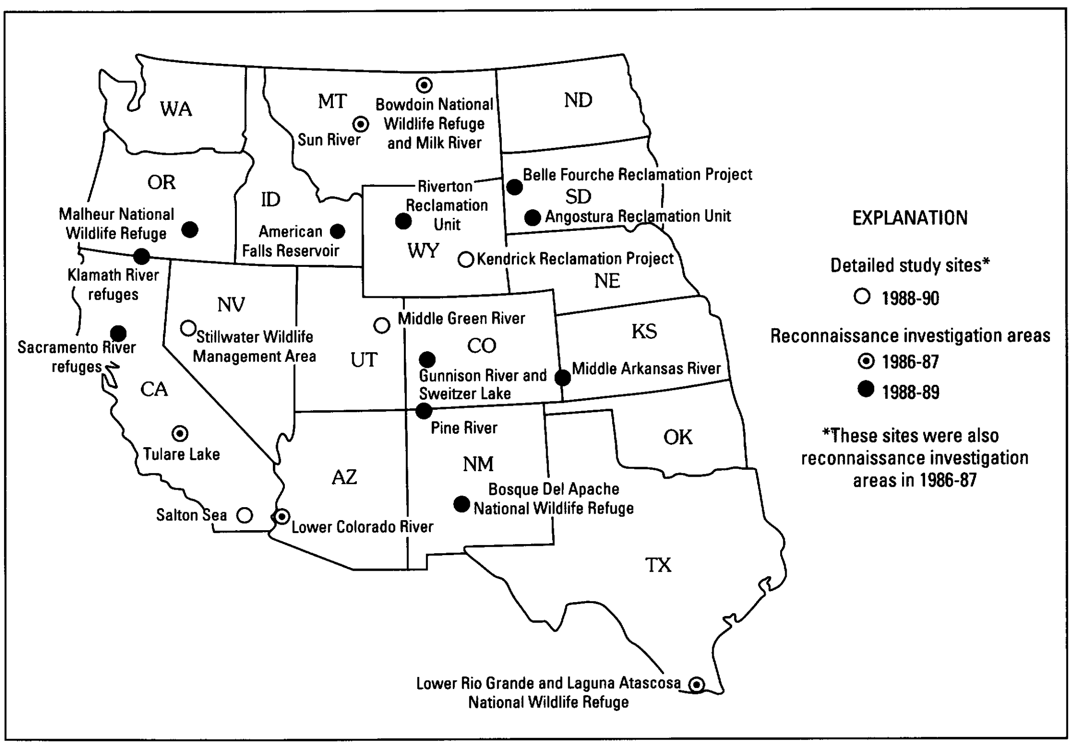


Figure 1. Study locations and dates, National Irrigation Drainage Program, Western United States.

TABLE 1. Water-resources investigations reports (WRIR) completed for reconnaissance investigations of water quality, bottom sediment, and biota associated with irrigation drainage

Area	Report number
Lower Colorado River valley, Arizona, California, and Nevada, 1986–87	WRIR 88–4002
Salton Sea area, California, 1986–87	WRIR 89–4102
Tulare Lake bed area, southern San Joaquin Valley, Calif., 1986–87	WRIR 88–4001
Bowdoin National Wildlife Refuge and adjacent areas of the Milk River basin, northeastern Montana, 1986–87	WRIR 87–4243
Sun River area, west-central Montana, 1986–87	WRIR 87-4244
Stillwater Wildlife Management Area, Churchill County, Nev., 1986–87	WRIR 89–4105
Lower Rio Grande valley and Laguna Atascosa National Wildlife Refuge, Tex., 1986–87	WRIR 87–4277
Middle Green River basin, Utah, 1986–87	WRIR 88–4011
Kendrick reclamation project area, Wyoming, 1986–87	WRIR 87–4255

TABLE 2. Constituents of concern in detailed study areas

Study area	Media	Constituents of concern
Kendrick reclamation project area, Wyoming.	Water	Selenium.
	Bottom sediment	Selenium, uranium.
	Biota	Selenium, boron.
Middle Green River basin, Utah.	Water	Selenium, boron, zinc.
	Bottom sediment	Selenium, uranium.
	Biota	Selenium, boron, zinc.
Salton Sea area, California.	Water	Selenium, boron, salinity.
	Bottom sediment	Selenium, DDD,* DDE.*
	Biota	Selenium, boron.
Stillwater Wildlife Management Area, Nevada.	Water	Arsenic, boron, uranium, salinity, unionized ammonia.
	Bottom sediment	Arsenic, selenium, lithium, mercury, molybdenum.
	Biota	Arsenic, selenium, mercury, boron, chromium, copper, zinc.

*Breakdown derivatives of DDT.

effects on fish, wildlife, and humans. Water samples were analyzed for major ions, nutrients, selected trace elements, radiochemical constituents, and for pesticides at sites where they were used. Samples of bottom sediment and biota were analyzed for selected trace elements and, at some sites, pesticides.

Because some constituents exceeded water-quality regulations or criteria in samples from four of the first nine study areas, the DOI Task Group made the decision to proceed with detailed studies of these four areas. These areas and the constituents of concern are given in table 2. Slightly elevated levels of some constituents were found in water, bottom sediment, or biota in some of the five remaining areas, but the levels were not considered of sufficient concern to recommend detailed studies; however, some level of long-term monitoring may be initiated at those five sites.

The four detailed studies are oriented toward meeting two goals: (1) to confirm that irrigation-induced water-quality problems exist and (2) to provide the scientific understanding needed to develop reasonable alternatives that will mitigate or resolve identified problems. Within this context, the working objective for a detailed study is to determine the extent, magnitude, and effects of contaminants associated with agricultural drainage and the sources and exposure pathways that cause contamination where contaminant effects are documented.

To ensure that all areas having problems related to irrigation drainage in Western States were identified, a comprehensive survey of all DOI irrigation projects and wildlife management areas was conducted in fiscal years 1988 and 1989. Fifteen additional areas that may require additional investigation were identified. These areas are undergoing intensive evaluation of existinginformation to determine whether a reconnaissance-level investigation is necessary.

Results of the completed reconnaissance-level investigations and preliminary data from the ongoing reconnaissance investigations and detailed studies provided the following generalizations for areas where problems have been detected:

- Elevated concentrations of trace elements have been detected in several of the study areas, and pesticides have been detected in some of the study areas;
- Alkaline, oxidized soils that contain elevated concentrations of trace elements in semiarid environments indicate potential problem areas;
- Selenium, boron, arsenic, and mercury are the constituents found most often at elevated concentrations in water, bottom sediment, and biota in the study areas;
- Concentrations of arsenic and selenium tend to vary inversely; and
- The highest concentrations of constituents occur in internal drainage basins.

Water planners and managers throughout the Western United States will use the results of these studies to alleviate water-quality problems resulting from irrigation drainage.

The Effects of Agricultural Land-Management Practices on Surface and Ground Water in the Piedmont of North Carolina

By Catherine L. Hill and Douglas A. Harned

Agricultural practices, such as how the land is tilled and how much and in what manner pesticides and herbicides are used, are major sources of sediment, nutrients, and synthetic organics in surface-water runoff and of nutrients and organics in ground water. The extent, however, to which agricultural practices serve as a nonpoint source of pollution is largely a function of how the agricultural land is managed.

Farmers can use land-management practices that control erosion, increase soil moisture, and reduce the transport of farm chemicals and fertilizer in runoff from the fields. These methods, which are generally referred to as best-management practices, include development of grassed waterways and field borders, strip cropping, contour farming, and crop rotation. In contrast, when traditional or standard land-management practices are used, waterways are poorly maintained, crop production is continuous and without rotation, and the rows are plowed straight without regard to slope or topography.

To better define how agricultural land-management practices affect water quality, the USGS in cooperation with the Guilford Soil and Water Conservation District and the U.S. Soil Conservation Service began a 6-year study in 1984 of four small basins in the Piedmont of North Carolina. The Piedmont, a physiographic province extending from Virginia through Alabama, is characterized by clayey soils, rolling topography, and abundant rainfall. This area was chosen because of the highly erosive nature of the soils and the ongoing local effort to convert existing farmland to best-management practices. Results of this study should be transferable to similar agricultural lands throughout the Piedmont physiographic region of the Southeastern United States.

The study is designed to monitor chemicals applied to the land through farming practices as well as nutrients resulting naturally from atmospheric deposition. It also monitors water quantity and quality of overland runoff, concentrations of chemical constituents percolating through the clay soils in the unsaturated zone, and constituents reaching the ground water. Farmers cooperating in the study are helping keep detailed records of the chemicals applied to their fields and of their farming activities such as plowing. Data collection is scheduled to end September 1990.

Four areas including two row-crop fields, a mixed land-use basin, and a forested basin were selected for study. The row-crop fields are adjacent—one having best-management practices (7.4 acres) and the other having standard-management practices (4.8 acres). The amount of sediment, nutrients, and selected organics in runoff and the volume of runoff were monitored for the two fields as were the nitrate plus nitrite and pesticide content of soil water.

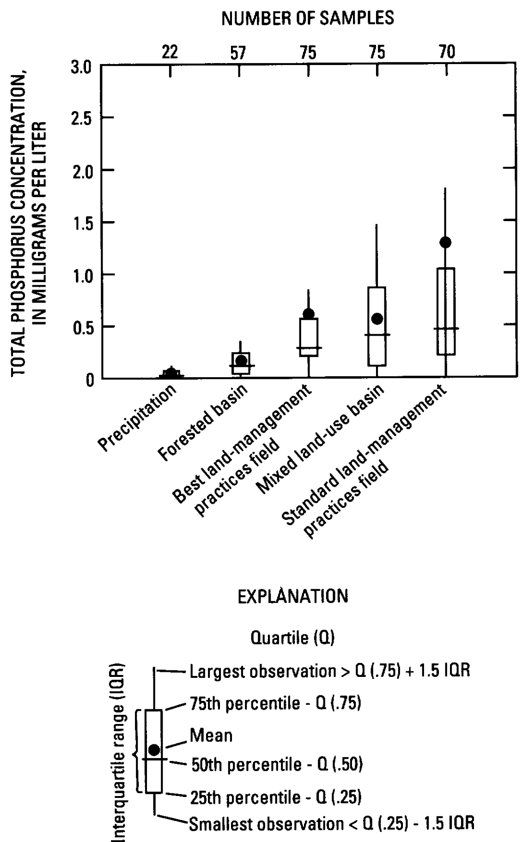
In the mixed land-use basin (665 acres), changes over time in water-quality constituents in runoff are being monitored at a streamflow gage, as standard-management practices are converted to best-management practices over the duration of the project. In the forested basin (44 acres), background hydrologic and chemical-quality conditions are monitored. These areas are within a 4-mile radius, and the effects of atmospheric deposition, which is monitored at one of the agricultural field sites, are assumed to be equal among all four areas.

Analysis of surface-water-runoff data through May 1989 indicates that for the two row-crop fields, in general, concentrations of sediment, nutrients, and selected organics in runoff from the field having best-management practices are dramatically lower than the concentrations found in the field having standard practices. A general relation appears to exist for nutrients and sediment concentrations for the four sites and for precipitation. With the exception of nitrogen, the lowest constituent concentrations are measured in precipitation, followed by increasing concentrations in runoff from the forested area, the field site having best land-management practices, and the mixed land-use site, with the standard-practices field site having the highest concentrations. Interestingly, nitrate plus nitrite concentrations were found to be higher in precipitation than those measured in runoff at the forested site, probably because the nutrient was bound up by the forest litter and also used by the plants.

The difference in sediment concentrations between the two agricultural fields is striking. The standard-management practices field had a mean concentration of 11,200 milligrams per liter (mg/L), compared with the best-management practices field mean concentration of 3,230 mg/L. Sediment concentrations for the mixed land-use basin were generally lower than those observed for the agricultural field sites because of the presence of 14 small farm ponds in the basin that act as sediment traps.

The erosion process, which creates suspended sediment and the resulting sediment yield, tends to sort the soil particles by carrying away the fine silts and clays associated with most of the soil fertility. Sediment yields—the amount of suspended sediment moving past the runoff gage—are consistently higher in the field having standard land-management practices than yields in the field having best land-management practices. During the 1987 water year, the sediment yield from the basin having standard practices was almost 36 tons per acre, compared with 5.4 tons per acre that came off the field having best-management practices.

A seasonal comparison of runoff differences between the two agricultural fields shows that the greatest amount of runoff occurred in the standard-management practices field during the growing season (May–September) and in the best-management practices field in the barren season (October–April). This is probably because during the growing season there is more bare, hardened ground, which promotes runoff, in the

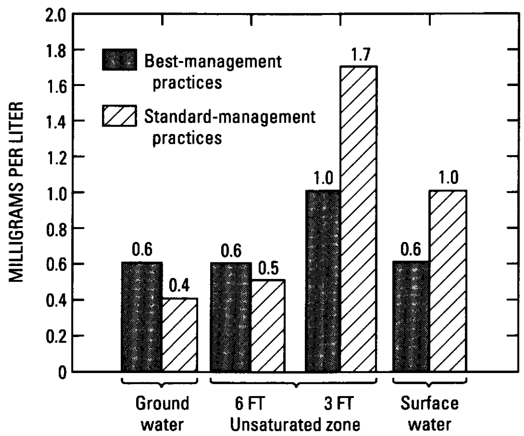


Comparison of total phosphorus concentrations, in milligrams per liter, in samples of precipitation, and of surface-water runoff from the forested and mixed land-use basins and the best land-management and standard land-management field sites.

standard-management practices field. In contrast, this same field has more plowed ground in the barren season. Plowing the ground increases the surface runoff and promotes infiltration by causing water to be trapped. In spite of the fact that the runoff is greater on the average in the best-management practices field during the barren season, sediment yields during this period are still lower than those observed for the standard-management practices field. This difference indicates that the effect of best-management practices in reducing sediment losses is significant enough to compensate for the additional runoff.

The effects of land-management practices on ground-water quality are not as apparent as the effects on surface water. Mean concentrations of total nitrate plus nitrite in the upper unsaturated zone (3 feet below land surface) are higher in the field having standard-management practices where concentrations averaged 1.7 mg/L compared with 1.0 mg/L in the field having best-management practices. Water samples collected in the unsaturated zone 6 feet below land surface and from ground water from 10 to 15 feet below land surface, however, have concentrations slightly higher in the best-management practices field than those measured in the standard-practices field. Levels of pesticide residues measured in soil samples tend to be higher in the best-management practices field compared with the standard-management practices field.

USGS hydrologists are continuing their sampling of surface and ground water in the four study areas. The project results thus far support the need for further study of the effects of land-management practices in clay-type soils on ground-water quality. In particular, the hydrologists will be interested to see what changes over time occur in water quality in the mixed land-use basin as it is converted to best-management practices.



Comparison of mean concentrations of total nitrate plus nitrite, in milligrams per liter, in samples of surface-water runoff, of water in the unsaturated zone, and of ground water from the two field sites having best land-management and standard land-management practices.

Relations Between Land Use and Nitrate Concentrations in Shallow Ground Water, Delmarva Peninsula

By Pixie A. Hamilton and Robert J. Shedlock

The USGS began to develop a National Water-Quality Assessment (NAWQA) pilot program in 1986. The long-term goals of the program are to describe the status of and trends in the quality of the Nation's surface- and ground-water resources and to provide a sound, scientific understanding of the primary natural and human factors that affect the quality of these resources.

The Delmarva Peninsula is one of seven pilot project areas in the NAWQA program. As a first step, USGS hydrologists gathered existing water-quality data, interpreted the compiled data, and then developed a preliminary regional water-quality assessment of ground water in the peninsula. Their assessment showed that the existing data were unsuitable for regional analysis because of inconsistent sampling methods, incomplete information on the locations and depth of wells, and the hydrogeology of the aquifers into which the wells tap. The assessment also showed that apparent relations between water-quality constituents, such as nitrate, and ancillary features, such as land use, may depend on the scale of the maps depicting the ancillary data. The implications of these findings are well illustrated by the relation between land use and nitrate concentrations in shallow ground water in the peninsula.

The Delmarva Peninsula, located in the Coastal Plain physiographic province, is comprised of most of Delaware and the entire Eastern Shore of Maryland and Virginia. The land area is about 6,050 square miles, of which about 48 percent is used for agriculture. Woodlands constitute about 31 percent of the land area and commonly are interspersed with agricultural areas. The degree to which agricultural lands and woodlands are interspersed depends in large measure on the physiography of the area. Poorly drained uplands, primarily located in the central part of the peninsula, are dominated by relatively small plots with interspersed woodlands and agricultural areas. Well-drained areas, which flank the central upland, typically are dominated by large agricultural tracts. Urban or built-up land, most extensive in the northern part of the peninsula, composes about 7 percent of the land area; the remaining land areas are wetlands or barren.

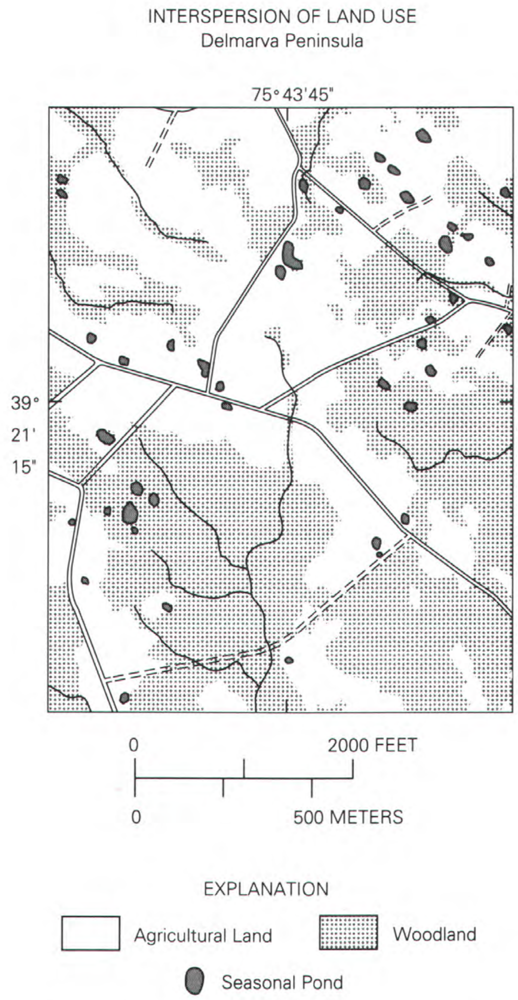
One of the chief water-quality concerns on the Delmarva Peninsula is elevated nitrate concentrations in shallow ground water, which probably are derived from human-related sources such as septic tank effluents, livestock wastes, and fertilizers. Results from previous studies show that the highest nitrate concentrations are found in agricultural areas and in urban or built-up land having well-drained sediments. Lowest nitrate concentrations are found in woodlands having poorly drained and relatively impermeable sediments.

Nitrate concentrations ranged from 0.1 to 59.0 milligrams per liter (mg/L) as nitrogen in samples collected from 399 wells in the surficial aquifer by USGS personnel from 1944 through 1987, prior to the start of the NAWQA program. The drinking-water standard for nitrate, established by the U.S. Environmental Protection Agency, is 10 mg/L as nitrogen. The initial analysis of the relations between nitrate concentrations in ground water and land use revealed median nitrate concentrations in ground-water samples from the 399 wells of 0.9 mg/L in woodlands, 2.9 mg/L in urban or built-up land, and 4.9 mg/L in agricultural areas.

Map of the Delmarva Peninsula, which is one of the pilot studies in the National Water-Quality Assessment Program.

The differences in these median nitrate concentrations indicate that land use does influence nitrate concentrations in ground water in the Delmarva Peninsula. The observed relations with land use, however, may be affected by the large differences in the depths of the wells (from 3 to about 300 feet) and differences in the time of sampling (from 1944 through 1987). For example, the depth at which the sample was obtained may introduce inaccuracy because deeper ground water may originate from more distant recharge areas that have different land use. The year the sample was obtained may also affect the land-use correlation because of improved methods of preserving samples. Preserving nitrate

Example of how woodlands (shaded) and agricultural land (unshaded) are interspersed in the Delmarva Peninsula (data digitized and GIS-generated from the Clayton, Del., 1:24,000-scale USGS topographic quadrangle map, 1977 photoinspection edition).



concentrations in water samples collected prior to the mid-1970's only included chilling to 39 °F at the time of sampling; the more recent standard procedure includes chilling and adding mercuric chloride, which improves the stability of nitrate concentrations. Therefore, early nitrate data may be misleadingly low.

Problems related to differences in the depth of wells and year of sample collection can be reduced by restricting the analysis to samples collected from shallow wells in the surficial aquifer during recent years. Thus, data since 1980 for nitrate concentrations at 62 of the 399 wells, all having depths less than or equal to 30 feet, were assessed separately. This analysis indicated median nitrate concentrations of 0.9 mg/L in urban or built-up land, 5.8 mg/L in agricultural areas, and 7.0 mg/L in woodlands, surprisingly high for ground water underlying woodlands. This may be caused by the relatively coarse resolution of the land-use data (at the 1:250,000 scale used in this analysis, the minimum differentiated size for agricultural and woodland areas is 40 acres, and a well located in the middle of a 35-acre farm surrounded by a forest often would be categorized as woodland) and the limited geographic distribution of the 62 wells (more than 35 percent are located in the poorly drained uplands where woodland and agricultural areas are well interspersed).

By using larger scale, more detailed maps (1:24,000 scale) that are shaded to distinguish woodlands from agricultural and urbanized areas, USGS hydrologists were better able to determine the relation of land use to the water-quality data for the 62 wells. Based on this analysis, median nitrate concentrations are 0.6 mg/L in woodlands and 6.7 mg/L in agricultural areas. Median nitrate concentration in urban or built-up land was not assessed because only 2 of the 62 wells are located in urbanized areas. These results are more consistent with the expectation that nitrate concentrations in ground water are lower in woodlands, which suggests that verifying apparent relations between nitrate concentrations and land use may depend upon the availability and use of more detailed land-use data.

The next step was for the hydrologists to collect samples for nitrate analyses from shallow wells that were installed in the surficial aquifer throughout the Delmarva Peninsula as part of the NAWQA project. These newly collected samples also were examined for land-use relations. The wells are located in subregions that have different hydrogeologic and physiographic features. Wells were drilled in woodland and agricultural areas and also in selected sites downgradient from these two predominant land uses in order to assess the impact of movement of nitrate in ground water from one area to another. Locations of the wells were selected without bias toward known or suspected problem areas, and all wells were constructed in the same way. The samples are being collected with consistent sampling methods. The scientists are also keeping a careful record of the predominant land use around (within a quarter-mile radius) and upgradient from the wells. Thirty-two wells, generally less than 30 feet in depth, were sampled from June through August 1988. Analysis of these samples indicate median nitrate concentrations of 0.1 mg/L in woodlands and 4.2 mg/L in agricultural areas. Again, median nitrate concentration in urban or built-up land was not assessed because only 2 of the 32 wells are in urbanized areas. Median nitrate concentrations are 0.1 mg/L in wells downgradient from woodlands and 3.7 mg/L in wells downgradient from agricultural areas. Again, these results are consistent with the expectation that nitrate concentrations in ground water are lower in woodlands.

Additional broad-scale and targeted samples from shallow ground water are being collected as part of the NAWQA project at more than 100 sites distributed among major physiographic, hydrogeologic, and land-use settings in the peninsula. By broadening the sampling sites, the USGS will gain further insight into methods for investigating relations between nitrate and other water-quality constituents and land use.

Ground-Water Quality in the United States—An Overview

Ground water is one of the most important natural resources of the United States. Degradation of ground-water quality is an issue of national concern because ground water is a major source for public water supply, for rural domestic use, for irrigation, and for self-supplied industrial use.

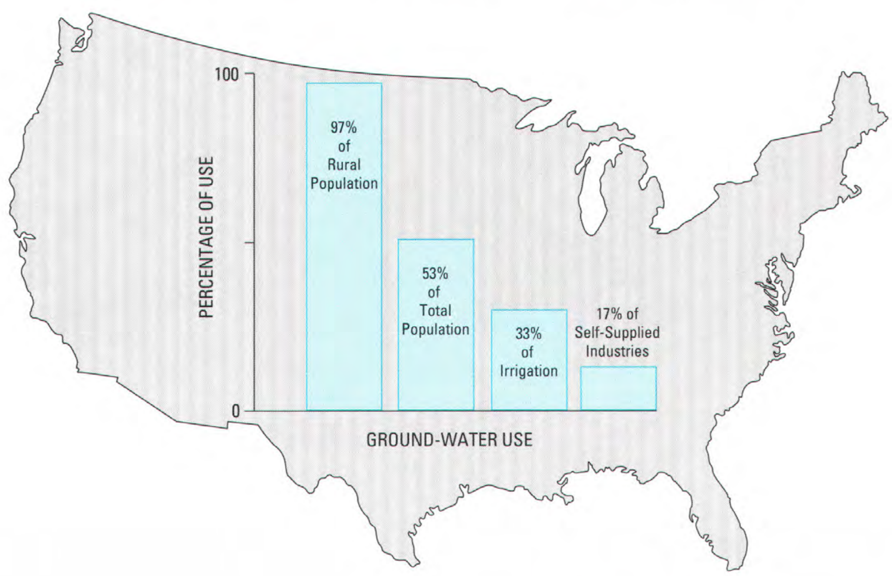
Information compiled by the USGS clearly shows that the United States has large amounts of potable ground water available for use. Even though the quality of most of the Nation's ground water is good, ground water in some locations contains one or more naturally occurring chemical constituents or properties that exceed Federal or State drinking-water standards or otherwise impair use, which include:

- Organisms, such as bacteria;
- Metals and other substances, such as arsenic, boron, nitrate, radium, radon, selenium, and uranium that are toxic to humans, livestock, or crops in relatively small concentrations; and
- Chloride, dissolved solids, fluoride, hardness, hydrogen sulfide, iron, manganese, and sulfate that are not necessarily toxic but that can impair the usefulness of the water for certain purposes.

Troublesome contamination of ground water falls into two basic categories related to the source or sources of the contamination. Point sources of pollution—such as waste-disposal sites, storage-tank leaks, and hazardous chemical spills—can cause high concentrations of a variety of toxic metals, organic chemicals, and petroleum products in ground water in localized areas. These types of local problems commonly occur in densely populated urban and industrialized areas. Contamination can also occur from nonpoint sources, such as agricultural activities or high-density domestic waste disposal (septic systems) in urban centers. Such contamination of ground water on a broad scale can enter shallow wells over large areas and can affect several counties.

A hydraulic connection also exists between surface- and ground-water resources. About 40 percent of the average annual streamflow in the United States is supplied by ground water, and during long dry periods, ground-water discharge provides nearly all of the base flow to streams. Therefore, if a persistent pollutant gets into an aquifer, that pollutant eventually could discharge into a stream.

At present, only a very small percentage of the total volume of potable ground water in the United States is contaminated from both point and nonpoint sources. USGS scientists caution, however, that available data about the occurrence of synthetic organic and toxic substances generally are inadequate to determine the full extent of ground-water contamination in the Nation's aquifers or to define trends in ground-water quality. To date, most information about the occurrence of these substances has come from the study



Percentage of ground-water use in the United States by major category (Alaska and Hawaii included in percentages).

of individual sites or areas where contamination has already been detected or suspected. Contamination in some areas may be more widespread than currently thought and there may be areas where contamination is present, but no studies have yet been conducted.

Furthermore, any assessment of the Nation's ground-water quality must be tempered by the fact that most water-quality descriptions largely are based on analyses of inorganic chemicals. Ground-water analyses of toxic constituents and synthetic organic chemicals are relatively scarce, but available data have led to the growing realization that these chemicals locally have contaminated shallow aquifers in many parts of the country. Also, existing data generally have been collected to monitor the quality of drinking-water supplies or to evaluate waste sites but not to provide an assessment of quality of ground-water resources where they occur.

Reports of contamination are likely to increase in the coming years as the search for contamination intensifies and as more sophisticated analytical techniques are used to detect trace amounts of toxic constituents and synthetic organic chemicals in water. The presence of organic or toxic chemicals in very small concentrations in ground water does not necessarily imply a health or environmental threat, but their presence does raise questions about the source of the chemicals and the possibility that concentrations might increase to toxic levels over time. It is on these issues that the USGS is concentrating much of its research in ground-water contamination.

Geologic Investigations

Mission

The basic mission of the Geologic Division is to evaluate the Nation's geologic structure and the geologic processes that have shaped it, to assess the Nation's mineral and energy resources, and to identify and investigate geologic hazards.

- Investigations of geologic hazards provide information for predicting and delineating hazards from earthquakes and volcanoes and for identifying engineering problems related to ground failure hazards.
- Regional geologic studies provide geologic maps and regional syntheses of detailed geologic data essential to mineral, energy, and hazard assessments.
- Offshore geologic studies identify and describe the mineral and petroleum resources of the offshore areas of the United States, including the Exclusive Economic Zone, an area one-third larger than the land area of the United States.
- Mineral resource investigations assess the distribution, quantity, and quality of the Nation's mineral resources, with particular emphasis on strategic and critical minerals.
- Surveys of energy resources provide assessments of the Nation's coal, petroleum, uranium, and geothermal resources and enhance capabilities to explore for and develop new sources of energy.

Highlights

Scenario for a Warmer World

By Richard Z. Poore

Human activities have resulted in significant increases of carbon dioxide and other radiatively active (greenhouse) trace gases in the Earth's atmosphere. Scientists agree that this increase in greenhouse gases will result in a global warming over the next few decades to centuries. Scientists are uncertain, however, about the magnitude of the global warming and how the effects of the warming, including changes in temperature, precipitation, winds, and ocean currents, will be distributed over the Earth's surface.

Determining the regional effects and impacts of future global warming represents major challenges to the scientific community. Anticipating the effects of climatic change is more than an intriguing scientific puzzle. Changing climate will affect the Nation's lands and waters and will cause, for example, substantial changes in agriculture and energy use. Thus, better understanding of future climatic change is important for policy makers at all governmental levels.

Studies of past climates, called paleoclimates, are one important approach that scientists can use to estimate how the Earth's environment will change with global warming. The Earth's climate is dynamic and has varied naturally through geologic time from conditions that were both significantly warmer and colder than modern conditions. Information on past climates and how climate changed in the past can provide valuable clues about how climatic change will occur in the near future and what the effect of that change will be on the Earth's environment and on life on Earth. The climate change program of the U.S. Geological Survey has started a major study of the Pliocene (a period between about 5.2 and 1.6 million years ago) as a "scenario for a time of greater warmth." The Pliocene Epoch was selected because it is the most recent interval for which we have evidence for climates that were substantially warmer than modern or near-modern climates.

The study of past intervals during which climates were substantially warmer than modern climates is useful in predicting the effects of global warming. In fact, recent studies of air bubbles trapped in ice cores from Antarctica document that atmospheric carbon dioxide has varied in the geologic past and that those variations correlate with major climate change. Thus, although the exact reasons for past climatic warmings and future global warming are not likely to be identical, past warm intervals may have been caused, in part, by a carbon dioxide greenhouse effect. Even without knowing the exact causes or forcing functions, the study of past warm intervals provides scenarios for greater warmth. These scenarios then can be used to test the ability of computer-generated general circulation models, to simulate the effects of global warming, and to provide an empirical data base to determine whether regional responses to warming are similar for all warm intervals regardless of the magnitude or cause of warming.

Reconstruction of past climatic conditions requires two basic types of data: environmental conditions and geologic age. Past environmental conditions are determined primarily through paleontologic and isotopic studies, which are methods for reconstructing past climates. Most plants and animals are sensitive to factors such as temperature and available moisture. Similarly, isotopic compositions of fossil shells and some mineral deposits are, in part, controlled by temperature and salinity conditions in which the shells or deposits were formed. Thus, mapping past distribution of fossil remains of plants and animals and analyzing isotopic composition of fossil shells and mineral deposits can be used to delineate past climatic conditions. Other studies, including geochemistry of sediments and sedimentary structures, are also useful for delineating past climatic conditions. In addition to information on past environmental conditions, one needs to know the geologic age that the fossils or deposits represent in order to construct a history of climate change or to reconstruct a discrete time interval. A wide variety of techniques, including biochronology, isotope stratigraphy, radiometric dating, paleomagnetism, and tephrochronology, are used to date materials that are used in climatic studies.

The major objective of the USGS effort is to construct a map summarizing climatic conditions during one or more warm intervals within the Pliocene. An example of this type of mapping, as shown in figure 1, contrasts distribution of assemblages of ostracodes in modern and Pliocene age marine sediments along the continental margin of the Eastern United States. Ostracodes are Crustacea that are very sensitive to environmental conditions such as temperature. The figure shows that, during the Pliocene, ostracode assemblages representing tropical, subtropical, and mild temperate climatic zones shifted northward along the eastern seaboard reflecting the increased temperature of waters along the coast. Sea level was also higher during the Pliocene because the total amount of water stored in continental glaciers was reduced, reflecting higher mean global temperature. The exact amount of sea-level rise cannot, however, be directly determined from figure 1 because the position of the Pliocene shoreline has been modified by local movements of the Earth's surface since Pliocene time.

In addition to including intervals when global climate was warm, the Pliocene is attractive for study because Pliocene flora and fauna are very similar to

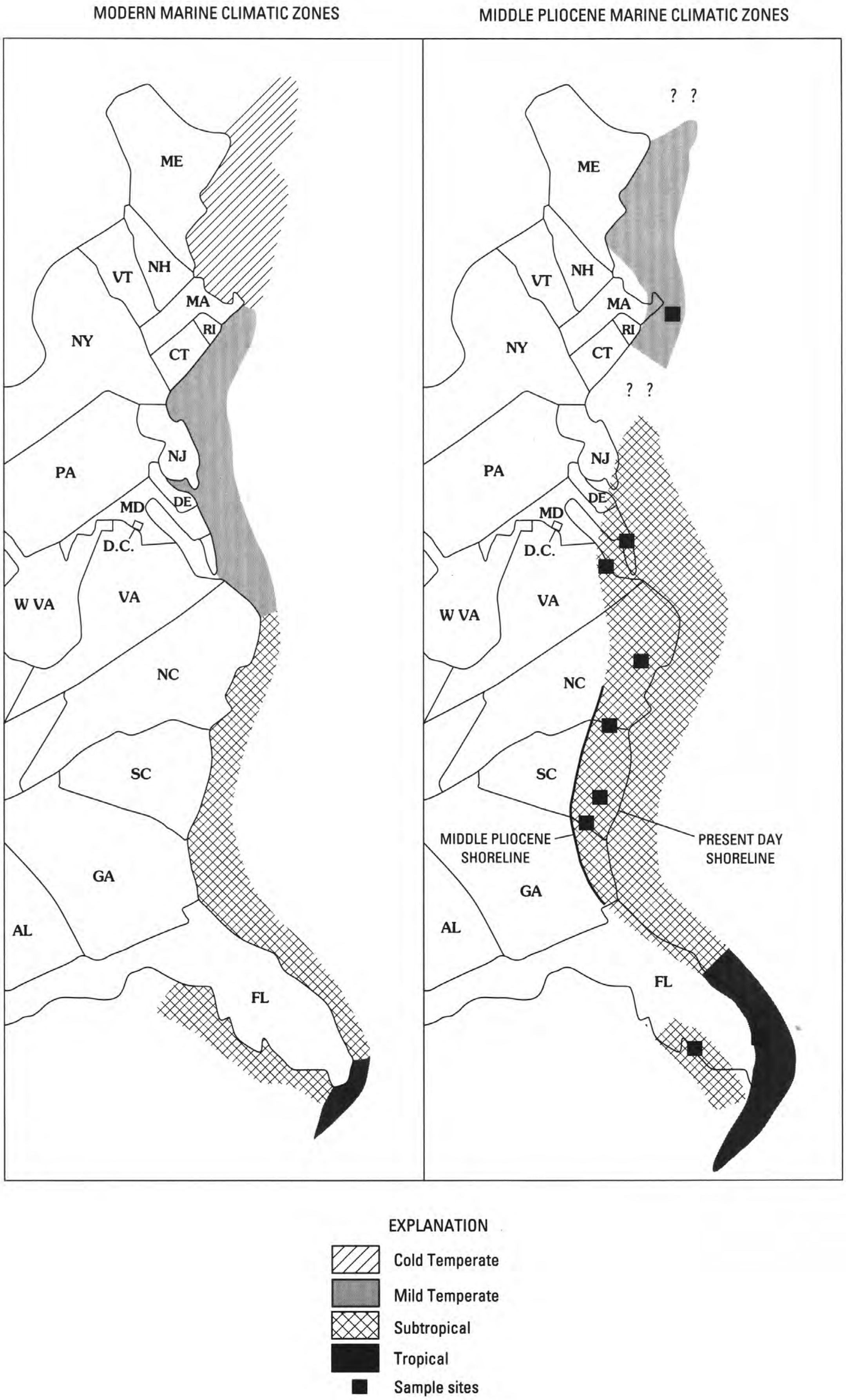


Figure 1. Distribution of temperature-dependent ostracode assemblages in modern (left) and Pliocene age (right) marine sediments along the continental margin of the Eastern United States. Note the subtropical climate zone in the middle Pliocene that extends as far as the New Jersey-New York border, the mild temperate climate zone in New England, and the absence of a cold temperate zone.

