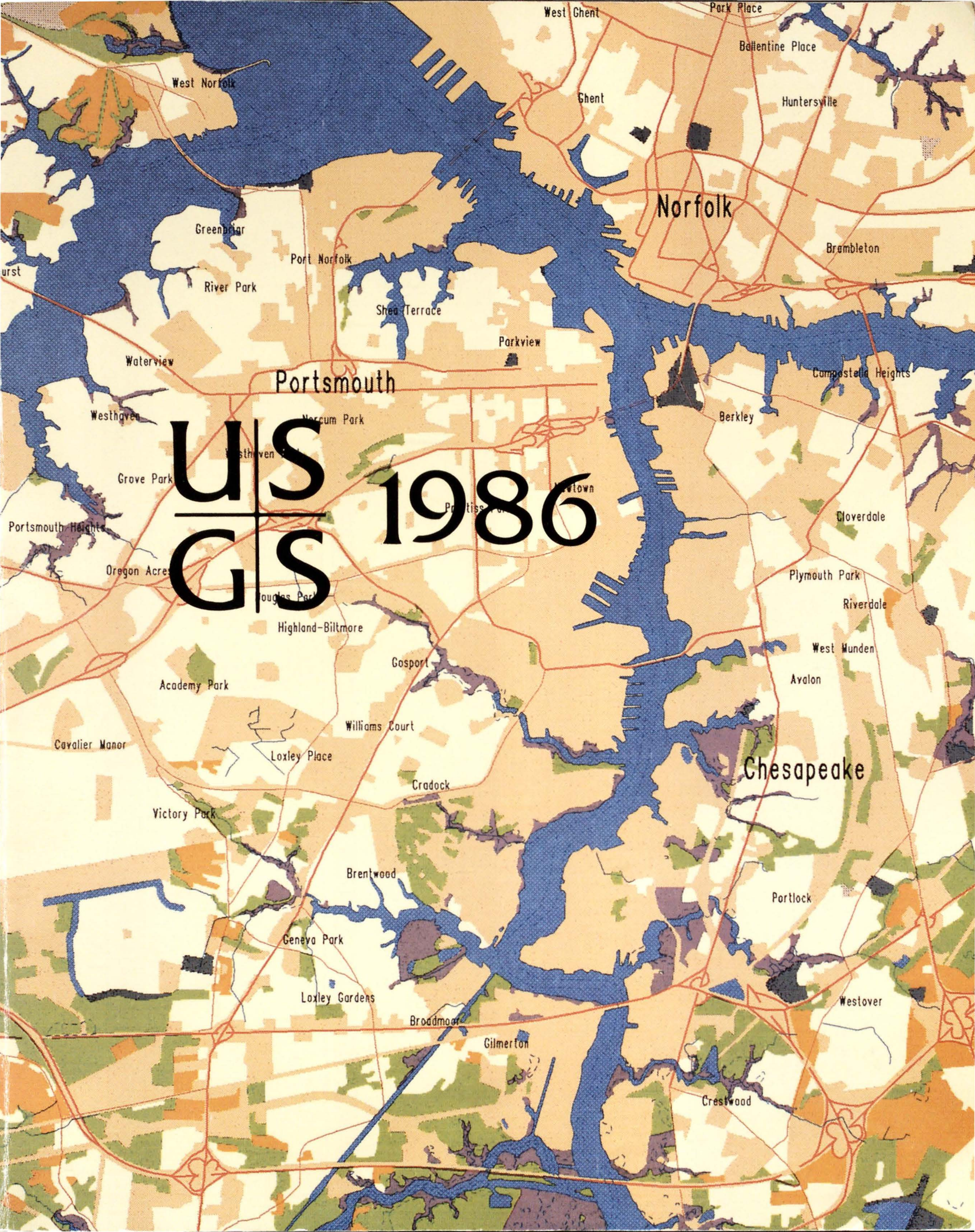

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West Ghent
Park Place
Ballentine Place
West Norfolk
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Huntersville
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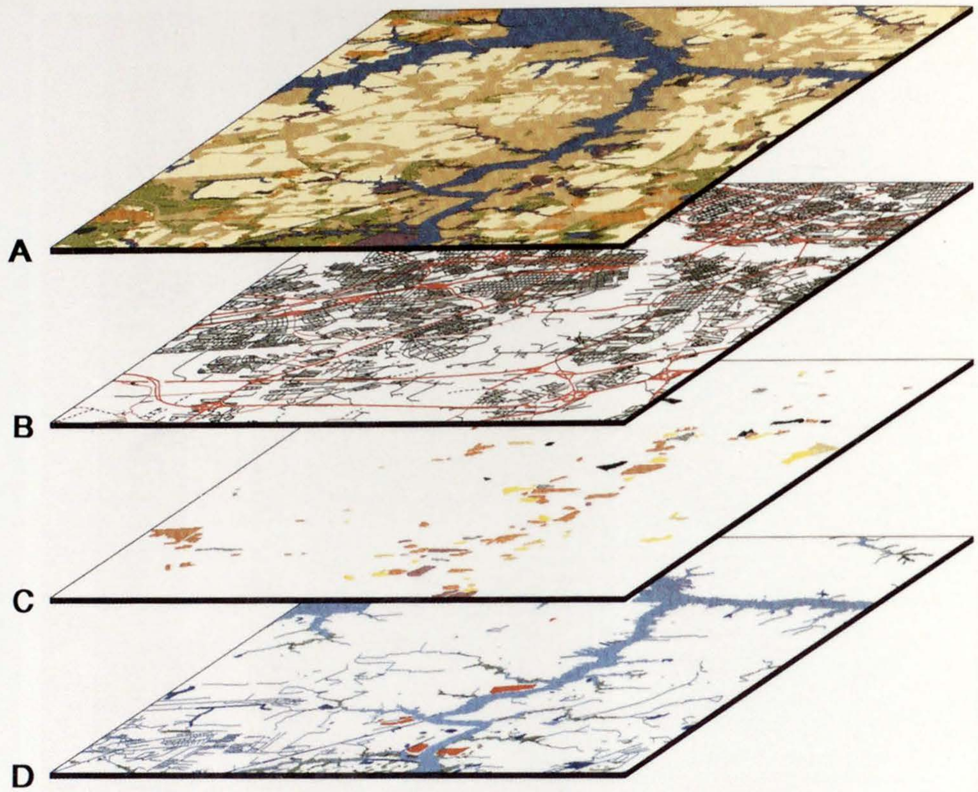
Greenbriar
Port Norfolk
Brambleton
River Park
Shea Terrace
Parkview
Waterview
Portsmouth
Campostella Heights
Westhaven
Berkley
Grove Park
Cloverdale
Portsmouth Heights
Oregon Acres
Plymouth Park
Riverdale
Highland-Biltmore
West Munden
Gosport
Avalon
Academy Park
Williams Court
Cavalier Manor
Loxley Place
Chesapeake
Cradock
Victory Park
Brentwood
Portlock
Geneva Park
Loxley Gardens
Westover
Broadmoor
Gilmerton
Crestwood



EXPLANATION

A. Land use-land cover

B. Transportation DLG

C. Potential hazardous waste

D. Hydrography DLG

Computerized geographic information systems (GIS) are now widely used to analyze and manage an enormous volume of land use data assembled from hundreds of sources. The cover of this volume is an image from the Elizabeth River Geographic Information System Project in Virginia. This study, conducted in cooperation with the Environmental Protection Agency, uses techniques developed in the Geological Survey's GIS Research Laboratory in Reston, Va.

A GIS image is constructed from layers of digital information. An example of this process is shown here. The four layers of information include transportation, hydrography, potential hazardous waste data, and photo-interpreted land use and land cover data. These layers can be combined to create products like the one shown on the cover, which was produced by overlaying some of the hydrography, transportation, and geographic names data on the land use data. A similar plot drawn on a computer screen can be used to access associated data. For example, when a potential hazardous waste site is identified on the screen, the computer can return a variety of stored information about the site, such as size, ownership, presence of pollutants, and vegetation. Thus, GIS technology provides a rapid, efficient means of analyzing data acquired from a wide variety of sources.

New GIS activities use digital spatial data sets to provide scientists and the public with opportunities to obtain useful insights and products. The article titled "Geographic Information System Development," found on page 102 of this volume, gives more detailed information on the Geological Survey's involvement in this new and rapidly expanding field.

United States Geological Survey Yearbook Fiscal Year 1986

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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

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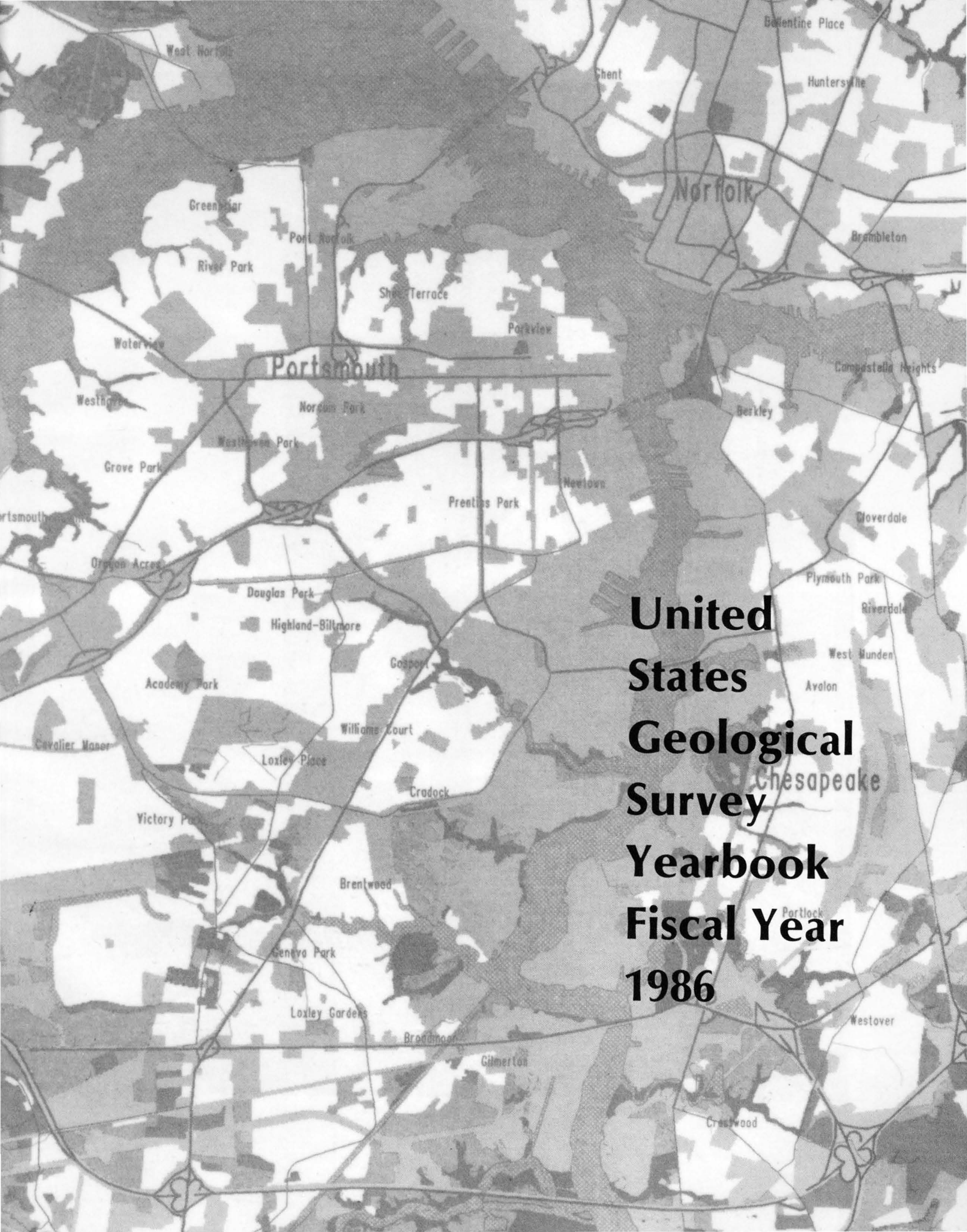

