
USGS 1988

United States Geological Survey Yearbook Fiscal Year 1988

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

United States Geological Survey Yearbook
ISSN 0892-3442

UNITED STATES GOVERNMENT PRINTING OFFICE: 1989

For sale by the Books and Open-File Reports Section, U.S. Geological Survey
Federal Center, Box 25425, Denver, CO 80225

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Cover artwork by Jeff Dietterle after a photograph published in Volume 2, 1879–1904, of the history of the U.S. Geological Survey, "Minerals, Lands, and Geology for the Common Defense and General Welfare," by Mary Rabbitt (1980).

A Global Perspective on the Role of the Earth Sciences

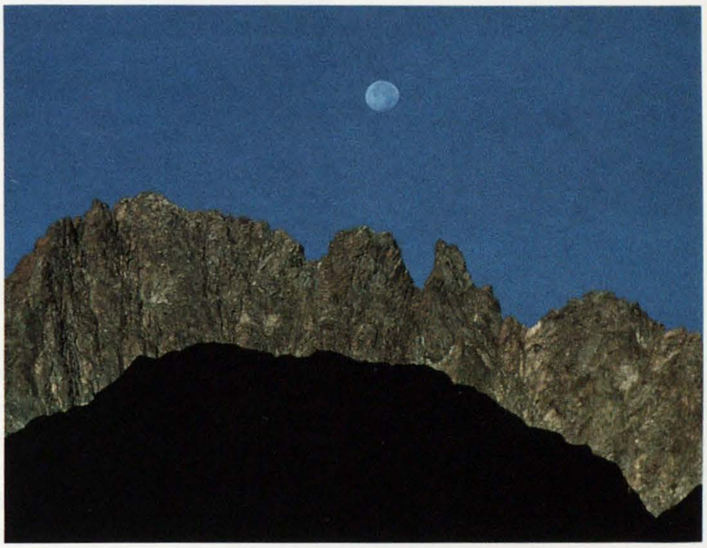
By Dallas L. Peck
Director, U.S. Geological Survey

Reflecting on the events of the 1988 fiscal year, I recall that it began with a troubling reminder to this agency and to the Nation as to how vulnerable we are to the capricious acts of nature—the October 1, 1987, earthquake that was centered near Whittier, Calif., in the greater Los Angeles metropolitan area. While the magnitude 5.9 tremor was not a truly large earthquake in a seismological sense, the impacts and effects of that shock were a striking reminder that we are not in control of the Earth, nor do we fully understand the geologic forces and processes that affect it. The challenge of understanding those forces is what makes earth science such an exciting field of research. As the Nation's principal earth science agency, the U.S. Geological Survey is charged with advancing understanding of the earth system, interpreting the significance of scientific findings, and communicating those findings to the policymakers and managers who need the information.

We must remind ourselves that the forces and processes at work on Earth are not mindful of calendars and new fiscal years, nor do they fit nicely within political boundaries. Whatever the season, administration, or political climate, the Earth functions on its own timeclock, with its own independent controls. In that independence of the Earth lies a special challenge for the earth scientist. We must be scientists who view the Earth as a whole and yet are able to relate that view to our particular human aspirations and boundaries; and we must also be able to study regions and smaller areas in great detail and then extrapolate that knowledge to a much broader, sometimes global, perspective.

I have had a unique opportunity during this past year to put that challenge into play. In what I see as an extraordinary companion role to that of USGS Director, I have had the privilege of serving as the Chairman of the Committee on Earth Sciences within the Federal Coordinating Council on Science, Engineering, and Technology, under the auspices of the President's Science Advisor.

That is quite a bureaucratic mouthful, but the chairmanship of the Committee has allowed me, and encouraged the USGS, to enter into a special arena in which we not only can but should play an important role. That special area is the emerging science of global change. By global change I refer to both short-term



(Facing page) Autumn on Mount Rainier, Washington. (Photograph by Stewart Tomlinson.) (Above) Moon over Ritter Ridge, central Sierra Nevada, California. (Photograph by Paul Hsieh.)

. . .we must concentrate our efforts on viewing the Earth as a complex, dynamic, and interactive global system.

and long-term changes and processes of the Earth's interactive spheres: the lithosphere, the Earth's surface and near surface; the hydrosphere, the world's freshwater and oceans; the atmosphere, the source of life-sustaining oxygen, but also, all too often, the destination of the results of human activities; the cryosphere, the cold reaches of the Earth's two poles and its high mountains; and the biosphere, the life—plant, animal, and human—of the Earth.

The implications and impacts of global change—what can already be documented and what can be deciphered from the geologic record—are many, including climate change, sea-level rise and fall, expansion and recession of enormous ice sheets, changes in plant and animal life, and volcanic eruptions. Clearly there is much to understand and much to do. The major charge to the Committee on Earth Sciences is to increase "the overall effectiveness and productivity of Federal research and development efforts directed toward an understanding of the Earth as a global system." That charge reinforces my belief that we must concentrate our efforts on viewing the Earth as a complex, dynamic, and interactive global system. Expertise from many different organizations and from a wide range of interrelated scientific disciplines is required to address the global system—meteorology, oceanography, hydrology, geology, biology, chemistry, and physics, to name only a few.

The USGS has much to contribute to the understanding of the Earth's system and natural and human-caused changes in it; indeed most of our activities could be interpreted to relate to global change. Our long history of scientific investigation has given us experience and abilities that will be important for monitoring aspects of global change, determining past changes and the causes and consequences of these changes, understanding some of the physical and chemical processes that are key to predicting global change, and evaluating possible management strategies for responding to changes affecting the land and hydrologic systems. The USGS also has long experience in managing large data bases such as those necessary to evaluate global processes and changes. This expertise is particularly appropriate for addressing a current major global-change concern, global warming.

Using large numerical models of the energy and mass balance of the atmosphere, scientists have predicted global warming of 2–5 degrees Celsius over the next half-century, assuming a doubling of atmospheric carbon dioxide concentrations due in part to emissions from the combustion of fossil fuels. These models have large uncertainties and differences, and they do not represent well some of the key components of the global system; however, they all indicate that warming would occur first and be greatest in magnitude at the poles. The USGS has a long history of conducting polar studies and glacier monitoring that could provide an early indication of global warming. Earlier this year the USGS published the first volume of a planned series of 11 atlases on the world's major glaciers that will provide an excellent foundation for monitoring such changes.

The USGS has been involved in numerous investigations of marine and terrestrial sediments, lake and cave deposits, ice, tree rings, and fossils that provide information on past climatic conditions. This information will be critical for determining natural short-term and long-term climatic variability. An article in this yearbook summarizes investigations on a sediment core from an ancient lake in California, which documented regional climatic changes for the past 3 million years.

Paleoclimate studies also can provide information on possible causes of climate change and environmental responses to these changes. While the general circulation models predict that climate changes will be accompanied by dramatic changes in the hydrologic system, current models do not represent the whole hydrologic cycle in sufficient detail to provide useful information on the significance of hydrologic changes to the environment. The

Half Dome at sunset, Yosemite National Park, California. (Photograph by Dallas L. Peck.)

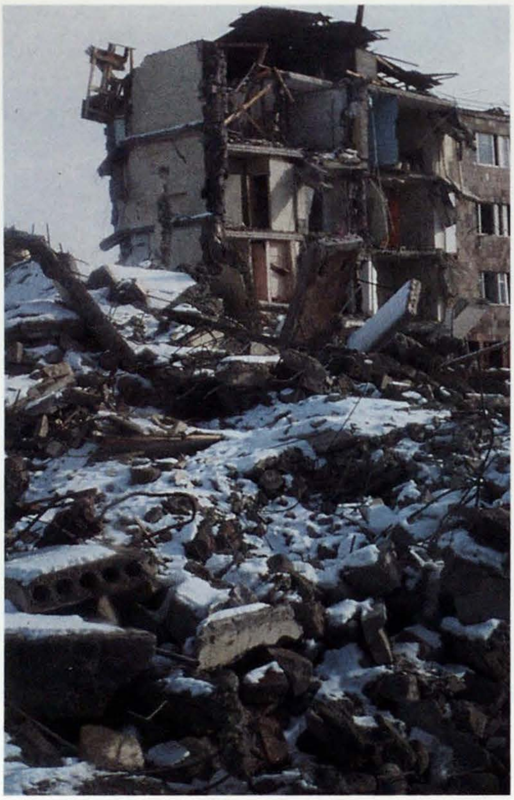
USGS has a clear role to play in improving scientific understanding of key processes in the hydrologic cycle such as evapotranspiration. Evaluations of hydrologic response to climate conditions, such as a recently started study of the Delaware River basin, also will be essential to estimating the effects of climate change.

Investigations of global scientific issues require large data bases. The National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the National Science Foundation, the Department of Energy, the United States Navy, and the USGS are working together, through the Interagency Working Group on Data Management for Global Change, to provide the scientific community with ready access to the data needed to study global change. The Working Group is designing a data base that would leave primary stewardship of most data to the scientists or agencies who collected them but enable access and integration of data bases from wherever they reside. A test of this concept will be conducted using existing Arctic data bases. The facilities and expertise of the Earth Resources Observation Systems Data Center, the USGS facility at Sioux Falls, S. Dak., which has extensive experience in satellite and remotely sensed data archiving and processing, would play a major role in this data base in managing land-observation data. Recently we signed an agreement with the National Aeronautics and Space Administration that would give responsibility to the USGS for archiving, processing, and managing land data from NASA's planned Earth Observing Satellites in the 1990's, similar to the role we have played in the past for Landsat data. Combined with other USGS geologic, hydrologic, and cartographic data bases, these satellite data will be central to studies of land-surface changes.

The activities in global change that I have mentioned represent a small fraction of the many exciting contributions that the USGS is making and will continue to make in this field. For our contributions to direct policy decisions effectively, we must continue to emphasize cooperation and coordination within the Federal and international scientific community.

Our global perspective is being altered continually by events occurring throughout the world. As I was preparing this message, another earthquake took place, one that took thousands of lives and caused great damage, and the study of which will likely occupy scientists, engineers, land-use and urban planners, and social scientists for many years to come. The magnitude 6.9 earthquake that struck the Armenian Soviet Socialist

Some of the devastation caused by the December 1988 earthquake in the Armenian Soviet Socialist Republic. (Photograph by John Filson.)



Republic on December 7, 1988, was a most tragic reminder—again—of the substantial loss of life and great economic losses that a damaging earthquake can cause in just a few minutes. The immediate worldwide offers of assistance from the scientific community were immensely gratifying. I was also pleased that the team of 17 U.S. experts who went to Armenia to assist Soviet scientists, engineers, and rescue officials was led by Dr. John Filson of the USGS and included six additional USGS scientists and technicians. They, along with scientists and engineers from the National Academy of Sciences, the National Institute of Standards and Technology, and several academic institutions, and with financial support from the National Science Foundation and other organizations, were able to assist in assessing the earthquake and in determining the reasons for its great damage.

A great deal can be learned in the aftermath of an earthquake. Scientists and engineers, working with land-use planners and rescue and relief groups, can ascertain much about geology, land use, engineering and building design, and how to manage the response to a destructive earthquake. All of this knowledge can help in the future to mitigate the effects of similar, inevitable earthquakes anywhere in the world.

In an effort to address the need to reduce the risks from earthquakes and other natural disasters, the National Academy of Sciences recently began planning for the International Decade for Natural Disaster Reduction to take place during the last decade of this century. The Decade will serve as a focus for concerted worldwide actions to reduce human suffering from earthquakes, landslides, floods, volcanic eruptions, and other natural hazards.

The USGS has a long tradition of working closely with the U.S. Department of State's Office of Foreign Disaster Assistance (OFDA) in responding to natural disasters worldwide. We frequently have sent our scientists to all corners of the world to assist OFDA and local officials and scientists in dealing with the effects of landslides, earthquakes, and volcanic eruptions. In the process, we have broadened our scientific knowledge of the Earth, a knowledge that can help reduce the probable magnitude of disasters occurring in similar terrains in the United States and elsewhere in the world.

Through these continuing international efforts and our participation in developing a national program for incorporation into the International Decade for Natural Disaster Reduction, the USGS is playing what I strongly feel to be an appropriate and supportive role in providing earth science in service to the national and the global community.

By the time that this yearbook is published, the USGS and the National Academy of Sciences will be busily preparing to host the 28th International Geological Congress. This prestigious convening of earth scientists from most of the nations in the world is held about once every four years. This is the Olympics of the earth sciences, an event at which we have the opportunity to present papers and enter into discussions that allow us to expand the boundaries of our scientific knowledge. This Congress, to be held July 9–19, 1989, in Washington, D.C., will mark the first time that the Congress has met in the United States since 1933. The previous Congress was held in Moscow in 1984 and the next one will be held in Japan in 1992. These are important meetings—important for the scientific knowledge that is exchanged and important for the spirit of cooperation that can be achieved.

While I have concentrated much of this message on the global and international aspects of the scientific work in which the USGS is involved, those activities represent only a portion of the wide range of Survey research and investigations. The exciting technology that is being developed in advanced cartographic systems—space-age mapping for the future—creative applications of sophisticated computer modeling in solving complex problems in dealing with toxic contaminants in surface- and ground-water resources, and rapidly improving predictive capabilities in dealing with natural disasters such as volcanic eruptions, landslides, and earthquakes are just a quick list of some of the day-to-day work in which our dedicated employees are engaged.

During my nearly 40 years as a scientist and manager with the USGS, the earth sciences have undergone a dramatic revolution, encompassing imaging and exploration of the planets, moons, and comets of the solar system; imaging and exploration of the deep seabed; development and acceptance of the theory of plate tectonics; development and use of computer technology to better understand hydrologic systems, geologic structure, and other applications; increased involvement in solving immediate earth science problems that directly affect people's lives through applications of "real-time geology"; and application of new technology, such as electron microprobes and advanced cartographic and geographic information systems. I see that revolution continuing, even accelerating. The integrated and cooperative efforts of many scientific disciplines in the study of global change will be part of that continuing revolution.

The USGS has a long and proud tradition of providing "Earth Science in the Public Service." As our Nation continues to face important questions concerning the availability and use of its land, water, energy, and mineral resources, the Survey's mission to provide the scientific information necessary to address these questions takes on added significance. The articles in this yearbook, which I must emphasize represent only a sampling of the many investigations and studies that are being conducted in this country and around the world, show that we continually rededicate ourselves to addressing those questions.

Large dunes at Great Sand Dunes National Monument, Colorado. The highest dune is about 800 feet high. Mature trees at base of dune are about 70 feet high. (Photograph by John R. Keith.)

National Mapping Program

Mission

The primary mission of the National Mapping Division is to conduct the National Mapping Program. This program, which involves collecting, archiving, and disseminating cartographic, geographic, and remotely sensed data, provides accurate and up-to-date basic cartographic data for the United States in forms that can be readily applied to present-day problems. Topographic maps at various scales illustrating detailed and precisely referenced information about natural and manmade features on the Earth's surface continue to be an important product of the U.S. Geological Survey. These maps provide basic cartographic information needed by most Federal, State, and local government agencies in dealing with key issues ranging from energy production to conservation, from preparing environmental impact statements to developing socially acceptable solutions for environmental problems, and from locating commercial facilities to designing public works.

In addition to maps, the National Mapping Program also produces cartographic data in computer-readable form. These data are used in computer-based resource information and management systems to evaluate alternative management plans and to study the effects of different policies.

(Above and facing page) Portions of the satellite image map of the Denali National Park and Preserve, Alaska. The satellite imagery was recorded by multispectral scanner on NASA Landsats 3 and 5. Mount McKinley is clearly shown on the facing page as the large white to blue (snow- and glacier-covered) mass near the center.

Highlights

Primary Mapping Economic Analysis

By Larry L. Amos, Carl D. Shapiro, and Donald H. Zoller

Mapping activities at the U.S. Geological Survey are undergoing major programmatic and technological transitions that will continue during the next several years. Programmatically, the USGS plans to have available initial national coverage of primary-scale quadrangle maps by the end of fiscal year 1990. There is now a growing demand for revision of previously completed primary maps where data have become outdated. As a result, the USGS is placing more emphasis and resources on map revision efforts.

A technological revolution also is taking place as computer storage and manipulation of map data are rapidly changing and improving the ways in which data can be used. In response to new requirements created by this changing technology, the USGS is digitizing its maps to the extent resources permit. The development and increased use of geographic information systems, which provide the technology for automated manipulation and analysis of these digitized map data, have intensified pressure on the USGS to provide more digitized cartographic data. To respond to this increasing demand, the USGS plans to implement advanced technology being developed by the Department of Defense. This advanced technology, called Advanced Cartographic Systems (ACS), will greatly increase production capacity and will allow the USGS to achieve significant cost savings over the next decade. An Advanced Cartographic Systems cost-effectiveness analysis, prepared in 1986, demonstrated that ACS is cost effective over a wide range of production levels. To help determine what production level is appropriate, the USGS initiated a primary mapping economic analysis. Because there is a time limit on the procurement of hardware and software required for the implementation of ACS, a decision on this production level has to be made in the near future.

Methodology

The assumption that primary map information is a public good is central to the methodology in this analysis. Because many parties can use the same map information at the same time, the benefits from the information in each map can be summed among its many users.

The model developed in this analysis examines the benefits and costs of revising primary map information in each 7.5-minute quadrangle in a sample of five States. A series of map revision cycles are examined to identify the best revision cycle for each quadrangle. The results obtained in the sample States then are extrapolated statistically to the Nation. The optimal ACS production capacity is derived directly from the optimal revision cycles.

The methodology incorporates the multiplicity of use into the benefit calculations. Rather than examining a small number of applications with dramatic benefits, a larger number of applications with smaller calculated benefits is studied. The existence of a large number of applications makes it possible to calculate a lower, conservative estimate of benefits for each application because the sum of these conservative estimates is still large enough to make the results meaningful.

Benefits in this analysis are defined as the amount that an organization would spend to update map information if current primary maps were not available. This definition provides a conservative estimate of the benefits for each application. The consumer surplus (that is, the difference between the amount a user is willing to pay and the amount that the user actually pays) is not included in this definition.

A decision tree was developed to model the different procedures by which map users could update primary map information if the USGS were not able to do so. The cost of implementing each of the branches of the decision tree was estimated from USGS map production records. As a result, the decision tree provided estimated costs of various levels of map revision that ranged from no activity to the maximum of a full map revision for eight layers of map information.

The decision-tree model was applied to 216 case studies in 5 States (Connecticut, Florida, Illinois, Oregon, and Utah). For each case study, information was collected on the appropriate branches of the decision tree and the geographic area where the application was conducted. The costs examined in this analysis included both the capitalization costs for ACS between fiscal years 1989 and 2000 and the production costs for revision of primary maps. Optimal map revision cycles were calculated for each of the 5,416 quadrangles in the 5 sample States by evaluating benefits and costs for 20 different map revision cycles, ranging from a 1-year cycle to a 20-year cycle.

The calculated best map revision cycles were projected to the Nation by classifying geographic areas in the five States and extrapolating the results to similar geographic areas in the Nation. Four dichotomous categories that could significantly affect the benefits or costs of map revision were selected for this extrapolation. These categories were urban/rural, Federal lands/non-Federal lands, energy lands/non-energy lands, and coastal areas/inland areas. These 4 dichotomous categories combine to form 16 unique conditions. Within each of the unique conditions, the mean optimal revision cycle was calculated in the five States. This result was then projected so that areas within the same classification category have the same optimal revision cycle throughout the Nation.

Results

The optimal revision cycles in the five sample States range from 1 year in selected urban and urbanizing areas to 5 years in most rural and remote areas. The results show that developing areas outside the traditional urban core may require primary map revisions as frequently as do urban core areas. Applications in urban and urbanizing areas and on Federal lands are key variables that suggest more frequent map revision in this model. Frequent optimal revision cycles in the Western States, where most Federal land is located, provide evidence of the large benefits from Federal applications.

An analysis of benefit and cost curves shows that, in the 5 sample States,

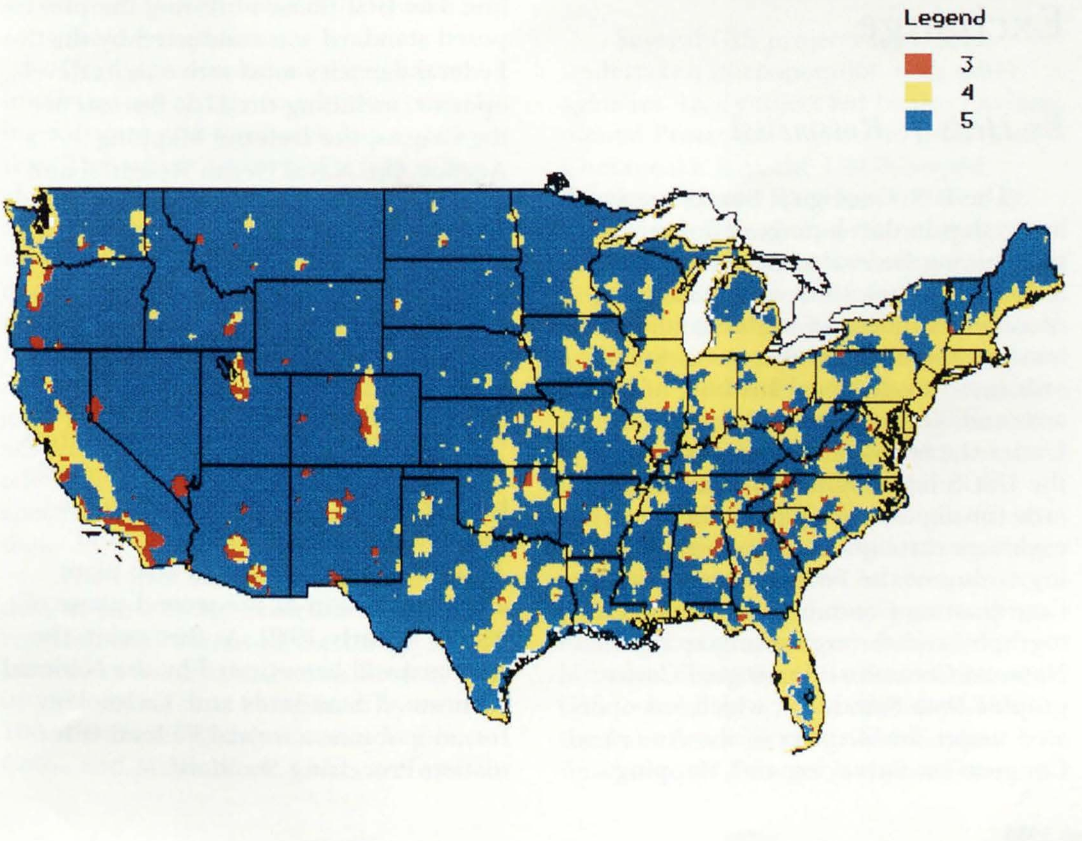


Figure 1. Optimal map-revision cycles based on extrapolated averaged benefits derived from a five-State sample area.

net benefits are maximized at a production level of approximately 1,200 quadrangles revised per year. At this production level, the present value of aggregate net benefits between 1989 and 2000 averages approximately $70,000 a quadrangle and corresponds to an average revision cycle of 4.5 years.

The patterns noted in the five States continue when the data are extrapolated to the conterminous United States as shown in figure 1. The importance of primary map revision in urbanizing areas is shown dramatically in the Eastern United States, where large population corridors extending beyond the traditional central city require more frequent revision than do rural areas. The optimal production level associated with the extrapolated national model is approximately 12,500 maps revised per year. Sensitivity analyses, where benefits are arbitrarily doubled or halved, show a range in the optimal map revision capacity for the U.S. Geological Survey of 10,000 to 17,000 maps a year.

Standards for Digital Cartographic Data Exchange

By Hedy J. Rossmeissl

The U.S. Geological Survey assumed leadership in developing, defining, and maintaining Federal earth science standards in February 1980 with the signing of a memorandum of understanding between the National Bureau of Standards (now the National Institute of Standards and Technology) and the USGS. Under the terms of this memorandum, the USGS has sought to develop standards for digital cartographic data exchange through the Standards Working Group of the Federal Interagency Coordinating Committee on Digital Cartography and through grants to the National Committee for Digital Cartographic Data Standards, which has operated under the auspices of the American Congress on Surveying and Mapping since 1982. A proposed "Standard for Digital Cartographic Data," published in the January 1988 issue of *The American Cartographer*, represents a merger of the efforts of these two groups.

The proposed standard consists of four parts: definitions and references, spatial data transfer specification, digital cartographic data quality, and cartographic features. The purpose of the proposed standard has evolved during its developmental period from an initial emphasis on data structure and content to a less restricted focus on transfer of digital cartographic data between dissimilar systems.

Following publication of the proposed standard, empirical testing was begun. A technical review board, chaired by the USGS, was established and charged with oversight of changes to the proposed standard resulting from testing. Testing involves several levels of effort. First a conceptual model of spatial data is needed to permit exchange of information between dissimilar systems. Once a conceptual model has been developed, the transfer process begins, which consists of taking data from a sender system, putting the data into standard form, then extracting the data from the standard form into a receiver system.

The first phase of testing the proposed standard was conducted by the Federal agencies most active in its development, including the U.S. Bureau of the Census, the Defense Mapping Agency, the Naval Ocean Research and Development Activity, and the USGS.

The second phase of testing, involving a cross section of government, university, and private-sector organizations, began in September 1988. The review board sought a broad spectrum of participants to thoroughly test application of the standard in as many discipline areas as possible. Submittal of the "Standard for Digital Cartographic Data" to the National Institute of Standards and Technology is expected to take place after completion of the second phase of testing in early 1989. At that point, the standard will be reviewed by the National Institute of Standards and Technology for adoption as a formal Federal Information Processing Standard.

Geographic Information Systems Research Laboratories—Bringing Data, Systems, and Users Together

By John C. Houghton

The essence of geographic information systems (GIS) technology is the ability to analyze the spatial aspects of data; the broad definition of GIS technology also encompasses data collection, storage, updating, and output. GIS analysis typically uses several different data sets, such as images and remotely sensed data, line data from topographic maps, the area covered by an aquifer or a volcano or a hazardous waste site, or a wide variety of other information.

The rapid evolution of GIS technology can be attributed to several factors. One factor is the rapidly increasing capabilities of computer and peripheral hardware. Another factor is the growing availability and sophistication of commercial GIS software. A third factor is the rapidly growing base of GIS users, which serves to defray the cost of hardware and software development.

The large number of users has an important advantage in addition to making software and hardware less expensive. The salient feature of a GIS is its ability to integrate many different kinds of data sets. This ability makes it a natural process to bring together heterogeneous disciplines. Teams conducting GIS studies include scientists not only from the USGS but also from other Federal agencies, national laboratories, State and local governments, nonprofit institutions, academia, and the private sector. These scientists provide different discipline perspectives and contribute a wide variety of data.

The rapid increase in GIS use is also due, in part, to the existence of GIS research laboratories in the USGS. A GIS laboratory was established in Reston, Va., in 1985 and is now being used by nearly 100 scientists. GIS laboratories in Denver, Colo., and Menlo Park, Calif., were established during 1988. Other USGS field offices are also adding to their spatial data processing capabilities. These GIS laboratories offer centralized facilities where new equipment and techniques can be investigated and the results passed on to others, where users with different backgrounds can work and learn together, and where expensive equipment can be shared by the many users.

In addition to earth-science research work in support of the Survey's mission, the GIS laboratories also perform an important educational function. The Reston GIS laboratory, for example, provides demonstrations on previous GIS projects, assists in the design of new projects, and conducts tours for more than 200 people a month. The GIS laboratories are also beginning to monitor and catalog digital data collected for particular projects.

GIS laboratories offer centralized facilities where new equipment and techniques can be investigated.

Several GIS projects have been undertaken in cooperation with other agencies. In a project led by the Environmental Protection Agency to help restore Chesapeake Bay, the USGS helped develop a spatial data base to test GIS techniques in analyzing the sources, transport, and impact of contamination on a highly urbanized watershed. In one scenario, GIS software was used to locate areas that were potentially affected by a source of lead contamination. In another cooperative project with the Environmental Protection Agency, GIS software was used to characterize a Superfund site during its 30-year life. One outcome was the ability to help position a monitoring well by determining the location of certain site features and their proximity to existing topographic and cultural-historical features. A demonstration of GIS technology was also developed with the U.S. Forest Service. The Copper Basin area of Prescott National Forest, Ariz., was used as a case study to evaluate the potential impact of a proposed land exchange. A GIS will be used as the foundation for a future environmental impact statement to describe a copper and molybdenum mining operation.

In another cooperative effort, the Survey is providing assistance to the U.S. Fish and Wildlife Service in the development of a comprehensive GIS data base for the Arctic National Wildlife Refuge. The U.S. Bureau of Land Management, the State of Alaska Department of Natural Resources, and the North Slope Borough are also actively participating in a cooperative effort to conduct biological and geological studies to investigate the area's vast potential oil and gas resources and to protect its wildlife.

These cooperative efforts demonstrate the broad utility of GIS technology and the importance of providing centralized facilities where data and ideas can be exchanged and developed.

Geographic Information System Modeling

By Louis T. Steyaert

Global changes in the Earth's natural system are current and critical issues of scientific investigation. Detecting and understanding the causes and implications of those changes demand sophisticated research tools and large earth-science data bases. One research approach that is under investigation by the USGS is the use of geographic information system (GIS) technology for global monitoring and scientific modeling.

A GIS is a computer hardware and software system designed to store, collect, manipulate, analyze, and display geographically referenced data. USGS scientists are investigating methods to incorporate the analysis of space- and time-dependent data into the GIS process. This research includes the use of GIS in combination with other modeling tools, such as statistical and numerical methods, as part of an overall systems approach to earth-science modeling involving, for example, land-surface monitoring, hydrologic and climatic processes, or impact assessments.

GIS modeling would allow scientists to go one step further into scientific inquiry.

As the community of GIS users continues to grow, earth scientists are investigating more complex data bases and developing quantified models for more diversified applications. Data available for GIS analysis have expanded rapidly in recent years and now include digital cartographic data (base categories of information and unique thematic maps of earth-science data), historical data (hydrologic, climatic, and geologic data), and daily satellite data for the entire globe. Some GIS applications involving these data require scientists to investigate and analyze the data across time, in three dimensions, or on a global scale. Therefore, in addition to fundamental GIS map applications such as map overlays and polygon or point reclassifications, GIS applications are incorporating surface, volume, and temporal analyses as well as interfaces with complex hydrological and meteorological flow modeling or economic modeling. The development of a systems approach for the integrated use of GIS technology and statistical and numerical methods will provide modeling capabilities that will enhance many operational monitoring systems, including those designed to help in understanding and tracking global change.

Recent trends in GIS applications underscore the need for statistical analysis procedures. For example, techniques for exploratory data analysis are essential to the investigation of complex data structures. Such analysis capabilities represent the first step in developing models of earth-science processes involving, for example, climatic and hydrologic systems.

Specifically, these techniques assist in the search for associations and dependencies among the data and in the identification of patterns (or randomness), clusters, outliers, anomalies, or trends in the data. The techniques may be considered, therefore, as effective ways to look at the data from a variety of perspectives and to explore the data base. To enhance the use of GIS technology, standard statistical methods for exploratory data analysis, including statistical graphics, and methods for smoothing and filtering data in both space and time need to be incorporated.

Preliminary research findings suggest that efficient global-change research involving land-surface monitoring and dynamic-process modeling requires the capability for interactive analysis based on a variety of software applications with high-speed computer response times. Such capabilities are necessary to efficiently investigate complex data structures; determine various time and space scales for analysis; explore data; search for associations; and develop, test, and use models in various scenarios. In this framework, GIS modeling would allow scientists to go one step further into scientific inquiry by permitting effective visualization of the many complex data sets involved, while simultaneously providing capabilities for quantified investigation of spatial and temporal patterns in the data.

These quantified analysis capabilities will further enhance the usefulness of GIS's for global-change research. Current GIS technology provides a comprehensive set of advanced functional tools for processing, managing, manipulating, and analyzing spatial data. GIS technology is ideally suited to integrating and analyzing spatial data themes such as base cartographic data, satellite-derived data on Earth surface and weather conditions, gridded outputs from general circulation models, and irregularly spaced data sets on climate and hydrology. The ability to integrate these diverse themes and to examine their interrelationships promises to make modeling in the GIS environment a premier method for investigating the complex questions of global change.

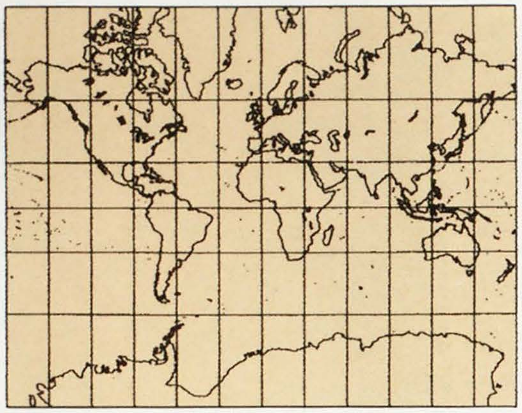
The National Gazetteer of the United States

By Roger L. Payne

The National Gazetteer series is being published in cooperation with the U.S. Board on Geographic Names as USGS Professional Paper 1200. A separate volume is being prepared for each State and territory. Two phases of compilation are required for each volume. Phase 1, which is now complete for all States and territories, includes the compilation of most of the 2 million named features (except roads and highways) found on the large-scale topographic maps of the USGS. Phase 2 includes research and compilation from other Federal and State sources and historical materials.

Each volume contains official and historical geographic names listed in alphabetical order. Variant names are cross-referenced to official or primary name listings. Each entry includes information on the type of feature, the official status of the name, the county in which it is located, the geographic coordinates (including sources of linear features), the elevation of the place of the feature, and the name of the topographic map on which the feature is found.

New Jersey was the first volume published in the gazetteer series in 1982. Volumes for Delaware, Kansas, Arizona, and Indiana have been published, and volumes for South Dakota, North Dakota, Florida, and Massachusetts are scheduled for publication in the near future. An abridged, concise volume containing the major populated places, physical features, and other key entries for all States is also being prepared. Currently, research and compilation of volumes for Oregon, Iowa, Alabama, Mississippi, Pennsylvania, North Carolina, Tennessee, Missouri, and Utah are underway.



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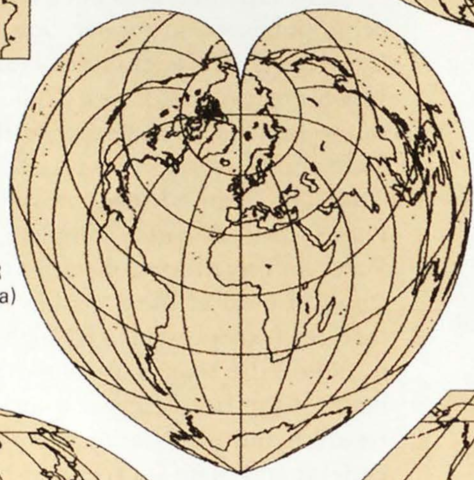

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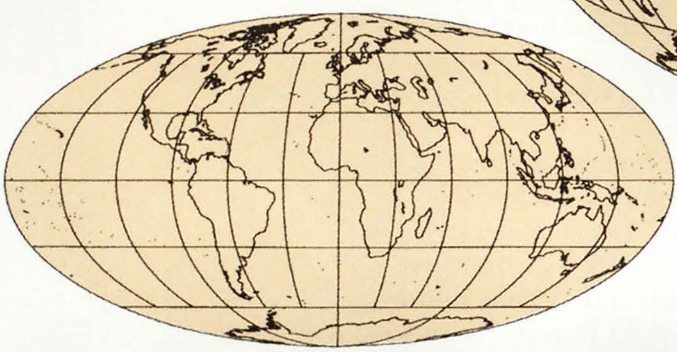

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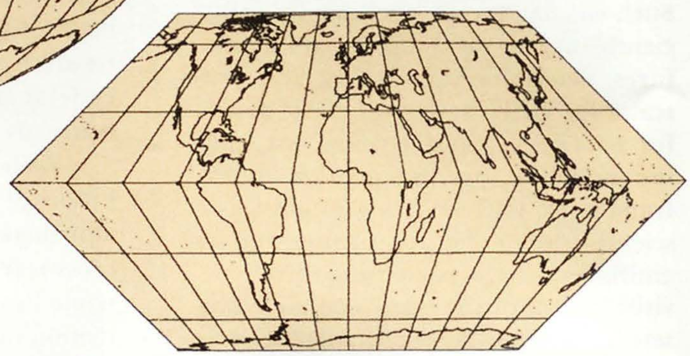

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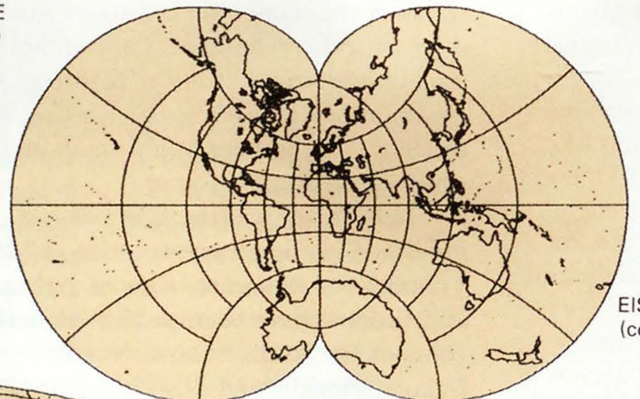

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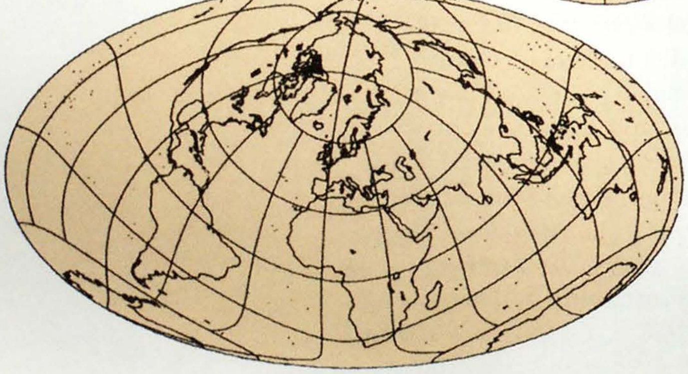

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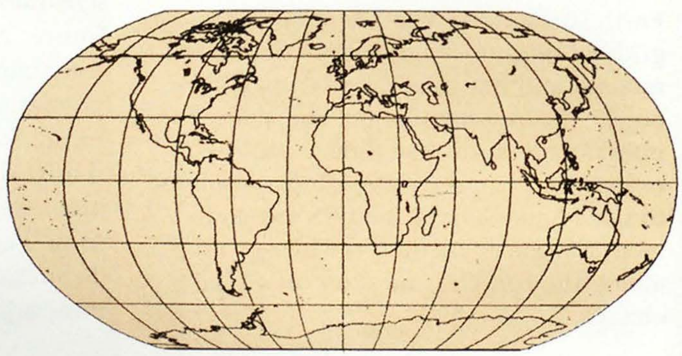


ROBINSON
(compromise)

Expert Map Projection Selection System

By Doyle G. Smith and John P. Snyder

Cartographers at the U.S. Geological Survey are developing a system for the computerized selection of map projections for special-purpose map and chart design applications. This system, named the Expert Map Projection Selection System (EMPSS), is a computer software package that uses object-oriented structures and artificial-intelligence programming methods. The EMPSS has been developed for use in the design of thematic maps and other customized map products of the type generally constructed within a geographic information system environment.

The map projection is one of the most important factors of any map or chart design. The validity and utility of any set of spatial geographic information are dependent upon the characteristics of the coordinate reference system or map projection in which the information is drawn. For this reason, it is important that the map designer select the map projection that most closely satisfies the usage requirements of each product to be created. Hundreds of map projections are available for product design. Each projection is defined by a set of physical attributes that describes its characteristic features and usages. Many of these attributes are common to several projections but in different combinations and at varying levels of applicability or utility. Selecting the best projection requires the indepth knowledge and practical experience of a human expert in the map projection domain. Human reasoning is the only process capable of weighing the subjective values and merits of different combinations of projection attributes to determine the best projection for any map or chart design.

The EMPSS package includes a base of information that contains human-expert technical descriptions and evaluations of the physical attributes of more than 50 of the most commonly used map projections. The computer accesses and organizes this human knowledge and expertise and makes it available to map and chart designers.

The EMPSS operates by asking the user a series of general questions about specific needs or applications. The answers to this series of 10 to 24 questions enable the system to construct an idealized set of specifications for the proposed application. Once this ideal model has been constructed, the system evaluates each of the map projections in the knowledge base against the ideal model, using the stored evaluative information provided by the human expert. The name of the map projection that compares most favorably to the specifications of the idealized model is provided to the user as the optimal projection for the proposed application or usage. The EMPSS also provides a numeric rating of the ability of this projection to satisfy the stated requirements, as well as the rating of other possible choices.

Map Projections

A map projection is used to portray all or part of the surface of the Earth on a flat surface. Every flat map misrepresents the surface of the Earth in some way. No map can rival a globe in truly representing the Earth's surface. Every projection has its own set of advantages and disadvantages; there is no "best" projection. Mapmakers must select the one best suited to their needs, so that the map will distort least the things they want to show most.

Mapmakers and mathematicians have devised almost limitless ways to project the image of the globe onto paper. Scientists at the U.S. Geological Survey have designed some projections for their specific needs, such as the Space Oblique Mercator, which allows them to produce maps from satellite images with little distortion. The examples on the facing page show several historically important projections and projections frequently used by mapmakers today.

An Enhanced Digital Line Graph Design

By Stephen C. Guptill and Robin G. Fegeas

The U.S. Geological Survey has been producing digital cartographic data in digital line graph format for almost a decade. During this time, the tasks for which the data are being used have become increasingly complex, placing information demands on the data that were not planned for in their initial design. To respond to these requirements, the Survey has designed an enhanced version of the digital line graph, termed Digital Line Graph—Enhanced (DLG–E).

The underlying philosophy behind DLG–E is to view cartography as an information transfer process centered on a spatial data base that can be considered, in itself, a multifaceted model of geographic reality. DLG–E data form the contents of the spatial data base. The DLG–E features must be representative of (and indeed must define) this multifaceted model of geographic reality.

In the DLG–E model, the phenomena of geographic and cartographic data are considered, in totality, as entities. An entity is a real-world phenomenon that is not subdivided into phenomena of the same kind. An entity (and its digital representation) is termed a feature. The concept of "feature" encompasses both entities and objects. The common attributes and relationships used to define the feature also apply to the corresponding entities and objects. Figure 2 illustrates the relationships among concepts of features, entities, and objects.

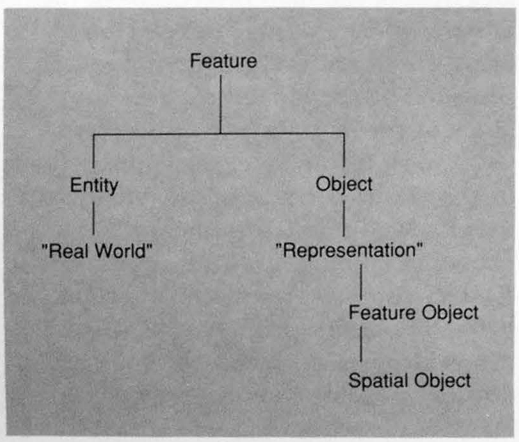


***Figure 2.** The concepts of feature, entity, and object.*

For example, one could declare a "bridge" to be a feature. A bridge is one of a number of built-up structures on or near the surface of the earth. Its definition may be further refined to a structure erected over a depression or obstacle to carry traffic. Thus, the feature "bridge" is an element of a set of phenomena (an "erected structure"), with the common attributes of function ("to carry traffic") and location. It also has the common relationship of spanning another feature ("over a depression or obstacle"). The real-world entity "bridge" is defined by the common attributes and relationships used to define the feature. For the bridge example, the entity "bridge" is the erected unit in the real world (fig. 3).

The underlying philosophy . . .is to view cartography as an information transfer process centered on a spatial data base that can be considered. . .a multifaceted model of geographic reality.

An object is the representation of all or part of an entity. For the bridge example, the objects include point, line, and area symbols and associated text on a map graphic, or a collection of records in a file of digital data (fig. 4). The concept of "object" encompasses both feature object and spatial object.

A feature object is an element used to represent the nonpositional aspects of an entity. In the example, the feature object represents the entity described by the definition of "bridge." Spatial objects are elements used to represent the position of an entity. Spatial objects are defined for zero-, one-, and two-dimensional objects. To be mapped, a feature object must be composed of one or more spatial objects.

Attributes are the spatial and nonspatial characteristics of the entities represented by the objects or of an attribute value. Spatial attributes describe an object's geographic location or geometric characteristic. The nonspatial characteristics of a feature include such concepts as shape, size, material composition, form, and function. The attributes for the bridge feature are given below (fig. 4). For every feature in the domain, each associated attribute must have an attribute value(s).

Features have relationships both with other features and with the spatial objects that represent them. Relationships are the spatial and nonspatial links between the objects. Nonspatial relationships are used to define the classes of objects that correspond to cartographic features. Spatial relationships include the topological relationships among objects. Taken collectively, these objects, attributes, and relationships make up the DLG–E data model.

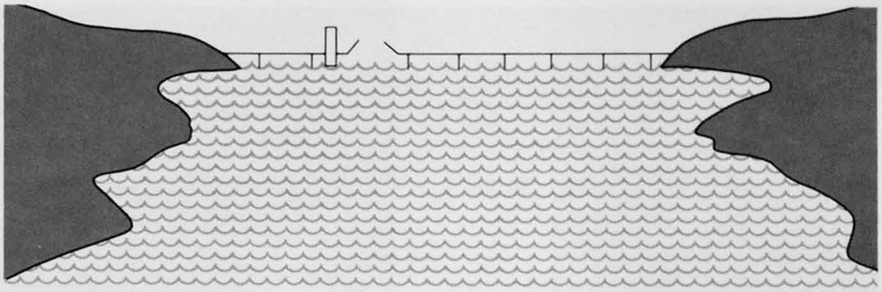
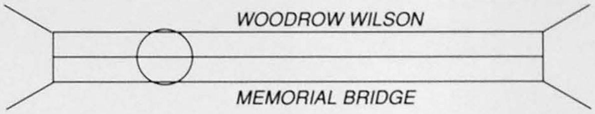


Figure 3. Example of an entity: Woodrow Wilson Memorial Bridge in the "real world."