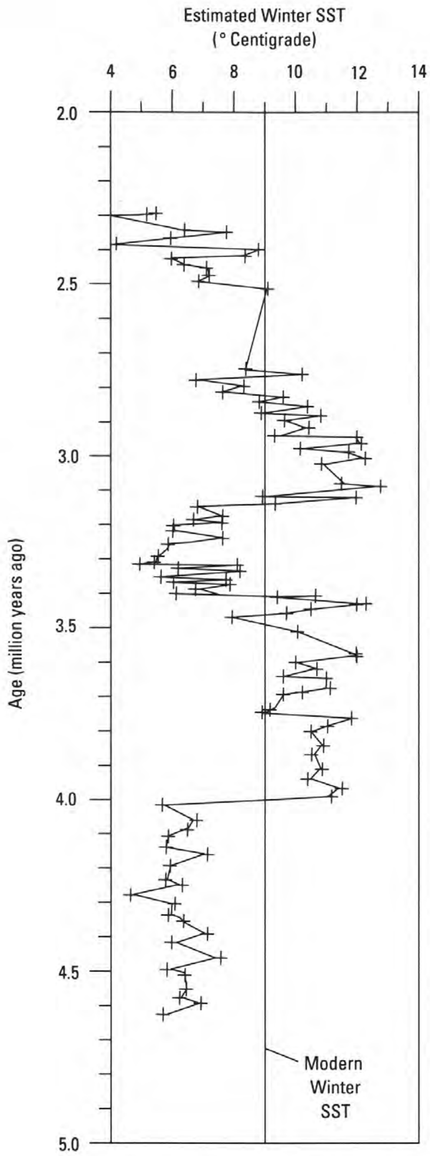


Figure 2. Winter (February) sea-surface temperature (SST) during the Pliocene and modern times.

modern flora and fauna; Pliocene records are widespread and easily accessible in both continental and marine settings, and most Pliocene records are relatively well preserved. All these features make it easier to quantify environmental information and to develop regional and even global patterns of past climatic data.

Estimated winter sea-surface temperature (SST) in the North Atlantic Ocean during part of the Pliocene, as shown in figure 2, is an example of how paleontological studies can help to quantify conditions of past climates. The temperature estimates are based on analysis of the relative abundances of microfossils found in sediments from a deep-sea core. Knowledge of the modern distribution of the same or similar microfossils is used to translate variations in the abundances of microfossil taxa in the core into estimates of Pliocene surface-water temperatures. Figure 2 shows that sea-surface temperatures were both warmer and cooler than modern conditions during the interval between 4.6 and 2.3 million years ago. In some cases the SST's were more than 3 °C above modern. Several intervals of higher SST identified on figure 2, such as the interval centered around 3.0 million years ago, are being evaluated as candidates for a global climate reconstruction representing a scenario for greater warmth. Such glimpses into the past may well give scientists an excellent view into the future of global warming—its extent and its effects—on the Earth's environment.

The USGS study of Pliocene climates is an international effort. The study includes formal cooperation with Soviet scientists as part of a U.S.-U.S.S.R. Bilateral Agreement on Environmental Protection. In addition climatic researchers from a variety of institutes in the United States, Japan, the United Kingdom, and Canada are collaborating with USGS scientists on one or more parts of the Pliocene study.

Dating Rocks and Minerals Using Lasers and Nuclear Reactors

By G. Brent Dalrymple

During the past decade, a variety of microanalytical techniques have been developed and applied to a broad spectrum of geological problems. None has proved more dramatic and revolutionary, however, than the application of a combination of lasers and nuclear reactors to the more precise measurement of geologic time by using the decay of naturally occurring potassium (^{40}K), which has a half life of 1.25 billion years, to the inert gas argon (^{40}Ar).

The use of nuclear reactors for measuring geologic time is not new. It was introduced in the mid-1960's as a variation of conventional potassium-argon (K-Ar) dating and is known as the ^{40}Ar-^{39}Ar method. Potassium is found in most rock-forming minerals. The half-life of its radioactive isotope, ^{40}K, is such that measurable quantities of argon, the stable "daughter" product, have accumulated in potassium-bearing minerals of nearly all ages. Because of this prevalence across geologic time, the amounts of potassium and argon isotopes can be measured accurately.

In the conventional method, adopted in the 1950's, the potassium and argon are measured quantitatively in separate procedures. The argon is measured by isotope dilution by using an inert-gas mass spectrometer. The potassium is measured by one of several standard chemical techniques, usually flame photometry. These separately acquired K and Ar data are then mathematically expressed in an equation that relates radioactive decay to geologic time. This method of dating has broader applicability than any other dating method. It has been and continues to be used to date samples of igneous, metamorphic, and even some sedimentary rocks—as old as 4.5 billion years (the age of Earth) and as young as a few thousand years—but the methods are time consuming and typically require a sample of a gram or more in weight.

The ^{40}Ar-^{39}Ar method has some significantly advantageous features. . . .

In the newer ^{40}Ar-^{39}Ar method of K-Ar dating, the sample is irradiated with fast neutrons in the core of a nuclear research reactor, such as the Training Research Isotope General Atomic reactor (TRIGA) used by the USGS in Denver, Colo. The neutrons convert a fraction of an isotope of potassium (^{39}K) to an isotope of argon (^{39}Ar). After irradiation, the argon is extracted by melting the sample with induction heating or a resistance furnace in an ultra-high vacuum and analyzed, as in the conventional technique, by using a mass spectrometer. Because the ratio of ^{39}K to ^{40}K is constant in all natural materials, the ^{39}Ar made from ^{39}K can be used as a "proxy" for the ^{40}K, and the age can be calculated directly from the $^{40}Ar/^{39}Ar$ ratio; a separate potassium measurement is unnecessary.

The ^{40}Ar-^{39}Ar method has some significantly advantageous features over the conventional method of K-Ar dating. First, it is more precise because the $^{40}Ar/^{39}Ar$ ratio can be measured more precisely than the conventional $^{40}Ar/^{40}K$ ratio, which involves the quantitative measurement of isotopes of different elements. Second, smaller samples are required, usually a few tens to a few hundreds of milligrams. Third, the newer method is considerably faster and requires only an hour or two once the samples have been irradiated in the reactor. Finally, the argon can be released from the sample in increments at successive temperatures, in what is called an incremental heating experiment. This results in a series of ages known as an age spectrum, which contains useful information about the original age and thermal history of the sample. The incremental heating method is especially useful for samples that have been thermally or chemically disturbed since they first formed because it reveals that the sample has been disturbed and often allows recovery of the crystallization age despite the disturbance.

The joining of a continuous, high-powered laser with a very sensitive mass spectrometer has resulted in substantial and important improvements in the ^{40}Ar-^{39}Ar dating method. The USGS is the third group in the world to develop a continuous laser system (fig. 3). The first such system was developed by the University of Toronto; the second system was developed by Princeton University.

The continuous laser system has several advantages compared to other methods of ^{40}Ar-^{39}Ar dating. The most significant advantage is the ability to determine the age of a single crystal—as small as 0.000001 grams for older material. This not only saves considerable effort in mineral separation but also permits dating of rare materials and of rock units that may contain contaminating crystals from older units. A second advantage is speed. Because the samples are small, the heating and cleanup times are short, and a complete age analysis typically takes only about 15 to 20 minutes. A third advantage is that the analyzing system

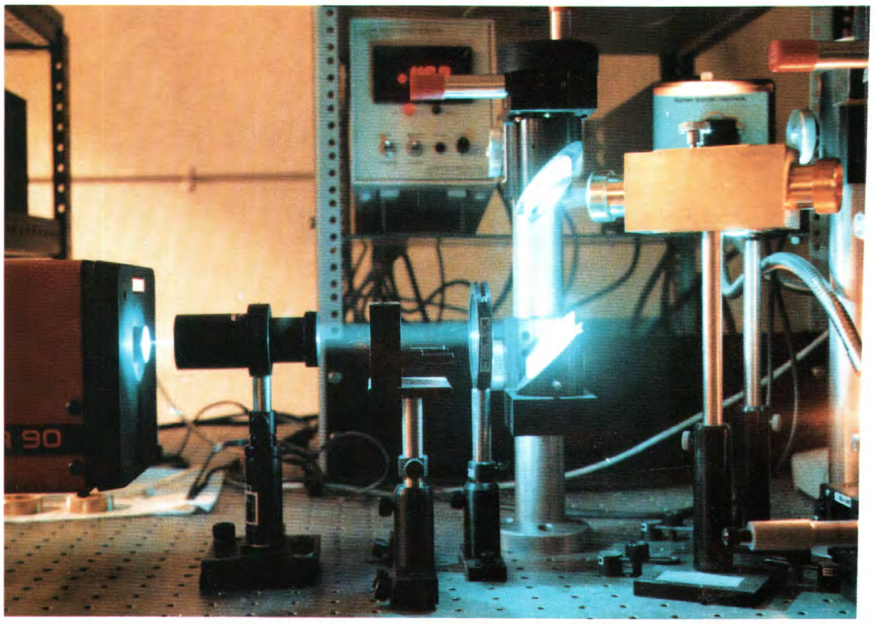


Figure 3. Laser microprobe system used in ^{40}Ar-^{39}Ar method of K-Ar dating of rocks and minerals. The laser is a 5-watt continuous argon-ion laser. The laser beam is focused by lenses and directed by mirrors through the glass window of a small, ultra-high vacuum sample chamber where it is used to heat and melt single mineral grains. The argon released by the heating is exposed to the metal-alloy gutters of the cleanup system, which remove the reactive gases. The purified argon is then admitted to the ultra-sensitive, ultra-clean mass spectrometer, and the isotopic ratios—from which the age is calculated—are measured. The laser-fusion process is monitored by a closed circuit television camera mounted on a microscope. A microscopic infrared radiometer, not shown in the photograph, is used to measure the temperature of the sample during laser heating and thus permits incremental heating experiments to be done on the single crystals. (Photograph by G. Brent Dalrymple.)

contributes less atmospheric argon (a contaminant in the experiment), and the low level of this contaminant results in very precise age determinations. Some typical single-crystal results from the USGS continuous laser system are shown in table 1.

A final advantage of the continuous laser system is that it is easily automated. In the USGS system, grain selection, laser operation, temperature measurement, valve operation, and video recording can all be controlled by the computer. This automation greatly increases the productivity of the system because

TABLE 1. $^{40}Ar/^{39}Ar$ age results on single crystals of potassium feldspar handpicked from a volcanic unit in the Medicine Lodge Basin, western Montana

Crystal weight (grams)	Calculated age (million years)
0.00089	45.99 ± 0.27
.00083	46.03 ± .28
.00073	46.04 ± .27
.00056	46.19 ± .37

the instrument can make measurements unattended overnight as well as during regular working hours.

The continuous laser ^{40}Ar-^{39}Ar dating system is being used to address a variety of interesting and important problems that could not be as accurately addressed with previous equipment and methods. Among these are the timing of mineralization associated with ore deposits, the age of volcanic units associated with key faunal assemblages, and coal deposits—all of which can be used in mineral assessments and exploration for economic deposits. The ages of seamounts and other volcanic features in the Pacific can also be determined, which provides essential keys to the history of this ocean basin.

Loss of Coastal Wetlands in Louisiana—A Cooperative Research Program to Fill in the Information Gaps

By S. Jeffress Williams and Asbury H. Sallenger, Jr.

Introduction

Once considered mostly worthless real estate in their natural state, wetlands around the country have long been subjected to draining and filling for additional farmland and for urban expansion. Wetlands also have been used as convenient repositories for waste and trash disposal. In the past two decades, however, people have come to realize that, in fact, wetlands of all varieties are immensely important to both the environmental and the economic health of the Nation.

Wetlands are important as habitats for large and varied populations of aquatic and terrestrial wildlife. They reduce the effects of flooding on developed areas, recharge ground-water resources, and serve as natural filters for reducing pollutants carried in ground water as well as rivers. In addition, wetlands support a wide array of recreational activities and function as spawning areas and nurseries for the majority of commercial and recreational fisheries, as well as supporting other important industries.

The natural processes of wetlands degradation as well as wetlands destruction and alteration by public agencies and individuals have resulted in the loss of more than 50 percent of the wetlands that existed in the contiguous United States at the start of European settlement. These wetlands losses are continuing, and nowhere is the problem greater than in the Mississippi River delta plain of Louisiana.

Louisiana accounts for an estimated 25 percent of the vegetated wetlands and 40 percent of the tidal wetlands in the 48 conterminous States. Currently, it is undergoing the greatest amount of wetlands loss and deterioration of any State in the Nation. An estimated 80 percent of the Nation's wetlands loss has occurred in Louisiana, and by current estimates, 40 to 60 square miles are lost each year. These losses are the result of a combination of physical erosion by waves and currents as well as conversion from marsh to open water by disintegration of the marshlands and submergence. The U.S. Army Corps of Engineers has predicted that if these rates of loss continue, nearly one million additional acres of valuable wetlands in Louisiana will be lost in the next 50 years.

The widespread loss and deterioration of wetlands in coastal Louisiana is due to a combination of natural long-term geologic processes and manmade effects on the Mississippi River and delta-plain region.

The Louisiana Delta Plain

The physical processes that cause coastal erosion and wetlands deterioration are complex, highly varied, and are still not particularly well defined or understood. The rates and magnitudes of future land loss, therefore, are not predictable with any high degree of confidence. Also, much debate still exists in the technical and scientific community about which of the natural and human-induced causes are most destructive. The natural causes range from hurricane and winter-storm effects to worldwide changes in sea level. Human-induced causes include dredging of navigation channels and subsidence from ground-water withdrawal.

The geologic record of the coastline and continental shelf of Louisiana shows clearly that over the past 6,000 to 8,000 years, large shifts in the course of the Mississippi River have occurred at about 1,000-year intervals. Such changes in the river's channel have been responsible for repeated cycles. These cycles are followed by rapid sediment compaction, subsidence, and massive erosion and wetlands deterioration as the river abandoned old channels and created new deltas.

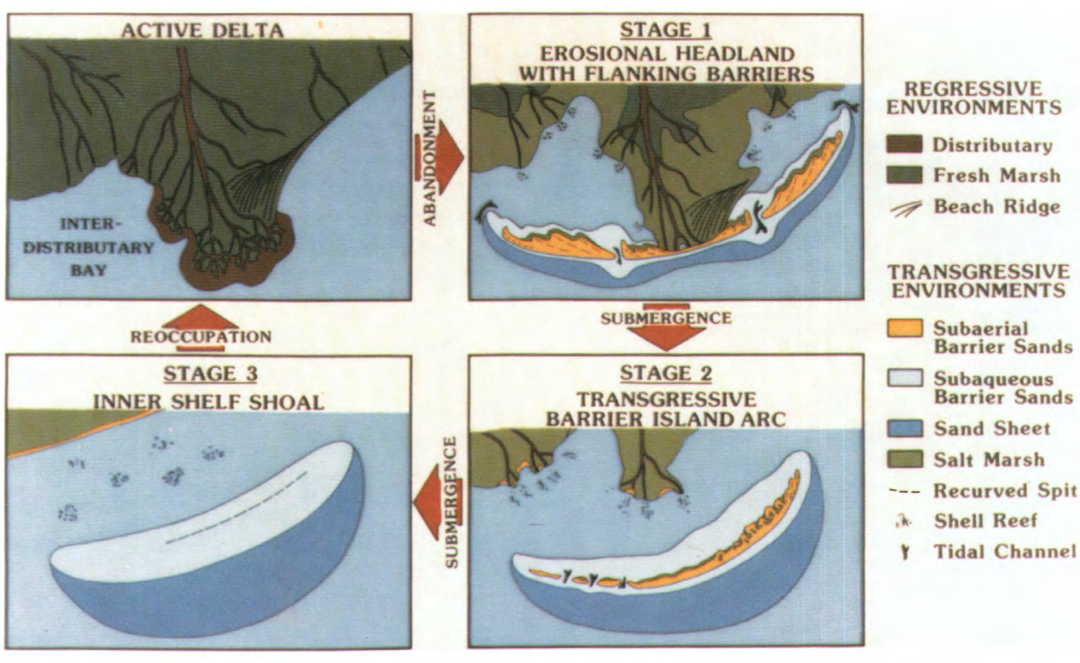
Because of these cyclic changes in the delta, sandy barrier islands form at the seaward ends of the delta plain. These barriers provide a buffer from ocean waves and currents and direct storm effects for the wetlands estuaries behind the barriers. With continued subsidence and a lack of coastal sediment, however, the barriers undergo rapid erosion, at rates up to 60 feet per year, and are broken into smaller, less protective segments when tidal inlets open during storms. Eventually, the coastal barriers are unable to maintain their geometry and become submerged sand bodies. Many examples of these former barriers can be seen as buried features on the Louisiana continental shelf.

The Effects of Human Activities

In addition to the natural geologic processes that cause coastal erosion and wetlands loss, human activities during the past century and, especially, in the past 50 years have had dramatic effects. Since

Oblique photograph of the Louisiana coast and wetlands showing the effects of natural processes and the impacts of human activities. (Photograph by S. Jeffress Williams.)

CYCLE OF COASTAL EROSION AND WETLANDS DETERIORATION



The origin and evolutionary history of the Louisiana delta plain region have been tied in the recent geologic past to shifts of the Mississippi River channel at 1,000-year intervals. Once the active delta is cut off from the source of river sediment, a cycle of coastal erosion and wetlands deterioration proceeds through the three-stage process shown. (Modified from Penland and others, 1988, Relative sea-level rise and delta-plain development in the Terrebonne Parish Region: Louisiana Geological Survey, Coastal Geology Technical Reports, no. 4, fig. 7, p. 10.)

the 1930's, dam building on the Mississippi River and most of its tributaries has, for example, reduced the volume of sediment being transported by the river and, therefore, available to the wetlands. The massive levees that channel the flow of the Mississippi River to enhance navigation and reduce flood potential have negative effects on the downstream wetlands. Floods that once provided sediments to build the wetlands no longer occur. The limited sediment that is carried by the river is now discharged far out on the continental shelf, rather than being distributed along the coast as it was before the levees were built. Deposition of silt and clay from river-borne sediments is necessary in the wetlands in order to counterbalance natural compaction and subsidence that occurs if the wetlands are not nourished and replenished by these sediments.

Additional activities that cause wetlands loss are an extensive system of canals and waterways that serve as pipeline paths, access for hydrocarbon exploration and production, and waterways for boat traffic. Not only do dredging and maintaining these canals impact the wetlands, but many of them that open to the Gulf of Mexico enable saltwater to intrude brackish and freshwater wetlands, which accelerates their deterioration. Other causes that are suspected to be important, but not well documented as yet, involve subsidence that is associated with the extraction of hard minerals and fluids in the shallow subsurface. For example, sulfur mining over salt domes has resulted in localized subsidence of tens of feet in just several decades. Forced drainage, where marsh areas are diked and large pumps are used to draw down the ground water, is a widespread practice for agriculture and development that seems to contribute to soil compaction and subsidence.

Role of USGS

Because significant gaps still exist in the information available on the processes of wetlands formation and loss, continued research is needed. Various measures and recommendations have been proposed to mitigate the natural and man-made causes. Considerable controversy exists, however, over some of the measures such as marsh management, river diversions, and barrier island restoration for mitigation and wetlands restoration. Much of the debate has to do with uncertainties in predicting the long-term success of these measures, all of which require large expenditures of time and money to design, construct, and then maintain.

The USGS is conducting research to provide the basic information needed to gain an improved understanding of the geologic processes causing coastal erosion and deterioration of wetlands environments. The USGS has two ongoing studies in Louisiana that focus on coastal erosion and wetlands loss. A cooperative effort with the Louisiana Geological Survey over the past four years has demonstrated the important role that the coastal barrier islands play in providing natural protection to bays, estuaries, and wetlands from ocean waves and surge flooding and from saltwater intrusion accompanying storms. A second study, which was started in late 1988 in cooperation with the U.S. Fish and Wildlife Service and Louisiana State agencies, is the Louisiana Wetlands Loss Study. This 5-year investigation is designed to assess the regional extent of wetlands loss and to provide the information base needed to better define the critical physical processes affecting wetlands environments.

These wetlands studies are being carried out through field research by USGS scientists and through contracts and cooperative agreements with scientists at Louisiana State University, the Louisiana Geological Survey, and private consultants. To fill the information gaps, the current USGS study is focused on:

- Mapping and interpreting the physical changes that have taken place along the Louisiana barrier coast and in the wetlands over the past several thousand years and particularly during the past 100 years.
- Developing a comprehensive coastal data base and using these data in a network of computer-based geographic information systems available in Federal, State, and local agencies and private companies.
- Comparing the sediment-deficient Terrebonne basin in the Louisiana delta plain with the sediment-rich Atchafalaya basin. These comparative investigations will focus on sediment compaction, sea-level rise, and land subsidence; effects of meteorological events such as hurricanes; dispersal of fine-grained sediments; movement of fresh- and saline water; processes of physical erosion; and conditions required for soils to develop in wetlands.
- Assessing the potential effectiveness of small-scale freshwater diversions from the Mississippi River as a mitigation measure for wetlands deterioration.

All of these studies will provide significant information on coastal wetlands and will enhance information that is currently incomplete, unavailable, or uncertain. Filling these information gaps is a significant step towards the President's stated goal of no net loss of wetlands. In turn, this information, which is provided to the technical community as well as Federal, State, and local coastal zone managers, can then be used to better manage our coastal resources and protect and preserve valuable wetlands.

Assessing Pollutant Transport and Accumulation in the Coastal Ocean—A Pilot Study in Boston Harbor and Massachusetts Bay

By Michael H. Bothner and Bradford Butman

The major objective of a multidisciplinary study of Boston Harbor and Massachusetts Bay is to provide a regional basinwide perspective of sediment and contaminant transport. The Boston area was selected for a pilot study because the U.S. Environmental Protection Agency (EPA) has designated the harbor as one of the most contaminated in the United States, because a comprehensive plan to cleanup the harbor is presently being implemented, and because the geometry, topography and sediment distribution provide a variety of sedimentary environments for study. The $6 billion cleanup effort, to be completed by the year 2000, includes the elimination of ocean discharge of sewage sludge, upgrading sewage treatment from primary to secondary (allowing for partial detoxification of the sludge), and the construction of a new ocean outfall approximately 8 miles seaward of the harbor mouth.

To assist in this cleanup effort, a clear need exists for basic scientific information that the USGS can provide concerning sediment distributions and pollutant transport processes in this coastal environment to aid in management and engineering decisions. This need exists in many coastal areas adjacent to major population centers where wastes are often discharged into the ocean, which is also used for recreation, fishing, and transportation.

The USGS study to address contaminant transport in Boston Harbor and Massachusetts Bay, called P-TRACE (Pollutant Transport and Accumulation in Coastal Embayments), uses the tools and disciplines of marine geology to map the distribution of sediment types, determine the present levels of chemical contaminants in the sediments, monitor water currents and sediment transport events, measure physical characteristics of bottom sediments, and estimate rates of sediment accumulation and mixing. The focus on sediments capitalizes on the fact that sediments in the aquatic environment have chemically active surfaces that adsorb a wide variety of dissolved pollutants. A quantitative understanding of sediment distributions and transport mechanisms contributes to the ability to predict the fate and effects of these pollutants. Knowing the location and areal extent of the different sediment types, bedrock outcrops, and bedforms generated by the action of ocean currents is also vital in designing an effective monitoring program. Such a monitoring program is necessary to assess the environmental impacts of ocean outfalls and is critical for selecting the locations for the instruments from which long-term current and sediment-transport measurements can be made.

A first stage in the pilot study was to conduct geophysical surveys of Boston Harbor and selected regions in Massachusetts Bay. Information from these surveys typically include sidescan-sonar, high-resolution seismic-reflection, and bathymetric data. The preliminary maps that have been generated from these data show the morphology and texture of the sea floor as well as the thickness of the sediments. Inferred areas of erosion and of sediment-pollutant accumulation have been identified that will aid significantly in the design of subsequent topical studies.

Currents and sediments that had been resuspended were measured in three locations in western Massachusetts Bay (depth range 72–216 feet) during the winter and spring of 1987. The near-bottom observations were made by means of an instrumented tripod (fig. 4). Currents, light transmission, and temperature were also measured at middepth and near the sea surface using moorings next to the tripods. Sediment traps were used to collect material suspended in the water column.

The mean current flow at station A was toward shore at all levels of the water column (fig. 5). This onshore flow suggests local recirculation in the region south of Nahant and that discharge of treated effluent in this location would be unwise because it would be transported toward the shore. The near-bottom observations showed resuspension of the surficial sediments during winter storms. The most severe storms resuspended sediments at each of the mooring locations, but the storms of less intensity resuspended material at only the two shallower sites (A and B, fig. 5). These data suggest that accumulation of fine-grained sediment may occur during the summer months when storms are infrequent but that the same sediments may then be resuspended and transported toward deeper water or protected inshore areas during winter storms.

The 1987 current measurements coincided with the largest April discharge on record from the Merrimack River, located just north of the study area. Sea-surface temperature maps obtained from satellite observations were examined to aid in the interpretation of the current measurements; the images showed a large surface plume extending southward from the Merrimack River and into Massachusetts Bay. A strong northwestward flow was observed that was associated with the western edge of the plume (fig. 6). These observations show the important influence of nonlocal forcing mechanisms, such as freshwater inflow from inland rivers, on circulation and sediment transport in Massachusetts Bay. These observations emphasize the need for expanding these studies to gain a broader regional perspective on what those mechanisms are and what their effects might be. Long-term synoptic observations are also essential to document and evaluate the importance of infrequent or catastrophic events, such as floods or strong storms, on sediment transport and coastal circulation.

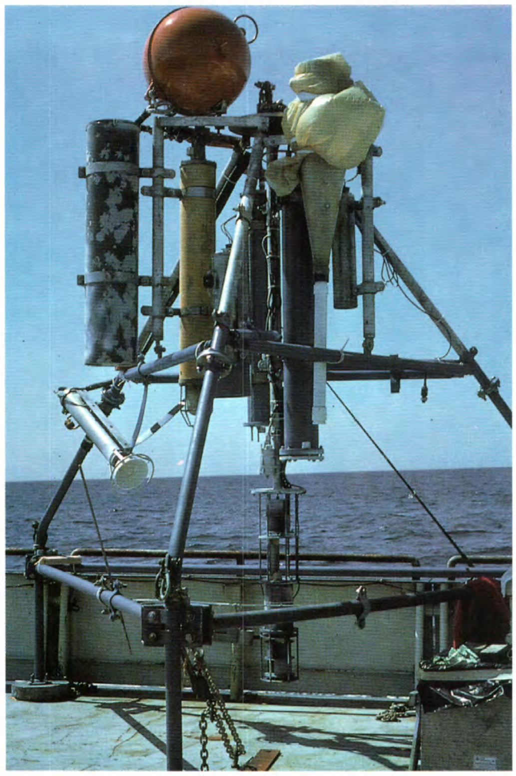
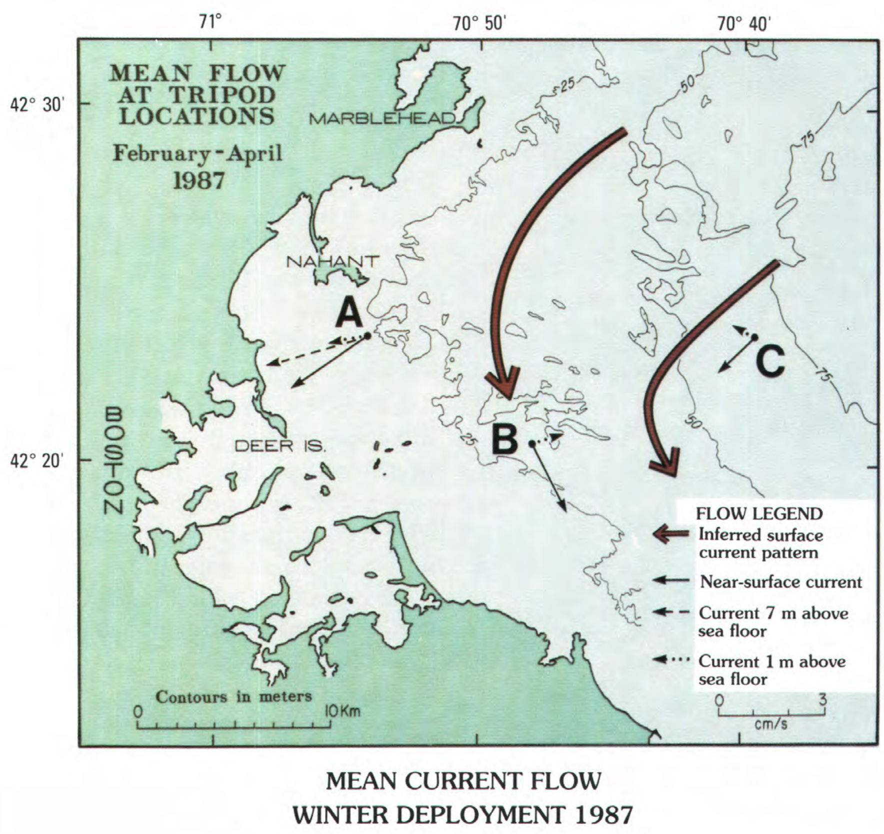


Figure 4. USGS bottom tripod system for long-term studies of currents and sediment transport. The instrument measures current, temperature, light transmission, and pressure, and it also photographs the sea bottom at selected intervals. Sediment traps obtain samples of sediment suspended in the water column. (Photograph by Bradford Butman.)

Figure 5. Western area of Massachusetts Bay showing mean flow at three locations (A, B, and C) measured during the winter and spring of 1987. Although weak, the observations are consistent with a mean shore-parallel flow near the surface and a weak net flow near the bottom. Note the onshore flow observed at station A south of Nahant at all instrument depths.



MEAN CURRENT FLOW
WINTER DEPLOYMENT 1987

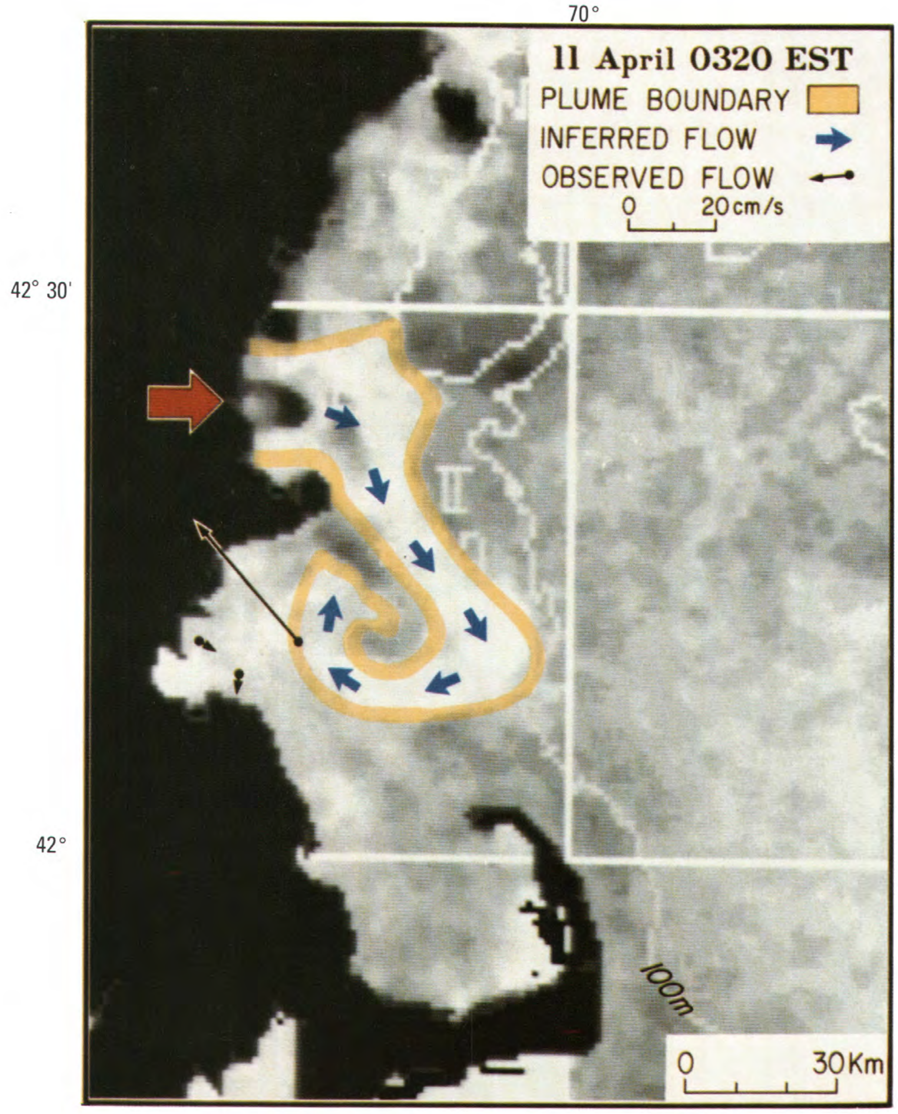


Figure 6. Sea-surface temperature derived from satellite observations showing plume of warmer water extending southward into Massachusetts Bay from the Merrimack River. Blue arrows show inferred flow; black arrows show near-surface flow measured by current meters at stations A, B and C. Note the strong northwestward flow associated with the western side of the river plume. Red arrow indicates the mouth of the Merrimack River. (Courtesy of University of Rhode Island.)

The geochemical and geotechnical studies within the cooperative program typically examine sediment characteristics that have developed over a time frame of years to centuries. Heavy metals (chromium, copper, lead, zinc, and so on) are found in significantly higher concentrations in surface sediments of the harbor in comparison with those in sediments deposited before the industrial revolution. The critical question to address is whether or not these contaminated sediments will remain as a long-term source of pollution after the principal sources are reduced or eliminated. Measurements of geotechnical properties are used to characterize the sediments at different locations to determine their suitability for use as fill material and as foundations for structures.

A number of radioactive isotopes have been analyzed in this study in order to determine the rates of sediment accumulation, the rates of sediment mixing (bioturbation), and the potential for pollutant accumulation. Lead-210, a sediment reactive isotope that behaves like many contaminants in the marine environment, can be used as a contaminant tracer. Measurements of lead-210 concentrations in a number of cores taken from undisturbed sediments from Boston Harbor and Massachusetts Bay show excess lead-210, between 0.6 and 2.3 times the amount predicted from atmospheric and seawater sources. In areas where increased accumulation of lead-210 has occurred, increased accumulation of other contaminants would be expected. Other isotopes such as carbon-14, thorium-234, and plutonium contribute to our understanding of where sediments are actively accumulating. Areas identified to look at sediment accumulations include Stellwagen basin offshore and protected areas of the harbor inshore. These areas of accumulation will be monitored to evaluate the long-term environmental effects of the new ocean outfall.

The critical question to address is whether or not these contaminated sediments will remain as a long-term source of pollution . . . .

A detailed sidescan-sonar survey over 31 square miles in Massachusetts Bay was conducted in April 1989 on the *RV Anderson*, a research vessel provided by the EPA. The sidescan imagery showed a complex pattern of sediment texture and roughness. A preliminary map, drawn at sea as the sidescan data were generated, outlined zones based on different acoustic signatures. Each zone was interpreted as representing different sediment types: areas of coarse gravel and (or) boulders, rippled sand, and smooth, fine-grained sediment. These interpretations were confirmed by photographing and sampling target locations identified aboard ship.

The preliminary map has been of use to State officials who are charged with deciding the location of the outfall for Boston's treated sewage effluent. An unexpected discovery made during the sidescan-sonar mapping operation was the existence of a previously uncharted shipwreck, approximately 100 feet long, at the edge of the survey area. A digital mosaic of the sidescan sonar data is currently being developed; once completed the digital data can be merged with other data sets, such as texture, bathymetry, or biological habitats, to provide a concise description of the sea floor.