United States Geological Survey Yearbook Fiscal Year 1986

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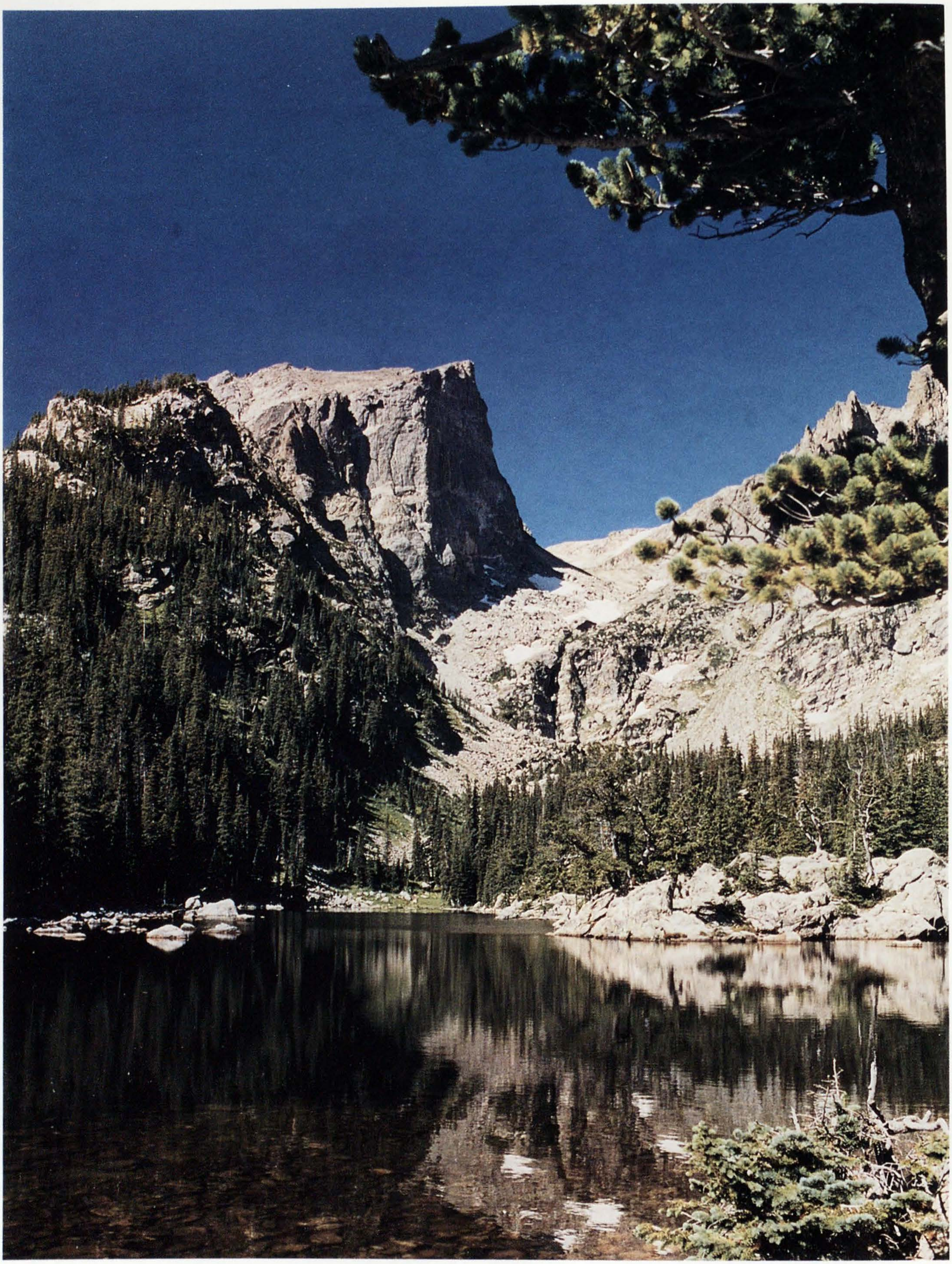
Bristlecone pine, Mount Evans, Colorado Front Range. (Photograph by Dawn Reed, U.S. Geological Survey.)



DEDICATION

This volume of the U.S. Geological Survey Yearbook is special, the first we have ever dedicated to an individual. While we were preparing this report, Vincent E. McKelvey, eminent scientist and former Director of the Geological Survey, died. Because of his deep devotion not only to his science but also to the agency and to the public that he served, we dedicate the 1986 Yearbook to Vince's memory.

In any organization, there are always those individuals who stand out as exemplary workers whose contributions remain long after their daily presence has ended. Vince was one of those people. He brought more to his time as Director than just his dedication to the science of geology; he brought a rich understanding of what the Geological Survey was all about. He held firm to the principle that the Survey's role is that of an impartial fact-finding agency that makes its results available to decisionmakers. He impressed upon us the need to pay close attention to national issues and to discerning and developing the earth-science information that addresses those concerns.

In one of his last public statements, Vince delivered a sobering reminder to earth scientists and our colleagues in private industry and at all levels of government: "Ten years ago, during the Nation's Bicentennial celebration, we first described the challenge to find the mineral and energy resources to build a second America in the next several decades. That challenge is still with us: we will have to find and develop in the next few decades the same amount of mineral and energy resources that we consumed in our first 200 years." To build a second America, the Nation must have results of scientific research and investigations that are readily available and readily usable.

Vince understood that the way in which the results of basic research and scientific investigations are presented can be as important as the result themselves, that how and how soon we make those results available can be as critical as the science we develop to produce those results. The earth-science information upon which we base our reputation for responsive public service must be communicated effectively. That need to communicate and to be responsive to the Nation we serve is a tremendous responsibility and one that we need to remember in dealing with

Colorado's Hallet Peak and Dream Lake. (Photograph by Dawn Reed and David Gates, U.S. Geological Survey.)

our cooperators and colleagues and with administrative and congressional officials.

Vince described the need to communicate as "one final problem that is in itself not primarily of a scientific character but is as difficult and important as the others—namely, the problem of communicating the results of our work to the public in a way that they can be understood and used."

The science of our Earth is as dynamic and as challenging as the planet we seek to understand and describe. The issues we deal with in the following pages underscore the importance of a continued dedication to the earth sciences. If we are to meet the challenges of the Earth's dynamic nature, unlock its critical resources, and build toward a safe and sound "second America," we must work hard, and we must work together as scientists, planners, managers, and legislators. Through the intensive cooperative framework that has been developed during the Geological Survey's long history with more than 1,000 other Federal, State, and local agencies and governments and through exchanges with academic and private industry organizations as well as with our many professional and scientific counterparts, we will work to ensure that the Nation has and will continue to have the necessary earth-science information.

As public scientists, we remember the example set by former Director McKelvey, and we rededicate ourselves to making continued strides in understanding the Earth and in providing knowledge in a useful fashion to the Nation that we serve.

Dallas L. Peck
Director

Vincent Ellis McKelvey
1916–1987

Vallecitos Nuclear Center, Pleasanton, Calif. (Photograph by Darrell Herd, U.S. Geological Survey.)

PERSPECTIVES

LOW-LEVEL RADIONUCLIDE TRANSPORT: A CASE STUDY

By Barbara J. Ryan

Introduction

Shallow land burial is the predominant method of disposing of low-level radioactive wastes in the United States. Wastes from private and commercial sources historically have been buried in six commercial repositories, three of which are currently active, while wastes generated by the Federal Government have been disposed of at seven sites (six are currently active) operated by the U.S. Department of Energy (fig. 1). The Low-Level Radioactive Waste Policy Act of 1980 (Public Law 96-573) and the Low-Level Radioactive Waste Policy Amendments Act of 1985 (Public Law 99-240) may result in the establishment of eight or more new commercial disposal sites by 1990. Under the provisions of the acts, each State is responsible for the disposal of low-level radioactive waste generated within its borders. To comply with the acts, most States are joining in compacts with neighboring States to develop regional disposal sites.

The U.S. Geological Survey has participated directly and indirectly (as a technical consultant to the U.S. Department of Energy, the U.S. Nuclear Regulatory Commission, and the U.S. Environmental Protection Agency) in hydrogeologic investigations at many of the low-level radioactive waste disposal sites around the country. Field studies have been (and in some instances continue to be) conducted at the following disposal sites and other related areas: Argonne National Laboratory, Ill.; Barnwell, S.C.; Beatty, Nev.; Bellfield, N. Dak.; Idaho National Engineering Laboratory, Idaho; Maxey Flats, Ky.; Oak Ridge, Tenn.; Savannah River Plant, Ga.; Sheffield, Ill.; Weldon Spring, Mo.; West Valley, N.Y.; and Wood River Junction, R.I. Studies of these sites have identified many of the hydrogeologic problems encountered in shallow land burial of low-level radioactive wastes. The objective of the ongoing Geo-

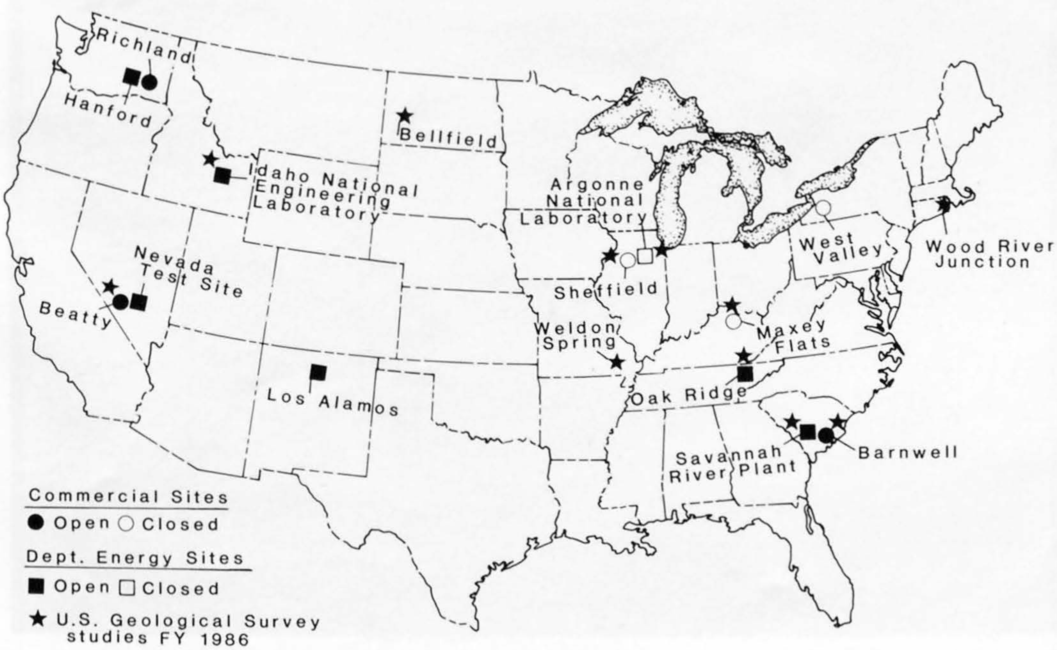


Figure 1. *Locations of low-level radioactive waste disposal sites and related U.S. Geological Survey studies.*

logical Survey Low-Level Radioactive Waste Program is to develop hydrogeologic guidelines that can be used by the U.S. Department of Energy to select and operate new sites for the disposal of low-level radioactive wastes and to provide advice and the results of studies of processes, environments, and techniques of hydrogeologic evaluations.

This perspective describes briefly the Sheffield, Ill., study, including the numerous avenues by which radionuclides can be transported through the hydrogeologic environment, and some of the conclusions reached during the 10 years that a team of Geological Survey scientists has been investigating the Sheffield site.

Site Description

The low-level radioactive waste disposal site near the northwestern Illinois town of Sheffield is situated on 20 acres of rolling terrain (fig. 2). Twenty-one trenches were constructed in glacial deposits and filled with radioactive waste from August 1967 through April 1978. Burial operations were suspended in 1978 when licensed burial space was depleted.

Nineteen of the 21 trenches were constructed in undisturbed deposits; the base of each trench was at least 10 feet above the water table. Two trenches were constructed above the existing land surface (like a raised bed) in fill consisting of compacted soil. Trenches ranged in length from 35 to 580 feet, in width from 8 to 70 feet, and in depth from 8 to 26 feet. Typical trench dimensions and the method of waste material deposition are shown in figures 3*A*, 3*B*, and 3*C*. Approximately 3,200,000 cubic feet of waste were buried in the 21 trenches.

Role of the U.S. Geological Survey

In 1976, the Geological Survey began a study of the mechanisms and avenues by which radionuclides might move within and from the Sheffield site. Because it was anticipated that water movement would play a primary role in releasing radionuclides from the trenches, the following aspects of the hydrologic environment were studied: (1) climatology; (2) surface hydrology, including runoff, sediment transport, and surface collapse; (3) geology;

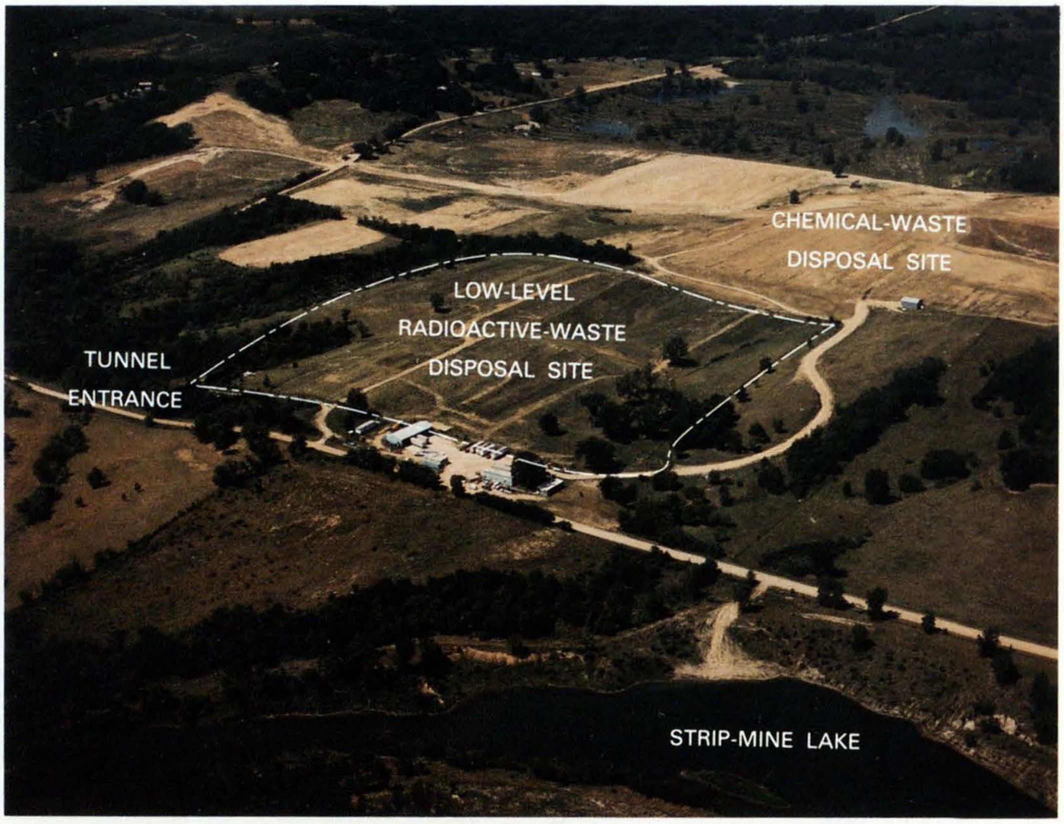


Figure 2. *Aerial view, looking west, of the Sheffield, Ill., low-level radioactive waste disposal site, summer 1985. (Photograph courtesy of Jerry Abbey Aerial Photography, Cambridge, Ill.)*