A



B

Feature: Bridge

Attributes:

Covering:	Not Covered
Drawbridge Category:	With Drawbridge
Name:	Woodrow Wilson Memorial Bridge
Number of Decks:	1
Operational Status:	Operational

→ To Component Spatial Objects

Figure 4. Examples of objects: Representations of the Woodrow Wilson Memorial Bridge. A, Graphic object; circle denotes drawbridge. B, Digital object.

Water Resources Investigations

Mission

The USGS 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 biologic 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.

(Facing page, top) View upriver toward the northwest of the alluvial valley of the Mississippi River a few miles above Ste. Genevieve, Mo. (Facing page, bottom) View of Lake Cumberland, a reservoir on the Cumberland River in Kentucky, showing sediment-laden river water (brown) flowing into the upper end of the lake. (Above) View upriver (west) showing mixing of the brown, sediment-laden water of the Ohio River (right) with the clearer water of the Mississippi River near Cairo, Ill. The photograph was taken on March 22, 1988, during the spring runoff of the Ohio River before the time of peak runoff in the upper Mississippi River. (Photographs by Robert H. Meade and Terry F. Rees.)

Highlights

Sediment-Transported Pollutants in the Mississippi River

By Robert H. Meade

The Mississippi River and its tributaries drain about 40 percent of the conterminous United States (fig. 1), and their waters have been used for a wide range of purposes—municipal, industrial, and agricultural—by the time they reach the Gulf of Mexico. Although an exceptional range of known pollutants has been identified in the Mississippi River system, and the river itself is perceived by scientists and the public alike to be polluted, there have been some signs of improvement in recent years.

Large cities have curtailed discharges of untreated sewage into the Mississippi River. The city of Memphis, Tenn., for example, which until 1977 discharged at least 100 million gallons of raw sewage per day into the Mississippi, now discharges only the treated effluent water from its secondary-sewage plants. Another improvement is the recent decrease in the quantity of lead transported by the Mississippi, a result of the nationwide change from leaded to unleaded gasoline. On the other hand, new chemicals and compounds are being introduced to the river every year. And, as pollution from point sources is gradually curtailed, the pollutants from nonpoint or diffuse sources assume greater importance. In 1987, to ascertain whether the water quality of the river was improving or deteriorating, USGS scientists began a comprehensive assessment of the Mississippi River between St. Louis, Mo., and New Orleans, La.

In addition to providing a present assessment of the water quality of the Mississippi, the study enables USGS scientists to pursue a program of multidisciplinary research on how pollutants are transported by large rivers. Research questions of interest include: How are pollutant substances partitioned between true solution in river water and adsorption onto sediment particles? Which specific fractions of the suspended sediment (the tiniest clay particles versus the coarsest silt grains, for example) are most important to the transport of specific pollutants? How do the various pollutants repartition themselves between adsorbed and dissolved phases when two great rivers, such as the Mississippi and Ohio, each with its own distinctive load of sediment and assemblage of pollutants, converge and gradually mix? How long can we expect a given pollutant adsorbed on a given sediment particle to remain in storage in any given part of the river system?

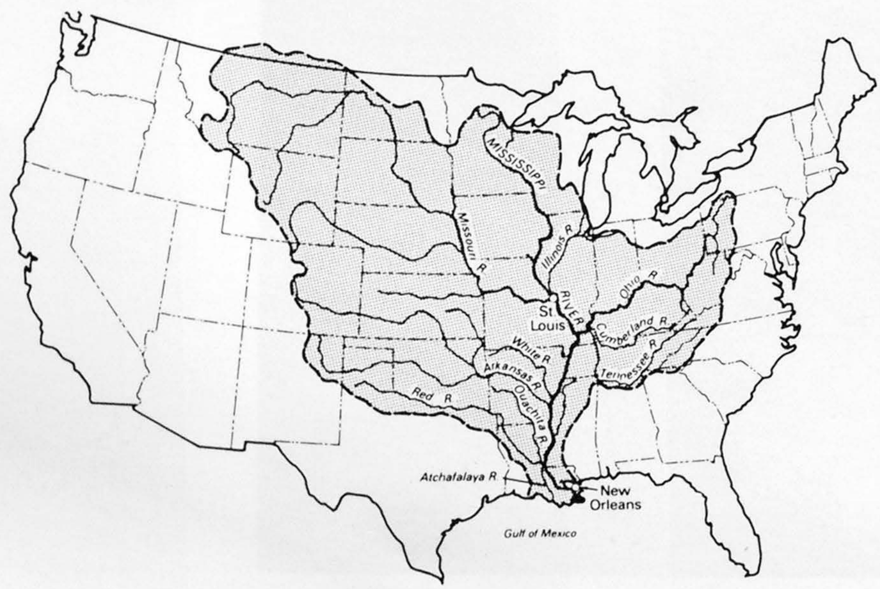


Figure 1. The Mississippi River drainage basin includes about 40 percent of the conterminous United States and a small area of Canada. A new study begun in 1987 is assessing the water quality of 1,200 miles of the Mississippi River and its major tributaries between St. Louis, Mo., and New Orleans, La.

The River

Although the Mississippi River discharges an average of 420 billion gallons per day to the Gulf of Mexico, not all parts of the drainage basin contribute water in equal measure. Nearly half of the total water in the Mississippi River comes from only one-sixth of the total drainage area—the Ohio River basin, which includes the drainage basins of the Tennessee, Cumberland, and Wabash Rivers (fig. 2). In contrast, the Missouri River, which drains 43 percent of the total area, contributes only 12 percent of the total water. The Mississippi, upriver

Another improvement is the recent decrease in the quantity of lead transported by the Mississippi.

of the confluence with the Missouri, contributes only 15 percent of the total water that is discharged to the Gulf.

The most striking feature of the lowermost part of the Mississippi River system is the diversion of part of the discharge out of the mainstem and down the distributary Atchafalaya River. This diversion began more than a century ago as part of the Mississippi River's natural tendency to change its lower course to the Gulf of Mexico every 1,000 years or so. Today, the proportion of the water discharge that goes down the Atchafalaya is held at 30 percent of the total (Mississippi River plus Red River) by the Old River Control Structures, completed by the U.S. Army Corps of Engineers in 1963 and 1987.

Sediment and River Quality

Suspended sediment is an important determinant of river quality because many of the pollutants, such as metals, hydrocarbons, and insecticides, are carried in the adsorbed state. The principal sources and quantities of suspended sediment transported by the Mississippi River in an average recent year are shown in figure 2. The present-day discharge of suspended sediment to the Gulf of Mexico by the Mississippi (including the Red-Atchafalaya) averages about 210 million tons per year. Most of the principal tributary sediment loads have been measured to a reasonable degree of accuracy, but the estimate of the sediment discharge of the Ohio River represents a major uncertainty. No comprehensive suspended-sediment data have ever been collected from the Ohio mainstem. Instead, the Ohio's contribution has been estimated from the difference between the sediment discharges measured in the Mississippi upriver (St. Louis) and downriver (Vicksburg, Miss.) from the mouth of the Ohio. This estimate, however, depends on the assumption that no sediment is being remobilized from storage in the banks and floodplains of the Mississippi between the Ohio River and Vicksburg, an assumption that needs to be tested.

The sediment picture in the Mississippi River was not always as shown in figure 2. In its natural state, the Missouri River was one of the world's most prodigious transporters of sediment. The journals of the Lewis and Clark Expedition of 1804–1806 contain numerous references to shifting sandbars, caving banks, and muddy waters in the Missouri. As recently as 1950, the Missouri River transported sediment in quantities nearly four times greater than it transports to the Mississippi today. Likewise, the Arkansas River before 1950 contributed nearly 10 times as much sediment as it contributes today. Sediment in both the Missouri and Arkansas Rivers was reduced drastically when large dams were constructed across them for hydropower and navigation purposes after World War II. The large reservoirs that formed behind these dams now trap much of the sediment that formerly reached the Mississippi.

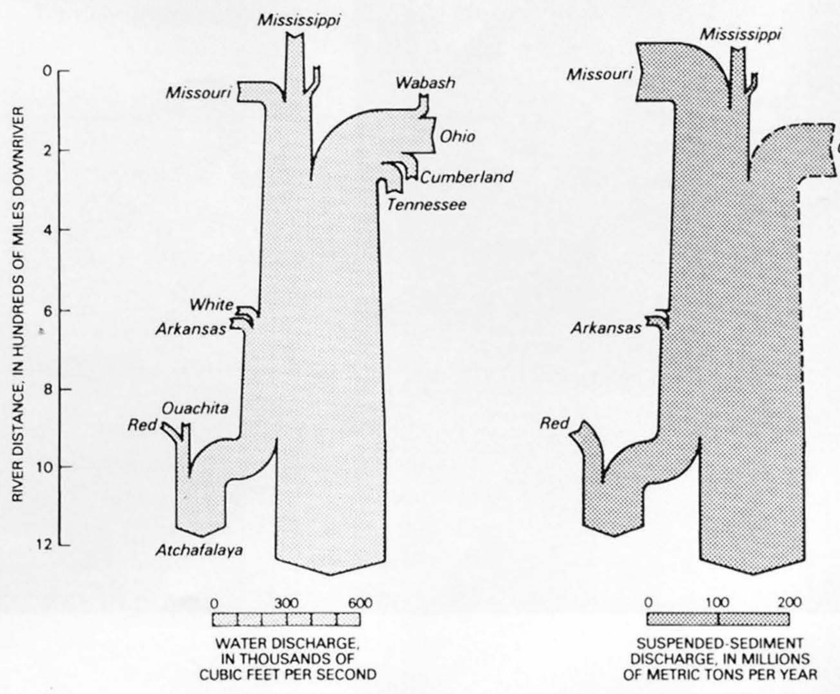


Figure 2. Discharges of water (left) and suspended sediment (right) in the lower 1,200 miles of the Mississippi River during an average recent year. Suspended-sediment data refer to average conditions prevalent around 1980 and were compiled by the U.S. Army Corps of Engineers. (Ohio River sediment contribution has a dashed outline to denote uncertainty.)

U.S. Geological Survey chemist steadies apparatus for collecting water and suspended sediment while R/V Acadiana *is being positioned for river sampling. Orange poles on the river bank (background) mark the alignment of the section to be sampled, Mississippi River at Helena, Ark. (Photograph by Robert H. Meade.)*

Sediment in the Ohio River, on the other hand, has increased over natural levels. Sediment discharges in the Ohio River basin were probably lower during the years before European settlement because the basin was covered by nearly continuous forests, which held the soil in place and retarded erosion. Two centuries of deforestation, crop farming, and coal mining has led to accelerated erosion and an increase of sediment in the Ohio River. On balance, however, the decrease of sediment in the western tributaries has been greater than the increase in the eastern parts of the basin, and the Mississippi now carries to the Gulf of Mexico only about half the sediment it carried before 1950.

Sediment in the Ohio River, on the other hand, has increased over natural levels.

Sediment storage is one further factor that confounds our understanding of suspended sediment and the fate of the pollutants attached to sediment particles in the Mississippi River. A river like the Mississippi transports much of its sediment load on a schedule that is episodic and discontinuous. Sediment particles may be transported for a distance downriver and then, if the river stage begins to fall, deposited on the river bed or along its banks. If the river is high enough to overflow its banks, sediment may be deposited on the floodplain. The length of time a particle spends in storage before the next episode of movement is highly variable and ranges from a few days for a particle stored on the river bed to tens or hundreds of years for a particle stored on the floodplain.

River-Quality Assessment: Procedures and Equipment

The reach of the river being studied in detail begins near the confluences of the Missouri and Illinois Rivers with the Mississippi near St. Louis and continues downriver to New Orleans. Samples are collected from the 57-foot Research Vessel *Acadiana*, operated by the Louisiana Universities Marine Consortium. The ship is equipped with sufficient laboratory and bunk space to accommodate a 3- to 4-week sampling trip along 1,200 miles of the Mississippi River and its principal tributaries. Two trips were completed in 1987, another one in 1988, and an average of two trips per year is planned for the next several years. At each of 16 stations, 9 on the Mississippi mainstem and 7 on tributaries, a comprehensive series of samples is collected to characterize the river water, the sediment carried in suspension, the materials resting on the river bottom, and (on one trip so far) the fish that feed on the bottom. Samples are given preliminary analysis and treatment aboard the research vessel and are shipped to the USGS laboratories in Denver, Colo., for comprehensive analysis of the full range of constituents, organic and inorganic, natural and man-made.

Preliminary Results

Although analyses are still in progress and results are preliminary, USGS chemists W.E. Pereira, C.E. Rostad, and T.J. Leiker have reported several interesting aspects of the organic pollutants. Some pollutants are found only in certain rivers. For example, fire retardants found in the Illinois River and a triazine-trione compound (an industrial chemical) found in the Ohio River are absent from other rivers and can be used as chemical fingerprints to trace the waters of the Illinois and Ohio through the Mississippi system. Atrazine and other herbicides are ubiquitous throughout the entire Mississippi system. Currently, 100 tons of atrazine per year, or 0.2 percent of the entire U.S. production, is estimated to be carried by the Mississippi River to the Gulf of Mexico. Catfish in the river contain significant levels of DDT and its metabolites in their fatty tissue. Even though the use of this insecticide has been banned in the United States since 1972, enough DDT and metabolites remain stored in river sediments to be ingested by the bottom-feeding catfish.

The Mississippi now carries to the Gulf of Mexico only about half the sediment it carried before 1950.

In order to gain experience and refine sampling techniques with minimal hazard to personnel and equipment, the first three sampling trips were made during periods of low river flow. Now that procedures are fairly well set, the next few sampling trips will be scheduled for periods when the river is expected to be deep and swift and when large quantities of sediment will be in transport. Over the next several years, other phases of river activity, such as rising stage and falling stage, will be sampled to achieve an understanding of how pollutants are transported and stored, and how these processes vary from one season to the next during an average river year. With this knowledge, we will be better equipped to assess the condition of the Mississippi River.

While an oceangoing freighter passes in the early morning light, U.S. Geological Survey research chemist adjusts microwave navigation equipment on a platform on the river bank in preparation for a day of sampling of the Mississippi River a few miles downriver from New Orleans, La. (Photograph by Robert H. Meade.)

Drought in the United States, 1987–88

By Thomas G. Ross

Drought occurred in the Southeast in 1986 and in the Pacific Northwest and much of California in 1987. Drought is again occurring in those areas and in other areas of the United States. Data collected by many agencies indicate below-normal precipitation, streamflow in the below-normal range, and low reservoir contents in the affected areas. Municipal water supply, stream water quality, agriculture, recreation, fisheries, navigation, and power generation all suffered adversely from the effects of the latest drought.

Just how severe is the drought of 1987–88? If measured in terms of streamflow, the severity of the drought can be assessed in terms of how low streamflow becomes (intensity), how widespread is the low streamflow (areal extent), and how long the low streamflow persists (duration). The amount of water stored in reservoirs is also an indicator of drought severity.

Drought Intensity

As a general measure of streamflow conditions, the combined flow of the three largest rivers in the lower 48 States—Mississippi, St. Lawrence, and Columbia—set a record low average June flow of 481 billion gallons per day (bgd), which is 45 percent below median. (Median streamflow is the middle value of monthly flows that occurred in a given month during the 1951–80 reference period. That is, streamflow was below this median value in 15 of the 30 years and above this value in the other 15 years.) The combined average flow of the rivers dropped 22 percent from May to June. Combined flow for June 1988, the lowest June flow of record, was less than 1 percent lower than the June 1934 flow, which was the previous June low for the period of combined record going back 59 years; the widespread extent of the current drought is shown by its effect on the three major U.S. river basins.

The intensity of the drought also is indicated by record low flows during June 1988 at 33 streamflow index stations in southern Canada and the conterminous United States. Thirty-one of these sites are on or east of the Mississippi River, including the Mississippi River at Vicksburg, Miss. On that river, the largest in the United States, the monthly average discharge of 139 bgd was 62 percent below median and 2 percent below the previous low for June, which occurred in 1934.

At the station with the longest period of record (99 years) of the 33 stations, Chippewa River at Chippewa Falls, Wis., June streamflow averaged 748 mgd, 79 percent below median and 23 percent below the previous low flow for June, which also occurred in 1934. Of the record low flows for June, 14 broke records set in the "Dust Bowl" years (1930–36).

Areal Extent and Duration

Areal extent and duration are two other measures of drought that must be taken into account. Streamflow maps for southern Canada and the conterminous United States for water years 1986, 1987, and 1988 (a water year covers the period October 1 to September 30) show both the areal extent and the duration of below-normal-range streamflow (fig. 3A–C). Streamflow conditions for May through September 1988 (fig. 3D–H) emphasize change during those months. Streamflow was in the below-normal range over about 38 percent of the area during May 1988, over about 60 percent of the area during June 1988, over about 50 percent of the area during July 1988, over about 39 percent of the area during August 1988, and over about 27 percent of the area during September 1988.

An overall measure of the duration of dry conditions is the departure of actual streamflow from the 1951–80 reference period median flow. The percent departure of actual flow from median since October 1983 for the 181 index streamflow stations in southern Canada and the United States (fig. 4A) shows that streamflow was above median for every month through April 1985, generally above median from May 1985

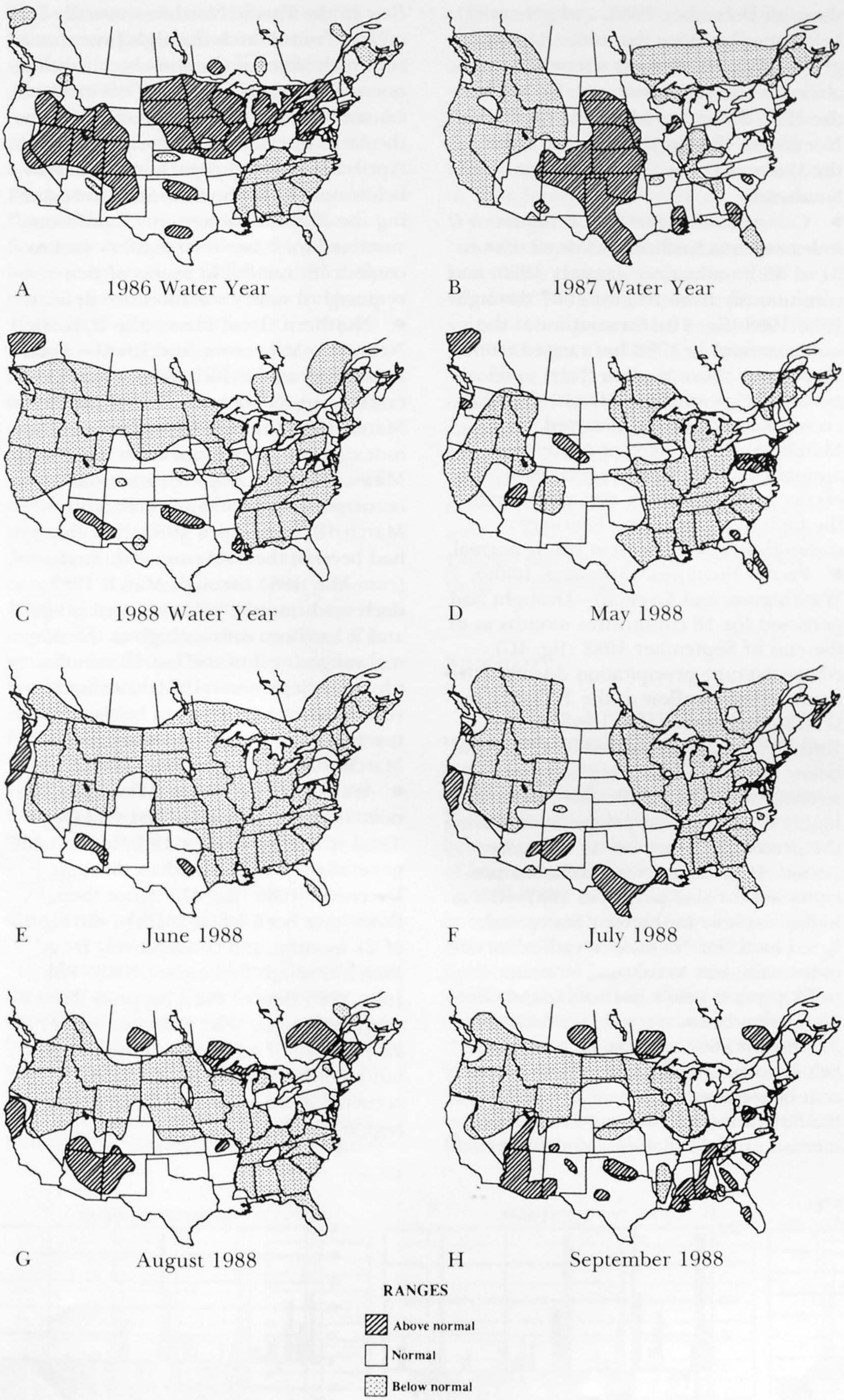


Figure 3. Streamflow conditions, conterminous United States and southern Canada. Above-normal flow is defined as flow higher than 75 percent of the flows at the site in a given month during the 1951–80 reference period. Below-normal flow is defined as flow lower than 75 percent of flows at the site in a given month during the 1951–80 reference period.

through December 1986, and generally below median since that time. Regional graphs (fig. 4B–F) show streamflow variability in five areas severely affected by the 1988 drought: California, the Pacific Northwest, the Northern Great Plains, the Western Great Lakes, and the Southeast.

- California—Streamflow at the six index stations has been below median in 31 of 43 months since January 1985, and continuously from August 1987 through June 1988 (fig. 4B). Streamflow at the index stations in 1988 has ranged from 38 percent above median (July) to 65 percent below median (March). No new record low flows have occurred since March. About 54 percent of the total annual runoff in California usually occurs from December through March, the highest in February. February streamflow was 71 percent below normal.
- Pacific Northwest (Montana, Idaho, Washington, and Oregon)—Drought had persisted for 18 consecutive months as of the end of September 1988 (fig. 4C). Above-average precipitation during April increased streamflow at the 17 index stations to 6 percent below median, but June streamflow decreased to 42 percent below median. Late spring and summer streamflow in the Pacific Northwest is highly dependent on precipitation during the preceding December to February period. Departure from normal of precipitation for that period in 1987–88 was highly variable in the four States and, based on a few National Weather Service index sites, was as follows: Montana, 19 to 73 percent below normal; Idaho, 15 to 46 percent below normal; Washington, 37 percent above normal to 34 percent below normal; and Oregon, 1 to 37 percent below normal. Actual streamflow for the last 12 months was much less than median until April 1988. Median streamflow in the Pacific Northwest usually increases from March through June due to snowmelt. Even if the snowpack is below normal, increases in streamflow can be caused by above-average precipitation in the form of rain, as was the case during April. Since the snowpack was generally below normal in the four-State area during the 1987–88 winter, any significant sustained increase in streamflow had to come from rainfall in excess of that required to satisfy soil-moisture deficits.
- Northern Great Plains (the Dakotas, Nebraska, Minnesota, and Iowa)—Total streamflow at the 16 index stations generally was well above median through March 1987 (fig. 4D). Conditions at the index station Mississippi River at St. Paul, Minn., are an example of what has occurred in the five-State area since March 1987: In April 1987, flow that had been in the above-normal range from May 1985 through March 1987 decreased into the below-normal range, and it has been only as high as the normal range for 7 of the last 18 months (through September 1988). During water year 1988, streamflow was below median for 9 months and consecutively from March through September.
- Western Great Lakes (Wisconsin, Illinois, Indiana, Michigan, and Ohio)—Total streamflow at the 18 index stations generally was above median through December 1986 (fig. 4E). Since then, flows have been below median during 15 of 21 months, and consecutively from March through September 1988. The June 1988 flow of the Chippewa River at Chippewa Falls, Wis., was cited earlier as an example of record low flows for June, but record low flows for June also occurred at 10 other index stations in the region.

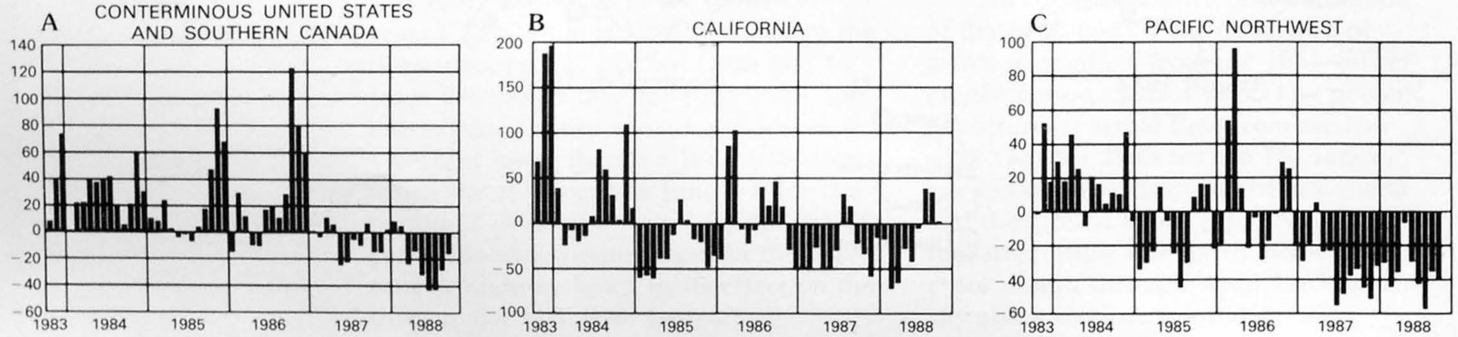


Figure 4. *Percent departure of actual monthly average streamflow from the 1951–80 reference period median flow for the period October 1, 1983–September 30, 1988. (Zero represents median flow for the reference period.)*

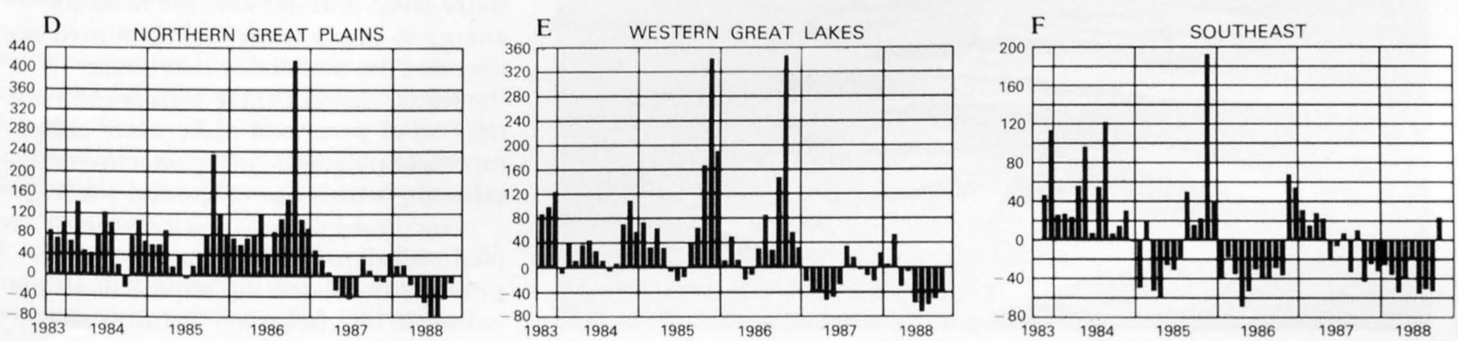
• Southeast—Actual streamflow has been below median for 14 of the last 17 months, 11 of them consecutive through August 1988 (fig. 4F). The Southeast includes those States in the area from the Mississippi River to the Atlantic Ocean and south of the Ohio River and the Pennsylvania State Line. Total streamflow at the 39 index stations in the Southeast has been at least 24 percent below median since October 1987 and was 55 percent below median for June 1988. In 8 of 12 months of the 1988 water year, streamflow has been lower than the streamflow in the comparable months of water year 1986. Figure 4F clearly shows the 1986 drought as 10 consecutive months of below-median streamflow and the 1988 drought as 11 consecutive months of below-median streamflow. During the current dry period, 17 new monthly low flows occurred at index stations from June 1987 through April 1988, 9 of them during March 1988, at sites from West Virginia to Alabama. There were no new low flows during May, but 16 new low flows occurred in the area during June. For example, streamflow of the French Broad River near Asheville, N.C. (92 years of record), was 23 percent below the previous June low, set in 1925, and 69 percent below median for June.

Contents of Reservoirs

Many areas of southern Canada and the conterminous United States are dependent on water stored in reservoirs for agricultural, municipal, and industrial water supply; for power generation; for recreational use, from water sports to fishing; and for maintenance of streamflow for fish migration. The cumulative effects of many months of below-normal-range streamflow are reflected in the amount of water stored in many reservoirs nationwide. Monthend index reservoir contents for September 1988 were in the below-average range at 34 of 100 reporting sites, including most reservoirs in New Jersey, North Dakota, Montana, Wyoming, Idaho, California, and Nevada. September 1988 contents were lower than those of September 1987 at 49 of the 100 sites, including most reservoirs in New Jersey, the Tennessee Valley, Nebraska, the Dakotas, Montana, Wyoming, California, Nevada, Utah, Colorado, and New Mexico. In the Southeast, 3 of the 10 index reservoirs with capacities greater than 1,000,000 acre-feet (an acre-foot is the amount of water necessary to cover 1 acre of land with water 1 foot in depth or about 326,000 gallons) had contents that were below those of September 1986.

Summary

Intensity, areal extent, and duration—record low flows at 33 index stations during June, 60 percent of the area of southern Canada and the conterminous United States with streamflow in the below-normal range, and many months of below-median flow—these three criteria define the current drought as severe in some areas through September 1988. Are we in for a repeat of the "Dust Bowl" years? The current drought has not had the duration of the drought of the 1930's, but many record low flows that occurred during the 1930's (and later and shorter drought episodes of the mid-1960's, 1977, and 1981) have been broken by new low flows set since 1985. Only weather and time will tell.



Reflections on Water Use in the United States

By Wayne B. Solley

A look at trends developed from USGS water-use estimates over the past 35 years shows that the Nation's total water use more than doubled from 1950 to 1985. Water withdrawals over the last 5 years, however, have declined by 10 percent. The drought that affected much of the Nation during 1988 also had its effects on water use. Spot sampling during the 1988 drought suggested that water use generally was higher than in recent years. Although nationwide estimates for 1988 were not available, there were some local estimates. Public water-supply withdrawals to meet the demands in Washington, D.C., for example, during June and July were 14 percent above the 5-year average. In parts of Nebraska, farmers and ranchers turned to ground water as a source for irrigation 1 month earlier than normal, and ground-water withdrawals were about twice the quantity withdrawn in recent years.

The USGS has compiled and published estimates of water use in the United States at 5-year intervals since 1950. These water-use estimates can be used to analyze trends in water use, to appraise present use, and to plan for future uses of the Nation's water resources.

The unusually low water level of 1988 exposed many of the sandbars on the bottom of the Mississippi River, such as this one opposite the town of Helena, Ark. A few days after this photograph was taken, a backhoe was able to trench the sandbar, providing a rare opportunity for USGS hydrologists to study the bed material of the Mississippi. (Photograph by Robert H. Meade.)

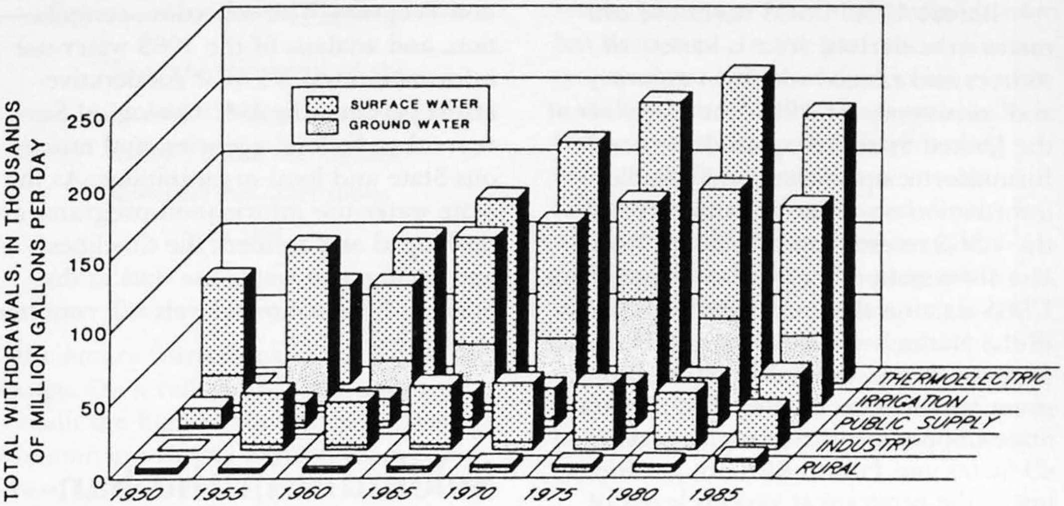
The latest 1985 data show that the 10 percent decline in total water withdrawals was observed in both surface-water and ground-water withdrawals. The largest decreases were in the thermoelectric power, industrial, and irrigation categories of use.

A total of 399 billion gallons per day of both fresh and saline water was withdrawn from lakes, reservoirs, streams, aquifers, and springs during 1985 to meet the needs for offstream uses such as domestic, commercial, industrial, irrigation, livestock, and thermoelectric power plants. Freshwater withdrawals alone averaged 338 billion gallons per day, equivalent to about 1,400 gallons per day for each person in the United States. In addition, water used for hydroelectric power generation, the only instream (nonwithdrawal) use compiled in 1985, was estimated to be 3,050 billion gallons per day, or 7 percent less than during 1980.

The decrease from 1980 to 1985 in total withdrawals is in contrast to an increasing trend that persisted from 1950 to 1980. A slackening in the rate of increase of total withdrawals from 1970 to 1975 and again from 1975 to 1980, however, marked a downward trend that was confirmed by the 1985 data.

The decrease in offstream use was widely spread across the Nation; 37 States reported less water withdrawn during 1985 than during 1980. Several factors might account for the downturn. Streamflow generally was more plentiful in 1985 than in 1980 because of more rainfall, which reduced the dependence on ground water for irrigation in many areas and the need to irrigate in some areas. On the other hand, demands on the ground-water system tend to lower water levels and increase the need for energy to pump water, which in turn can decrease the availability and quality of the water. Each of these factors can raise the cost of water and make water users, especially irrigators, more selective and efficient in their use of ground water.

Increased use of recycled water, coupled with depressed commodity prices, probably decreased the requirements for industrial and irrigation withdrawals.



Trends in water withdrawals by water-use category and source of supply for rural, industry, public supply, irrigation, and thermoelectric power uses, 1950–85.

Finally, the 1985 estimates are based on more reliable information and analysis than previous estimates in this series. In many instances, it seems that previous estimates may have been too high.

Two water-use categories that are exceptions to the downturn are "public supply" and "rural domestic and livestock." During 1985, withdrawals for public supply were about 7 percent and rural use about 39 percent more than during 1980. The 7-percent increase in public-supply withdrawals corresponds to a 7-percent increase in population served, and the large increase in withdrawals for rural use mainly reflects large increases in fish farming, particularly in Arkansas, Idaho, and Mississippi.

Other highlights from the 1985 data include the following:

- The average withdrawal of freshwater in the United States is equivalent to about 1,400 gallons per person per day for all uses; however, the amount varies greatly from State to State, ranging from a high of 22,200 gallons per capita per day in Idaho to a low of 152 gallons per capita per day in Rhode Island. High per-capita values are characteristic of thinly populated States having large acreages of irrigated land.
- Withdrawals for domestic purposes averaged 78 gallons per capita per day for people served by their own water system and 105 gallons per capita per day for people served by a public-supply system.
- Estimates of withdrawals by source indicate that, during 1985, total surface-water withdrawals were 325,000 million gallons per day (Mgal/d), or 10 percent less than during 1980, and total groundwater withdrawals were 74,000 Mgal/d, or 12 percent less than during 1980.
- More water was withdrawn in California (nearly 50,000 Mgal/d) than in any other State, more than twice as much as in either Texas or Idaho, the next largest users. Four states—California, Texas, Idaho, and Florida—accounted for 28 percent of the water withdrawn in the Nation.
- More water was withdrawn (187,000 Mgal/d) during 1985 for thermoelectric power plants to generate electricity than for any other category of offstream use; however, this total was 13 percent less than during 1980. About 56,000 Mgal/d was saline water.
- Irrigation ranks second in offstream water withdrawals in the U.S.—137,000 Mgal/d during 1985, 6 percent less than during 1980. Irrigation accounts for about 80 percent of all consumptive water use in the United States.
- More than 90 percent of the irrigation water was withdrawn in the Western United States. In contrast, almost 90 percent of the thermoelectric power withdrawals were in the Eastern United States.
- The total amount of consumptive-freshwater use—that is, water withdrawn that is evaporated, transpired, incorporated into products and crops, consumed by humans or livestock, or otherwise removed from the immediate water supply—averaged 92,300 Mgal/d during 1985, or 9 percent less than during 1980.

Before 1980, USGS water-use estimates were derived from a variety of sources and ranged widely in accuracy and consistency. In 1977, the Congress of the United States recognized the need for uniform, up-to-date, and reliable information on water use and directed the USGS to establish a National Water-Use Information Program to complement USGS data on the availability and quality of the Nation's water resources. Thus, the National Water-Use Information Program became part of the USGS Federal-State Cooperative Program; as of 1988, 49 States and Puerto Rico are participating in the program at various levels of involvement.

The National Water-Use Information Program is designed to be the source for accurate, consistent, timely, and accessible water-use information. The goals of the program are to collect and compile reliable site-specific and aggregated water-use information, to develop and refine computerized water-use information systems at State and national levels, to devise new methods and techniques to improve the collection and the analysis of water-use information, and to disseminate the information in ways that are beneficial to a variety of users. As the National Water-Use Information Program develops, more emphasis will be placed on interpretive studies and the integration of water-use information with other water-resources projects.

The latest national water-use estimates were compiled for 1985 and are published in U.S. Geological Survey Circular 1004, "Estimated Use of Water in the United States in 1985." A new Aggregated Water-Use Data System (AWUDS) was developed and installed on each USGS District computer to store and manage the water-use information compiled for this report. Although the information is published by State and water-resources region, the AWUDS data base contains more than 120 data elements for 3,225 counties and 222 water-resources subregions.

Analysis of field data and evaluations of existing water-use data were more comprehensive and more detailed in the compilation of data for the 1980 and 1985 water-use reports than for previous water-use reports thanks to support from the broader National Water-Use Information Program. The collection, compilation, and analysis of the 1985 water-use information was a 2-year cooperative effort between the U.S. Geological Survey, other Federal agencies, and numerous State and local organizations. As the State water-use information programs are developed and refined, the timeliness and accuracy of water-use data at the State and the national levels will continue to improve.

Selenium in the San Joaquin Valley: Sources, Distribution, and Mobility

By Robert J. Gilliom

Agricultural drainage problems in the San Joaquin Valley of central California have attracted national attention since 1983, when selenium in water from subsurface tile-drainage systems in the central part of the western valley was found to have toxic effects on waterfowl. Other constituents of drain water, particularly dissolved solids, boron, chromium, and molybdenum, may cause water-quality problems also, but selenium is the most widespread problem and the most limiting constraint on management alternatives.

This article summarizes the results and implications of USGS studies and related research by others through 1987, the halfway point of a 5-year study, on the sources, distribution, and mobility of selenium in the San Joaquin Valley. The USGS is a participating agency in the San Joaquin Valley Drainage Program, which is cooperatively managed by the U.S. Department of the Interior and the State of California.

Geologic Source and Distribution in Soil

Selenium-related problems are most likely to occur in areas where soils are formed of sediments from the marine

Three specific areas of the western San Joaquin Valley. . .have the highest selenium concentrations in soil.

sedimentary formations of the Coast Range. On a valleywide scale, soils that contain the highest concentrations of selenium are clearly derived from the Coast Range. Three specific areas of the western San Joaquin Valley—the alluvial fans in the vicinity of Panoche and Cantua Creeks, an area southwest of the town of Lost Hills, and the Buena Vista Lake Bed area—have the highest selenium concentrations in soil. These areas of the valley have the greatest potential for selenium-related problems in places where saline soil or ground water occur. High concentrations of selenium occur in subsurface drain water in the vicinity of all three areas.

Effects of Irrigation on the Ground-Water Flow System

The key to evaluating the origin and present-day distribution of high-selenium concentrations in ground water is understanding the redistribution by irrigation water of soluble forms of selenium. Irrigation has had regional-scale effects on ground-water recharge and discharge and on the movement of soluble salts, including selenium. The dominant influences on ground water since the early 1900's have been increased recharge of irrigation water to ground water in the semiconfined zone and historic pumping of ground water from the confined zone.

These agricultural activities have caused the water table to rise over much of the western part of the valley. The rising water table reflects a net recharge rate to the ground-water system in excess of its capacity to transport water to areas of discharge. Importation of surface water has led to increased application of irrigation water and hence increased rates of recharge to the system. Concurrently, pumpage from the confined zone has decreased. In the past, tile-drainage systems have been installed in areas with a shallow water table. These systems have been effective in artificially removing enough shallow ground water to maintain the water table at desired depths in the confines of the drained area, but their use is limited by the poor quality of the shallow ground water that is collected. This water-table rise probably will continue in the future if present irrigation practices continue in the absence of other changes in the ground-water system.

Distribution of Selenium in Ground Water

The present-day areal and depth distribution of selenium in the ground water of the central western valley is the result of a combination of natural processes and changes in the hydrologic system caused by irrigation and ground-water withdrawals. In the natural hydrologic system, soluble forms of selenium are concentrated along with other solutes in saline soils of the lower and middle parts of Coast Range alluvial fans. The first few decades of irrigation of the alluvial-fan soils leached much of the readily mobile selenium from the soil into the ground water. The present-day areal distribution of selenium in shallow ground water follows many of the same general patterns of soil salinity before much of the area was extensively irrigated (figs. 5 and 6). Within about 10 to 20 feet below the water table, selenium concentrations commonly range from 10 to 50 micrograms per liter (μg/L), but they are 10 to 100 times higher where the water table has been near the land surface and evaporative concentration has occurred. Within the range of 20 to 150 feet below the water table, an interval of variable thickness occurs in which selenium concentrations are commonly 50 to more than 1,000 μg/L. Water in this interval is derived principally from recharge of earlier irrigation water. Native ground water, with selenium concentrations of less than 10 μg/L, is below the high-selenium water.

The large quantity of high-selenium ground water in the central part of the

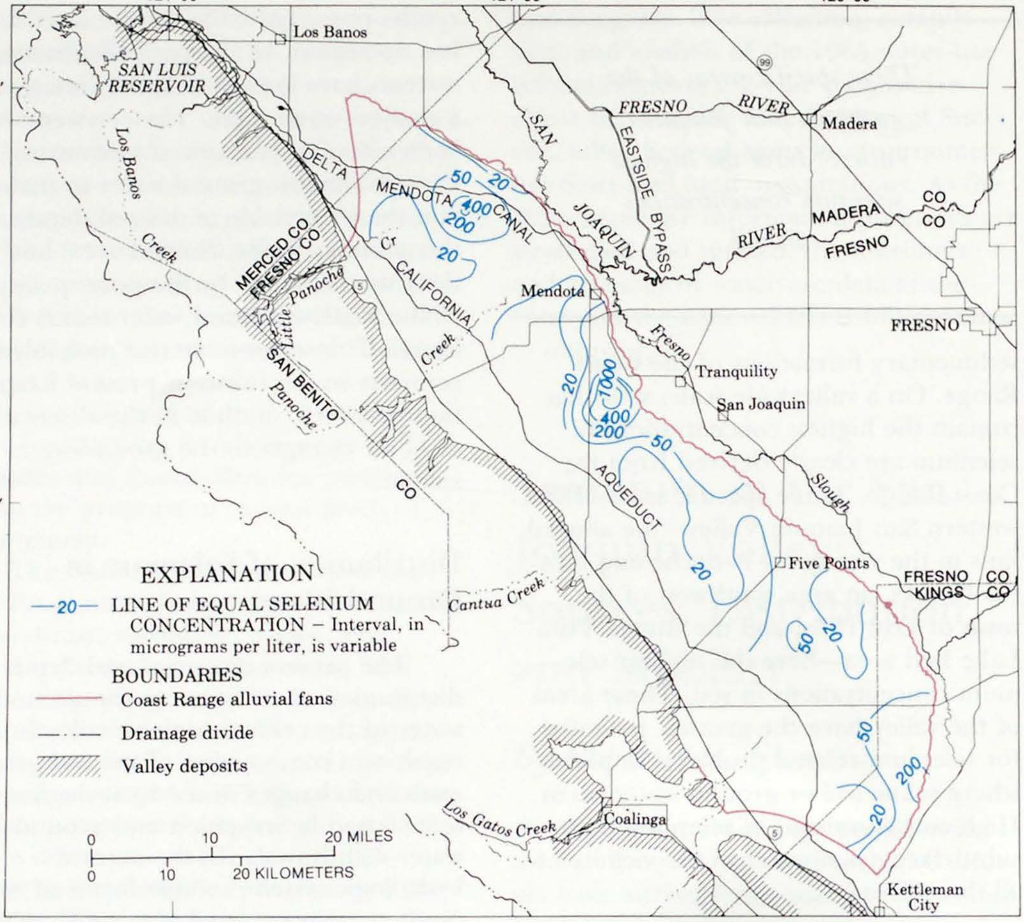


Figure 5. Selenium concentrations in shallow ground water, 1986.