The USGS study in coastal Massachusetts is closely coordinated with other agencies and research organizations through the Massachusetts Bay's Management Committee. USGS participates on this committee along with representatives from each of the Federal and State agencies that has an interest in the coastal environment of Massachusetts. The committee, which is spending $1.6 million for a carefully coordinated research program through 1991, has applied to EPA to include Massachusetts Bay/Cape Cod Bay into the National Bays Program.

The USGS has just concluded a Cooperative Agreement with the Massachusetts Water Resources Authority (MWRA), the independent State agency that provides water and sewer service to the Boston Metropolitan area, to establish a long-term current and sediment-transport monitoring station in western Massachusetts Bay near the proposed site of the new ocean outfall. This station will provide the first long-term measurements in Massachusetts Bay, and the observations will be used to assess the importance of seasonal variability and infrequent catastrophic events on sediment transport. New conditional sampling instrumentation will be developed to collect samples of suspended material at the height of major storms. This new equipment will improve estimates of the concentration and composition of suspended matter during storms when resuspension and transport of bottom sediments (and any associated contaminants) may be most significant and when sampling from a surface ship is impossible.

Analyzing Nevada's Undiscovered Resources

By Donald A. Singer and Robert C. Jachens

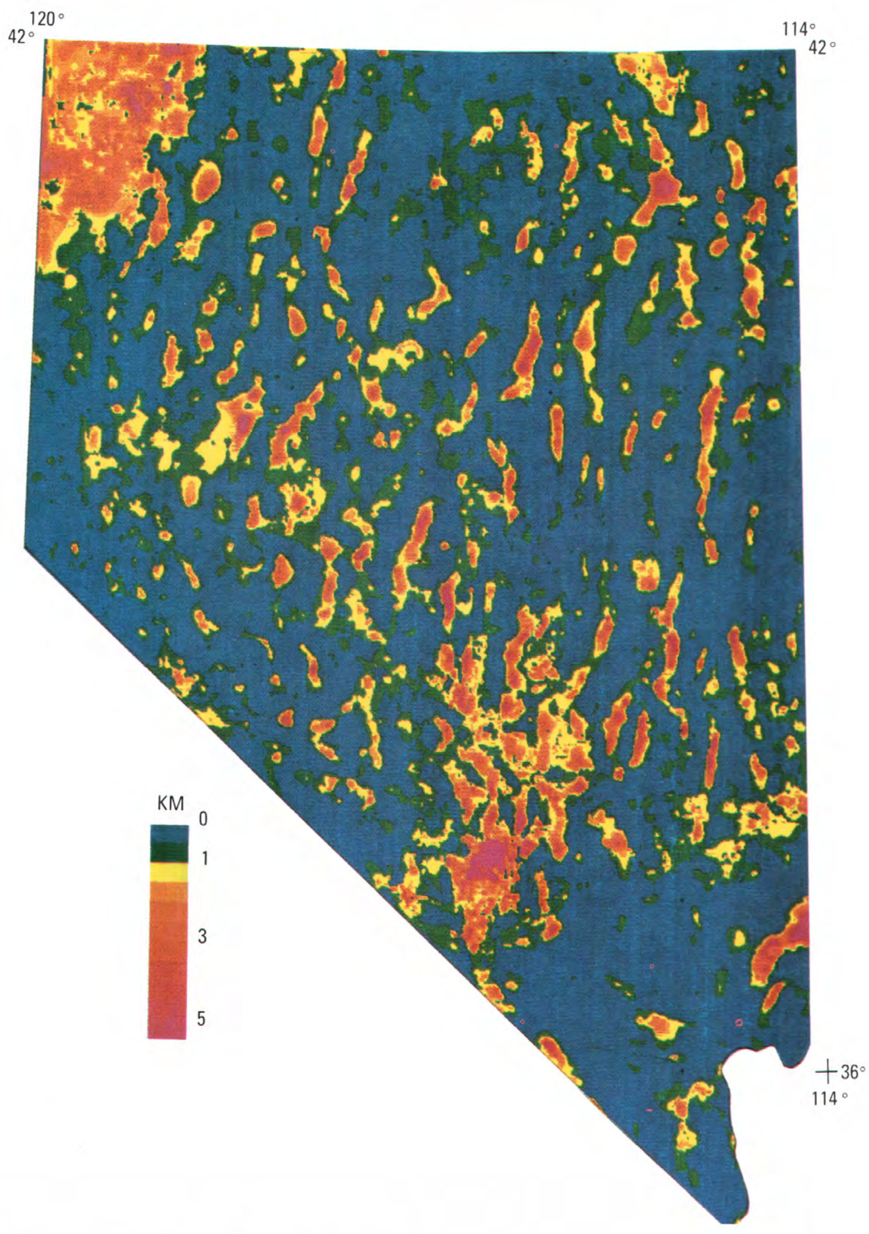
Nevada was the Nation's largest silver producer 120 years ago. Today, in spite of the fact that over 50 percent of Nevada's 110,500-square-mile surface is covered with what appears to be barren rocks and gravels, the State is the largest gold producer. Because the majority of metal-bearing mineral deposits exposed at the surface are believed to have already been found, a prime concern of a joint project of the USGS and Nevada Bureau of Mines and Geology has been to disclose the nature of and the depth to possible mineral deposits under this apparently barren cover.

The overall goal of the team of geologists, geophysicists, and geochemists is to provide an analysis of Nevada's mineral resources that can be used to help plan economic development, consider alternate uses of land, plan exploration, and estimate the availability of minerals under different conditions. Because of the extent to which potential mineral resources are covered, an important condition affecting the value of minerals in Nevada is the depth at which the deposits are located. Depth affects the chances of discovery, because deeper deposits are much more difficult and, therefore, more costly to discover; depth affects economic potential, because deeper deposits are significantly more costly to mine. The cooperative analysis currently underway is limited to the deposits and their permissive geologic environments that occur within the upper 1 kilometer (0.6 mile) of the Earth's crust.

A three-part resource assessment process is used because of its ability to respond to each of the diverse problems mentioned above and to use a variety of information and resource assessment methods. In this three-part assessment process (1) areas are delineated according to the types of deposits their geology will permit; (2) grade-tonnage models are used to estimate the amount of metal and some characteristics of ore; and, (3) estimates are made of the number of deposits of each type in the delineated areas.

Areas or domains are delineated that may contain particular deposit types as inferred by analogy with deposits in similar geologic settings elsewhere. In order to construct the boundaries of these areas, it is necessary to have a geologic map, and it is desirable to have accompanying mineral occurrence, geophysical, exploration, and geochemical information. This information must be integrated with information about the geologic environment of different types of mineral deposits to delineate the area. The keystone to combining all of this diverse information is the use of a mineral deposit model. The USGS has published such deposit models (USGS Bulletin 1693), which allow linkage of deposit types to geologic environments.

Figure 7. Thickness of Cenozoic cover, in kilometers, based on an analysis of regional gravity data in Nevada.



In order to make the connection of deposit type to geologic environment, it is necessary to recognize and map the relevant geologic settings in Nevada. This task is the primary purpose of producing maps that address geology, gravity field, magnetic field, pre-Tertiary geology (older than 63 million years), Tertiary geology (63 million to 2 million years old), ages of young volcanic deposits, intrusive rocks, neotectonics, known mineral deposits, and mineral resources. Each of the maps is being prepared in digital form so that hypotheses can be quickly tested, derivative maps generated (fig. 7), and the information disseminated to other researchers.

The geologic map of the State being used in this analysis is modified from that published in 1978 in that rock units are grouped to represent geologic environments that would permit the formation of different types of mineral deposits. It also includes new information on the ages of igneous rocks. Because the geologic map represents the geology that is exposed and therefore best known, it is the foundation for most of the other studies.

Analysis of regional gravity data is being used to estimate the thickness of younger rocks that have most recently been deposited. From these gravity data, the scientists were able to produce another gravity map from which the gravity components of thick deposits of young rock and unconsolidated sediments have been removed. This map is used to help identify the rock types of the concealed basement layer, to delineate major crustal structures and boundaries, and to identify concealed plutons (intrusions of igneous rocks) and calderas (large basin-shaped volcanic depressions), all of which can reflect geologic environments permissive for the formation of certain types of mineral deposits.

The analysis of magnetic data focuses on the distribution of near-surface magnetic sources in order to delineate bodies of shallowly buried magnetic rock. Typically these are Tertiary and

Quaternary (2 million to 10,000 years old) volcanic rocks. The three-dimensional information provided by the analysis affects the mineral resource assessment in that certain types of mineral deposits, such as porphyry and skarn copper deposits and platinum, are associated with magnetic rocks.

Many kinds of mineral deposits owe their origin to intrusive igneous rocks. Knowledge of where these plutonic rocks occur is critical in identifying where these types of deposits could exist. A new geophysical tool, which relies primarily on magnetic data, is used to locate unexposed plutonic rocks.

In order to explicitly consider depth in this study, we must deal with volumes of rock and must combine the rock units so that they represent consistent geologic environments. A new type of geologic map is required to portray these rock groups because a number of different geologic environments may overlap in the 1 kilometer (0.6 mile) beneath any given locality on the surface. The complexity of display requires two different maps. The first map of the pre-Tertiary geology shows older rocks that may host mineral deposits related to later igneous activity or may contain mineral deposits that formed at the same time as the rocks. The second map, Tertiary geology of Nevada, concentrates on the young igneous rocks and related calderas that are closely related to many of the mineral deposits of Nevada.

Ages of young volcanic rocks when compared with the ages of different kinds of mineral deposits provide key information about the development and nature of the mineral deposits and also provide new light on the geologic development of Nevada.

Geologic, geomorphic, geophysical, and well-log data are being analyzed to infer the approximate subsurface geometry of fault-bounded basins in Nevada. By analyzing this more recent tectonic activity, scientists can better determine the depth of environments permissive for older deposits and about the spatial distributions of younger rocks that may be associated with the mineral deposits formed at shallow depths, possibly near faults related to the basins.

Types of mineral deposits and occurrences that have already been found in

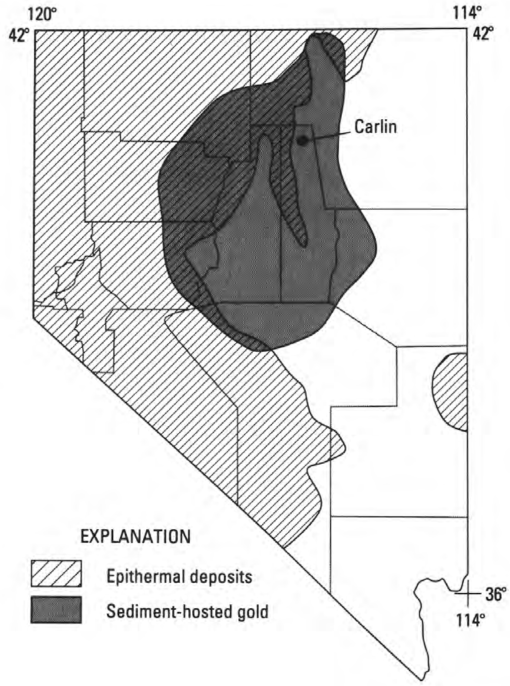


Figure 8. Distribution of epithermal mineral deposits (formed at relatively shallow depths by circulation of hot fluids) and of sediment-hosted gold deposits in Nevada.

specific geologic environments in Nevada not only confirm that the environments are permissive for the same deposit types, but they also suggest the possibility of genetically related deposit types. For the first time, approximately 1,600 mineral deposits and occurrences have been classified by deposit type. Maps of the locations of Cenozoic (63 million to 10,000 years old) deposits show a remarkable pattern in which volcanic-hosted epithermal deposits of gold, silver, mercury, and manganese in Nevada are distributed in a C-shaped pattern (fig. 8) with the interior of the C generally devoid of these deposit types, despite the widespread distribution of volcanic rocks. Sediment-hosted gold deposits, such as the Carlin deposit, are restricted (with minor overlap) to the interior of the C. Because the sediment-hosted gold deposits originally formed at a deeper level in the crust, are related to different types of faults, and were formed earlier than the epithermal deposits, important new information about the geologic evolution of Nevada and about where different types of deposits might exist has been revealed.

As noted above, specific geologic environments suggest the possibility of certain types of mineral deposits. The converse is also true; the distribution of different types of known mineral deposits suggest the presence of geologic environments that may not be evident from existing geologic maps. The mineral-resource analysis portion of this project builds on each of the other sections and, like the other sections, contains new results that will require many geoscientists to reexamine their existing concepts of mineral resources in Nevada.

Each of the researchers is addressing part of the overall problem of analyzing and predicting Nevada's mineral resources. The interdisciplinary nature of the research for this cooperative venture has amplified and reinforced each part of the project and has led to products not otherwise obtainable.

Uranium in the United States

By Joseph S. Duval

Background

Uranium-238 is a radioactive element that occurs naturally in trace amounts in all types of rocks and soils. Uranium is chemically mobile in oxidizing environments and many of the rock-forming and surface processes result in uranium concentrations that are characteristic of a particular rock or soil. For this reason, a map of the uranium distribution in rocks and soils can provide information useful to understanding geologic and soil formation processes. Uranium is itself of interest as a fuel for nuclear energy, but because it is often associated with other elements, it also can be useful in mineral exploration applications.

The USGS, in cooperation with the U.S. Environmental Protection Agency, has compiled aerial gamma-ray data obtained during the National Uranium Resource Evaluation (NURE) Program sponsored by the U.S. Department of Energy to create a map showing surface concentrations of uranium-238 for the conterminous United States.

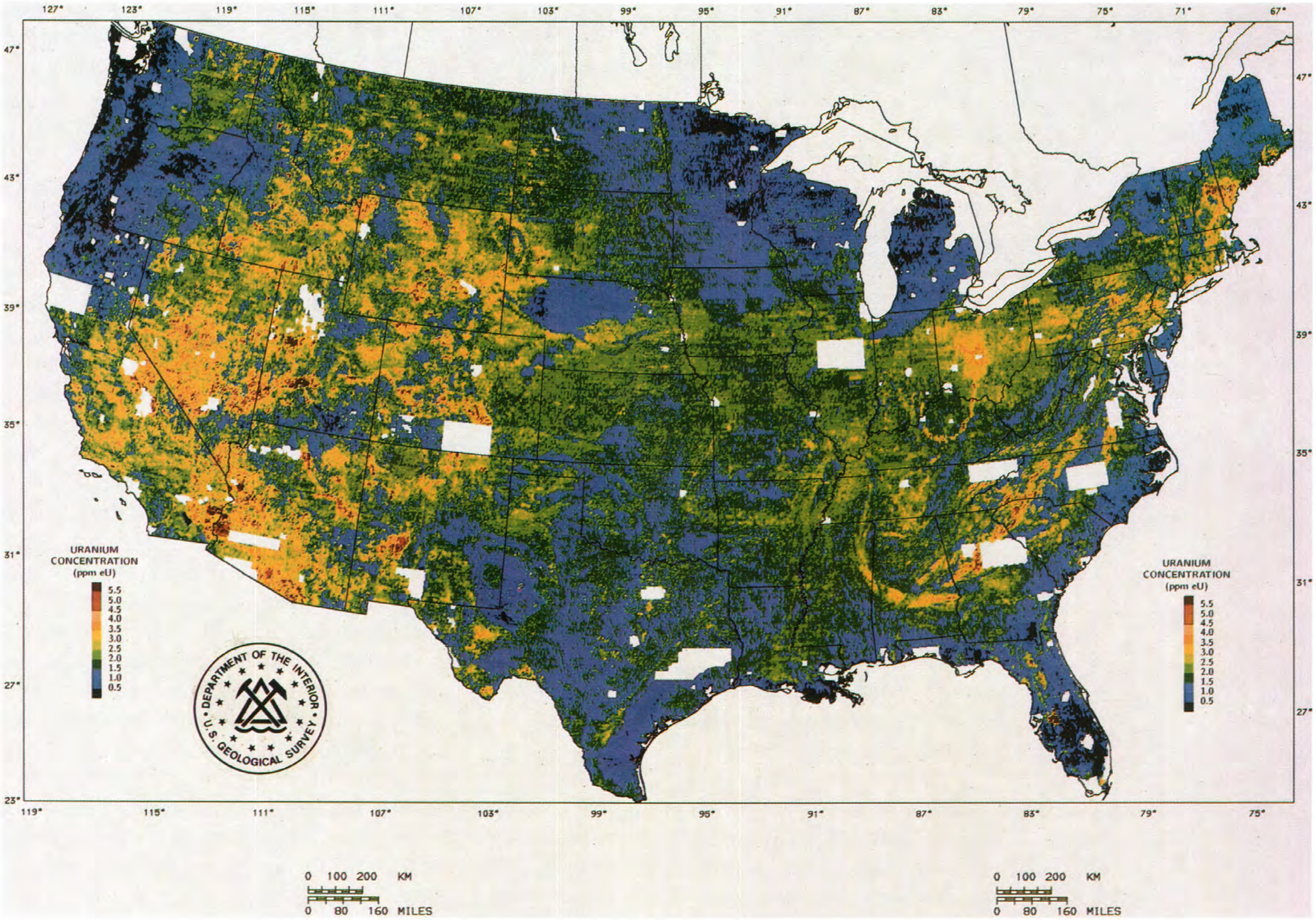
Health Hazards and Uranium Concentrations

Because uranium produces radioactive decay products, its presence in the environment in various forms presents health hazards. Radon-222 in indoor air, for example, is known, under certain conditions and at certain exposure levels, to cause lung cancer. Radium-226 in water supplies has been shown to cause other forms of cancer. These health risks underscore the need to have the best possible picture of where uranium occurs in the geologic environment.

The data on the map showing uranium distribution for the conterminous United States are grouped into intervals of 0.5 parts per million (ppm) equivalent uranium (eU). The term "equivalent" is used because radioactive disequilibrium can occur in the uranium decay series, and the gamma-ray measurement is not a direct measure of the uranium. Where blank areas exist on the map, no data are available.

States and regions having large areas of low values (less than 1.5 ppm eU) are Oregon, western Washington, northern California, northwestern Nebraska, northern Maine, Michigan, Wisconsin, Minnesota, Florida, and the outer coastal plains of New Jersey, Delaware, Maryland, North Carolina, South Carolina, and Georgia. In the Western States, these low values generally occur in areas underlain by igneous rocks having low original uranium content. In the coastal areas of the Southern and Eastern States, the low values occur in areas underlain by marine sands of low uranium content. In the North-Central States, the low values are caused by high soil moisture that attenuates the gamma-ray signal.

The higher concentrations of uranium are associated with granites, granitic metamorphic rocks, black shales, phosphatic rocks, and Tertiary rhyolites (between 63 and 2 million years old). Most of the granites and granitic metamorphic rocks are distributed in the Western and Eastern States with only a few occurrences in the Central States. Some of the granites having the highest uranium concentrations are the Conway granite in New England and the Silver Plume granites in Colorado. Phosphatic rocks in Alabama, Mississippi, and Flor-



Distribution of uranium-238 in the conterminous United States (ppm, parts per million; eU, equivalent uranium).

ida have elevated uranium concentrations. Tertiary rhyolites in southwestern New Mexico, western Utah, Nevada, Arizona, southwestern California, Idaho, and Wyoming also have high uranium concentrations. Some of the more radioactive black shales occur in Utah, Ohio, and Kentucky.

The distribution patterns seen in Ohio and Kentucky provide information relevant to soil formation processes associated with glaciers. In central Ohio, the uranium is widely dispersed as a result of glacial processes, but, below the glacial boundary in Kentucky and southern Ohio, the elevated uranium values are more localized and occur in areas underlain by the Devonian black shales. Some of these areas have concentrations greater than 5.0 ppm eU. Similar processes have affected the uranium distribution in the New England States. In Maine, the areas of highest uranium concentrations are underlain by rocks described as two-mica granites. The areas to the south and east of the granitic intrusions also have elevated uranium concentrations (greater than 2.5 ppm eU) and presumably the surface soils (of which the concentrations are being measured by the gamma-ray data) contain materials displaced by glacial scour from the granitic rocks. Other locally higher uranium concentrations in Maine occur along the Atlantic Coast and in north-central Maine and are also related to two-mica granites.

Radon Potential

Uranium maps have been especially useful in understanding the source and presence of indoor radon. Because an aerial gamma-ray system is measuring the gamma-ray flux from the decay of Bismuth-214 (a radon-222 decay product) in the ground, the aerial gamma-ray data provide estimates of the concentrations of radon-222 in the soil gas. The USGS has conducted field studies in Montgomery County, Md., of the appar-

. . . surface gamma-ray data can be used to estimate the radon in the soil gas.

ent surface concentrations of uranium in the soils by using gamma-ray measurements and of radon in the soil gas. The results indicate that the surface gamma-ray data can be used to estimate the radon in the soil gas. Other studies compared the average indoor radon in counties in New Jersey to the average apparent surface concentrations of radium [1 picocuries per gram (pCi/g) radium = 0.333 ppm eU], and the results indicate that the average radium concentrations can be used to estimate the average indoor radon levels in New Jersey. Average indoor radon levels for houses in townships in Washington, Oregon, and Idaho were also compared to surface concentrations of radium. The results of this study also suggest a predictive relation. Scientists caution, however, that townships underlain by highly permeable soils (soils through which water percolates greater than 6 inches per hour) constitute a distinct subset compared to townships having less permeable soils. Highly permeable soils apparently increased the average indoor radon for a given concentration of radium by about a factor of 6.

All of the above results indicate that the map of the surface concentrations of uranium can be used to estimate average indoor radon levels, but only in a relative sense. In other words, an area in a particular region of the country having 4 ppm eU should result in higher average indoor radon levels than another area in the same region having 2 ppm eU. But because of differences in soil conditions, climate, and house construction, 4 ppm eU in New Jersey would not be expected to result in the same average indoor radon levels as 4 ppm eU in Colorado. Areas having inherently permeable soils should tend to have higher average indoor radon levels than areas having less permeable soils if the areas have similar uranium concentrations.

The compilation of the NURE aerial gamma-ray data to produce a map of the surface concentrations of uranium for the conterminous United States has resulted in a reasonably accurate representation of the distribution of uranium in the surface rocks and soils, and general agreement exists between mapped geology and the patterns seen in the uranium distribution. Because of the relation between uranium and radon, this map is also useful as a tool for estimating indoor radon levels. This map, however, cannot be used to directly estimate the radon levels because of the effects of permeability, housing construction, and differences in soil weathering profiles. With this map as a starting point, local and regional planners and managers have an important tool to use in identifying areas that warrant additional study to determine the radon potential of a specific area. This map also should prove useful for understanding other geologic, geochemical, and soil formation processes.

National Mapping Program

Mission

The primary mission of the National Mapping Division is to provide accurate and up-to-date basic cartographic information for the United States in forms that can be readily applied to present-day problems. Maps, aerial photographs, satellite images, digital data, and geodetic control information represent some of the cartographic products available. Topographic maps at various scales, which illustrate detailed and precisely referenced information about natural and manmade features on the Earth's surface, continue to be important products. These maps provide basic cartographic information that is needed by most Federal, State, and local government agencies in dealing with key issues ranging from satisfying energy demands to conserving natural resources, from identifying environmental problems to developing acceptable solutions, and from locating commercial facilities to designing public works.

In addition to maps, cartographic data in computer-readable form are becoming increasingly important. These data are used in computer-based resource and geographic information systems to evaluate alternative management plans and to study the effects of different policies.

Highlights

Mapping Modernization

By Eugene C. Napier, Ernest B. Brunson, and K. Lea Ginnodo

When the U.S. Geological Survey was established in 1879, topographic mapping was conducted as an adjunct to geologic studies. Soon, topographic maps were recognized as having intrinsic value as well as value for many other applications. From this beginning, the concept of preparing standard topographic maps for multipurpose use was conceived, and the first standard quadrangle map was completed in 1881. Since that time, the USGS's topographic mapping program has undergone several transitions as users' needs for more detailed map information increased and as mapping procedures and technology evolved. The current transition began in 1979 when the USGS formally initiated the Digital Cartography Program.

The widespread use of computers and associated technology has generated new and increasing demands for map

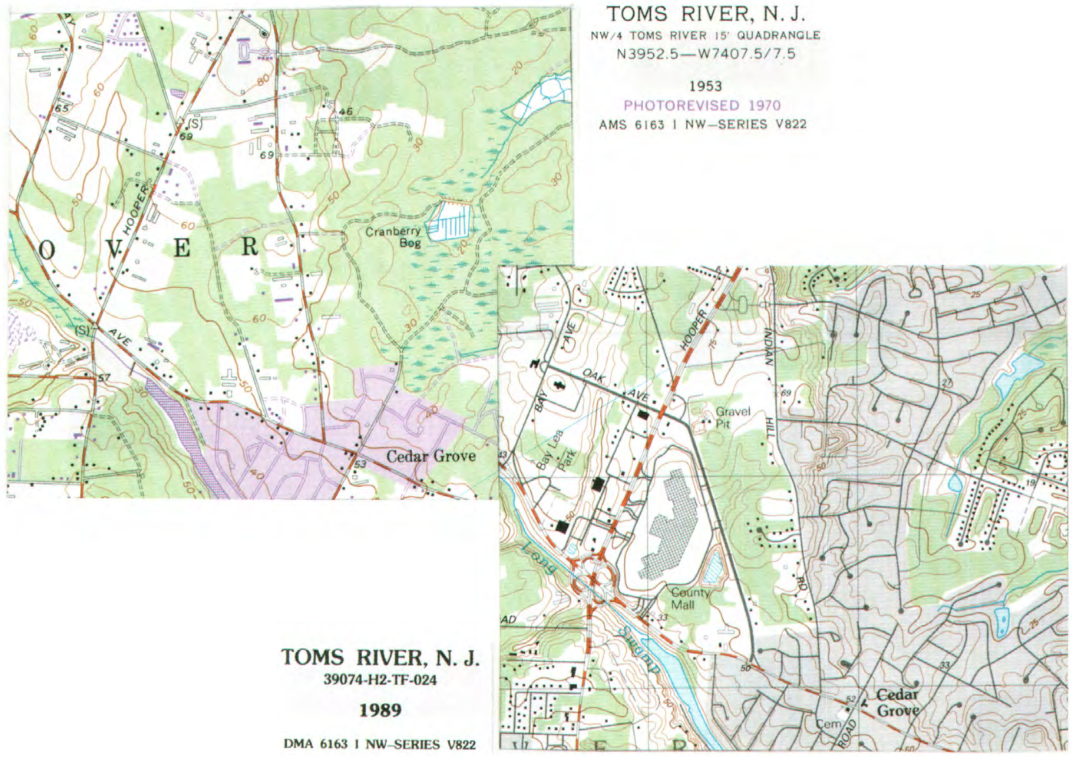


Figure 1. Map revision will be a major focus of the National Mapping Division's activities for the next decade. The need to keep map information current is clearly seen in the dramatic changes shown in these examples of an area in New Jersey. In the 1989 map, note the expanded road system and cloverleaf interchange, the large shopping mall, and the extensive residential development (gray area).

information in computer-compatible form. Since 1979, user requirements for accurate and current cartographic data in both digital and graphic forms have accelerated beyond the capacity of the National Mapping Division to produce them.

. . . The USGS has undertaken an extensive mapping modernization effort . . . .

To respond to this increasing demand, the USGS has undertaken an extensive mapping modernization effort that includes major technical and programmatic transitions. The objective of this modernization effort is to develop and implement advanced digital cartographic systems and production procedures in the USGS's cartographic production centers by the mid-1990's. This modernization will make it easier to revise maps more frequently and to prepare and maintain more up-to-date cartographic products.

Tasks underway to accomplish this ambitious goal include expanding and improving mass digitizing capabilities; modifying data structures to support increased content and access requirements; developing digital revision capability; developing digital product-generation capabilities for standard, derivative, and digital products; improving quality control; and supporting advanced spatial analysis and applications. When these tasks are completed and the digital cartographic systems are fully operational in the mid-1990's, the USGS will be able to meet increasing requirements to keep current the Nation's 57,000-plus primary-scale maps (fig. 1).

A Primary Mapping Economic Analysis, completed in fiscal year 1989, showed that there are significant economic benefits to computer-based map revision. Further, the analysis showed that the current target of revising maps on a 10-year cycle is conservative and that there would be greater benefits if the revision cycles were shorter.

The mapping modernization effort represents a substantial and timely program change in the USGS. It appropriately takes advantage of state-of-the-art mapping technology and will result in a highly responsive digital cartographic production system. Attaining this goal of modernizing the National Mapping Program will enhance the USGS's ability to meet national requirements for up-to-date multipurpose cartographic data and map products.

The concerns of both scientists and policymakers are now focused on the potential for long-term changes. . . .

Geographic Information Contributes to Studies of Global Change

By Raymond D. Watts

The summer of 1988 was hot and dry. Farmers in the northern Great Plains endured massive crop failures, and Washington, D.C., sweltered in the hottest summer since the 1930's. Political attention was focused on concerns about the effects of human alteration of the global environment, including its climate.

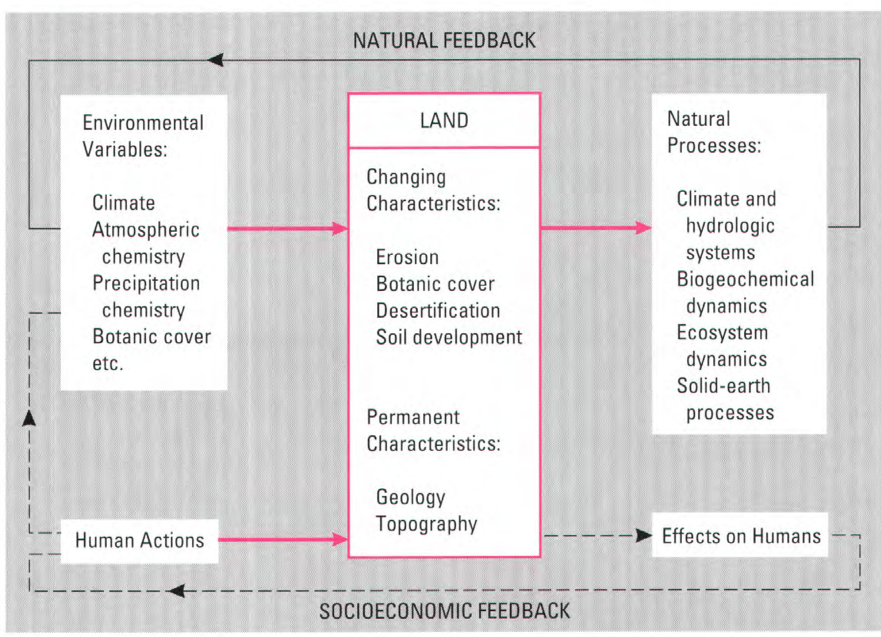
In congressional testimony, one scientist expressed "99 percent confidence" that the weather of 1988 was attributable to enhanced greenhouse heating of the atmosphere—a result of higher atmospheric carbon dioxide concentrations from the burning of fossil fuels and deforestation. Most scientists, however, would not agree that such a direct connection has been established. In spite of great progress, current understanding of many aspects of climatic behavior remains rudimentary.

Today's computer models of climate are just beginning to incorporate realistic oceanic behavior, and their descriptions of land-atmosphere interactions are woefully inadequate. On short time scales (days to weeks), the atmosphere, oceans, and biosphere are relatively independent. On slightly longer time scales (months, seasons, years), the atmosphere, oceans, and biosphere affect each other, but feedbacks are relatively unimportant. On yet longer time scales (years, decades, centuries), all parts of the Earth's environmental system interact and affect each other—but in ways that scientists do not understand qualitatively, much less quantitatively. The concerns of both scientists and policymakers are now focused on the potential for long-term changes that will span decades or centuries and involve the entire, tightly coupled, land-ocean-atmosphere global environmental system.

The land component participates in global environmental processes in many ways. It is a new challenge to geographers and cartographers to describe and to measure the role that land plays in order to provide quantitative information that is useful in the development of computer models of the global environment. One of the major challenges to scientists who study global change is to identify the relative roles of human and natural processes and the ways that environmental change, once begun, feeds back through natural and human behavior to effect further change.

The USGS is undertaking studies of the land relationships indicated by red lines in figure 2. The central question of these studies is how to provide descriptions of land characteristics that will serve

Figure 2. Relationships of human activities and natural processes acting on the land, effects of land changes on natural processes and on humans, and feedbacks into further land change. The relationships represented by red lines are to be examined by the National Mapping Division for application to interdisciplinary global studies.



the needs of scientists who study global environmental change. Ecologists, meteorologists, atmospheric chemists, and scientists from numerous other fields need information about topography, geology, botanic cover (including seasonal variations), soils and soil development, erosion, and other land characteristics. Global modeling studies require information different from that needed for local process studies. For geographers, cartographers, and others who build essential data bases, an understanding of resolution and accuracy requirements is a prerequisite for an effective contribution to the interdisciplinary global research program.

Computer models of environmental processes are a distillation of current scientific knowledge. They are quantitative by nature and design; they describe, for example, reservoirs, flows, temperatures, and other characteristics numerically. Limitations in computer size and speed force modelers to characterize the land, its features and behavior, in aggregates. The complexity of our immediate neighborhood, which is so familiar, is therefore lost when a regional representation is formed. Few studies have been done on the quantitative validity of such generalization. The National Mapping Division is studying the problems of quantitative scaling of environmental observations and descriptions as part of its effort to develop strategies for observing and describing the land portion of the global environment. The strategy-development efforts are, themselves, interdisciplinary studies done in collaboration with scientists of many agencies, institutions, and disciplines. Once the strategies are developed, the data gathering will also be interdisciplinary, multi-institutional endeavors.

The USGS's EROS Data Center is home to a 20-year archive of Landsat images (both digital and film) as well as to millions of scenes of satellite and aerial photographs that provide a unique set of historical environmental observations. The Data Center's activities are expanding considerably in support of interdisciplinary studies of global change. The Data Center will become the long-term archive for data obtained by NASA's Earth Observing System, Eos—set for launch in the mid-1990's. These observations and others will provide an enduring resource for scientists who study the function and changes in the global environment.

The Digital Topographic Map of the Future

By John E. Findley

Scientists in many different disciplines, both in government and the private sector, use and depend upon reliable earth science data. Until the mid-1970's, analog data in the form of printed line maps and image products were the sole source of base cartographic data. More recently, base cartographic and other earth science data have been made available in digital or computer-generated form. These data were initially developed for use only by scientists and were typically distributed on 9-track computer tape without supporting software. The user community, therefore, was effectively limited to persons having some background in the earth sciences (particularly a working knowledge of coordinate geometry and transformations), a reasonable level of programming skill or access to programming resources, and access to a mainframe or large minicomputer.

Before microcomputers and the development of the geographic information systems industry, these limitations were not significant impediments. Few users possessed the knowledge to effectively use the data, and even fewer had access to adequate computing resources. Today, however, with the phenomenal computing power that is readily available in the microcomputer market at reasonable prices, and the flexible data integration and manipulation software that is available from numerous vendors, the potential user community of earth science data has become enormous. The USGS and other suppliers of digital spatial data need to evolve with the user community and with applicable technology and, accordingly, to provide data in forms compatible with emerging hardware and software systems.

Toward this end, the USGS is investigating several novel approaches for providing users with reliable and accurate data on a number of different media. One such approach is an ongoing research effort called the "Digital Topographic Map of the Future," the objective of which is to develop prototype models of advanced digital data sets on CD–ROM (Compact Disk–Read Only Memory) that depict county-based geographic information. This project proposes to test not only a novel medium for data distribution (CD–ROM) but also a novel spatial coverage (county versus the traditional quadrangle base) and a novel marketing approach in which data display and processing software will be packaged with the data. The goal is to develop a distribution package that will permit novice users to create or display custom maps from standard National Mapping Program digital data by using personal computers. The initial test CD–ROM will contain software to allow users to display digital line graph, digital elevation model, Geographic Names Information System data, and orthophotoimages of Arlington County, Va.

Large-Scale Image Mapping—Digital Orthophotoquads

By John E. Findley

The USGS is the Federal agency that is responsible for providing much of the spatial information that is used by scientists to review, analyze, and evaluate geographic information. In the past, this spatial information was conveyed primarily by aerial photographs, line maps, data digitized from maps, and standard orthophotoquads. The USGS has developed advanced techniques to produce a new product termed a "digital" orthophotoquad from aerial photographs.