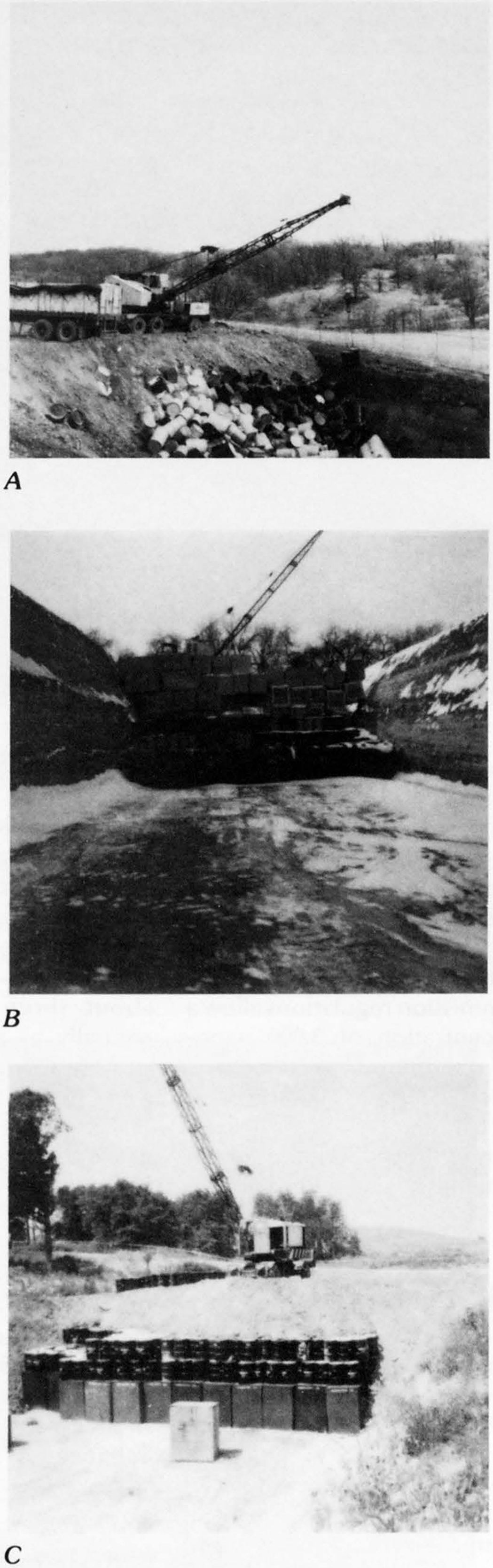


Figure 3. *Methods of low-level radioactive waste disposal at Sheffield, Ill.* A, *Undated.* B, *Winter 1977.* C, *Summer 1976. (Photographs courtesy of US Ecology, Inc., Louisville, Ky.)*

(4) unsaturated- and saturated-zone hydrology; (5) water chemistry; and (6) gas transport. Research into surface-water hydrology, unsaturated-zone flow, and gas transport is still being conducted at the site.

The order in which these six research topics have been presented approximates the manner in which water moves through the hydrologic cycle and thus encourages a process-oriented view of radionuclide transport. The Geological Survey's investigation of climatology and surface hydrology at the site allows estimation of the rate, timing, and amount of infiltrating water that would be available to transport radionuclides from the buried waste material. Studies of the geohydrology of the unsaturated and saturated zones identify potential or preferential paths of flow. Studies of water chemistry and gas transport define naturally occurring reactions and the effects of low-level waste burial on these reactions.

Climatology

Microclimate and evapotranspiration (loss of water from soil and plants to the overlying atmosphere) were studied at the site from July 1982 through June 1984. Continuous measurements were made of incoming and emitted long- and short-wave radiation, net radiation, soil heat flux, soil temperature, horizontal wind speed, and wet- and dry-bulb air temperatures. Instruments used to monitor the meteorological regime are shown in figure 4.

Annual mean precipitation (36 inches) and mean temperatures (51 °F) were almost identical to long-term averages from nearby National Weather Service stations. Three methods were used to estimate evapotranspiration: an energy budget, an aerodynamic profile, and a water budget. Yearly estimates from all three methods ranged from 24.8 to 25.8 inches and averaged 70 percent of annual precipitation and 75 percent of annual potential evapotranspiration. Seasonal trends in evapotranspiration rates were similar to those in net radiation; the highest rate usually occurred in July, and the winter months exhibited the lower rates. Precipitation that infiltrates is either stored in the unsaturated zone, where it becomes available for evaporation or transpiration, or moves downward toward the saturated zone. The amount of water stored in the unsaturated zone at Sheffield is greatest in early spring and least in late summer.

Figure 4. *Instruments used for meteorological and unsaturated zone monitoring at Sheffield, Ill., spring 1984. (Photograph by M. Peter deVries, Water Resources Division, U.S. Geological Survey.)*

Water extracted from alfalfa, brome grass, and red clover samples collected from three locations from 1982 through 1985 was analyzed for tritium. Tritium is the only radionuclide in pore water and ground water at the site that has been detected in concentrations above background levels (about 0.2 nanocuries per liter). (Nuclear Regulatory Commission regulations allow a maximum concentration of 3,000 nanocuries per liter of tritium for release into water.) Tritium concentrations in the plant extracts ranged from 1 to 14 nanocuries per liter; alfalfa (the deepest rooted plant) contained the highest concentrations.

Surface-Water Hydrology

Surface runoff and sediment transport were monitored in three basins that comprise two-thirds of the 20-acre site, in an approximately 4-acre undisturbed basin near the site, and in four plots that averaged 100 square feet in size. Two of the small plots were located on trench covers, and two were in the undisturbed basin.

Mean annual surface runoff from the waste disposal site averaged 8 inches from July 1982 through June 1984, in comparison with less than 2 inches from the undisturbed basin. Surface runoff from the small onsite plots also was greater than that from the small offsite plots; however, very little runoff occurred from any plots during periods of high evapotranspiration.

Annual sediment carried in runoff from the 20-acre site (2 tons per acre) was more than 200 times that carried from the 4-acre undisturbed area. However, collapse moved about three times as much sediment annually as surface runoff did. Approximately 300 surface collapses (figs. 5*A*, 5*B*) were recorded at the site from October 1978 through December 1985. Two-thirds of the collapses were recorded in February, March, and April. Although collapse rates for the second half of the period of record were 2.5 times the rates during the first half, the mean volume of collapse cavities during the second half was only 43 percent of the mean volume of collapses that occurred during the first half of the period. In addition to affecting the stability of the surface at the site, the collapse features may enhance recharge (fig. 5*B*).

Geology

Much of the early research at the Sheffield site concentrated on defining the complex stratigraphy. Lake sediments, glacial till, glacial outwash, and wind-deposited sediments compose the unconsolidated deposits at the site. These sediments are underlain by Pennsylvanian-age shales and mudstones. Deposits range from small isolated lenses to fairly extensive, continuous beds; materials range in size from clay-sized particles to cobbles.

Figure 5. *Surface collapse features at Sheffield, Ill.* A, *Recollapse created a hole about 4 feet wide, spring 1984.* B, *Radiation detection probe of collapse feature approximately 5 feet deep, fall 1985. (Photograph* A *by John R. Gray and* B *by M. Peter deVries, Water Resources Division, U.S. Geological Survey.)*

A

B

Hydrology of the Unsaturated Zone

To study and collect data on water moving through the unsaturated zone, a horizontal tunnel 6 feet in diameter and approximately 400 feet long was constructed beneath 4 waste trenches (fig. 6). Instruments included soil-moisture tensiometers, piezometers extending through the tunnel floor to the saturated zone, soil-suction lysimeters, and gravity-drain lysimeters.

During the spring, which is generally a wet season in the Midwest, water moves from the surface through the unsaturated zone to the saturated zone. The heterogeneity and layering of different geologic units cause the rates of water movement to vary substantially throughout the site. Sloping interfaces between materials that have different physical properties can provide preferential pathways for flow, adding a horizontal component to otherwise vertical water movement in the unsaturated zone. Because of the complexity of the site, delineation of individual flow paths is not practical.

Concentrations of tritium originating in the buried waste vary seasonally in the unsaturated zone. Increased tritium concentrations occur in the spring, possibly because shallow pore water moves upward under the increasing influence of evapotranspiration and deeper pore water moves downward as seasonal recharge to the saturated zone.

Hydrology of the Saturated Zone

More than 100 observation wells and borings were drilled at and adjacent to the site to study the hydrology of the saturated zone. Most of the geologic units, with the exception of a pebbly sand unit, have relatively low hydraulic conductivities, on the order of 10^{-7} to 10^{-9} feet per second. The hydraulic conductivity of the pebbly sand unit, which underlies roughly two-thirds of the site, ranges from approximately $2x10^{-3}$ to $8x10^{-7}$ feet per second. This unit grades from a clean, well-sorted pebbly sand in the eastern part of the site to a moderately sorted, silty sand in the western part.

Figure 6. *Tunnel entrance, looking south, before natural grade was reestablished, winter 1978. (Photograph by James B. Foster, Water Resources Division, U.S. Geological Survey.)*

The generally eastward flow in the saturated zone probably represents the greatest potential for moving radionuclide contamination offsite, especially in the more permeable pebbly sand unit, where relatively high ground-water velocities (up to 2,500 feet per year) have been measured. Tritium, in addition to having been detected in several wells both onsite and offsite, has been detected in seeps along the edge of a strip-mine lake east of the site (fig. 2).

Water Chemistry

Approximately 30 soil-suction lysimeters were used to collect unsaturated-zone pore-water samples from trench caps, between the trenches, beneath the trenches, and offsite. Observation wells were used to collect water from the saturated zone; precipitation samples also were collected. Samples were analyzed for major cations and anions, dissolved organic carbon (DOC), pH, specific conductance, alkalinity, gross alpha and beta radiation, and tritium.

Analysis indicated that the chemistry of waters in the flow system is as follows: precipitation, calcium sulfate; unsaturated zone, calcium magnesium bicarbonate; and saturated zone, magnesium bicarbonate. The chemistry of water in the various geologic units was influenced by the units' mineralogy.

For sampling points in the unsaturated zone, increasing DOC and tritium concentrations corresponded to the proximity of the trenches. Offsite, DOC and tritium in the unsaturated zone were near detection limits. For sampling points in the saturated zone, DOC concentrations ranged from background (0.2 milligrams per liter) to 6.3 milligrams per liter, and tritium concentrations ranged from background (0.2 nanocuries per liter) to approximately 175 nanocuries per liter.

Gas Transport

Bacterial decomposition of buried wastes produces gases that are transported from the waste-disposal trenches through the unsaturated zone, to either the atmosphere or the saturated zone. A two-dimensional network of gas piezometers, consisting of five sampling ports in each of three boreholes, was used to collect gas samples analyzed for nitrogen, oxygen plus argon, carbon dioxide, methane, ethane, propane, isobutane, n-butane, carbon-14 dioxide, tritiated water vapor, and radon-222.

Natural background concentrations and gas concentration gradients near the waste trenches were determined for subsequent use in calculating fluxes of waste-generated gases. Horizontal gradients of carbon-14 dioxide and methane that originated in the buried waste were identified. A gradient of carbon dioxide was indicated but could not be accurately defined, because concentrations were affected by downward fluxes of carbon dioxide from the root zone. Concentrations of the other gases were measured, but no discernible gradients were noted.

Conclusions

Many factors affect the quantity, rate, and timing of both water and solute movement, and combined research efforts at the Sheffield site have led to a better understanding of the hydrogeologic environment necessary for shallow land burial of low-level radioactive wastes. In addition to the findings and results already mentioned, several conclusions drawn from this research can be used by the U.S. Department of Energy to help select and operate new sites for the burial of low-level radioactive wastes. Although these conclusions are not all-encompassing, they do represent factors that warrant consideration in the disposal of low-level radioactive wastes.