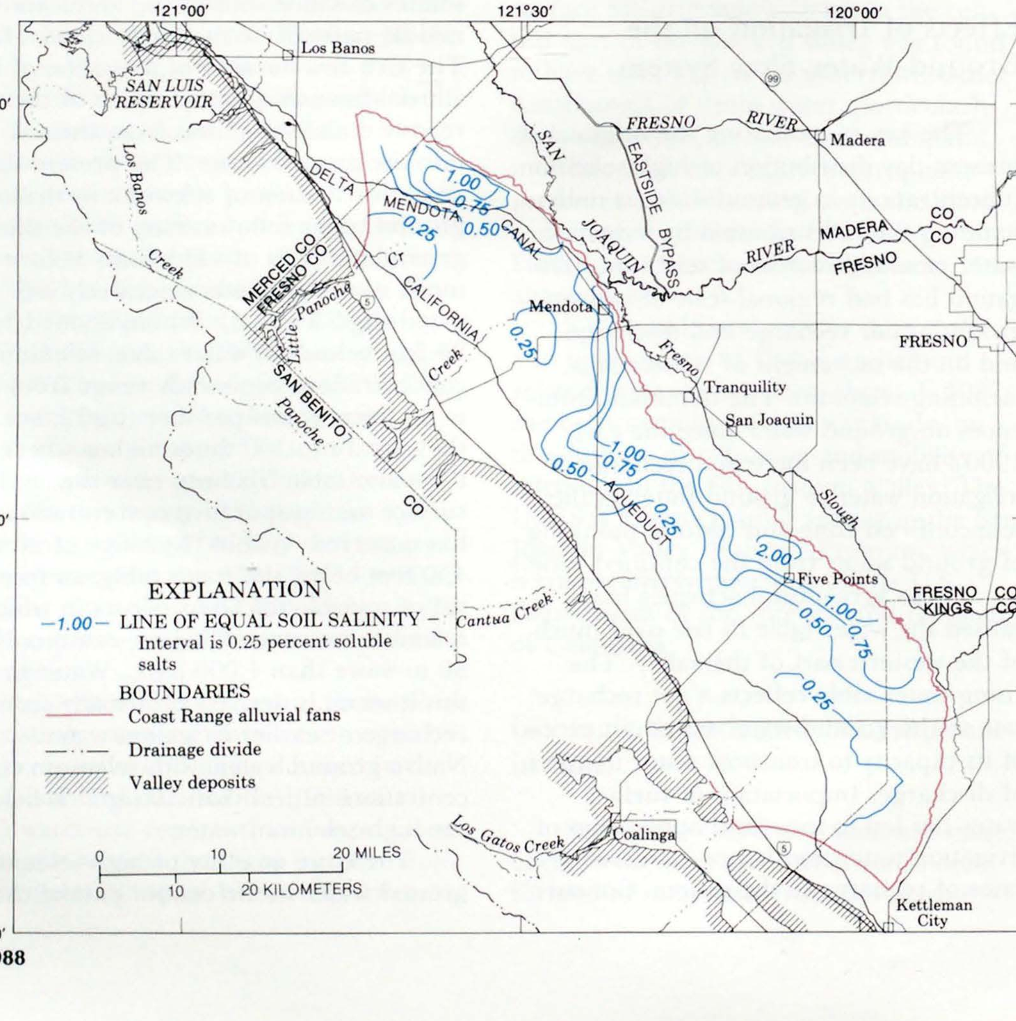


Figure 6. Soil salinity in the early 1940's.

study area makes it desirable to use management practices that leave this water where it is, rather than bring it to the land surface or allow it to move into parts of the aquifer that may be used for water supply. Low concentrations of selenium in water near the water table imply that, where evaporative concentration is controlled, continued irrigation with low-selenium water will result in a growing volume of this low-selenium ground water. Drainage strategies aimed at removing this low-selenium ground water near the water table may be feasible in some areas, but selenium concentrations still may substantially exceed water-quality criteria.

Selenium in Tile-Drain Water

Drainage systems play a key role in the evaluation of management alternatives because of their effective control of the water table and the large number of systems already in operation. Selenium concentrations vary greatly between drainage systems but tend to be consistent over time in drain water from a particular system. The exception is the first 1 to 5 years, when concentrations tend to be the highest and most variable. The low variability of selenium concentrations in water from existing mature drainage systems underscores the fact that drainage systems withdraw ground water, which tends to be of a generally constant chemical character in a particular place.

Selenium from the San Joaquin River probably is not having a measurable effect on water quality in...San Francisco Bay at present.

The high variability in selenium concentrations between existing drainage systems reflects the high variability of selenium in shallow ground water, variable hydrologic conditions at individual fields, and the age of the drainage systems. Detailed study of individual drained fields shows that local water-table history, geologic conditions, irrigation history, and drainage-system design, all factors that vary greatly between fields, can markedly affect the type of water that is removed by the drains.

Mobility of Soil Selenium

Soils that contain selenium and are irrigated are a source of selenium in shallow ground water. Readily soluble forms of selenium in present-day soils are only a small fraction of the total selenium, but the quantities of soluble selenium can be substantially different between soils in different fields and at different depths. For example, in one field that had been irrigated for decades and tile-drained for 15 years, the soils were highly leached throughout the unsaturated zone. In two fields irrigated for just as long, but drained for less than half as long, saline soils with substantial quantities of soluble selenium were at the 3-foot depth, even though the near-surface soils were highly leached. Even after 40 years of irrigation, water percolating through soils of these latter two fields still contains high concentrations of selenium.

Even in the most highly leached soils, dissolved-selenium concentrations in solution ranged from a median of 13 μg/L at the 1-foot depth to 20 μg/L at the 3-foot depth. These selenium concentrations probably are the minimum that occur in actual recharge water passing through this soil to the ground water. These concentrations probably result from the slow dissolution of slightly soluble forms of selenium, which may be a long-term source at such levels of leaching. Thus, even after the most soluble forms of selenium have been leached from the soil by earlier irrigation, continued irrigation can result in recharge to ground water that contains lower, but still undesirably high, concentrations of selenium.

Selenium in the San Joaquin River

At the present time, drain water from about 77,000 acres of tile-drained farmland eventually flows to the San Joaquin River, mainly from two tributaries, Salt and Mud Sloughs. Water from individual drainage systems that discharge to waterways that eventually reach these sloughs or smaller tributaries contains from less than 10 to 4,000 μg/L of selenium, and mixtures of these waters contain from 20 to 100 μg/L. Concentrations of selenium in the San Joaquin River depend primarily on the magnitude of the selenium load from the sloughs and dilution by low-selenium water from all other sources of streamflow to the river. There are no substantial gains or losses of selenium between the sloughs and the delta.

During the study period, selenium concentrations at several sites on the river at times exceeded proposed water-quality criteria. Available data indicate that selenium from the San Joaquin River probably is not having a measurable effect on water quality in the delta and San Francisco Bay at present. Selenium concentrations in the San Joaquin River can be reduced by limiting tile-drain water discharges to Salt and Mud Sloughs and may be partly controllable by dilution with water from low-selenium sources in the basin.

Role of Sediment Chemistry in Water Quality

By Arthur J. Horowitz

Recent USGS research in sediment chemistry has concentrated on two major types of investigation: those intended to provide usable techniques for collecting, concentrating, and analyzing both suspended and bed sediments and those designed to explain the processes—the concentrating and releasing mechanisms—that control sediment-chemical concentrations.

One of the major problems facing investigators working with suspended sediments has been to obtain adequate quantities of material for study and analysis. The standard method of collecting and concentrating suspended sediment using membrane filtration is inadequate for large-scale national programs. At best, current filtration techniques permit the processing of only 1 to 2 quarts of water per hour. Use of a centrifuge in the laboratory permits the processing of 3 to 5 quarts of water per hour. More rapid techniques have been investigated that permit the processing of water samples at the rate of 1 to 4 quarts per minute for the separation of suspended sediments for trace-element analyses. A similar study is now underway to see if these techniques can be used for organic analyses.

Significant shifts in suspended-sediment concentrations...have been detected...over distances of as little as 16 to 33 feet.

To adequately assess how chemicals are transported in sediments, scientists must have representative samples from different areas and at different time intervals; thus they must know how the distribution of suspended sediment varies across a section of river. Even when the most accurate measuring methods currently available are used, significant shifts in suspended-sediment concentrations and their associated chemical components have been detected in river cross sections in as little as 20 to 30 minutes and over distances of as little as 16 to 33 feet.

The development of models designed to predict sediment-associated trace-element transport requires a two-pronged approach: (1) A thorough understanding of the relation among riverine flow and bed, bank, and overbank deposits and the conditions that induce sediment movement or deposition and (2) a thorough understanding of the interaction between sediments (suspended and bed) and water. A further issue is the accurate modeling of suspended-sediment transport. At present, most sediment-transport models deal with sand-sized (>63 micrometers) particles; however, the highest trace-element concentrations are associated with the silt- and clay-sized (<63 micrometers) fractions. The USGS began a 2-year study in 1988 to investigate and model fine-sediment transport. Studies are also underway to help clarify sediment-water interactions.

Research to develop an understanding of the geochemical processes that influence the accumulation of trace elements in a variety of benthic organisms from different segments of the food chain is continuing in both the natural environment and the laboratory. These studies include assessments of trace-element partitioning in oxidized sediments and of the physiological processes that influence the accumulation of trace elements and their effects on organisms. These studies also will define the relation between trace-element concentrations in sediments and concentrations of those trace elements in biota.

Reliable Remediation of Contaminated Aquifers

By Steven M. Gorelick

In the United States alone, more than 29,500 uncontrolled hazardous-waste sites have been inventoried by the U.S. Environmental Protection Agency. If the trend during the past 10 years continues, the number will exceed 33,000 by early 1990. It is estimated that about 80 percent of these sites have the potential to cause contamination of ground water. Once ground water is contaminated, it can cost millions of dollars and can take decades to restore an aquifer to a condition where the water is again usable. In some industrialized areas, many sites and many aquifers have been contaminated. For example, in California's Santa Clara Valley ("Silicon Valley") where ground water furnishes half of the water supply, there are more than 50 significantly contaminated sites, and private industry alone has spent more than $200 million on remediation since 1982.

Given this nationwide problem, scientists at the U.S. Geological Survey have developed computer models to analyze and to serve as an aid in the design of site-specific, reliable ground-water restoration schemes. At the forefront of this

Once ground water is contaminated, it can cost millions of dollars and can take decades to restore an aquifer.

new methodology are techniques that use combined simulation-management models to identify the ground-water withdrawal strategies that will most effectively remediate or restore contaminated aquifers. As the name implies, the models join computer simulation techniques, which predict the pattern of subsurface-contaminant migration, with advanced mathematical and statistical methods, which determine the most economical design for a remediation scheme.

These simulation-management models determine the best location and pumping rates for wells that could be used to reliably contain and remove contaminated water. The major component of the models is computer simulation to describe contaminant migration. Unfortunately, the physical, chemical, and biological mechanisms controlling transport of underground contaminants are highly complicated.

Ignoring the chemical and biological mechanisms, even the simplest soluble compound will migrate and spread because of highly variable transmission and storage properties in aquifers. The transmission property, known as hydraulic conductivity, varies from place to place, both laterally and vertically. This variation can be more than a factor of 10 within the distance of a few meters. Much of the uncertainty in predicting contaminant migration stems from the variability of aquifer properties. The simulation models are based on the physics of subsurface flow and require knowledge of local aquifer properties, yet it is virtually impossible to measure the tremendous spatial variability over a substantial portion of an aquifer. Therefore, the variation must be characterized statistically. Statistical information on the spatial variability of aquifer properties is specified in the simulation models, which then produce statistical information on the chances that contamination will occur at a particular time and place.

Finally, the simulation-management model determines the best remediation strategy using ground-water withdrawals so that water-quality standards are met at a desired reliability, perhaps 90 percent, at water-supply wells. This promising tool for aquifer management requires substantial computer effort. The assessment and design of reliable remediation schemes must be analyzed for each particular hazardous-waste site; thousands of simulations are needed to quantify the uncertainty of subsurface-contaminant migration.

Microbial Reduction of Iron in Sedimentary Environments

By Derek R. Lovley

It is becoming increasingly apparent that microorganisms catalyze many of the important geochemical reactions that influence the quality of water supplies. A new group of microorganisms, the dissimilatory iron-reducing bacteria that catalyze most of the reduction of ferric iron to ferrous iron in sedimentary environments, has been discovered. Before this discovery, iron reduction was thought to be a trivial process in the metabolism of bacteria and much of the iron reduction in sedimentary environments was thought to be abiological. Now it is clear that direct microbial activity is required for the reduction of iron in most environments and that models of iron geochemistry must consider the physiological limitations and capabilities of the iron-reducing microorganisms.

Microbial iron reduction converts insoluble ferric iron oxides to more soluble ferrous iron forms, which affect water quality in several ways. High concentrations of dissolved iron are one of the most prevalent ground-water quality problems. Furthermore, the extent of microbial iron reduction also controls the fate of toxic trace metals in aquatic environments. Iron oxides bind trace metals and concentrate them in the sediments. When microorganisms reduce iron, the trace metals are released into the surrounding water. In a similar manner, microbial iron reduction releases the phosphate held by iron oxides in the bottom sediments of lakes and estuaries. This released phosphate is often the nutrient that controls the development of nuisance algal blooms. Excessive growth of algae, for example, is thought to produce the low levels of oxygen in waters of some areas of the Potomac River Estuary and Chesapeake Bay.

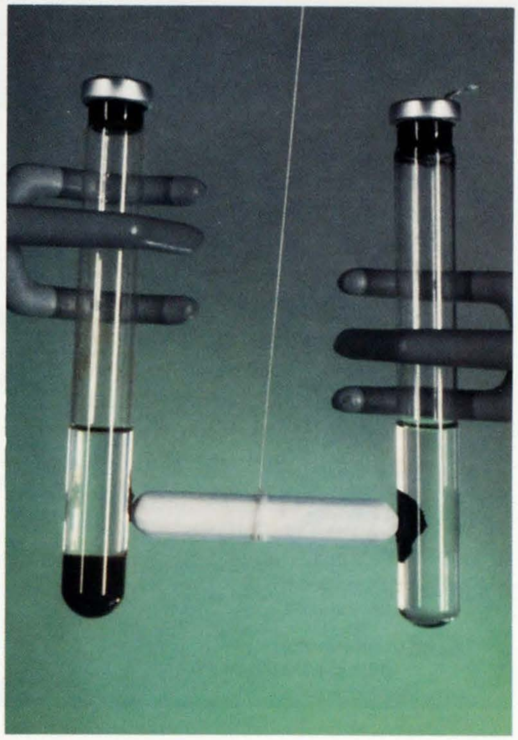
Studies conducted with freshwater sediments from the Potomac River Estuary in Maryland resulted in the isolation of the first microorganism known to break down organic compounds to carbon dioxide with the reduction of iron or manganese. The organism does not fit any previously described genera and has temporarily been given the strain designation *GS-15*. Organisms with a similar metabolism appear to be distributed in a wide variety of environments, as such organisms were subsequently found in brackish-water estuarine sediments and in a deep aquifer in which products of iron reduction were degrading the water quality.

Studies on sediments and various iron-reducing isolates demonstrated that most naturally occurring organic compounds may be decomposed by iron-reducing bacteria. However, each particular type of iron-reducing bacteria can only metabolize a restricted number of compounds. Therefore, food chains of several different types of iron-reducing bacteria are required to completely oxidize sediment organic matter.

Iron-reducing microorganisms were also found to be potentially important in the removal of organic contaminants from water supplies. Aromatic compounds such as benzene are common organic contaminants of ground water. Geochemical evidence suggests that iron reduction is an important mechanism for oxidizing these compounds and, thereby, mitigating their adverse effects. An iron-reducing organism was isolated that could oxidize aromatic compounds by using the iron oxides naturally present in the sediments of aquifers. The metabolism of this organism demonstrates a likely mechanism for the oxidation of aromatic contaminants with iron reduction and provides a model organism (*GS-15*) with which to begin studying the factors controlling the rate of contaminant removal by this process.

Iron-reducing bacteria were found to generate copious quantities of ultra-fine-grained magnetite as a product of iron reduction, a novel mechanism for the magnetization of sediments that may have important implications for fields of study such as paleomagnetism. This metabolism also provides a likely mechanism for the development of the massive accumulations of magnetite in ancient iron ore deposits and for the magnetic anomalies associated with hydrocarbon deposits.

Studies on the metabolism of iron-reducing bacteria, and microorganisms involved in other anaerobic (oxygen-free) geochemical cycles such as methane production and sulfate reduction, have led to the development of mathematical models of these processes. These models, which are based upon the physiological characteristics of the sediment microorganisms, have been found to accurately predict the distribution of important organic and inorganic constituents in the waters of a wide variety of anaerobic environments. As more is learned about the microorganisms responsible for catalyzing geochemical reactions, these models will increase in predictive power.



Magnetite production by the dissimilatory iron-reducer GS-15. *The brown ferric oxide at the bottom of the tube prior to growth was not attracted to the magnet. During growth,* GS-15 *converted the ferric oxide to magnetite, a magnetic mineral.*

National Water-Quality Assessment Program

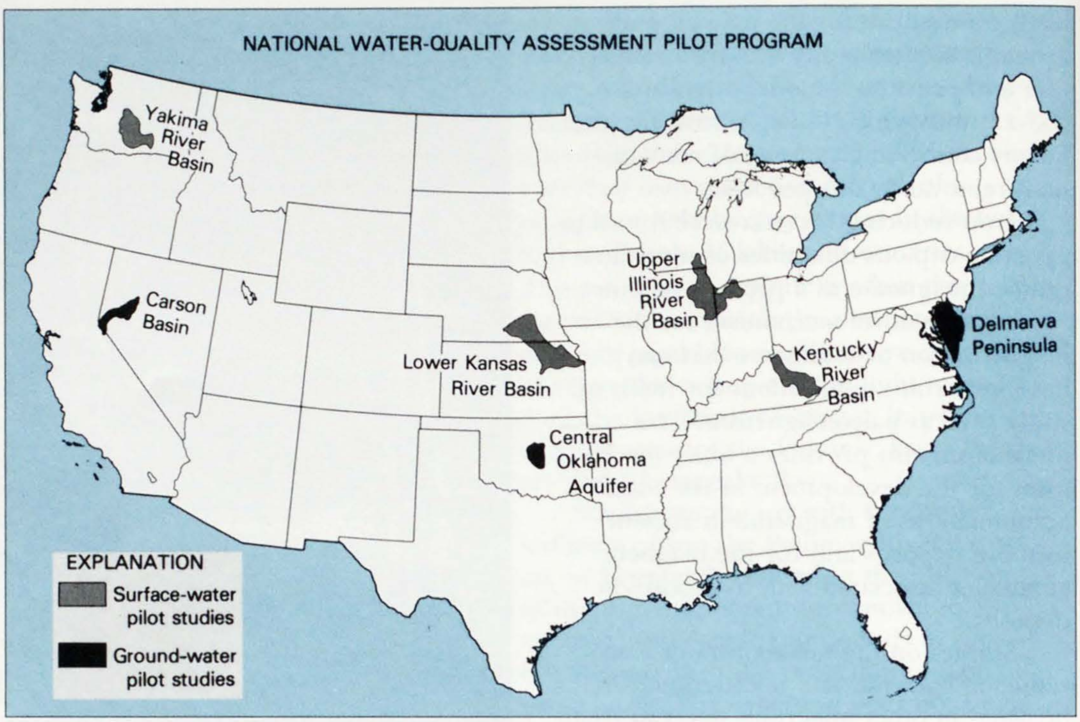
By William M. Alley and William G. Wilber

During the past two decades, Federal, State, and local governments and industry have made significant commitments to the protection of water quality. Estimates by the Bureau of Economic Analysis show that about $184 billion was spent from 1972 to 1982 for water pollution abatement and control. Future expenditures for pollution abatement and control through the year 2000 have been projected to be as much as $600 billion. Given the large financial investments in water-quality management and protection already made, the potential for even larger investments in the future, and the concerns about solving myriad problems, there is a need for reliable and nationally consistent information on the status of and trends in the quality of the Nation's water resources, as well as for scientifically valid explanations of these conditions and trends.

Critical to understanding water quality is the ability to make comparisons among different locations and over time. Consistent information is necessary to make valid comparisons. Although this need has been well recognized for a long time in conducting individual water-quality studies, it is only recently that the need for nationally consistent information to make valid regional and national comparisons about current water-quality conditions and about changes in these conditions has been well recognized.

Because of this stated need for nationally consistent water-quality information, beginning in 1986, the Congress has annually appropriated funds for the U.S. Geological Survey to test and refine concepts for a National Water-Quality Assessment Program. Such a full-scale program would provide a nationally

Locations of the seven pilot projects of the National Water-Quality Assessment Program.



consistent description of current water-quality conditions for a large part of the Nation's water resources; define long-term trends (or lack of trends) in water quality; and identify, describe, and explain the major factors that affect water-quality conditions and trends.

The program will focus on water-quality conditions that are prevalent or large in scale and persistent in time.

Determining the best method of conducting such an assessment is complicated by the many water-quality constituents that must be sampled for, the large water-quality variations in time and among locations, and the high cost of collecting and analyzing samples. At present, the program is in a pilot phase. Seven pilot projects, representing a range of hydrologic environments, were selected to test and further refine the assessment concepts; four projects focus primarily on surface water, and three projects focus primarily on ground water. A decision to proceed to a full-scale national program will be made in 1990. The decision will be influenced by an ongoing evaluation of the design and potential utility of the program by a committee of the National Academy of Sciences.

The program will focus on water-quality conditions that are prevalent or large in scale and persistent in time. Regional degradation of water quality, such as occurs from nonpoint sources of pollution or from a high density of point sources, will be emphasized.

As presently envisioned, the national program will be accomplished through investigations of about 120 study units—aquifer systems and river basins—that are distributed throughout the Nation and that incorporate about 80 percent of the Nation's water use. By using these discrete study units, the scientists will be able to examine the causes of observed water-quality conditions, which is vital if the program is to be useful to managers and policy makers at Federal, State, and local levels.

The collection of data and the interpretation and communication of findings will be conducted by small teams of individuals who are familiar with the study areas. Having the same team of individuals responsible for the collection and interpretation of data will help ensure that the data are of high quality and that they lead to relevant and meaningful interpretations. The 120 study units will be linked together through a prescribed set of study approaches and protocols for sample collection, sample handling, laboratory analysis, and quality assurance. Data for the study units will be collected and interpreted on a nationally consistent set of water-quality constituents. Consistent records will be recorded on streamflow and basin characteristics, well and aquifer characteristics, and land use and other measures of human activity. In addition, written reports will contain similar information for each study unit; and finally, data will be stored in national data files, where they will be available to the user community upon request.

Assessment activities in each of the study units will be done on a rotational rather than continuous basis, and only a portion of the study units will be studied in detail at a given time. For each study unit, 3- to 5-year periods of intensive data collection and analysis will be alternated with longer, less intensive periods of study.

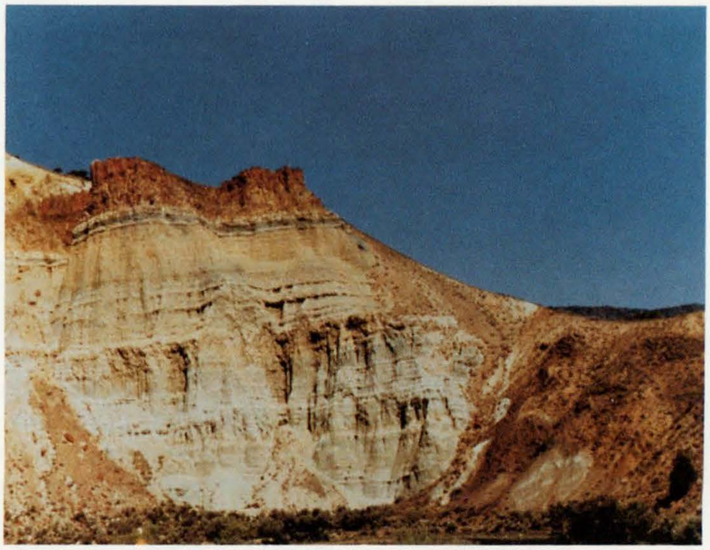
Even a very effective National Water-Quality Assessment Program will not and should not eliminate the need for other water-quality data-collection activities. For some issues and questions, the sampling requirements and procedures may be different from those which this program is designed to address. By providing a strong, high-quality National Water-Quality Assessment Program, the USGS will help underpin and unify the Nation's water-quality activities. Such an assessment program should satisfy a significant share of the water-quality information needs of the country.

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.



(Facing page) Redwall Limestone in the Grand Canyon, seen from the Colorado River. (Photograph by Jane Eggleston.) (Above) Cathedral Rock at the John Day Fossil Beds, eastern Oregon. (Photograph by Joseph Jones.)

Highlights

Erosion of Louisiana's Coastal Barriers

By Asbury H. Sallenger, Jr., Bruce E. Jaffe, and S. Jeffress Williams

Nearly three-quarters of the U.S. population lives within an hour of the Nation's coasts. Coastal erosion and wetland loss, therefore, are serious problems with long-term economic and social consequences. Developed areas face billions of dollars in property damage and potential loss of life as a result of long-term erosion and storm impacts, and valuable wetlands are being altered at rapid rates. Of the 30 States bordering the oceans, the Gulf of Mexico, or the Great Lakes, all are undergoing some erosion and 26 are presently experiencing an overall net erosion of their shorelines. The National Academy of Sciences has forecast increasing rates of sea-level rise, which means that erosion is likely to accelerate in the future.

Because of natural and manmade causes, Louisiana has the highest rates of coastal erosion and wetland loss of any region in the United States. In the Mississippi River delta plain, rates of wetland loss exceed 80 square miles per year. Louisiana's barrier islands, which serve to protect wetlands, are eroding, in some places as much as 65 feet per year. The islands are decreasing in area as they migrate landward. For example, between 1890 and 1979, Louisiana barrier islands decreased in area by 37 percent. If this rate of land loss continues, the barrier islands will disappear, which in turn will accelerate the destruction of valuable wetlands. Louisiana contains 41 percent of the Nation's wetlands, which support a $1 billion annual fishery industry.

Many of the processes contributing to barrier island erosion are poorly understood and are not quantifiable with any degree of confidence. These processes must be better understood in order to predict the future shoreline response and, thus, allow better management of our coastal resources. In 1986, the U.S. Geological Survey and the Louisiana Geological Survey began a planned 5-year study focused on the processes causing barrier island erosion.

Valuable wetlands are being altered at rapid rates.

Long-term erosion of Louisiana's barrier islands is due both to sea-level rise, relative to the land, and to diminishing sand supply. The primary objectives of the study are to better quantify processes related to sea-level rise and sand supply and to present the results in a form that can be applied to such practical problems as predicting future changes.

The study is divided into three main parts:

- Investigating the geologic framework within which the barriers have formed and migrated landward. This work uses cores and geophysical information to provide a broad regional understanding of the historical development of the barrier islands and a conceptual understanding of the processes of barrier island erosion.
- Developing a better quantitative understanding of the various processes responsible for erosion. We have focused on only a few of the many processes, including relative sea-level rise, overwash,

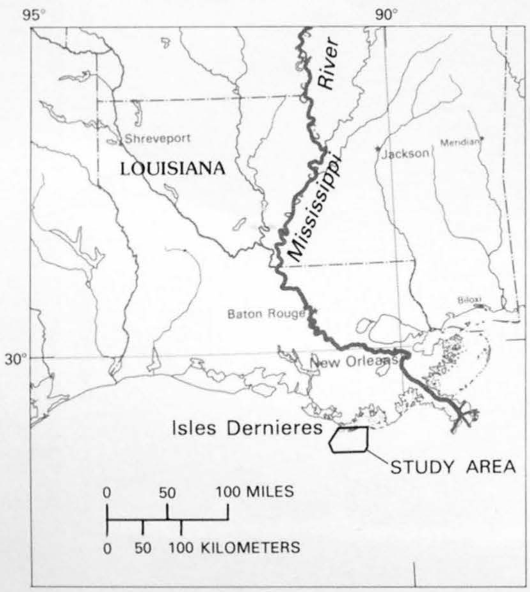


Figure 1. *Location of the Isles Dernieres barrier islands.*

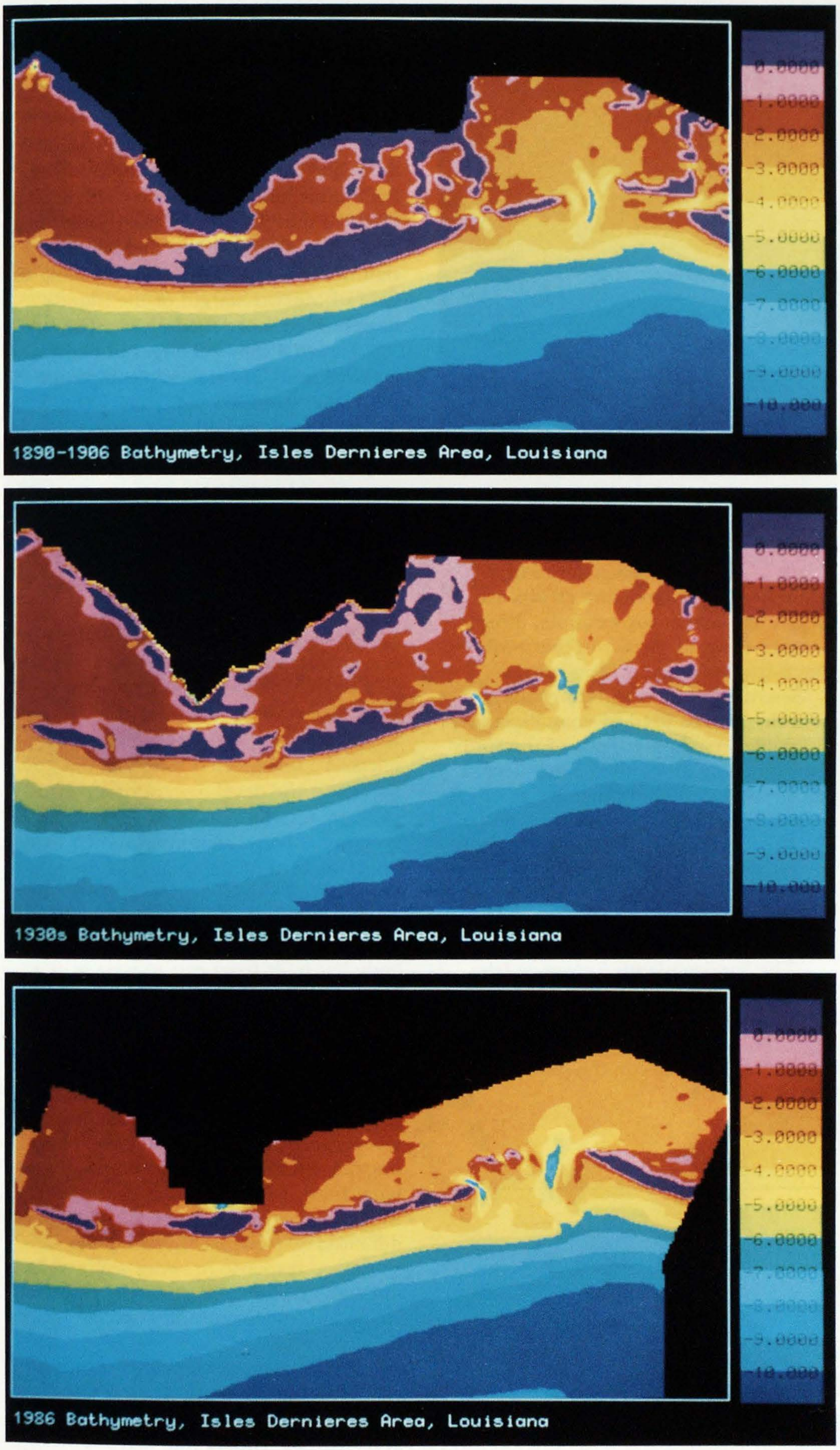


Figure 2. *Computer-generated bathymetric maps of the Isles Dernieres region from 1890–1906 (top), 1930's (middle), and 1986 (bottom). Depths are shown by colors; each color represents a depth of 3 feet. Purple represents subaerial land and black depicts areas of no data. The length of the rectangular display is 31 miles.*

Aerial oblique photograph of the eastern end of the Isles Dernieres barrier island chain as of June 1986. (Photograph by S. Jeffress Williams.)

net offshore sediment transport, and gradients of sediment transport along the length of the shoreline. A series of experiments and modeling efforts are being undertaken; for example, direct measurements of the waves that wash over a barrier island during storms.

- Assembling the research results in a form that can be used by coastal planners and engineers. Applications of the study results include developing better techniques for determining the rate at which artificially nourished beaches should be renourished and predicting future shoreline erosion so that coastal planners can properly locate new construction at a safe distance landward from the eroding shoreline.

The barrier islands known as Isles Dernieres (fig. 1) were studied in three surveys, done in 1890–1906, the 1930's, and 1986. Results of these surveys show considerable changes in the islands and nearby seafloor.

Proper management and protection of our Nation's coastal resources require knowledge of the patterns and rates of sediment movement.

Bathymetry contours from each survey are shown in figure 2. At the turn of the century, the Isles Dernieres was a nearly continuous island. By the 1930's, the islands had become narrower and more inlets had been incised, dividing the island into four segments. By 1986, the islands had become fairly narrow, less than 0.6 mile at most locations, and the previously opened inlets had widened significantly. Historically, places along the Gulf of Mexico margin of the islands have eroded more than 65 feet per year.

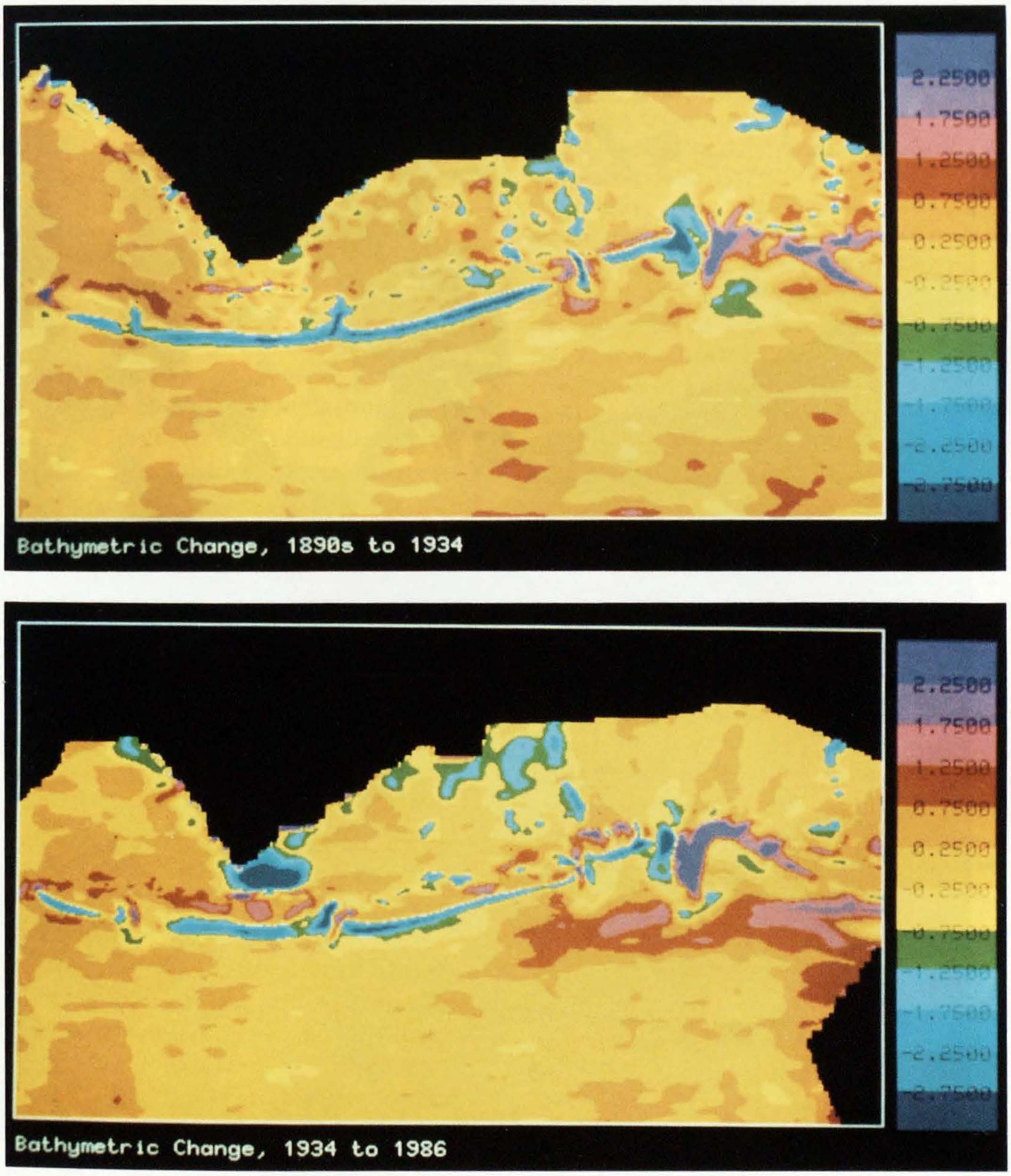
Figure 3 shows changes in bathymetry over time. For the map comparing the 1890's to 1930's bathymetry (fig. 3, top), the elongated blue pattern represents erosion on the Gulf margin of the barriers as the barriers migrate landward. Some of the erosion is in excess of 8 feet. The blue pattern, adjacent to the purple/red pattern and in the vicinity of the major inlets, represents longshore migration of the inlet of several miles.

Between the 1930's and 1986, there is a similar pattern of erosion on the Gulf face of the barrier, associated with shoreface retreat, and further evidence for the continued longshore migration of inlets. An unexpected aspect of this comparison is the development of a broad elongate (6.5 feet thick, 12 miles long) accretional body, composed mostly of sand, seaward of the mouth of the inlets forming the entrance to Terrebonne Bay (between Isles Dernieres to the west and Timbalier Island to the east). This sand body has built from east to west over a 50-year period in water depths of 16 feet and distances offshore of a little over 2 miles. The sand body is the result of sand bypassing the inlet, and, as its westward growth continues, it could eventually provide a source of new sand to the severely eroding Isles Dernieres. This unexpected result suggests that the sediment budget for these islands cannot simply be viewed in the classic two-dimensional sense of shoreline and shoreface response to rising sea level but must also include the effects of changes in the longshore movement of sand along the coast.

Proper management and protection of our Nation's coastal resources require knowledge of the patterns and rates of sediment movement, like that shown in figures 2 and 3. For example, in order to determine the cost effectiveness of a beach nourishment project one needs to know how often to return and renourish the beach. Knowledge of the rates and patterns of movement of sediments will help determine the constraints of beach nourishment and other types of projects.

The results discussed here represent only one part of the overall study effort. By better understanding the geologic framework within which erosion occurs and improving our understanding of the processes of erosion, we hope to be able to improve our ability to forecast future erosion not only in Louisiana but also in other threatened coastal areas.

Figure 3. *Amounts of vertical change between historical bathymetric surveys—1890's–1934 (top) and 1934–1986 (bottom). Individual colors represent a 1.6-foot (0.5-meter) interval of vertical change in bathymetry. The sign indicates erosion (−) or accretion (+). For example, green indicates erosion between 2.5 feet (0.75 meter) and 4.1 feet (1.25 meters), whereas red indicates accretion between 2.5 feet and 4.1 feet.*

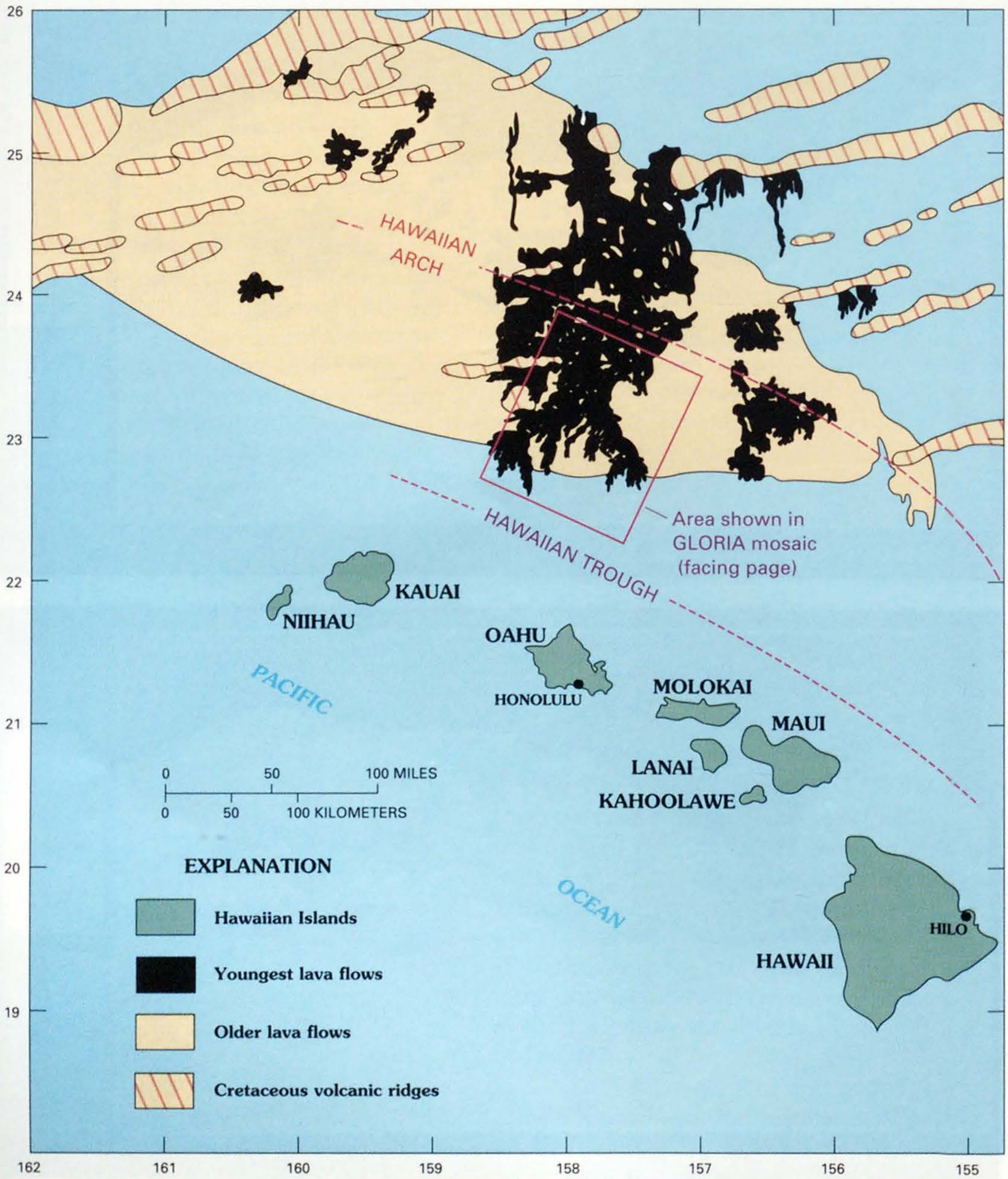


Hawaiian Submarine Lava Flows

By Robin T. Holcomb

A sonograph mosaic (facing page) of about 4,700 square nautical miles (16,000 km^2) of the ocean floor 80 nautical miles (150 km) north of Oahu, Hawaii, shows a part of the newly recognized North Hawaiian Arch Volcanic Field. The image was produced from data gathered by the GLORIA long-range sidescan sonar system in the spring of 1988 aboard the R/V *Farnella* as a part of the U.S. Geological Survey program to map the Exclusive Economic Zone (EEZ) around the Hawaiian Islands. This is part of a comprehensive effort to map the deep seafloor of the U.S. EEZ—an area of some 3 million square nautical miles.

The high contrast of this reproduced mosaic emphasizes the difference between Cenozoic lava flows (dark) and older, thick sediment (light). Similar young lava flows occupy 8,700 square nautical miles (30,000 km^2) of a volcanic field having a total area of 44,000 square



nautical miles (150,000 km^2), much larger than the Hawaiian Islands. The thin tongues of lava have flowed southwest down the inner flank of the Hawaiian Arch toward the Hawaiian Trough, a depression created by downbowing of the crust under the weight of the Hawaiian volcanoes. Lava flows of the volcanic field are interbedded with deposits of landslides from the islands, indicating that the field has been intermittently active during the last few million years. Some flows that have very little sediment cover may be as young as a few thousand years.

These and other large submarine lava flows discovered recently east and south of Hawaii and elsewhere at low latitudes, for example, are thought by USGS scientists to rapidly deliver large amounts of heat into the ocean, possibly affecting weather patterns on a global scale. The weather phenomenon called El Niño occurs where the normal pattern of easterly driven wind and ocean circulation is altered to a westerly pattern. The cause of this switch is not clearly understood. The heating effect of the submarine lava flows, however, may be sufficient to warm the ocean currents, upsetting the balance between temperature and atmosphere and activating the reversal in the direction of motion, thereby triggering El Niño.