To produce these digital orthophotoquads, computer-generated files, created by scanning aerial photographs, are digitally rectified by using a digital elevation model to remove displacement of features in the photograph due to changes in elevation. The resulting digital orthophotoquad accurately portrays ground distance and the spatial relationships among objects in the image. A major advantage of the digital orthophotoquad is that advanced computer processing, such as image enhancement, data merging, and digital mosaicking, can be applied to improve the interpretability of the photograph, to allow other geographic and cartographic data to be simultaneously considered, and to permit adjacent photographs to be joined into a single larger map.

In a pilot project with the Soil Conservation Service, Department of Agriculture, the USGS prepared 140 3.75- by 3.75-minute digital orthophotoquads (quarter-quadrangles) at 1:12,000 scale over Dane County, Wis. Both the scale and the location were selected as being the most useful for a number of potential applications. Samples of corresponding soft-copy products also were produced for this project for evaluation by the Soil Conservation Service. Several additional prototype products are being prepared to determine the usefulness of orthophoto quarter-quadrangles for selected areas,

Digital orthophotograph of Black Earth, Wis., created by using advanced computer techniques.

especially those urban and suburban areas that are experiencing rapid change and development. The USGS and the Soil Conservation Service also are evaluating the use of digital orthophotographs in geographic information system applications. Continued development of both hard-copy and digital orthophoto products will provide a valuable addition to the USGS's National Mapping Program, particularly the National Digital Cartographic Data Base.

U.S. Geological Survey-Census Bureau Cooperation Continues—Production of Agricultural Atlas

By Loreen G. Utz

When the Nation's census takers have finished gathering the information on the population of the United States, the work on producing the results of the 1990 decennial census will have just begun. Maps will be needed to help statisticians, demographers, policymakers, and others use the myriad of information from the census.

The USGS expects to plot data for more than 6,000 maps during the 3-year period following the 1990 census in continued support to the Bureau of the Census.

The USGS has been working with the Census Bureau since 1983 in preparation for the 1990 census. As part of an amendment to that working agreement, the two agencies began a cooperative pilot project in fiscal year 1989 to test methods for producing publication-quality maps from digital data. By using information from the recent Census of Agriculture and land-use information and film plots supplied by the USGS, the Census Bureau will produce the 1987 Agricultural Atlas of the United States. From this pilot project the two agencies will determine the most effective method to use in preparing the extensive number of maps for the 1990 decennial census.

Work on the pilot project began in June 1989. The USGS provided land use information for the Agricultural Atlas by using the data from its 1:7,500,000-scale "Land Use" map in the National Atlas of the United States of America. When the pilot project began, no digital data were available for this map; only the map separates used in the original printing existed. In the mapmaking process, information to be portrayed on the map is color separated into individual sheets that are used in the offset printing process. To capture the graphic data from the original map separates in digital form, the USGS used a method called raster scanning, in which the lines and other markings on a map are converted into computer-readable form. Photographic methods were used to combine the separate map sheets to make a color proof for each of the 16 different land use categories. Each of the color proofs was scanned and edited to remove extraneous detail. The resulting raster data files were sent to the Census Bureau, where they were subsequently converted to a format compatible with Census data.

From this pilot project the two agencies will determine the most effective method to use in preparing the extensive number of maps for the 1990 decennial census.

Over 300 maps—about 200 dot distribution maps and about 100 choropleth (thematic) maps—will be produced for the 1987 Agricultural Atlas of the United States. Dot distribution maps consist of dot symbols representing the collected statistics. Because the data were collected by county, each county will be portrayed with an appropriate number of dots representing the density of the data. Evenly distributed dots throughout each county would mislead map users into believing that the data are also evenly distributed.

To present a more accurate portrayal, the Bureau of the Census will apply land-use information to influence the distribution of the dots. For example, if a county produces 435,000 bushels of wheat and 1,000 bushels are represented by 1 dot, then 435 dots would be placed in that county. However, any land within that county that is classified as urban or woodland would receive no dots because one would assume that no wheat would be grown in those areas.

The choropleth maps will consist of county units, colored to create lighter or darker areas in direct proportion to the density of distribution of the theme subject. Each county is treated as a single unit without regard for the actual location of the theme within the county.

The production of the 1987 Agricultural Atlas of the United States will serve as a prototype for the production of the thousands of maps that will result from the 1990 decennial census.

Side-Looking Airborne Radar Glacier Research

By John E. Jones, Bruce F. Molnia, Robert M. Krimmel, and James W. Schoonmaker, Jr.

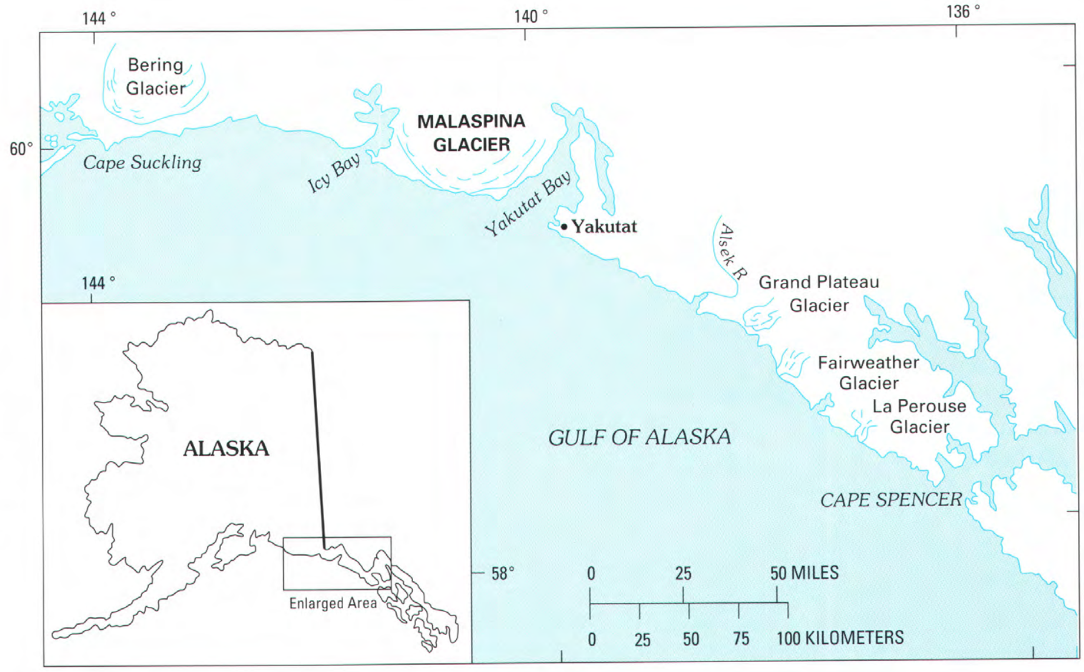
A USGS study of Malaspina Glacier found that certain bands of airborne and satellite radar images show large patterns of complex bright and dark radar backscatter on the surface of the glacier. These patterns, 0.3 to 6.0 miles in length, create a visual image that resembles bedrock features and the topography of nearby mountains, such as cirques and drainage networks. When inspecting airborne radar images from 1976, 1980, and 1986 and Seasat satellite radar images from 1978, along with topographic maps prepared from aerial photographs flown in 1958 and 1978 and other data sets, scientists found that the patterns have been stationary for nearly 30 years. This finding is unusual because ice-flow velocities of Malaspina Glacier are typically 0.1 mile a year near the center of the glacier and up to 3.0 miles a year in localized areas of the glacier during surges. A team of scientists visited the glacier in September 1988 to investigate both the causes of the discrepancy between ice-flow velocities and stationary patterns and the characteristics of the glacier's surface corresponding to the backscatter patterns.

Investigators found that the patterns on the radar images generally correspond to adjacent topographic highs and lows of the glacier's surface. The bright signatures are usually topographic highs that are characterized by extensive crevassing; the dark signatures are topographic lows having few crevasses. Because the patterns remain stationary while the ice moves across the patterns, the investigators hypothesize that the glacier's surface features mimic the configuration of the glacially and fluvially eroded bed at depths as great as 3,000 feet below the ice surface. Like standing waves in a flowing stream, the topographic lows, or swales, appear to be areas of compressional flow, while the topographic highs are characterized by extentional flow.

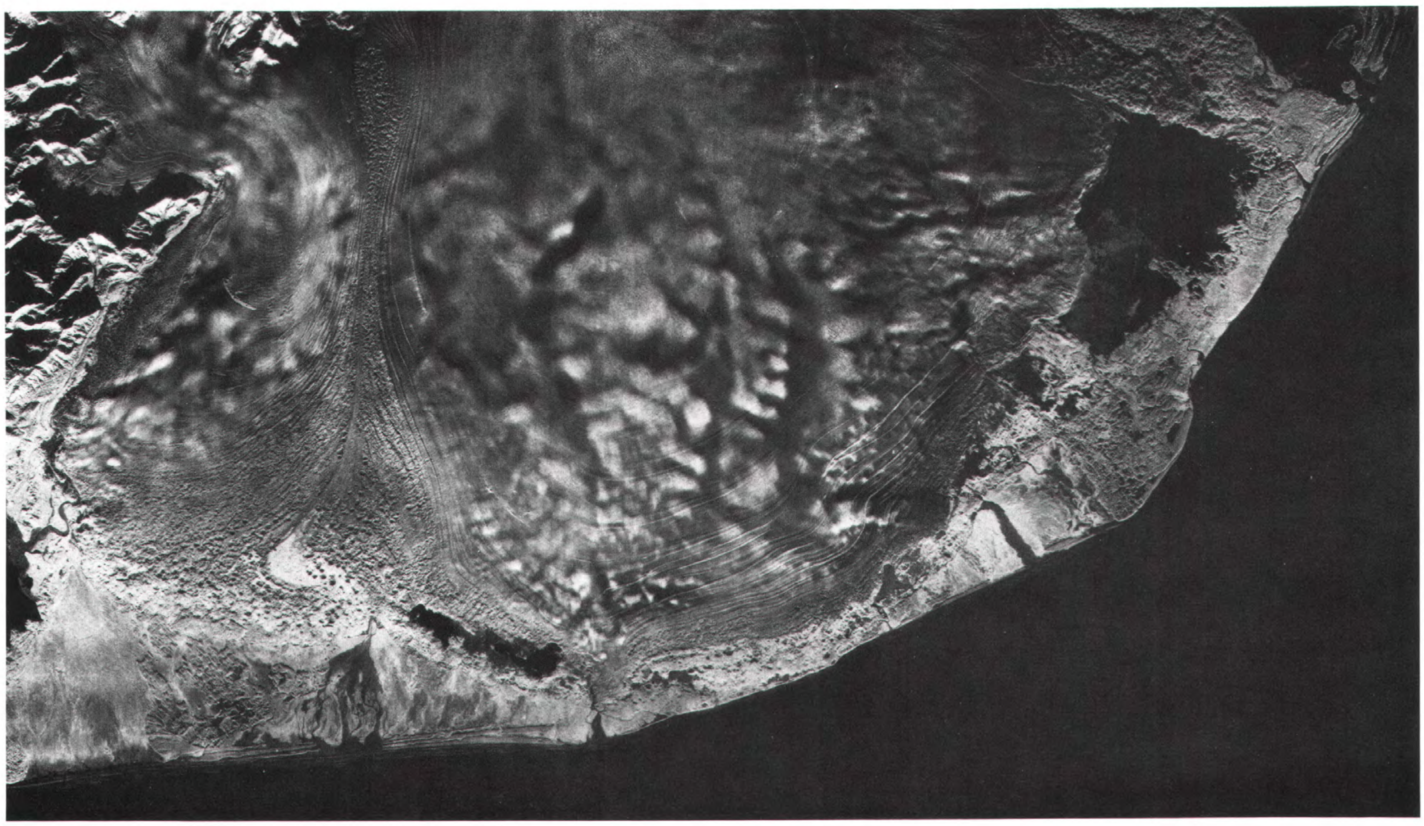
Airborne and satellite radar detect the features because crevasses and large hummocks on topographic highs act as radar reflectors and backscatter a large portion of the signal, whereas water and snow in the smoother surfaced topographic lows reduce the return signal. Scientists plan to conduct ice-penetrating radar surveys to develop this concept further. The investigation is also being expanded to Bering, Hubbard, and Grand Plateau Glaciers, all located along the coast of southern Alaska.

These observations and hypotheses have important implications. Because crevassed and uncrevassed zones can be identified by using radar data, safe landing sites and transportation routes can be mapped to facilitate geologic exploration. This technique was used successfully during the 1988 field investigation of Malaspina Glacier. Further, if the surface topography on this glacier and other ice sheets is an expression of subglacial morphology, then it may be possible to develop a fluid dynamics model for estimating ice volume in support of global-change investigations. This model would use remotely sensed data to measure ice-sheet area, flow velocities, wave

Location map showing Malaspina Glacier and other area glaciers.



X-band side-looking airborne radar image acquired in November 1986 of part of the Malaspina Glacier, Alaska. A number of unusual radar backscatter responses are shown that resemble the adjacent terrain. These features correlate to topographic highs and lows on the glacier's surface. The area shown is approximately 25 by 40 miles.



amplitude, and other parameters needed to estimate volume. In addition, because Malaspina Glacier has an area of more than 1,600 square miles and is similar in many ways to the continental ice sheets of the Pleistocene Epoch, the study of Malaspina may give us a better understanding of the dynamics of ice sheets and also may help us to unravel the course of events, both climatological and biological, that accompanied the advance and retreat of the Pleistocene ice sheets—a critical piece in sorting out the global-change puzzle.

International Activities

Mission

The U.S. Geological Survey continued to be active in international studies in science and technology as an adjunct to its domestic program during FY 1989. Authorization for foreign investigations is provided by the Organic Act, as revised, and the Foreign Assistance Act and related legislation. Activities are conducted under bilateral or multilateral agreements that require approval by the U.S. Departments of the Interior and of State. The following factors largely influence decisions as to whether the studies are in the interests of the U.S. Government:

- Domestic research objectives will be expanded in scope and achieved through the comparative studies of scientific phenomena nationally and internationally.
- Information about existing and potential foreign resources of interest to the United States will be obtained and incorporated in worldwide data bases.
- Scientific knowledge, understanding, expertise, and reputation of the USGS and of the United States in the earth sciences will be broadened and appropriately recognized internationally.
- Relations with foreign counterpart institutions will be developed and maintained, and the programs will facilitate scientific cooperation, technology transfer, and data exchange.
- International programs of other Federal agencies, academia, and the private sector will be supported; in particular the Department of State will receive adequate scientific information required to formulate foreign policy objectives and decisions.

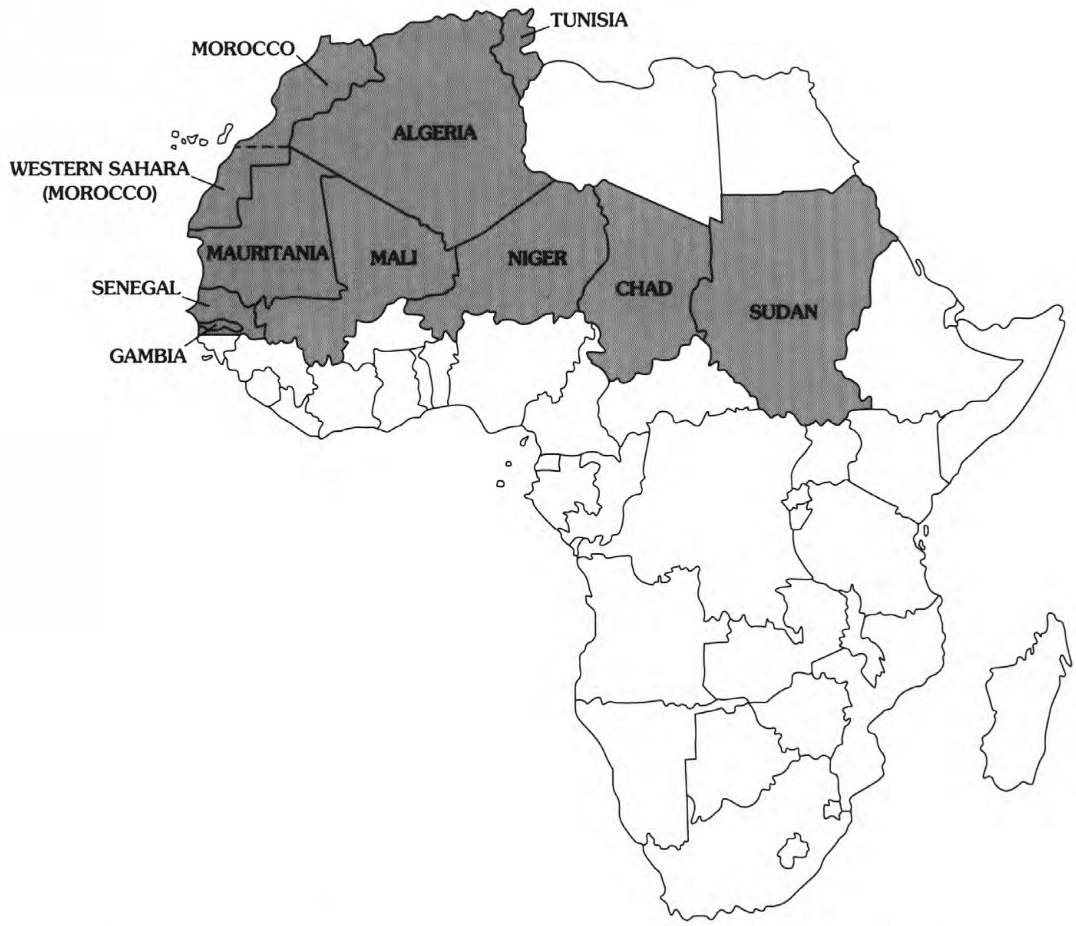
Funds for USGS technical assistance to foreign countries, including all training programs either within or outside the United States, are supplied by other Federal agencies, international organizations, or foreign governments. Assistance programs provide for transfer of technology to foreign nationals by advice, training, and demonstrations. A small amount of the funds appropriated annually to the USGS for research is used in cooperative ventures with foreign counterpart organizations that also supply funding and (or) services-in-kind. Cooperative projects range from individual scientist-to-scientist discussions, correspondence, and exchange visits on topics of mutual interest to jointly staffed, formally organized, bilateral scientific research, and multilaterally coordinated investigations that focus on a variety of scientific phenomena.

Highlights

Seasonal Vegetation Mapping by Satellite for Grasshopper and Locust Control in Africa

By G. Gray Tappan, Dean Tyler, and Donald G. Moore

While rainfall in both the Saharan and sub-Saharan countries of Africa has broken the drought of the mid-1980's, it also has produced favorable habitat conditions for the breeding of grasshoppers and locusts. The resulting insect infestations threaten the region's ability to produce sufficient food supplies. Monitoring vegetation conditions favorable to grasshoppers and locusts is essential for effective control programs. In support of an international effort to control these pests, The 10 countries that have participated in the greenness mapping program.

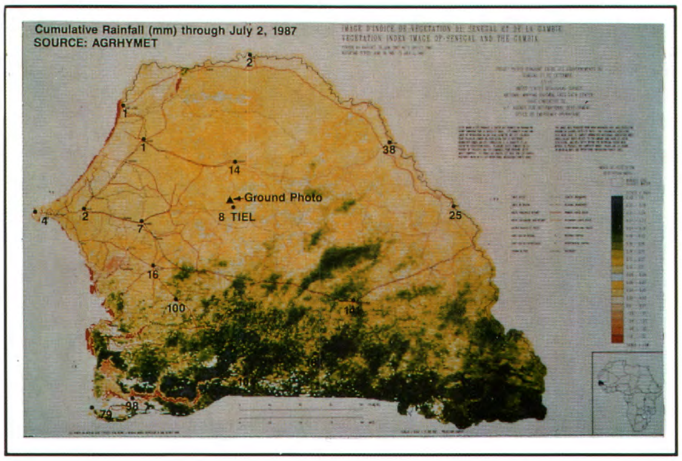


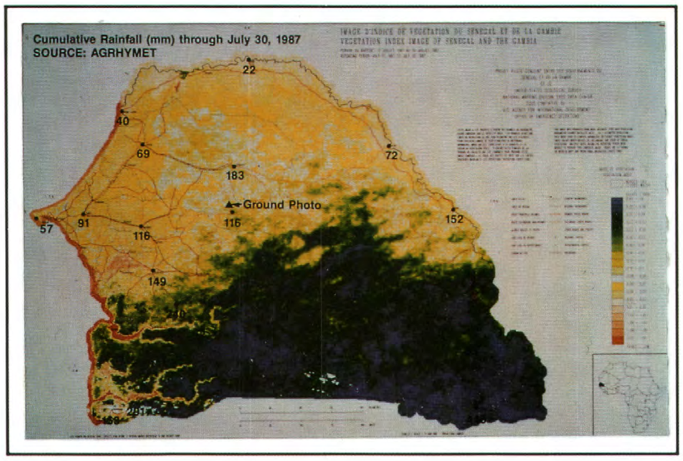
the U.S. Agency for International Development requested the EROS Data Center of the U.S. Geological Survey in Sioux Falls, S. Dak., to develop and put into place a seasonal vegetation monitoring program. The program uses National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer (AVHRR) satellite data and USGS geographic information systems technology.

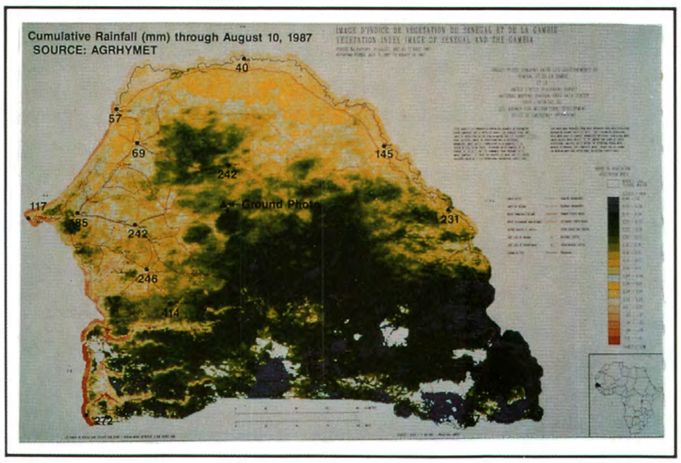
The greenness field sheets provide information on favorable grasshopper and locust habitats.

Data received daily from the AVHRR were merged with a cartographic data base to produce Normalized Difference Vegetation Index (greenness) field sheets. The field sheets are produced at a scale of 1:2,500,000 (1 inch represents about 40 miles) for most countries and are sent by express mail from South Dakota to Africa every 2 weeks. The greenness information, which relates to vegetation growth and condition, is used to monitor the complex seasonal patterns of greening-up and drying of vegetation on a countrywide basis through the critical periods of vegetation growth and grasshopper and locust activity.

The field sheets are used by numerous organizations involved in grasshopper and locust control in Africa. The primary users include national crop protection services in Africa, the U.S. Agency for International Development, and the United Nations Food and Agriculture Organization. Training is provided to users in each country on how to interpret and to use the information in their surveillance systems. Grasshopper and locust control teams use the sheets for planning and conducting field and aerial surveys to locate infestation areas more efficiently. Sheet use is based on the principle that seasonal rainfall triggers both the growth of herbaceous vege-







A series of greenness field sheets of Senegal that indicate the development of vegetation cover triggered by the northward advancement of rains. The adjacent ground photographs were taken near Tiel, Senegal. The photograph dates of June 22, July 21, and August 3 fall within the three periods represented by the sheets. A qualitative comparison between the greenness values and actual ground conditions can be made. (Ground photographs by Philip K. Mueller, private collection.)

tation and the hatching of grasshopper and locust eggs. By focusing on land areas that are greening or already green, survey teams can significantly narrow the areas to be covered by both land and aerial survey efforts.

Because of the success and widespread acceptance of the field sheets, the program has been used in 10 countries in Africa: Algeria, Chad, Gambia, Mali, Mauritania, Morocco, Niger, Senegal, Sudan, and Tunisia. During 1989,

A United Nations Food and Agriculture Organization locust expert (front right) and staff from the Mali Crop Protection Service interpret probable locust habitats to support field operations. Based on their assessment, a helicopter or a field survey crew will be dispatched to confirm the status of grasshoppers and the desert locust. (Photograph by Gray Tappan, TGS Technology, Inc.)

Mali Crop Protection Service staff evaluate a habitat heavily infested with the desert locust, while the locust take to the air. (Photograph by Gray Tappan.)

approximately 1 billion hectares were monitored every 2 weeks. The next and necessary phase is to establish the monitoring capability in Africa. The USGS is currently transferring the capability to the Agriculture-Hydrology-Meteorology Center in Niger, which oversees a regional program in sub-Saharan Africa that provides a data collection and distribution network for tracking climatic and agricultural conditions. The USGS is also transferring the technology to a regional north Africa institute in Tunisia.

Lessons from the December 7, 1988, Spitak, Armenia—Earthquake

By Walter W. Hays

Introduction

Armenia, a Soviet Socialist Republic, is located in an environment where, over time, the collision of the Eurasian and Arabian tectonic plates has produced a broad zone of faulting and crustal deformation that extends southward from the Caucasus Mountains in Armenia to northern Turkey and Iran. The December 7, 1988, earthquake that centered on Spitak, Armenia, is the latest in a long series of earthquakes in the region that reflects the ongoing collision of the plates. The magnitude 6.8 earthquake was one of the worst disasters of the 20th century. It struck Spitak at 11:41 a.m., local time, and left an estimated 25,000 dead, 18,000 injured, 510,000 homeless, and reconstruction costs of $16 billion. It reminded the world of the damage that an earthquake can do to a nation, its urban centers, gross national product, and to the fabric of the society.

An earthquake disaster can serve as an all-too uncomfortable reminder of how unprepared an area may be to cope with such a calamity. Such disasters show whether or not preparedness planning and mitigation measures were adequate. They also test the siting, design, and construction practices for lifelines, buildings, and critical facilities. Perhaps most critically, earthquakes and their aftermath stretch the capacity of the populace to respond to these disasters and to modify their activities and practices during the recovery period.

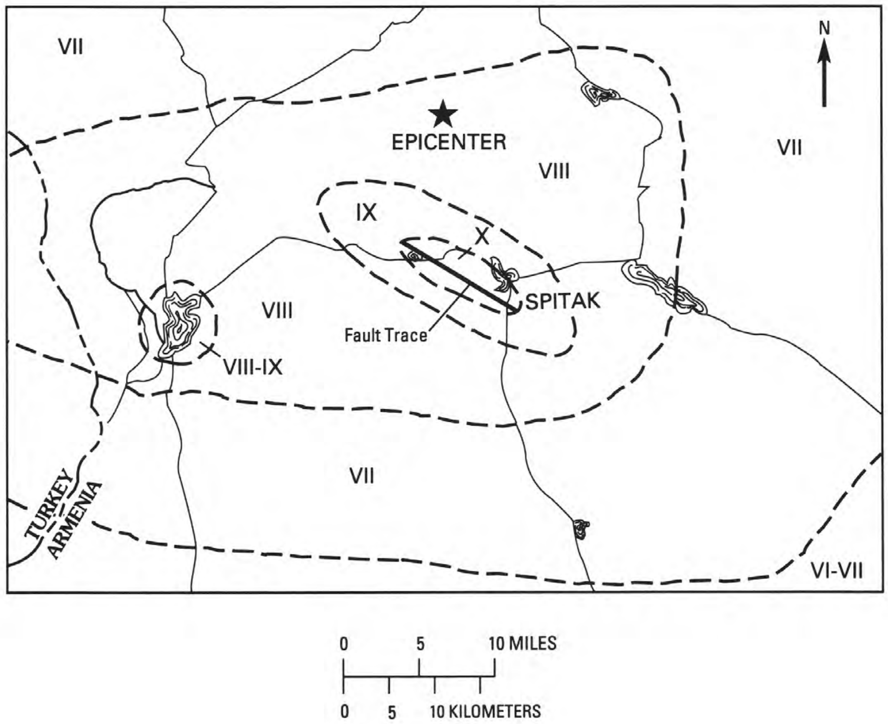
Important Lessons

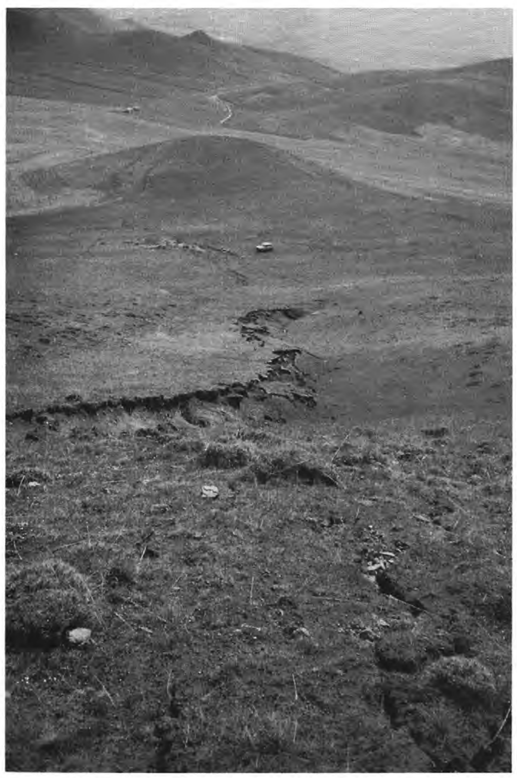
Multidisciplinary studies of the 1988 Armenia earthquake by a U.S. team of experts in cooperation with their Soviet counterparts and previous studies of other earthquakes have taught us many important lessons. Several of these lessons, which have direct bearing on the disaster in Armenia, are as follows:

- The parameters of the fault located near Spitak shaped the nature of the disaster. The Spitak fault, which released the December 7, 1988, earthquake, is a reverse fault that is tectonically related to the much more prominent North Savan fault. Both faults were mapped prior to the earthquake, and these maps showed that the faults had moved in the last 10,000 to 2 million years. The Spitak fault broke the surface on December 7th over a distance of 9 miles, which resulted in nearly 6.6 feet of vertical movement or displacement.
- Unfortunately, as such disasters prove, a community that has not prepared for a damaging earthquake is particularly vulnerable to disaster, especially if damaging earthquakes have occurred in the past. Despite past damaging earthquakes, Armenia was unprepared for the December 7th earthquake. In 1967, a magnitude 5.1 earthquake centered near Spitak caused minor damage. The most significant recent event in the area, a magnitude 6.5 earthquake that occurred on May 28, 1926, caused severe damage in Leninakan (formerly known as Alexanderkan).
- The destructiveness of an earthquake depends on its size, proximity to an urban center, the soil underlying the buildings, facilities, and lifelines in the center, and the state-of-preparedness in the centers.

Villages like Spitak and Stephankan took a "direct hit" in the epicentral region. Leninakan, although 25 miles from the epicenter, sustained heavy damage because the soil underlying the city amplified the ground motion. This phenomenon was similar to that experienced in Mexico City in the September 19, 1985, Mexico earthquake.

- In such a disaster, a community is always working against time. Critical time frames for responses by a community range from a few seconds to centuries, which compounds the difficulties in providing adequate preparation and hazard response. By being better aware of what the timing is of various earthquake hazards and necessary responses, communities can be better prepared.

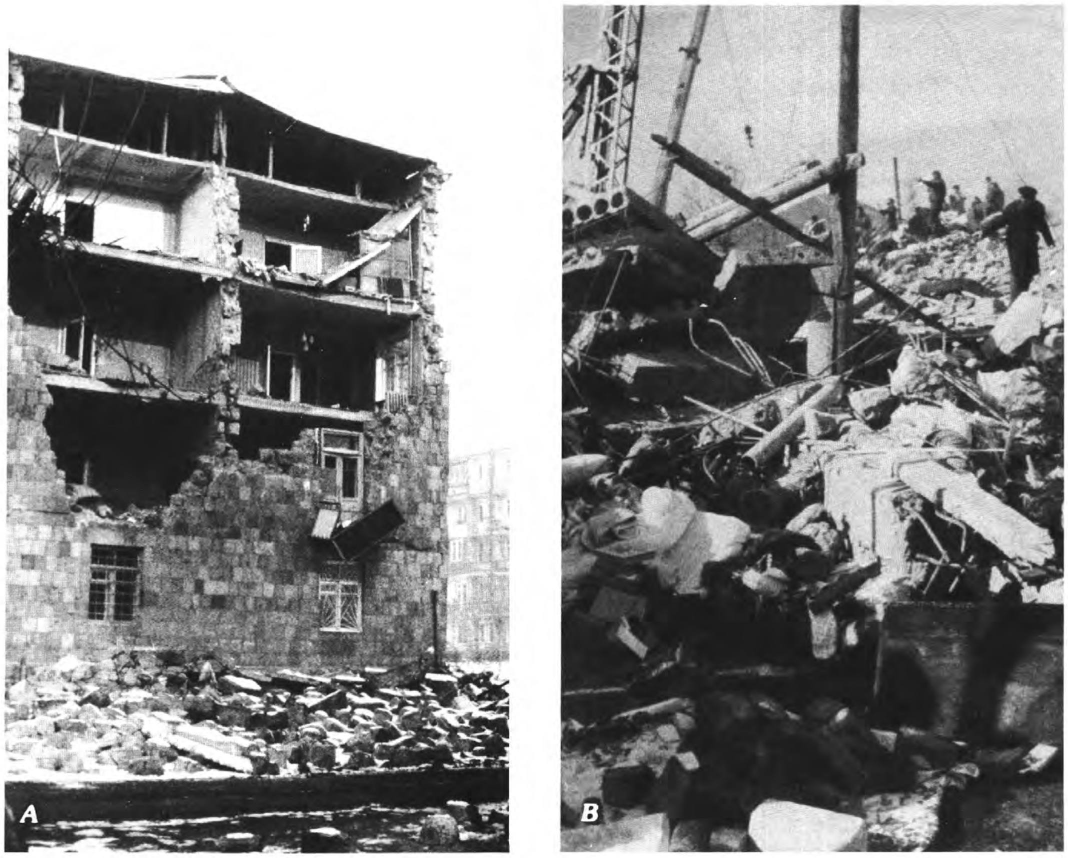




Spitak fault that generated the December 7, 1988, earthquake. The fault broke the surface over a distance of 9 miles and had nearly 6.6 feet of vertical displacement. (Photograph by Earthquake Engineering Research Institute, El Cerrito, Calif.)

Seconds—For duration of ground shaking (Spitak probably experienced less than 10 seconds of ground shaking).
Minutes—Before the first aftershock occurs (a magnitude 5.8 aftershock occurred 5 minutes after the main shock, causing damaged buildings, schools, hospitals, and factories to collapse).
Hours to a few days—For emergency

Damage to buildings having load-bearing walls made of stone, which were the predominant construction type in Spitak, Armenia, ranged from damage that typically occurred at building corners (*A*) to the total destruction of buildings (*B*). (Photographs by Earthquake Engineering Research Institute, El Cerrito, Calif.)



response and search and rescue activities (90 percent of the people rescued from the collapsed buildings were saved in the first 24 hours).

Years to decades—For community preparedness and recovery programs (a warning of the increased probability for a damaging earthquake in the region was issued prior to the earthquake by Soviet scientists, but the warning had not been acted upon).

Decades to centuries—For the seismic cycles of active faults to come full circle with the consequent fault rupture; that is, another earthquake which begins the cycle again (Armenia has many active faults that have been mapped; determination of their seismic cycle is in progress).

The disaster in Armenia would have been lessened if the earthquake had occurred 5 minutes later when the school children were outside the schools that were destroyed and on their way home for lunch. Although communities have no control over the exact times of earthquakes, there are effective steps that can be taken to lessen effects. In Armenia, greater efforts need to be made to increase the level of personal preparedness and increase communitywide preparedness.

- Earthquake predictions and hazards warnings are only of limited value when the responsible society is not able to properly address and implement the scientific knowledge available. Although Soviet authorities had been advised 3 years ago by their scientists of the increased probability of a damaging earthquake in Armenia, the capability to respond at the community level was not yet in place. It is unfortunate that it sometimes takes a disaster of such large proportion to ensure that available scientific expertise and knowledge is used to properly plan for disasters. We in the United States are not as prepared as we should be for similar disasters in many earthquake-prone areas of the country. Only in California, where more than 50 years of earthquake preparedness and mitigation strategies have been studied and implemented, are we able to survive a 7.1 magnitude earthquake like the one that occurred in Santa Cruz, Calif., on October 17, 1989, with only 62 deaths.
- Extensive building damage occurs in earthquakes because we often underesti-

mate the amplitude, frequency composition, and duration of the ground shaking. The Armenian earthquake had a local epicentral intensity of IX–X, whereas the buildings were designed to only withstand an intensity VII, which was only about one-eighth the actual force level of the earthquake. One reason why the building design was not adequate to withstand the ground shaking was that the ground motion amplification properties of the soil had not been taken into account in the zoning and building codes.