- A seemingly simple geologic setting may, in fact, be quite complex. As additional drilling and other investigations are conducted and as the data base expands, previously unmapped or generalized lithologic features may become evident and quite significant. These features may have a major effect on water and radionuclide movement, in both the unsaturated and the saturated zones.
- Scale becomes a significant factor in trying to predict the avenues or pathways for radionuclide transport. In an areal appraisal, for example, hydrogeologic and hydraulic properties can be averaged without introducing undue errors in the end result; in a detailed site study, however, such averaging may cause significant errors.
- Accurate records concerning trench construction, dimensions, contents, and durability of the postburial trench cap are essential for evaluating methods of disposal, determining potential contaminants, and monitoring water and radionuclide movement from the trenches.
- Good surface drainage, a grass cover, and a compacted soil layer are essential to reduce soil erosion, infiltration of precipitation, and offsite migration of radionuclides.
- Early, continuous, and long-term monitoring are required. The site may not function the same way over time. Vegetation and erosion continually change, for example, and trench-cap collapse may occur; precipitation and runoff may change; and other natural or artificial events may occur to change the hydrologic regime.
- In designing networks to monitor radionuclide release to the biosphere, it may be necessary to take a multidisciplinary approach and investigate radionuclide movement by soil gases, plants and animals, and surface and ground water.
- Constituents released from the burial trenches may not be limited to radionuclides. Other inorganic and organic constituents were detected at the Sheffield site, for example.
- Although the unsaturated zone is difficult to monitor because soil tensions inhibit the extraction of water, water-quality data from that zone should detect the release of contaminants from the waste trenches earlier than water-quality data from the saturated zone.
- Long-term maintenance is required to preserve the site. A vegetative cover, for example, will reduce erosion and increase evapotranspiration, but the establishment of deeply rooted plants may reduce the effectiveness of the trench cap and thus increase the potential for release of radionuclides. Differential compaction of the backfill and void space created by the decay and corrosion of waste containers may also result in the collapse of the trench caps and intertrench areas, providing access to infiltrating water and increasing the potential for release of radionuclides.

PRIMARY QUADRANGLE MAPPING: A PROGRAM IN TRANSITION

By Michael J. Chambers and Randle W. Olsen

Introduction

During the past 40 years, the U.S. Geological Survey has provided the Nation's map users with primary quadrangle map coverage at 1:24,000 scale in the lower 48 States and 1:63,300 scale in Alaska. This effort has produced about 50,000 separate maps. By the end of fiscal year 1986, primary quadrangle maps and related map products were available for about 92 percent of the country. Completion of initial coverage is scheduled for the beginning of fiscal year 1990.

As the number of areas needing primary coverage has decreased and the need for revised maps and digital cartographic data has increased, the Survey's traditional mapping program has become a program in transition.

Primary Mapping Program

The Primary Mapping Program is designed to provide current and accurate cartographic data to the user community nationwide. To accomplish this objective, the program has two long-range goals: (1) to provide primary cartographic data of standard content, currency, and accuracy to satisfy Federal, State, and local user needs and (2) to provide primary cartographic data in digital form from the National Digital Cartographic Data Base (NDCDB).

To attain these long-range goals and to continue the development of the Survey's digital systems, two special studies were conducted in 1985. One study concerned the programmatic issues of transforming from graphic to primarily digital techniques for map production while coping with a growing need to revise existing maps. The second study concerned the technical aspects of the transition. On the basis of these two studies, an integrated development production plan was adopted to guide the Geological Survey through the remainder of the century.

Primary Mapping Program Objectives

To provide the Nation with primary cartographic data of standard content, currency, and accuracy, six objectives must be obtained:

1 Complete initial national coverage at the primary map scales by fiscal year 2000. This undertaking will require the completion of 3,200 7.5-minute quadrangles in unmapped areas.
2. Convert 1,500 existing "T-maps" to published 7.5-minute format. T-maps were originally compiled during the 1950's and 1960's at 1:24,000 scale but published at 1:62,500 scale, which was the common map scale at that time. This objective is scheduled for completion in fiscal year 1991.
3. Recompile 5,000 substandard maps so that they reflect the most accurate and current data possible before they are digitized and entered into the NDCDB. This effort is expected to be completed in fiscal year 1999.
4. Recompile 6,280 deficient maps that reflect inappropriate contour intervals and (or) incomplete Public Land Survey System data. The objective is to accomplish recompilation of those data by fiscal year 1997.
5. Convert 8,300 provisional edition maps to standard maps before digitizing. Provisional maps, created to expedite national coverage, were produced by using modified techniques such as handlettering for contours, elevations, and descriptive labels. The graphic presentation of features and labels must be

consistent with that of standard maps before digitizing.

6. Maintain primary cartographic data already meeting standards of content, currency, and accuracy. About 32,000 of the Survey's primary maps meet these standards and thus can be digitized without revision. The objective is to maintain the primary cartographic data in a 10-year cycle of inspection and revision.

The estimated cost of the work required to attain these six goals is approximately $286 million (1985 dollars).

Program Development

As maps are revised, they will be digitized according to user requirements. As figure 1 shows, provisional map conversion will be implemented, but the method of conversion (graphic, digital, or a combination of both) is dependent on advances in digital technology.

Resources devoted to the ongoing revision program will increase as (1) the inventory of existing maps grows through 1989, (2) the deficient maps are corrected through 1999, (3) the maps that lack currency are added to the program, and (4) increased emphasis is placed on revision procedures to respond to new user requirements. Because procedures required to complete primary mapping and to convert substandard and deficient maps will be similar to those used to meet current requirements, the skills needed for traditional cartographic operations will remain essentially the same.

MARK II

The Geological Survey has been developing a major new production system, called MARK II, which has as its goal the implementation of advanced automated technologies and production procedures that will satisfy National Mapping Program requirements through the year 2000. At that time, the NDCDB should contain digital data representing the primary map series and other smaller scale series.

The goals for the MARK II effort within the National Mapping Program are to develop and implement specific production capabilities, including the establishment of more effective map revision procedures and improvements in product quality. The production scheme is shown in figure 2.

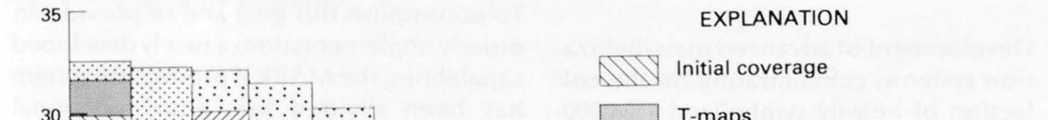


Figure 1. *Long-range plan for national cartographic baseline.*

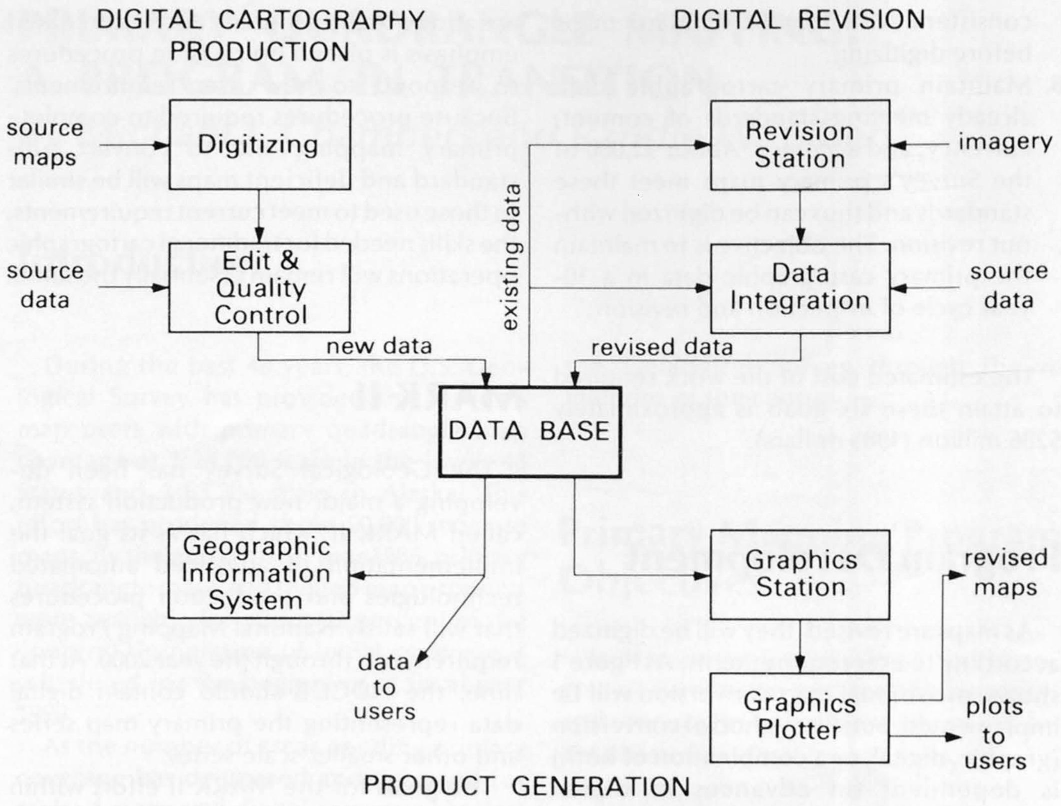


Figure 2. *MARK II production scheme for the 1990's to complete digitizing of primary source maps, to initiate and implement a digital map revision capability, and to provide users with high-quality cartographic products from digital data.*

MARK II Development Objectives

The development strategy proposed for MARK II addresses its major production capabilities and has the following objectives:

- Development of advanced mass digitization systems, concentrating on the collection of heavily symbolized 1:24,000-scale source data.
- Development of improved data verification and testing procedures, concentrating on improved automated data checking. Completion of data standards is included.
- Development of techniques for producing topographic and thematic graphic products from digital data contained in the NDCDB.
- Provision of digital data suitable for analysis and application by geographic information systems and related technologies.
- Development of an improved production management system to efficiently task and track multiple production activities.
- Improvement of NDCDB operations and structure to ensure that the data are maintained for optimum use in production.

MARK II System Design

The MARK II effort will result in the implementation of advanced automated technology and production procedures in Geological Survey map production centers. To accomplish this goal and to provide an orderly implementation of newly developed capabilities, the MARK II production system has been divided into four functional components, each under a component manager and designed to handle a specific portion of the production process. Each component has been further subdivided into a series of development modules, currently numbering 48, which consist of a set of defined and assigned tasks.

Data production component.—The data production component deals with all phases of data collection, editing, processing, quality control, and revision before data are entered into the NDCDB. This component is the largest and most complicated portion of the system to be developed. It includes both the development of efficient mass digitization and automatic feature-recognition capabilities for traditional cartographic symbolization and the development of methods for extracting features from imagery. The subsequent introduction of new equipment, software, and procedures into an already operational system will require skillful management.

Data base component.—The data base component is designed to implement improvements in the NDCDB that will enable a central data repository to support almost all of the Survey's map production activities. The development of two levels of data bases is required: (1) operational data bases located in each production center to support product generation and (2) an archival data base that will provide a central repository for data supporting the operational data bases. These data bases will be linked with high-speed data communication systems to transfer data and to support the public sale and distribution of products.

Product generation component.—The product generation component is designed to provide the capability to produce a variety of cartographic products, both graphic and digital, from base category data in the NDCDB.

Production management component.—The production management component is designed primarily as a two-way interface between the MARK II production system and the Primary Mapping Program production requirements and authorization systems. This interface will include reporting procedures and production tracking to ensure that MARK II activities are appropriately related to the requirements for digital and graphic products.

Conclusion

The Primary Mapping Program is now in a transitional stage. Essential to this transition is the National Digital Cartographic Data Base, which will evolve to become the central focus of most mapping activities, including maintenance and revision of the primary map series.

The design, development, and implementation of the MARK II system represent a major development activity within the Geological Survey. MARK II will take advantage of modern mapping technologies that will permit the Survey to become more responsive to user needs for digital cartographic data. The timing of this effort is essential to meet known and anticipated data requirements.

The Geological Survey has completed a long-range plan to bring all primary maps up to acceptable standards by the year 2000. To take advantage of the benefits associated with digital cartography, the Survey also plans to complete loading primary-scale digital cartographic data into the National Digital Cartographic Data Base by the same year. The plan is ambitious but will allow the Geological Survey to accomplish its mission to fully support Federal, State, and private user requirements for both graphic and digital cartographic data products.

PREDICTING THE NEXT MAJOR EARTHQUAKE IN THE PARKFIELD AREA OF CALIFORNIA

By William H. Bakun

In 1985, seismologists from the U.S. Geological Survey and the University of California, Berkeley, forecast that a moderate-sized earthquake of magnitude 6 is likely to occur in the Parkfield area of California within the next several years (1985-93). This forecast was the first to be officially endorsed and accepted by both the National and the California Earthquake Prediction Evaluation Councils. Parkfield lies along the San Andreas fault in a sparsely populated area of the California Coast Ranges 170 to 180 miles from San Francisco, about midway to Los Angeles. Five similar moderate (magnitude 6) earthquakes have occurred on the Parkfield section of the San Andreas fault since 1857. The intervals between earthquakes (in 1881, 1901, 1922, 1934, and 1966) have been remarkably uniform, the mean being 21.9±3.1 years. (Although the 1934 earthquake departed from the regular pattern by occurring a decade too early, the 1966 earthquake conformed to the regular pattern in that the 44-year period between 1922 and 1966 is twice the mean interval.) If the next Parkfield earthquake conforms to the pattern, it will occur before 1993, most probably in early (January) 1988. Figure 1 shows the epicenters of earthquakes associated with the 1934 and 1966 events.