Probabilities of Large Earthquakes in California

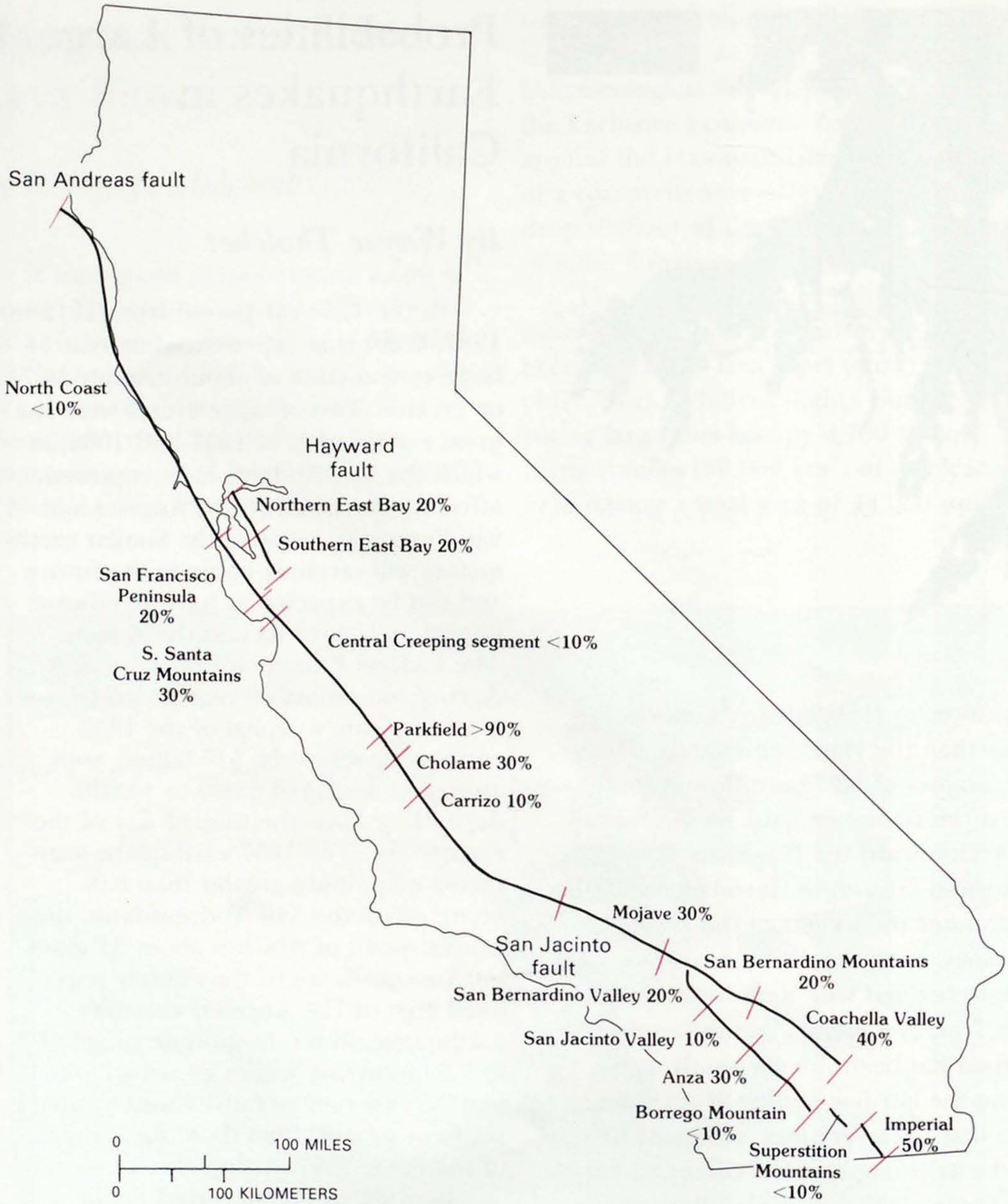
By Wayne Thatcher

In the 175-year period from 1812 to 1987, California experienced at least 11 large earthquakes of about magnitude 7 or greater. Two of these events were the great earthquakes of 1857 and 1906, in which the San Andreas fault ruptured, affecting the areas of Los Angeles and San Francisco, respectively. Similar earthquakes will certainly occur in the future and can be expected to have significant impact on California and the Nation. The Federal Emergency Management Agency has estimated that property losses resulting from a repeat of the 1857 earthquake would be $17 billion, with estimated deaths of 3,000 to 14,000, depending upon the time of day of the earthquake. The 1857 earthquake (estimated magnitude greater than 8.0) occurred on the San Andreas fault, the nearest point of which is about 31 miles (50 km) northeast of the densely populated area of Los Angeles; a smaller earthquake, in the magnitude range of 7 to 7.5, occurring within an urban area may be expected to cause losses comparable to or greater than those for a repeat of the great 1857 earthquake.

Because of the increased public interest in and concern about expected losses from future earthquakes in California, the National Earthquake Prediction Council, a body of academic and government scientists advisory to the Director of the U.S. Geological Survey, recommended an evaluation of the probability of occurrence of large (magnitude 7 or greater) earthquakes in California. In response to this recommendation, the USGS formed a working group on California earthquake probabilities, which met several times in 1987–88 to review and assess the state of knowledge that would allow calculation of earthquake probabilities on specific segments of the San Andreas fault (fig. 4).

The probabilities were based on a model for time-dependent increase of earthquake probability. The model has its

Figure 4. Probabilities of major earthquakes along segments of the San Andreas, Hayward, San Jacinto, and Imperial faults for the 30 years 1988–2018.



origin in the cycle of stress accumulation and release that characterizes the earthquake cycle. The working group assumed that, following an earthquake large enough to rupture an entire segment of a fault (termed a characteristic earthquake), the potential for a future large earthquake along that fault segment is initially small and increases as a function of time as the motion of the earth's crust again builds the stress on the fault toward the limit for failure. These properties of recurring earthquakes are qualitatively expressed in the seismic gap hypothesis, which states that the potential for a future earthquake is greater along those active fault segments having had long periods of time since the last characteristic earthquake. To determine time-dependent probabilities, the faults were divided into their recognizable segments; the potential for a future large earthquake on each segment was calculated on the basis of the time that has elapsed since the most recent large earthquake and fault parameters such as slip rate and amount of displacement. The time interval chosen for the probability calculations was 30 years—1988 to 2018; similar calculations using the same models were performed for 5-year, 10-year, and 20-year intervals, as well.

- The 30-year probability of large earthquakes is highest in southern California. The 62-mile-long (100-km-long) Coachella Valley segment has the highest probability (0.4 or 4 in 10) of producing an earthquake of magnitude 7.5 in the next 30 years. A major earthquake has not occurred there since about A.D. 1680. The Mojave segment, part of the source region of the great 1857 earthquake, has a 30-year probability of 0.3.

- Evaluation of the earthquake probability for the southern San Andreas fault depends on the future behavior of the San Bernardino Mountains segment of the fault. If the San Bernardino Mountains segment slips independent of the adjacent segments, the expected magnitude of earthquakes on the southern San Andreas fault would be about 7.5, with a 0.7 probability of at least one such event in the next 30 years. If the San Bernardino Mountains segment slips along with either the Mojave segment to the north or the Coachella Valley segment to the south, then the resulting earthquake would approach the size of the 1857 earthquake and would have a 30-year probability of 0.6.
- The probability of large earthquakes within the next 30 years along fault segments in the San Francisco Bay area is also significant. The total probability for all fault segments evaluated is 0.5. The Hayward fault has produced two earthquakes in historical time, in 1836 and 1868; both had estimated magnitudes approaching 7. The Northern East Bay segment of the Hayward fault, the Southern East Bay segment of the Hayward fault, and the San Francisco Peninsula segment of the San Andreas fault each have a probability of 0.2 of an earthquake of magnitude 7 in the next 30 years. The 30-year probability of a great earthquake along the North Coast segment, extending north from the San Francisco Peninsula, is less than 0.1.
- Fewer data are available about the recurrence of large earthquakes along five separate segments of the San Jacinto fault. During the course of the probability study, the late November 1987, magnitude 6.6 Superstition Hills earthquake more than 100 miles south of Whittier, Calif., occurred on one of these segments. The USGS estimated a probability of 0.5 for the four remaining segments combined, for the occurrence of earthquakes of about magnitude 7 within the next 30 years. The segment of the San Jacinto having the highest probability is the Anza segment (0.3). The others are San Bernardino Valley segment, 0.2; San Jacinto Valley segment, 0.1; and the Borrego Mountain segment, less than 0.1.
- The Imperial fault, spanning the Mexico-U.S. border, has produced two magnitude 6.6 or greater earthquakes in the past half century. A 50-percent probability of a 6.5 or greater earthquake in the next 30 years is estimated.

The 30-year probability of large earthquakes is highest in southern California.

Recent moderate earthquakes in Whittier and Coalinga, Calif., serve as a reminder that not all active faults have been recognized everywhere in California. Although almost all well-studied California earthquakes of magnitude 7 and larger have, in fact, occurred on faults having clear surface expressions, some faults capable of events of this size have not been identified. This is particularly true in the Transverse Ranges of southern California, where shallowly dipping thrust faults and major folds dominate the tectonic environment and where the configuration of faults at depth is known to be exceedingly complicated. Thus, not all potential sources of large California earthquakes have been identified in these probabilistic analyses.

The assessment of long-term seismic hazard on California's major faults is an active and rapidly developing field. New data and improvements in the model on which the assessments are based will probably lead to revision and refinement in the probabilities assigned here to segments of the San Andreas system. The total regional values, however, support the main conclusion that the probability of a major earthquake on the San Andreas in southern California within the next 30 years is high, about 0.6, and that the probability approaches 0.5 for both the San Francisco Bay area in northern California and the San Jacinto fault in southern California.

Developing a Climate Record for the Past 3 Million Years

By David P. Adam

Global climatic change has attracted increasing attention in recent years as human activities have grown to a scale that could affect the climate. The carbon dioxide content of the atmosphere has increased by about 20 percent since the Industrial Revolution; consumption of fossil fuel and deforestation have contributed, possibly substantially, to this increase. In addition, deforestation threatens tropical rain forests and can alter local and regional weather patterns. Manmade chlorofluorocarbon gases have made their way into the upper atmosphere and are affecting the ozone layer.

U.S. Geological Survey scientists are studying these and other effects of human activities by studying computer models of climate. These models can offer predictions of the behavior of future climates under various conditions. In order to verify the accuracy of these models, however, scientists must test them to see how well they can reproduce the climates of the past.

Historical records provide one type of climatic data against which to judge the results of models but have the disadvantage that they span at most only a few hundred years. In order to evaluate model results for conditions outside the range documented in the historical instrumental records, it is necessary to study the evidence of past climatic conditions preserved in the extensive geologic record.

Many lake, bog, and alluvial sediments have yielded records of past events and environmental conditions through their physical properties and the biological remains preserved in them. However, most of these records span no more than the past few tens of thousands of years. Studies of these records have provided a relatively good understanding of the dynamics of climate change during the present interglacial period and during the transition from the last glacial period to the present interglacial. By contrast, much less is known about how climate changes when the world passes from an interglacial climate into a glacial climate, or from a climate like the present interglacial into an even warmer mode. Therefore the USGS has sought to locate longer records of past climates.

Studies by the USGS Climate Change Program in northeastern California and south-central Oregon since 1983 have produced a detailed record of regional climatic changes that spans the past 3 million years. The most important record is from a 334-meter (1,095-foot) sediment core from an ancient lake at the town of Tulelake, Siskiyou County, Calif. Paleontologic studies have described changes in the frequencies of pollen grains, diatoms and other algae, fish remains, and ostracodes at various depths within the core; examples of these changes are shown in figure 5. These changes can be interpreted in terms of regional events, including not only climate changes but also volcanic, tectonic, and geomorphic changes. Such changes are also observed in the geochemical record extracted from the core.

In addition to the fossils found in the core, numerous volcanic ash layers (tephra) are well preserved. Because each ash layer identifies the same time horizon, wherever it occurs, studies of the major- and trace-element composition of volcanic glass, using electron microprobe techniques, provide a means by which to correlate the Tulelake record with records at other localities where the same ash layers have been found. The ages of many of the tephra layers are already known from prior age analyses done at other localities, and dates determined elsewhere can thus be reliably correlated with particular horizons in the Tulelake core. For example, the Rockland ash bed (fig. 5) was erupted from Mt. Lassen about 0.4 million years ago, is found in many locations in California, and has been used to interpret changes in the drainage history of central California. The DSDP–173–3/4 ash bed, also shown on figure 5, has been found both at Tulelake and in a sediment core from the northeastern Pacific Ocean off the coast of Oregon. That ash layer thus provides a firm link between the continental climate record at Tulelake and the more thoroughly studied marine climatic record.

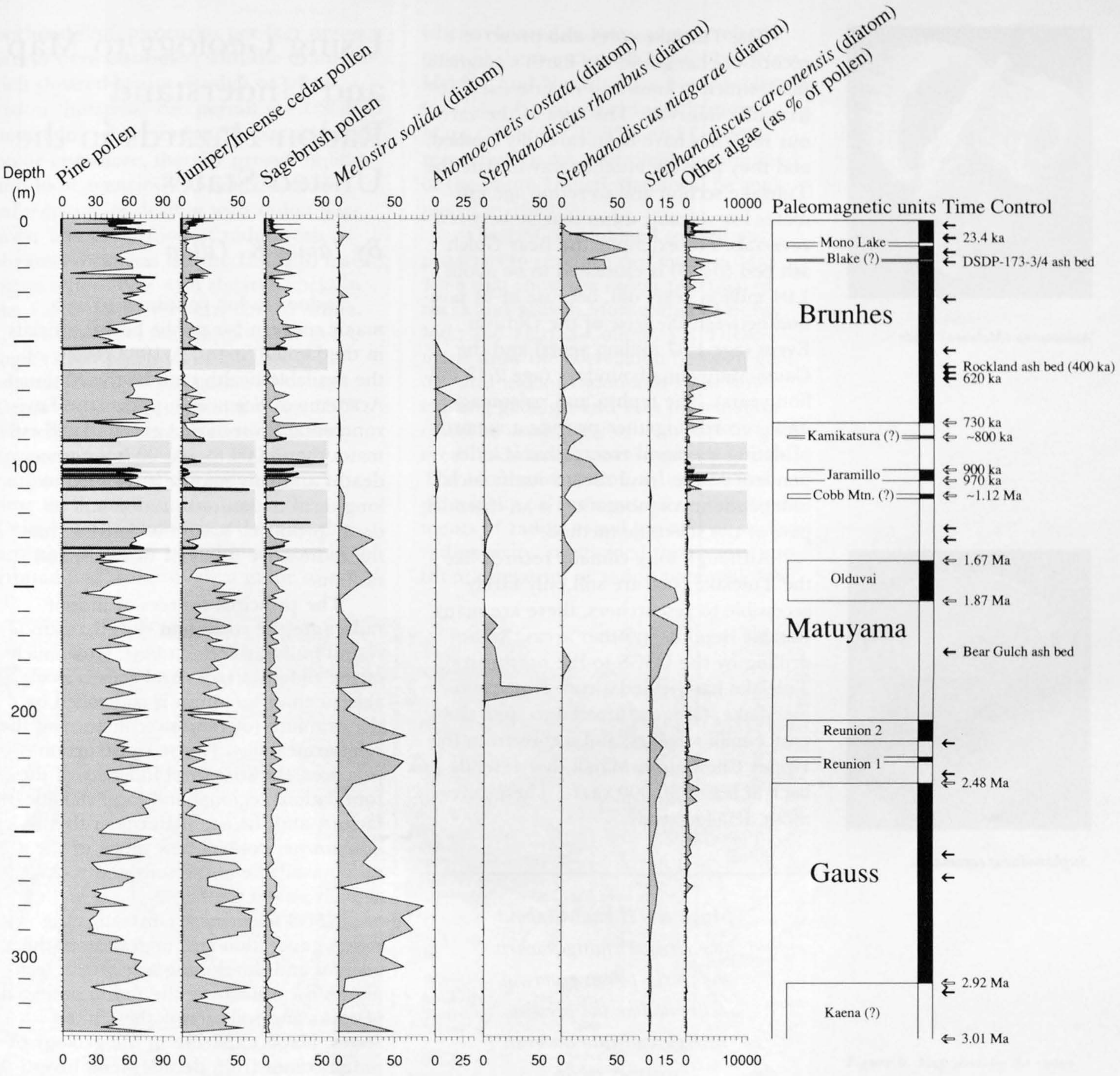
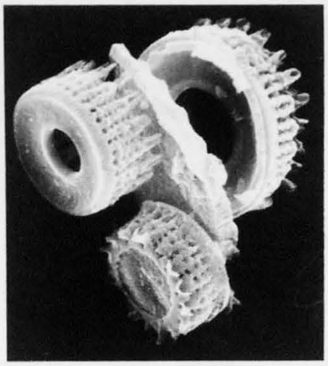
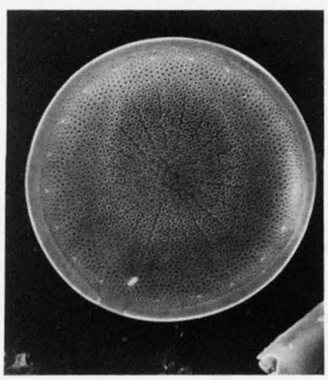


Figure 5. Selected variables plotted against depth for a 1,095-foot core from Tulelake, Siskiyou County, Calif. Age increases with depth; the oldest deposits shown are about 3 million years old. Pollen types are expressed as percent of total pollen; diatoms are expressed as percent of total diatoms. Paleomagnetic timescale is shown at right (ka = 1,000 years; Ma = 1 million years). The black boxes indicate intervals during which the Earth's magnetic field was oriented as it is today, and the unshaded boxes indicate intervals during which the Earth's magnetic field was reversed. Solid arrows indicate positions of volcanic ash layers (tephra) used to correlate the core with other areas; hollow arrows indicate ages of paleomagnetic boundaries as determined by other studies. The pollen curves reflect variations in the regional vegetation in response to climate. High frequencies of pine pollen indicate times of relatively moist conditions. High frequencies of juniper pollen at the expense of pine reflect more open, less heavily forested conditions, and hence less available moisture. High frequencies of sagebrush pollen represent cold, dry conditions that were most common during glacial times. The lightly shaded boxes shown on the pollen curves indicate parts of the section where no pollen was recovered. A major change in the behavior of the regional vegetation that took place about 1.6 million years ago (about the top of the Olduvai Event) corresponds to the onset of continental glaciation in the Northern Hemisphere. The frequencies of the various diatoms reflect changing conditions within the lake and also evolutionary changes in the diatoms. For example, the diatom Anomoeoneis costata *prefers saline waters, and the peak in its frequency from 50–90 meters depth reflects the relatively high salinity of the lake about 500,000 years ago. The peaks in frequency of "other algae" (note the very compressed scale for the curve) reflect a well-developed lake; when "other algae" are scarce, the lake was probably shallower or seasonal in nature.*



Aulacoseira (Melosira) solida



Stephanodiscus carconensis

The Tulelake cores also preserve a record of changes in the Earth's magnetic field, which is known to reverse itself at irregular intervals. The ages of the various reversals have been carefully studied, and they provide another way to date the Tulelake section and to refine age estimates for volcanic ashes that lie between reversals. For example, the Bear Gulch ash bed (fig. 5) is estimated to be about 1.94 million years old, because of its position between the base of the Olduvai Event (age 1.87 million years) and the Gauss-Matuyama boundary (age 2.48 million years). The tephra and paleomagnetic records together provide a means of dating the fossil record that is independent of the fossil record itself; such independent corroboration is an essential part of the scientific method.

Although long climatic records like the Tulelake core are still only rarely accessible to researchers, there are many suitable deposits in other areas. Recent drilling by the USGS to the northeast of Tulelake has yielded a core from Summer Lake, Oreg., estimated to span the past 1 million years, and a core from the Upper Chewaucan Marsh that extends back at least 750,000 years. These cores await detailed study.

Much less is known about how climate changes when the world passes from...a climate like the present interglacial into an even warmer mode.

Future studies of these and other long, continuous sediment records will provide better understanding of how the Earth's climate has behaved in the past, better constraints against which to evaluate climate models, and thus a better understanding of how human activities may affect climate and what the long-range impact of climate change on the environment may be.

Using Geology to Map and Understand Radon Hazards in the United States

By James K. Otton

Indoor radon continues to be a major concern for public health officials in the United States. A 1988 review of the available health data by the National Academy of Sciences supports the Environmental Protection Agency's 1986 estimates that 5,000 to 20,000 lung cancer deaths annually may be attributed to long-term exposure to radon and its decay products. Radon is derived from the radioactive decay of uranium and radium.

The principal sources of indoor radon are the rocks and soils that surround building foundations. How much of the radon in rocks and soils is available to enter buildings is controlled by the uranium (or radium) content and the soil permeability. House construction practices, the structural integrity of the foundation, regional and local climatic factors, and the use patterns of the homeowner control how much of the radon available in the soils and rocks actually enters the home.

USGS scientists are investigating radon generation and migration in the ground and developing assessment techniques for estimating the radon potential of rocks and soils across the United States. USGS expertise in the geology of radon comes from decades-long investigations of uranium and its radioactive decay products in ore deposits and other natural and manmade settings.

Current concerns began with the discovery of high radon levels in a home near Boyertown, Pa. USGS geologists mapped the rocks and measured the soil gas radon concentrations in the neighborhood near the house and found three distinct rock types: a biotite-hornblende gneiss, a quartz-feldspar gneiss, and a uranium-rich quartz-feldspar gneiss; the uranium enrichment was caused by shearing of the gneiss. All the very high readings of indoor radon in the neighborhood (200 picocuries per liter or more) were associated with the uranium-rich sheared gneiss. Studies of such radon "hotspots" can permit the USGS to determine where radon "hotspots" may occur elsewhere, thereby providing State and local agencies with much-needed information in dealing with radon hazards. The association of radon with sheared rocks has led the USGS to investigate other areas with sheared rocks in the Eastern and Western United States.

A basic tool for mapping the geologic radon potential of an area is the aeroradiometric data gathered by the Department of Energy in the late 1970's. The data have been used to map the apparent (or equivalent) uranium or radium content of the soils and rocks near the Earth's surface across the United States. Such maps describe the probable strength of radon sources in the ground and will provide a guide to areas where elevated indoor radon levels are most likely to occur. Maps of Ohio, New Mexico, and Nevada have been published (as USGS Geophysical Investigations Maps GP–968, GP–979, and GP–982, respectively). An equivalent-radium map of the entire United States will be completed in 1989.

The USGS combined several approaches to produce two maps in May 1988 that show the radon potential of rocks and soils in Montgomery County, Md., and Fairfax County, Va. These maps show the correlation between geology and indoor radon and show how existing geologic and soils information could be used alone or with rapidly gathered field data to assess radon potential. The Montgomery County map, based principally on geology and field measurements of radon in soil gas and of surface radioactivity, subdivided the county into three categories of radon potential (low,

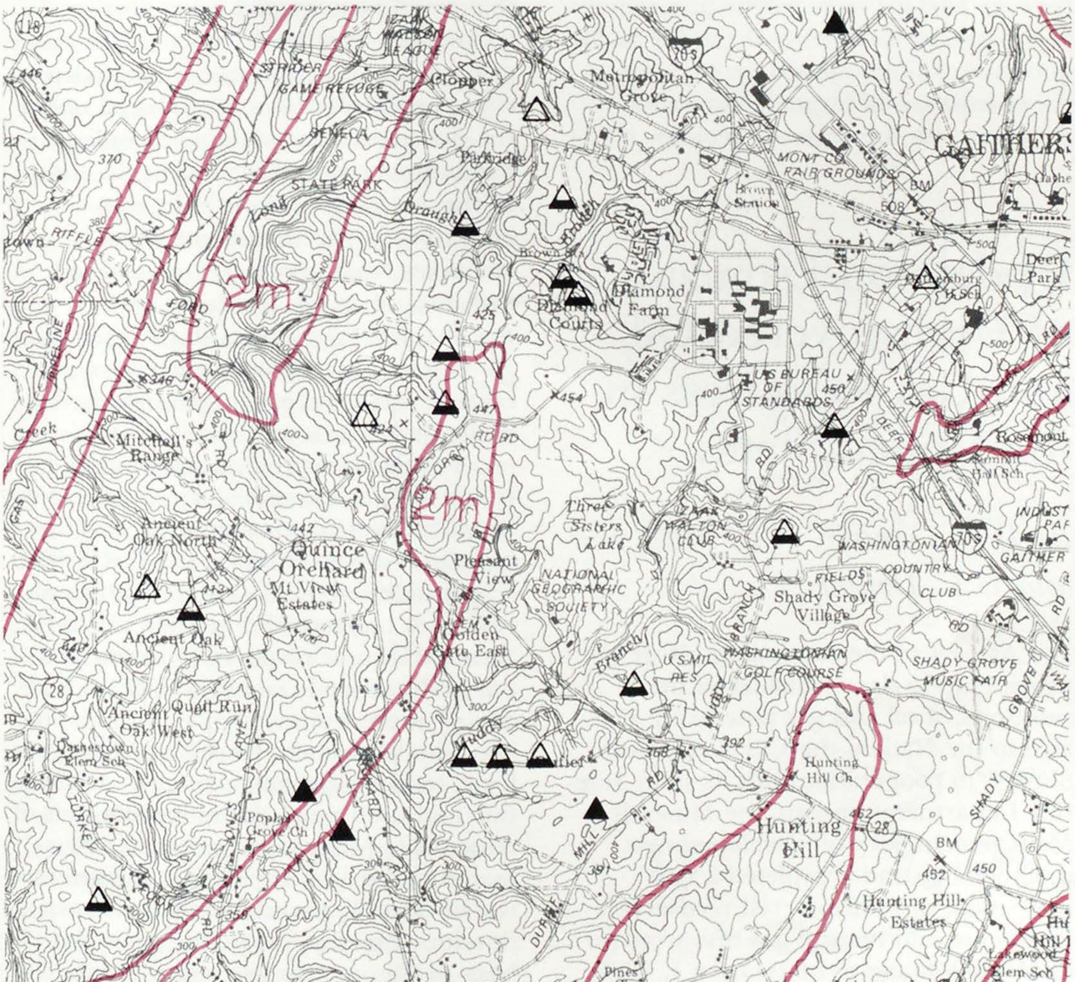


__Figure 6.__ Map showing the radon potential of part of Montgomery County, Md., northwest of Washington, D.C. The mapped areas are ranked 1 to 3 with "1" having lowest radon potential and "3" having high radon potential; the letters refer to the rock type underlying the surface. For example, 2m indicates mafic or ultramafic rocks having a moderate potential for elevated radon levels; 2s indicates schist having moderate radon potential. Indoor radon concentrations, in picocuries per liter of air, are shown by triangles: open triangle, less than or equal to 4; half-filled triangle, greater than 4 but less than 20; solid triangle, greater than 20.

moderate, and high). The Fairfax County map, based primarily on geology, aeroradioactivity, and soil permeability mapping, subdivided the county into five radon potential categories. A part of the radon potential map for Montgomery County is shown in figure 6.

Geologic investigations may also contribute to understanding seasonal variations in indoor radon. Long-term study of radon in soils at the Denver Federal Center by USGS scientists has shown that the radon content of soil gas at a depth of 3 feet decreases by an order of magnitude from late winter to late summer, as soil moisture and related factors decrease. The apparent periodic variations in the geologic potential of radon may explain, in part, why there are seasonal variations in indoor radon.

Ongoing investigations by the USGS are focusing on how gas migrates through soils and rocks, the relation between surface radioactivity and radon in soil gas, methods to evaluate the radon potential of undeveloped ground, and the correlation of large indoor radon data sets with the regional geology.

Update on Estimates of Undiscovered Oil and Gas Resources in the United States

By D.L. Gautier, R.F. Mast, and G.L. Dolton

As part of the continuing effort to provide up-to-date estimates of the resources of oil and gas potentially available to the Nation, the U.S. Geological Survey, in cooperation with its sister Interior Department bureau, the Minerals Management Service, developed new methodology and completed a new assessment of undiscovered recoverable petroleum and natural gas resources for the United States as of January 1, 1987. Such estimates are an essential part of the foundation on which the Nation can develop a sound energy policy and can make critical decisions on public land use and resource management.

In estimating the amounts of oil and gas available for immediate and future development and use, scientists use two broad categories: reserves and resources. *Reserves* include the amounts of oil and gas that have been measured or closely estimated through engineering and geophysical techniques; *resources* include the more speculative and long-range estimates of what volumes of oil or gas can be expected to be found based upon estimates of geologic parameters such as the likelihood of oil-trapping structures that have not actually been tested by drilling or other hard, measuring methods.

The commodities included in the assessment were crude oil, natural gas, and natural gas liquids. This assessment was divided into "undiscovered recoverable resources," those resources that exist in conventional geologic reservoirs and that could be extracted using current technology, and "undiscovered economically recoverable resources," those that could be developed and produced under the price-cost relationships, excluding exploration costs, prevailing at the time of the assessment. Specifically not addressed in the assessment were resources from very heavy oil and tar deposits, oil shales, gas from low-permeability "tight" sandstone reservoirs, gas from fractured shale reservoirs, coalbed methane, gas in geopressured shales and brines, and gas hydrates.

For this most recent assessment, which follows a long history of petroleum resource assessments dating back to the early part of this century, the USGS was responsible for estimating undiscovered resources onshore and in State offshore areas. MMS was responsible for estimating undiscovered resources beneath Federal offshore waters.

This assessment considered new geologic, technologic, and economic information and used more definitive methods of resource appraisal than previous assessments. As part of an effort to ensure the widest possible evaluation of the newly developed methodology, the geologic basis of this current assessment has undergone review by the Association of American State Geologists and the overall methodology and general assumptions

United States oil and gas reserves and resources

Estimates for oil are given as billion barrels of oil; estimates for gas are given as trillion cubic feet. Reserves include expected additions to known reserves by expansion of fields. The low and high estimates are given as probability levels, F_{95} and F_5. There is a 95 percent probability of finding more than the low estimate, and only a 5 percent probability of finding more than the high estimate. The Total United States probability figures are derived by a statistical process, not by simple addition of the individual probability figures. Totals of individual means may differ slightly due to independent rounding of individual means.

	Reserves		Recoverable resources						Economically recoverable resources					
	Oil	Gas	Oil			Gas			Oil			Gas		
			Low	High	Mean	Low	High	Mean	Low	High	Mean	Low	High	Mean
Onshore and State waters	45.3	250.1	19.6	51.9	33.3	178.7	346.7	254.0	13.9	45.0	26.6	145.6	239.1	188.7
Federal offshore	5.9	55.3	9.2	25.6	16.1	97.8	204.8	145.1	4.0	14.3	8.2	44.3	113.8	74.0
Total United States	51.2	305.4	33.2	69.9	49.4	306.8	507.2	399.1	20.7	53.8	34.8	208.2	325.5	262.7

are undergoing review by the National Academy of Sciences.

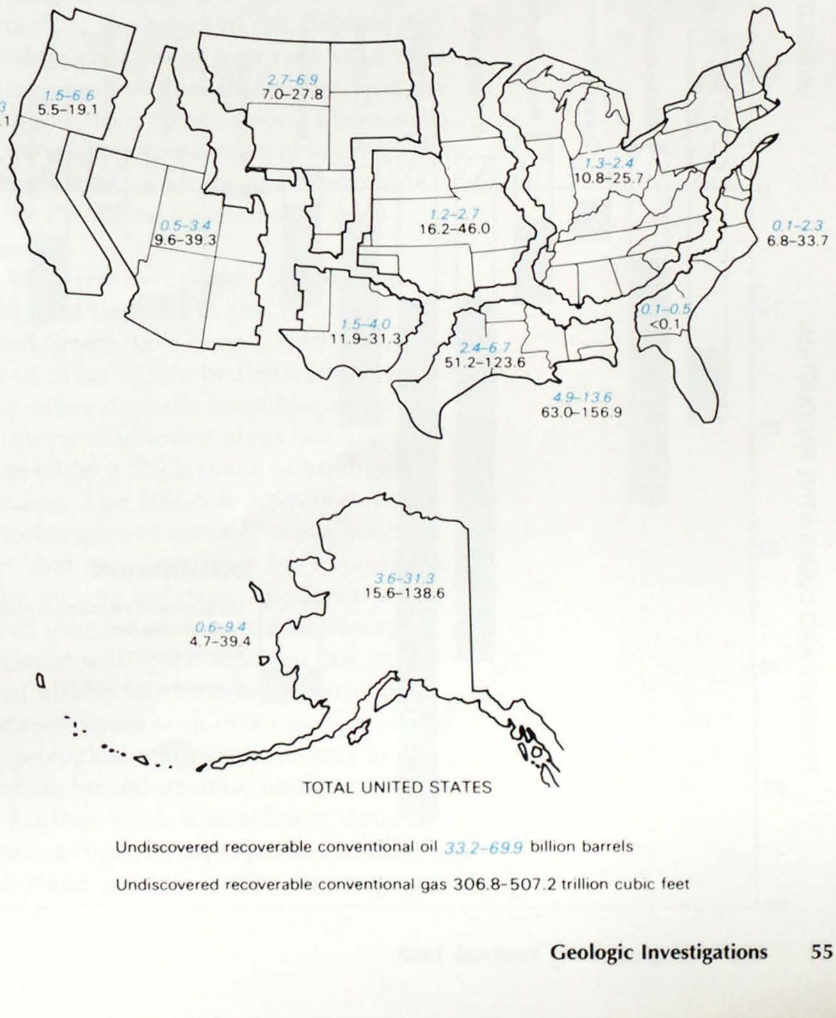
The scientists used an oil and gas "play analysis" approach for the new assessment. For this approach, the United States was divided into 13 regions (9 onshore and 4 offshore). The 13 regions were further divided into 115 provinces. Within each onshore province, some of which extended out into the State offshore areas, the scientists identified "plays" as a group of geologically related known accumulations or undiscovered accumulations, and (or) prospects having similar hydrocarbon sources, reservoirs, and traps. Resource estimates for those undiscovered accumulations greater than 1 million barrels of oil or 6 billion cubic feet of natural gas were made by analysis of the petroleum geology and exploration history of oil and gas plays in each province. This included analysis of large computer data bases containing exploratory drilling data and field-size data for known fields. A statistical extrapolation technique was used to determine recoverable and economically recoverable resource estimates for onshore and State offshore undiscovered accumulations containing less than 1 million barrels of oil or 6 billion cubic feet of gas. Because this new methodology incorporated expected field size and depth ranges, economically recoverable resources could, for the first time, be calculated based on specific economic assumptions that excluded exploration costs.

The undiscovered recoverable conventional resources for the entire United States are estimated to range from 33 to 70 billion barrels of oil and from 307 to 507 trillion cubic feet of natural gas. Corresponding estimates for natural gas liquids in this category range from 6 to 12 billion barrels.

For the category of economically recoverable resources, estimates range from 21 to 54 billion barrels of oil and from 208 to 326 trillion cubic feet of natural gas. Corresponding estimates for natural gas liquids range from 5 to 8 billion barrels.

Looking at the reserve picture, measured reserves at the time of the assessment were 29.5 billion barrels of oil and 206.6 trillion cubic feet of gas. It was further estimated that an additional 21.7 billion barrels of oil and 98.8 trillion cubic feet of natural gas will be added to reserves through expansion of known fields.

The 13 regions of the United States used for the new estimate; estimates of undiscovered recoverable oil and gas resources are shown for each region.



The results from the current assessment differ from those of previous assessments. Although certain regions, such as the offshore Gulf Coast, show increased undiscovered resources in the current assessment, the overall numbers are reduced from the 1980 estimate. This change is due to such factors as the incorporation of five additional years of drilling information and new sources of field data, as well as the use of the more specific play analysis approach. The play approach allowed for more specific use of existing geologic data and more direct application of computerized data from 1.8 million oil and gas exploration and development wells than was previously possible. In addition, new sources of data on oil and gas field size were used in this assessment.

The change in the resource estimates also results from discoveries of oil and gas since 1980, which shifted some of the undiscovered resources from previous assessments into reserve categories. While assumptions about future prices of commodities and technology changes also influenced the results, the overall decline in estimates of undiscovered resources is primarily due to reevaluations that reflect new geological data from exploration drilling in several major regions that were expected to have significant petroleum potential. The new data do not substantiate that expectation. For example, major discoveries that had been expected in frontier exploration of offshore areas off Alaska and the Atlantic and onshore in the overthrust belt of the Western United States did not occur. Moreover, most other onshore regions did not meet the resource occurrence expectations postulated in earlier assessments, although estimates increased in a few areas, such as Alaska. The massive exploration efforts of the industry in the late 1970's and early 1980's simply did not confirm some of the geological expectations for large new accumulations of oil and gas that were included in earlier estimates. Furthermore, most onshore plays showed a decline in sizes of fields discovered over the history of the play.

From the results of this assessment, it is clear that the most prospective areas remaining in the United States for undiscovered oil and gas resources are onshore northern Alaska and the onshore and offshore Gulf Coast (fig. 7). Other important potential resource areas include the Rocky Mountain region, the onshore and offshore Pacific Coast, the mid-continent region, and offshore Alaska.

Because of the critical importance of timely and reliable estimates of oil and gas resources, such assessments will be an ongoing effort of the USGS and other agencies and will be produced on a regular basis, in order to ensure the availability of this information in planning for the Nation's future energy security.

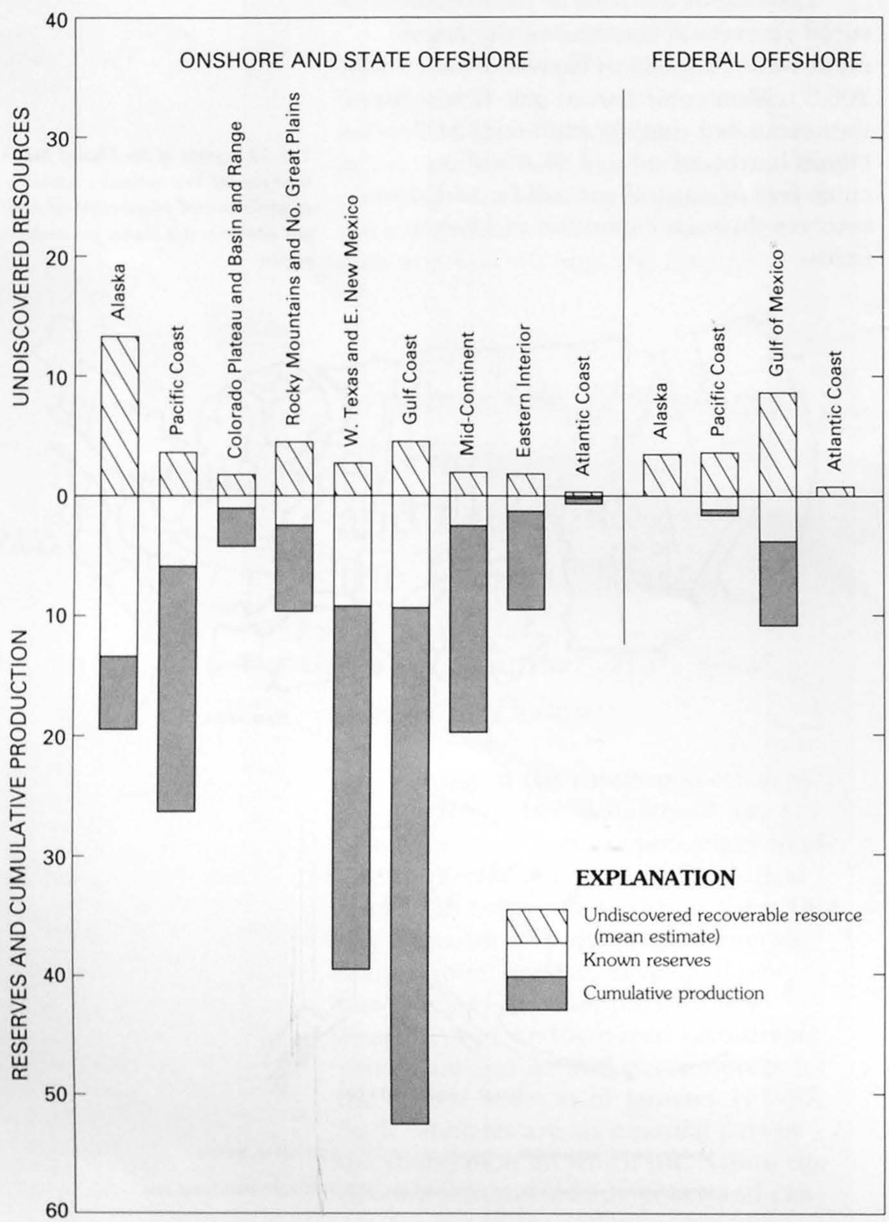


Figure 7. A comparison of crude oil reserves and resources provides a striking contrast between the amounts of crude oil that have already been discovered (cumulative production and reserves) and the smaller amounts of undiscovered recoverable resources that remain to be found and produced. Amounts shown are billions of barrels of oil.

Research Advances in the Identification of Disseminated Gold Deposits

By Michael P. Foose

Much of the recent increase in domestic metallic minerals exploration has involved the search for disseminated gold deposits in the Western United States. These deposits consist of extremely fine-grained gold dispersed in sedimentary or volcanic rock. Although deposit grades are generally very low (typically between 0.05 and 0.3 ounces of gold per ton of ore), bulk mining and inexpensive ore-treatment techniques make them very attractive exploration targets.

Work by the U.S. Geological Survey in the early 1960's was instrumental in identifying and defining these previously unrecognized deposits. Subsequent USGS research has continued to add critical geological, geochemical, and geophysical information needed to understand and explore for these deposits. Important advances in the last year include development of new geologic models, exploration criteria, and geophysical detection techniques.

The development of an ore-deposit model that can be successfully used in mineral exploration requires an understanding of the processes by which the deposit forms. A recently completed cooperative study by the USGS and Freeport Gold Co. on the disseminated gold deposit at Jerritt Canyon, Nev., integrated the results of several different specialized studies to show the following conclusions:

- Gold is associated with the introduction of silica into the host sedimentary rocks.
- The gold-bearing fluids trapped in the rock indicate that gold was transported in compositionally diverse, moderately saline fluids; gold was deposited when these fluids mixed with oxygen-rich, less saline waters, and the temperature of deposition was between 200 and 250 °C (390 and 480 °F).
- Isotopes of hydrogen, oxygen, and sulfur can be used as chemical fingerprints to further document the role of fluid mixing in gold precipitation.
- The organic material found in the rocks that host these deposits, which has long been an enigma, was not introduced with the gold but may have acted as an agent to precipitate gold.

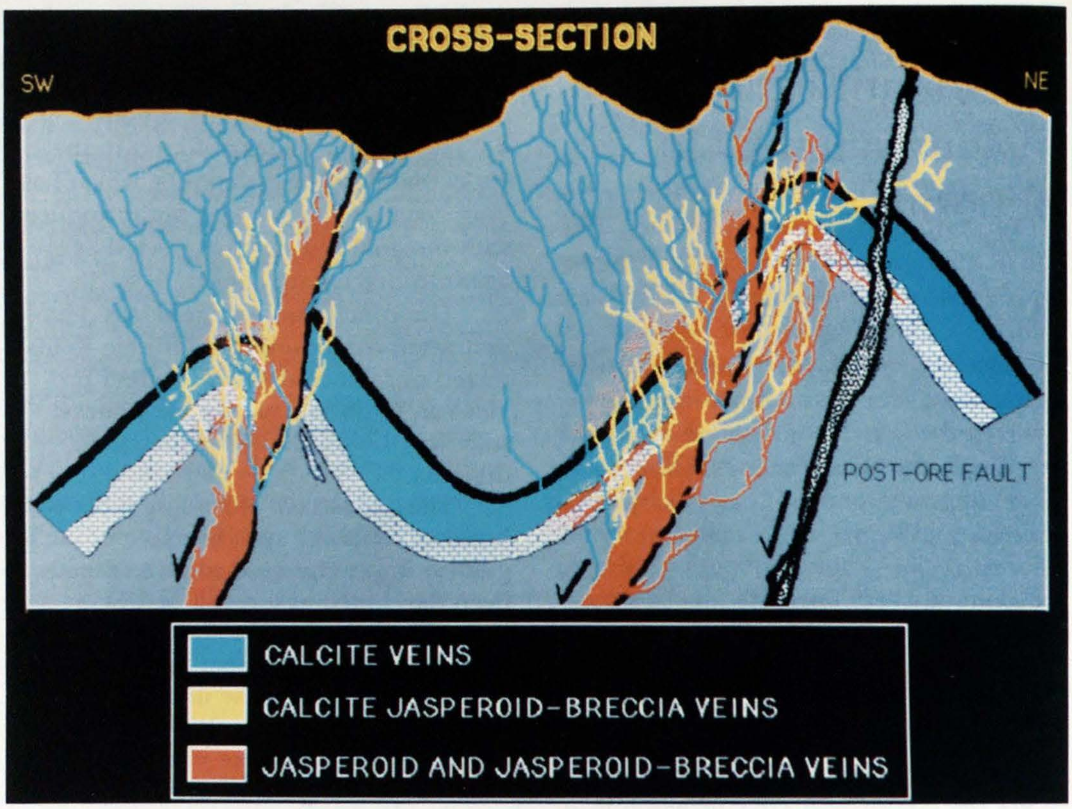
The conclusion that gold was deposited when compositionally diverse fluids mixed in fault-controlled aquifers provides an important model for understanding the formation of such gold deposits.

The actual task of finding a deposit, however, requires specific exploration guides. Important guides have recently been developed as a result of USGS research on the Pinson and Preble deposits in Nevada. The waters that transported the gold at these deposits flowed along high-angle faults. Where gold was deposited, silica in these waters both locally replaced parts of the enclosing sediments and also formed crosscutting veins. Geologic maps show that the most silica-rich veins occur close to the main fault and the center of the deposit, whereas carbonate-rich veins are more common at the edges of the deposit (fig. 8). Subtle changes in host-rock mineralogy and composition also accompany the changes in vein composition. The association of vein composition and zoning with gold provides an important new tool to specifically locate disseminated gold deposits.

With few exceptions, the disseminated gold deposits in the Western United States have been found in mountainous areas where bedrock is exposed. Many other deposits must be present in the intervening lower areas but are obscured by a thick cover of younger sediment. The USGS is actively developing techniques to identify areas beneath cover that may be targets for exploration by the mining industry. Because the margins of granitic plutons are commonly associated with gold deposits, one of the recent efforts has integrated aeromagnetic techniques with other geophysical and geological mapping methods to delineate buried granitic bodies.

Further work is now being done to identify geophysical properties to distinguish those granitic bodies that are most

Figure 8. *Cross section showing the changes in vein composition around some sediment-hosted disseminated gold deposits. Silica-rich (jasperoid) veins occur near the center of the gold deposit, while carbonate-rich (calcite) veins occur peripheral to the main mineralized area.*



likely to be associated with disseminated gold. The results will help provide a unique look at the resource potential of covered parts of much of the Western United States and outline exciting new areas for further mineral exploration and research.

Digital Geologic Data Sets: The Example of the Quebec–Maine–Gulf of Maine Global Geoscience Transect

By David B. Stewart

Although many kinds of geologic data currently exist in digital form, and numerous techniques have been used to digitize and display them, there is no standard format and attribute-coding scheme. Generally, digital data have been generated to fulfill the requirements of a specific research effort, without being designed for other applications. Thus, the digital data may be difficult for others to access and to apply to different problems or research efforts. A generic digital format for geologic data that can be supported widely by geological organizations such as the USGS and by software vendors would enable digitized data to be readily distributed and used throughout the geological community.

The Quebec–Maine–Gulf of Maine Global Geoscience Transect (fig. 9) is one of a number of extensive regional transects being conducted under procedures established by the International Lithosphere Program of the Inter-Union Commission on the Lithosphere, established by the International Council of Scientific Unions. Geographic information systems technology is being used by a team of USGS, Geological Survey of Canada, Maine Geological Survey, and university researchers to digitize and display numerous geographic, geologic, and geophysical data sets and their derivatives for a transect 547 miles long, 61 miles wide, and 20 to 28 miles deep to the base of the Earth's crust in the region.