We in the United States are not as prepared as we should be for similar disasters in many earthquake-prone areas of the country.

- Good, quality construction can provide a margin of safety that can help compensate for the uncertainties that scientists and engineers still face in siting and design. The quality of construction and detailing were inadequate in Armenia to meet the force of the earthquake. Modern buildings designed and constructed in the 1970's failed and caused numerous deaths primarily because the floor systems were not constructed and anchored in a way that allowed them to absorb the energy along with the structure.
- Despite whatever preparations are made and however carefully buildings are constructed, almost all earthquakes produce "surprises" because knowledge about the nature and effects of earthquakes is often lacking or what is known has not been properly applied. A damaging earthquake exposes the flaws in siting and design of structures and lifeline systems, construction practices, emergency response, and personal and community preparedness. In each of these areas, through the proper use of scientific information, much can be done to correct these critical flaws and to develop effective response plans to mitigate the effects of natural hazards.

Although the Spitak earthquake was not a surprise in terms of the seismotectonic framework of the region, the disaster brought some harsh realities to light. The first 24 hours of search and rescue efforts were hampered by the winter environment. The disaster also paid grim testimony to the vulnerability of precast reinforced concrete frame buildings, many of which still exist in the Armenian capitol of Yerevan and in other parts of the Soviet Union. Perhaps most emotionally devastating was the extremely high death toll, which, combined with the harsh winter conditions, made burial of the dead difficult and created public health concerns.

Using the Lessons Learned

On May 23–27, 1989, representatives of the United States team that went to Armenia after the December 7th earthquake and other specialists met with their Soviet counterparts in Yerevan to share their insights with representatives of the French and Japanese teams. It is hoped that these insights will aid the Soviet's reconstruction program and also serve as the basis for other cooperative endeavors to reduce the chances of a disaster like this one from happening again in the Soviet Union or in the many other parts of the world that are vulnerable to natural disasters.

Galeras Volcano Provides Opportune Site for Hazard Response Workshop

By Mary Ellen Williams

When Galeras Volcano near Pasto, Colombia, became visibly active in February 1989 after 2 years of intermittent precursor activity, it afforded the perfect site and opportunity for an international workshop on rapid response to volcanic crisis. The imminent potential for disaster was present throughout the training

Galeras Volcano, Pasto, Colombia, May 1989, site of the international volcano workshop. (Photograph by David H. Harlow.)

session (May 8–29, 1989). This workshop, which was originally planned to take place in Arequipa, Peru, gave participants an opportunity for hands-on training during a real crisis. Although the activity of Galeras Volcano had a substantial impact on the local economy, the volcano stabilized, and no mass evacuations were ordered.

The workshop was held to assist in national and local efforts to respond to unrest at Galeras Volcano and to provide training to Latin American countries that were concerned with actions and problems associated with emergency response to volcanic crises. The 50 participants in the workshop came from Argentina, Bolivia, Chile, Colombia, Ecuador, Guatemala, and Peru. A dozen instructors from Colombia, Ecuador, and the United States taught the workshop sessions.

Held in cooperation with the Instituto Nacional de Investigaciones Geológicos Mineras (INGEOMINAS) of Colombia and the Colombia Geological Survey, the workshop was designed as a training activity by the Volcano Disaster Assistance Program (VDAP) of the USGS. VDAP is cooperatively funded by the USGS and the Agency for International Development's (AID) Office of U.S. Foreign Disaster Assistance (OFDA). Additional support for the workshop was given by Unesco's World Organization of Volcano Observatories (WOVO), USAID/Bogota and Guatemala City, and the State of Nariño, the city of Pasto, and the Oficina Nacional para Asistencia de Desastres of Colombia.

Prior to the establishment of the VDAP in 1986, the USGS and OFDA had mobilized their responses to volcanic disasters on a case-by-case basis. From those responses to volcanic crises, it was decided that to develop and to maintain a core team of scientists and technicians—VDAP—who could provide rapid response, assessment, monitoring, and training would be a more effective way to reduce the effects of volcanic hazards. Perhaps one of the most important aspects of the VDAP effort is that it assists developing countries to build their own technical institutions and to enhance their own response capabilities before volcanic crises occur.

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The first week of the workshop was devoted to familiarizing the participants with Galeras Volcano, volcano hazards in general, various monitoring and forecasting techniques, data analyses, and methods of effective civil defense response by means of formal talks, videotapes, and field visits. The participants then were divided into groups to work with INGEOMINAS and public service groups to improve the monitoring and forecasting facilities on Galeras, to define hazards and risks associated with the volcano, and to assist ongoing education, information, and communication activities by national and local governmental and civil defense groups.

The groups specifically addressed the following:

- Hazards evaluations—Geologic field work to determine the nature and distribution of ash, gas, and other eruptive products of past volcanic activity; solicitation and compilation of historical observations; and compilation of meteorologic data that pertain to volcanic hazards.

- Risk assessment—Determination of civil infrastructure and population within the hazards zones.
- Monitoring-forecasting—Seismic, deformation, geochemical monitoring, and upgrading and organizing a computer facility at Pasto Observatory.
- Information-education—Evaluation and development of pamphlets and posters for the public; development of a videotape on volcanic hazards and Galeras Volcano.

During the last week, the working groups summarized their studies and produced reports and other products that could be used by Colombian groups in response to an eruption of Galeras Volcano. These products were also intended to be used as guides in planning responses to future volcano crises in the participants' countries. On the final day, the findings and products were reviewed in a closing conference. Local and national Colombian officials and U.S. Embassy personnel joined the participants and instructors in reviewing the products and discussing the findings. Written reports were submitted to the workshop organizers.

A resolution was also written and signed by workshop participants recognizing the need and giving full support to the formation of the Centro Andino du Volcanologia to assist at Galeras and to provide technical training and support during any future volcanic crisis in other locations in South America.

As a result of the workshop in Pasto, Colombia, VDAP was able to contribute to strengthening the volcano observatory at Pasto. This recently established observatory had been sharing equipment with another Colombian volcano observatory in Manizales. The Manizales Observatory was established with assistance from the U.S. Government during the volcanic eruption of Nevado del Ruiz in 1985. Equipment for the Pasto Observatory has now been augmented substantially by the U.S. Government, and for several months, U.S. technical advisors for VDAP have monitored the volcano with the Colombians. A transfer of this equipment to the Government of Colombia is in progress.

Scientists measuring deformation, Galeras Volcano, Pasto, Colombia, May 1989. (Photograph by David H. Harlow.)

United States Hosts International Gathering of 6,000 Earth Scientists

By Bruce B. Hanshaw

Introduction

Just over 6,000 earth scientists, exhibitors, and guests representing 104 countries around the world gathered in Washington, D.C., from July 9 through 19 to attend the 28th Session of the International Geological Congress (IGC). The Congress was cohosted by the U.S. National Academy of Sciences and the U.S. Geological Survey, in cooperation with nearly 150 scientific societies, governmental bodies, universities, industrial organizations, and individual sponsors. The United States has hosted two previous IGC's, the 5th in 1891 and the 16th in 1933. Fourteen members of the last U.S.-hosted (1933) IGC attended a reunion with other honored guests and IGC officials. The 28th was the largest Congress in its 121-year history.

The 28th Congress featured more than 3,000 scientific and technical presentations on the latest research in geology, geochemistry, geophysics, and allied disciplines. Also featured were nearly 50 pre- and post-Congress field trips to geologically significant areas across the United States, including Hawaii and Alaska. One trip, exploring the Scotia arc region, was the first formal geologic field trip ever to visit the Antarctic continent. During the Congress itself, 20 shorter trips studied aspects of the geology of the Washington, D.C., area.

The scientific program of the Congress addressed current problems facing the geological sciences, many of worldwide concern, and stressed the increasingly interdisciplinary nature of approaches to their solution. Two one-half-day all-Congress colloquia shed new light on fields of major interest to the world earth-science community, dealing with planetary geology and world natural resources, which included invited presentations by international panels of experts in these fields.

Innovations

The 28th IGC introduced several programmatic features not seen at previous Congresses. With the Youth Congress program, the IGC reintroduced and expanded an activity seen at only two previous Congresses. The Youth Congress provided 85 young people, aged 13–19, who accompanied their parents to the IGC, with entertaining and educational opportunities to increase their knowledge and interest in the earth sciences. Activities included hunting for fossil shark teeth, exploring local caves, hiking through the rocky Potomac River Gorge, going "behind the scenes" at museums of the Smithsonian Institution, and visiting the Goddard Space Center of the National Aeronautics and Space Administration.

Grant programs that had been used in some previous Congresses to help defray expenses of scientists from developing countries became a formal part of the 28th IGC program. The Geohost Grant Program helped individual scientists, principally those from developing countries, to attend the Congress by partially subsidizing the expenses incurred within the United States. Selection to the program was competitive. A panel composed of representatives of the IGC, International Union of Geological Sciences, Unesco, and the Association of Geoscientists for International Development chose 50 grantees and 15 alternates from among 400 qualified applicants.

The Travel Grant Program, like the Geohost Program, helped individual scientists, principally from developing countries, to attend the Congress by partially subsidizing travel costs to Washington, D.C. This program which was funded entirely by Unesco, provided funds to 43 participants from 41 developing countries. Thirty-eight of the 43 grantees also received funds from the Geohost program.

A program of short courses and workshops provided participants ways and means to exchange and share state-of-the-art knowledge in areas of scientific or technological interest. Short courses were presented by discipline specialists in an instructional format to professional earth scientists who desired specialized training in a new discipline or merely wished to broaden their general knowledge. Workshops provided selective forums at which knowledge of new research could be shared and discussed among specialists in a subject area.

Poster sessions, a meeting presentation format growing in popularity, allocated wall space on which a presenter could hang maps, diagrams, photographs, and brief explanatory text. The presentation material remained on display for one-half day. The author was present during that time to interact with interested colleagues, explaining, discussing, and defending the posted results.

The IGC Gazette, part of the publicity and news media activities of the 28th IGC, was a 4-page daily newspaper that focused attention on scientific themes and issues of that day's symposia and poster sessions. The Gazette also featured articles and editorials about the organization and management of the Congress, the history and infrastructure of geological science, announced social activities, and kept delegates informed of last-minute schedule changes. News releases issued in advance of the Congress and daily news conferences, radio feeds, and interviews with scientists during the Congress ensured that word of the Congress, its activities, and advances in the earth sciences reached a wide national and international audience.

International Geological Congress Awards

The Spendiarov Prize from the USSR Academy of Sciences, the most prestigious award given at the IGC and presented to an outstanding scientist in the host country, was presented to Susan Werner Kieffer of the U.S. Geological Survey. Kieffer joined the USGS in 1979 and was elected to the National Academy of Sciences in 1986. Kieffer, who is the first woman and the third American to win the Spendiarov Prize, was cited for her "contributions to our knowledge of the Earth and the planets" and for her prolific research in fields ranging from volcanology and planetology to thermodynamics and river hydraulics. Her research has included work on mechanisms of eruption for volcanoes and geysers, the prediction of thermodynamic properties of minerals, and the effect of shock waves during planetary impacts.

The Hans Cloos Medal, the highest award of the International Association of Engineering Geology (IAEG) was presented to David Varnes on July 13. Varnes, an engineering geologist with the USGS for the past 48 years was honored for his contributions to the scientific basics of engineering geology and for his service to the profession and the IAEG. A recognized specialist in the study of landslides, Varnes is now working on methods of predicting earthquakes. He has made significant contributions to science through the publication of more than 100 papers, booklets, and monographs. His book, "Landslide Hazard Zonation," has become a classic in the field. Varnes also was cited for his contributions to the development of the IAEG.

Looking Ahead: 29th International Geological Congress

Japan will host the 29th International Geological Congress (IGC), scheduled from August 24 to September 3, 1992, in Kyoto. The Congress will meet in the Kyoto International Conference Hall, which is a fully equipped, modern convention facility located in the northern suburbs of Kyoto City. The site, noted for its beautifully tailored Japanese-style gardens, is a convenient base from which to tour old Kyoto, the ancient capital of Japan, and other attractions.

The 29th will be the first IGC held in an active island-arc setting. Thus, the scientific program will focus on geologic processes and phenomena that characterize or are associated with island arcs. A range of field trips to geologically important areas of Japan and neighboring countries will emphasize island-arc geology and geophysics.

Abu Dhabi Image Mapping

By Jean-Claude M. Thomas

In seeking a sound scientific basis upon which to effectively manage and conserve their critical ground-water resources, the Emirate of Abu Dhabi of the United Arab Emirates sought the cooperation of the USGS. Under a Memorandum of Understanding between the USGS and the National Drilling Company, an agency of the Emirate of Abu Dhabi, a project was begun in October 1988 to exchange scientific and technical knowledge to augment the scientific capabilities of the National Drilling Company.

The project is designed specifically to assess the ground-water resources of the Al Ain and Liwa Oasis areas—the two major areas in Abu Dhabi where significant freshwater is known to occur. This project, which involves a staff of nine USGS scientists and support staff based in Al Ain, provides an opportunity to apply ground-water systems-assessment techniques and methodologies developed in the U.S. domestic programs in a foreign, arid environment having marked hydrologic, physiographic, and geologic differences from better known domestic terrains. New knowledge gained from the Abu Dhabi studies will in turn be applied by USGS scientists to enhance future domestic ground-water assessment programs.

The water-resources assessment project was hampered by three factors: (1) the lack of systematic map coverage of the Emirate of Abu Dhabi at the 1:20,000 and (or) 1:50,000 scales, (2) the need to be able to locate water wells, and (3) the need to map the geology and hydrogeology quickly. Satellite image maps of the area have answered these needs. An image map of the country at the 1:250,000 scale was prepared and found particularly useful for delineating areas. This mosaic of nine individual Landsat Thematic Mapper images was assembled by computer. The mosaic displays the data of band 2 (green-yellow), band 4 (near-infrared), and band 7 (middle infrared) of the Thematic Mapper. For the first time, an "adjustable" filter was used on the data from these various bands, which eliminates haloing and ringing in areas of high tone contrast, for example, contrast between dark ocean and light beach, ophiolite rocks and limestone, oasis vegetation, and sands (fig. 1).

More detailed image maps at the 1:20,000 scale for field work and at the 1:50,000 scale for compilation and publication were generated by merging data from two satellites. These image maps

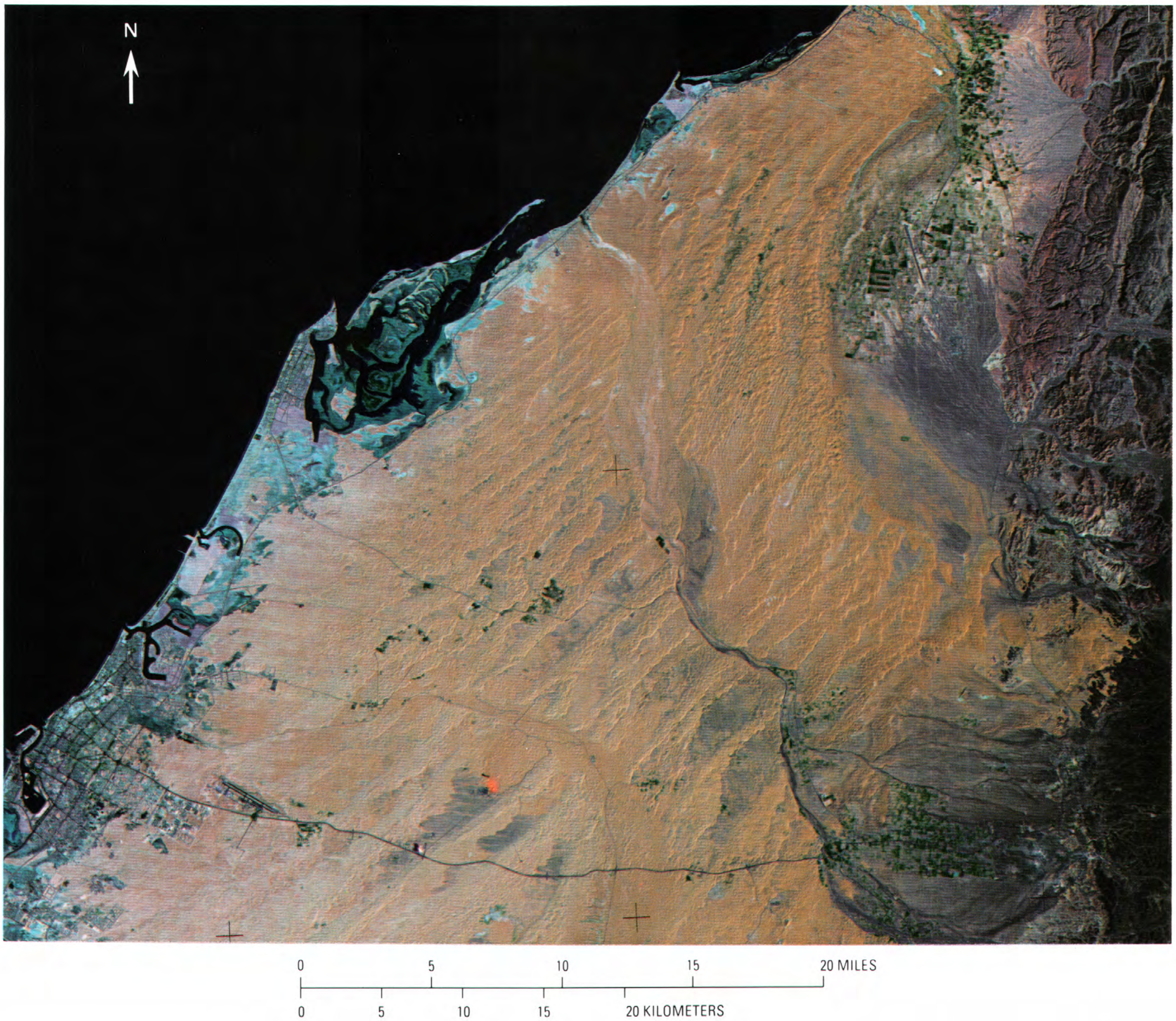
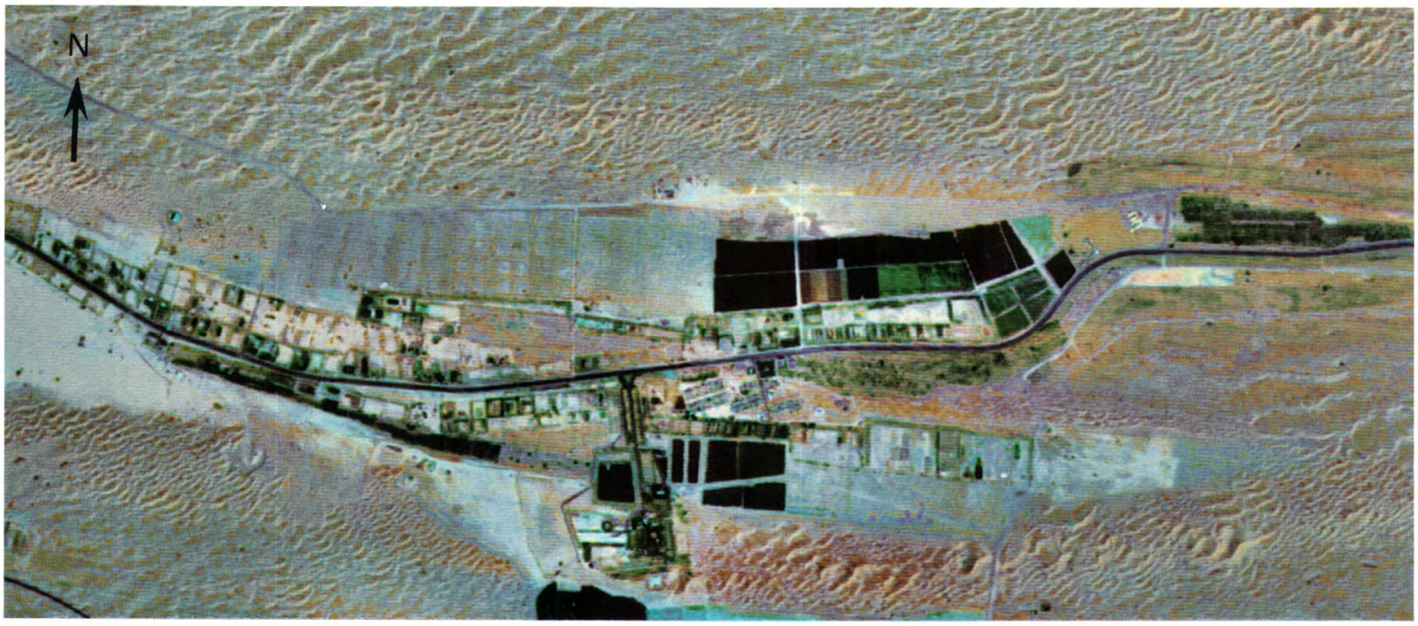


Figure 1. Emirate of Abu Dhabi, United Arab Emirates Landsat satellite image map. Note to the east the dark ophiolite rocks and the metamorphosed younger sedimentary rocks of the Musandam peninsula, in the southeast the agricultural town of Al Dhaid, and to the southwest the cities of Al Sharjah and Ajman.



Abu Dhabi road, 1:50,000-scale image map. Note the light green strips of irrigated acacias that protect the road, cultivated areas, and village of Al Khazna from drifting sands.

display the most useful radiometric information from the Landsat Thematic Mapper bands 2, 4, and 7 and add to it the sharpness of the 10-meter resolution of the French SPOT (Satellite pour l'Observation de la Terre) High Resolution Visible Panchromatic.

To date, 47 image maps have been completed in support of the groundwater research project in the Al Ain piedmont areas, and another 56 are being generated for the Liwa Oasis area within a short timeframe. The specifications and quality control of the work are performed by the USGS and most of the work is done by private contractors.

Other International Program Activities

The strengthening of earth-science institutions in foreign countries, training of foreign nationals, and exchange of scientists are activities integral to all international programs. During FY 1989, 79 nationals from 22 countries received training in the United States. Fifty-seven visiting scientists from 16 countries either conducted research at the USGS or at other facilities as arranged by the USGS. USGS personnel trained more than 60 foreign-national scientists and technicians either individually in-country or collectively in groups at scheduled regional training sessions. Examples include the marine geology course in Turkey (31 participants). More than 30 countries benefited from these USGS overseas training efforts.

Many staff scientists represent the USGS or the U.S. Government while they serve as officers, committee members, or participants in international organizations, commissions, and associations; for example, many hundreds of hours of effort were provided by USGS personnel, in cooperation with hundreds of other U.S. earth scientists, in the preparation and presentation of the 28th International Geological Congress in Washington, D.C., during July 1989. James F. Devine, USGS Assistant Director for Engineering Geology, was appointed Senior Science Advisor to the United Nations International Decade of Natural Disaster Reduction. He will serve in Switzerland from December 1988 to June 1990 to establish the Secretariat and implement the Decade.

Activities with sponsoring countries listed in the following text were conducted by the USGS in FY 1989 under bilateral agreements sanctioned by the Departments of State and of the Interior:

Australia
Hydrologic network design.
Bangladesh
Strengthening the Geological Survey of Bangladesh; mapping the extensive Ganges Brahmaputra Delta.
Bolivia
Evaluation of SPOT/LANDSAT images and map revision at 1:50,000 scale.
Canada
Marine geology; geophysics; water resources; acid rain; ore deposit models; platinum group elements; Great Lakes seismicity; Arctic research; mapping data exchange; border digital mapping; atmospheric deposition.
Chile
Seismic zoning; improved earthquake-resistant designs.
China
Surveying and mapping research—cartographic applications of remote sensing and development of geographic information systems. Earth sciences research—pyrophyllite deposits; comparative geochemical anomalies in Xinjiang and Southwestern United States; modeling for Bayan Obo iron-niobium-rare earth deposit in Inner Mongolia; exploration for gold and uranium deposits. Surface-water research—sediment transport; hydrologic equipment and measurements; hydrologic extremes; analytical techniques; hydrologic data exchange; cold regions hydrology; isotope research. Earthquake research—deep crustal structures in fault zones; premonitory phenomena; crustal stress; seismic networks; rock mechanics; intraplate active faults.
Costa Rica
Biochemical research; coal resource assessment review.
Dominican Republic
Study of biochemical corrosion of gates of the Sabama Yequa Reservoir.
El Salvador
Geologic hazards assessment; evaluation of seismic hazards and compilation of seismic risk map.
France
Oceanography; geophysics; radioactive wastes; minerals assessment; bore-hole geophysics application to water resources; sea-ice monitoring; remote sensing in polar regions.
Germany
Marine seismology; radioactive wastes; petroleum resource assessment; Antarctica research; sea-ice monitoring; marine minerals assessment.
Greenland
Ice-penetrating radar surveys.
Hungary
Petroleum resource potential of the Pannonian Basin; geophysics.
Iceland
Geophysics; geology; hydrology.
India
Multidisciplinary workshops; ground-water modeling and data-base development; identification of mutually beneficial joint projects.
Indonesia
Volcano hazard mapping; institution development in marine geology; peat swamps as coal field analogs.
Italy
Installation of digital seismographs; earthquake reconstruction; improvement of capability for early warnings of volcanic eruptions; Antarctic research.
Japan
Deeply buried mineral deposits; gold deposits; debris-flow hazards; sediment transport on continental shelves and in estuaries.
Jordan
Seismic network; remote sensing.
Korea
Sedimentary basin analysis; ground-water evaluations; Antarctic research.
Mexico
Border mapping cooperation and information exchange; structure and mineralization of the Sonoran Desert.
New Zealand
1:50,000-scale mapping in McMurdo Sound of Antarctica.
Norway
Digital sonar images data processing.
Pakistan
Coal resources exploration and assessment; regional framework studies; institutional modernization of Geological Survey of Pakistan.
Panama
Earthquake hazards mitigation; humid regions hydrology.
Portugal
Massive sulfide deposits in the Iberian pyrite belt.

Saudi Arabia
Mineral resources assessment and data base; geographic and geologic cartography; geochemistry and geophysics; Landsat image maps; seismic network; strengthening of the earth sciences community.

Senegal
Ground-water modeling and data network.

Spain
Ground-water geochemistry and flow systems; remote sensing for mineral deposits; earthquake research; marine geology of continental margins; water-resources management and pollution reduction; gold-alunite deposits; hydrochemistry in Canary Islands.

Suriname
Ground-water modeling.

Turkey
Marine geology training course.

United Arab Emirates
Ground-water resources assessment of Abu Dhabi; remote sensing image maps.

United Kingdom
GLORIA seafloor sonar imaging surveys; Antarctica remote-sensing image mapping and geographic information systems.

USSR
Earthquake prediction; estimation of seismic risk and seismic sources; marine mineral resources; global change; Arctic permafrost; Antarctic research; research-personnel exchanges.

Venezuela
Geologic mapping and mineral resources assessment of the Guyana shield; erosion rates and sediment composition of the Orinoco River.

Yugoslavia
Soils surveys; geochemical exploration methods; seismology and earthquake hazards; granite metamorphic complexes; remote sensing; coal quality.

Programs in which activities were conducted under multilateral agreements in FY 1989 included the following:

- International Strategic Minerals Inventory, cooperative studies by USGS and U.S. Bureau of Mines with Australia, Canada, West Germany, South Africa, and the United Kingdom to develop a global assessment of strategic commodities including cobalt, nickel, platinum, titanium, and tin.
- Global Seismic Network, the generation of a comprehensive, unrestricted seismic data base for fundamental earthquake monitoring and research (150 stations in 54 countries).
- Famine Early Warning System, (FEWS), the application of geographic information systems to target populations at risk of famine in eight sub-Saharan and Horn of Africa countries: Mauritania, Mali, Burkina, Niger, Chad, Sudan, Ethiopia, and Mozambique.
- AGRYMET, identification of remote sensing data requirements to make agricultural, hydrological, and meteorological assessments in nine west African countries: Mauritania, Senegal, Gambia, Guinea-Bissau, Cape Verde, Mali, Niger, Burkina, and Chad.
- Grasshopper and locust habitat identification and monitoring by remote sensing in Chad, Mali, Mauritania, Niger, and Sudan. (See article on p. 69.)
- Antarctic research including acquisition of seismic and other geophysical data, geodetic data, aerial photography, and satellite imagery to produce base maps and to assess changes due to global change in the glaciers and ice sheets comprising the margin of Antarctica; multinational crustal transect studies; operation of the Scientific Committee on Antarctic Research's (SCAR) Library for Cartography and Geodesy; seismology and data telecommunications at the South Pole; ice-cap motions, sea-ice monitoring; ice-penetrating radar surveys; biochemistry of lakes.
- Interagency Volcano Early Warning Disaster Assistance Program provides for emergency responses worldwide to crises related to volcanic eruptions. (See article on Galeras Workshop, p. 75.)
- Advisory consultations, particularly in resource assessment methodologies, to intergovernmental geoscience organizations in eastern Asia; preparation of regional base maps at 1:2,000,000 scale covering approximately 12 million square miles.
- Circum-Pacific Mapping Project, program coordination and the cartographic preparation of about 60 thematic maps.
- Southwestern Pacific offshore exploration for petroleum resources.
- Ground-water modeling, Senegal River Basin, Senegal and Mauritania.

- Advisory coordination and training in coastal geologic hazards and resources assessments in the western-southwestern Pacific.
- Technical expertise provided to agencies of the United Nations as requested: Gold geology and chemistry (Turkey); gamma-ray spectrometry (Cameroon); installation of geophysical computer programs (China); geotechnical measurements on unconsolidated sediments (China); marine geology workshop (Turkey); geoscientific studies of the South Pacific (Fiji); design and implementation of computerized hydrologic data bases (India); ground-water modeling (Suriname).
- Technical expertise provided to member nations of the Pan American Institute of Geography and History (PAIGH) through the Commissions on Cartography and Geophysics as requested; remote sensing applications (Bolivia); onshore-offshore mapping (Central American nations).

Information Systems Activities

Mission

The Information Systems Division provides support and services to the Director of the U.S. Geological Survey, to major programs in each division of the USGS, to the Department of the Interior, and to other government agencies on information technology and automated data processing (ADP). The Division operates the USGS's mainframe computer located in Reston, Va., and Technology Information Centers and minicomputers in four ADP Service Centers nationwide. The Division assists users in acquiring ADP and telecommunications hardware, software, and services; coordinates and improves information systems through systems analysis and design; provides user education and assistance; and conducts research into better ways to use computer technology to solve mission-related problems. The Division coordinates, manages, and operates voice, data, and radio communications for the USGS, including GEONET, the data communications network of the Department of the Interior, from which gateways provide access to other national networks and supercomputer systems.

Highlights

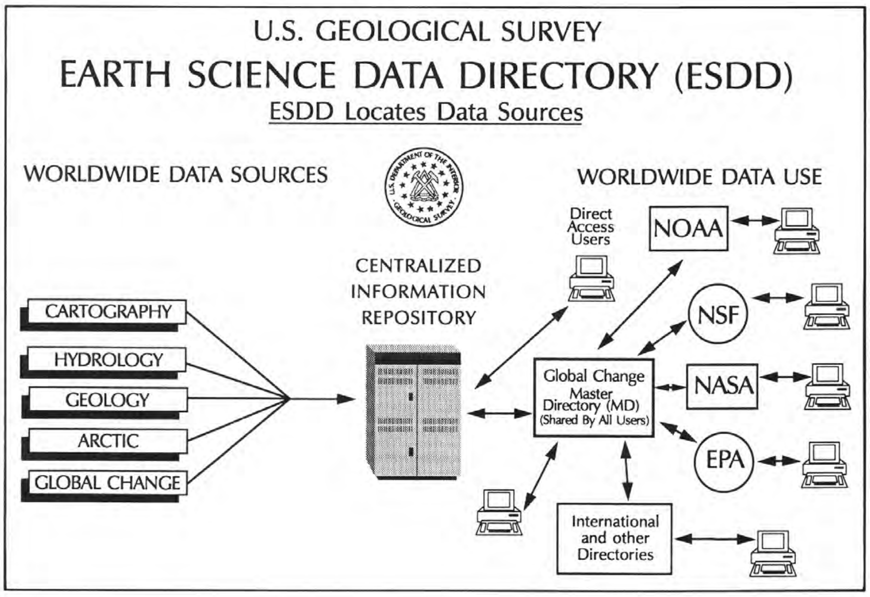
Earth-Science Data Search Solution

By C.R. Baskin

Researchers and scientists, managers and planners alike are increasingly finding the solution to their search for sources of earth-science data in the Earth Science Data Directory (ESDD). Operational since 1985, ESDD now involves a large community of participants—both contributors and users—who find the directory a useful source and outlet of information for a variety of projects, everything from global change and polar research to industrial site development.

Not only does ESDD deliver information from a U.S. Geological Survey mainframe computer about the location of a data source, but it also provides considerable descriptive material about the source of that data. Because ESDD can be accessed from almost any local computer terminal equipped with a modem and telecommunications software, and because its powerful, menu-guided search features make it extremely easy to use, it is easy to understand the rapid growth in its use. The availability of the ESDD on compact disk since mid-1988 has extended its use to an even broader community.

A substantial subset of the ESDD is the Arctic Environmental Data Directory (AEDD). Now that AEDD is expanding to include information about Antarctica, it will aid scientists and researchers who are concerned with polar processes at both poles and the relation of these processes to global change. The AEDD is being used to provide a connection between polar scientists and global change data sets through a shared "interoperable directory," created for the U.S. Global Change Research Program by the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the National Science Foundation, and the USGS. The "interoperable directory" allows researchers to tap the complete coverage of the directories of all of these agencies by simply querying any one agency directory. Among many others, AEDD data sets include those relating to sea ice, polar mammals, marine life, Arctic soils, mean snow depth, climate,



USGS Amdahl 5890 stores and delivers references to earth-science and natural-resource data.

geology, oceanography, glaciology, remote sensing, and terrestrial ecosystems.

In today's fast-paced world of earth-science and natural-resource research, developmental planning, and environmental monitoring projects, a geographic information system is often an essential component in problem solving. Over one-fourth of the respondents to a 1988 ESDD user survey, for example, indicated that the directory had helped them to locate data for use in a geographic information system. One respondent said, "It has allowed us to view what other data are available for the State for future use." The ESDD is a mechanism having many users who will be increasingly better served as the directory continues to grow. ESDD contains more than 2,000 references to data from over 200 sources. System users—more than 150 authorized online—are located in all parts of the country and include all levels of government, the university community, and the private sector. Coverage has been extended to include sources in every State. New sources of references and new users of ESDD are continually being sought by the USGS in order to develop an even more effective solution to the researcher's quest for reliable and accessible earth-science data.

Local Area Networking at the U.S. Geological Survey

By Kathleen Schabacker

The number of USGS scientists, administrators, and support personnel who are using local area networking technology has grown rapidly over the past several years. A local area network (LAN) is an excellent method for sharing both information and computing resources. It is a communications network whose components are located within a relatively small geographic area (for example, within a building) and are tied together via telecommunications wiring so that all components are physically accessible to all other components. Examples of the components that can be linked together are personal computers, workstations, file "servers," printers, and mini- and mainframe computers. A file server can be a microprocessor having storage capacity to store sharable data files; the printer could be a high-quality laser printer to which all the LAN users can direct output. With a LAN, users can enjoy the convenience of a desktop processor and at the same time benefit from equipment that provides the power of mainframe processing, the sharing of data and information, and the quality of expensive laser printers without duplication of equipment.

Different hardware specifications (for example, Ethernet, Appletalk) and software protocol standards [for example, Transmission Control Protocol/Internet Protocol (TCP/IP), Xerox Network Services (XNS)] exist that can be combined to create a LAN. Successful implementation is the result of much analysis and planning. For this reason, the USGS has begun to define local area networking policies and guidelines so that users can more easily procure and implement the most applicable hardware and software for their needs.

Local area networks can also be interconnected, which makes them even more powerful and accessible as shared resources. Geographically dispersed areas can be connected via long distance telecommunications links (wide area networking); in the case of the USGS, many of the local area network facilities (GEOLAN) are connected via the wide area network facility (GEONET). Procurements for new computer systems, such as the Department of Interiorwide Distributed Information Systems II procurement that provides high performance information systems and services to satisfy a multitude of departmental needs, now specify LAN capabilities.