The Geological Survey established an earthquake prediction experiment at Parkfield to observe the final stages of the process leading up to the predicted earthquake. Four observational networks (seismic, geodetic survey, continuous strain, and creep) are now monitoring the central San Andreas fault near Parkfield (fig. 2). A very dense network of seismograph stations monitors details of seismicity within and near the preparation zone, the region surrounding the epicenter of the 1966 earthquake (see fig. 2). Signals from the seismographs near Parkfield are telemetered continously to the central data-processing facility in Menlo Park, Calif. The signals are automatically and continously monitored by a real-time processor that, within a few minutes, routinely locates earthquakes in central California. Beeper and paging systems have been established to notify the appropriate scientists within minutes of all significant seismicity near the preparation zone.

A dense geodetic network having line lengths of 3 to 19 miles spanning the fault has been measured every 1 to 2 years since

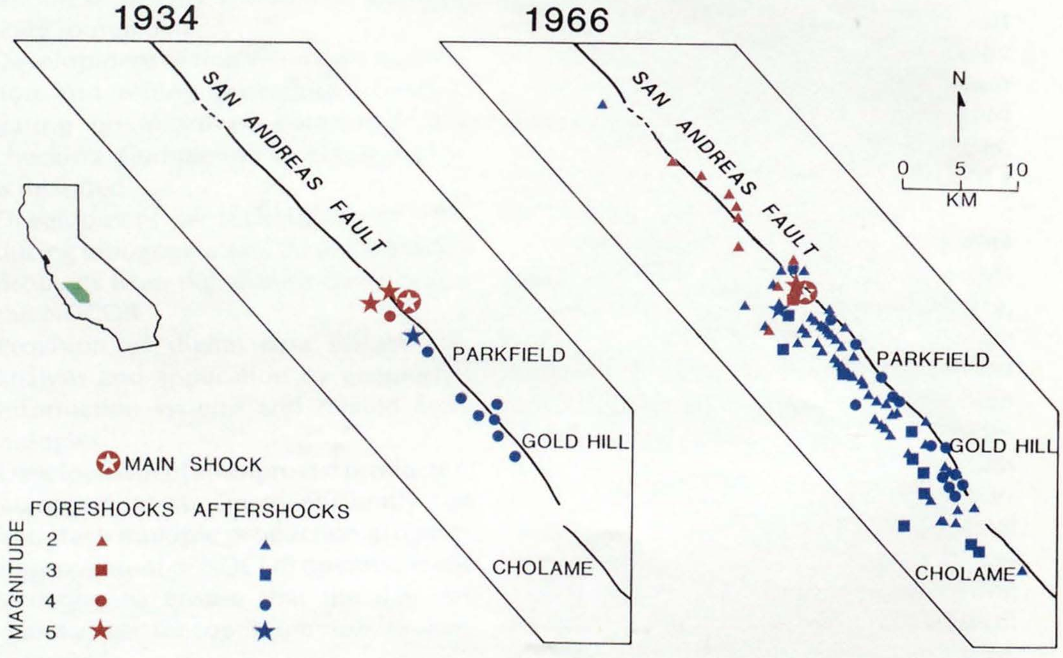


Figure 1. *Map of the Parkfield area of California showing epicenters of earthquakes associated with the 1934 and 1966 Parkfield earthquakes. In 1934, only shocks of magnitude 4 or greater can be accurately located; in 1966, shocks of magnitude 2 or greater recorded between January 28 and June 30, 1966, are shown.*

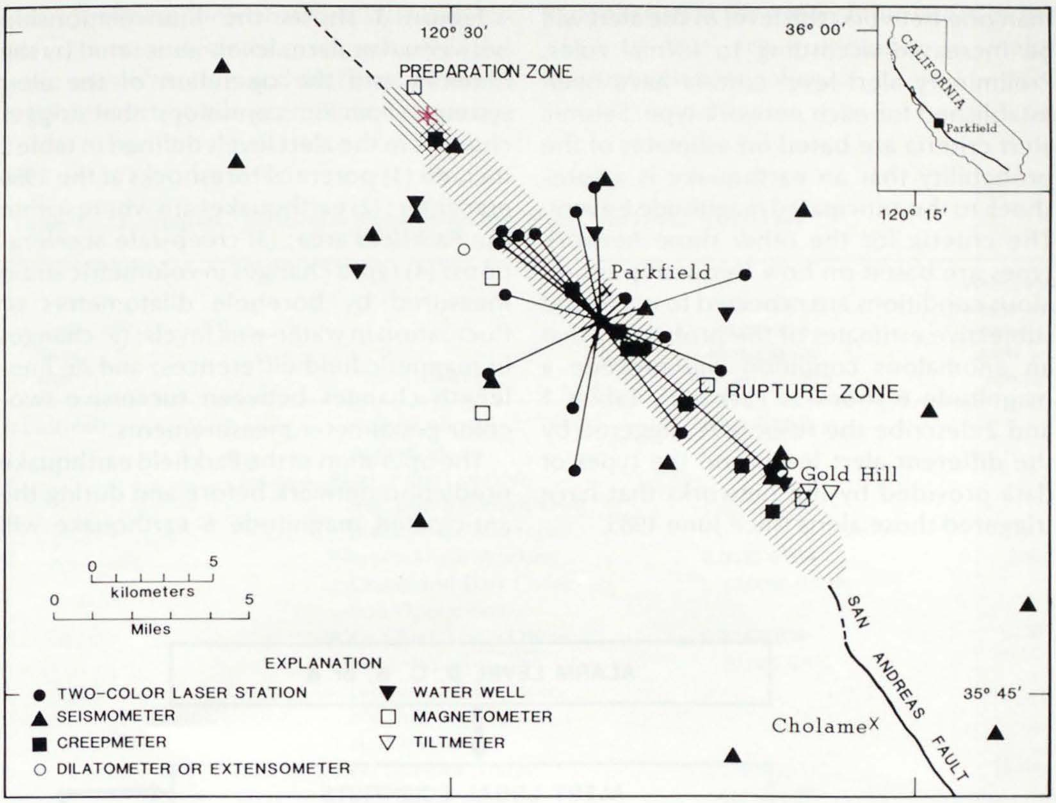


Figure 2. *The Parkfield, Calif., earthquake prediction experiment. Clusters of seismometers, creepmeters, dilatometers, and other geophysical instruments arrayed about central two-color laser geodimeters have been deployed along the San Andreas fault at Parkfield. The instruments are centered in the reach of the fault that is expected to rupture in a magnitude 6 earthquake sometime between 1985 and 1993 (most probably 1988). The epicenter of the 1966 event is indicated by a red asterisk.*

1969. The lengths of lines spanning the rupture zone are measured several times each week by a two-color laser distance-measuring geodimeter capable of resolving length changes of about 0.04 inches over lines 3 to 5 miles long. Borehole volumetric strainmeters (dilatometers) also are being installed in the Parkfield area to provide continuous data having a sensitivity of about 1 part per billion over periods of a few hours. In addition, a number of wire strainmeters (creepmeters) span the surface trace of the San Andreas fault near Parkfield. These creepmeters can resolve a few fractions of an inch of anomalous fault slip and are well suited to detect premonitory slip of the magnitude that may have occurred in 1966.

Parkfield Earthquake Prediction Scenarios and Response Plans

The Geological Survey will attempt to issue a short-term warning (minutes to days) to government officials of the anticipated shock on the basis of precursory phenomena recorded by the prototype earthquake prediction network. Anomalous conditions that would change the assessment of the earthquake's imminence and the action that would be taken by the Survey have been defined. A Survey planning document has been prepared describing the conditions that would trigger a Geologic Hazards Warning to the California Office of Emergency Services (OES). Responsibility for communicating these warnings to the public, to local governments, and to the press resides with OES.

A probabilistic approach to earthquake prediction has been adopted at Parkfield. The likelihood that the anticipated shock will occur in the near future increases as anomalous conditions (for example, increased seismicity) increase. Couching warnings in such a framework explicitly allows for the possibility that warnings will not be followed by the anticipated magnitude 6 shock in the near future. For example, warnings will take the form, "There is a 1 in 5 chance (0.22 probability) that the anticipated magnitude 6 shock will occur in the next 24 hours; the probability of the shock in the next 72 hours is at least 0.37."

If any of the four observational networks now monitoring the Parkfield area detects an anomalous state with respect to the normal background condition of the networks, an alert will be indicated. If anomalous conditions are observed from more than one network, the level of the alert will be increased according to formal rules. Preliminary alert-level criteria have been established for each network type. Seismic alert criteria are based on estimates of the probability that an earthquake is a foreshock to the anticipated magnitude 6 event. The criteria for the other three network types are based on how frequently anomalous conditions are expected to occur and subjective estimates of the probability that an anomalous condition will precede a magnitude 6 shock at Parkfield. Tables 1 and 2 describe the responses triggered by the different alert levels and the types of data provided by the networks that have triggered those alerts since June 1985.

Figure 3 shows the interrelationship between the alarm levels generated by the network and the operation of the alert systems. Specific conditions that trigger changes in the alert levels defined in table 2 include (1) potential foreshocks at the 1966 epicenter; (2) earthquakes anywhere within the Parkfield area; (3) creep-rate accelerations; (4) rapid changes in volumetric strain measured by borehole dilatometers or fluctuation in water-well levels; (5) changes in magnetic field differences; and (6) line-length changes between successive two-color geodimeter measurements.

The operation of the Parkfield earthquake prediction network before and during the anticipated magnitude 6 earthquake will

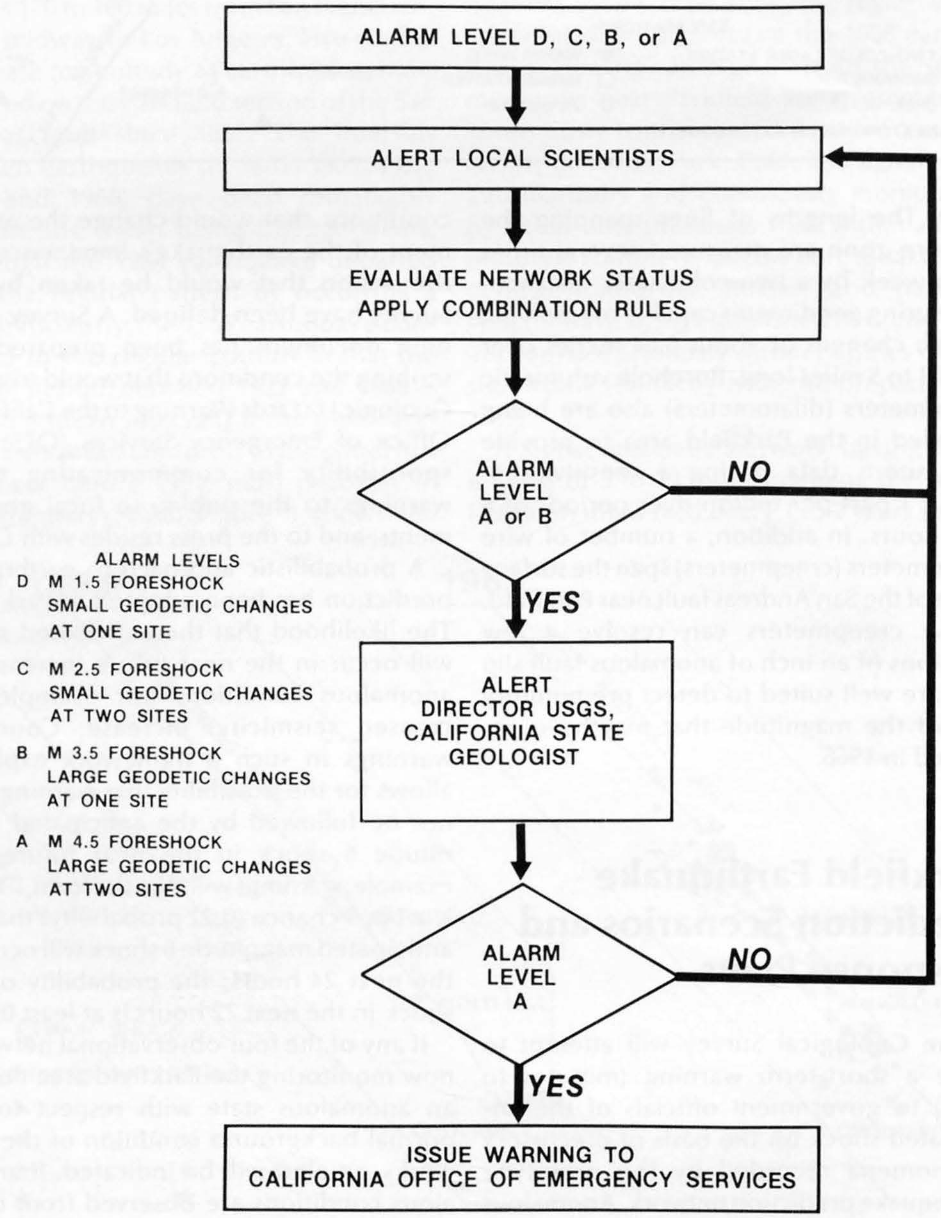


Figure 3. *Decision process and various alarm levels triggered by changes recorded by the Parkfield earthquake prediction network.*

provide information on which instrumentation systems and interpretive methodologies were most valuable and accurate, so that a reliable earthquake prediction system can be developed for use in other areas of the country that are vulnerable to major damaging earthquakes.