This transect runs from the stable interior platform of the continent near Quebec City, Quebec, across the complex Paleozoic Appalachian orogen, which was split by continental rifting in the Mesozoic (165 million years ago) to form the Atlantic Ocean, and reaches the ocean basin south of Georges Bank. The data set for this large area consists of samples of data for the United States and Canada that have different reference bases and projections. It includes parts of several different geologic maps and combines terrestrial and marine data of numerous types. Therefore, the data present the opportunity to develop and apply a generic digital format to display and analyze a complex regional problem. Because this transect has been so successful, it will be a useful prototype for other large regional geologic syntheses underway within the USGS, in other governmental agencies, and around the world in the Global Geoscience Transect project.

The Digital Line Graph (DLG) format developed by the USGS for planimetric data was extended to be a prototype for a standard DLG to describe the geologic data for this transect. The prototype standard DLG coding scheme that was developed can be readily edited or extended, can be used to prepare colored geologic maps, cross sections, and three-dimensional models for publication, and may be widely applicable to other regional geologic problems or transects.

More than 300 formations and hundreds of plutonic rock masses have been successfully represented and can be readily displayed at any scale.

The coding scheme provides a mechanism for describing geological data such as age, composition, rock type, tectonic setting, the formal or informal name of the rocks, and map color and pattern, by attaching numeric attributes to the digital data. The three-digit major codes and four-digit minor codes used are compatible with the USGS planimetric DLG and are based on widely used conventions for naming rock units.

This data set...will stimulate novel interpretations of the processes that affected the crust of this region.

To create the digital data, geologic maps of Maine and Quebec on stable base materials were machine-scanned to capture geographic boundaries, bedrock geology, and major hydrographic features such as large lakes and streams, shorelines, and offshore islands. A draft map of the Gulf of Maine was digitized by hand. The standard planimetric DLG codes were applied to the hydrographic and geographic data.

Because the standard scale for Global Geoscience Transects is 1:1,000,000, only linear geologic features such as contacts and faults were shown in addition to the areas (polygons) of mapped units. A major and minor attribute code was assigned to each linear feature; different kinds of faults were assigned different codes on the basis of the node-to-node direction of the line (arc) so that symbols identifying the type of fault are shown only on the appropriate side of each fault line.

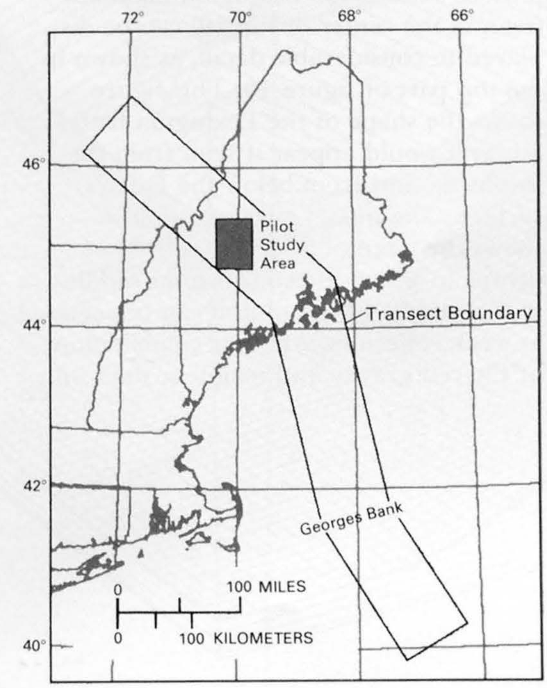


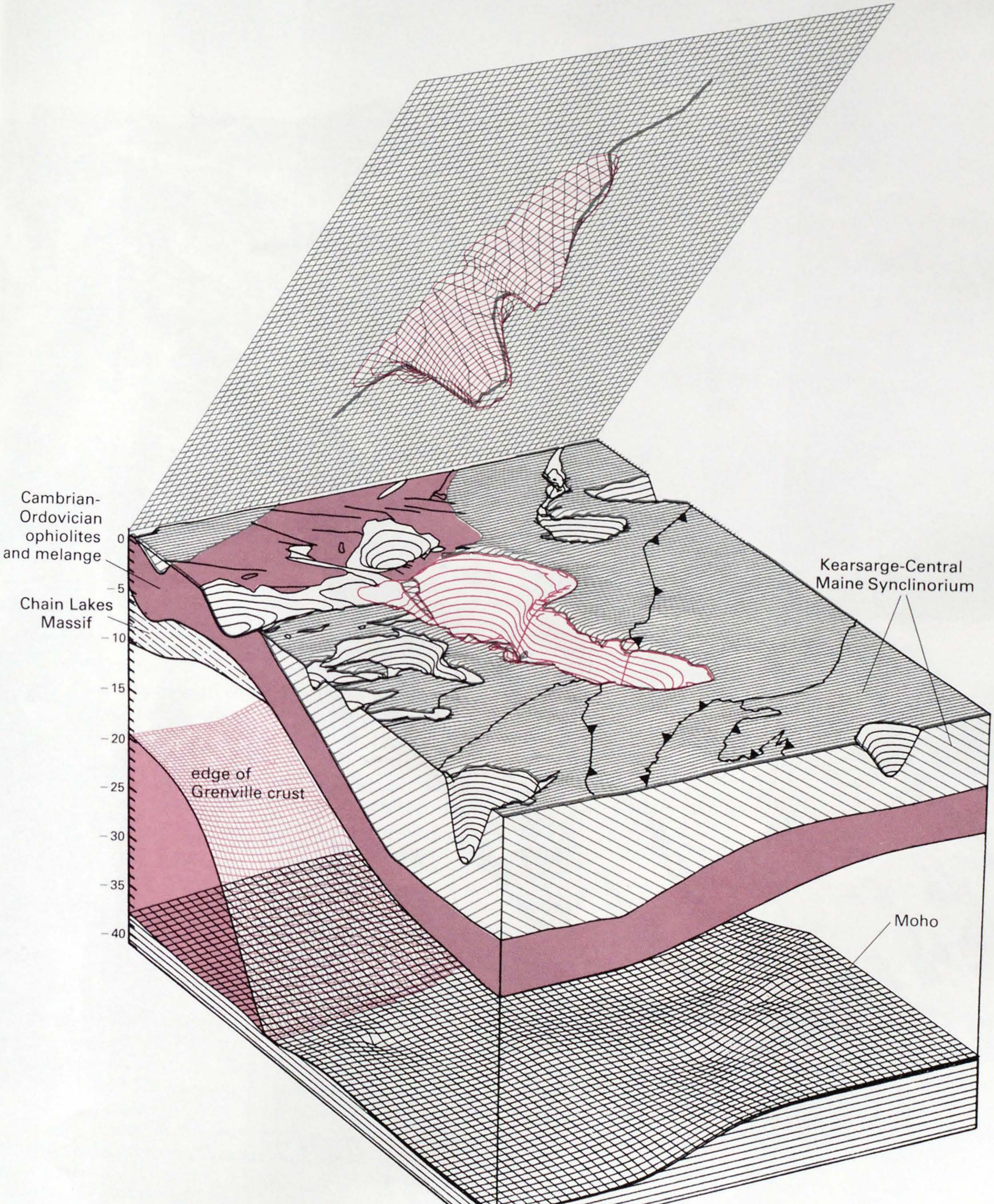
Figure 9. Index map showing the location of the Quebec-Maine-Gulf of Maine transect and the pilot study area.

After being digitized, the various geologic maps were merged, which required substantial amounts of editing to match up the geologic contacts. Nonetheless, more than 300 formations and hundreds of plutonic rock masses have been successfully represented and can be readily displayed at any scale. They can also be selectively sorted and edited by using widely available software and hardware. Because this data set exists in a generic DLG format, it can be sampled, subdivided, and transferred electronically to networked computers that combine geologic, geographic, and geophysical data in new ways to show unprecedented details about the Earth's crust, which will stimulate novel interpretations of the processes that affected the crust of this region.

An example of a computer-generated three-dimensional model of the Earth's crust is shown in figure 10. It was created from digital data sets. The digital geological data were generalized and are shown draped on a digital elevation model of the topography of the region. The shapes of granitic and gabbro plutons (massive bodies of intruded rock), as determined by gravity models for the regional gravity data and measured densities of field samples, are shown in the model as cavities with depth contours at 0.6-mile (1-kilometer) intervals. The modelled shapes of individual plutons such as the Lexington batholith (seen in the center of fig. 10) can be displayed in considerable detail, as shown in the top part of figure 10. This figure shows the shape of the Lexington batholith as it would appear if seen from the southwest and from below the Earth's surface. The model in figure 10 also shows the trace of a seismic reflection profile in which the conspicuous saddle in the middle of the pluton can be seen as weak reflectors. Another combination of filtered gravity and magnetic data with intermediate wavelengths was used to model the shape of this pluton, and the results were consistent with the model shown in figure 10. The availability of all these digitized data on a common base and in compatible formats enables ready comparisons to be made between diverse kinds of geological and geophysical data. Figure 10 also shows the approximate shape of the Kearsarge-Central Maine (Merrimack) synclinorium, the base of Cambrian to Ordovician (approximately 540 to 485 million years old) ophiolite and melange assemblages and the underlying Chain Lakes massif of Precambrian age (more than 570 million years old), the southeastern edge of Grenville-type crust (more than 880 million years old), and the base of the Earth's crust (Moho), all inferred from, and constrained by, digital seismic reflection and refraction data. Because the surfaces shown in this model are all digitized, a geological cross section through the model can be drawn quickly in any direction.

Work on the Quebec–Maine–Gulf of Maine transect has demonstrated the ability to make compatible and transferable many large geographic, geologic, and geophysical data sets. A key component of this effort was the development of a widely applicable DLG code for geologic maps to describe rock names, ages, lithologies, compositions, structures, tectonic setting of deposition, and linear map features, such as faults and contacts. The DLG codes, which are compatible with the standard planimetric DLG in use by the USGS, can be considered for use as a prototype for a geologic standard. Unquestionably, further development of this code for geologic point data (such as strike and dip measurements) and for surficial deposits is required, but that is believed to be readily achievable. Thus, progress toward the development of a standard digital code that could result in mapping uniformity and compatibility in geoscience mapping has begun.

Figure 10. *Three-dimensional model of region near Lexington batholith (bottom) and of Lexington batholith seen from below. Route of seismic reflection profile shown by heavy black line crossing batholith in top part of figure.* ▶



Cambrian-Ordovician ophiolites and melange
Chain Lakes Massif
0
-5
-10
-15
-20
-25
-30
-35
-40
edge of Grenville crust
Kearsarge-Central Maine Synclinorium
Moho

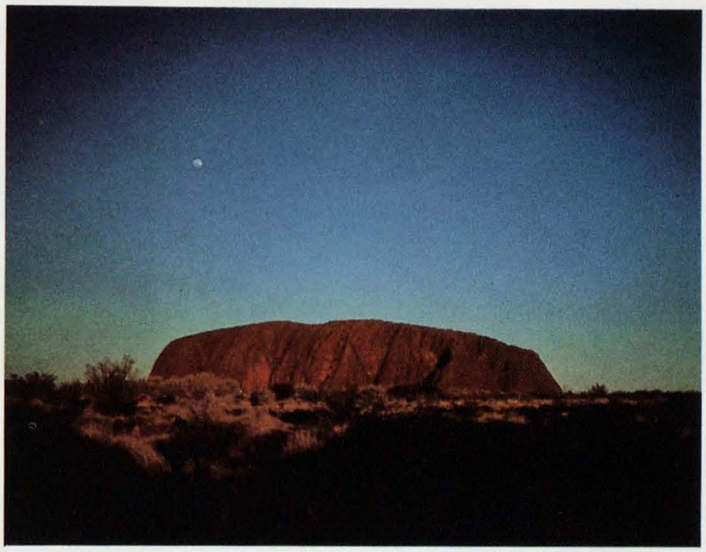
International Activities

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 fiscal year 1988. Authorization for the 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 annually appropriated 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 focusing on a variety of scientific phenomena.



(Facing page) North face of Mount Everest. (Photograph by Judy Fierstein.) (Above) Ayers Rock, Australia. (Photograph by Jean Weaver.)

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. One example of such representation is evident in the many hours of effort provided by the USGS, 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.

Highlights

International Decade for Natural Disaster Reduction

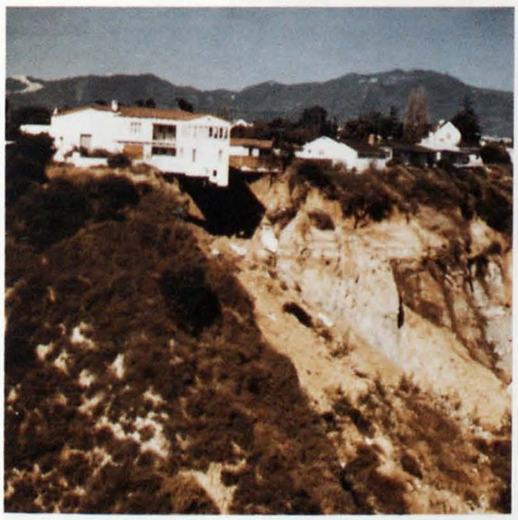
By Walter W. Hays

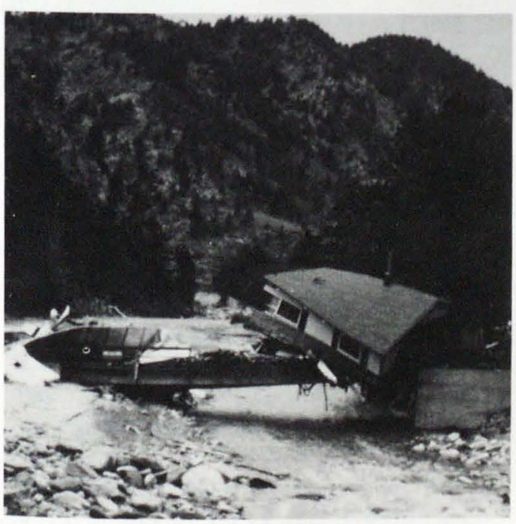
Background

Throughout history, humanity has found itself in conflict with naturally occurring events of geologic, hydrologic, and atmospheric origin. This conflict has been demonstrated repeatedly when people build urban centers at the water's edge, in or near active fault systems capable of generating earthquakes, on steep slopes, near active volcanoes, or at the urban-wilderness interface prone to wildfires. Naturally occurring, recurrent events such as floods, windstorms, tsunamis, earthquakes, landslides, volcanic eruptions, and wildfires have tested human-engineered works many times and have often found them unable to withstand the forces generated by the event. In the past 20 years, for example, events like these throughout the world have claimed more than 2.8 million lives and adversely affected 820 million people; single disasters have caused economic losses of billions of dollars. Industrialized countries like the United States and Japan have been able to absorb the socioeconomic losses of past natural disasters, but the economies of many developing countries have been devastated by losses equal to a large percentage of their gross national product (GNP). Furthermore, the magnitude of the losses is increasing at a rapid rate as the building wealth of nations is expanded to meet the needs of rapidly increasing population, often without adequate consideration of the potential threat posed by the recurrent natural hazards, and without implementing effective loss-reduction measures because of lack of knowledge or lack of technical capability.

A Decade for Disaster Reduction

In July 1984, at the Eighth World Conference on Earthquake Engineering in San Francisco, Dr. Frank Press, President of the U.S. National Academy of Sciences, proposed the concept of a decade devoted to the reduction of losses throughout the world from natural hazards that are characterized by their rapid onset and the potential for causing great sudden loss. Later, the slowly developing hazards of drought and desertification were added. In early 1987, a panel of experts was convened by the National Academy of Sciences to develop a conceptual framework for the decade (1990–2000). On December 1, 1987, the United Nations passed a resolution by unanimous consent, supporting the establishment of the International Decade for Natural Disaster Reduction (IDNDR) and encouraging all nations to cooperate in achieving the decade's primary goal—to devise strategies to reduce loss of life, property damage, and social and economic disruption from natural hazards. Since then, the United Nations organized, within the framework of IDNDR, a committee of 25 international experts drawn from all over the world to advise them in their strategic planning for IDNDR. This committee met on July 5–6, 1988, in Geneva, Switzerland, and again on October 3–6, 1988, in New York City. Meetings in Morocco (January 1989) and Japan (April 1989) will complete the committee's activities to plan strategies for cooperative worldwide endeavors in collection, dissemination, and application of existing knowledge in loss reduction measures; identification of gaps in





(Clockwise from lower left) Wrecked house and other debris including a mobile home lodged on a damaged bridge 0.5 mile downstream from Drake, Colo., following a flash flood of the Big Thompson River in August 1976. Sliding of unstable earth materials undermined this canyon rim on a coastal terrace in the Pacific Palisades area of southern California; annual losses from landslides reach $2 billion per year. Yellowstone, Wyoming, on August 28, 1988. The North Fork wildfire is in the background. The convection column reached 50,000 feet. (Photograph by Bob Gayle, U.S. Forest Service.) Lava shoots 1,000 feet into the air during a high-fountaining episode of the 1983-to-present Pu'u 'O'o eruption of Kilauea Volcano. (Photograph by J.D. Griggs.) A lahar (mud flow triggered by the melting of snow and ice) in the May 18, 1980, eruption of Mount St. Helens reached the Toutle River, 25 miles west-northwest of the crater, destroying homes.

(Clockwise from top left) Two wings of the Nueva Leon apartment complex containing 400 apartments overturned during the Mexico City earthquake of September 19, 1985. An estimated 10,000 to 20,000 people were killed in the earthquake, and economic losses reached $6 billion. This 9-story apartment house in Leninakan was damaged beyond repair by the December 7, 1988, earthquake in the Soviet Republic of Armenia. View of Madison Canyon landslide in southwestern Montana. Rocks from the mountaintop dropped about 1,300 feet and reached a speed of about 100 miles per hour following the 1959 Hebgen Lake earthquake. Twenty-six people were buried by the landslide. This furniture factory in Leninakan was extensively damaged by the Armenian earthquake. At least 150 people were killed in this building alone; the death toll for this earthquake is estimated to be 25,000.

knowledge and initiation of new research to fill them; acceleration of continuing research that can yield additional insight into the physical processes of natural disasters; and transfer of technology.

Role of the U.S. Geological Survey

The USGS will have an opportunity to contribute substantially to the goals of IDNDR through the participation of the United States in the Decade for Natural Disaster Reduction. National research programs of the USGS are designed to improve physical understanding of the mechanisms, to map the spatial and temporal distribution of the expected physical effects, and to foster the creation and implementation of loss-reduction measures to mitigate the physical effects of earthquakes, landslides, volcanic eruptions, floods, and, to a lesser extent, tsunamis. The USGS has considerable experience in mobilizing people and equipment following earthquakes, volcanic eruptions, and landslides. The USGS has organized, convened, and contributed to hundreds of workshops, conferences, and training activities on geologic and hydrologic hazards in the United States and throughout the world; it has also contributed substantially throughout the world to model building codes, microzonation strategies, and preparedness planning.

Many types of hazard maps are produced through USGS programs. In the United States, flood-hazard maps are constructed to quantify the threat from the approximately 6 million miles of riverine watershed and more than 6 million dwellings and nonresidential buildings located in flood plains. All States are at risk from flooding, precipitation, snow melt, thunderstorms, tornadoes, and the storm surges generated in hurricanes. Ground-shaking and ground-failure hazard maps are constructed to depict the primary hazards expected from earthquakes occurring in the approximately 150 zones capable of generating earthquakes throughout the Nation. No State is free from these two earthquake hazards, although the frequency of damaging earthquakes is much greater in Alaska and California than in the remainder of the Nation. Landslides occur in all the States and Territories; California, Alaska, Utah, Kentucky, West Virginia, Tennessee, Puerto Rico, Ohio, Washington, and American Samoa have the most extensive landslide problems. Parts of Alaska, Hawaii, Washington, Oregon, Idaho, California, Nevada, Utah, Arizona, and New Mexico are at risk from the effects of potential volcanic eruptions. Damaging tsunamis in the past have struck Hawaii, Alaska, Washington, Oregon, California, Puerto Rico, and the Virgin Islands.

Hazard maps are an integral part of loss-reduction strategies implemented by State and local governments. They contribute to a wide range of risk management strategies, such as

- Prevention—Controlling the source of the event in a way that changes the physical characteristics of the physical phenomena generated in the event.
- Protection—Building structures to withstand the physical phenomena generated in the event.
- Land-use control—Identifying and avoiding sites where an event is expected to have the greatest severity.
- Site modification—Modifying the physical characteristics at the site of man's works in order to increase the likelihood of survival in an event.
- Alert and warning—Providing advance notice to the affected population on the location, severity, and time of an impending event.
- Short-term protection—In response to an alert or warning, performing actions to strengthen existing structures and lifeline systems so that they will be able to withstand an impending event.
- Emergency preparedness—Making comprehensive plans to deal with the entire spectrum of expected requirements from an event.
- Indemnification—Spreading the potential economic losses from an event over a large population through insurance and other financial strategies.
- Recovery planning—Making plans to accelerate the recovery process after a disaster-generating event.

People throughout the world stand to receive considerable benefit from the IDNDR. As we cooperatively learn more and share that knowledge through the IDNDR, we can be more effective in reducing losses from natural hazards worldwide.

The China Digital Seismograph Network

By Jon R. Peterson

Introduction

Long earthquake histories in both countries prompted the United States and China to develop the means by which to cooperatively study earthquakes and seek ways to mitigate their effects. In 1980 the State Seismological Bureau (SSB) of the People's Republic of China, the U.S. Geological Survey, and the National Science Foundation signed the Earthquake Studies Protocol that initiated research programs to benefit the earthquake hazards reduction program in both nations. In October 1987, a panel of experts was convened in the People's Republic of China (PRC) to review the project, a policy required by the PRC Government to insure that design goals have been met. The panel, which included seismologists from France, Norway, and West Germany as well as the United States and China, visited facilities in Beijing, Lanzhou, and Shanghai.

During China's long history, earthquakes have repeatedly destroyed major urban areas. According to the SSB, in the 20th century, 104 earthquakes of magnitude 7 or larger have stricken 21 of the 30 Chinese administrative provinces, autonomous regions, and municipalities. In the past 37 years, earthquakes in China have killed 237,000 people and injured 763,000 others. In comparison, there have been 20 earthquakes of magnitude 7 or greater in the United States in this century, causing 1,380 deaths and more than $5 billion in property damage.

High-quality observational data are essential to earthquake studies. Thus, a high priority in planning cooperative activities was the modernization of data acquisition systems in China. Their purpose is twofold: to provide high-quality digital data for investigations of earthquakes in China and to supplement the data collected from the global seismograph network for the use of research scientists throughout the world. The global seismograph network operated by the U.S. Geological Survey comprises stations in more than 60 countries and islands and is the major source of freely exchanged seismological data. Extending the global network into China has long been an important goal of the scientific community.

Discussions between the USGS and the SSB led to an agreement-in-principle, signed in May 1983, to cooperatively establish the China Digital Seismograph Network (CDSN). Funding for the network was provided by the SSB and, in this country, by the USGS and the Defense Advanced Research Projects Agency. The task of implementing the cooperative agreement was assigned in China to the SSB Institute of Geophysics and in the United States to the USGS Seismological Laboratory in Albuquerque, N. Mex. Work on the CDSN began soon after the agreement was signed and was completed three and one-half years later. The network was operated for a one-year trial period then officially accepted and inaugurated in October 1987. The CDSN is an important cooperative effort that was highlighted as a "success story" by the U.S.–PRC Joint Commission on Science and Technology. It is one of many projects in recent years that have brought American and Chinese scientists and engineers together for the benefit of both nations.

Network Plan

The CDSN was planned as a national network consisting of nine digital seismograph stations, a data management center, and a network maintenance center. The USGS agreed to design and develop the seismograph systems and to provide equipment for four of the stations, software for the data management system, parts and equipment for the network maintenance center, and training for Chinese engineers and technicians. The SSB agreed to provide equipment for five of the stations and hardware for the data management center, prepare all of the sites, and operate the network. Responsibility for assembly and installation of the equipment was shared.

The four U.S.-supplied seismograph systems were installed at Baijatuan (near Beijing), Kunming, Mudanjiang, and

Lanzhou; the five PRC-supplied seismograph systems were installed at Enshi, Hailar, Sheshan, Qiongzhong, and Urumqi. The data management and network maintenance centers were both installed in Beijing.

All of the new station equipment was installed at observatories that have been operated as part of the China national network. Thus, experienced personnel were available to assist with the installation and operation of the instruments. Data are recorded at the stations on high-density tape cartridges that are replaced at two-week intervals. The station tapes and operator logs are then sent by mail or other means to the data management center located in Beijing.

The functions of the data management center are to collect the network tapes, examine the quality of the data, assemble network-day tapes, and archive the data. A network-day tape contains the data from all stations in the network for a specific Julian day (the Julian Calendar is a numerical calendar system that operates from day 1 through day 365 beginning on January 1), which is a much more convenient form than station tapes for data users. The day tapes are the most important products of the center and are distributed to research scientists and other organizations.

Network Instrumentation

The type of digital seismograph system installed in China consists of seismometers that produce electrical signals in proportion to Earth motion, digital encoders that sample and convert the signals to a stream of digital words, and tape cartridges or other media used for recording the data. Other critical components include a clock so that the earthquake signals can be accurately timed, a radio to synchronize the clock to transmitted timing signals, a calibrator used to check the sensitivity of the seismometers, visual drum recorders to display signals at the station, a terminal for the operator, a microcomputer to control the data processing, and a backup power system that keeps the equipment operating if line power fails.

Seismograph systems have improved dramatically during the past decade. New broadband force-balance seismometers produce usable signals over a frequency bandwidth from 0.00002 Hz to 10 Hz, a range sufficient for recording diurnal solid Earth tides, free oscillations of the Earth, long-period surface waves, and short-period body waves, all in a single channel of data. The dynamic recording range of a seismograph has been extended as well. Dynamic recording range is the ratio of the largest signal that can be recorded to the smallest signal that can be detected. The typical drum type recorder used for many years to record earthquakes has a width of about 300 millimeters and a resolution of about 0.5 millimeter, so its dynamic range is 600 to 1 (assuming that the pen or light beam can travel the full width of the recorder). In contrast, the dynamic range achieved in digital recording is now approaching 10,000,000 to 1. To match this, a drum recorder would have to be several kilometers wide. The much greater bandwidth and dynamic range of modern seismographs permits seismologists to use more powerful analytical techniques, especially in the study of earthquake source mechanisms and Earth structure.

The CDSN seismograph system has six seismometers: three of these are broadband seismometers, configured as one vertical and two horizontal components to sense Earth motion in all directions, and the other three are short-period seismometers, also operated in a triaxial configuration. The seismometers are usually installed in underground vaults, although in the CDSN a few are installed in 100-meter boreholes to avoid

Personnel processing station tapes at the China Digital Seismic Network. (Photograph by John P. Hoffman.)

surface noise. The seismometer signals are filtered, digitized, and formatted, then recorded on high-density tape cartridges together with a time code and other information needed to process the data. Long-period and very-long-period signals derived from the broadband signals are recorded continuously; broadband and short-period signals are recorded in a triggered mode, that is, only when an earthquake signal is detected by an automatic signal detector in the microcomputer.

The data management center is equipped with a minicomputer, several tape drives and disk drives, and a variety of terminals and plotters used to display and monitor the station data as the tapes are being processed. Much of the time and effort expended on the assembly of the data management system went into the development of the highly specialized application software needed for its operation. The design of the data management center was modeled on the data collection center at the USGS Albuquerque Seismological Laboratory, which is used to process data from the global seismograph network.

The network maintenance center, which is located next to the data management center, is equipped with a complete seismograph system used for testing and training, a wide range of test equipment needed to diagnose and repair electronic boards, and a large stock of spare parts and boards. One program objective has been to make the CDSN as self-sustaining and self-sufficient as possible. This objective has been successfully met; only a few electronic boards and components have been returned to the United States for repair.

Network Deployment

Because of the desire of the Chinese to participate in design and assembly of the CDSN systems, the decision was made to develop and assemble the CDSN systems at the Albuquerque Seismological Laboratory. Most of the equipment for the stations was purchased during 1984 and 1985. Eleven data systems were assembled: nine for the network stations, one for the network maintenance center, and one to remain at the Albuquerque Laboratory to serve as a test bed for future hardware and software changes. Development of data management system hardware and software was completed in late 1985, and the assembly and testing of the data systems were completed in early 1986.

As equipment was being assembled in the United States, the stations were being prepared in China under the supervision of the Institute of Geophysics. Modifications were needed at most of the stations to support the new equipment. At some stations it was necessary to construct roads and new power facilities; most needed backup generators and air conditioning. Boreholes were drilled and cased at two of the stations to accommodate special borehole seismometers. New facilities were also needed to house the data management and network maintenance centers.

Extending the global network into China has long been an important goal of the scientific community.

Because training is the key to successful, self-sustained operation of the network, Chinese engineers and technicians have spent a total of 4 months at Albuquerque in two training programs, and in China there have been training programs for the station operators. The training has been especially effective because of the intense interest and dedication shown by the Chinese in this program.

The first station equipment was installed at Baijatuan in February 1986 to be used as a demonstration and training system. In May 1986, USGS and Chinese personnel began deploying equipment at the remaining eight sites. During an 8-week period, the installation team made a complete circuit of China installing the station equipment.

Installation of the data management system took place in February with additional work in June 1986. The first network-day tapes were assembled on

October 1, 1986; this is considered to be the date when the network became operational and at which the one-year trial period began.

Results and Conclusions

The panel of experts that met in China in October 1987 to review the CDSN project expressed their evaluation of the project's success as follows:

> The CDSN represents a unique contribution to seismology. It will provide new data of fundamental importance to the study of earthquake activity in China. The data will enable scientists to obtain fundamental new insight in the structure of the crust and upper mantle. Furthermore, the CDSN will be a key contribution from China to the international network of digital seismic stations and will thus be instrumental in a wide variety of studies making use of global seismic data.

Since its inauguration, the CDSN has consistently produced reliable, high-quality earthquake data that are being used for a variety of research applications in China, the United States, and many other countries that share the data. Information from the network is providing a new look at the structure and composition of the crust of eastern Asia. It also will be useful in determining the geological evolution of the Tibetan plateau and in studying the collision boundary of the Indian and Asian crustal plates. Yet the establishment of the CDSN is a milestone, not a final objective. Plans are already being made to expand the network into southwest China. Experiments are being planned for telemetering data from the stations to Beijing by satellite, and there are plans to continue updating the technology to insure that the CDSN remains a state-of-the-art scientific facility.

The deployment of the CDSN has been a particularly rewarding experience for those who were fortunate enough to take part in the project. The Chinese, Americans, and one New Zealander worked together to solve a myriad of technical and logistical problems while striving to learn and appreciate each other's customs and cultures—they were successful in both endeavors.

U.S.–Canada Border Mapping Using Digital Cartographic Techniques

By Hedy J. Rossmeissl

An official series of U.S.–Canada border maps was published for the International Boundary Commission (IBC) between 1900 and 1930. The maps were prepared at various scales, depending on the detail and complexity of the information along the border. Because of the age and information content of this original series of maps, the IBC expressed an interest in obtaining a new, updated series of maps.

The U.S. Commission of the IBC provided funding to the U.S. Geological Survey for a cost-share border digital demonstration project. Officials of the USGS and Canada's Department of Energy, Mines and Resources agreed to produce a prototype border map as a derivative product from their established digital quadrangle mapping and data base programs. The IBC specified that graphic products should be produced for the series, that the international boundary line should be the focus of each map in the series, that each boundary monument and its designation should be shown, that the content of the new maps should be at least as detailed as the original boundary maps, and that the new maps should use standard topographic symbols.

Both countries use digital techniques, but they follow different procedures to collect cartographic information. Cartographers from each country addressed the technical challenges of establishing compatible standards, file formats, and coding schemes for the digital data and incorporating map design, symbology, and graphic specifications in order to generate a graphic product.

Each mapping agency collected the digital information for the pilot project from their standard topographic mapping series. For the United States, a 1:24,000-scale topographic map was used; for Canada, a 1:50,000-scale map was used. The test area chosen for the project covered a part of the border between New York, Ontario, and Quebec near Cornwall, Canada. Because each agency uses different data collection procedures, coding schemes, and data standards, one existing coding scheme was adopted to limit the translation process to only one agency's data set. The Canadian coding scheme was chosen because it accommodated the requirement of IBC to produce a graphic product.

The USGS developed computer programs and translation tables to convert its digital data to the Canadian format. After the translation was complete, the Canadian data set was integrated with the U.S. data set, and the map edges were checked for alignment accuracy between the two sets. The data were then prepared for graphic production and shipped to Canada, where 1:25,000- and 1:50,000-scale prototype maps were produced. The prototype maps were forwarded to the International Boundary Commission in April 1988 and are presently undergoing review.

The project provided the opportunity for both mapping agencies to use data collected from standard digital methods to produce derivative graphic products. Working together, the agencies successfully overcame several technical challenges such as solving data compatibility issues, translating data codes from one scheme to another, and presenting graphic data digitally.

Saudi Arabian Gold Investigations

By Arthur A. Bookstrom

The continued high price of gold on the international market, in contrast to depressed prices for many other mineral commodities, has prompted the Government of Saudi Arabia to put a high priority on gold exploration and development. Consequently, the USGS Saudi Arabian Mission, which provides support for cooperative U.S.-Saudi Arabian studies, is focusing its current gold investigations on exploration and evaluation of gold prospects thought to have economic potential, mapping and sampling of mineral belts known to contain gold occurrences, and reconnaissance to identify new prospects and gather preliminary information needed to establish priorities for further work.

The gold deposits of Saudi Arabia are hosted by late Precambrian (more than 570 million years old) rocks of the Arabian Shield in the western part of the Arabian Peninsula (fig. 1). The Arabian and Nubian Shields are large areas along the sides of the Red Sea, where Precambrian rocks are exposed in the eroded core of a broad uplift around the younger Red Sea rift. Sedimentary cover rocks, which host oil fields in the eastern part of the Arabian Peninsula and contain phosphate deposits in northern Saudi Arabia, have been uplifted, tilted back away from the Red Sea rift, and stripped by erosion from the Precambrian basement rocks of the Arabian Shield.

Regional geological work by USGS geologists shows that the Arabian Shield consists of at least five geologically distinct terranes, or microplates, that meet along four suture zones. Gold and copper deposits (some of the copper deposits also contain gold) tend to be concentrated in mineral belts, many of which are within or near these suture zones.

Most known gold occurrences in the Arabian shield show evidences of ancient mining activities (pits, trenches, stopes, dumps, grindstones, slag piles, and former village sites). The largest ancient mine known to date is at Mahd adh Dhahab in the central part of the shield. Gold is present in gold and silver tellurides and as native gold in this mine. Inscriptions on rocks and carbon-14 dating of charcoal in slag indicate mining at about 800 A.D. Older tailings are of unknown age but may date to about 1,000 B.C. Waste dumps indicate that miners of ancient times extracted about 700,000 ounces of gold. From 1939 to 1954, another 700,000 ounces of gold was extracted by the Saudi Arabian Mining Syndicate.

In 1972, a USGS geologist recognized the potential for a hidden orebody south of the existing workings at Mahd adh Dhahab. Four core holes were drilled to test geochemical anomalies in the geologically favorable area. The first three holes revealed no significant mineralization, but the fourth hole hit high-grade ore, containing as much as 60 grams of gold per ton of ore. After additional drilling, USGS geologists estimated a possible resource of 1.1 million tons, with an average grade of 27 grams of gold and 73 grams of silver per ton of ore. When subsequent drilling confirmed the USGS results, the orebody was put into production.

After the success at Mahd adh Dhahab, during the late 1970's, emphasis shifted toward complete geological mapping of the Arabian Shield, as a basis for future minerals exploration and development. In addition to mapping, the USGS explored for copper, zinc, gold, silver, tin, tungsten, and nickel and carried out topical studies on the geochronology and petrology of the felsic plutonic rocks of Saudi Arabia. These previous studies provide the background for current USGS efforts in gold exploration.

Gold prospects now being explored and evaluated are in the Jabal Ishmas–Wadi Tathlith gold belt, a regional concentration of gold occurrences that lies within a suture zone in the southeastern part of the Arabian Shield. Current projects are at the Farah Garan ancient mine and in the Farah Garan–Kutam and Halahila mineral belts, in the southeastern corner of the Arabian Shield, and at Ishmas Kabir and B'ir Jarbuah about 200 miles north of Halahila.

At Farah Garan, the host rocks contain finely laminated to massive sulfides of iron, copper, and zinc, along with minor amounts of arsenic, gold, and sil-

Figure 1. Locations of ancient gold mines discussed in text that are now being reexamined.

ver. The gold-bearing deposits of Farah Garan are similar to those of Al Masane to the north, where mineable reserves of copper-zinc-gold-silver ore are awaiting production. The current work at Farah Garan follows the discovery of significant amounts of gold (8.7 grams per ton over 8.6 meters) encountered during previous USGS drilling. Detailed geological, geochemical, and electromagnetotelluric geophysical surveys have been done as the basis for a five-hole core drilling program that is in progress. In addition, stream-sediment geochemical sampling and geological mapping are being done to explore a large area around Farah Garan for the presence of other deposits like Farah Garan and Al Masane.

The Ishmas Kabir ancient gold mine is located at the intersection of a suture zone with a younger strike-slip fault zone. The ancient mine is marked by sand-filled trenches surrounded by a row of mine dumps. Dump samples from the ancient workings show moderate grades (3 to 7 grams per ton). Four core holes, drilled to intersect the steeply dipping orebody at depth, showed that it pinches out and gold grades decrease with depth.

Although drilling results at Ishmas Kabir were negative, geological work in the area has revealed another, perhaps more promising, prospect at B'ir Jarbuah. The ancient mines of B'ir Jarbuah are in and along quartz veins and veinlets. Mapping, trenching, and sampling have revealed spotty, high-grade concentrations of visible native gold in some of the quartz veins and veinlets. The highest assay reported was 163 grams per ton of gold over 7.1 meters. Further geological and geochemical work is planned to test the continuity and extent of the gold deposits of B'ir Jarbuah and the vicinity.

Reconnaissance to identify new prospects is being initiated with a review of known mineral belts and gold occurrences. The USGS library in Jeddah and the computerized Mineral Occurrence Documentation System (MODS), established during geologic mapping of the Arabian Shield, are the starting points for this work. In addition, satellite imagery will be used to help identify hydrothermally altered areas, and wadi-sediment geochemical surveys will be used to identify new prospects in promising areas. Emphasis will be placed on the search for near-surface, bulk-mineable, and heap-leachable gold deposits, which can now be economically mined to very low grades and which may have been missed by the ancients. One deposit of that type has recently been discovered in Saudi Arabia, and the chances are good that others remain to be found.

Mineral Resource Investigations in Venezuela

By Norman Page, Jeff Wynn, and Gary Sidder

In late 1987, a technical assistance project, supported financially by Corporacion Venezolana de Guayana, was initiated between the U.S. Geological Survey (USGS) and Tecnica Minera (TECMIN), which is part of the Corporacion, to investigate the mineral resources of the Guayana shield, in Venezuela.

The shield consists of largely unexplored areas of Precambrian (more than 570 million years old) volcanic, granitic, and sedimentary rocks that are possible hosts of undiscovered mineral deposits containing one or more of the following commodities: gold, diamonds, bauxite, iron, manganese, chromium, titanium, copper, lead, zinc, tin, rare-earth elements, nickel, and platinum-group elements. In general, the shield in eastern Venezuela is composed of thick sequences of low-grade metavolcanic and metasedimentary rocks, basalt, tuff, and other pyroclastic rocks, which are intruded locally by ultramafic and gabbroic rocks. To the west and south, flows, tuffs, breccias, and subvolcanic and plutonic granite are notably unmetamorphosed but do contain local areas of contact metamorphism and hydrothermal alteration.

TECMIN is charged with exploring the shield area and identifying undiscovered and undeveloped ore deposits; two groups of personnel, each using different techniques, are employed. The Inventory Group examines the entire area of the

La Gran Sabana, Venezuela, near the Brazilian border. (Photograph by Jeff Wynn.)

shield by geoscience mapping and also describes the flora, fauna, and microclimate; the Exploration Group examines smaller areas of Government mineral concessions in detail. The USGS presently has two resident geoscientists, one associated with each group; as many as ten other USGS geoscientists work with the groups on temporary assignments of 1 to 3 months.

The visiting USGS scientists carried out field studies with their counterparts from the Exploration Group of TECMIN in ten concessions during fiscal year 1988. The major focus of these investigations was to explore for undiscovered gold deposits. Most of the concession areas are underlain by parts of greenstone belts containing volcanic and sedimentary rocks at low grades of metamorphism. Such conditions are permissive for gold deposits of the low sulfide-gold-quartz vein type and the exhalative (gaseous volcanic emissions) type, and possi-

Location of the part of the Guayana Shield (in red) that is in Venezuela.

bly also for massive sulfide deposits. One area contains gold-quartz-carbonate veins and possible chromite deposits. Other areas were evaluated for potential mineralization associated with intrusive dikes, felsic volcanic rocks including ash-flow tuffs, and placer diamond-gold deposits. At least two new prospective areas containing gold-quartz-carbonate veins were identified. Recommendations also were made to discontinue exploration efforts in two areas.

To improve the technology for mineral resource assessment and exploration in Venezuela, the facilities for preparing and analyzing samples are being upgraded. At the same time, training in handling, preparing, and analyzing samples has begun. The Exploration Group of TECMIN also assesses the available geophysical information, both airborne and ground data. Aeromagnetic data for several concession areas were examined, and preliminary interpretations were made, to be verified during field work.

The Inventory Group examined areas drained by the Caura and Paragua Rivers in the south-central part of the shield. Besides various types of sandstones, much of the area appears to be underlain by felsic volcanic rocks including welded ash-flow tuffs. Gabbroic, diabasic, and granitic intrusive rocks also appear to be major components. Evidence for mineralization, including copper and tin minerals, alteration products, and visible gold, was observed at several localities. The geologic field observations are integrated with the interpretations of the geology made from photographic and side-looking airborne radar (SLAR) images in an attempt to locate areas where mineral deposits may be present.

Training activities by the USGS, both in the field and laboratory and through teaching of short courses, form an important part of the project. Short courses on mineral deposit modeling, mineral resource assessment techniques, and digital geologic map preparation systems were presented to counterpart geoscientists. The courses have contributed to increasing the number of Venezuelan geologists who can recognize the types of rocks and geologic environments that may host a broad range of different types of mineralization.

Antarctic Mapping—Thirty Years Since the International Geophysical Year

By Frederick S. Brownworth

The U.S. Geological Survey first participated in Antarctic surveying and mapping activities in 1957–58, when William H. Chapman, a USGS cartographer, traveled to Antarctica to take part in the International Geophysical Year program effort in the Ronne Ice Shelf-Filchner Ice Shelf area. The following year, in 1958–59, Chapman wintered over at Byrd Station and subsequently established geodetic control for the Survey's first three Antarctic mapping projects: the Horlick Mountains, the Whitmore Mountains, and the Executive Committee Range. Since then, 30 employees have wintered over, principally at the South Pole Station, and 91 employees have participated in 136 summer assignments, either conducting geodetic field survey operations or acquiring aerial photography for future mapping programs.

Early Reconnaissance Mapping

In 1959–60, the USGS began a major program to prepare topographic reconnaissance map coverage at 1:250,000 scale for the unmapped and largely unexplored coastal regions and rock outcrop areas of western Antarctica. The plan was to provide base maps to support scientific research programs, aerial reconnaissance activities, geologic field investigations, and thematic mapping. Today, 30 years later, 91 topographic maps have been published that provide coverage for the Transantarctic Mountains from Cape Adare to the Shackleton Range, Marie Byrd Land, the Ellsworth Mountains, the Pensacola Mountains, and the Executive Committee Range. The USGS has recently resumed the compilation of nineteen 1:250,000-scale maps in the southern Antarctic

Two USGS cartographers conduct surveys in support of ice-movement studies. In the background, Mount Erebus, an active volcano, rises 12,447 feet above nearby McMurdo Sound.

Peninsula areas and along the coast westward to Thurston Island. Twenty-three published sheets are being revised to show recently established geodetic control stations, U.S. Board on Geographic Names place-name additions, new Antarctic Treaty nations' research stations, and the boundaries of Specially Protected Areas and Sites of Special Scientific Interest.

Large-Scale Topographic Mapping

In December 1970, the USGS began 15-minute topographic quadrangle mapping at 1:50,000 scale. The first project consisted of eight quadrangles covering the Taylor and Wright Valleys in the Dry Valleys area of northern Victoria Land. More recently, in March 1988, a mapping requirements meeting was held to identify future needs. These new requirements include 1:50,000-scale topographic mapping for selected areas within the Freyberg Mountains, Queen Alexandra Range, Ellsworth Mountains, and Pensacola Mountains, to support geologic studies, and portions of the Dry Valleys area, to support detailed glaciological investigations.

Geodesy

USGS cartographers first wintered over at the old South Pole Station in February 1973 in support of two projects, which are still active today. The first project, Doppler Satellite Tracking, was to collect data from U.S. Navy navigational satellites for geodetic and mapping purposes. The data are also used annually to reset the true geographic South Pole marker on the basis of Doppler ice-movement data. The second project was the Antarctic Seismic Project, a part of the Worldwide Standardized Seismograph Network. The data from this project are transmitted daily to the USGS National Earthquake Information Service to help locate earthquake hypocenters and pinpoint origin times.

The Survey's first practical field experience with Doppler satellite surveying technology was during the austral summer of 1971–72. This technology provided a means to upgrade and to add to the existing geodetic control network and to recompute the data on the 1972 earth-centered coordinate system. Plans for the future are to use the more advanced Global Positioning System and the 1984 coordinate system.

The USGS first obtained gravity data concurrent with the Doppler satellite observations with a La Coste-Romberg gravimeter in 1985–86 in the Beardmore Glacier area. During 1986–87, gravity data were collected in the Dry Valleys area; these data will be extended during 1988–89.