> *... the USGS has begun to define local area networking policies and guidelines so that users can more easily procure and implement the most applicable hardware and software for their needs.*

Different hardware and software can reside on different LANs. To allow these different systems to talk to one another, specialized equipment such as "gateways" can connect networks that use different communications software protocols, and "repeaters" can connect networks that use different physical media. "Routers" are available to send data across a network in the most efficient way, and "bridges" are used to filter and forward data across a network.

Local area networks exist at many USGS sites across the country. The National Coal Resources Database System, the many geographic information systems being used, the distributed information systems of water-resources information, and the Federal Financial System of the Department are just a few of the major applications that use local area networking. Because of the flexibility that LANs afford, the USGS has begun development of a network system that is truly capable of sharing information and resources throughout the USGS.

Generating Color Separations of Geologic Maps on Low-Cost Computer Systems

By Alex Acosta and Janet Barrett

Geologic maps are the basic tools by which scientists, planners, and managers can study the rocks and structure beneath the surface of the Earth and other planets. These maps allow scientists to see the planet as it would appear with all the overlying materials stripped away to reveal the layers of rock below. To portray the complex structure of these buried rock layers, geologic maps are produced in multiple colors.

Color separations for printing these geologic maps may be generated by using manual or computerized methods. The manual method is labor-intensive and time-consuming and requires several photographic products. The computerized procedure requires few photographic products to prepare a map for scanning. In the computerized procedure, manual steps include preparing the geologist's original compilation, editing the scanned version of the map, tagging polygons, and doing some color coding. The computerized procedure helps to reduce or eliminate materials, labor, time, and registration errors.

As part of a productivity enhancement effort begun in 1989, USGS computer scientists are experimenting with a procedure on a general-purpose computer to produce the necessary color separations for printing geologic maps. The computer scientists are also developing a procedure using a low-cost personal computer that will make this capability available to field geologists. With this procedure, field geologists will be able to do more detailed processing of their original field work on their own computers.

Figure 1. Author's original line drawing on a shaded-relief base map of Mars. This is a photographically enlarged subarea of the original. North is to the top.

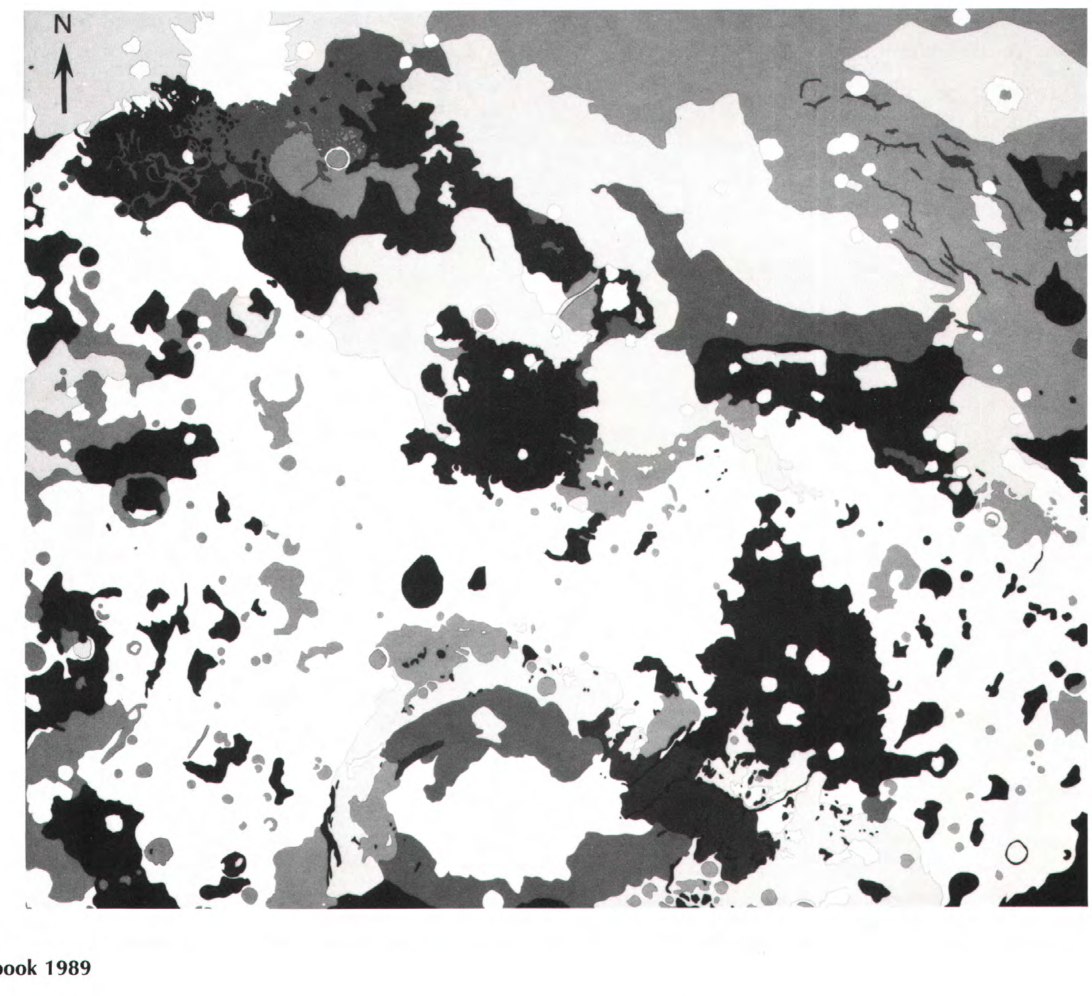


Figure 2. A photographically reduced version of a yellow color separation. The gradation in gray-tone exemplified by this version of the original is induced by the limits in the eye's resolving power to detect the varying dot patterns. Light-toned areas would be covered with yellow ink in the printed map.

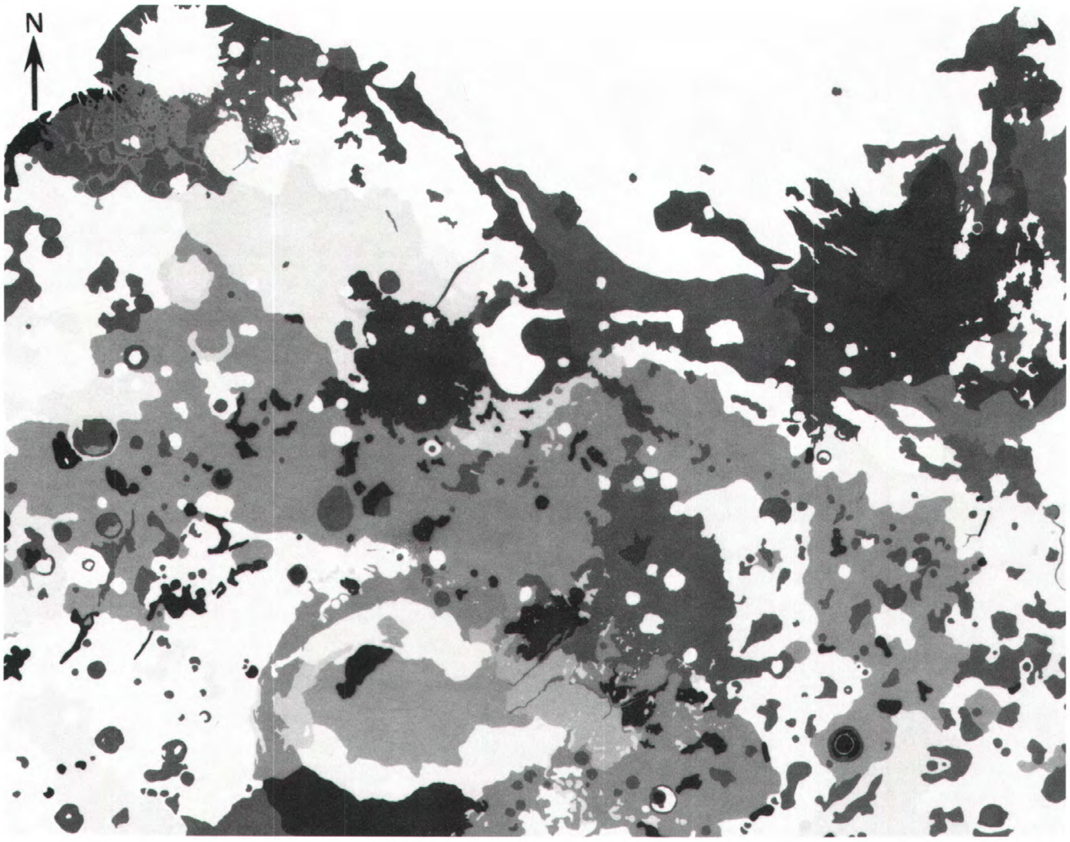


Figure 3. A computerized peel-coat. The areas of all polygons have been filled with corresponding tag values. Open-window negatives are generated by assignment of tag values in the computer.

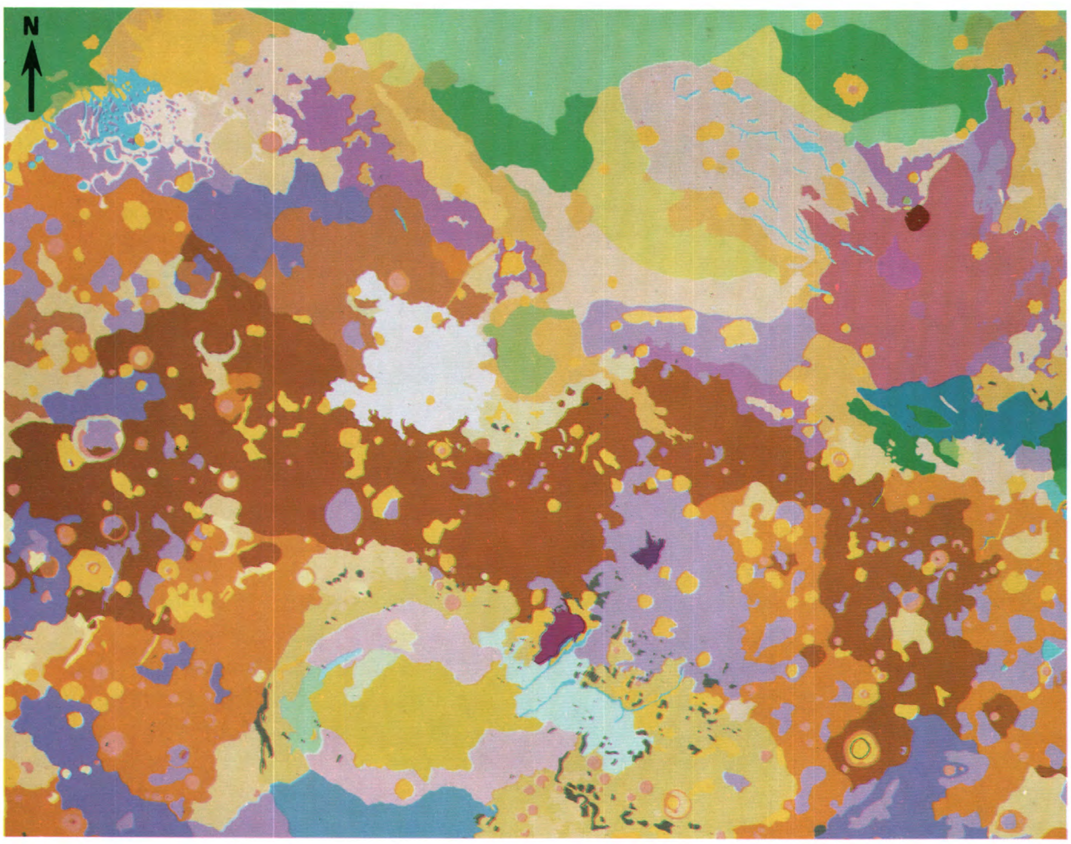


Figure 4. A colored geologic map. The computerized peel-coat was interactively colored to produce this product.

Parallel Processing—Powerful Tool for the Earth Sciences

By Rick MacDonald

The complex processes of nature, the still mysterious forces at work deep beneath the Earth, and the puzzling phenomena of natural hazards are excellent candidates for the applications of new computer technologies. Earth science has the wide range and complexity of disciplines that challenge the leading edge of computer technology. Each new research venture in earth science demands more and more computing resources. Research interests that can benefit from better computational tools include projects in geology, hydrology, seismology, volcanology, geochemistry, geography, and cartography. Much can be learned, for example, from constructing dynamic computer models of the core and mantle of the Earth, which allows an unprecedented insight into the forces that drive the Earth's tectonic plates. Other computer models can predict how toxic and radioactive contaminants behave as they travel in ground-water systems. Three-dimensional geographic information systems, which can be used to integrate almost infinite permutations and combinations of geologic, hydrologic, and topographic information, allow scientists to analyze relations among the Earth's properties and to understand better the processes at work.

Each new research venture in earth science demands more and more computing resources.

Supercomputers are one of the exciting new and developing technologies that can provide the data-handling resources to unlock the mysteries of the Earth's processes. Newer supercomputers employ a wide variety of "architectures", including scalar, vector, parallel, vector-parallel, and massively parallel. Scalar and vector architectures are familiar to most earth and computer scientists—these are the more standard computing environments that use conventional programming and a sequential processor in analyzing data.

Parallelism, however, introduces a high degree of complexity into the effective use of computers. One reason is that sufficient software tools have not been developed for parallel processors. Also, scientists have been trained to view computers as sequential processors and to program them accordingly. Also, because scientists have viewed computers as only sequential machines, they have been slow to conceptualize the mathematical algorithms that would help them to solve problems more effectively through parallel processing.

Parallel Processing

Parallelism in computer systems is not a new concept. Operating systems have been designed for years with the capability for either simulated or actual parallel operation. Forms of parallelism have been considered in hardware design ever since the early days of computers. Parallelism has been defined as "a collection of processing elements that can communicate and cooperate to solve large problems fast." Parallel processing systems can be characterized by the number of processor elements (CPU's) that it has, how much memory it has, how the memory is distributed, how the processor elements communicate, what form of interconnection network it possesses, and how the processor elements are synchronized. Some examples of parallelism are as follows:

- Timesharing—Multiple users are served by a computer, allowing more than one user at the same time to access the computer.
- Batch processing—Multiple jobs share time on a single processor.
- Multiprocessing—Multiple jobs are distributed among independent processors.
- Vectorization—Identical computations on elements in an array are performed simultaneously by using specialized hardware.

- Multiple functional units—Computation is shared between functional units designed to work in parallel within the same processor.
- Pipelining—Parts of one computation overlap parts of the previous computation when they use different hardware resources.
- Concurrentization—A single job is programmed to run on multiple processors in parallel.

The cost of circuitry has inhibited, until recently, the use of more parallelism in computer architectures. But with the cost of hardware components undergoing dramatic reductions, parallelism has become a viable solution to the problem of speeding up computer systems. Since the ultimate limitations to how fast a computer can be run are controlled by the natural laws of physics, parallelism may be the only way to increase the speeds of computers.

USGS Activities in Parallel Processing

The USGS has begun several projects to explore the potential benefits of parallel processing in the earth sciences. For example, a project is underway in which fundamental earth-science algorithms such as fluid flow through porous media and development of evenly spaced data grids from randomly dispersed satellite data of the Earth's surface are being examined in a generic parallel processing architecture. Much already has been published about the mathematical algorithms that are used in sequential processing of earth-science data. The new USGS project is examining methods and techniques that enable scientists to apply the algorithms to general parallel processing platforms. In this way, a knowledge base will be established that will form the kernel for future parallel processing efforts in the USGS.

As industry continues to incorporate this kind of architecture, more and more so-called general-purpose computers can be expected to take on the advanced characteristics of leading edge platforms that use parallel processing. Thus, knowledge about how these architectures can be used most effectively in earth-science research will be necessary.

Administrative and Facilities Support

Mission

The Administrative Division provides administrative direction and coordination in support of the scientific and technical programs of the U.S. Geological Survey. This support includes policy guidance and program direction and provides leadership and authority for various administrative management and technical support functions, including personnel, manpower utilization, finance, administrative management systems, management analysis, records management, procurement and contract negotiation, property and facilities management, motor vehicle management, security, and safety. The Division also manages the development, maintenance, and operation of the financial management system for the entire Department of the Interior. These functions are carried out at the National Center in Reston, Va., and through Regional Management Offices in Denver, Colo., and Menlo Park, Calif.

The John Wesley Powell Federal Building, Reston, Va. (Photograph by Dave Usher.)

Highlights

Credit Card Sales and Bankcards for Small Purchase Procurement

By Charlotte H. Goodson, Wendy R. Hassibe,[1] and Betty B. Brodes

As part of a continuing effort to use technology advances in automation in the areas of financial management, the U.S. Geological Survey is testing two unique programs for the use of bankcards and credit cards. These innovative initiatives include credit card sales to the general public for USGS products and the use of bankcards by Federal employees for small purchase procurements.

Credit Card Sales

The USGS offers a multitude of cartographic products and book reports for sale at 19 offices throughout the United States. These products include aerial photographs, topographic maps, mineral and energy resource maps, satellite images, selected separate sheets for the National Atlas, scientific reports, and many other products of interest to the general public and specialized users. The USGS began using credit cards for sales during fiscal year 1989 with the idea of improving service to its many customers.

Because the USGS had been considering the use of bank-cards for several years, the bureau was ready when the Treasury Department offered support in

[1] Of the National Mapping Division.

. . .credit card sales have resulted in a six-percent increase in revenue.

providing governmentwide contracts for credit card services from financial institutions. The USGS evaluated four financial institutions before selecting the Mellon Bank to provide Visa and MasterCard sales and then worked together in implementing procedures to track the financial data from the point of sale to inclusion on internal and external financial reports. Not only has the credit card option improved customer service and been a great convenience to the public, credit card sales have resulted in a six-percent increase in revenue.

The Use of Bankcards for Small Purchase Transactions

The Federal Government uses simplified, or small purchase procedures for the procurement of goods and services totaling $25,000 or less. At the USGS, the majority of these small purchases are accomplished by written purchase orders, authorized cash transactions, and orders placed against agreements negotiated with small businesses.

To streamline small purchase procedures, the USGS initiated a pilot bankcard project in fiscal year 1989 utilizing the Department of Commerce Bankcard system. For the pilot program, approximately 90 bankcards were issued to personnel in the Southeast Region District Offices of the Water Resources Division.

The use of bankcards for official purchases is expected to provide purchasing and project personnel with an efficient and cost-effective procurement method. Bankcards may be used for over-the-counter and telephone order transactions in much the same way as personal credit cards. Merchants accepting the card for Government purchases collect payment from the Federal Government through channels established by the credit card company and the parent bank.

Cardholders are authorized to use bankcards within the limits stated in their Delegation of BankCard Authority and consistent with all applicable procurement regulations. Transactions are reviewed and approved by an approving official and are subject to review by the Office of Procurement and Contracts, the Office of Financial Management, or other reviewing authorities.

In fiscal year 1990, bureauwide implementation of the bankcard program is anticipated under the Federal Supply Schedule contract awarded by the General Services Administration to Rocky Mountain Bankcard Systems, Inc.

Business and Economic Development Program

By Betty B. Brodes

The U.S. Congress has enacted several programs that utilize the federal procurement process to directly assist small and small, disadvantaged businesses in obtaining awards of federal contracts. The USGS supports these programs through its efforts to achieve the Business and Economic Development Program (BEDP) goals that are established annually in conjunction with the Department of the Interior.

The USGS was selected to receive the Department of the Interior's Unit Award for Excellence of Service during fiscal year 1989. This award is presented annually by the Secretary of the Interior to a bureau or office that either meets or exceeds each of its business and economic development program goals. The USGS not only met, but exceeded its fiscal year 1989 small business, minority business, women-oriented business, and labor surplus area set-aside program goals. These annual goals represent a percentage of the total procurement dollars and are based on historical data and advance procurement plans. The success was a result of continuing positive efforts on the part

Secretary of the Interior, Manuel Lujan, Jr., presenting the Minority Entrepreneur of the Year Award to Dorothy J. White, President, Miracle Cleaning Services, Inc. Under Secretary, Frank A. Bracken, offers congratulations at the award ceremony held on October 16, 1989. (Photograph by Tami A. Heilemann.)

of contracting and project personnel to identify new opportunities for BEDP participation in USGS programs.

In a related accomplishment, for the second consecutive year, a USGS nominee was selected to receive the Department's Minority Entrepreneur of the Year Award. Secretary Lujan presented this year's award to Miracle Cleaning Services, Inc., in recognition of excellence of performance in janitorial and trash removal services at the National Center. Miracle Cleaning Services was chosen from other small, disadvantaged businesses who have provided outstanding service to Interior offices and bureaus.

As another example of efforts to expand small business procurement, a cooperative effort between Business and Economic Development Specialists and USGS personnel in all Water Resources Division District Offices has resulted in increased representation in small and small, disadvantaged business conferences that are sponsored by congressional delegations, civic organizations, and other government agencies. This outreach activity provides information about USGS programs to the small and minority-owned business community and identifies these firms as potential suppliers of USGS activities.

Administrative Automation

By Eliot J. Christian

People, funds, facilities, and equipment all are needed to carry out the scientific research and technical programs of the USGS. The administrative management of these resources throughout the USGS is a cooperative effort in financial management, personnel services, facilities management, property management, safety and improvement efforts, and administrative systems management. Automation is becoming an increasingly critical factor in accomplishing the management of resources within applicable laws and regulations—at the lowest possible cost.

Automation efforts have been proceeding on two levels: A Strategic Initiative aimed at large scale automated applications affecting whole organizations, and an Office Automation Initiative aimed at enhancing the productivity of individuals.

Strategic Initiative

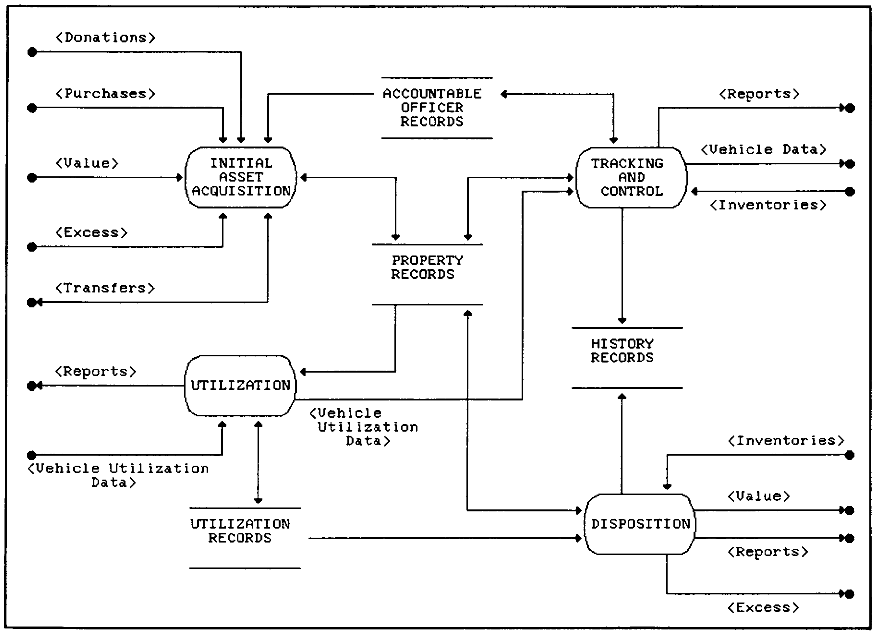
Enhancing administrative processing through automation is a major focus of efforts to help USGS managers to manage resources efficiently. Four strategic goals with respect to administrative automation are currently being pursued:

- Automated administrative systems should be easily accessible to all who need them.
- An electronic flow of information should replace paper processing wherever possible.
- Administrative procedures should be streamlined and standardized.
- A high level of integration among administrative systems should exist.

Automated Administrative Systems Should be Accessible. The intent is to design administrative Automated Data Processing (ADP) applications that are both effective and easy to use, especially with an eye toward encouraging use of efficient, USGS-wide systems rather than redundant, independent systems. While working toward a full range of automation support for administrative processing, it is recognized that no one set of centrally maintained systems can serve all the needs of all the users at all detail levels needed. Given that a measure of local administrative processing is appropriate and desirable, a major challenge is to design centralized processes so that they either can stand alone or can complement a range of distributed processes. Toward that end, administrative information databases are being placed in a central repository that is readily accessible to all users. The USGS is also pursuing (1) standard telecommunications interfaces that will make it easier to share information and (2) increased software compatibility among the various administrative systems. By so doing, a foundation is being laid for integrating more fully the various USGS automated applications that can share common databases.

An Electronic Flow of Information Should Replace Paper Processing Wherever Possible. One aspect of administrative processing that has already been a prime candidate for increased efficiency is the handling of information that is represented on paper. Since it is often the case that much of this information is eventually transformed into a machine-readable form, one goal is to move that data entry function as close as possible to the source of the information. Replacing the paper flow of information with electronic information at the earliest point in an automated system is a less costly way to move information, and it also can help to reduce data being entered more than once and improve the reliability of the data.

The first step is to identify the information being moved and the paths by which it flows. In classic system analysis style, a given set of work processes is broken down to reveal where information may be needlessly generated or handled inefficiently, and from this analysis a new set of processes is designed. However, a problem with this approach occurs when work areas are handled separately. If a system is defined too narrowly at the outset, a specific work area may be improved internally, but it will not be apparent how that island of automation can be connected to others or how the approach used could be applied in other areas. As a consequence, opportunities for improving the flow of information can be missed entirely. Recognizing the need for a broad and unified approach, efforts are underway to comprehensively analyze internal administrative procedures and to produce a model of administrative information processing.



Property management level data-flow diagram. One of the tools that is used in building an Information Model.

Administrative Procedures Should be Streamlined and Standardized. Streamlining and standardizing procedures are keyed to meeting the USGS's needs for administrative services with a minimum of burden. As part of this effort, an ongoing review of administrative systems is in use throughout the Bureau to identify opportunities for streamlining operations and eliminating duplication. One recent review in this program focused on personnel systems and generated several specific recommendations that are now being pursued. The paperless processing in the USGS of Requests for Personnel Action (Standard Form 52) is an outgrowth of this effort.

At a basic level, the challenge to streamline and standardize administrative procedures demands that information requirements first be reduced to their barest essentials. Efforts are underway to develop an administrative information processing model that will help to identify what information must be delivered by the users served and what information can be made available to those users.

Administrative Systems Should be Highly Integrated. Without a high level of integration among administrative systems, users can be burdened with confusing procedures for providing information and could receive information that is arrayed piecemeal instead of in a concise form. A related concern is that gaps between what should be related systems make for more internal work than would be necessary to achieve the same end result. Since highly integrated systems are also more easily maintained than separate or discrete systems, a strong incentive clearly exists to integrate administrative systems wherever possible.

The recent creation of two Departmental Administrative Service Centers, one hosted by the USGS and one hosted by the Bureau of Reclamation (BOR), was a major step toward integration among administrative systems. The USGS has the lead role in the financial management area, represented by the comprehensive Federal Financial System just implemented this year; BOR has the lead role in the area of Personnel and Payroll Processing. The systems are also targeted by the Office of Management and Budget as model systems with application throughout the Federal Government. Since the Federal Financial System is able to be expanded into additional administrative functional areas, such as procurement and property management, USGS leadership in this system presents a real opportunity for enhancing integration among administrative systems.

Office Automation Initiative

In addition to working on broad-based ADP applications that affect the whole USGS, the Administrative Division has implemented minicomputer applications that provide automation support for internal administrative processes. Three minicomputer systems in operation at USGS regional centers in Reston, Va., Denver, Colo., and Menlo Park, Calif., are linked via GEONET, a nationwide data communications system, forming a network having very advanced capabilities, including a true distributed database. Two of the major applications implemented during fiscal year 1989 on these minicomputers are the Property Management System and the Procurement Management Information System. One advantage gained from conversion of the Property Management System to this network of minicomputers is support for on-line processing and editing of data, which in turn improves the quality and timeliness of property data and reduces the amount of time needed to respond to inquiries. USGS employees can now access information and generate reports for selected data in the property database, thereby reducing the need for duplicate systems within the Bureau. The new Procurement Management Information System provided additional flexibility. Used to track and report on contract, grant, and purchasing workload, it has been making special reporting needs and adaptation to changing requirements much easier to accomplish.

Understanding the problems that arise when offices have incompatible automated systems, the Administrative Division set out to build a cohesive system for office automation divisionwide that would also accommodate connection with systems in the other USGS divisions. Consequently, the division standardized word processing, electronic mail, and other computing activities throughout all offices by using the MS-DOS based personal computer (PC) as a standard. This PC-based office automation approach has allowed for a fully compatible set of equipment and software that covers a wide range of needs, ranging from Computer Aided Design (CAD) systems and software engineering to desktop publishing, as well as document preparation and distribution.

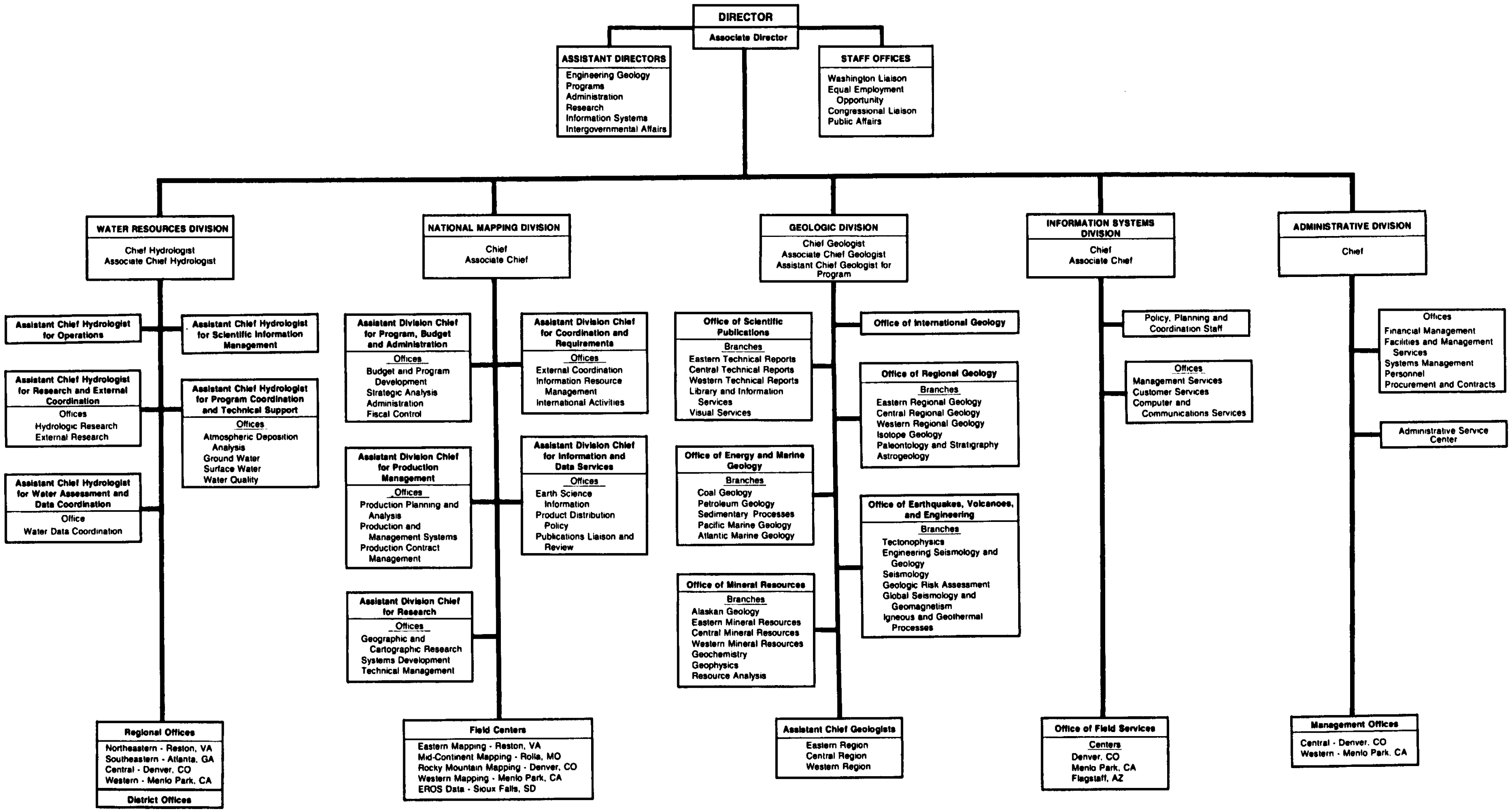
PC-based local area networks have been established at Headquarters and regional centers to tie together office automation capabilities. The use of local area networks at USGS regional centers has permitted the local sharing of printers and large capacity disk drives, and also provides for common electronic filing. By connecting these networks together via GEONET, the local networks further support the sharing of information in electronic form. Each site's local area network also has telecommunications gateway facilities to allow employees at all sites to access the Division's networked minicomputers and other USGS computer systems. Recently, Compact Disk Read Only Memory (CD-ROM) servers have been placed on the network so that each user can have immediate desktop access to many billions of characters of information organized with sophisticated search and retrieval software.

Examples of recent applications of automation support to a variety of administrative tasks include:

- Computer Aided Design (CAD) systems using the AutoCAD software on networked personal computers are now installed and operational in USGS regional and headquarters offices. Users enter architectural drawings of the buildings into the system and are able to accommodate changes as needed. Not only does the handling of construction drawings with CAD yield a better product at a lower cost, the new system also helps improve standardization of information.
- The new Automated Solicitation and Contract Preparation system allows for the rapid generation of solicitation and contract documents tailored to the requirements of a specific acquisition. Sophisticated information processing and document assembly form the heart of the system, supplemented by relevant information from the Federal Acquisition Regulations. From the client perspective, this system helps reduce the lead time necessary to issue a solicitation document and also improves the quality of contract documents.
- Building maintenance can also be scheduled and tracked via computer, using an off-the-shelf PC-based software package.
- New PC-based software supports a paperless system for the collection, calculation, and transmission of time and attendance information. The system was developed based on a system available from the Department of Commerce and pilot tested by the Administrative Division. The system is now being tested in other USGS divisions and in other agencies.

ORGANIZATION OF THE GEOLOGICAL SURVEY

U.S. Department of the Interior



Guide to U.S. Geological Survey Information and Publications

To buy maps of all areas of the United States and to request USGS catalogs, pamphlets, and leaflets (limited quantities free), write or visit:
U.S. Geological Survey
Distribution Branch
Building 810
Denver Federal Center, Box 25286
Denver, CO 80225

To buy Alaska maps, residents of Alaska may write or visit:
U.S. Geological Survey
Alaska Distribution Section
101 12th Avenue, Box 12
Fairbanks, AK 99701

To buy USGS book publications, to request USGS circulars, or to obtain information on the availability of microfiche or paper-duplicate copies of open-file reports, write:
U.S. Geological Survey
Books and Open-File Reports Section
Federal Center, Box 25425
Denver, CO 80225

To get on the mailing list for the monthly list of New Publications of the U.S. Geological Survey (free), write:
U.S. Geological Survey
Distribution Support Section
582 National Center
12201 Sunrise Valley Drive
Reston, VA 22092

To subscribe to Earthquakes and Volcanoes, a bimonthly, nontechnical, glossy digest that provides up-to-date information on earthquakes, volcanoes, and related natural hazards around the world, write:
Superintendent of Documents
Government Printing Office
Washington, DC 20402

To obtain information on cartographic data and on programs, publications, and services, or to obtain copies of reports and maps, write or visit the U.S. Geological Survey Earth Science Information Centers at the following addresses:
Alaska:
Room 101
4230 University Dr.
Anchorage, AK 99508–4664

Room 113, U.S. Courthouse
222 W. 7th Ave., #53
Anchorage, AK 99513–7546

California:
Federal Bldg., Room 7638
300 N. Los Angeles St.
Los Angeles, CA 90012

Rm. 3128
Bldg. 3, Stop 532
345 Middlefield Rd.
Menlo Park, CA 94025

504 Custom House
555 Battery St.
San Francisco, CA 94111

Colorado:
169 Federal Bldg.
1961 Stout St.
Denver, CO 80294

Room 1813
Box 25046, Stop 504
Bldg. 25, Denver Federal Center
Denver, CO 80225–0046

District of Columbia:
Main Interior Bldg., Room 2650
18th and C Sts., NW
Washington, DC 20240
(When visiting, use E St. entrance)

Mississippi:
Bldg. 3101
Stennis Space Center, MS 39529

Missouri:
Room 231
1400 Independence Rd.
Rolla, MO 65401

Utah:
8105 Federal Bldg.
125 S. State St.
Salt Lake City, UT 84138

Virginia:
1C402 National Center, Stop 507
12201 Sunrise Valley Dr.
Reston, VA 22092

Washington:
678 U.S. Courthouse
W. 920 Riverside Ave.
Spokane, WA 99201

To obtain information on aerial photographs and satellite and space images, write or visit:
U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198

To obtain assistance in locating sources of water data, identifying sites at which data have been collected, and obtaining specific information, write:
U.S. Geological Survey
National Water Data Exchange
National Center, Stop 421
12201 Sunrise Valley Dr.
Reston, VA 22092

To obtain information on ongoing and planned water-data acquisition activities of all Federal agencies and many non-Federal organizations, write:
U.S. Geological Survey
Office of Water Data Coordination
National Center, Stop 417
12201 Sunrise Valley Dr.
Reston, VA 22092

To obtain information on water resources in general and about the water resources of specific areas of the United States, write:
U.S. Geological Survey
Hydrologic Information Unit
National Center, Stop 419
12201 Sunrise Valley Dr.
Reston, VA 22092

To obtain information on geologic topics such as earthquakes and volcanoes, energy and mineral resources, the geology of specific areas, and geologic maps and mapping, write:
U.S. Geological Survey
Geologic Inquiries Group
National Center, Stop 907
12201 Sunrise Valley Dr.
Reston, VA 22092

To obtain information on mineral resources, write or visit:
Minerals Information Office*
Main Interior Bldg., Room 2647
18th and C Sts., NW
Washington, DC 20240

*A joint venture of the U.S. Geological Survey and the U.S. Bureau of Mines.