Table 1. *Earthquake prediction experiment alert levels, Parkfield, California*

Alert level	Response	Probability of magnitude 6 earthquake in next 24 (72) hours	Anticipated time interval between alerts, in months
n (normal)	Continue normal operation.	0.001-0.0035	--
e	Alert project personnel; possible equipment malfunction and repair.	--	--
d	Alert Parkfield Working Group and Data Collection Operations.	0.0035-0.014 (0.0068-0.028)	2-6
c	Alert Chief, USGS Office of Earthquakes, Volcanoes, and Engineering, and respond to alert level d.	0.014-0.059 (0.028-0.11)	6-18
b	Alert Director (USGS) and California State Geologist (California Division of Mines and Geology) and respond to alert level c.	0.059-0.22 (0.11-0.37)	18-54
a	Issue Geologic Hazard Warning and respond to alert level b.	>0.22 (>0.37)	>54

Table 2. *Summary of Parkfield alerts, June 1985 through May 1986*

Date	Network type	Observed data	Alert level
06/08/85	Seismic	M = 1.5	d
07/12/85	Seismic	M = 3.0	d
08/06/85	Continuous strain (two-color laser).	Coseismic and postseismic changes from Kettleman Hills earthquake.	d
12/14/85	Seismic	M = 3.1	d } Combine to c-level alert.
12/1/5	Creep	1-mm creep surge	d }
12/29/85	Creep	2-mm creep surge	d } Combine to c-level alert.
12/30/85	Seismic	M = 2.9	d }
01/01/86	Creep	0.4-mm creep event	d }
01/15/86	Seismic	M = 2.6	d
01/28/86	Seismic	M = 2.2	d } Combine to c-level alert.
01/30/86	Water-well fluctuations.	00.5 parts per million fractional change in water volume.	d }
03/04/86	Seismic	M = 2.5	d
04/02/86	Seismic	M = 2.1	d
04/08/86	Continuous strain (two-color laser).	Deep slip event(?)	d
04/26/86	Seismic	M = 2.5	d

Central Region headquarters
Building 25, Federal Center
Denver, Colorado

Western Region headquarters
Building 3, Menlo Park facility
Menlo Park, California

National Center
Reston, Virginia

GEOLOGICAL SURVEY MISSIONS AND PROGRAMS

MISSIONS

The U.S. Geological Survey was established by an Act of Congress on March 3, 1879, to answer the need for a permanent agency at the Federal level to conduct investigations into the "geological structure, mineral resources, and products of the national domain." Although a number of laws and executive orders have expanded and modified the scope of the bureau's responsibilities over its 107-year history, the Geological Survey has remained principally a scientific and technical agency rather than a developmental or regulatory one. Today, the Geological Survey is mandated to assess onshore and offshore energy and mineral resources; to provide information to help society mitigate the impact of floods, earthquakes, landslides, volcanoes, and droughts; to monitor the Nation's ground- and surface-water supplies; to assess the quality of the Nation's water resources; and to provide mapped information on the Nation's lands and land use. The Geological Survey is the principal source of scientific and technical expertise in the earth sciences within the Department of the Interior and the Federal Government.

ORGANIZATION

The Geological Survey is headquartered in Reston, Va. 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 functions through an extensive organization of field offices located throughout the 50 States and Puerto Rico. At the national level, the functions of the Survey are coordinated through Assistant Directors for Administration, Programs, Research, Information Systems, Intergovernmental Affairs, Engineering Geology, and Management Applications.

BUDGET

In fiscal year 1986, the Geological Survey had obligational authority for $600.8 million, $412.7 million of which came from direct appropriations; $8.6 million came from estimated receipts from map sales, and $188.2 million came from reimbursement. The Survey was reimbursed for work performed for other agencies whose needs for earth-science expertise complement Survey program objectives. Work done for State, county, and municipal agencies is almost always done on a cost-sharing basis.

Most of the appropriations and reimbursements received by the Survey in fiscal year 1986 are distributed through budget activities that roughly correspond to its geologic, hydrologic, mapping, and administrative areas of responsibility. Budget tables appear on page 143 .

PERSONNEL

At the end of fiscal year 1986, the Geological Survey had 8,062 permanent full-time employees. The Survey's diversified earth-science research programs and services are reflected in its workforce, which is composed of personnel in more than 160 disciplines; more than half of that workforce possesses a Bachelor's or higher level degree. Almost half of the Survey's staff is made up of professional scientists, and approximately a quarter consists of technical specialists. Hydrologists, geologists, and cartographers predominate among the professional group, which includes members of more than 30 other disciplines, such as geophysics, chemistry, and engineering.

Permanent employees are supported by those other than full-time permanent employees, including many university students and faculty members as well as part-time employees. This relationship with the academic community has made the expertise of many eminent scientists available to the Survey and has provided greater flexibility in solving earth-science problems. Students have also proved valuable in meeting surges in the workload, especially during the field season. Academic institutions have also provided a means of recruiting young professionals of demonstrated ability for permanent full-time positions upon completion of their studies.

AWARDS AND HONORS

Each year, employees of the Geological Survey receive awards that range from modest 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 quality of the individuals who are the Geological Survey. The Survey is pleased to acknowledge those individuals who became members or officers in professional societies and those who received the Department of the Interior's highest honor, the Distinguished Service Award.

Professional Societies

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.

Susan W. Kieffer, Geologist, was elected to membership in the National Academy of Sciences.

Joel L. Morrison, Assistant Chief for Research, National Mapping Division, was elected President of the International Cartographic Association.

Lowell E. Starr, Chief, National Mapping Division, was elected Chairman of the Committee on Topographic Maps and Aerophotogrammetry of the Pan American Institute of Geography and History.

Alan R. Stevens, Assistant Chief, Eastern Mapping Center, was elected President of the American Society of Photogrammetry and Remote Sensing.

Department of the Interior Distinguished Service Awards

The Department of the Interior's Distinguished Service Award.

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 Donald Hodel to 13 Geological Survey employees in 1986. These individuals and the bases for their awards are:

Gordon D. Bennett, Hydrologist, in recognition of his outstanding contributions to the Geological Survey in the field of hydrology and technical management of water resources programs.

Thomas J. Buchanan, Assistant Chief Hydrologist for Operations, in recognition of his outstanding technical and managerial contributions to the water resources programs of the Geological Survey.

Cornelia C. Cameron, Geologist, in recognition of her exceptional achievements in the Geological Survey's mineral resources programs, for her outstanding leadership in the field of peat resources and evaluations, and for the excellence of her research in earth science.

William A. Cobban, Geologist, in recognition of his distinguished research in the fields of paleontology and stratigraphy and outstanding contributions to geological synthesis in the programs of the Geological Survey.

Alden P. Colvocoresses, Cartographer, for his outstanding contributions in the use of satellite remote sensing for mapping from space.

Robert M. Hamilton, Chief Geologist, in recognition of his outstanding achievements as a geophysicist and as administrator and manager of wide-ranging earth-science programs.

Blair F. Jones, Research Hydrologist, in recognition of his outstanding contributions to the Geological Survey in geochemical research and scientific leadership.

Malcolm Ross, Geologist, in recognition of his outstanding leadership in the Geological Survey in the study of asbestos minerals and in his recognition of and emphasis on the different health effects of individual minerals.

Francis T. Schaefer, Supervisory Hydrologist, in recognition of his outstanding contributions to technical program development and administrative management in the Geological Survey.

Jack J. Stassi, Central Region Management Officer, in recognition of his outstanding contributions to the Geological Survey in directing its budget management activities and in providing regional administrative support services.

John G. Vedder, Geologist, in recognition of his outstanding contributions to the Geological Survey and for his knowledge of the stratigraphy, structural evolution, and resource potential of the Pacific margin regions.

Isaac J. Winograd, Hydrologist, in recognition of his exceptional contributions to the science of hydrogeology and the application of this knowledge to problems of water supply and disposal of the Nation's toxic wastes.

Gordon G. Wood, Geologist, in recognition of his major innovative achievements in the formulation and direction of national and international coal resources assessment and programs.

Drill-core rig in Cajon Pass, California. (Photograph courtesy of Lee Silver, Deep Observation and Sampling of the Earth's Continental Crust, Inc.)

PROGRAM DESCRIPTIONS

The following sections describe briefly the programs of Geological Survey Divisions.

Geologic Division

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 its 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, a total area of 3.9 billion acres.
- Mineral resource investigations assess the distribution, quantity, and quality of the Nation's mineral resources, particular emphasis being placed 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.

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 for 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, Denver, Colo., and Menlo Park, Calif., and at field centers in Flagstaff, Ariz., Anchorage, Alaska, and Woods Hole, Mass.

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 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.

Land Resource Surveys

The Geologic Framework and Synthesis 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, and age determinations of rocks are key components of this program.

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

The Climate Change Program conducts research on the prehistoric natural variability of past climate, on the extent of man's influence on natural patterns of change, and on the magnitude of climate change demonstrated in the geologic record.

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 and adjacent slope and deep-ocean areas. Results of these studies and analysis of new information are essential for energy and mineral resource evaluation of these areas.

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

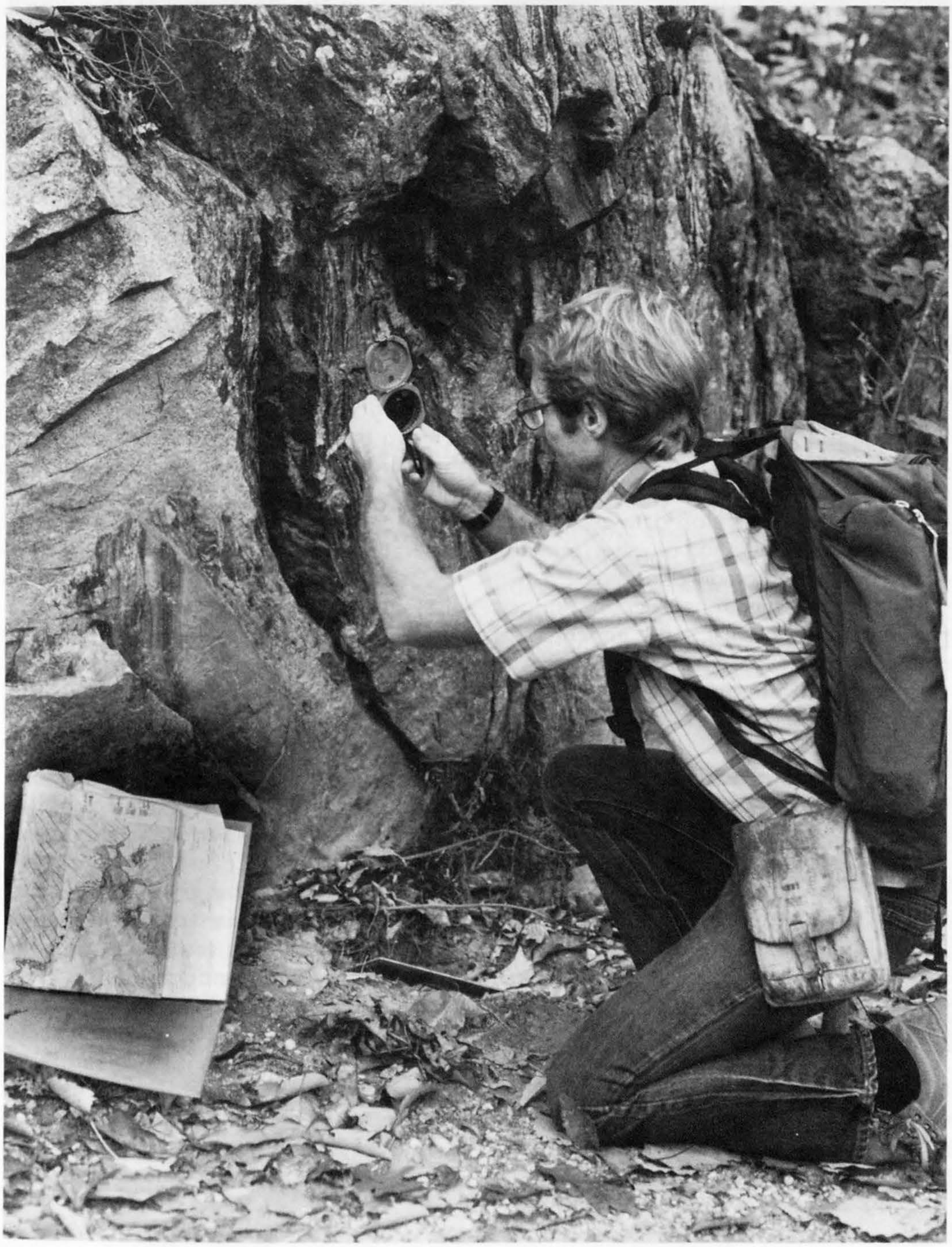
Mineral Resource Surveys

The Alaska and Conterminous United States Mineral Resource Assessment Programs are comprehensive scientific surveys to identify significant new targets for industry exploration.

The Mineral Resources of Public Lands Program assesses the mineral resource potential of areas proposed for inclusion in the Forest Service and Bureau of Land Management sections of the National Wilderness Preservation System to ensure that land planners and Congress have enough information to make necessary decisions.