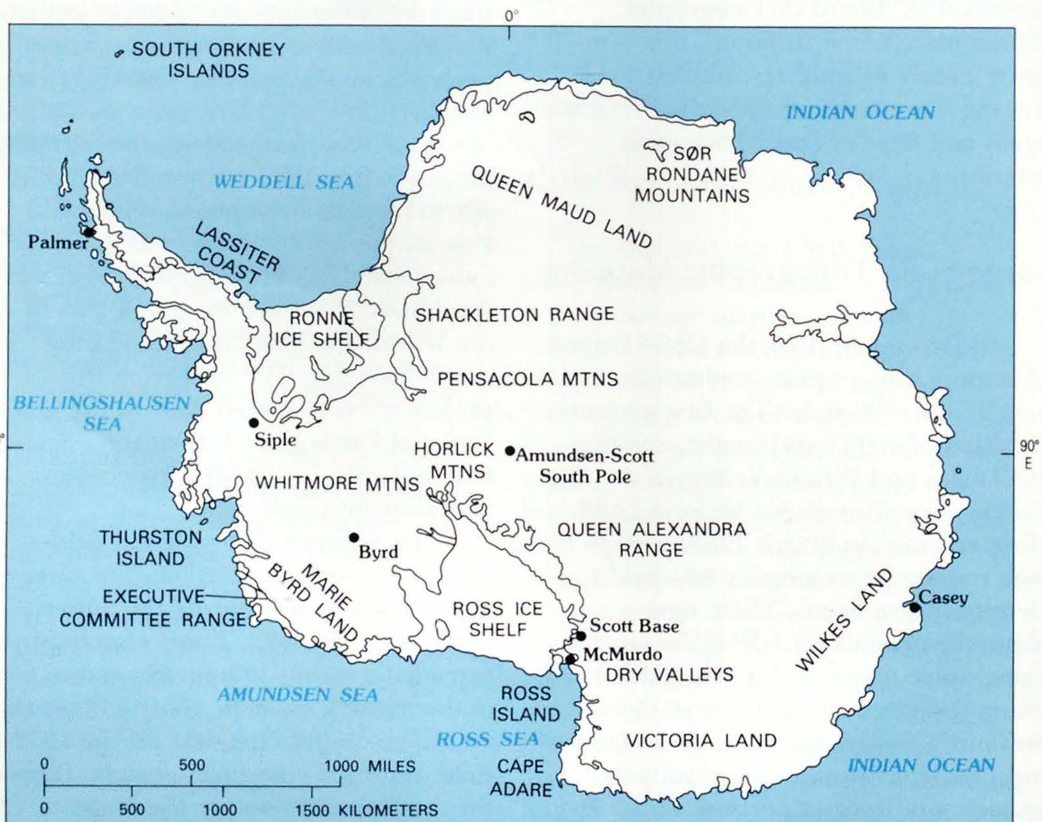
This imagery will be used. . .to assess any changes in the margin of Antarctic coastal features, which might reflect climatic change. . .

Aerial Photography

In 1960–61, the USGS began providing a photographic advisor to the U.S. Navy to assist in procuring mapping photography. During the following years, more than 1 million square kilometers of black-and-white coverage were acquired. Future aerial photographic requirements will most likely include larger scale (1:30,000) natural-color and color-infrared coverage to meet field investigators' needs as well as black-and-white panchromatic coverage to support large-scale topographic mapping.

Landsat Satellite Data

The USGS recognized in the early 1970's that Earth Resources Technology Satellite (now Landsat) imagery could make a unique contribution to Antarctic mapping and began a systematic effort to collect the image data. The data were used in the first image processing systems to prepare multispectral scanner image maps of large geographical areas, and five small-scale Landsat image maps of Antarctica were published. The USGS is now preparing digitally mosaicked and enhanced Landsat 1:250,000-scale, multicolored image maps for the Dry Valleys area and plans to prepare similar Land-



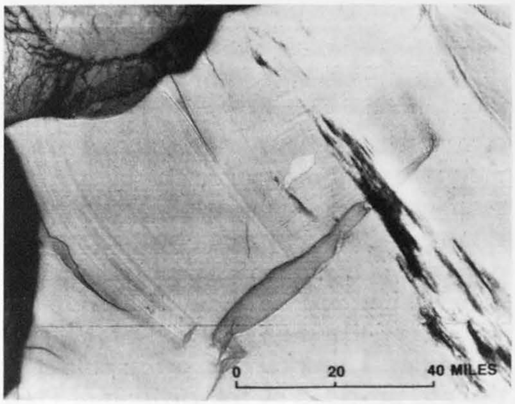
Location of selected stations and physical features in Antarctica.

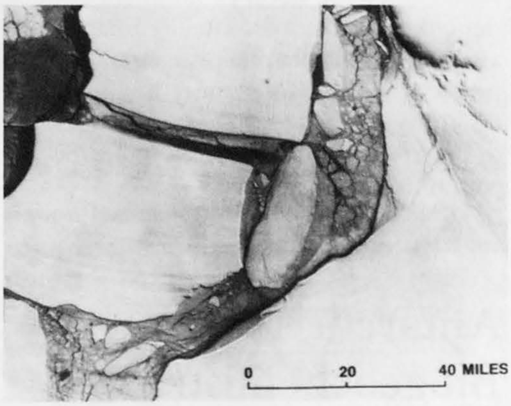
sat 1:250,000- and 1:100,000-scale image maps of the Siple Coast and experimental Systeme Probatoire d'Observation de la Terre (a French satellite) 1:50,000-scale image maps of selected areas.

In 1988–89, the USGS plans to acquire 150 Landsat Thematic Mapper scenes for the entire coastal area of the Antarctic continent. This imagery will be used for comparison with the Landsat multispectral scanner data of the early 1970's to assess any changes in the margin of Antarctic coastal features, which might reflect climatic change, and for other scientific applications.

Cooperative Programs

The USGS has cooperative programs with (1) the National Environmental Satellite, Data, and Information Service of the National Oceanic and Atmospheric Administration and the National Remote Sensing Centre of the United Kingdom Royal Aircraft Establishment, to prepare an Advanced Very High Resolution Radiometer digital data base and image map of Antarctica, (2) the National Aeronautics and Space Administration, to prepare Landsat image maps of the Siple Coast, and (3) the New Zealand Department of





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Atlas of Antarctic Glaciers

The first published chapter in an inventory of the world's glaciers being coordinated by the USGS focuses on Antarctica and provides scientists with a means to monitor changes in the margins of this icy continent that may be linked to climatic changes.

The satellite-image atlas of Antarctica is the first chapter in an 11-part series, "Satellite Image Atlas of Glaciers of the World," being produced by the USGS as Professional Paper 1386. Each chapter or subchapter is authored by one or more of the 50 scientists from 30 countries who have collaborated on the atlas project.

The enormous area of ice concentrated in the glaciers of Antarctica—about 5.3 million square miles, including about 91 percent of the total volume of glacier ice on Earth—influences the temperature, wind, and weather patterns over the entire Earth. Changes in the volume and dynamics of the ice sheet, therefore, may cause global climate changes. In turn, changes in the temperature of the planet can affect the volume and dynamics of the Antarctic ice sheet.

Certain glacier features are unique to the Antarctic. For example, nearly half of the coastline of Antarctica is fringed by "ice shelves," floating ice sheets that rise and fall with the tide. They are nourished partly by the seaward extension of land glaciers, partly by the accumulation of snow on their upper surface, and partly by bottom freezing. They are dissipated mainly by the calving of icebergs from their seaward edges.

Byrd Glacier in the Transantarctic Mountains is one of the largest valley glaciers in the world and possibly the most active glacier draining any part of the East Antarctic plateau. Byrd Glacier drains an area of 393,000 square miles, greater than any other glacier in the world. Flow features on its surface can be traced over a distance of 112 miles.

The accompanying figure shows two Landsat images acquired before (November 11, 1973) and after (October 18, 1986) a major calving event on the Filchner Ice Shelf. The size of the newly created icebergs totalled more than 4,000 square miles, or slightly less than the State of Connecticut.

Survey and Land Information, to prepare 15-minute, 1:50,000-scale topographic quadrangle maps.

Scientific Committee on Antarctic Research (SCAR) Library

The USGS houses and maintains the SCAR Library for the National Science Foundation at the USGS National Center in Reston, Va. The library serves as the repository and distribution point for all Antarctic photographic and cartographic materials produced by the United States and materials distributed by other SCAR nations. Plans in the near future are to reinventory the library's holdings of geodetic control records, satellite images, aerial photographs, maps, charts, and publications and to encode the information into a series of digital data bases to better serve the Antarctic scientific community.

Antarctic Lakes: Biogeochemistry of Dissolved Organic Material in Lakes in the Dry Valleys

By Diane M. McKnight

In temperate lakes and streams, dissolved organic material is derived both from the plants and soils of the surrounding watersheds and from the microscopic algae in the water and larger plants along the shores. This dissolved organic material is a heterogeneous mixture of organic compounds consisting largely of two classes of organic acids, fulvic acid and hydrophilic acid. These two organic acid fractions are geochemically and biologically reactive, and they significantly influence the chemistry and transport of many organic pollutants and trace-metal contaminants; they also hinder the proliferation of algae by absorbing the wavelengths of light required for growth. A long-term goal of the USGS organic-geochemistry researchers has been to understand the relationship between the sources of these acid classes and their chemical structure and reactivity. Dissolved organic material from many diverse aquatic environments has been isolated, characterized, and compared. A particularly important question is whether the dissolved organic material in the world's oceans, which is a significant global carbon reservoir, is derived chiefly from land-surface runoff or from marine plant life.

The permanently ice-covered lakes in the McMurdo dry valleys of southern Victoria Land in Antarctica provide an excellent opportunity to study this problem because their watersheds are extremely barren and have only a few isolated patches of moss as their vegetation. In contrast, abundant algal populations develop in the water column of the lakes during the austral (southern) summer, and algal mats cover the bottom sediments. During the 1987–88 austral summer, USGS research scientists conducted a field study of dissolved organic material and microbial populations in Lake Fryxell and Lake Hoare in the Taylor Valley. Logistical support in Antarctica was provided by the Division of Polar Programs of the National Science Foundation under the Biology and Medical Sciences Program. To obtain sufficient quantities of organic material, large volumes of lake and stream water (as much as 480 gallons) were filtered to remove particulate matter; the filtrate was collected in stainless steel milk cans and processed at a field laboratory on the lakeshores. In addition, chemical constituents, dissolved gases, and rates of microbial processes were measured both onsite, by methods such as gas chromatography, and in the research laboratory at McMurdo Station.

Initial interpretation of the field data indicates that the main source of dissolved organic material in these lakes is degraded algal material in the anoxic (oxygen-less) lake sediments. In Lake Fryxell, for example, the concentration of dissolved organic carbon increased with depth, from values of 3 milligrams of carbon per liter just below the ice cover to values of 25 milligrams of carbon per liter above the lake sediments. The acid samples are being characterized

Processing large-volume water samples from Lake Hoare: the filtration unit is in the sled on the left, the 10-gallon milk cans are used to collect the water from the filtration unit, and the crates are used to transport the full cans by helicopter to the research laboratory at McMurdo Station. (Photograph by E.D. Andrews.)

by many different analytical methods, including elemental analysis and nuclear magnetic resonance spectroscopy. Results from these analyses will be used to test hypotheses about the formation pathways of fulvic and hydrophilic acids from algal material and will allow comparison of these microbial samples with samples from other aquatic environments.

Modern Analogs of Coal Formation

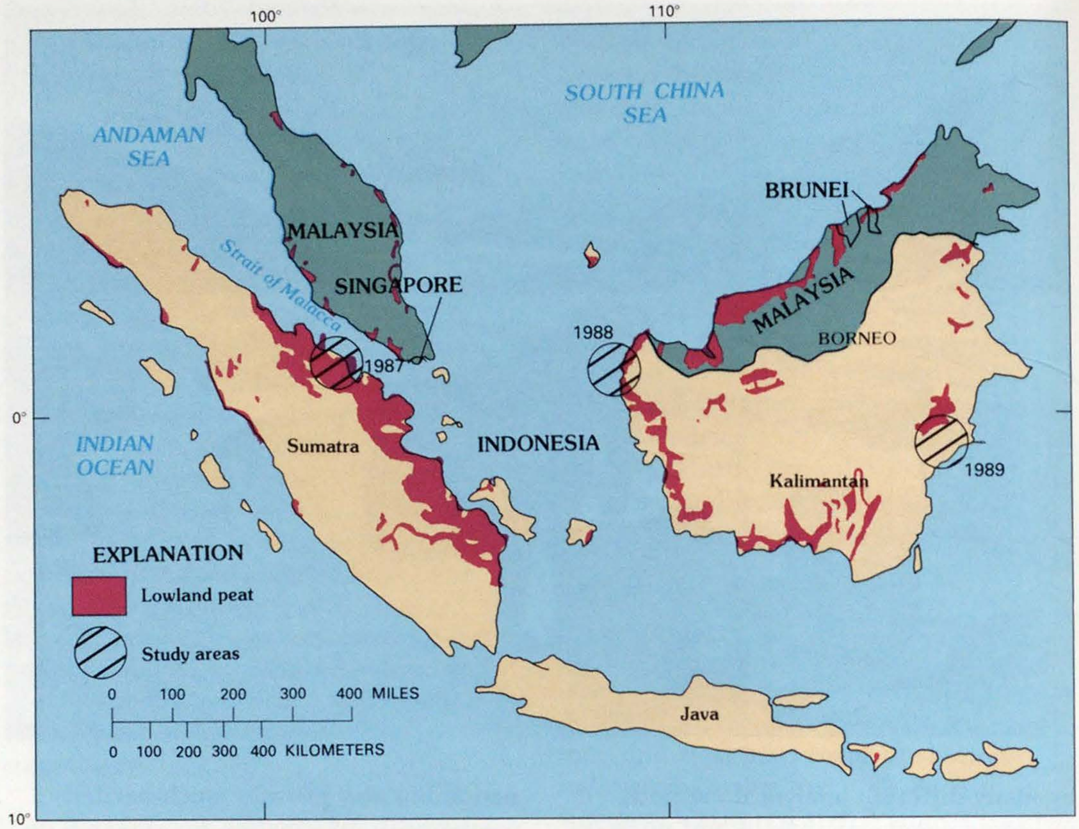
By C. Blaine Cecil

The U.S. Geological Survey, in cooperation with the Directorate of Mineral Resources of the Republic of Indonesia, recently began a three-phase program to study peat deposits, which are modern analogs of coal-forming environments. These studies are conducted in a variety of geologic settings in various parts of Indonesia (fig. 2). Phase one was completed in 1987, phase two was conducted during the summer of 1988, and phase three will begin in July of 1989. These studies not only provide significant international benefit in assisting another nation but also provide much-needed comparative information for research on domestic coal.

Under the proper geologic conditions of burial pressure, temperature, and time (usually millions of years), peat is transformed into coal. Therefore, studies of areas where peat is now forming, such as the current program, provide basic scientific data for determining the geologic factors that control the occurrence, quantity, and quality of coal beds. The data derived from this study may contribute to (1) more efficient and cost-effective methods in coal exploration and resource and reserve assessments; (2) improved methods in mine planning based on new information on geologic controls on coal-bed thickness and geometry; and (3) new technologies in coal preparation and use based on new information on the geologic factors that control the chemical and physical properties of coal.

Previous work by the USGS has shown that much of the coal resources of the 48 conterminous States formed in tropical or subtropical environments. The Republic of Indonesia is an ideal location for a modern analog study because of the apparent similarities between coal-bearing strata in the North American and Indonesian rock record and condi-

Figure 2. Study areas for the 1987 and 1988 field seasons and the area proposed for 1989.



tions of peat formation there today. In Indonesia, vast peat swamps cover thousands of square miles of lowland environments. Thick deposits of peat (as thick as 40 feet) of excellent quality (less than 0.3 percent sulfur, less than 3.0 percent ash, and about 10,000 BTU dry basis) are present over vast coastal areas. In this tropical, equatorial setting, rainfall is high and evenly distributed throughout the year. As a result of these conditions, weathering is intense and nutrients are depleted from upland soils. Because of the intense weathering, most of the rivers that traverse the peat swamps contain very little sediment (tens of parts per million). Peat can form because of the high rainfall and extremely low input of sediment into the depositional basins.

Approximately 18,000 years ago, during a lower stand of sea level, the continental shelf of the region was exposed as a large land mass (fig. 3). At present, the sea covers the continental shelf, which results in an extensive shallow sea and the drowning of the mouths of rivers, thereby creating estuaries. The extensive coastal plain environment is partly the result of these sea-level changes and partly the result of colliding plates of the Earth's crust. This plate movement has created foreland basins that allow for peat formation, along with accumulation of other sediments derived from rising mountains and volcanoes. The sediments are modified and redistributed because of sea-level changes that are caused by fluctuating continental glaciation. In a few million years, this setting may allow the peat to be incorporated into the rock record as high-quality coal.

Coastal Sumatra

Phase one of the study, covering approximately 18,000 square miles, was conducted in Riau Province, in the central Sumatra basin. The area is bounded on the southwest by soils that are at the inland margin of the coastal peat deposits, on the northwest and southeast by estuaries, and on the northeast by the Straits of Malacca.

Sedimentation in the region is controlled by basin subsidence, the tropical ever-wet climate, and fluctuations in sea level. The central Sumatra basin is subsiding because of faulting and subduction along the southwestern margin of Sumatra in the Sunda trench. The wet tropical climate of the region is the result of the permanent equatorial low-pressure zone (tropical convergence). Changes in sea level are known to have occurred during the last 30,000 years.

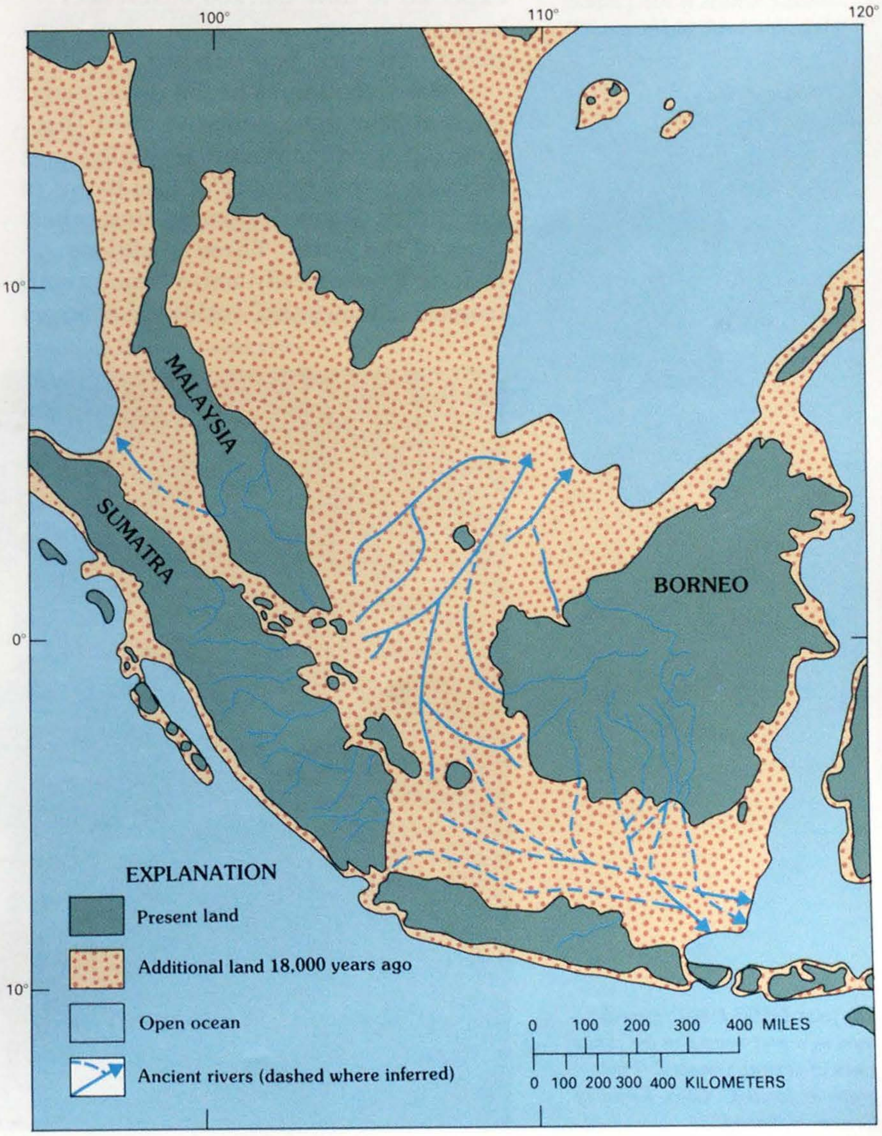
Laterally extensive domed peat deposits are forming on the coastal plain and on offshore islands. These deposits form because organic matter is accumulating faster than it can decay. High rainfall and dissolved organic acids inhibit decay and cause leaching of mineral matter, leading to the low concentrations of ash (less than 3 percent) and sulfur (less than 0.5 percent) in the peat. Sand and clay are generally being removed from the vicinity of the peat swamps by tidal currents; sediments are being deposited only in a few places in the estuaries and in the Straits of Malacca. Most sediment is being transported northwest through the Straits to the Andaman Sea.

West Kalimantan

Phase two was conducted in a coastal setting in West Kalimantan (fig. 2). This study covered an area of approximately 9,300 square miles bounded on the east by the estuary of the Sambas River and on the west by the open water of the South China Sea. This second area was chosen for study because sedimentation is occurring on an open shallow shelf, seaward of a significant peat deposit. Such environments appear to be common in the rock record, but the modern counterpart has not been studied extensively.

Sedimentation is controlled by tidal currents in the Sambas estuary and by tidal and longshore currents along the coast. Like the Sumatra estuaries, the Sambas is erosional except near the mouth where a mouth bar or tidal delta appears to be developing. In contrast to the coastline of Sumatra, the coast in the study area of West Kalimantan may be slowly building seaward, as the result of clay being deposited in the intertidal and near-shore environments and sand forming small beaches and tidal flats. The offshore area is similar to the area offshore of Sumatra; the bottom surface appears to be erosional and highly irregular. The seafloor is covered by a thin veneer of coarse-grained sand and gravel, composed of fragments of shells and the oxidized tracts of burrowing marine organisms, which have been eroded from the underlying silty clay. The oxidized burrows record three probable changes in sea level. First, during an earlier period of high sea level (approximately 30,000 years ago), burrowing marine organisms left tracks and trails in the silty clay bottom sediment. These burrows were mineralized with an iron carbonate mineral known as siderite. Approximately 18,000 years ago, during a lower stand of sea level, this bottom surface was exposed to the atmosphere, which oxidized the iron carbonate to iron oxide. Finally, about 5,000 years ago, sea level rose to its present position. Bottom currents are presently eroding and redepositing the burrows and shell fragments. These sea-level changes combined with the wet tropical climate of the region have

__Figure 3.__ Land area of the continental shelf that was exposed approximately 18,000 years ago during a time of lower sea level.



resulted in the formation of a thick (more than 26 feet), laterally extensive (approximately 62 square miles) domed peat deposit.

Future Studies

The field area for phase three of the research is expected to be in East Kalimantan (fig. 2). This area has been tentatively selected for study because of the physical contrast with the other two study areas. The area includes an inland basin surrounded by upland areas. One major drainage, the Mahakam River, passes through this basin. In further contrast, the peat in the basin is expected to have a planar rather than a domed upper surface. Therefore, ground and surface water may be the primary source of water, rather than the rainwater source for the other two areas. This area is expected to have marked differences in peat thickness and quality when compared to domed peat deposits.

Many conditions of the three study areas appear to be similar to those that controlled sedimentation, including peat formation, in a number of coal basins in the United States, Indonesia, and other parts of the world. These conditions include a tectonically active basin, a wet tropical climate, and worldwide changes in sea level. The interactions of these processes have resulted in sedimentary systems that have little sediment input so that thick, high-quality, laterally continuous peat deposits can form. Such conditions appear to be responsible for the formation of coal deposits of known or inferred tropical or subtropical origins. These studies in Indonesia are expected to help answer remaining questions about the geologic processes that control the occurrence and quality of coal in the rock record. The answers will lead to more efficient and cost-effective methods in coal-resource assessment, exploration, and development.

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 fiscal year 1988, 54 nationals from 22 countries received training in the United States; 41 visiting scientists from 17 countries conducted research at the USGS or at other facilities arranged by the USGS. Survey personnel trained more than 121

The joint USGS-DMR research team in a peat swamp in the coastal plain of central Sumatra. (Photograph by James C. Cobb, Kentucky Geological Survey.)

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 Chile (15 participants), the hazards course in Italy (20), the cartography course in Bangladesh (22), and the deformation monitoring volcano hazards evaluations in Colombia (30), Peru (6), and Guatemala (5). Eighteen countries benefited from these USGS overseas training efforts.

Activities with the countries listed below were conducted by the USGS in fiscal year 1988 under bilateral agreements sanctioned by the Departments of State and of the Interior:

Argentina
Mapping with satellite imagery.

Bangladesh
Strengthening the Geological Survey of Bangladesh.

Bolivia
Evaluation of SPOT/Landsat images and map revision at 1:50,000 scale; mineral deposits modeling workshop on gold and silver.

Canada
Marine geology; geophysics; ore-deposit models; water resources; platinum-group elements; Great Lakes seismicity; Arctic research; mapping data exchange; border digital mapping; atmospheric deposition.

Chile
Seismic zoning; improved earthquake-resistant designs; marine-geology training course.

China
Surveying and mapping—cartographic applications of remote sensing and development of geographic information systems. Earth sciences—pyrophyllite deposits; comparative geochemical anomalies in Xinjiang and southwestern United States; modeling for Bayan Obo iron-niobium-rare earth deposit in inner Mongolia; comparative geology of southern China and western U.S. Surface water—sediment transport; hydrologic equipment and measurements; hydrologic extremes; analytical techniques; cold-regions hydrology; hydrologic data exchange. Earthquakes—deep crustal structures in fault zones; premonitory phenomena; crustal stress; seismic networks; rock mechanics; intraplate active faults.

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.

A fishing village on a stream draining one of the peat swamps in the coastal plain of central Sumatra. (Photograph by Sandra Neuzil.)

France
Oceanography; geophysics; radioactive wastes; minerals assessment; borehole geophysics application to water resources; sea-ice monitoring; remote sensing in Polar regions.

Germany
Marine seismology; radioactive wastes; petroleum resource assessment; Antarctic research; sea-ice monitoring; marine minerals assessment.

Hungary
Petroleum resource potential of the Pannonian Basin; geophysics.

Iceland
Geophysics; geology; hydrology.

India
Multidisciplinary workshops; identification of mutually beneficial joint projects.

Indonesia
Volcano monitoring; marine geology; peat swamps as coal field analogs.

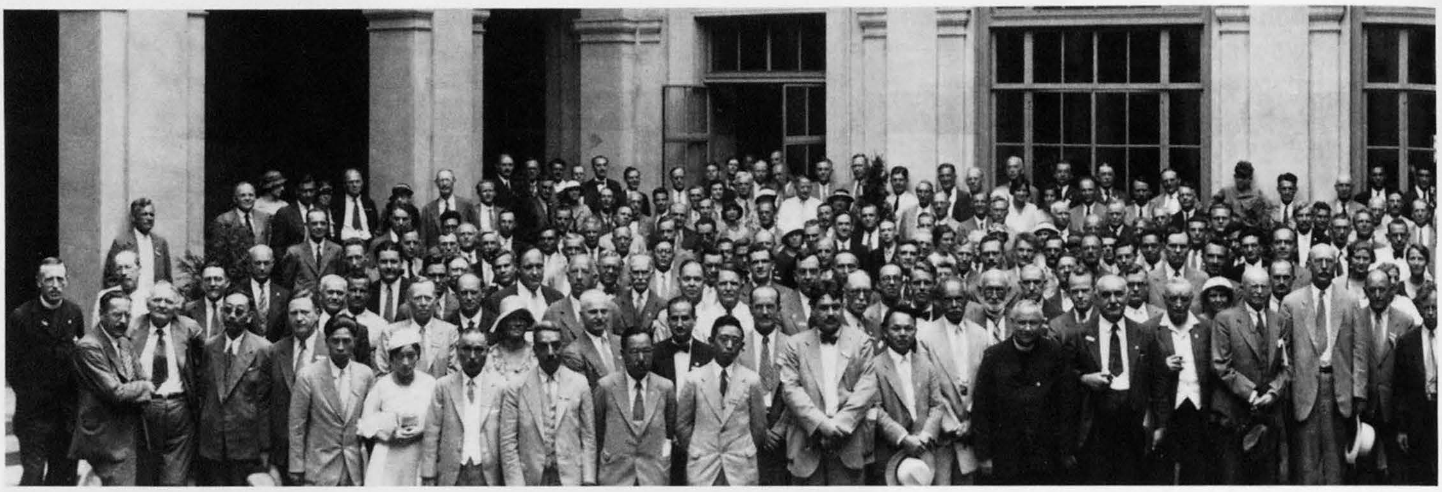
Italy
Installation of digital seismographs; earthquake reconstruction; training course on hydrological and landslide hazards; improvement of capability for early warnings of volcanic eruptions.

Japan
Deeply buried mineral deposits; gold deposits; debris flows; sediment transport on continental shelves and in estuaries.

Jordan
Seismic network; remote sensing.

Korea
Sedimentary basin analysis.

Mexico
Border mapping cooperation; color image maps.



New Zealand
1:50,000-scale mapping in McMurdo Sound of Antarctica.

Norway
Digital sonar images data processing; soil genesis and hydrochemical weathering assessment.

Pakistan
Coal resources exploration and assessment; institutional modernization of Geological Survey of Pakistan.

Panama
Earthquake hazards mitigation.

Papua New Guinea
Mineral resource assessment.

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.

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.

United Arab Emirates
Ground-water resources assessment of Abu Dhabi.

United Kingdom
GLORIA seafloor sonar imaging surveys; Antarctica remote sensing image mapping.

USSR
Earthquake prediction; estimation of seismic risk and seismic sources; marine mineral resources; climate changes; cooperative project discussions.

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

Yugoslavia
Agrogeology; soils surveys; geochemical exploration methods; seismology and earthquake hazards; granite metamorphic complexes; remote sensing; coal quality; water and soil sampling.

Programs in which activities were conducted under multilateral agreements in fiscal year 1988 included

- Executive briefing on strategic planning to reduce economic impacts of earthquake hazards worldwide in preparation for a forthcoming cooperative program.
- International Strategic Minerals Inventory, cooperative studies by the USGS and the 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, and titanium.
- 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 coun-

Members of the 16th International Geological Congress held in Washington, D.C., in 1933.

tries: Mauritania, Senegal, Gambia, Guinea-Bissau, Cape Verde, Mali, Niger, Burkina, and Chad.

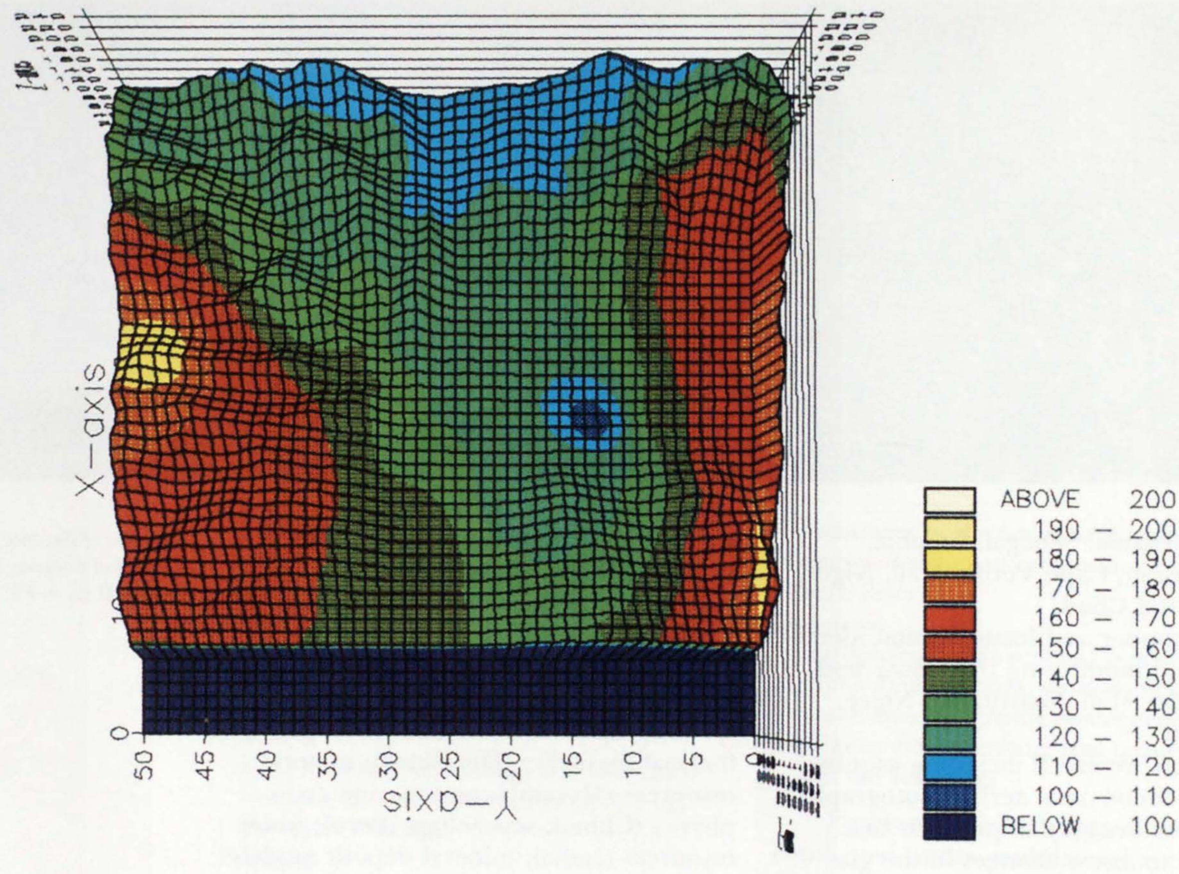
- Grasshopper and locust habitat identification and monitoring by remote sensing in Chad, Mali, Mauritania, Niger, and Sudan.
- Antarctic research including acquisition of geodetic data, aerial photography, and satellite imagery to produce base maps and to assess changes in the glaciers and ice sheets composing the margin of Antarctica due to global change; operation of the Scientific Committee on Antarctic Research (SCAR) Library for Cartography and Geodesy; seismology and data telecommunications at the South Pole; ice cap motions, sea-ice monitoring, and low-frequency-radar ice experiments; lakes in dry valleys as related to the global carbon cycle.
- Interagency Volcano Early Warning Disaster Assistance, which provides for emergency responses to crises related to volcanic eruptions.
- 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.
- Mineral deposit evaluations for the Pacific Trust Territories; assessment work on Guam and Saipan.
- Circum-Pacific Mapping Project, program coordination and the cartographic preparation of about 60 thematic maps.
- Comparative earthquake and tsunami potential for zones in the Circum-Pacific.
- Southwestern Pacific offshore exploration for petroleum resources.
- 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: spectrographic analyses (Guyana); geothermal feasibility (Honduras); mineral resources (Mozambique); marine geophysics (China); seismology (Peru); water resources (India); mineral deposit modeling workshop (Chile).

28th International Geological Congress

For the first time since 1933, the United States played host to the International Geological Congress. The National Academy of Sciences and the USGS were the official hosts for the 28th session of the Congress, held in Washington, D.C., July 9–19, 1989.

The goal of the Congress is to encourage the advancement of fundamental and applied research in the earth sciences worldwide. To achieve this goal, an international congress is organized about every 4 years by scientists in member countries of the International Union of Geological Sciences. The Congress brings together a broad representation of the world's earth scientists for a unique opportunity to exchange scientific information and concepts.

The Congress provides a special forum for new and sustained international exchange of geological knowledge. It is an event with long-term value in the continuing effort to advance worldwide understanding of the Earth and thereby improve our capability to manage its resources wisely.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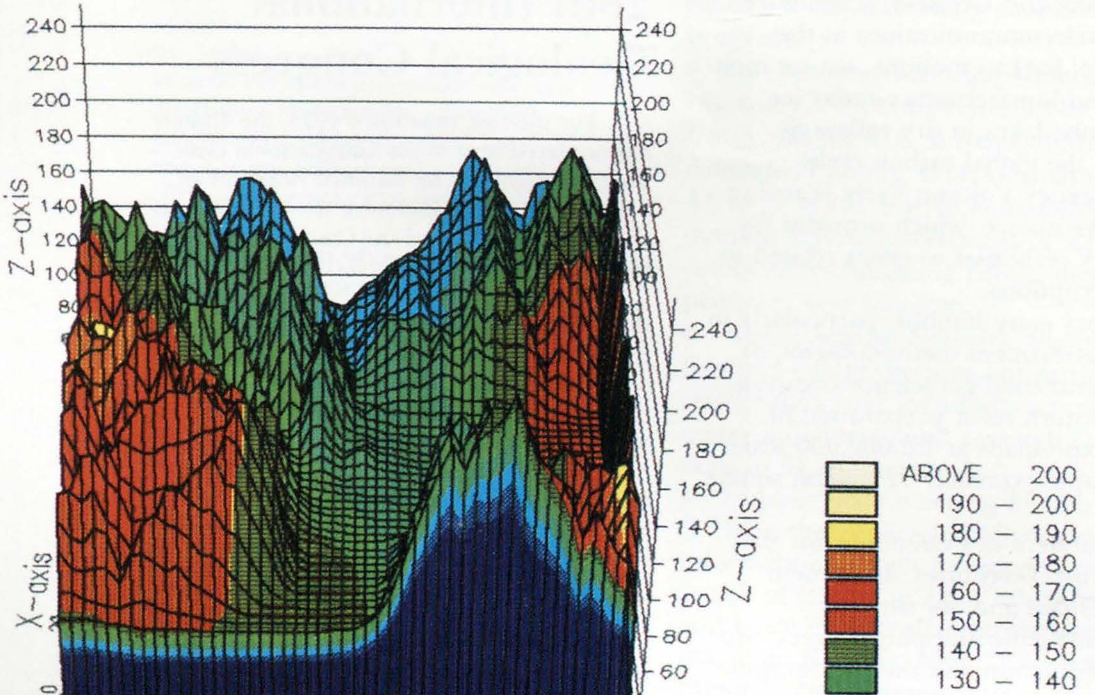
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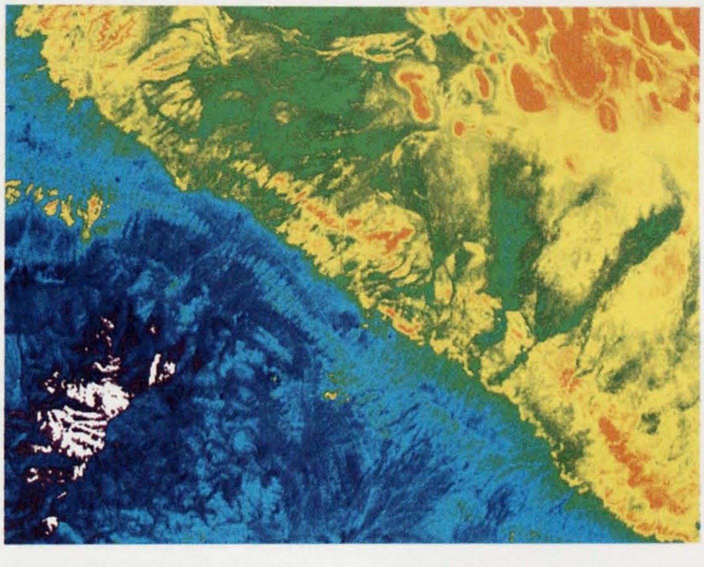
Information Systems Activities

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 Survey'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 system 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.



(Facing page) One of the functions of the Information Systems Division is to assess computer technology for the other USGS divisions. These perspective images were produced for geographic information system training and were later used to assess vendor software before purchase. The images are two views of elevation data overlain by contoured gravity data for the Nabesna, Alaska, area. They were produced on a personal computer and plotted on an in-house inkjet plotter. (Above) This Thematic Mapper Landsat image is the result of an assessment project performed by the Geologic and Information Systems Divisions. It shows the arid region around Delta, Utah, where mineralized alteration zones may be detected through spectral signature analysis.

Highlights

Supercomputing Activities in the USGS

By Rick MacDonald

A number of significant events during fiscal year 1988 marked the U.S. Geological Survey's first steps toward the use of supercomputers for processing earth-science data. For some time, this special class of computational resource had been used primarily by the physical science and engineering disciplines. The benefits offered by high-speed computing to these fields are equally applicable to the solid earth sciences. Several conferences and workshops recently concluded that much could be gained by applying supercomputers to common problems in the earth sciences, such as surface- and ground-water modeling problems, numerical simulation of geologic processes (especially those involving solid three-dimensional visualizations of tectonic movement, volcanic phenomena, and seismological processes), and the integration of raster and vector data sets. As a participant in this ongoing dialog in the earth-science community, the USGS initiated two activities, a supercomputer technology study and a survey of supercomputer centers, to determine how the USGS could apply this technology to its best advantage. Some background about supercomputers will provide a basis for understanding the importance of those activities.

Supercomputer Characteristics

Supercomputers elude an exact definition because their capabilities change so rapidly with the continuous infusion of technological innovation. One characteristic seems definite. Supercomputers can solve in minutes numerically intensive computing problems or answer other kinds of questions that would take nonsupercomputers days or weeks to solve. By some measures, the larger and more expensive supercomputers can solve some problems hundreds of times faster than popular general-purpose computers. Table 1 is an extraction from a series of tables published by the Argonne National Laboratories that attempts to measure the performance of computers processing a standard suite of numerically intensive problems. Some of the computers used in the USGS are included in this table. Caution should be used when interpreting such results, as they merely portray a crude reference to relative performance. Benchmarks of actual applications are much more desirable for refined comparisons.

How do supercomputers achieve their performance gains over general-purpose computers? Three basic techniques are usually employed. First, the use of high-performance components can accelerate the switching times, or processing speeds, associated with numeric computations. As an example, the CRAY–2 supercomputer has a central processing unit clock speed of 4.2 nanoseconds, or 4.2 billionths of a second. High-performance components are extremely difficult to manufacture and are very expensive. This technique has obvious limitations, because components cannot switch faster than the speed of light. Technology advances provided by exploitation of superconductivity may allow further performance gains with switching circuits.

Table 1. *Comparison of selected computers' computational speeds in solving a system of linear equations using FORTRAN programming language*

Computer	Millions of Floating-Point Operations per Second
ETA 10–E	52
CRAY X–MP–4	39
CRAY–2	18
IBM 3090–200/VF	12
Alliant FX/8	7.6
Amdahl 5860 HSFPF	3.9
CONVEX C–1/XP	3
Amdahl 470 V/8	1.5
Prime P6350	1.2
Prime P9955II	.72
DEC VAX 8650	.7
VAX 11/785 FPA	.2
Sun–3/260, 20 MHZ 68881	.11
Apple Mac/Levco Prodigy 4	.076
IBM AT	.012

Second, special circuits called vector processors enable the supercomputers to process with one instruction an entire sequence of data that would need several hundreds or thousands of instructions in a general-purpose computer. Data of this type are frequently used in mathematical models of earth-science processes. One possible application in the USGS would be the three-dimensional electromagnetic modeling of arbitrary earth structures.

Finally, the use of multiple processors operating concurrently can speed up the solution of problems that can be partitioned into relatively independent steps. This process is called parallel processing, as opposed to sequential processing.

Supercomputers will often use all three techniques to achieve dramatic performance gains. Some special-purpose computers rely exclusively on the use of many processors that can be linked in parallel and hence are called massively parallel processors.

Supercomputer Technology Study

The USGS formed a technology study team to examine several issues and to provide an information base from which the bureau could make future decisions with respect to acquisition of supercomputing resources. Among the most important issues were the operating systems used by supercomputers, the ability of supercomputers to interface with communications networks and other equipment, the visualization or graphical capabilities offered by supercomputers, the software available for supercomputers and its ease of use, and the cost of acquiring supercomputing resources.

The study team discovered that much progress has been made in improving the usability of supercomputers, especially in interfacing with the operating systems and in automating the process of writing programs that take advantage of the vector processors for increased speed. A distinct trend toward use of Unix, a popular operating system used by many scientists, was noted. The results of the study group were reported to the Survey's Information Systems Council and provided to a second group that was surveying supercomputer centers.

Survey of Supercomputer Centers

This group assessed the resources available at the 12 supercomputing facilities throughout the United States. The issues considered by this group were similar to those considered by the technology study team but were oriented to the capabilities of facilities that might be used by USGS scientists, rather than to the inherent characteristics of supercomputers being offered in the marketplace.

Results

Using the information gained from the technology study and the survey of supercomputer centers, the USGS developed agreements with the Department of Energy's Los Alamos National Laboratory (LANL), the San Diego Supercomputer Center (SDSC), where CRAY supercomputers are used, and the Florida State University Computer Center, where Control Data Cyber 205 and ETA–10 supercomputers are used. These centers will provide supercomputer support to USGS scientists and will also collaborate with USGS scientists on joint projects in computational geoscience. A special fund to encourage use of the LANL supercomputers was established by the Director and is being administered by the Information Systems Division. The Information Systems Division also arranged high-speed communications links to all 3 locations via GEONET and the National Science Foundation network and arranged for initial training on supercomputers at SDSC, where 23 earth and computer scientists received introductory training.

The Information Systems Division has established a data base of information about supercomputing resources that includes technical characteristics of current hardware and software products, supercomputing centers, and networking resources. Training and education in the techniques of supercomputer use is underway so that USGS scientists will be able to employ supercomputers as a tool in their research effectively. The team studying supercomputing technology is continuing its efforts to keep the USGS up-to-date in understanding current and future supercomputer capabilities.