U.S. Geological Survey
Minerals Information Office
c/o Mackay School of Mines
University of Nevada - Reno
Reno, NV 89557–0047

U.S. Geological Survey
Minerals Information Office
Corbett Bldg.
210 E. 7th Street
Tucson, AZ 85705

U.S. Geological Survey
Minerals Information Office
656 U.S. Courthouse
W. 920 Riverside Dr.
Spokane, WA 99201

Budget Information

U.S. Geological Survey budget authority for fiscal year 1989, by appropriation for Surveys, Investigations, and Research
[Dollars in thousands]

Activity/Subactivity/Program Element	Fiscal Year 1989[1] enacted
National Mapping, Geography, and Surveys	**$ 94,235**
Primary Mapping and Revision	**35,379**
Digital Cartography	**13,931**
Small, Intermediate, and Special Mapping	**13,302**
Intermediate-Scale Mapping	4,378
Small-Scale and Other Special Mapping	1,725
Geographic Information Systems Research and Applications	2,084
Land Use and Land Cover Mapping	1,533
Image Mapping	3,582
Advanced Cartographic Systems	**17,716**
Earth Resources Observation Systems	**8,599**
Data Production and Dissemination	4,160
Applications and Research	4,439
Cartographic and Geographic Information	**3,808**
Side-Looking Airborne Radar	**1,500**
Geologic and Mineral Resource Surveys and Mapping	**178,199**
Geologic Hazards Surveys	**48,390**
Earthquake Hazards Reduction	34,688
Volcano Hazards	11,513
Landslide Hazards	2,189
Geologic Framework and Processes	**28,385**
National Geologic Mapping	17,559
Deep Continental Studies	3,062
Geomagnetism	1,735
Climate Change	1,031
Coastal Erosion	4,998
Mineral Resource Surveys	**47,518**
National Mineral Resource Assessment Program	24,534
Strategic and Critical Minerals	9,717
Development of Assessment Techniques	13,267
Energy Geologic Surveys	**27,323**
Evolution of Sedimentary Basins	5,277
Coal Investigations	7,338
Oil and Gas Investigations	5,606
Oil Shale Investigations	586
Geothermal Investigations	5,909
Uranium-Thorium Investigations	2,094
World Energy Resource Assessment	513
Geologic and Mineral Resource Surveys and Mapping—Continued	
Offshore Geologic Surveys	**26,583**
Offshore Geologic Framework	26,583
Water Resources Investigations	**145,321**
National Water Resources Research and Information System—Federal Program	**75,600**
Data Collection and Analysis	21,106
National Water Data & Information Access Program	1,936
Coordination of National Water Data Activities	989
Regional Aquifer Systems Analysis	11,069
Core Program Hydrologic Research	8,682
Improved Instrumentation	1,679
Water Resources Assessment	1,371
Toxic Substances Hydrology	12,588
Nuclear Waste Hydrology	3,851
Acid Rain	2,935
Scientific and Technical Publications	2,259
National Water-Quality Assessment Program	7,135
National Water Resources Research and Information System—Federal-State Cooperative Program	**58,900**
Data Collection and Analysis, Areal Appraisals, and Special Studies	50,145
Water Use	3,940
Coal Hydrology	4,815
National Water Resources Research and Information System—State Research Institutes and Research Grants Program	**10,821**
State Water Resources Research Institutes	5,677
National Water Resources Research Grants Program	4,381
Program Administration	763
General Administration	**16,330**
Executive Direction	4,732
Administrative Operations	9,960
Reimbursements to the Department of Labor	1,638
Facilities	**17,421**
National Center—Rental Payments to GSA	14,524
National Center—Facilities Management	2,897
Total	**$451,506**

[1] Funding shown represents appropriated dollars and does not include reimbursable funding from Federal, State, and other non-Federal sources.

U.S. Geological Survey budget for fiscal years 1986 to 1989, by activity and sources of funds[1]

[Dollars in thousands; totals may not add because of rounding]

Budget activity	1986	1987	1988	1989
Total	**$600,852**	**$620,585**	**$662,101**	**$ 670,897**
Direct program	412,667	432,114	448,233	[1]451,988
Reimbursable program	188,185	188,471	213,868	[2]218,909
States, counties, and municipalities	59,945	63,088	68,609	69,577
Miscellaneous non-Federal sources	12,111	13,667	12,775	14,194
Other Federal agencies	116,129	111,716	132,484	135,138
National Mapping, Geography, and Surveys	**112,562**	**118,462**	**120,845**	**126,457**
Direct program	84,117	88,542	90,541	94,235
Reimbursable program	28,445	29,921	30,304	32,222
States, counties, and municipalities	1,975	1,841	1,579	1,520
Miscellaneous non-Federal sources	9,568	10,276	[2]10,021	10,804
Other Federal agencies	16,902	17,804	18,705	19,898
Geologic and Mineral Resource Surveys and Mapping	**206,463**	**209,553**	**224,708**	**215,882**
Direct program	165,585	169,239	177,278	178,329
Reimbursable program	40,878	40,314	46,750	37,553
States, counties, and municipalities	1,320	1,365	1,138	961
Miscellaneous non-Federal sources	348	938	368	682
Other Federal agencies	39,210	38,011	45,244	35,910
Water Resources Investigations	**248,598**	**254,288**	**278,380**	**287,154**
Direct program	135,152	142,130	149,471	145,635
Reimbursable program	113,446	112,158	128,910	141,520
States, counties, and municipalities	56,650	59,882	65,893	67,095
Miscellaneous non-Federal sources	2,161	2,437	2,354	2,700
Other Federal agencies	54,635	49,839	60,662	71,725
General Administration	**14,515**	**18,285**	**17,746**	**19,059**
Direct program	14,246	17,084	14,684	16,330
Reimbursable program (Federal)	269	1,201	3,062	2,729
Miscellaneous non-Federal sources	1	1	3	0
Other Federal agencies	268	1,200	3,060	2,729
Facilities	**13,615**	**15,109**	**16,252**	**17,450**
Direct program	13,567	15,067	16,214	17,421
Reimbursable program	48	42	38	29
Computer services to other accounts	**5,099**	**4,835**	**4,804**	**4,856**
Reimbursable program	5,099	4,835	4,804	4,856
Miscellaneous non-Federal sources	33	15	29	7
Other Federal agencies	5,066	4,820	4,775	4,849
Operation and Maintenance of Quarters	**---**	**52**	**45**	**38**
Direct program	---	52	45	38

[1] Direct program includes $451,506 for current year, $130 for Contributed Funds, $314 for last year's unobligated balance, and $38 for Operation and Maintenance of Quarters.

[2] Includes $7,953 for map receipts previously shown under direct program column.

U.S. Geological Survey reimbursable funds from other Federal agencies for fiscal years 1986 to 1989, by agency

[Dollars in thousands]

Budget activity	1986	1987	1988	1989
Department of Agriculture	2,756	1,247	3,392	3,638
Department of Commerce	104	100	50	0
National Oceanic and Atmospheric Administration	8,675	7,993	6,138	5,327
Department of Defense	27,343	30,551	39,462	40,478
Department of Energy	24,341	24,361	26,800	31,630
Bonneville Power Administration	170	274	258	311
Department of the Interior	18,852	14,787	17,166	14,076
Bureau of Indian Affairs	5,033	4,280	4,664	2,190
Bureau of Land Management	2,447	1,748	1,773	1,317
Bureau of Mines	122	14	29	0
Bureau of Reclamation	8,734	6,647	6,715	5,926
Minerals Management Service	342	125	291	222
National Park Service	1,043	977	1,069	1,304
Office of the Secretary	701	538	1,983	2,206
Office of Surface Mining	129	260	352	264
Fish and Wildlife Service	301	198	290	648
Department of State	8,625	4,740	9,896	10,082
Department of Transportation	133	300	794	1,479
Environmental Protection Agency	1,878	2,726	3,591	3,096
National Aeronautics and Space Administration	4,343	4,380	4,877	4,952
National Science Foundation	162	472	535	630
Nuclear Regulatory Commission	1,154	1,834	1,589	1,797
Tennessee Valley Authority	264	101	269	170
Miscellaneous Federal agencies	12,264	13,030	13,371	12,623
Miscellaneous services to other accounts	5,066	4,820	4,775	4,849
Total	**$116,129**	**$111,716**	**132,963**	**135,139**

U.S. Geological Survey Offices

Headquarters Offices	Central Region	Western Region
National Center **12201 Sunrise Valley Drive** **Reston, VA 22092**	**Denver Federal Center** **Box 25046** **Denver, CO 80225**	**345 Middlefield Rd.** **Menlo Park, CA 94025**

Office	Name	Telephone Number	Address
Office of the Director			
Director	Dallas L. Peck	(703) 648–7411	National Center, Stop 101
Associate Director	Doyle G. Frederick	(703) 648–7412	National Center, Stop 102
Special Assistant (Washington Liaison) and Deputy Ethics Counselor	Jane H. Wallace	(202) 343–3888	Rm. 2648, Interior Bldg. Washington, DC 20240
Assistant Director for Research, Acting	Stephen E. Ragone	(703) 648–4450	National Center, Stop 104
Assistant Director for Engineering Geology (Acting)	Eugene H. Roseboom, Jr.	(703) 648–4423	National Center, Stop 106
Assistant Director for Administration	Jack J. Stassi	(703) 648–7200	National Center, Stop 201
Assistant Director for Programs	Peter F. Bermel	(703) 648–4430	National Center, Stop 105
Assistant Director for Intergovernmental Affairs	John J. Dragonetti	(703) 648–4427	National Center, Stop 109
Assistant Director for Information Systems	James E. Biesecker	(703) 648–7108	National Center, Stop 801
Congressional Liaison Officer	Talmadge W. Reed	(703) 648–4457	National Center, Stop 112
Chief, Public Affairs Office	Donovan B. Kelly	(703) 648–4460	National Center, Stop 119
Director's Representative—Central Region	Harry Tourtelot	(303) 236–5438	Denver Federal Center, Stop 406
Director's Representative—Western Region	George Gryc	(415) 329-4002	Western Region Headquarters, Stop 144
Special Assistant to the Director for Alaska	Philip J. Carpenter	(907) 271–4138	4230 University Drive, Suite 201 Anchorage, AK 99508
Administrative Division			
Chief	Jack J. Stassi	(703) 648–7200	National Center, Stop 201
Administrative Operations Officer	Timothy E. Calkins	(703) 648–7204	National Center, Stop 203
Professional Services Specialist	William A. Schmidt	(703) 648–7221	National Center, Stop 118
Administrative Program Specialist	H.T. Davis	(703) 648–7203	National Center, Stop 201
Office of Personnel, Chief	Maxine C. Millard	(703) 648–7442	National Center, Stop 215
Office of Procurement and Contracts, Chief	John K. Peterson	(703) 648–7373	National Center, Stop 205
Office of Financial Management, Chief	Roy J. Heinbuch	(703) 648–7604	National Center, Stop 270
Office of Facilities and Management Services, Chief	William F. Gossman, Jr.	(703) 648–7338	National Center, Stop 207
Office of Systems Management, Chief	Phillip L. McKinney	(703) 648–7256	National Center, Stop 206
Administrative Service Center, Chief	Phillip L. McKinney	(703) 648–7256	National Center, Stop 206
Central Regional Management Officer	George A. Honold	(303) 236–5900	Denver Federal Center, Stop 201
Western Regional Management Officer	George F. Hargrove, Jr.	(415) 329–4150	Western Region Headquarters, Stop 11
Information Systems Division			
Chief	James E. Biesecker	(703) 648–7108	National Center, Stop 801
Associate Chief	Doug R. Posson	(703) 648–7106	National Center, Stop 801
Office of Customer Services, Chief	Virginia L. Ross	(703) 648–7178	National Center, Stop 805
Office, Computer and Communications Services, Chief	Wendy A. Budd	(703) 648–7103	National Center, Stop 807
Office of Management Services, Chief	Vacant	(703) 648–7100	National Center, Stop 802
Office of Field Services, Chief	Fred B. Sower	(303) 236–4944	Denver Federal Center
National Mapping Division			
Chief	Lowell E. Starr	(703) 648–5748	National Center, Stop 516
Associate Chief	Roy R. Mullen	(703) 648–5745	National Center, Stop 516
Assistant Division Chief for Research	Joel L. Morrison	(703) 648–4640	National Center, Stop 519
Assistant Division Chief for Program, Budget and Administration	Richard E. Witmer	(703) 648–4611	National Center, Stop 514
Assistant Division Chief for Information and Data Services	Gary W. North	(703) 648–5780	National Center, Stop 508
Assistant Division Chief for Coordination and Requirements	Gene A. Thorley	(703) 648–5743	National Center, Stop 590
Assistant Division Chief for Production Management	Vacant	(703) 648–4146	National Center, Stop 511
Eastern Mapping Center, Chief	K. Eric Anderson	(703) 648–6002	National Center, Stop 567
Mid-Continent Mapping Center, Chief	Merle E. Southern	(314) 341–0880	1400 Independence Rd., Rolla, MO 65401

Office	Name	Telephone Number	Address
National Mapping Division—Continued			
Rocky Mountain Mapping Center, Chief	Randle W. Olsen	(303) 236–5825	Denver Federal Center, Stop 510
Western Mapping Center, Chief	John R. Swinnerton	(415) 329–4251	Western Region Headquarters
Earth Resources Observation System Data Center, Chief	Allen H. Watkins	(605) 594–6511	EROS Data Center, Sioux Falls, SD 57198
Geologic Division			
Chief Geologist	Benjamin A. Morgan III	(703) 648–6600	National Center, Stop 911
Associate Chief Geologist	William R. Greenwood	(703) 648–6601	National Center, Stop 911
Assistant Chief Geologist for Program	David P. Russ	(703) 648–6640	National Center, Stop 911
Administrative Officer	Elwood H. Like	(703) 648–6611	National Center, Stop 912
Manpower Officer for Scientific Personnel	John D. McGurk	(703) 648–6628	National Center, Stop 911
Policy and Budget Officer	Norman E. Gunderson	(703) 648–6650	National Center, Stop 910
Office of Scientific Publications, Chief	John M. Aaron	(703) 648–6077	National Center, Stop 904
Office of Regional Geology, Chief	Mitchell W. Reynolds	(703) 648–6959	National Center, Stop 908
Office of Earthquakes, Volcanoes, and Engineering, Chief	Robert L. Wesson	(703) 648–6714	National Center, Stop 905
Office of Energy and Marine Geology, Chief	Gary W. Hill	(703) 648–6470	National Center, Stop 915
Office of Mineral Resources, Chief	Glenn H. Allcott	(703) 648–6100	National Center, Stop 913
Office of International Geology, Chief	A. Thomas Ovenshine	(703) 648–6047	National Center, Stop 917
Assistant Chief Geologist, Eastern Region	Jack H. Medlin	(703) 648–6660	National Center, Stop 953
Assistant Chief Geologist, Central Region	Harry A. Tourtelot	(303) 236–5438	Denver Federal Center, Stop 911
Assistant Chief Geologist, Western Region	William R. Normark	(415) 329–5101	Western Region Headquarters, Stop 19
Water Resources Division			
Chief Hydrologist	Philip Cohen	(703) 648–5215	National Center, Stop 409
Associate Chief Hydrologist	John N. Fischer	(703) 648–5216	National Center, Stop 408
Assistant Chief Hydrologist for Scientific Information Management	James F. Daniel	(703) 648–5699	National Center, Stop 440
Assistant Chief Hydrologist for Operations	William B. Mann IV	(703) 648–5031	National Center, Stop 441
Assistant Chief Hydrologist for Research and External Coordination	Robert M. Hirsch	(703) 648–5041	National Center, Stop 436
Office of Hydrologic Research, Chief	Roger G. Wolff	(703) 648–5043	National Center, Stop 436
Office of External Research, Chief, Acting	Robert M. Hirsch	(703) 648–6807	National Center, Stop 424
Assistant Chief Hydrologist for Program Coordination and Technical Support	Verne R. Schneider	(703) 648–5229	National Center, Stop 414
Office of Atmospheric Deposition Analysis, Chief	Ranard J. Pickering	(703) 648–6874	National Center, Stop 416
Office of Ground Water, Chief	Eugene P. Patten, Jr.	(703) 648–5001	National Center, Stop 411
Office of Surface Water, Chief	Charles W. Boning	(703) 648–5301	National Center, Stop 415
Office of Water Quality, Chief	David A. Rickert	(703) 648–6862	National Center, Stop 412
Assistant Chief Hydrologist for Water Assessment and Data Coordination	David W. Moody	(703) 648–6856	National Center, Stop 407
Office of Water Data Coordination, Chief	Nancy C. Lopez	(703) 648–5019	National Center, Stop 417
Northeastern Region, Chief	Stanley P. Sauer	(703) 648–5817	National Center, Stop 433
Southeastern Region, Chief	James L. Cook	(404) 331–5174	Richard B. Russell Federal Bldg. 75 Spring St., SW., Suite 772 Atlanta, GA 30303
Central Region, Chief	James F. Blakey	(303) 236–5920	Denver Federal Center, Stop 406
Western Region, Chief	T. John Conomos	(415) 329–4403	Western Region Headquarters, Stop 470
District Offices			
Alabama	D. Briane Adams	(205) 752–8104	520 19th Ave. Tuscaloosa, AL 35401
Alaska	Philip J. Carpenter	(907) 271–4138	4230 University Dr., Suite 201 Anchorage, AK 99508
Arizona	Robert D. Mac Nish	(602) 670–6671	Federal Bldg., FB–44 300 W. Congress St. Tucson, AZ 85701
Arkansas	Ector E. Gann	(501) 378–6391	2310 Federal Office Bldg. 700 W. Capitol Ave. Little Rock, AR 72201

Office	Name	Telephone Number	Address
California	John M. Klein	(916) 978–4633	Rm. W–2234 Federal Bldg. 2800 Cottage Way Sacramento, CA 95825
Colorado	Charles A. Pascale	(303) 236–4882	Box 25046, Stop 415 Denver Federal Center Denver, CO 80225
Connecticut (See Massachusetts)			
Delaware (See Maryland)			
District of Columbia (See Maryland)			
Florida	Irwin H. Kantrowitz	(904) 681–7620	227 N. Bronough St. Suite 3015 Tallahassee, FL 32301
Georgia	Jeffrey T. Armbruster	(404) 986–6860	6481–B Peachtree Industrial Blvd. Doraville, GA 30360
Hawaii	William Meyer	(808) 541–2653	677 Ala Moana Blvd., Suite 415 Honolulu, HI 96813
Idaho	Jerry L. Hughes	(208) 334–1750	230 Collins Rd. Boise, ID 83702
Illinois	Richard P. Novitzki	(217) 398–5353	Champaign County Bank Plaza 102 E. Main St., 4th Floor Urbana, IL 61801
Indiana	Dennis K. Stewart	(317) 290–3333	5957 Lakeside Blvd. Indianapolis, IN 46278
Iowa	Richard A. Engberg	(319) 337–4191	P.O. Box 1230 Rm. 269 Federal Bldg. 400 S. Clinton St. Iowa City, IA 52244
Kansas	Thomas L. Huntzinger	(913) 842–9909	4821 Quail Crest Pl., Lawrence, KS 66049
Kentucky	Alfred L. Knight	(502) 582–5241	2301 Bradley Ave. Louisville, KY 40217
Louisiana	Darwin D. Knochenmus	(504) 389–0281	P.O. Box 66492 6554 Florida Blvd. Baton Rouge, LA 70896
Maine (See Massachusetts)			
Maryland	Herbert J. Freiberger	(301) 828–1535	208 Carroll Bldg. 8600 La Salle Rd. Towson, MD 21204
Massachusetts	Ivan C. James II	(617) 565–6860	10 Causeway St., Rm. 926 Boston, MA 02222
Michigan	T. Ray Cummings	(517) 377–1608	6520 Mercantile Way, Suite 5 Lansing, MI 48911
Minnesota	William J. Herb	(612) 229–2600	702 Post Office Bldg. 180 E. Kellogg Blvd. St. Paul, MN 55101
Mississippi	Michael W. Gaydos	(601) 965–4600	Suite 710 Federal Bldg. 100 W. Capitol St. Jackson, MS 39269
Missouri	Daniel P. Bauer	(314) 341–0824	1400 Independence Rd., Mail Stop 200 Rolla, MO 65401
Montana	Joe A. Moreland	(406) 449–5263	Rm. 428 Federal Bldg. 301 S. Park Ave. Helena, MT 59626
Nebraska	Michael V. Shulters	(402) 437–5082	Rm. 406 Federal Bldg. 100 Centennial Mall, North Lincoln, NE 68508
Nevada	William J. Carswell, Jr.	(702) 882–1388	Rm. 224 Federal Bldg. 705 N. Plaza St. Carson City, NV 89701
New Hampshire (See Massachusetts)			
New Jersey	Donald E. Vaupel	(609) 771–3900	Suite 206, Mountain View Office Park 810 Bear Tavern Rd. West Trenton, NJ 08628

Office	Name	Telephone Number	Address
New Mexico	Russell K. Livingston	(505) 262–6630	Pinetree Office Park, Suite 200 4501 Indian School Rd., NE. Albuquerque, NM 87110
New York	L. Grady Moore	(518) 472–3107	P.O. Box 1669 343 U.S. Post Office and Courthouse Albany, NY 12201
North Carolina	James F. Turner	(919) 856–4510	P.O. Box 2857, Rm. 436 Century Postal Station 300 Fayetteville Street Mall Raleigh, NC 27602
North Dakota	William F. Horak	(701) 250–4601	821 E. Interstate Ave. Bismarck, ND 58501
Ohio	Steven M. Hindall	(614) 469–5553	975 W. Third Ave. Columbus, OH 43212
Oklahoma	Kathy D. Peter	(405) 231–4256	Rm. 621, 215 Dean A. McGee Ave. Oklahoma City, OK 73102
Oregon (See Washington)			
Pennsylvania	David E. Click	(717) 782–4514	P.O. Box 1107, 4th Floor Federal Bldg., 228 Walnut St. Harrisburg, PA 17108
Puerto Rico	Allen L. Zack	(809) 783–4660	GPO Box 4424 Bldg. 652 GSA Center Hwy 28, Km. 7.2, Pueblo Viejo San Juan, PR 00936
Rhode Island (See Massachusetts)			
South Carolina	Rodney N. Cherry	(803) 765–5966	Suite 677A, 1835 Assembly St. Columbia, SC 29201
South Dakota	Richard E. Fidler	(605) 353–7176	Rm. 317 Federal Bldg. 200 4th St., SW. Huron, SD 57350
Tennessee	Ferdinand Quinones-Marquez	(615) 736–5424	A–413 Federal Bldg. and U.S. Courthouse Nashville, TN 37203
Texas	Charles R. Burchett	(512) 832–5791	8011 Cameron Rd., Bldg. 1 Austin, TX 78753
Utah	Harvey L. Case	(801) 524–5663	Rm. 1016 Administration Bldg. 1745 W. 1700 South Salt Lake City, UT 84104
Vermont (See Massachusetts)			
Virginia (See Maryland)			
Washington	Garald G. Parker, Jr.	(206) 593–6510	1201 Pacific Ave., Suite 600 Tacoma, WA 98402
West Virginia	David H. Appel	(304) 347–5130	603 Morris St. Charleston, WV 25301
Wisconsin	Vernon W. Norman	(608) 274–3535	6417 Normandy Ln. Madison, WI 53719
Wyoming	James E. Kircher	(307) 772–2153	2617 E. Lincolnway Suite B Cheyenne, WY 82001

Cooperators and Other Financial Contributors

Cooperators listed are those with whom the U.S. Geological Survey had a written agreement cosigned by USGS officials and officials of the cooperating agency for financial cooperation in fiscal year 1989. Parent agencies are listed separately from their subdivisions whenever there are separate cooperative agreements for different projects with a parent agency and with a subdivision of it. Agencies are listed in alphabetical order under the State or territory where they have cooperative agreements with the USGS. Agencies with whom the USGS has research contracts and to whom it supplied research funds are not listed.

Cooperating office of the U.S. Geological Survey
g—Geologic Division
n—National Mapping Division
w—Water Resources Division

Alabama
Alabama Department of—
Environmental Management (w),
Highways (w);
Anniston, City of (w);
Birmingham, City of, Water Works Board (w);
Butler County Water Authority (w);
Coffee County Commission (w);
Dauphin Island Water Authority (w);
Geological Survey of Alabama (n,w);
Greenville, City of, Water Works and Sewer Board (w);
Harvest-Monrovia Water and Fire Protection Authority (w);
Huntsville, City of, Public Works (w);
Jefferson County Commission (w);
Montgomery, City of, Water Works and Sanitary Board (w);
Ragland, City of (w);
State Climatologist (w);
Sumter, County of (w);
Tuscaloosa, City of (w);
University of Alabama–Tuscaloosa (w)

Alaska
Alaska Department of—
Fish and Game (w),
Military and Veterans Affairs, Division of Emergency Services (w),
Natural Resources, Division of—
Geological and Geophysical Surveys (w),
Technical Services (w),
Transportation and Public Facilities (w);
Alaska Energy Authority (w);
Anchorage, Municipality of (w);
Fairbanks North Star Borough (w);
Juneau, City and Borough of (w);
Kenai Peninsula Borough (w);
Matanuska Susitna Borough (w);
Sitka, City and Borough of (w);
University of Alaska, Fairbanks (w)

American Samoa
American Samoa, Government of (n,w)

Arizona
Arizona Department of—
Environmental Quality (w),
Health Services (w),
Transportation (w),
Water Resources (w);
Arizona Municipal Water Users Association (w);
Arizona State Land Department (w);
Arizona State University (g);
Central Arizona Water Conservation District (w);
Colorado Department of Highways (w);
Franklin Irrigation District (w);
Gila Valley Irrigation District (w);
Gila Water Commissioner, Office of (w);
Maricopa County—
Flood Control District (w),
Municipal Water Conservation District No. 1 (w);
Metropolitan Water District of Southern California (w);
Northern Arizona University (g);
Pima County Department of Transportation (w);
Safford, City of, Water, Gas, and Sewer Department (w);
Salt River Valley Water Users Association (w);
San Carlos Irrigation and Drainage District (w);
Scottsdale, City of, Water Resources Department (w);
Show Low Irrigation Company (w);
The Navajo Tribal Council, Division of Water Resources (w);
Tohono Oldham Nation (w);
Tucson, City of (w);
University of Arizona (w);
Yuma, City of (w)

Arkansas
Arkansas Archaeological Survey (n);
Arkansas Department of—
Health (w)
Pollution Control and Ecology (w);
Arkansas Game and Fish Commission, Fisheries Division (w);
Arkansas Geological Commission (n,w);
Arkansas Soil and Water Conservation Commission (w);
Arkansas State Highway and Transportation Department (w);
Arkansas-Oklahoma: Arkansas River Compact Commission (w);
Independence, County of (w);
Little Rock Municipal Water Works (w)

California
Alameda County—
Flood Control and Water Conservation District (Hayward) (w),
Water District (w);
Antelope Valley-East Kern Water Agency (w);
California Department of—
Boating and Waterways (w),
Conservation (g),
Health Services (w),
Parks and Recreation (w),
Transportation (w),
Water Resources—
Central District (Sacramento) (w),
Northern District (Red Bluff) (w),
San Joaquin District (Fresno) (w);
California Office of Emergency Services (n);
California State University-Bakersfield (g);
California Water Control Board, Colorado Region (w);
Carpinteria County Water District (w);
Casitas Municipal Water District (w);
Coachella Valley Water District (w);
Contra Costa County—
Department of Health Services (w),
Flood Control and Water Conservation District (w);
Crestline-Lake Arrowhead Water Agency (w);
Desert Water Agency (w);
East Bay Municipal Utility District (w);
East Valley Water District (w);
Energy Technology Center, Canoga Park (g);
Fox Canyon Groundwater Management Agency (w);
Fresno Metropolitan Flood Control District (w);
Goleta Water District (w);
Humboldt Bay Municipal Water District (w);
Imperial County Department of Public Works (w);
Imperial Irrigation District (w);
Indian Wells Valley Water District (w);
Inyo County Water Department (w);
Lompoc, City of (w);
Los Angeles County Department of Public Works (w);
Los Angeles Department of Water and Power (w);
Los Angeles Metropolitan Water District (g);
Madera Irrigation District (w);
Marin County Department of Public Works (w);
Marin Municipal Water District (w);
Menlo Park, City of (g);
Mendocino County Water Agency (w);
Merced, City of (w);
Merced Irrigation District (w);
Modesto Irrigation District (w);
Mojave Water Agency (w);
Mono, County of (w);
Montecito Water District (w);
Monterey County Flood Control and Water Conservation District (w);
Monterey Peninsula Water Municipal District (w);
Oakdale-South San Joaquin Irrigation District (w);
Orange County—
Environmental Management Agency (w),
Water District (w);
Oroville-Wyandotte Irrigation District (w);
Pechanga Indian Reservation (w);
Poway, City of (w);
Rancho California Water District (w);
Regional Water Quality-Lahontan Region (w);
Riverside County Flood Control and Water Conservation District (w);
Sacramento Municipal Utility District (w);
Sacramento Regional County Sanitation District, Department of Public Works (w);
San Benito County Water Conservation and Flood Control District (w);
San Bernardino County Flood Control District (w);
San Bernardino Valley Municipal Water District (w);
San Diego, City of, Water Utility (w);
San Diego, County of, Department of—
Planning and Land Use (w),
Public Works (w);
San Francisco, City and County of, Public Utilities Commission (w);
San Francisco Water Department (w);
San Luis Obispo County Government Center (w);
San Mateo County Department of Public Works (w);
Santa Barbara, City of, Department of Public Works (w);
Santa Barbara County—
Flood Control and Water Conservation District (w),
Water Agency (w);
Santa Clara Valley Water District (w);
Santa Cruz, City of, Water Department-City Hall (w);
Santa Cruz County Planning Department (w);
Santa Maria Valley Water Conservation District (w);
Santa Ynez River Water Conservation District (w);
Scotts Valley Water District (w);
Sonoma County—
Planning Department (w),
Water Agency (w);

Stanford University (g);
Tahoe Regional Planning (w);
Tulare County Flood Control District (w);
Turlock Irrigation District (w);
United Water Conservation District (w);
University of California, Berkeley (g);
Ventura County Public Works Agency (w);
Water Resources Control Board (w);
Westlands Water District (w);
Woodbridge Irrigation District (w);
Yolo County Flood Control and Water Conservation District (w);
Yuba County Water Agency (w)

Colorado

Arkansas River Compact Administration (w);
Arvada, City of (w);
Aspen, City of (w);
Aurora, City of (w);
Bent, County of (w);
Boulder, City of (w);
Boulder, County of, Department of Public Works (w);
Breckenridge, Town of (w);
Castle Pines Metropolitan District (w);
Castle Pines North Metropolitan District (w);
Castle Rock, Town of (w);
Centennial Water and Sanitation (w);
Cherokee Water and Sanitation District (w);
Colorado Department of Health (w);
Colorado Division of—
- Mined Land Reclamation (w),
- Water Resources, Office of the State Engineer (w);

Colorado River Water Conservation District (w);
Colorado School of Mines (g);
Colorado Springs, City of—
- Department of Public Utilities (w),
- Office of the City Manager (w);

Delta County Board of County Commissioners (w);
Denver, City and County, Board of Water Commissioners (w);
Denver Regional Council of Governments (w);
Eagle County Board of Commissioners (w);
Englewood, City of, Wastewater Treatment Plant (w);
Evergreen Metropolitan District (w);
Fort Collins, City of (w);
Fountain Valley Authority (w);
Garfield, County of (w);
Glendale, City of (w);
Glenwood Springs, City of (w);
Golden, City of (w);
Grand County Board of Commissioners (w);
Jefferson County Board of County Commissioners (w);
Longmont, City of (w);
Loveland, City of (w);
Lower Fountain Water-Quality Management Association (w);
Metropolitan Denver Sewage Disposal District No. 1 (w);
Moffat, County of (w);
Northern Colorado Water Conservancy District (w);
Northglenn, City of (w);
Pikes Peak Area Council of Governments (w);
Pitkin County Board of Commissioners (w);
Pueblo Board of Water Works (w);
Pueblo County Commissioners (w);
Pueblo County Department of Public Safety and Operations (w);
Pueblo West Metropolitan District (w);
Rio Blanco, County of (w);
Rio Grande Water Conservation District (w);
St. Charles Mesa Water Association (w);
Southeastern Colorado Water Conservancy District (w);
Southern Ute Indian Tribe (g,w);
Southwestern Colorado Water Conservancy District (w);
Steamboat Springs, City of (w);
Thornton, City of (w);
Trinchera Conservancy District (w);
Uncompahgre Valley Water Users Association (w);
Upper Arkansas Area Council of Governments (w);
Upper Arkansas River Water Conservancy District (w);
Upper Eagle Valley Water and Sanitation Districts (w);
Upper Yampa Water Conservancy District (w);
Urban Drainage and Flood Control District (w);
Ute Mountain Indian Tribe (w);
Vail Valley Conservation Water Authority (w);
Westminster, City of (w);
Yellow Jacket Water Conservancy District (w)

Connecticut

Connecticut Department of Environmental Protection (g,n,w);
Fairfield, Town of, Conservation Commission (w);
New Britain, City of, Board of Water Commissioners (w);
South Central Connecticut Regional Water Authority (w);
Torrington, City of (w);
Yale University (g)

Delaware

Delaware Department of Natural Resources and Environmental Control (w);
Geological Survey (n,w)

District of Columbia

Department of Public Works (w);
Metropolitan Washington Council of Governments (w)

Florida

Boca Raton, City of (w);
Bradenton, City of (w);
Brevard County, Board of County Commissioners (w);
Broward County—
- Environmental Quality Control Board (w),
- Water Resources Management Division (w);

Cape Coral, City of (w);
Cocoa, City of (w);
Cottondale, City of (w);
Daytona Beach, City of (w);
Edgewater, City of (w);
Englewood Water District (w);
Escambia County Board of County Commissioners (w);
Florida Department of—
- Environmental Regulation, Bureau of Laboratories and Special Programs (w),
- Natural Resources (w)—
  - Division of—
    - Marine Resources (w),
    - Recreation and Parks (Hobe Sound) (w),
    - Recreation and Parks (Tallahassee) (w),
    - Survey and Mapping (n),
- Transportation (n,w);

Florida Institute of Phosphate Research (w);
Florida Keys Aqueduct Authority (w);
Fort Lauderdale, City of (w);
Fort Walton Beach, City of (w);
Game and Freshwater Fish Commission (w);
Hallandale, City of (w);
Highland Beach, Town of (w);
Hillsborough, County of (w);
Hollywood, City of (w);
Jacksonville, City of—
- Department of Health and Environmental Services (w),
- Department of Planning (w),
- Water Services Division (w);