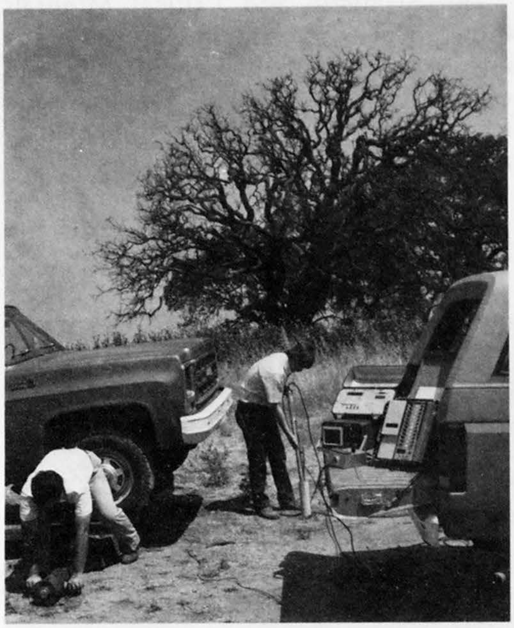
The Strategic and Critical Minerals Program develops new mineral resource assessment techniques to identify and estimate the potential of domestic and foreign mineral resources for U.S. military and economic needs.

The Development of Assessment Techniques Program carries out basic and



Geologist examining an outcrop in the field. (Photograph by Fred K. Miller, U.S. Geological Survey.)

applied research on the origin and the geologic, geochemical, and geophysical expressions of mineral deposit systems.



Determining seismic velocities of near-surface geologic materials. (Photograph by L.J. Hwang, U.S. Geological Survey.)

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 evaluation of water, mineral, and hydrocarbon resources.

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

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

The Oil Shale Investigations Program conducts research to assess oil shale resources, including investigation of the structure and chemistry of oil shale deposits and identification of 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 regional, national, and foreign 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 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

Mission

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

- Systematically collects and analyzes data to evaluate the quantity, quality, and use of the Nation's water resources and provides results of these investigations to the public.
- Conducts water resources appraisals describing the occurrence, availability, and physical, chemical, and 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 manmade 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.

Organization

Water Resources Division headquarters is in Reston, Va. The Chief Hydrologist, the Associate Chief Hydrologist, and four 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, 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 product of the program is an annual National Water Summary that describes hydrologic events and water conditions for the water year and provides a State-by-State overview of specific water-related issues.

National Water-Quality Assessment Program

The Geological Survey began a National Water-Quality Assessment Program to (1) provide nationally consistent descriptions of the current status of water quality in a large, diverse, and geographically distributed portion of the Nation's water resources; (2) provide a baseline for evaluating future trends in water quality and, where possible, define trends in water quality over recent decades; and (3) 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 Geological Survey conducts research and investigations into the disposal and release 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 earth-science considerations 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.

Handling toxic waste material. (Photograph by Stephen C. Delaney, U.S. Environmental Protection Agency.)

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 research data to mitigate existing and future 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 Geological Survey is providing 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. The 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 Geological Survey and State or local government agencies. One of the program's unique characteristics is that the Geological Survey performs most of the work on behalf of the cooperators. A variety of hydrologic data collection activities and water resources investigations is included, for which the Geological Survey represents the national responsibilities and more than 900 cooperating agencies represent State and local interests.

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 Research Institute Program

The State Water Research Institute 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. Institute research projects are carried out in all water-related fields, including engineering and the physical, biologic, 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 1984. Competitive grants are awarded on a dollar-for-dollar matching basis to qualified educational institutions, foundations, private firms, individuals, or agencies of local or State governments. Research is supported on water-resources-related problems of national interest.

National Mapping Division

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, produces maps and related cartographic information in graphic and digital form.

To accomplish this mission, the Division:

- Collects, compiles, and analyzes information about natural and manmade features on 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.
- Develops and applies advanced cartographic techniques and systems to geographic information systems.
- Develops and maintains a digital cartographic and geographic data base for multipurpose needs.
- Coordinates Federal mapping, digital cartographic, and remote sensing activities as designated by the Office of Management and Budget.
- Represents the national interest through participation in international mapping and training activities.

The Geological Survey is responsible for all functions that relate to domestic geographic names, including staff support to the interdepartmental Board on Geographic Names.

The Geological Survey also compiles, publishes, and maintains the National Gazetteer of the United States of America and manages the National Geographic Names Data Base.

Organization

Division headquarters, located in Reston, Va., is composed of three primary organizational units: Plans and Operations, Research, and Information and Data Services. Four mapping centers (Reston, Rolla, Mo., Denver, Colo., and Menlo Park, Calif.), the Earth Resources Observation Systems Data Center (Sioux Falls, S. Dak.), and the Printing and Distribution Center (Reston, Denver, and Fairbanks, Alaska) perform the operational mapping, remote sensing, printing, product distribution, and data dissemination activities.

Map Production

The Geological Survey prepares, prints, and distributes base, topographic, and selected thematic maps of the Nation that are used extensively for land planning, land management, and recreation purposes.

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. These detailed maps are continually updated and revised. Current program emphasis is on the production and maintenance of maps of urban areas and rapidly developing coastal areas, energy areas, and public lands.

Intermediate-scale maps prepared at the 1:100,000-scale quadrangle format are used by the Bureau of Land Management for displaying resource inventories, the Bureau

Cartographer preparing a peel coat. (Photograph courtesy of National Mapping Division.)

of the Census for support of the 1990 Decennial Census, and other agencies.

The 1:250,000-scale map series provides complete topographic coverage of the United States. These maps are widely used by Federal and State agencies for preparing other base and special-purpose maps. 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, produced in graphic and digital formats 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 National Atlas program provides 1:2,000,000- and 1:7,500,000-scale maps and smaller scale maps, digital cartographic data, and other information on key physical, environmental, cultural, socioeconomic, and historical characteristics of the Nation.

Image Mapping

The Geological Survey prepares photo-image products in response to specific requirements of Federal and State agencies, particularly the Bureau of Land Management, the Soil Conservation Service, the Forest Service, and the Customs Service. These products include:

- Orthophotoquads, produced from aerial photographs and prepared in standard scales and formats meeting National Map Accuracy Standards.
- Side-looking airborne radar data for use in image mapping, geologic mapping, and geologic resource surveys.
- Landsat Multispectral Scanner and Thematic Mapper satellite data for use in preparing image map products.

Since 1978, the Geological Survey has served as the designated lead agency in a multi-Federal-agency National High-Altitude Photography Program to avoid duplication in contracting high-altitude photography and to achieve a consistent and systematic photographic data base of the conterminous United States.

Digital Cartography

The Geological Survey continues to expand and improve the National Digital Cartographic Data Base to make cartographic and geographic data available in a form suitable for computer-based analyses. The Division is responsible for coordinating digital cartographic activities throughout the Federal Government. The Division chairs the Federal Interagency Coordinating Committee on Digital Cartography, which is responsible for the exchange of information and ideas on technology and methods for managing and using digital spatial data. Current projects include digitizing 1:100,000-scale transportation and hydrographic data in cooperation with the Bureau of the Census, providing digital cartographic data for derivative maps, and digitizing geographic data from 1:24,000-scale maps to meet new Federal and State needs.

Geographic Information Systems Research and Applications

The Division is working with the other Divisions in the bureau to establish a sound geographic information systems research base, to conduct applications projects, and to encourage Geological Survey scientists to use this powerful tool in their investigations. Current emphasis is on the application of new techniques in the generation of thematic maps, including microcomputer-based map compilation, Scitex color separations, and image processing. High priority is being given by interdivisional and interbureau groups to the development of data standards, data exchange formats, data base management systems, and the definition of an advanced geographic information system for earth-science studies.

Earth Resources Observation Systems

Remotely sensed data are produced, archived, and distributed through the Earth Resources Observation Systems (EROS)

Program. The largest users of the data are Government agencies and private firms involved with the exploration and assessment of energy, mineral, and renewable resources. EROS scientists also conduct research leading to new and improved remote sensing and spatial data applications.

The EROS Data Center in Sioux Falls, S. Dak., serves as the repository and public distribution facility for a growing archive of over 8,300,000 aerial photographs and side-looking radar images from various Federal programs. The center cooperates with the National Oceanic and Atmospheric Administration and the Earth Observation Satellite Company (the commercial Landsat system operator) to perform final ground processing and distribution of Landsat satellite data.

National Mapping Research

The Geological Survey has pioneered investigations that have led to major developments and significant changes in surveying and mapping. The Mapping Research Program, which is centered on geographic and cartographic research, emphasizes spatial data analysis, applications of remote sensing and geographic information systems, and advanced digital cartographic production techniques.

The Division has embarked on a major research and development plan (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 establish the National Digital Cartographic Data Base.

The Geological Survey has expanded its production of multicolor satellite image maps and, in cooperation with the Defense Mapping Agency and the National Geodetic Survey, is developing applications of the NAVSTAR Global Positioning System, which is a satellite navigation and positioning system for attaining positional data to geodetic standards.

Information Services

The Geological Survey disseminates much of the Nation's earth-science information through its Public Inquiries Offices, National Cartographic Information Centers, and the Earth Resources Observation Systems Data Center. The information comes in many forms, from maps and books to computer-readable magnetic tapes. Approximately 75,000 different maps and books are available for purchase, and about 5,300,000 copies are sold annually. Additionally, of the approximately 8,300,000 different aerial and space images available for sale, about 200,000 copies are sold annually. Geological Survey maps are also currently available from more than 3,200 authorized commercial map dealers nationwide.

Administrative Division

Mission

The Administrative Division provides administrative direction and coordination in support of the scientific and technical programs of the 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, financial management, administrative management information systems, management analysis and improvement efforts, procurement and contracting, property and space management, and safety. These functions are carried out at the National Center in Reston, Va., and through regional management offices in Denver, Colo., and Menlo Park, Calif.

Organization

The Division is composed of five headquarters branches. Financial Management and Systems Management are centralized headquarters functions and have no regional counterparts. Administrative Services, Personnel, and Procurement and Contracts provide operational support to Geological Survey field units through the regional management offices.

Information Systems Division

Mission

The Information Systems Division provides guidance, technical support, and automated data processing (ADP) services to other Geological Survey Divisions, the Department of the Interior, and other Government agencies. The Division also supports planning and policy development and provides program coordination and review for Geological Survey information systems and ADP technology. To meet these objectives, the Division:

- Develops information systems policy.
- Develops long-range information resource management plans.
- Administers data bases.
- Designs, implements, and manages telecommunications networks.
- Conducts research in computer science.
- Guides the acquisition of ADP resources.
- Provides computer support services, conducts user assistance training, and consults on computer sciences.

The Division is assisting the bureau in establishing a system to improve access to earth-science information. By means of microcomputers, 27 Geological Survey public contact points (in 20 cities located in 16 States and the District of Columbia) now have available earth-science information data bases to aid users of Geological Survey data and products. One of these information data bases provides data reference input from various State Governments and organizations. The Survey has established a telecommunications service within the bureau to link programs in different Divisions through a nationwide communications network called GEONET. In addition, the Division is designing local area networks to integrate a wide range of computing devices.

Organization

The Information Systems Division has its headquarters office in Reston, Va. Service centers in Reston and in Menlo Park, Calif., Denver, Colo., and Flagstaff, Ariz., provide assistance to users.

The Assistant Director for Information Systems chairs the Information Systems Council, which is composed of representatives from each Division and each field region. The council recommends policies, coordinates computer science research and technology, and provides guidelines for major computer systems and information management programs for the Geological Survey.

SIGNIFICANT ACCOMPLISHMENTS OF RESEARCH PROGRAMS: 1986

SELENIUM IN AGRICULTURAL DRAINAGE WATER, SAN JOAQUIN VALLEY, CALIFORNIA

The San Joaquin Valley is a vital natural resource in which over $5 billion worth of agricultural commodities are produced annually from more than 5 million acres of irrigated farm land. The valley is also the site of several State and Federal waterfowl management areas that are key stopping points for migratory waterfowl along the Pacific flyway. Several of these waterfowl management areas presently depend on agricultural wastewater for all or part of their water supply. Potential adverse effects of agricultural wastewater on waterfowl have recently been realized at Kesterson Reservoir, a 1,200-acre series of shallow impoundments that was jointly managed by the U.S. Bureau of Reclamation as an agricultural drainage-water storage facility and by the U.S. Fish and Wildlife Service as a national wildlife refuge.

Subsurface agricultural drainage water began flowing to Kesterson Reservoir in 1978 and ceased in 1985, under a State regulatory order. Since 1982, a high incidence of mortality and birth defects among waterfowl using the refuge has been linked to the presence of high concentrations of the trace element selenium in the drainage water. The U.S. Geological Survey found that concentrations of dissolved selenium in drainage waters flowing into the canal that supplies water to Kesterson Reservoir ranged from 140 to 1,400 micrograms per liter (parts per million). The drainage water came from farm drainage systems consisting of buried grids of perforated pipe that are designed to lower the water table by removing shallow ground water and thus keep excessive moisture from the crop root zone. Subsurface drainage systems have already been installed in about 85,000 acres of agricultural land in the western San Joaquin Valley, and as much as 200,000 additional acres of farm land in the western valley area are affected by shallow water tables and need drainage. Drainage water from only about 8,000 acres has flowed to Kesterson Reservoir; the drainage from the remaining 77,000 acres has gone to local evaporation ponds or to various water conveyance facilities that eventually discharge to the San Joaquin River or tributary sloughs. Thus, the potential problem encompasses far more than just Kesterson Reservoir.