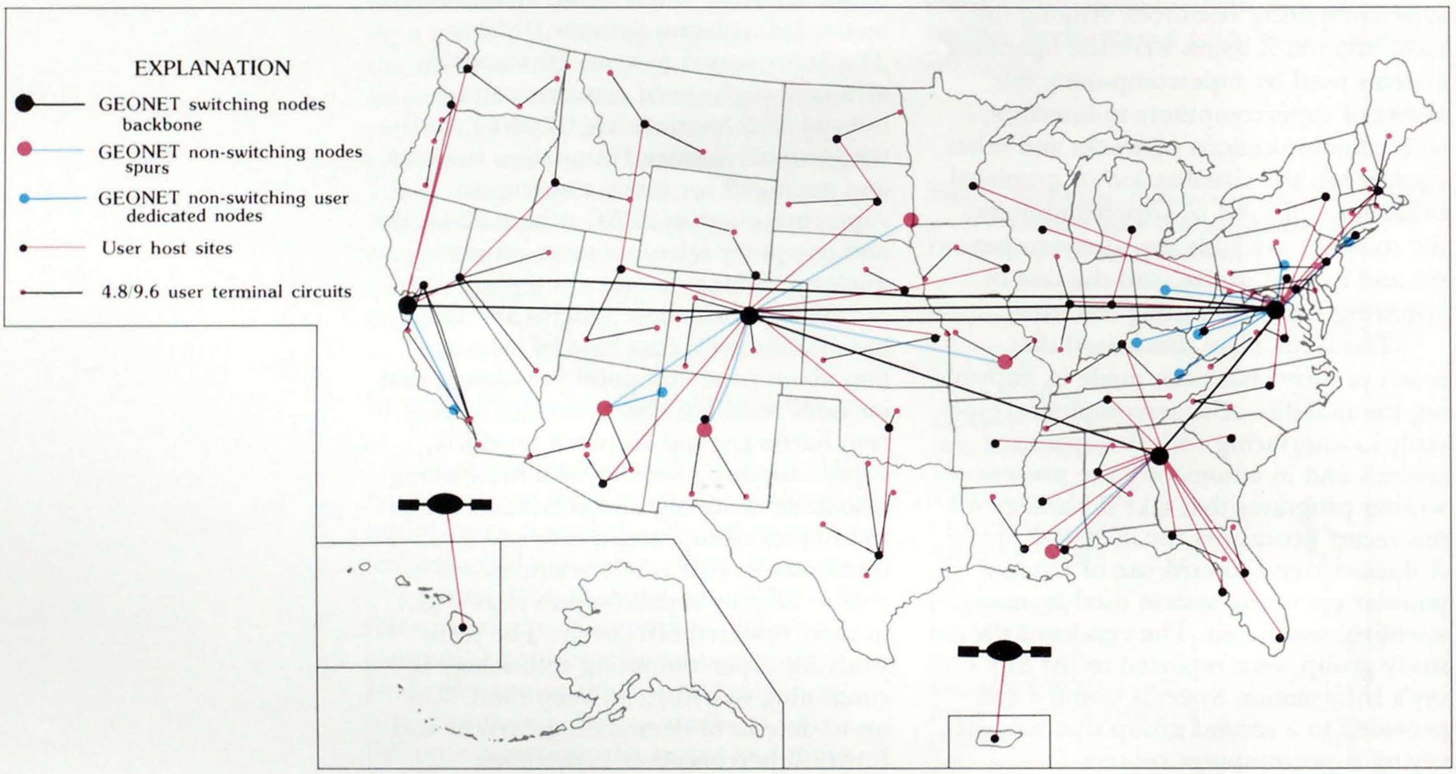
Wide-Area Data Communications Networks Used Within the USGS

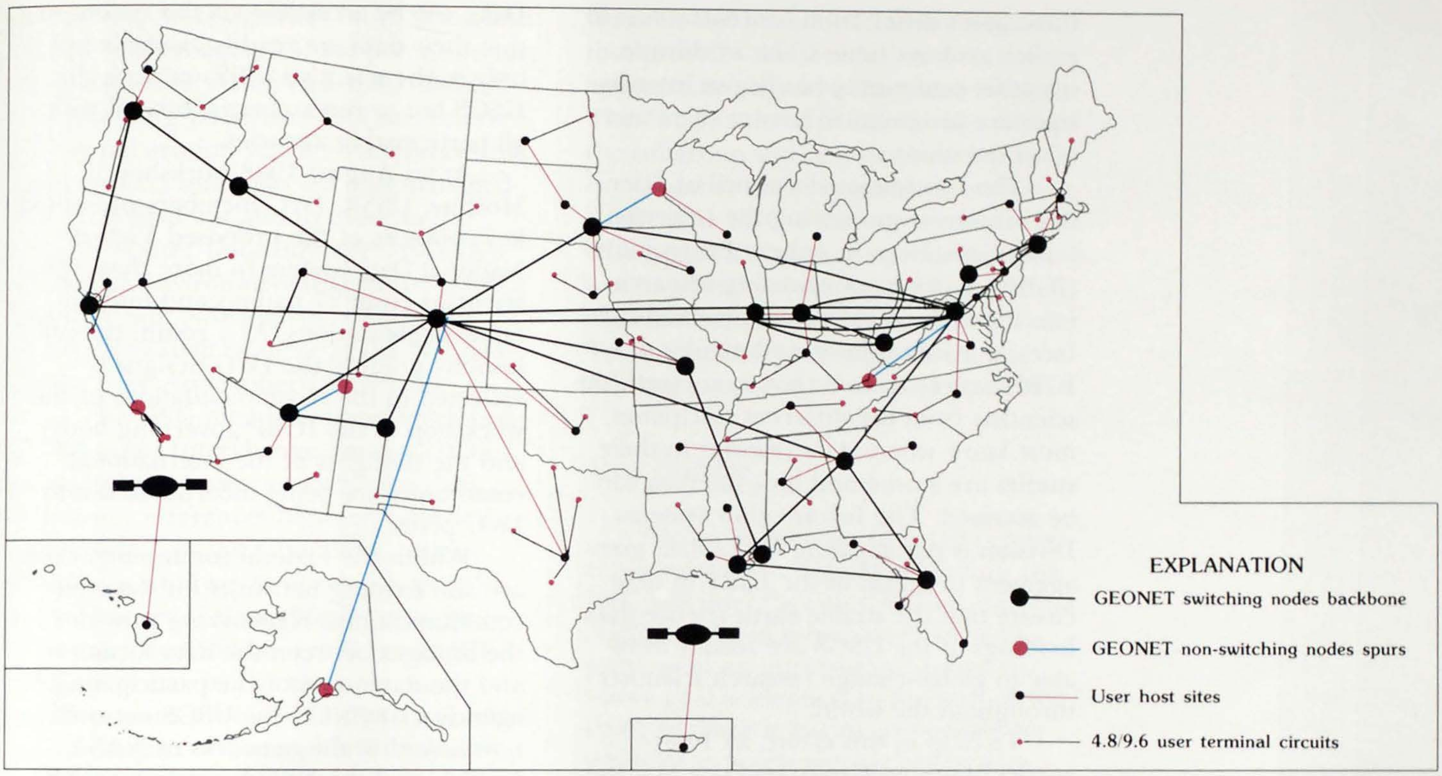
By Jim Hott and Pete Cadenas

During fiscal year 1988, the USGS used several data communications networks. These networks included GEONET, managed and operated by the USGS to provide nationwide data communications for the Department of the Interior; SPAN, the National Aeronautics and Space Administration's (NASA) Space Physics Analysis Network, which allows information exchange with the NASA scientific community; NSFNET, the National Science Foundation Network, which enables USGS scientists to access supercomputers; BITNET, which connects hundreds of universities and research centers; and the Federal Telecommunications System (FTS), which provides dial-access communications.

GEONET connects users to 150 computer systems and enables USGS scientists to share data easily and quickly. The network provides a path for terminal users and remote job-entry stations to reach USGS computers including the newly formed Administrative Service Center in Reston, Va. During 1988, GEONET was reconfigured from a relatively small shared-backbone, large dedicated-star network (December 1987 map) to a more extensive shared-backbone, smaller star network (December 1988 map). This change in GEONET was motivated by the increasing need to share facilities and lower overall USGS data communications expenditures. In December 1987, GEONET cost components represented about 40 percent shared facilities and 60 percent dedicated facilities; by December 1988, GEONET cost components were expected to change to 65 percent shared and 35 percent dedicated. Shared facilities—equipment, software, and circuits—are those used by more than one USGS division or DOI bureau. With the reconfiguration, overall cost of end-to-end GEONET will drop, while network performance will remain at prior levels. While the number of network node locations increased 50 percent in 1988, the overall end-to-end circuit mileage actually decreased. Additionally, during 1988, Alaska service was added to GEONET as a shared service for DOI bureaus.

GEONET configuration completed in December 1987.





GEONET configuration completed in December 1988.

GEONET's new connection to SPAN permits data communication among USGS, NASA, and National Oceanic and Atmospheric Administration scientists. This facilitates worldwide studies of the earth's changing environment, such as global climate change, by giving scientists from many disciplines access to earth-science information. All SPAN hosts can be accessed from GEONET, and all GEONET hosts can be accessed from SPAN.

Responding to a growing need to provide USGS scientists with access to state-of-the-art supercomputing facilities, the USGS installed high-speed circuits from three USGS locations to NSFNET. NSFNET provides communications access to several supercomputer centers in the United States including the San Diego Supercomputer Center, Florida State University, and Los Alamos National Laboratory. Supercomputers will enable better processing of complex earth-science models and are expected to help the USGS make continued progress in understanding earth-science processes. Internetworking with NSFNET is essential to support the data transfers to and from supercomputer sites.

Membership in BITNET provides access to computers at more than 1,500 universities and research centers in the United States and abroad. It provides USGS scientists more opportunities to exchange information with colleagues in the university community.

The USGS has dozens of offices in locations where on-site network resources are not cost effective. Users at these sites who require data-communications support use FTS, provided by the General Services Administration, or commercial long-distance toll service to connect with desired computing services.

By providing several options for communicating data across the county, the Information Systems Division continues to serve the changing needs of the USGS scientific community.

Data Management for Global Change

By Doug Posson

Dramatic increases in concentrations of certain atmospheric gases, such as carbon dioxide, methane, and various nitrogen oxides, have caused worldwide concern about the relationship between these increases and global temperature changes. To what extent are the activities of man contributing to this greenhouse effect? How do current concentrations of these gases differ from concentrations in earlier geologic times? The worldwide scientific community has begun interdisciplinary programs to answer these and other questions.

The International Council of Scientific Unions is sponsoring the International Geosphere-Biosphere Programme (IGBP). IGBP is coordinating research into the interactions of oceans, land surfaces, the atmosphere, and mankind. IGBP has recognized that, to succeed, the scientists from the different disciplines must know where data relevant to their studies are stored and how the data can be accessed. The Information Systems Division is participating in the data management program of the IGBP to help ensure that the sizable earth-science data holdings of the USGS are readily available to global-change research scientists throughout the world.

To help in this effort, an Interagency Working Group on Data Management for Global Change (IWG) was charged with providing the scientific community with easy access to the data needed to study global change. The principal member agencies of IWG are the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the USGS, the Department of Energy, and the United States Navy. In addition, the Department of Agriculture and Department of State participate as observing member agencies.

Linking The Data

The IWG developed the concept of a Virtual National Data System, to be available in 1995 for use by scientists interested in accessing global-change data, so that the scientists using the system need not be concerned about which agencies have the data. The system will not be a large, centralized data facility. Rather, the data system will use existing data resources to the maximum practicable extent to make access to global-change data as easy and inexpensive as possible for the research community. For example, data centers that already exist within the United States, such as the USGS EROS Data Center in Sioux Falls, S. Dak., will be accessible via the system so that their data are readily available not only to the scientists affiliated with the USGS but to researchers affiliated with all participating agencies.

At an August 1988 workshop in Moscow, USSR, IWG members presented key concepts of the proposed Virtual National Data System to more than 130 scientists from 27 nations and international organizations. As a result, the philosophy guiding the IWG designs is reflected in the recommendations of the workshop to the IGBP governing body, and the thoughts of the international community are being incorporated into IWG plans.

Within the Federal community, there are also existing networks for data telecommunications. Networking provides the linkages between the data facilities and the data users of the participating agencies. GEONET, the USGS network, is now linked to the networks of NASA, NOAA, and the NSF to provide online access to the data directories and data-storage facilities of each of the agencies.

Finding The Data

Scientists studying global change are faced with a problem: It is difficult to find which agency has data for a given geographical coverage, time period, or specific set of parameters. This is because the data directories of various agencies were developed independently of one another and are not compatible. Also, not all the data sets that have potential for use in global-change studies are referenced in existing data directories.

The IWG agreed to build a directory that would allow the various agencies to search for needed data. This "interoperable" directory was developed by NASA. This directory will, in effect, link all global-change data references in the data directories of each agency to the data directories of the other agencies. ESDD, the Earth Science Data Directory, is the USGS data directory that is being used for this interagency process. ESDD is managed by the Information Systems Division and contains more than 1,700 references to earth-science data sets. A few dozen of the most heavily used USGS data sets have been referenced. The remaining data sets in ESDD are from 1 or more agencies in 47 States and other Federal agencies, the private sector, and academia. As an example, researchers querying ESDD for data sets relevant to coastal erosion will find references not only to data sets collected and managed by the USGS but also to those in the NASA Master Data Directory, NOAA's National Environmental Data Referral Service, and NSF's earth-science data directories such as those at the National Center for Atmospheric Research.

The IWG members have developed a Directory Interchange Format (DIF) that makes it easier to exchange data directory references between agencies' directories. At the same time, each agency is working to develop a more complete set of data references in its directory that will be useful for global-change research. For example, many earth-science processes in the Arctic, such as the impact of atmospheric temperature on glacial melting, may be significant in the study of global change. The task is to identify such data sets and reference them in the interoperable directory. The USGS Polar Studies Coordinator, under the sponsorship of the Interagency Arctic Research Policy Committee, is working with Survey scientists interested in Arctic research to load more than 80 USGS references to Arctic data sets into ESDD. Through the mechanisms of the DIF and the interoperable directory, these data references will be accessible to both Arctic and global-change researchers who use the data directories of the other participating agencies.

Problems To Be Solved

The IWG is working to identify critical areas where obstacles exist to achieving the goals defined by the member agencies. Critical problems facing users of the Virtual National Data System are being addressed. One deals with the realities of pricing and cost accounting for computer and telecommunications services. While costs are kept as low as possible, the data system must have a means of billing for the data, computer time, and telecommunications resources used by each researcher. It must be able to "balance the books" so that the agency that provides the services receives the appropriate payments for those services. The Information Systems Division chairs the subgroup working on these issues.

Another set of issues deals with standards. The IWG is not attempting to develop data exchange standards, but it is working with the member agencies and the National Institute of Standards and Technology to encourage the use of existing standards as much as possible.

The Future

The global-change research community is worldwide. Determining how the IWG will interact with scientists and data organizations in other countries is the purpose of an international subgroup whose goal is identical to the goal of the IWG: to make it as easy as possible for scientists to access global-change data. When foreign scientists seek data from the United States' data system, they will benefit from the work of the IWG (which is to coordinate the data holdings within this country) and share in the costs. Similarly, the IWG will cooperate with international organizations to facilitate access by U.S. scientists to data gathered and managed by institutions in other countries.

Excellence of Service Award

The Department of the Interior Excellence of Service Award was given as a unit award to the Information Systems Division task force for the Office of Surface Mining Reclamation and Enforcement (OSMRE). The task force worked with OSMRE and contractors to install and implement the Applicant Violator System. The system allows authorities to determine if applicants for mining permits are violators of the requirements of the Surface Mining Control and Reclamation Act of 1977. The task force provided technical guidance, user assistance, computer operations and production scheduling, and special service arrangements and handled all service complaints 24 hours a day, 7 days a week, from January to October 1987.

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.

(Facing page) Computer Aided Design (CAD) systems, shown here in use within the Office of Facilities and Management Services, National Center, produce plans and other graphic displays of building features, by capturing and manipulating data on USGS facilities. (Photograph by William Dize.) (Above) Building 5, at the USGS campus in Menlo Park, Calif. (Photograph by Michael Moore.)

Highlights

State-of-the-Art Federal Financial System

By Eliot J. Christian and Mary L. Griles

During 1988, the USGS provided administrative and systems-management leadership to install the Federal Financial System (FFS), an off-the-shelf standardized financial management system, throughout the Department of the Interior. The USGS and the Bureau of Reclamation were the first two bureaus scheduled for FFS implementation in October 1988.

The FFS will replace and consolidate a variety of incompatible financial management systems throughout the ten bureaus of the Department of the Interior (DOI) into one modern system. Four additional bureaus, the Bureau of Land Management, Bureau of Mines, Bureau of Indian Affairs, and Fish and Wildlife Service, are scheduled for implementation in October 1989. The remaining bureaus and offices, which include the National Park Service, Minerals Management Service, Office of Surface Mining, and Office of the Secretary, are scheduled for implementation the following October. It is estimated that significant savings will accrue from this installation over the 10-year life of the system.

The FFS system operates on the newly installed Amdahl 5890 mainframe computer located at the USGS National Center in Reston. Remote terminals connected to a front-end processor allow direct data entry to the mainframe. The DOI's data communications network, GEONET, provides the telecommunications capability to link field operations with the main computer.

The FFS is a completely menu-driven system; it provides state-of-the-art capability that includes data-base design and extensive reference tables, which reduce the need for extensive hardcoded programs. Highlights of the FFS capabilities include the following:

- On-line maintenance—FFS is a table-driven system, meaning that nearly all edit and update controls reside in tables, rather than in hard computer code, and these tables are maintained on-line.
- On-line processing—All FFS editing and updating can be done on-line. FFS features extensive, table-defined transaction editing; for example, it can check the validity of an account number and verify fund availability.
- Single source of data entry—Information is entered one time, and all edits and updates can be done at that time.
- Reporting capabilities—As a result of its on-line nature and data base design, FFS supports extensive on-line query and reporting capabilities.
- Prompt payment support—FFS supports prompt payment requirements such as system-calculated due dates, discount determination, and automated interest and penalty calculation.
- Remote data entry—FFS supports entry of data such as commitments, receiving reports, and error corrections.
- Security—FFS allows system access to be controlled at numerous levels by function, organization, and document type. For example, security could be set up so that offices could only see the data that affect their accounts but higher levels of management could review any data within the division.

...significant savings will accrue from this installation over the 10-year life of the system.

To administer this project, the USGS established a FIRM (Financial Information Resource Management) support team, including staff from throughout the bureau, which receives management support from the USGS Administrative Division and guidance from management offices at the Department of the Interior. The finance office of each of the bureaus implementing FFS established its own

FIRM team. Technical support services were purchased from the American Management System, Inc. (AMS), to enhance the software and provide technical support to meet identified special requirements. AMS was awarded the contract for software and technical support.

The efforts of the people working on this project throughout fiscal year 1988 focused on acceptance testing, training, and preparing for the changeover to the new system.

Acceptance Testing

During fiscal year 1988, the FFS software was installed and tested to determine how well the new system performed basic accounting functions and to identify changes to the software that might be needed. The FIRM teams tested the software by entering on-line and batch transactions, testing production or volume performance, making on-line inquiries, and performing simulations of nightly, monthly, and annual processing operations. USGS accountants, managers, and system users spent many hours defining values for the many user-maintained reference tables found in FFS. The table-driven processing of FFS allows the user to process transactions with a minimum number of keystrokes. The rules that FFS uses when processing transactions were chosen by each bureau to reflect the accounting policy of its own agency.

Training

Specific bureau training requirements were identified, along with target audiences, training locations, and facilities, and a training schedule was established. The training curriculum and materials were modified and enhanced to reflect specific needs of the bureaus involved. The training included instruction on system functions, transaction processing, data entry, and inquiry, as well as the more technical aspects of system operations and system maintenance. Training sessions were held in Reston, Va., Denver, Colo., and Menlo Park, Calif.

Changing to the New System

Tasks required to change over to the new system included converting existing procedures, programs, and files to the new system; performing manual and automated conversion of programs and files; and verifying the conversion results. Systems currently in use at the bureaus, such as the payroll system, that must be linked with FFS were identified. Existing programs that linked systems were modified, and new programs were written and tested to verify that the two systems could still share information. The FFS data base and reference tables were loaded and reviewed to verify that table data were correct. Reporting requirements were compared with available FFS reports, needs for additional reports were identified, and new reports were created. System operations related to daily, weekly, and annual job cycles were proposed, and routines to back up and restore the data base were developed and tested. Security for the system was developed to protect data from unauthorized use.

In addition to implementing the system in the next group of bureaus, the FIRM team in each bureau will share the responsibility for maintaining the production system. These duties will include operating a hotline for assistance, resolving hardware and software problems, conducting ongoing training, coordinating system changes, and monitoring new system-development activities.

With the start-up of FFS, the Department of the Interior has taken an important step toward its goals of improving the efficiency of financial management operations, reducing the number of accounting systems, standardizing the processing of accounting data and payments, and reducing the cost of financial management operations within the Department. In order to take these goals one step further, the USGS was also designated by the Department of the Interior as an Administrative Service Center (ASC) to provide automated data processing services to all bureaus of the DOI and, as negotiated, to other Federal agencies. A second ASC was established at the Bureau of Reclamation in Denver, which will handle the new payroll and personnel system and FFS processing for Denver-based Interior bureaus. Efforts are also underway to encompass budgeting, procurement, and property management within the FFS.

The USGS ASC will focus on centralized systems and data-base design services for administrative applications, tailored to serve a community of users with local administrative staff. The Information Systems Division in Reston will provide the mainframe computer and telecommunications services necessary to process the supported administrative systems.

The USGS comes to the task of hosting an ASC with a proven track record of success in the data-processing arena and in large-scale IBM-compatible data processing. The USGS has provided services nationwide for a wide variety of program functions, both within the USGS and in other Federal and State agencies. In addition to the FFS efforts, the USGS initiated and continues to manage the highly successful Department-wide telecommunications network known as GEONET. The USGS also developed a very successful "paperless" system for processing personnel actions that is now being recognized governmentwide. Based on these experiences, the USGS is poised to provide improved administrative ADP services to the Department of the Interior, and potentially to other Federal agencies as well.

Facilities Management

By Lavera Hamidi

The U.S. Geological Survey has assumed more responsibility for facilities management by accepting delegated General Service Administration (GSA) building operations and lease management functions. Over the years, the USGS has worked successfully with GSA to acquire office and special-purpose space to support our scientific programs nationwide; more than 90 percent of the space currently occupied by USGS is GSA-provided. The nature of USGS earth science programs requires laboratory, computer, and other specialized facilities that benefit from the closer bureau management and supervision allowed by the GSA delegations of responsibility.

Background

In 1981, GSA initiated a pilot program to test the feasibility of delegating building operations authority to its tenant agencies. GSA was interested in testing its premise that tenant agencies could operate their buildings more responsively than and as economically as GSA. Several major agencies agreed to participate, and by 1985 the program had expanded to a total of 10 agencies and 24 buildings in the Washington, D.C., area. Each delegation was slightly different, depending on the individual circumstances and the negotiations that took place. On the basis of the program's success, the Office of Management and Budget in 1985 directed GSA to expand and accelerate the program to encompass all Federal agencies in single-tenant buildings nationwide, setting a target date of September 30, 1986, for accomplishment. The USGS took an active role in the new program to delegate buildings operations and maintenance.

Operations and Maintenance

In August 1987, GSA delegated building operations and maintenance responsibilities for Reston, Va., where the

USGS is the sole tenant in Government-owned space. These responsibilities include day-to-day facility support necessary for physical maintenance of the buildings, such as cleaning, mechanical operation, preventive maintenance, energy management, repairs and alterations, monitoring of concessions, contracting, space assignment and lease management, and guard service. The USGS was required to establish a cleaning and grounds maintenance program, a preventive maintenance program for all building operating equipment, and an energy management and conservation plan. GSA transferred funds, manpower, and support contracts for these facilities, in addition to responsibility for payment of all utilities and fuel bills.

Currently, the USGS manages the operation and maintenance of the John Wesley Powell Federal Building in Reston, with a budget of about $5 million; this headquarters facility has over 1 million gross square feet and houses some 2,400 employees. The USGS also accepted limited responsibility for operations and maintenance of smaller, leased facilities in Golden, Colo., and Flagstaff, Ariz.

Lease Management

Early in fiscal year 1988, the USGS completed implementation of GSA-delegated lease management authority for more than 120 leased sites nationwide encompassing more than 2.2 million square feet of space. Lease management requires that the designated agency perform periodic inspections to ensure compliance with lease terms, establish a register to record all complaints and their resolutions, and provide written notification to the lessor of non-performance with terms of the lease. These documents must be maintained in an on-site lease enforcement file. In addition, responsibilities now performed by USGS employees, formally designated as GSA contracting officer representatives, include managing the lease, verifying utility bills, ordering services beyond those provided during normal working hours, and contracting for low-dollar repairs and alterations.

The John Wesley Powell Federal Building, Reston, Va. (Photograph by Kathleen K. Gohn.)

Benefits

The USGS has realized a number of benefits since assuming these delegations:

- Improvements in building-service quality and responsiveness through streamlining of service procedures and organization.
- Improved performance of service contracts through better monitoring and ability to make contract specifications more responsive to specific buildings and to USGS scientific program needs.
- Savings from energy conservation at the John Wesley Powell Building in Reston, due primarily to direct control of building heating, air-conditioning, ventilation, and electrical systems and the incentive to apply savings to meet deferred maintenance needs.
- More flexibility and greater control to direct funds and staff time to meet the program requirements deemed most critical and to respond more quickly to shifting program needs during the year.
- Improved ability to integrate planning, requirements development, and implementation for alteration projects to meet program needs within required timeframes.

Future of the Program

In concert with GSA, the USGS is continuing to review further opportunities for delegation. An operations and maintenance delegation for several USGS buildings in Menlo Park, Calif., is being considered.

People and Programs of the U.S. Geological Survey

Mission

Our Nation is faced with some serious questions concerning 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 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. Collecting, analyzing, and disseminating the scientific information necessary to answer these questions is the primary mission of the U.S. Geological Survey.

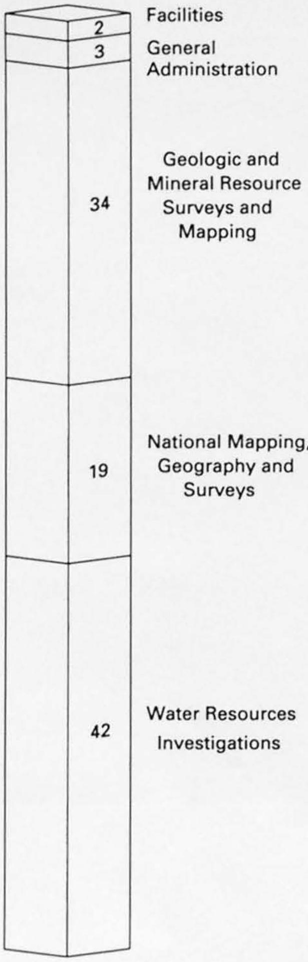
The U.S. Geological Survey was established by an Act of Congress on March 3, 1879, to provide a permanent Federal agency to conduct the systematic and scientific "classification of the public lands, and examination of the geological structure, mineral resources, and products of the national domain."

Since 1879, the research and factfinding 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 principally a scientific and technical agency rather than a developmental or regulatory one. 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 consists of maps, data bases, and 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."

(Facing page) Elk Creek Lake Park, Lakewood, Colo. (Photograph by Bill Price.) (Above) Molten lava reaches the ocean at Kalapana, Hawaii. (Photograph by J.D. Griggs.)

Percentage of Total Funds by Activity



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 Survey conducts its research and investigations through an extensive organization of regional and field offices located throughout the 50 States, Puerto Rico, and the Trust Territories.

In fiscal year 1988, the USGS had obligational authority for $662.1 million, $448.2 million of which came from direct appropriations; $7.4 million came from estimated receipts from map sales, and $206.5 million came from reimbursements. The Survey 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 1988 were distributed to geologic, hydrologic, mapping, and administrative areas of responsibility. Budget tables appear at the back of this section.

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 and the Cascades Volcano Observatory, in Vancouver, Wash., are the principal field research centers for this program.

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.

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. Exclusive Economic Zone. Results of these studies and analysis of new information are essential for energy and mineral resource evaluation 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 carry out the water-resources investigations and data-collection programs of the Division in all 50 States, Puerto Rico, the Virgin Islands, and the Trust Territories.

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.

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 and thereby provide 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.

Hazardous Waste Hydrology Programs

The USGS conducts research and investigations into the disposal of hazardous chemical and radioactive wastes to provide information that will help in alleviating their effects on the Nation's water resources. The Survey 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 comprises 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 900 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 of 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.

Today's programs serve a diversity of needs and users.

National Mapping Division

Organization

The headquarters of the National Mapping Division is located in Reston, Va., and is composed of three primary organizational units: Plans and Operations, 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 Data Center (Sioux Falls, S. Dak.) perform the operational mapping, remote sensing, printing, product distribution, and data dissemination activities.

To accomplish its mission, the Division concentrates its activities in four major program areas. These program areas and specific activities are as follows:

Mapping Coordination

- Coordinates requirements for maps and digital cartographic data of Federal agencies (under authority of Office of Management and Budget Circular A–16).
- Coordinates requirements of State and local agencies and provides required map products.
- Chairs the Interior Digital Cartography Coordinating Committee and the Federal Interagency Coordinating Committee on Digital Cartography.
- Provides leadership in the use of digital spatial data and the development of digital cartographic data exchange standards.
- Provides staff support to the interdepartmental U.S. Board on Geographic Names.

Primary topographic maps. . .are especially useful where detailed information is needed for all types of land and resource management.

Map and Digital Cartographic Data Production

- Collects, compiles, and analyzes information about natural and manmade features of the Earth's surface and documents changes in those features.
- Produces and maintains a series of accurate, up-to-date, general-purpose base and thematic maps at primary, intermediate, and small scales.
- Provides image products derived from satellite imagery and aerial photography in response to specific requirements of Federal and State agencies.
- Adds to and maintains the National Digital Cartographic Data Base to meet the requirements of all users for digital cartographic products and services.

Information Management and Dissemination

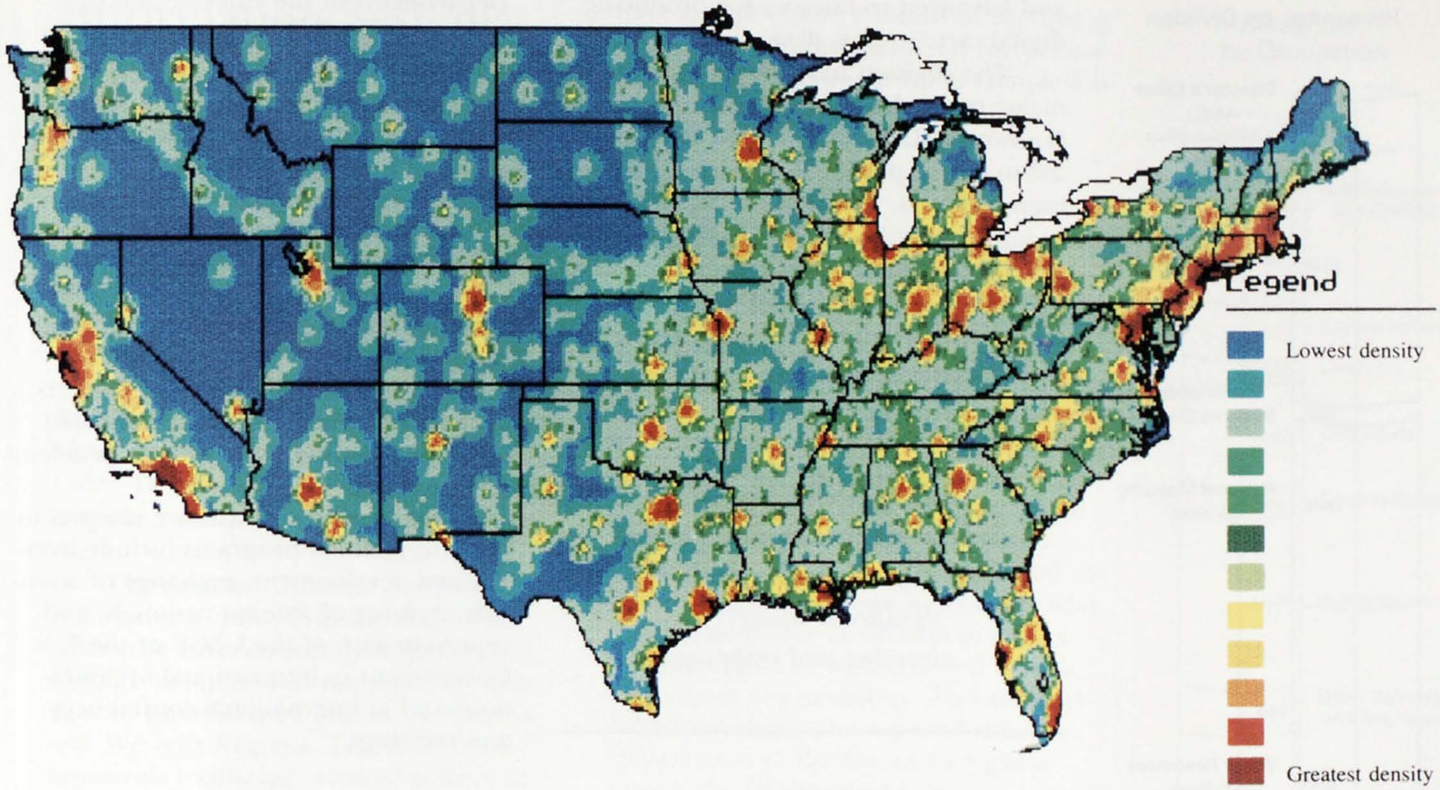
- Archives, manages, and makes available cartographic, remotely sensed, and other earth-science data in digital and graphic forms.
- Distributes more than 8 million maps a year.
- Collects, analyzes, and disseminates information about cartographic and geographic data holdings of Federal and State agencies and private-sector organizations.

Research and Technology

- Conducts research to support cartographic production and related activities.
- Provides technical assistance and technology to other Federal and State agencies in the coordination, development, and application of various spatial data and cartographic, geographic, remotely sensed, and image data.
- Conducts research to develop geographic information system applications, with emphasis on cooperative projects that demonstrate the integration of spatially related earth-science data.

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



Population density map from the Geographic Names Information System, developed for the Primary Mapping Economic Analysis (discussed in an earlier article). Map developed from 4,000 discrete points representing population centers of 5,000 and above.

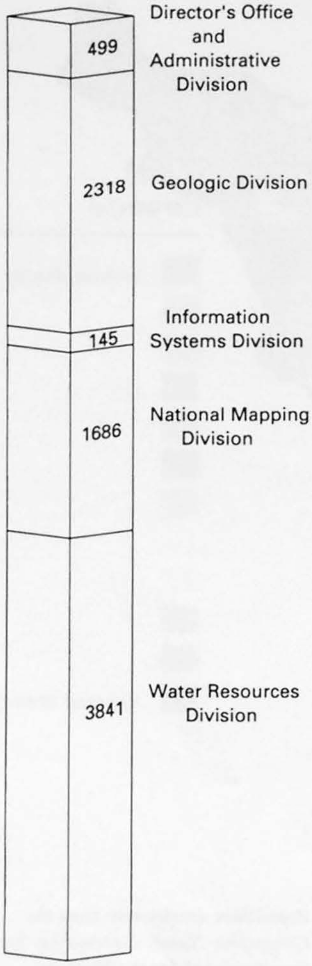
scales, in digital form, and as reproductions of aerial photographs and satellite images. Digital data are available from the National Digital Cartographic Data Base as digital line graphs or digital elevation models.

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, Personnel, by Division



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.

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Information Services

The USGS disseminates much of the Nation's earth-science information through its Public Inquiries Offices, National Cartographic Information Centers (NCIC), 49 NCIC/State affiliated offices, and the Earth Resources Observation Systems Data Center. The information comes in many forms, from maps and books to computer-readable magnetic tapes and compact disks. About 130,000 different maps and books and about 8.9 million aerial and space images are available for purchase. USGS maps are also currently available from more than 3,600 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 Survey'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 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. The Division also manages the development, maintenance, and operation of the financial management system for the entire Department of the Interior.

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.

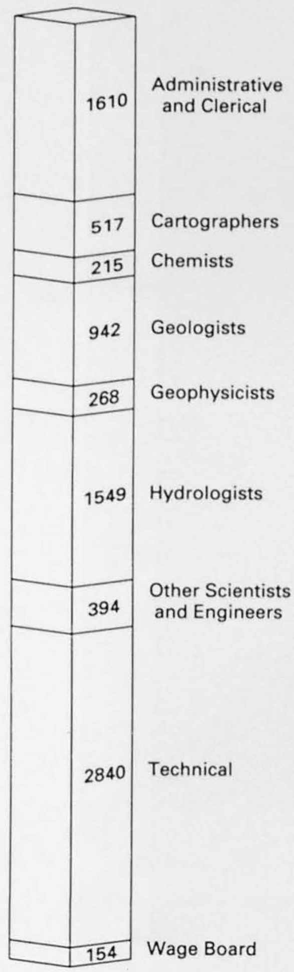
The Assistant Director for Information Systems is the Division Chief. He chairs the Information Systems Council, which is composed of the top ADP manager in each Division and in the Central and Western Regions. The council recommends technology-related policies to the Director, coordinates computer science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

Personnel

At the end of fiscal year 1988, the USGS had 8,489 permanent full-time employees. The Survey'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 relationship 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.

Personnel, by Occupation



Awards and Honors

Each year, USGS employees receive awards 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 the Survey 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 Department of the Interior's highest honor, the Distinguished Service Award, the Presidential Rank Award, and two USGS awards.

Service in professional societies is one of the most important contributions a scientist can make. Societies play a fundamental role in disseminating knowledge as well as provide a forum in which new ideas are tested. The active participation of Survey scientists in professional societies attests to the scientific vitality of the bureau. The bureau is particularly proud of those individuals who have been elected to society presidencies or chairmanships of society committees by their professional peers.

Pat S. Chavez, Jr., Research Physical Scientist, National Mapping Division, was awarded the Alan Gordon Memorial Award by the American Society for Photogrammetry and Remote Sensing for his development of algorithms for processing both satellite imagery for cartographic applications and sonar data for the marine sciences.

Alden P. Colvocoresses, Research Cartographer, National Mapping Division, was elected President of the American Society for Photogrammetry and Remote Sensing for the period 1988–89.

G. Brent Dalrymple, Geologist, Geologic Division, was named president-elect of

The large number of these awards attests to the high caliber of Survey personnel.

the American Geophysical Union for the period July 1, 1988–June 30, 1990.

Wallace deWitt, Jr., Geologist, Geologic Division, received the Distinguished Service Award of the American Association of Petroleum Geologists in recognition of 44 years of exemplary geologic work and many years of varied services to AAPG.

George Gryc, Geologist, received an Honorary Life Membership Award from the Alaska Geological Society, in recognition of his continuing service and contributions to the Society and to Alaskan geology.

Janet L. Gwen, Geologist, Geologic Division, was selected as the 1987 recipient of the Steven Champlis Memorial Award at the Rocky Mountain Section, American Association of Petroleum Geologists–Society of Economic Paleontologists and Mineralogists meeting.

Kathleen M. Johnson, Geologist, Geologic Division, was awarded the Distinguished Service Award of the Association for Women Geoscientists for outstanding service.

Michael P. McDermott, Marketing Program Manager, National Mapping Division, was elected President of the Washington, D.C., Chapter of the American Marketing Association for the period 1987–88.

Alan Mikuni, Cartographer, National Mapping Division, was elected President of the Northern California Region of the American Society for Photogrammetry and Remote Sensing for the period 1988–89.

Marshall E. Moss, Assistant Chief Hydrologist for Research and External Coordination, Water Resources Division, was elected General Secretary/Treasurer of the American Geophysical Union for the period 1988–92.

Waverly J. Person, Geophysicist, Geologic Division, received a special achievement award from the National Association of Government Communicators for two decades of service as the government's chief scientific spokesman to the public and news media on occurrences of earthquakes worldwide.

Verne R. Schneider, Chief of the Office of Surface Water, Water Resources Division, was named Engineer of the Year for the U.S. Geological Survey by the National Society of Professional Engineers.

David B. Stewart, Geologist, Geologic Division, was elected President of the Mineralogical Society of America for the period November 1987–88.

Department of the Interior Distinguished Service Awards

The highest honor given by the Department of the Interior to its employees is the Distinguished Service Award. Symbolized by a gold medal, this award for outstanding achievement was presented by Secretary of the Interior Donald Paul Hodel to ten USGS employees or their representatives:

Michael H. Carr, Geologist, Geologic Division, for exceptional contributions to geologic exploration of the planets.

Dan A. Davis, Associate District Chief of the Hawaii District Office, Water Resources Division, in recognition of his outstanding career as a water-resources scientist and administrator, and exceptional achievements in island hydrology throughout the Pacific Ocean.

Frank C. Frischknecht (posthumously), Geologist, Geologic Division, for outstanding leadership in pioneering in the field of airborne geophysics, and for his influential advocacy and development of a wide variety of electrical geophysical methods.

Paul E. Needham, Scientific Advisor for Geodesy and Advanced Systems, National Mapping Division, for outstanding technical guidance and leadership and invaluable contributions to the U.S. Geological Survey's surveying and digital mapping programs.

Mary C. Rabbitt, Geologist, Geologic Division, for her major contribution to the earth science history of the United States through historical research and studies of the USGS.

Vernon B. Sauer, Hydrologist, Water Resources Division, in recognition of his outstanding contributions to the development of theory and procedures for applications of hydraulic principles to problems related to the surface-water programs of the U.S. Geological Survey.

David W. Scholl, Geologist, Geologic Division, for his dynamic leadership of the marine geology program and for his productive scientific research into the geology of active continental margins.

Mitsunobu Tatsumoto, Research Chemist, Geologic Division, for his outstanding contributions to the development of multi-isotopic geochemistry as a new research tool to investigate fundamental problems of crust-mantle evolution of mafic and silicic rocks, the understanding of lunar history, and the origin of meteorites.

Gene A. Thorley, Digital Cartography Program Manager, National Mapping Division, for outstanding contributions to scientific research in the field of remote sensing and for notable management of scientific programs in digital cartography and geographic information systems.

Edwin P. Weeks, Research Hydrologist, Water Resources Division, in recognition of his exceptional contributions to the understanding of ground-water flow and transport of dissolved gases and chemical constituents in the unsaturated zone.

Presidential Rank Awards

Presidential Rank Awards are granted by the Office of Personnel Management in recognition of prolonged, high-quality accomplishments by career members of the Senior Executive Service. The awards are presented each year by the President and are granted at the distinguished (the highest level) and the meritorious ranks. In 1988, awards were given to the following USGS employees:

Philip Cohen, Chief Hydrologist, Water Resources Division, was given the distinguished rank award for sustained extraordinary accomplishment in management of the USGS Water Resources Division and for directing the Division's technical support to other Federal, State, and local government agencies in water and other earth-science research and investigations.

James E. Biesecker, Assistant Director for Information Systems, was given the meritorious rank award for exceptional guidance in the planning and management of information resources in the USGS, which have had a major impact on the use of computing resources in the USGS, the Department of the Interior, and other Federal agencies and on the effective use of information technology in the earth sciences.

Lawrence A. Borgerding, Chief of the USGS Mid-Continent Mapping Center, was given the meritorious rank award for his innovative approaches to USGS mapping program activities, for his cost-saving and future-oriented plans and program management, and for his aggressive pursuit of equal employment opportunity and affirmative action programs for the recruitment and professional development of ethnic minority members.

Edgar A. Imhoff, Manager of the San Joaquin Valley Drainage Program, was given the meritorious rank award for fostering cooperative relationships with high-ranking officials at all levels of government and for developing a management strategy for the San Joaquin Valley Drainage Program, a cooperative, interdisciplinary effort of five Federal and State agencies to address the agricultural drainage problems of the San Joaquin Valley.

Lowell E. Starr, Chief of the USGS National Mapping Division, was given the meritorious rank award for his leadership, managerial competence, and scientific knowledge. Under his direction, the National Mapping Program of the USGS has led the way to innovative automated procedures in mapmaking and to the use of advanced computer technology in mapping and the design and application of sophisticated geographic information systems.

John Wesley Powell Awards

Each year the U.S. Geological Survey 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.

The Powell award is named in honor of the second director of the USGS. Awards in 1988 were given to the following people:

John McPhee, a journalist from Princeton, N.J., who was selected in the private-citizen category for his writing about geology and geologists. His books and articles describe many fundamental ideas underlying modern geology and have contributed significantly to the mission of the USGS by communicating the results of scientific investigations to the public and by increasing public awareness of the USGS.

Hugo F. Thomas, State Geologist, Hartford, Conn., who was selected in the State and local government category for his long-standing participation as a cooperator and his outstanding contributions to the earth sciences and to the programs and missions of the USGS. His contributions have advanced many USGS programs and have had a positive effect on cooperative efforts with other States.

Harold Moellering, Professor, Department of Geography, The Ohio State University, Columbus, Ohio, who was selected in the academic category for his role as chairman of the National Committee for Digital Cartographic Data Standards from 1982 to 1987 and for his outstanding contributions to the effort of the USGS to develop and promulgate standards for digital spatial data. Under his leadership the NCDCDS received acclaim from mapping professionals throughout the world.

Handicapped Employee of the Year

Edith Becker Chase, a senior editor, Water Resources Division, Reston, Va., was named the U.S. Geological Survey Handicapped Employee of the Year. She was cited for her distinguished 35-year career as a scientific writer and editor, having overcome a profound hearing impairment. She is widely recognized for her contributions to the scientific publications of the USGS. The award is made annually to a USGS employee as part of the observance of National Employ the Handicapped Week.

Experience with the Visually Handicapped

By Kathryn Gunderson

In September 1987, the USGS entered into an agreement with the Virginia Department for the Visually Handicapped to provide a training program for Amy W. Meade. Amy, who had been a USGS student employee, had recently become blind after graduating from college. The 3-month training program, conducted by the Information Systems Division, was aimed at helping Amy become computer-literate, thus acquiring the skills to become productively employed. Another goal of the program was to determine whether permanent employment at the USGS was desirable and practical for both Amy and the Survey.

The USGS has had an active program to recruit and hire employees who are handicapped.