Jacksonville Electric Authority, Research and Environmental Affairs (w);
Jacksonville Beach, City of (w);
Lake County Board of County Commissioners (w);
Lake County Water Authority (w);
Lake Mary, City of (w);
Lee County Board of County Commissioners (w);
Leon County—
- Courthouse (w),
- Department of Public Works (w);

Madison, City of (w);
Manatee County—
- Board of County Commissioners (w),
- Public Health Unit (w);

Marion County Board of Commissioners (w);
Metropolitan Dade County Department of Environment Resources Management (w);
Miami-Dade Water and Sewer Authority (w);
Northwest Florida Water Management District (w);
Ocala, City of (w);
Palm Beach County Board of County Commissioners (w);
Perry, City of (w);
Pinellas, County of (w);
Polk County Board of County Commissioners (w);
Pompano Beach, City of, Water and Sewer Department (w);
Port Orange, City of (w);
Quincy, City of (w);
Reedy Creek Improvement District (w);
Sanford, City of (w);
Sarasota, City of (w);
Sarasota, County of (w);
South Florida Water Management District (w);
South Indian River Water Control District (w);
Southwest Florida Regional Planning Council (w);
Southwest Florida Water Management District (w);
St. Johns, County of (w);
St. Johns River Water Management District (w);
St. Petersburg, City of (w);
Stuart, City of (w);
Suwannee River Authority (Live Oak) (w);
Suwannee River Authority (Trenton) (w);
Tallahassee, City of—
- Electric Department (w),
- Streets and Drainage (w),
- Underground Utilities (w),
- Water Quality Laboratory (w);

Tampa, City of (w);
Tampa Port Authority (w);
University of Florida, Center for Wetlands (w);
Volusia, County of (w);
Walton, County of (w);
West Coast Regional Water Supply Authority (w);
Winter Park, City of (w)

Georgia

Albany, City of (w);
Albany Water, Gas, and Light Commission (w);
Bibb County Board of County Commissioners (w);
Blairsville, City of (w);
Brunswick, City of (w);
California Air Resources Board (w);
Clayton County Water Authority (w);
Cobb, County of (w);
Covington, City of (w);
Georgia Department of—
- Natural Resources—
  - Environmental Protection Division—
    - Water Management Branch (w),
    - Water Quality Support Program (w),
  - Geologic Survey (n,w),
- Transportation (w);

Georgia State University, Department of Geology (g,w);
Gwinnett, County of (w);
Helena, City of (w);
Macon-Bibb County Water and Sewage Authority (w);
Moultrie, City of (w);
Summerville, City of (w);
Thomaston, City of (w);
Thomasville, City of (w);
Valdosta, City of (w);
Walton County Board of Commissioners (w)

Guam

Guam, Government of (w)

Hawaii

Hawaii, County of, Department of Water Supply (w);
Hawaii Department of—
Land and Natural Resources, Division of Water and Land Development (w),
Transportation (w);
Honolulu Board of Water Supply (w);
Honolulu, City and County of, Department of Public Works (g,w);
Kauai, County of, Department of Water Supply (w);
Maui, County of, Department of Water Supply (w)

Idaho

Boise, City of (w);
College of Southern Idaho (w);
EG&G Idaho, Inc., Idaho Falls (g);
Idaho Department of—
Fish and Game (w),
Health and Welfare (w),
Lands (n),
Transportation (n),
Water Resources (w);
Shoshone, County of (w);
Shoshone-Bannock Tribes, (w);
Southwest Irrigation District (w);
Sun Valley Water and Sewer District (w);
Teton County Board of Commissioners (w);
Water District No. 01 (Idaho Falls) (w);
Water District No. 31 (Dubois) (w);
Water District No. 32D (Dubois) (w)

Illinois

Bloomington and Normal Sanitary District (w);
Cook County Forest Preserve District (w);
Decatur, City of (w);
DeKalb, City of, Public Works Department (w);
DuPage County Forest Preserve, Planning and Development Section (w);
DuPage County Department of Environmental Concerns (w);
Illinois Department of—
Energy and Natural Resources—
State Water Survey Division, Special Studies (w),
Geological Survey Division (n),
Transportation—
Division of Highways (n),
Division of Water Resources (n,w);
Illinois Environmental Protection Agency, Division of Water Pollution Control (w);
Lake County Department of Management Services (n);
Metropolitan Water Reclamation District of Greater Chicago (w);
Springfield, City of (w)

Indiana

Carmel, Town of (w);
Elkhart, City of, Water Works (w);
Indiana Department of—
Environmental Management (w),
Highways (w),
Natural Resources (n)—
Division of Water (w),
Division of Parks (w);
Indianapolis, City of, Department of Public Works (w)

Iowa

Carroll County Health Department (w);
Cedar Rapids, City of (w);
Charles City, City of (w);
Des Moines, City of (w), Water Works (w);
Fort Dodge, City of (w);
Guthrie County Health Department (w);
Iowa Department of—
Transportation, Highway Division (w),
Natural Resources, Geological Survey Bureau (n,w);
Iowa State University (w);
Marshalltown, City of (w);
University of Iowa—
Institute of Hydraulic Research (w),
Hygienic Laboratory (w),
Physical Plant (w),
Sewage Disposal Plant (w);
Sioux City, City of (w);
Union Electric Company (w);
Waterloo, City of (w)

Kansas

Arkansas River Compact Administration (w);
Clay, County of (w);
Emporia, City of, Department of Public Works (w);
Equus Beds Groundwater Management District No. 2 (w);
Geary, County of (w);
Hays, City of (w);
Iowa Tribe of Kansas and Nebraska (w);
Kansas Department of—
Health and Environment (w),
Transportation (w);
Kansas Geological Survey (n,w);
Kansas State Board of Agriculture, Division of Water Resources (w);
Kansas State University (w);
Kansas University—
Center for Research, Inc. (w),
Department of Geology (w);
Kansas Water Office (w);
Kickapoo Tribe of Kansas (w);
Linn, County of (w);
Prairie Band of Potawatomi (w);
Sac and Fox Tribe of Missouri (w);
Sedgwick, County of (w);
Sumner, County of (w);
Wichita, City of (w)

Kentucky

Elizabethtown, City of (w);
Hardin County Water District (w);
Jefferson, County of, Department of Public Works and Transportation (w);
Kentucky Department of Natural Resources and Environmental Protection Cabinet (w);
Louisville Metropolitan Sewer District (w);
University of Kentucky, Kentucky Geological Survey (n,w);
University of Louisville (w)

Louisiana

Capital-Area Groundwater Conservation Commission (w);
East Baton Rouge Parish (w);
Jefferson Parish Department of Public Utilities (w);
Louisiana Department of—
Environmental Quality (w),
Transportation and Development—
Materials Lab (w),
Office of Public Works (n,w),
Wildlife and Fisheries (w);
Louisiana Geological Survey, Louisiana State University (w);
Sabine River Compact Administration (w);
West Monroe, City of (w)

Maine

Androscoggin Valley Council of Governments (w);
Cobbossee Watershed District (w);
Greater Portland Council of Governments (w);
Maine Department of—
Conservation, Geological Survey (n,w),
Environmental Protection (w),
Inland Fisheries and Wildlife (w),
Transportation (n,w);
North Maine Regional Planning Commission (w);
Penobscot Valley Council of Governments (w);
University of Maine (w)

Maryland

Anne Arundel County Planning and Zoning Office (w);
Baltimore County—
Department of Permits and Licenses (w),
Department of Public Works (w),
Office of Planning and Zoning (w);
Calvert County Courthouse, Planning and Zoning (w);
Caroline County Courthouse (w);
Carroll County Commission (w);
Howard County Department of Public Works (w);
Johns Hopkins University (g);
Maryland Department of the Environment (w);
Maryland Geological Survey (n,w);
Maryland State Highway Administration (w);
Maryland Water Resources Administration (w);
Montgomery County—
Department of Environmental Protection, Division of Environmental Planning and Monitoring (w),
Storm Water Management (w);
Poolesville, Town of (w);
St. Marys County Commissioners (w);
Upper Potomac River Commission, Waste Treatment Facilities (w);
Washington Suburban Sanitary Commission (w)

Massachusetts

Barnstable County Commissioners (w);
Massachusetts Department of—
Environmental Management, Division of Water Resources (w),
Environmental Pollution—
Division of Water Pollution Control (w),
Division of Water Supply (w),
Fisheries, Wildlife, and Environmental Law Enforcement, Division of Fisheries and Wildlife (w),
Hazardous Waste Facility, Site Safety Council (w),
Public Works (w);
Massachusetts Institute of Technology (g);
Massachusetts Water Resources Authority (g,w);
Metropolitan District Commission—
Parks, Engineering and Construction Division (w),
Watershed Management Division (w);
New England Interstate Water Pollution Control Commission (w);
Woods Hole Oceanographic Institute (g)

Michigan
Ann Arbor, City of, Wastewater Treatment Plant (w);
Battle Creek, City of (w);
Cadillac, City of, Wastewater Treatment Plant (w);
Clare, City of (w);
Coldwater, City of, Board of Public Utilities (w);
Elsie, Village of, Department of Public Works (w);
Flint, City of, Department of Public Works and Utilities (w);
Genesee County Drain Commission, Division of Water and Waste Services (w);
Huron-Clinton Metropolitan Authority (w);
Huron, County of (w);
Imlay, City of (w);
Kalamazoo, City of, Department of Public Utilities (w);
Lansing, City of, Board of Water and Light, Water and Stream Division (w);
Macomb, County of (w);
Mason, City of (w);
Michigan Department of—
Natural Resources (w),
Transportation (w);
Negaunee, City of, Water and Wastewater Treatment Plant (w);
Norway, City of (w);
Oakland County Drainage Commission (w);
Otsego County Road Commission (w);
Portage, City of (w);
Wayne, County of, Division of Environmental Health (w);
Ypsilanti, City of (w)

Minnesota
Beltrami County SWCD (w);
Elm Creek Conservation Commission (w);
Fond Du Lac Reservation Business Committee (w);
Leech Lake Reservation Business Committee, Division of Resources Management (w);
Lower Red River Watershed Management District (w);
Metropolitan Waste Control Commission (w);
Mille Lacs Reservation Business Committee (w);
Minneapolis Water Works (w);
Minnesota Department of—
Natural Resources, Division of Waters (w),
Transportation (w);
Red Lake Tribal Reservation Business Committee (w);
Rochester Public Utilities (w);
St. Paul, City of (w), Water Utility (w);
University of Minnesota, Department of Soil Science (w)—
Landscape Architecture Program (n);
Remote Sensing Laboratory (n);
White Earth Reservation Business Commission (w)

Mississippi
Harrison, County of—
Board of Supervisors (w),
Development Commission (w);
Jackson, City of (w);
Jackson, County of—
Board of Supervisors (w),
Port Authority (w);
Mississippi Department of—
Environmental Quality—
Bureau of Geology (w),
Bureau of Land and Water Resources (w),
Bureau of Pollution Control (w),
Highways (w);
Pat Harrison Waterway District (w);
Pearl River Basin Development District (w);
Pearl River Valley Water Supply District (w)

Missouri
Branson, City of (w);
Cape Girardeau, City of (w);
Little River Drainage District (w);
Missouri Department of—
Conservation (w),
Health (w),
Natural Resources—
Division of Environmental Quality (w),
Division of Geology and Land Survey (n,w),
Land Reclamation Commission (w);
Missouri Highway and Transportation Commission (n,w);
Springfield, City of, City Utilities, Engineering Department (w);
Watershed Commission of the Ozarks (w);
University of Missouri-Columbia, Department of Geology (w)

Montana
Fort Belknap Indian Community (w);
Fort Peck Tribes (w);
Helena, City of (w);
Lower Musselshell Conservation District (w);
Montana Bureau of Mines and Geology (w);
Montana Department of—
Fish, Wildlife, and Parks (w),
Health and Environmental Sciences (w),
Highways (w),
Natural Resources and Conservation (w),
State Lands (w);
Salish and Kootenai Tribes of Flathead Reservation (w);
Wyoming State Engineer (w)

Nebraska
Central Platte Natural Resources District (w);
Kansas-Nebraska Big Blue River Compact Administration (w);
Lincoln, City of (w);
Little Blue Natural Resources District (w);
Lower Loup Natural Resources District (w);
Lower Platte South Natural Resources District (w);
Lower Republican Natural Resources District (w);
Middle Niobrara Natural Resources District (w);
Middle Republican Natural Resources District (w);
Nebraska Department of—
Environmental Control (w),
Water Resources (w);
Nebraska Natural Resources Commission (w);
Nemaha Natural Resources District (w);
North Platte Natural Resources District (w);
South Platte Natural Resources District (w);
Twin Platte Natural Resources District (w);
University of Nebraska, Conservation and Survey Division (w);
Upper Elkhorn Natural Resources District (w);
Upper Loup Natural Resources District (w);
Upper Niobrara White Natural Resources District (w);
Upper Republican Natural Resources District (w)

Nevada
Carson City Department of Public Works (w);
Carson Water Subconservancy District (w);
Clark County Regional Flood Control District (w);
Clark County Sanitation District (w);
Desert Research Institute, University of Nevada (g);
Elko, County of (w);
Las Vegas, City of (w);
Las Vegas Valley Water District (g);
Legislative Counsel Bureau (w);
Mackay School of Mines (w);
Nevada Bureau of Mines and Geology (g,n,w);
Nevada Department of—
Conservation and Natural Resources—
Division of Environmental Protection (w),
Division of Water Resources (w),
Transportation (w);
Regional Water Planning and Advisory Board of Washoe County (w);
South Lake Tahoe Public Utility District (w);
Summit Lake Paiute Tribe (w);
Tahoe Regional Planning Agency (w)

New Hampshire
New Hampshire Department of Environmental Services (g,w);
Governor's Energy Office (g)

New Jersey
Bergen County Department of Public Works (w);
Brick Township Municipal Utilities Authority (w);
Bureau of Mines and Mineral Resources (w);
Cape May, City of (w);
Delaware River Joint Toll Bridge Commission (w);
Gloucester County Planning Commission (w);
Lower, Township of, Municipal Utilities Authority (w);
Morris City Municipal Utilities Authority (w);
New Brunswick, City of (w);
New Jersey Department of—
Agriculture (w),
Environmental Protection, Division of Water Resources (w);
North Jersey District Water Supply Commission (w);
Passaic Valley Water Commission (w);
Somerset County Board of Chosen Freeholders (w);
West Windsor, Township of (w);
Wildwood, City of (w)

New Mexico
Alamogordo, City of (w);
Alamo Navajo Band (w);
Albuquerque, City of (w);
Albuquerque Metropolitan Arroyo Flood Control Authority (w);
Canadian River Municipal Water Authority (w);
Costilla Creek Compact Commission (w);
Council of Bernalillo (w);
El Paso Water Utility (w);
Gallup, City of (w);
Highlands University (w);
Jemez River Indian Water Authority (w);
Las Cruces, City of (w);
Los Alamos, County of (w);
Middle Rio Greater Conservation District (w);
Navajo Indian Nation (w);
New Mexico Bureau of Mines and Mineral Resources, Energy and Mineral Department (w);
New Mexico Environmental Improvement Division (w);
New Mexico Department of Highways (w);
New Mexico Mining and Minerals (w);
New Mexico State University Agricultural Experiment Station (w);
Office of the State Engineer (w);
Pecos River Commission (w);
Pueblo of Acoma (w);
Pueblo of Laguna (w);
Pueblo of Zuni (w);
Raton, City of (w);
Rio Grande Compact Commission (w);
Rio San Jose Flood Control District (w);
Ruidoso, Village of (w);
San Juan, County of (w);
Santa Fe Metropolitan Water Board (w);
Santa Rosa, City of (w);
Vermejo Conservancy District (w)

New York
Amherst, Town of, Engineering Department (w);
Auburn, City of (w);
Brookhaven, Town of (w);
Chautauqua, County of, Department of Planning and Development (w);
Cheektowaga, Town of (w);
Chenango, County of (w);
Cornell University—
Department of Natural Resources (w),
Department of Utilities (w);
Cortland County Planning Department (w);
Dutchess, County of, Environmental Management (w);
Hamilton College (g);
Hudson-Black River Regulating District (w);
Kiryas Joel, Village of (w);
Long Island Regional Planning Board (w);
Monroe, County of, Department of Health (w);
Nassau, County of—
Department of Health (w),
Department of Public Works (w);
New York City Department of Environmental Protection, Air and Water Resources-Energy (w);
New York State Department of—
Environmental Conservation—
Division of Fish and Wildlife (w),
Division of Water (w),
Transportation, Bridge and Construction Bureau (w);
New York State Geological Survey (g);
New York State Power Authority (w);
Nyack, Village of, Board of Water Commissioners (w);
Onondaga, County of—
Department of Drainage (w),
Water Authority (w);
Orange County Water Authority (w);
Saratoga, County of, Environmental Management Council (w);
Seneca County Soil Conservation District (w);
State University of New York–Albany (g);
Suffolk, County of—
Department of Health Services (w),
Water Authority (w);
Temporary State Commission (w);
Tompkins, County of, Department of Planning (w);
Ulster, County of, County Legislators (w);
Westchester, County of—
Department of Planning (w),
Department of Public Works (w)

North Carolina
Asheville, City of (w);
Bethel, Town of (w);
Brevard, City of (w);
Chapel Hill, Town of (w);
Charlotte, City of (w);
Durham, City of, Department of Water Resources (w);
Forsyth, County of (w);
Greensboro, City of (w);
Guilford County S.W.C.D. (w);
High Point, City of (w);
Lexington, City of (w);
Mecklenburg, County of (w);
North Carolina State Department of—
Human Resources (w),
Natural Resources and Community Development (n,w),
Transportation, Division of Highways (w);
Orange Water and Sewer Authority (w);
Raleigh, City of (w);
Rocky Mount, City of (w);
Triangle Area Water Supply Monitoring, Project Steering Committee (w)

North Dakota
Dickinson, City of (w);
Lower Heart River Water Resources District (w);
Minot, City of, Public Works Department (w);
North Dakota Department of—
Game and Fish (w),
Highways (w),
Parks and Recreation (w);
North Dakota Geological Survey (w);
North Dakota State University (w);
Oliver County Board of Commissioners (w);
Public Service Commission (w);
State Water Commission (w);
Three Affiliated Tribes Natural Resources Department (w)

Ohio
Akron, City of (w);
Canton, City of, Water Department (w);
Columbus, City of (w);
Eastgate Development and Transportation Agency (w);
Fremont, City of (w);
Lima, City of (w);
Lucas, County of (w);
Miami Conservancy District (w);
Ohio Department of—
Natural Resources (w),
Transportation (n,w);
Ohio Environmental Protection Agency (w);
Ohio Water Development Authority (w);
Ross, County of (w);
Sandusky, County of, Department of Health (w);
Seneca Soil and Water District (w);
Toledo Metropolitan Area Council of Governments (w);
University of Cincinnati, Department of Geology (w);
University of Toledo (w);
Wood, County of (w)

Oklahoma
Ada, City of (w);
Altus, City of (w);
Central Oklahoma Master Conservancy District (w);
Fort Cobb Reservoir Master Conservancy District (w);
Lawton, City of (w);
Lugert-Altus Irrigation District (w);
Mountain Park Master Conservancy District (w);
Norman, City of, Public Works (w);
Oklahoma City, City of, Department of Water Resources (w);
Oklahoma Department of Transportation (n);
Oklahoma Geological Survey, University of Oklahoma (g,w);
Oklahoma State Health Department (w);
Oklahoma Water Resources Board (w);
Tulsa, City of—
Water and Sewer Department (w),
Department of Storm Water Management (w)

Oregon
Clark County Intergovernmental Resources Center (w);
Confederated Tribes of Warm Springs Indian Reservation (w);
Coos Bay-North Bend Water Board (w);
Eugene, City of, Water and Electric Board (w);
Jackson, County of (w);
Klamath Falls, City of (w);
Klamath Tribe (w);
McMinnville, City of, Water and Light Department (w);
Oregon Department of—
Fish and Wildlife (w),
Forestry (n),
Geology and Mineral Industries (n),
Human Resources, Oregon Health Division, Drinking Water Program (w),
Natural Resources, Analysis and Planning Management Services Division (w),
Transportation, Highway Division (w),
Water Resources (w);
Oregon State University (g);
Portland, City of—
Bureau of—
Environmental Services (w),
Water Works (w)

Pennsylvania
Academy of Natural Sciences of Philadelphia (w);
Allentown, City of, Engineering Department (w);
Berks, County of (w);
Bethlehem, City of (w);
Bucks, County of (w);
Chester, County of, Water Resources Authority (w);
Delaware County Solid Waste Authority (w);
Delaware River Basin Commission (w);
Erie, County of, Department of Health (w);
Harrisburg, City of, Department of Public Works (w);
Indiana, County of (w);
Joint Planning Commission of Lehigh-Northampton Counties (w);
Lancaster County Planning Commission (w);
Letort Regional Authority (w);
Media Borough Water Department (w);
New York State Department of Environmental Conservation (w);
Oley, Township of (w);
Philadelphia, City of, Water Department (w);
Pennsylvania Department of—
Environmental Resources—
Bureau of Community Environmental Control (w),
Bureau of Mining and Reclamation (w),
Bureau of Soil and Water Conservation (w),
Bureau of Topographic and Geologic Survey (g,n,w),
Bureau of Water Quality Management (w),
Bureau of Water Resources Management (w);
Susquehanna River Basin Commission (w);
University Area Joint Authority (w);
University of Delaware, Geological Survey (w);
Williamsport, City of, Bureau of Flood Control (w)

Puerto Rico
Puerto Rico Aqueduct and Sewer Authority (w);
Puerto Rico Department of Natural Resources (w);
Puerto Rico Environmental Quality Board (w);
Puerto Rico Industrial Development Company (w);
Puerto Rico Mineral Resources Development Corporation (g);
Puerto Rico Planning Board (w);
Virgin Islands Department of Natural Resources (w);
Virgin Islands Water and Power Authority (w)

Rhode Island
Governor's Office of Energy Assistance (w);
Narragansett Bay Water Quality Commission (w);
New Shoreham, Town of (w);
Rhode Island State Department of Environmental Management, Division of Water Resources (w);
State Water Resources Board (w)

South Carolina
Beaufort-Jasper County Water Authority (w);
Charleston Commission of Public Works (w);
Cooper River Water Users Association (w);

Donaldson Development Commission (w);
Georgetown County Water and Sewer District (w);
Grand Strand Water and Sewer Authority (w);
Irmo, Town of (w);
Lexington, County of (w);
Myrtle Beach, City of (w);
Oconee County Sewer Commission (w);
Richland, County of (w);
South Carolina State—
Department of Health and Environmental Control (w),
Department of Highways and Public Transportation (w),
Geological Survey (w),
Public Service Authority (w),
Water Resources Commission (w);
South Carolina Sea Grant Consortium (w);
South Carolina Wildlife and Marine Resources Department (w);
Spartanburg Sanitary Sewer District (w);
Spartanburg Water System (w);
Waccamaw Regional Planning and Development Commission (w);
Western Carolina Regional Sewer Authority (w)

South Dakota
East Dakota Water Development District (w);
Lawrence, County of (w);
Oglala Sioux Tribe (w);
Rapid City, City of (w);
Sioux Falls, City of (w);
Sisseton-Wahpeton Sioux Tribe (w);
South Dakota Department of—
Game, Fish and Parks (w),
Transportation (g,w),
Water and Natural Resources—
Geological Survey Science Center (w),
Water Development Division (w),
Water Quality Division (w),
Water Rights Division (w);
South Dakota School of Mines and Technology (w);
Watertown, City of (w);
West Dakota Water Development District (w)

Tennessee
Alcoa, City of (w);
Bartlett, City of (w);
Blountville, City of, Utility District (w);
Dickson, City of (w);
Eastside Utility District (w);
Emergency Management Agency (w);
Germantown, City of (w);
Gladeville Utility District (w);
Hamilton, County of, Office of Emergency Management (w);
Hixson Utility District (w);
Humphreys County Commissioners (w);
Jackson, City of, Utility Division (w);
Lawrenceburg, City of (w);
Lebanon, City of (w);
Lincoln, County of, Board of Public Utilities (w);
McMinnville, City of (w);
Memphis, City of—
Department of Public Works (w),
Light, Gas, and Water Division (w);
Memphis State University (w);
Metropolitan Governments, Nashville, City of, and Davidson, County of (w),
Department of Public Works (w);
Millington, City of (w);
Murfreesboro, City of, Water and Sewer Department (w);
North Stewart County Utility District (w);
Rogersville, Town of (w);
Sevierville, City of (w);
Shelby, County of, Public Works (w);
Tennessee Department of—
Agriculture (w),
Health and Environment (w)—
Construction Grants and Loans (w),
Division of Superfund (w),
Office of Water Programs (w),
Transportation—
Division of Research (w),
Division of Structures (w);
Tennessee State Planning Office (w);
Tennessee Wildlife Resources Agency (w);
Union City, City of (w);
Upper Duck River Development Agency (w);
Wartrace, City of (w);
Webb Creek Utility District (w)

Texas
Abilene, City of (w);
Arlington, City of (w);
Austin, City of (w);
Bexar-Medina-Atascosa Counties, Water Improvement District No. 1 (w);
Brazos River Authority (w);
Carrollton, City of (w);
Coastal Industrial Water Authority (w);
Colorado River Municipal Water District (w);
Corpus Christi, City of (w);
Dallas, City of, Public Works Department (w);
Edwards Underground Water District (w);
El Paso, City of, Public Service Board (w);
Fort Stockton, City of (w);
Fort Worth, City of, Water Department, Water Pollution Control (w);
Franklin, County of, Water District (w);
Gainesville, City of (w);
Galveston, County of (w);
Garland, City of (w);
Graham, City of (w);
Greenbelt Municipal and Industrial Water Authority (w);
Guadalupe-Blanco River Authority (w);
Harris, County of, Flood Control District (w);
Harris-Galveston Coastal Subsidence District (w);
Houston, City of (w);
Lavaca-Navidad River Authority (w);
Lower Neches Valley Authority (w);
Lubbock, City of (w);
Lunar and Planetary Institute (g);
Nacogdoches, City of (w);
North Central Texas Municipal Water Authority (w);
North Texas Municipal Water District, Research and Development (w);
Northeast Texas Municipal Water District (w);
Orange, County of (w);
Pecos River Commission (w);
Red Bluff Water Power Control District (w);
Red River Authority (w);
Runaway Bay, City of (w);
Sabine River Authority of Texas (w);
Sabine River Compact Administration (w);
San Angelo, City of (w);
San Antonio, City of—
Department of Environmental Management (w),
Department of Water Resources Management (w),
Public Service Board (w),
Water Board (w);
San Antonio River Authority (w);
San Jacinto River Authority (w);
Tarrant, County of, Water Control and Improvement District No. 1 (w);
Texas Water Commission (w);
Texas Water Development Board (n,w);
Titus, County of, Fresh Water Supply District No. 1 (w);
Trinity River Authority (w);
University of Texas (g);
Upper Guadalupe River Authority (w);
Upper Neches River Municipal Water Authority (w);
West Central Texas Municipal Water District (w);
Wichita, County of, Water Improvement District No. 2 (w);
Wichita Falls, City of (w)

Trust Territory of the Pacific Islands
Federated States of Micronesia (w)—
State of Kosrae (w),
State of Ponape (w),
State of Yap (w);
Northern Mariana Islands, Government of (w),
Commonwealth of, Utility Commission (w);
Republic of Palau (w);
Samoa, Government of (w)

Utah
Bear River Commission (w);
Ogden River Water Users (w);
Salt Lake City/County Department of Health (w);
Salt Lake, County of, Division of Flood Control (w);
Tooele, City of (w);
Tooele, County of (w);
University of Utah (g);
Utah Department of—
Agriculture, Environmental Quality Section (w),
Health, Division of Environmental Health (w),
Natural Resources—
Geological and Mineral Survey (g,n,w),
Oil, Gas and Mining Division (w),
Water Resources Division (w),
Water Rights Division (w),
Wildlife Resources Division (w),
Transportation (w);
Utah Health Department, Division of Environmental Health (w);
Utah Office of Planning and Budget (n);
Weber Basin Water Conservancy District (w);
Weber River Water Users (w)

Vermont
Agency of Natural Resources (g,n);
Department of Environmental Conservation (w)

Virginia
Accomack, County of (w);
Alexandria, City of (w);
Henrico, County of, Department of Public Utilities (w);
James City, County of (w);
James City Service Authority (w);
Loudoun, County of (g);
Mount Rogers Planning District Commission (w);
Newport News, City of (w);
Northampton, County of (w);
Northern Virginia Planning District Commission (w);
Prince William Health District (w);
Roanoke, City of (w);
Southeastern Public Service Authority of Virginia (w);
Southeastern Virginia Planning District Commission (w);
University of Virginia, Department of Environmental Sciences (w);
Virginia Department of—
Mines, Minerals, and Energy, Division of Mineral Resources (n),
Transportation (w);
Virginia Beach, City of, Department of Public Utilities (w);
Virginia Polytechnic Institute and State University (g);
Virginia State Water Control Board (w);
Williamsburg, City of (w);
York, County of (w)

Washington
Bellevue, City of, Public Works Department (w);
Centralia, City of, Light Department (w);
Chelan, County of, Public Utility District No. 1 (w);
Confederated Tribes of the Umatilla Indian Reservation (w);
Douglas, County of, Public Utility District No. 1 (w);
Hoh Indian Tribe (w);
King, County of, Department of Public Works (w);
Kitsap, County of, Public Utility District No. 1 (w);
Lewis, County of, Board of Commissioners (w);
Pend Oreille, County of (w);
Pierce, County of (w);
Portland, City of, Bureau of Water Works (w);
Quinault Business Committee (w);
Seattle, City of, Department of Lighting (w);
Skagit, County of (w), Department of Public Works (w);
Snohomish, County of (w);
Tacoma, City of, Department of—
  Public Utilities (w),
  Public Works (w);
Thurston, County of, Department of—
  Health (w),
  Public Works (w);
Washington Department of—
  Ecology (w),
  Emergency Management (w),
  Fisheries (w),
  Natural Resources (g,n),
  Transportation (w);
University of Washington (g);
Upper Skagit Indian Tribe (w);
Walla Walla, City of (w);
Whatcom, County of, Department of Public Works (w);
Yakima Tribal Council (w)

West Virginia
Eastern Panhandle Regional Planning and Development Council (w);
Jefferson County Commission (w);
Morgantown, City of, Utility Board (w);
Region VII Planning and Development Council (w);
Research Corporation, Marshall University (w);
Washington Public Service District (w);
West Virginia Department of—
  Health, Office of Environmental Health Services (w),
  Highways (w),
  Natural Resources, Division of Water Resources (w);
West Virginia Geological and Economic Survey (n,w)

Wisconsin
Balsam Lake Protection and Rehabilitation District (w);
Beaver Dam, City of (w);
Big Muskego Dam Drive (w);
Chippewa, County of, Land Conservation Department (w);
Dane, County of—
  Department of Public Works (w),
  Regional Planning Commission (w);
Delavan, Town of (w);
Fond Du Lac, City of (w);
Fowler Lake Management District (w);
Green Bay Metropolitan Sewerage District (w);
Green Lake Sanitary District (w);
Hillsboro, City of (w);
Lac Courte Oreilles Governing Board (w);
Little Muskego Lake District (w);
Madison Metropolitan Sewerage District (w);
Menominee Indian Tribe of Wisconsin (w);
Norway, Town of (w);
Oconomowoc Lake, Village of (w);
Okauchee Lake Management District (w);
Oneida Tribe of Indians (w);
Peshtigo, City of (w);
Powers Lake, District of (w);
Pretty Lake Protection and Rehabilitation District (w);
Red Cliff Band of Lake Superior Chippewas (w);
Rock, County of (w);
Sand Lake, Town of (w);
Southeastern Wisconsin Regional Planning Commission (w);
Stockbridge-Munsee Tribal Council (w);
Thorp, City of (w);
University of Wisconsin, Extension, Geological and Natural History Survey (n,w);
Waukesha Water Utility (w);
Waupun, City of (w);
Wind Lake Management District (w);
Wisconsin Department of—
  Natural Resources (w),
  Transportation, Division of Highways (w)

Wyoming
Attorney General (w);
Cheyenne, City of (w);
Evanston, City of (w);
Evansville, Town of (w);
Gillette, City of (w);
Midvale Irrigation District (w);
Northern Arapahoe Tribe (w);
Pinedale, City of (w);
Shoshone Tribe, Shoshone Business Council (w);
Teton, County of (w);
Uinta, County of (w);
Water Development Commission (w);
Western Wyoming Community College (w);
Wyoming Department of—
  Agriculture (w),
  Environmental Quality (w);
Wyoming State Engineer (n,w);
Wyoming Water Research Center (w)

Federal Cooperators

Central Intelligence Agency (g,n)

Department of Agriculture
Agricultural Stabilization and Conservation Service (w);
Forest Service (g,n,w);
National Agricultural Statistics Service (n);
Office of International Cooperation and Development (w);
Soil Conservation Service (n,w)

Department of the Air Force (w)
Air Force Academy (w);
Edwards Air Force Base (g);
Hanscom Air Force Base (g);
Headquarters, AFTAC/AC (g);
Kelly Air Force Base (w);
Occupational and Environmental Health Laboratory (w);
Vandenberg Air Force Base (w)

Department of the Army (n,w)
Aberdeen Proving Ground (w);
Belvoir RD&E Center (g);
Corps of Engineers (g,n,w);
Engineer Topographic Laboratory (w);
Fort Carson Military Reservation (w);
Intelligence Center and School (n);
Picatinny Arsenal (w);
Waterways Experiment Station, Vicksburg (g);
White Sands Missile Range (w)

Department of Commerce
Bureau of the Census (n);
National Institute of Standards and Technology (g);
National Ocean Service (n);
National Oceanic and Atmospheric Administration (g,n,w);
National Weather Service (n,w)

Department of Defense Agencies
Defense Advanced Research Projects Agency (g);
Defense Logistics Agency (w);
Defense Mapping Agency (n);
Defense Nuclear Agency (g);
National Guard Bureau (w)

Department of Energy (g,w)
Albuquerque Operations Office (w);
Bonneville Power Administration (w);
Chicago Operations Office (g);
Hanford Project (w);
Health and Environmental Research (g);
Idaho Operations Office (w);
Los Alamos National Laboratory (g);
Nevada Operations Office (g,w);
Oak Ridge Operations Office (g,w);
Sandia National Laboratories (g,w);
Savannah River Operations Office (g,n,w);
Situ-Field Research, Morgantown, West Virginia (g);
Test Operations Office, Las Vegas, Nevada (g)

Department of the Interior
Bureau of Indian Affairs (g,w);
Bureau of Land Management (g,n,w);
Bureau of Mines (w);
Bureau of Reclamation (g,n,w);
Minerals Management Service (g,n,w);
National Park Service (g,n,w);
Office of the Secretary (w);
Office of Surface Mining Reclamation and Enforcement (w);
U.S. Fish and Wildlife Service (g,w)

Department of the Navy (w)
Naval Missile Test Center (g);
Naval Oceanographic Office (g);
Naval Weapons Center, China Lake (g,w);
Office of Naval Research (g);
U.S. Marine Corps (w)

Department of State
Agency for International Development (g,n,w);
Foreign and Nonforeign Governments (g);
Government of Saudi Arabia (g);
International Boundary and Water Commission, U.S. and Mexico (n,w);
International Joint Commission, U.S. and Canada (w)

Department of Transportation
Federal Highway Administration (g,w);
Maritime Administration (g);
U.S. Coast Guard (w)

Department of Treasury
U.S. Customs Service (n)

Environmental Protection Agency (g,n,w)
Corvallis Environmental Research Laboratory (w);
Environmental Monitoring Systems Laboratory (g);
Office of Environmental Processes and Effects Research (g);
Office of Radiation Programs (g)

Federal Emergency Management Agency (w)

Federal Energy Regulating Commission Licensees (w)

National Aeronautics and Space Administration (g,n,w)

National Science Foundation (g,n,w)

Nuclear Regulatory Commission (g)

Tennessee Valley Authority (n)

Veterans Administration (g,w)

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University of British Columbia (g)

University of Otago, New Zealand (g)

United Nations
Organization of American States (w);
United Nations Development Program (w);
Unesco (g);
World Bank (g)

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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