A training plan was developed with two major objectives: (1) to have the employee acquire a basic understanding of computing concepts and specific hardware and software and (2) to apply this knowledge to existing USGS applications. The first part of the plan included training in the use of various hardware and software including the IBM PC/XT, Artic Vision Speech Synthesizer, Word Perfect word processing package, dBASE III Plus data base management package, and WYLBUR mainframe software. Good timing helped with the second part of the plan. On October 1, 1987, the Information Systems Division began a new customer-assistance service referred to as the Help Desk. Having learned these computer skills, Amy assisted in monitoring calls to the Help Desk, while she also worked on several other projects. At the end of the 3-month training period, the USGS hired Amy as a Computer Assistant. Her newly acquired skills and the benefits they provided to the USGS make her a valued employee and an asset to the organization.

The training program undertaken by the Information Systems Division is just one example of a continuing effort by the U.S. Geological Survey to support employees with special needs. The USGS historically has had an active program to recruit and hire employees who are handicapped. There are a number of employees in the National Mapping Division, for example, who have profound hearing disabilities and who are actively employed as professional cartographers and cartographic technicians. The USGS is strongly committed to continuing to identify employment opportunities for those who might be considered occupationally limited and to seek out new positions and new possibilities for these employees, such as the successful experience with Amy Meade.

The Spirit of Volunteerism in the USGS

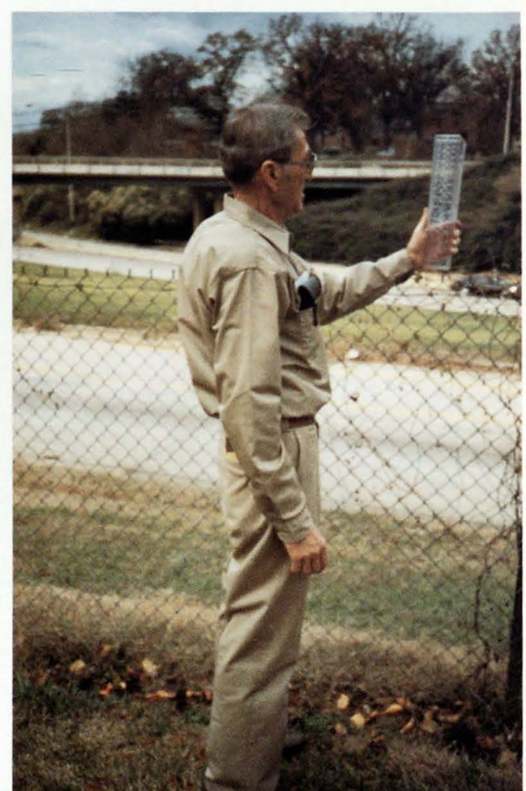
By Maxine C. Jefferson

The spirit of volunteerism is a special one in the U.S. Geological Survey. More than 580 volunteers contributed more than 100,000 hours of their time to the USGS during fiscal year 1988. These volunteers are retired USGS employees, teachers, college students, high school students, and other community members who volunteer their time and talents because of their interest in public service and in the earth science mission of the USGS. The Volunteer for Science Program is a companion program to the national Take Pride in America public awareness campaign, which encourages citizens to help take care of the public resources through volunteer efforts. From its modest beginning in 1986 with only 55 volunteers, the program has grown remarkably, and now more than 780 volunteers have donated their services.

The program is of benefit both to the USGS and to the volunteers. Some volunteers welcome access to sophisticated scientific equipment and technology and the opportunity for field work. Students have been able to develop USGS work projects in cooperation with academic institutions that have provided college credit in their pursuit of a degree. USGS retirees and other retired citizens have a chance to continue to make contributions to their life-long field of research, or maybe to try their hand at a new area in which they have always had an interest but never had the time to pursue. Some volunteers have degrees in science but earn their living in other professions; by volunteering, they feel that they are "keeping a hand in science." The benefits derived by the USGS are even more obvious. The volunteers have been involved in planning for the 28th International Geological Congress and in such major USGS projects as the Radon Project, the Continental Margin Mapping Program, the Mineral Resources Appraisal Project, the Glacier National Park Project, and the Arctic Alaska Project. They have also performed project support assignments involving such duties as recording rainfall measurements, field mapping, constructing streamflow gaging stations, and preparing scientific reports.

In July 1988, the USGS was honored by Secretary of the Interior Donald Paul Hodel for the success of the Volunteer for Science Program and was included in a White House ceremony in which the President recognized contributions made to the Take Pride in America Campaign. In further recognition of the Volunteer for Science Program, the second annual Volunteer Recognition Ceremony was held at the National Center in August 1988. The Director presented special Certificates of Appreciation to 65 volun-

The program has grown remarkably, and now more than 780 volunteers have donated their services.



teers who worked on project assignments at the national headquarters of the USGS. In this ceremony, he thanked them for "taking pride, by taking part." Similar ceremonies of recognition were held in major USGS field locations.

Pleased with the results of the program so far, the USGS plans to continue community outreach, increase the number of volunteers, and broaden the scope of activities wherever possible. The U.S. Geological Survey is convinced that a quality corps of volunteers will continue to make significant contributions to the earth sciences and will continue to sustain the spirit of the American tradition of volunteerism.

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 information about the natural resources of the Nation. The results of USGS investigations are published in its scientific reports and in its topographic, geologic, and

About 130,000 different maps and books are available for purchase.

hydrologic maps. About 130,000 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 through the news media.

During fiscal year 1988, the USGS produced 5,308 new and revised topographic, geologic, and hydrologic maps; printed 11,147,000 copies of different maps; distributed 7,569,989 copies of maps; and sold 5,217,699 copies for $7,879,698. The number of reports approved for publication by the USGS in fiscal year 1988 was 5,073, with 70 percent designated for publication in professional journals and monographs outside the USGS and the remainder scheduled for publication by the Survey. In addition, 170,578 copies of technical reports of various classifications were distributed. These included 11,429 different book titles, with a distribution of 165,006 copies and a revenue of $310,464. Also, 1,068 new reports were released to the open files to make a total of more than 27,000 open-file reports available. Of these, sales of 30,644 copies generated an income of $265,609. Of the 124 titles in the USGS general-interest publications series, 518,533 copies were distributed to meet inquiries from the general public. Additionally, of the approximately 8.9 million different aerial and space images available for sale, about 180,000 copies are sold annually. USGS maps are also currently available from more than 3,600 authorized commercial map dealers nationwide.

Minerals Information Office

By Susan M. Marcus

The U.S. Geological Survey recognized a need to serve the public better by creating public access to the vast USGS resources of minerals information. Mineral products touch each of us in our daily lives and represent, in the words of the American Mining Congress, the building blocks of society. The future availability of minerals needed for the Nation's economic well-being and defense security depends on timely access to current minerals information. The USGS and the U.S. Bureau of Mines (USBM) have a combined minerals expertise that spans such diverse fields as the origins of mineral deposits and the development of new metallurgical techniques. These two agencies created the Minerals Information Office as a cooperative approach to improve public service.

The office is designed as a "one-stop shopping place" for mineral resources inquiries. The office is located in room 2647 of the Interior Building at 18th and C Streets NW in Washington, D.C. Minerals experts in the office provide information and access to USGS and USBM databases, commodity specialists, and publications for the benefit of the public, industry, and State and Federal officials. The office also seeks to improve the exchange of information among Federal agencies and other generators and users of minerals information.

The opening ceremony for the Minerals Information Office was held on June 21, 1988, and was attended by representatives of industry, media, State and Federal governments, and the general public. Under Secretary of the Department of the Interior Earl Gjelde and Assistant Secretary James W. Ziglar joined USGS Director Dallas L. Peck and USBM Director T S Ary in cutting a platinum ribbon.

Mineral commodities have been and will continue to be featured in a series of activities sponsored by the Minerals Information Office. Platinum and gold were the featured commodities during fiscal year 1988. Exhibits showed regions of the United States thought to have potential for undiscovered conventional and unconventional platinum resources. Samples of platinum ore from Stillwater, Mont., were given away to members of the public who visited the MIO. Gold-related activities included a series of well-received public lectures and demonstrations in the Department of the Interior Museum, exhibition of examples of gold ore from domestic and foreign mines, free distribution of gold-ore samples from the Homestake Mine in South Dakota, and dissemination of fact sheets and brochures about gold.

Computer data bases at the office can provide instant responses to inquiries for information. The USGS Resource Oriented Computer System (ROCS) permits retrieval of graphic and tabular data on mineral resources throughout the world; paper copies of the screen displays are available on site. Data bases also include political and administrative boundaries, ownership, and information about USGS mineral-resource programs and research that can be searched in ways designed to meet each user's specific needs.

The Minerals Information Office also serves as a collector of data that can be used by USGS scientists. Data are compiled and digital files are acquired to enhance the breadth and depth of information available to government researchers. Sources of data include other government agencies, both Federal and State, as well as private industry.

Response to the new office has been positive. The office has replied to both general and technical inquiries and is a favorite stop of visitors to the Interior Building. Additional Minerals Information Offices are being established in conjunction with USGS Field Centers in Tucson, Ariz., Reno, Nev., and Spokane, Wash., to serve the needs of information users and USGS researchers in those regions. The western Minerals Information Offices will become operational during 1989.

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, write:
Superintendent of Documents
Government Printing Office
Washington, DC 20402

To obtain information on programs, publications, and services or to obtain copies of reports and maps, visit the U.S. Geological Survey Public Inquiries Offices at the following addresses:
Alaska:
Room 101
4230 University Dr.
Anchorage, AK 99508–4664

E–146 Federal Bldg.
701 C St.
Anchorage, AK 99513

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

Rm. 3128
Bldg. 3, Stop 533
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

District of Columbia:
2650 Main Interior Bldg.
18th and E Sts., NW
Washington, DC 20240

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

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

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

To obtain information on cartographic data, write or visit the U.S. Geological Survey National Cartographic Information Centers (NCIC) in the following States:
Alaska:
U.S. Geological Survey
National Cartographic Information Center
4230 University Dr.
Anchorage, AK 99508–4664

California:
U.S. Geological Survey
Western Mapping Center
National Cartographic Information Center
345 Middlefield Rd.
Menlo Park, CA 94025

Colorado:
U.S. Geological Survey
Rocky Mountain Mapping Center
National Cartographic Information Center
Box 25046, Stop 504
Bldg. 25, Denver Federal Center
Denver, CO 80225

Mississippi:
U.S. Geological Survey
National Cartographic Information Center
Bldg. 3101
Stennis Space Center, MS 39529

Missouri:
U.S. Geological Survey
Mid-Continent Mapping Center
National Cartographic Information Center
1400 Independence Rd.
Rolla, MO 65401

Virginia:
U.S. Geological Survey
National Cartographic Information Center
1C402 National Center, Stop 507
12201 Sunrise Valley Dr.
Reston, VA 22092

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 data, 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
2647 Main Interior Bldg.
18th and C Sts., NW
Washington, DC 20240

Budget Information

U.S. Geological Survey budget authority for fiscal year 1988, by appropriation for Surveys, Investigations, and Research
[Dollars in thousands]

Activity/Subactivity/Program Element	Fiscal Year 1988[1] enacted
National Mapping, Geography, and Surveys	**$ 90,541**
Primary Mapping and Revision	**35,732**
Digital Cartography	**14,063**
Small, Intermediate, and Special Mapping	**13,442**
Intermediate-Scale Mapping	4,426
Small-Scale and Other Special Mapping	1,734
Geographic Information Systems Research and Applications	2,113
Land Use and Land Cover Mapping	1,543
Image Mapping	3,626
Advanced Cartographic Systems	**13,217**
Earth Resources Observation Systems	**8,797**
Data Production and Dissemination	4,254
Applications and Research	4,543
Cartographic and Geographic Information	**3,790**
Side-Looking Airborne Radar	**1,500**
Geologic and Mineral Resource Surveys and Mapping	**177,161**
Geologic Hazards Surveys	**48,828**
Earthquake Hazards Reduction	35,013
Volcano Hazards	11,593
Landslide Hazards	2,222
Geologic Framework and Processes	**27,200**
National Geologic Mapping	17,804
Deep Continental Studies	3,088
Geomagnetism	1,760
Climate Change	1,046
Coastal Erosion	3,502
Mineral Resource Surveys	**47,040**
National Mineral Resource Assessment Program	23,737
Strategic and Critical Minerals	9,861
Development of Assessment Techniques	13,442
Energy Geologic Surveys	**28,911**
Evolution of Sedimentary Basins	5,350
Coal Investigations	7,424
Oil and Gas Investigations	5,674
Oil Shale Investigations	592
Geothermal Investigations	5,967
Uranium-Thorium Investigations	3,388
World Energy Resource Assessment	516
Geologic and Mineral Resource Surveys and Mapping—Continued	
Offshore Geologic Surveys	**25,182**
Offshore Geologic Framework	25,182
Water Resources Investigations	**149,147**
National Water Resources Research and Information System—Federal Program	**78,662**
Data Collection and Analysis	22,234
National Water Data & Information Access Program	1,978
Coordination of National Water Data Activities	1,039
Regional Aquifer System Analysis	11,537
Core Program Hydrologic Research	9,254
Improved Instrumentation	1,707
Water Resources Assessment	1,404
Toxic Substances Hydrology	12,697
Nuclear Waste Hydrology	4,288
Acid Rain	2,993
Scientific and Technical Publications	2,316
National Water-Quality Assessment Program	7,215
National Water Resources Research and Information System—Federal-State Cooperative Program	**59,644**
Data Collection and Analysis, Areal Appraisals, and Special Hydrological Studies	50,670
Water Use	3,979
Coal Hydrology	4,995
National Water Resources Research and Information System—State Research Institute and Research Grants Program	**10,841**
State Water Resources Research Institutes	5,677
National Water Resources Research Grants Program	4,381
Program Administration	783
General Administration	**14,684**
Executive Direction	4,655
Administrative Operations	8,391
Reimbursements to the Department of Labor	1,638
Facilities	**16,214**
National Center—Standard Level User's Charge	13,335
National Center—Facilities Management	2,879
Total	**$447,747**

[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 1985 to 1988, by activity and sources of funds[1]

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

Budget activity	1985	1986	1987	1988
Total	**$604,664**	**$600,852**	**$620,585**	**$662,101**
Direct program	417,021	412,667	432,114	[1]448,233
Reimbursable program	187,643	188,185	188,471	[2]213,868
States, counties, and municipalities	59,454	59,945	63,088	68,609
Miscellaneous non-Federal sources	26,075	12,111	13,667	12,775
Other Federal agencies	102,114	116,129	111,716	132,484
National Mapping, Geography, and Surveys	**115,155**	**112,562**	**118,462**	**120,845**
Direct program	85,469	84,117	88,542	90,541
Reimbursable program	29,686	28,445	29,921	30,304
States, counties, and municipalities	1,93	1,975	1,841	1,579
Miscellaneous non-Federal sources	9,450	9,568	10,276	[2]10,021
Other Federal agencies	18,299	16,902	17,804	18,705
Geologic and Mineral Resource Surveys and Mapping	**216,921**	**206,463**	**209,553**	**224,708**
Direct program	169,851	165,585	169,239	177,278
Reimbursable program	47,070	40,878	40,314	46,750
States, counties, and municipalities	1,016	1,320	1,365	1,138
Miscellaneous non-Federal sources	13,261	348	938	368
Other Federal agencies	32,793	39,210	38,011	45,244
Water Resources Investigations	**238,131**	**248,598**	**254,288**	**278,380**
Direct program	133,408	135,152	142,130	149,471
Reimbursable program	104,723	113,446	112,158	128,910
States, counties, and municipalities	56,500	56,650	59,882	65,893
Miscellaneous non-Federal sources	3,327	2,161	2,437	2,354
Other Federal agencies	44,896	54,635	49,839	60,662
General Administration	**15,354**	**14,515**	**18,285**	**17,746**
Direct program	15,244	14,246	17,084	14,684
Reimbursable program (Federal)	110	269	1,201	3,062
Miscellaneous non-Federal sources	---	1	1	3
Other Federal agencies	110	268	1,200	3,060
Facilities	**13,089**	**13,615**	**15,109**	**16,252**
Direct program	13,049	13,567	15,067	16,214
Reimbursable program	40	48	42	38
Miscellaneous services to other accounts	**6,014**	**5,099**	**4,835**	**4,804**
Reimbursable program	6,014	5,099	4,835	4,804
Miscellaneous non-Federal sources	37	33	15	29
Other Federal agencies	5,977	5,066	4,820	4,775
Operation and Maintenance of Quarters	**---**	**---**	**52**	**45**
Direct program	---	---	52	45

[1] Direct program includes $447,747 for current year, $117 for Contributed Funds, $324 for last year's unobligated balance, and $45 for Operation and Maintenance of Quarters.

[2] Includes $7,410 for map receipts previously shown under direct program column.

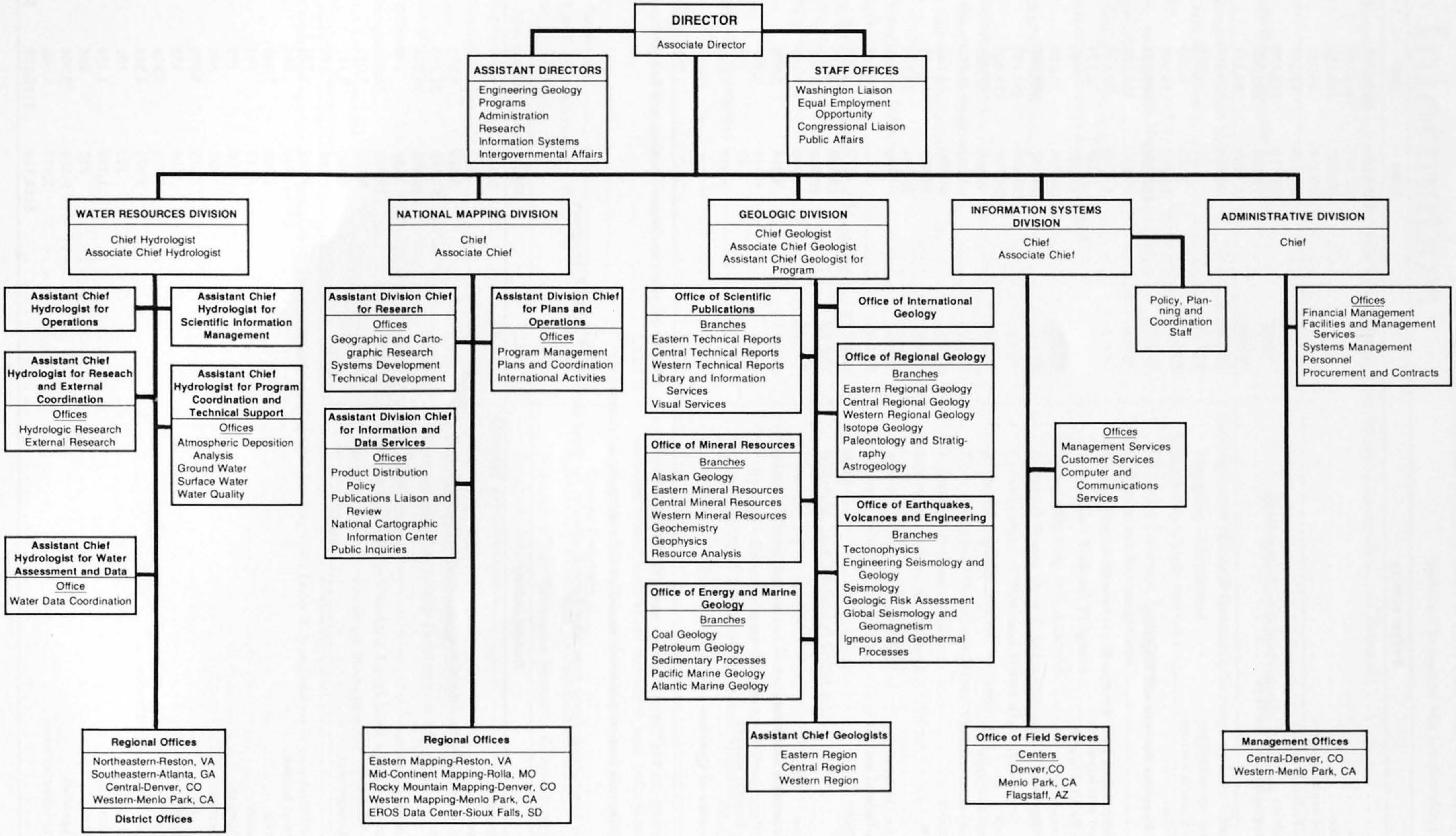
U.S. Geological Survey reimbursable funds from other Federal agencies for fiscal years 1985 to 1988, by agency

[Dollars in thousands]

Budget activity	1985	1986	1987	1988
Department of Agriculture	3,066	2,756	1,247	3,392
Department of Commerce	617	104	100	50
National Oceanic and Atmospheric Administration	6,876	8,675	7,993	6,138
Department of Defense	31,883	27,343	30,551	39,462
Department of Energy	15,893	24,341	24,361	26,800
Bonneville Power Administration	132	170	274	258
Department of the Interior	19,859	18,852	14,787	17,166
Bureau of Indian Affairs	5,530	5,033	4,280	4,664
Bureau of Land Management	2,900	2,447	1,748	1,773
Bureau of Mines	54	122	14	29
Bureau of Reclamation	8,510	8,734	6,647	6,715
Minerals Management Service	744	342	125	291
National Park Service	1,122	1,043	977	1,069
Office of the Secretary	17	701	538	1,983
Office of Surface Mining	90	129	260	352
Fish and Wildlife Service	892	301	198	290
Department of State	619	8,625	4,740	9,896
Department of Transportation	458	133	300	794
Environmental Protection Agency	1,476	1,878	2,726	3,591
National Aeronautics and Space Administration	3,979	4,343	4,380	4,877
National Science Foundation	242	162	472	535
Nuclear Regulatory Commission	1,236	1,154	1,834	1,589
Tennessee Valley Authority	247	264	101	269
Miscellaneous Federal agencies	9,554	12,264	13,030	13,371
Miscellaneous services to other accounts	5,977	5,066	4,820	4,775
Total	**$102,114**	**$116,129**	**$111,716**	**132,963**

ORGANIZATION OF THE U.S. GEOLOGICAL SURVEY

Department of the Interior



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	Bruce R. Doe	(703) 648–4450	National Center, Stop 104
Assistant Director for Engineering Geology	James F. Devine	(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
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
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
Special Assistant to the Director for Alaska	Philip A. Emery	(907) 271–4138	4230 University Drive, Suite 201 Anchorage, AK 99508
Administrative Division			
Chief	Jack J. Stassi	(703) 648–7200	National Center, Stop 201
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
Administrative Operations Officer	Timothy E. Calkins	(703) 648–7204	National Center, Stop 203
Office of Personnel, Chief	Maxine C. Millard	(703) 648–7442	National Center, Stop 215
Office of Procurement and Contracts, Chief	Paul A. Denett	(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
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 211
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	Gayle F. Gordon	(703) 648–7157	National Center, Stop 807
Office of Management Services, Chief	Wendy A. Budd	(703) 648–7103	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 Plans and Operations	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
Eastern Mapping Center, Chief	K. Eric Anderson	(703) 648–6002	National Center, Stop 567
Mid-Continent Mapping Center, Chief	Lawrence H. Borgerding	(314) 341–0880	1400 Independence Rd., Rolla, MO 65401
Rocky Mountain Mapping Center, Chief	Merle E. Southern	(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

Office	Name	Telephone Number	Address
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
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, Acting	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, Acting	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	Frank T. Carlson	(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, Acting	Ernest F. Hubbard	(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 A. Emery	(907) 271–4138	4230 University Dr., Suite 201 Anchorage, AK 99508
Arizona	Robert D. Mac Nish	(602) 629–6671	Federal Bldg., FB–44 300 W. Congress St. Tucson, AZ 85701
Arkansas	Ector E. Gann	(501) 378–6391	2301 Federal Office Bldg. 700 W. Capitol Ave. Little Rock, AR 72201
California	John M. Klein	(916) 978–4633	Room 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

Office	Name	Telephone Number	Address
Connecticut (See Massachusetts)			
Delaware (See Maryland)			
District of Columbia (See Maryland)			
Florida	Irwin H. Kantrowitz	(904) 681–7620	227 North 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 Room 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., Room 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 West 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 South 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 North 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
New Mexico	Robert L. Knutilla	(505) 262–6630	Pinetree Office Park, Suite 200 4501 Indian School Rd., N.E. 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

Office	Name	Telephone Number	Address
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	Charles R. Burchett	(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 W. Boning	(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	P.O. Box 1125 2120 Capitol Ave., Rm. 4006 Cheyenne, WY 82003

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 1988. 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);
Alabama Surface Mining Commission (w);
Alabaster, City of (w);
Anniston, City of (w);
Ashville, Town of (w);
Birmingham, City of (w);
Calhoun County Commission (w);
Coffee County Commission (w);
Dauphin Island Water Authority (w);
Geological Survey of Alabama (g,n,w);
Heflin, City of (w);
Huntsville, City of (w);
Jacksonville, City of (w);
Jefferson County Commission (w);
Mobile, City of (w);
Montgomery, City of (w);
Prattville, City of (w);
Reece City, Town of (w);
Southwide Water Works (w);
Sumter, County of (w);
Tuscaloosa, City of (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 (g,w),
Technical Services (w),
Transportation and Public Facilities (w);
Alaska Power Authority (g,w);
Anchorage, Municipality of—
Department of Health and Human Services (w),
Department of Solid Waste Services (w),
Water and Wastewater Utility (w);
Dillingham, City of (w);
Fairbanks, City of (w);
Fairbanks North Star Borough (w);
Juneau, City and Borough of (w);
Kenai Peninsula Borough (w);
Matanuska Susitna Borough (w);
Petersburg, City of (w);
Sitka, City and Borough of (w);
University of Alaska, Fairbanks (w);
Wasilla, City of (w)

American Samoa
American Samoa, Government of (w)

Arizona
Arizona Bureau of Geology and Mineral Technology (g);
Arizona Department of—
Environmental Resources (w),
Water Resources (w);
Arizona Geological Survey (g);
Arizona State Land Department (w);
Arizona State University (g);
Colorado Department of Highways (w);
Franklin Irrigation District (w);
Gila Valley Irrigation District (w);
Maricopa County—
Flood Control District (w),
Municipal Water Conservation District No. 1 (w);
Metropolitan Water District of Southern California (w);
Pima County Transportation and Flood Control District (w);
Safford, City of (w);
Salt River Valley Water Users Association (w);
San Carlos Irrigation and Drainage District (w);
Scottsdale, City of (w);
Show Low Irrigation Company (w);
The Navajo Nation (w);
Tucson, City of (w)

Arkansas
Arkansas Department of Pollution Control and Ecology (w);
Arkansas Game and Fish Commission, Fisheries Division (w);
Arkansas Geological Commission (g,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)

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 (g,w),
Water Resources—
Central District (Sacramento) (n,w),
Northern District (Red Bluff) (w),
San Joaquin District (Fresno) (w);
California Office of Emergency Services (n);
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);
Fresno Metropolitan Flood Control District (w);
Georgetown Divide Public Utility 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 Department of Water and Power (w);
Madera Irrigation District (w);
Marin County Department of Public Works (w);
Marin Municipal Water District (w);
Merced, City of (w);
Merced Irrigation District (w);
Mojave Water Agency (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);
Rancho California Water District (w);
Riverside County Flood Control and Water Conservation District (w);
Sacramento Department of Health Services (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 (w), 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 Flood Control and Water Conservation District (w);
Santa Maria Valley Water Conservation District (w);
Santa Ynez River Water Conservation District (w);
Scotts Valley Water District (w);
Siskiyou County Flood Control and Water Conservation District (w);
Sonoma County—
Planning Department (w),
Water Agency (w);
Tahoe Regional Planning (w);
Terra Bella Irrigation District (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);

Western Municipal 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);
Chaffee, County of (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 Geological Survey (g);
Colorado River Water Conservation District (w);
Colorado Springs, City of—
Department of Public Utilities (w),
Office of the City Manager (w);
Colorado Water Conservation Board (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);
Fruita, City of (w);
Garfield, County of (w);
Glendale, City of (w);
Glenwood Springs, City of (w);
Grand County Board of 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);
North Kiowa-Bijou Ground Water Management District (w);
North LaJunta Water Conservancy District (w);
Pikes Peak Area Council of Governments (w);
Pitkin County Board of Commissioners (w);
Pueblo Board of Water Works (w);
Pueblo Civil Defense Agency (w);
Pueblo County Commissioners (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 River Water Conservancy District (w);
Upper Black Squirrel Ground Water Management District (w);
Upper Eagle Valley Water and Sanitation Districts (w);
Upper Yampa Water Conservancy District (w);
Urban Drainage and Flood Control District (w);
Water Users No. 1 (Rangely) (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)

Delaware
Delaware Department of Natural Resources and Environmental Control (w);
Geological Survey (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);
Collier, County of (w);
Cocoa, City of (w);
Cottondale, 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–
Division of—
Marine Resources (w),
Recreation and Parks (Hope Sound) (w),
Recreation and Parks (Tallahassee) (w),
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 Commission (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),
Solid Waste Authority (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);
Quincy, City of (w);
Reedy Creek Improvement District (w);
Sarasota, City of (w);
Sarasota, County of (w);
South Dade Soil and Water Conservation District (w);
South Florida Water Management 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);
Suwannee River Water Management District (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
Alabama Economic and Community Affairs (w);
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 (g)—
Environmental Protection Division—
Water Management Branch (w),
Water Quality Support Program (w),
Geologic Survey (n,w),
Transportation (w)—
Materials and Research (w);
Georgia State University (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)

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, City and County of—
Board of Water Supply (w),
Department of Public Works (w);
Kauai, County of, Department of Water Supply (w);
Maui, County of (w)

Idaho

Boise, City of (w);
College of Southern Idaho (w);
Idaho Department of—
Fish and Game (w),
Health and Welfare (w),
Transportation (n),
Water Resources (w);
Idaho Geological Survey (g);
Shoshone, County of (w);
Shoshone-Bannock Tribes, Fort Hall Business Council (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 (Duboise) (w)

Illinois

Bloomington and Normal Sanitary District (w);
Cook County Forest Preserve District (w);
Decatur, City of (w);
DeKalb, City of (w);
DuPage County Forest Preserve, Planning and Development Section (w);
DuPage County Department of Environmental Affairs (w);
Illinois Department of—
Energy and Natural Resources, State Water Survey Division (w),
Transportation—
Division of Highways (n),
Division of Water Resources (n,w);
Illinois Environmental Protection Agency, Division of Water Pollution Control (w);
Illinois State Geological Survey (g,n);
Metropolitan Sanitary District of Greater Chicago (w);
Springfield, City of (w);
Vermilion County Conservation District (w)

Indiana

Carmel, Town of (w);
Elkhart, City of, Water Works (w);
Indiana Department of—
Environmental Management (w),
Highways (w),
Natural Resources (g,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 (w);
Iowa Geological Survey (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);
Barton, County of (w);
Clay, County of (w);
Emporia, City of (w);
Equus Beds Groundwater Management District No. 2 (w);
Geary, County of (w);
Hays, City of (w);
Kansas Department of—
Health and Environment (w),
Transportation (w);
Kansas Corporation Commission (w);
Kansas Geological Survey (g,n,w);
Kansas State Board of Agriculture, Division of Water Resources (w);
Kansas State University (w);
Kansas Water Office (w);
Linn, County of (w);
Olathe, City of (w);
Pawnee Watershed (w);
Sedgwick, County of (w);
Southwest Kansas Groundwater Management District No. 3 (w);
Trego, County of (w);
Western Kansas Groundwater Management District No. 1 (w);
Wichita, City of (w);
Wyandotte, County 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);
Lincoln Trail Health Department (w);
Louisville Metropolitan Sewer District (w);
University of Kentucky, Kentucky Geological Survey (n,w);
University of Louisville (w)

Louisiana

Bayou LaFourche Freshwater District (w);
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 State University and A&M College (w);
Sabine River Compact Administration (w);
Slidell, City of (w)

Maine

Androscoggin Valley Council of Governments (w);
Cobbossee Watershed District (w);
Maine Department of—
Conservation, Geological Survey (g,n,w),
Environmental Protection (w),
Inland Fisheries and Wildlife (w),
Transportation (w);
North Kennebec Regional Planning Commission (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);
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 (w);
Washington Suburban Sanitary Commission (w)

Massachusetts

Barnstable County Commissioners (w);
Brewster, Town of (w);
Harwich, Town of (w);
Massachusetts Department of—
Environmental Management, Division of Water Resources (g,w),
Environmental Quality Engineering—
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 Water Resources Authority (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 (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 (w);
Flint, City of, Department of Public Works and Utilities (w);
Genesee County Drain Commission, Division of Water and Waste Services (w);
Grand Traverse County Board of Commissioners (w);
Huron-Clinton Metropolitan Authority (w);
Imlay, City of (w);
Kalamazoo, City of, Department of Public Utilities (w);
Kalamazoo County Board of Commissioners (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—
 Agriculture (w),
 Natural Resources (w),
 Transportation (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 (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);
Minnesota Geological Survey (g);
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);
Western Minnnesota Resource, Conservation and Development Association (w);
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—
 Highways (w),
 Natural Resources—
  Bureau of Geology (w),
  Bureau of Land and Water Resources (w),
  Bureau of Pollution Control (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 (g,n,w),
  Land Reclamation Commission (w);
Missouri Highway and Transportation Commission (n,w);
Springfield, City of, City Utilities, Engineering Department (w)

Montana
Fort Peck Tribes (w);
Helena, City of (w);
Lewis and Clark, County of (w);
Lower Musselshell Conservation District (w);
Montana Bureau of Mines and Geology (g,w);
Montana Department of—
 Fish, Wildlife, and Parks (w),
 Health and Environmental Sciences (w),
 Highways (w),
 Natural Resources and Conservation (w),
 State Lands (w);
Montana State University (w);
Office of the Governor (w);
Salish and Kootenai Tribes of Flathead Reservation (w);
University of Montana (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);
Nebraska Department of—
 Environmental Control (w),
 Water Resources (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);
Clark County Department of Public Works (w);
Clark County Regional Flood Control District (w);
Clark County Sanitation District (w);
Douglas, County of (w);
Elko, County of (w);
Las Vegas, City of (w);
Las Vegas Valley Water District (g,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),
 Human Resources, Division of Health, Consumer Health Protection Services (w),
 Transportation (w);
Nevada Senate Interim Finance Committee (w);
Regional Water Planning-Advisory Board (w);
Reno, City of (w);
South Lake Tahoe (California), City of (w);
South Lake Tahoe Public Utility District (w);
Summit Lake Paiute Tribe (w);
Tahoe Regional Planning Agency (w);
University of Nevada-Reno, Department of Civil Engineering (w)

New Hampshire
New Hampshire Department of—
 Environmental Services (w),
 Resources and Economic Development (g),
 Transportation (w)

New Jersey
Bergen County Department of Public Works (w);
Brick Township Municipal Utilities Authority (w);
Camden County Board of Chosen Freeholders (w);
Cape May, City of (w);
Gloucester County—
 Health Department (w),
 Planning Commission (w);
Greenwich, Township of (w);
Lower, Township of, Municipal Utilities Authority (w);
New Jersey Department of—
 Agriculture (w),
 Environmental Protection, Division of Water Resources (g,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);
Albuquerque, City of (w);
Albuquerque Metropolitan Arroyo Flood Control Authority (w);
Canadian River Municipal Water Authority (w);
Costilla Creek Compact Commission (w);
El Paso Water Utility (w);
Gallup, City of (w);
Highlands University (w);
Las Cruces, City of (w);
Las Vegas, City of (w);
Los Alamos, County of (w);
Navajo Indian Nation (w);
New Mexico Bureau of Mines and Mineral Resources (g,w);
New Mexico Environmental Improvement Division (w);
New Mexico Department of Highways (w);
New Mexico Interstate Stream Commission (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);
Ruidoso, Village of (w);
Santa Fe Metropolitan Water Board (w);
Santa Rosa, City of (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);
Cornell University—
Department of Natural Resources (w),
Department of Utilities (w);
Dutchess, County of, Environmental Management (w);
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 (w), Division of Water (w),
Transportation, Bridge and Construction Bureau (w);
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 of, Department of Public Works (w);
Oswego, County of, Health Department (w);
Saratoga, County of (w);
Schuyler, County of (w);
Suffolk, County of—
Department of Health Services (w),
Water Authority (w);
Tug Hill Commission (w);
Tompkins, County of, Department of Planning (w);
Ulster, County of, County Legislators (w);
Westchester, County of—
Department of Health (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);
Jacksonville, City 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);
University of North Carolina, Charlotte (w)

North Dakota
Dickinson, City of (w);
Lower Heart River Water Resources District (w);
North Dakota Geological Survey (g,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);
Geauga County Planning Commission (w);
Lima, City of (w);
Lucas, County of (w);
Miami Conservancy District (w);
Ohio Air Quality Development Authority (w);
Ohio Department of—
Natural Resources (w),
Transportation (n,w);
Ohio Environmental Protection Agency (w);
Ohio State University (w);
Ohio Water Development Authority (w);
Roseville, City of (w);
Ross, County of (w);
Sandusky, County of (w);
Seneca Soil and Water District (w);
Toledo Metropolitan Area Council of Governments (w);
University of Toledo (w);
Wood, County of (w)

Oklahoma
Ada, City of (w);
Altus, City of (w);
Central Oklahoma Master Conservancy District (w);
Edmond, City of (w);
Fort Cobb Reservoir Master Conservancy District (w);
Foss Reservoir Master Conservancy District (w);
Lawton, City of (w);
Lugert-Altus Irrigation District (w);
Mountain Park Master Conservancy District (w);
Norman, City of (w);
Oklahoma City, City of (w), 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 (w)—
Water and Sewer Department (w),
Department of Storm Water Management (w)

Oregon
Clark County Intergovernmental Resources Center (w);
Confederated Tribes of—
Umatilla Indian Reservation (w),
Warm Springs Indian Reservation (w);
Coos Bay-North Bend Water Board (w);
Douglas, County of, Department of Public Works (w);
Eugene, City of, Water and Electric Board (w);
McMinnville, City of, Water and Light Department (w);
Oregon Department of—
Fish and Wildlife (w),
Forestry (n),
Geology and Mineral Industries (g,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);
Portland, City of, Bureau of Environmental Services (w)

Pennsylvania
Academy of Natural Sciences of Philadelphia (w);
Allentown, City of (w);
Berks, County of (w);
Bethlehem, City of (w);
Chester, County of, Water Resources 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);
Lancaster County Planning Commission (w);
Letort Regional Authority (w);
Media Borough Water Department (w);
Neshaminy Water Resources Authority (w);
New York State Department of Environmental Conservation (w);
Philadelphia, City of, Water Department (w);
Pennsylvania Department of—
Agriculture (w),
Environmental Resources—
Bureau of Mining and Reclamation (w),
Bureau of Topographic and Geologic Survey (g,n,w),
Bureau of Water Quality Management (w),
Office of Water Resources Management (w);
Susquehanna River Basin Commission (w);
University Area Joint Authority (w);
University of Delaware, Geological Survey (w);
Williamsport, City of (w)

Puerto Rico
Puerto Rico Aqueduct and Sewer Authority (w);
Puerto Rico Department of Natural Resources (g,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);
University of Puerto Rico (w)

Rhode Island
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);
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);
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 Water Resources Research Institute (w);
South Carolina Wildlife and Marine Resources Department (w);
Spartanburg Sanitary Sewer District (w);
Spartanburg Water System (w);
University of South Carolina (g);
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 (w),
Water and Natural Resources—
Geological Survey Science Center (g,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);
Bell Buckle, City of (w);
Dickson, City of (w);
Eastside Utility District (w);
Franklin, City of (w);
Hamilton, County of (w);
Hixson Utility District (w);
Humphreys, County of (w);
Hyson Utility District (w);
Jackson, City of (w);
Lawrenceburg, City of (w);
Lincoln, County of, Board of Public Utilities (w);
Memphis, City of, Light, Gas, and Water Division (w);
Memphis State University (w);
Metropolitan Governments, Nashville, City of, and Davidson, County of (w);
Murfreesboro, City of (w);
Rogersville, Town of (w);
Sevierville, City of (w);
Shelby, County of (w);
Tennessee Department of—
Health and Environment (w)—
Construction Grants and Loans (w),
Division of Superfund (w),
Environmental Policy Group (w),
Division of Groundwater Protection (w),
Division of Solid Waste Management (w),
Transportation, Division of Research (w);
Tennessee State Planning Office (w);
Tennessee Wildlife Resources Agency (w);
Union City, City of (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—
Planning and Engineering (w),
Public Works Department (w);
Edwards Underground Water District (w);
El Paso, City of, Public Service Board (w);
Fort Stockton, City of (w);
Franklin, County of, Water District (w);
Gainesville, City of (w);
Galveston, County of (w);
Garland, City of (w);
Georgetown, 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 Colorado River Authority (w);
Lower Neches Valley Authority (w);
Lubbock, City of (w);
Nacogdoches, City of (w);
North Central Texas Municipal Water Authority (w);
Northeast Texas Municipal Water District (w);
Orange, County of (w);
Pecos River Commission (w);
Red Bluff Water Power Control District (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),
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 Bureau of Economic Geology (g);
Texas State Department of Highways and Public Transportation (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);
Upper Guadalupe River Authority (w);
Upper Neches River Municipal Water Authority (w);
Upper Trinity Basin Water Quality Compact (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);
Republic of Palau (w)

Utah
Bear River Commission (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);
Utah Department of—
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);
Weber Basin Water Conservancy District (w)

Vermont
Department of Natural Resources (n);
Office of the State Geologist (g)

Virginia
Accomack, County of (w);
Alexandria, City of (w);
Clarke, County of (w);
Henrico, County of (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 Mined Land Reclamation (w),
Division of Mineral Resources (g,n),
Transportation (w);
Virginia Beach, City of (w);
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, Lights Department (w);
Chelan, County of, Public Utility District No. 1 (w);
Douglas, County of, Public Utility District No. 1 (w);
Hoh Indian Tribe (w);
King, County of (w)—
Department of Public Works (w),
South Regional Water Association (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);
San Juan County Board of Commissioners (w);
Seattle, City of, Department of Lighting (w);
Skagit, County of (w), Department of Public Works (w);
Snohomish, County of (w);
Spokane Agency (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 (g,w),
Emergency Management (w),
Fisheries (w),
Natural Resources (g,w),
Transportation (w);
University of Washington (g);
Walla Walla, City of (w);
Whatcom, County of, Department of Public Works (w);
Yakima Tribal Council (w)

West Virginia
Jefferson County Commission (w);
Morgantown, City of, Utility Board (w);
Washington Public Service District (w);

West Virginia Department of—
Energy (w),
Highways (w),
Natural Resources, Division of Water Resources (w);
West Virginia Geological and Economic Survey (n,w)

Wisconsin
Bad River Tribal Council (w);
Balsam Lake Protection and Rehabilitation District (w);
Beaver Dam, City of (w);
Big Muskego Lake District (w);
Chippewa, County of, Land Conservation Department (w);
Dane, County of—
Department of Public Works (w),
Regional Planning Commission (w);
Delavan, Town of (w);
Delavan Lake Sanitary District (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);
Middleton, City of (w);
Morris Lake Management District (w);
Noquebay Lake District (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);
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 (g,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);
Laramie, County of (w);
Northern Arapahoe Tribe (w);
Shoshone Tribe, Shoshone Business Council (w);
Sublette, County of (w);
Uinta, County of (w);
Water Development Commission (w);
Western Wyoming Community College (w);
Wyoming Department of—
Agriculture (w),
Economic Development and Stabilization Board (w),
Environmental Quality (w),
Highways (w);
Wyoming Geological Survey (g);
Wyoming State Engineer (n,w);
Wyoming Water Research Center (w)

Federal Cooperators

Central Intelligence Agency (g,n)

Department of Agriculture
Agricultural Research Service (w);
Agricultural Stabilization and Conservation Service (n);
Forest Service (n,w);
National Agricultural Statistics Service (n);
Soil Conservation Service (g,n,w)

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

Department of the Army (n,w)
Aberdeen Proving Ground (w);
Army Signals Warfare Laboratory (n);
Avionics R and D Activity (g);
Coastal Engineering Research Center (g);
Corps of Engineers (g,n,w);
Fort Carson Military Reservation (w);
Mobility Equipment Research and Development Command (g);
Picatinny Arsenal (w);
Research Office, Triangle Park, NC (g);
Waterways Experiment Station, Vicksburg (g,w);
White Sands Missile Range (w)

Department of Commerce
Bureau of the Census (n);
Coastal Plains Regional Action Planning Commission (g);
National Ocean Survey (n);
National Oceanic and Atmospheric Administration (g,n,w);
National Weather Service (g,n,w)

Department of Defense Agencies
Defense Advanced Research Projects Agency (g);
Defense Logistics Agency (w);
Defense Mapping Agency (g,n);
Defense Nuclear Agency (g);
Defense Intelligence Agency (g,n)

Department of Energy (n,w)
Albuquerque Operations Office (g,w);
Bonneville Power Administration (w);
Chicago Operations Office (g,w);
Idaho Operations Office (g,w);
Lawrence Livermore Laboratory (g);
Los Alamos National Laboratory (g);
Nevada Operations Office (g,w);
Oak Ridge Operations Office (g,w);
Office of Energy Research (g);
Procurement Operations Office (g);
Richland Operations Office (g,w);
San Francisco Operations (g);
Sandia National Laboratories (g,w);
Savannah River Operations Office (n,w);
United States Arms Control and Disarmament Agency (g);
Western Area Power Administration (g,n,w)

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

Department of Justice (w)

Department of the Navy (w)
Naval Explosive Ordnance Disposal 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);
International Boundary and Water Commission, U.S. and Mexico (w);
International Joint Commission, U.S. and Canada (w)

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

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

Environmental Protection Agency (n,w)
Corvallis Environmental Research Laboratory (w);
Environmental Monitoring Systems Laboratory (g);
Office of Environmental Engineering and Technology (g);
Office of Pesticides Programs (w);
Office of Waste Programs Enforcement (w)

Federal Emergency Management Agency (g,w)

Federal Energy Regulating Commission Licensees (w)

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

National Science Foundation (g,n,w)

Navajo and Hopi Indian Relocation Commission (g)

Nuclear Regulatory Commission (g)

Tennessee Valley Authority (n,w)

Veterans Administration (g,w)

Other Cooperators and Contributors

Government of Saudi Arabia (g,w)

People's Republic of China (g,w)

United Nations
United Nations Development Program (g,w);
UNESCO (w);
World Meteorological Organization (w)

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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U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849