The U.S. Geological Survey, in cooperation with the U.S. Bureau of Reclamation, the U.S. Fish and Wildlife Service, and the State of California, began a 5-year study in late 1984 of the source, distribution, mobility, and fate of selenium in water and soil throughout the western San Joaquin Valley. The study is designed to answer key questions about selenium, including:

- Where does the selenium come from?
- How much selenium is in the soil?
- What factors cause selenium to be released from the soil?
- How does selenium get into shallow ground water?
- What is the areal distribution of selenium in the shallow ground water?
- Is selenium contaminating water-supply aquifers in the area?
- How much selenium is reaching the San Joaquin River and San Francisco Bay?

Although the studies designed to address these questions are still in their early stages, there have been some important early findings about the distribution of selenium in soil, ground water, and the San Joaquin River. Considered together, early data from all these studies suggest a conceptual model of the processes affecting the distribution of selenium. This model forms the basis of our continuing studies.

Distribution of Selenium

A first step in understanding the nature and scope of the selenium problem is to assess the present-day distribution of selenium in soil and ground water. The accompanying map shows the areal distribution of selenium in the soil, in shallow ground water, and in regional aquifers of the western San Joaquin Valley. The highest concentrations of selenium in the entire San Joaquin Valley are in soils and shallow ground water located on the western side of the valley in the alluvial fan areas of Panoche and Cantua Creeks, which drain the Diablo Range. Concentrations generally are low in the deeper regional aquifers commonly used for water supply.

The highest selenium concentrations in soil occur between the coalescing fans of Panoche and Cantua Creeks near the contact between the alluvial fans and dipping sedimentary rocks at the western edge of the valley. The highest concentrations of selenium in shallow ground water were observed downgradient from high-selenium soils, where evaporation of shallow ground water greatly increased its selenium concentration.

Depth Distribution in Ground Water

Comparing the distribution of selenium in shallow ground water with that in deeper underlying ground water shows that selenium generally decreases with depth. But how fast, at what depth, and why? Initial data from two sites (P1 and P4, fig. 1) point to some possible answers to these questions.

The data suggest that the shallowest ground water along this section has selenium concentrations in the 1- to 50-micrograms-per-liter range. Selenium concentrations in water more than about 200 feet below the water table are mostly less than detectable. In between, in the range of 20 to 200 feet below the water table, there appears to be a selenium-rich zone that probably narrows in thickness from P4 to P1. In addition, data from a detailed field-study site located south of the P1-P4 section (but in a setting similar to that midway between P1 and P4) show a similar depth distribution. Since data are so sparse at this stage in our studies, the challenge is to develop a reasonable explanation of this pattern that can then be tested.

Conceptual Model

On the basis of the areal distribution data for soils and water shown on the maps, the data from multiple-depth sampling wells, and detailed data from individual fields, a working conceptual model that attempts to explain the distribution of selenium at the regional scale has been developed. This model, although preliminary and unverified, provides a unified framework for continuing studies that will undoubtedly result in changes and expansions to the model.

Under natural conditions, the highest selenium concentrations probably occurred in the uppermost part of the aquifer, with no fresher water above. Concentrations were likely highest at low elevations where the natural flow system (fig. 1) brought ground water near the land surface, where it was evaporated. Concentrations were likely low to moderately high in areas where the water table was more than several feet below the land surface. Initial irrigation of soils as early as 1900 probably leached most of the readily soluble selenium during the first decade or more of irrigation. The result appears to have been the formation of a zone of ground water overlying what was the natural surface of the aquifer before irrigation began and in which selenium concentrations are higher than normal.

Continuing irrigation in recent decades has added progressively fresher water to the top of the aquifer as the amount of readily soluble selenium in the soil was depleted. Thus, this fresher water apparently has displaced the higher selenium water downward. This pattern is clearest where the water table has always been too far below the land surface for evaporation to occur. The pattern is least clear where the water table is close to the land surface, where continued evaporation of ground water has occurred and thus affected selenium concentrations.

The low concentrations of selenium in the deep parts of the aquifer system may be related to a combination of the climatic conditions under which those aquifer materials and the water in them were deposited and the chemically reducing conditions in part of the aquifer that greatly reduce the solubility of selenium. Past climates in the

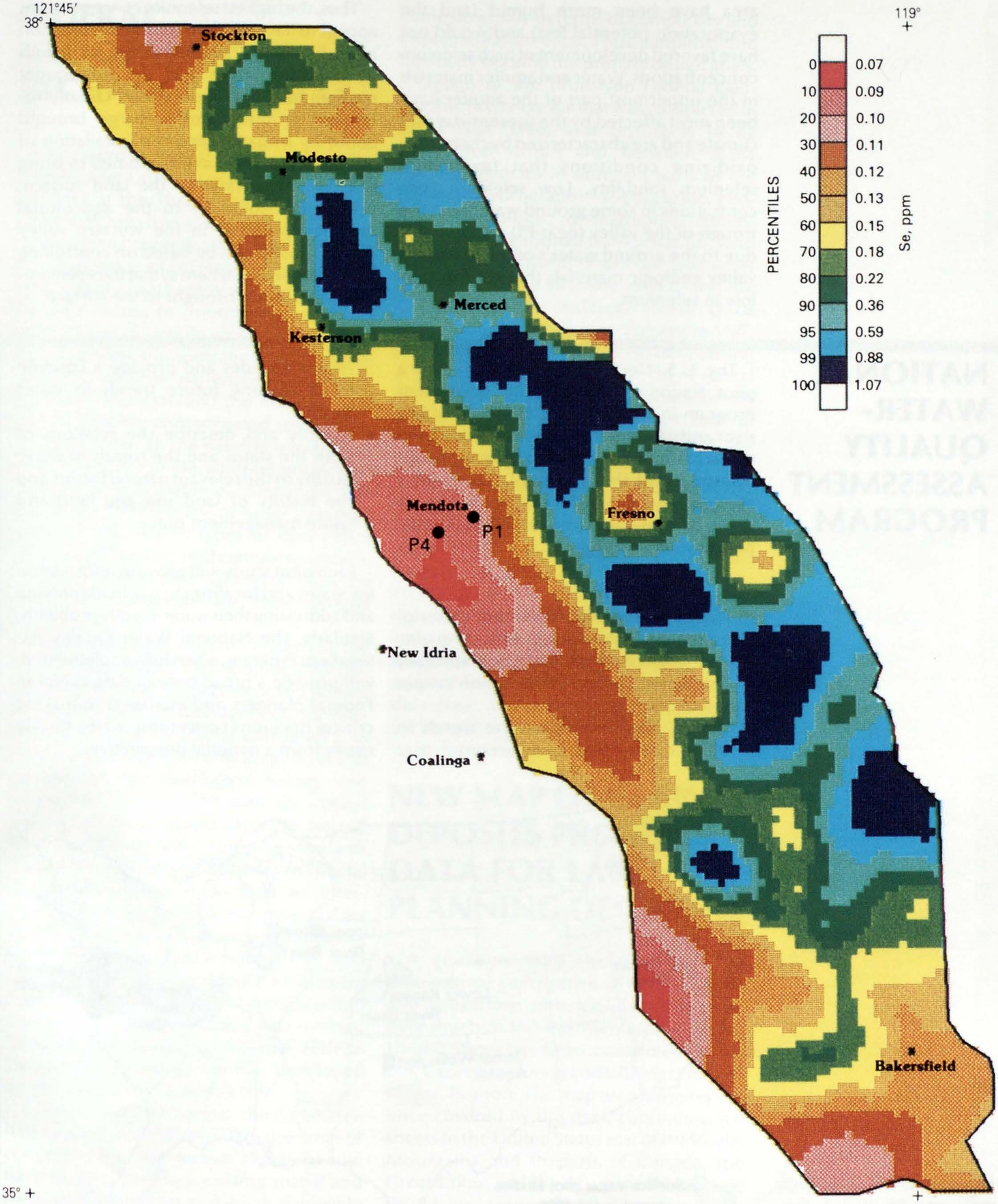


Figure 1. *Selenium concentrations in ground water in the San Joaquin Valley of California.*

area have been more humid (and the evaporation potential less) and would not have favored development of high selenium concentrations. Water and aquifer materials in the uppermost part of the aquifer have been most affected by the present-day arid climate and are characterized by chemically oxidizing conditions that favor high selenium solubility. Low selenium concentrations in some ground water near the trough of the valley (near P1) are probably due to the ground water's origin in eastern valley geologic materials that are naturally low in selenium.

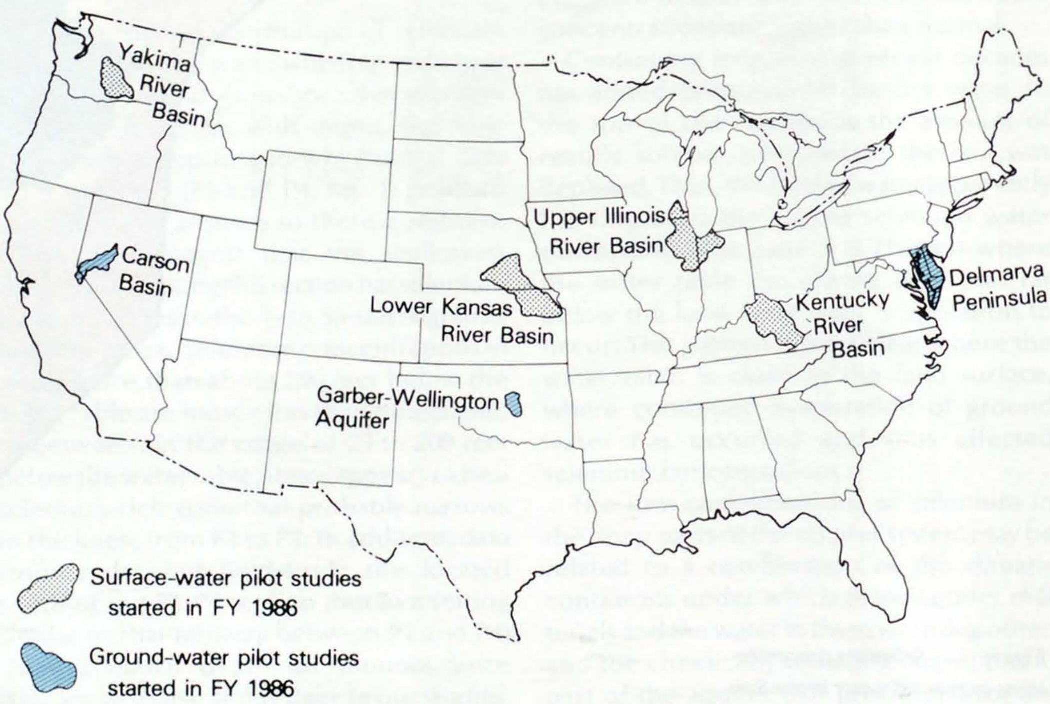
Thus, the highest selenium concentrations appear to have resulted from a combination of the leaching of selenium from saline soils by irrigation water and the subsequent evaporation of ground water. Greatly increased ground-water recharge brought about by irrigation and the installation of subsurface drains have combined to bring selenium-rich water to the land surface. Economical solutions to the agricultural drainage problem in the western valley may, in the future, be based on controlling the ground-water system so that the selenium-rich water is not brought to the surface.

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

The U.S. Geological Survey initiated a pilot National Water-Quality Assessment Program in 1986. Pilot studies in seven key river and ground-water basins are designed to test methods for conducting a nationwide assessment of the quality of the Nation's surface- and ground-water resources. In general terms, the purposes of the full-scale programs are to:

- Provide nationally consistent descriptions of the current status of water quality in a large, diverse, and geographically distributed portion of the Nation's water resources.
- Where possible, define the trends in water quality that have occurred over recent decades and provide a baseline for evaluating future trends in water quality.
- Identify and describe the relations of both the status and the trends in water quality to the relevant natural factors and the history of land use and land and waste management practices.

Each pilot study will provide information for States and localities to use in identifying and addressing their water-quality problems. Similarly, the National Water-Quality Assessment Program, when fully implemented, will provide a broad base of data useful to Federal planners and managers in making critical decisions concerning water-quality issues from a national perspective.



Locations of the seven pilot study areas for the U.S. Geological Survey's National Water-Quality Assessment Program.

FEDERAL GEOGRAPHIC EXCHANGE FORMAT

The recent nuclear accident at Chernobyl in the Soviet Union, together with the 1979 accident at the Three Mile Island nuclear plant in Pennsylvania, has focused national attention on how authorities might expedite the evacuation of citizens from an affected area. Ideally, authorities should have immediate access to information regarding the location of people within a threatened area, available transportation routes out of the area, weather patterns that influence radiation dispersal, and the direction and rate of possibly contaminated streamflow. Unfortunately, all the needed information is not found in a single, comprehensive data base, nor is it available in compatible data structures and formats. In order to merge different yet related types of data into a single data base for rapid computer analysis, all the various data elements must be uniform in structure for computerized handling.

As a result of discussions concerning the exchange of digital cartographic information, the Office of Management and Budget created the Federal Interagency Coordinating Committee on Digital Cartography in 1983. Consisting of 27 Federal agencies and chaired by the Geological Survey, the committee was charged with the critical task of "developing and adopting, for use by all Federal agencies, common standards of content, format, and accuracy for digital cartographic data to increase its interchangeability and enhance its potential for multiple use." A first step toward meeting these standards is delineating the data structures and formats needed to facilitate the interagency exchange of computerized cartographic and geographic data (termed "spatial" data). The prototype Federal Geographic Exchange Format, developed by the committee, is such a step.

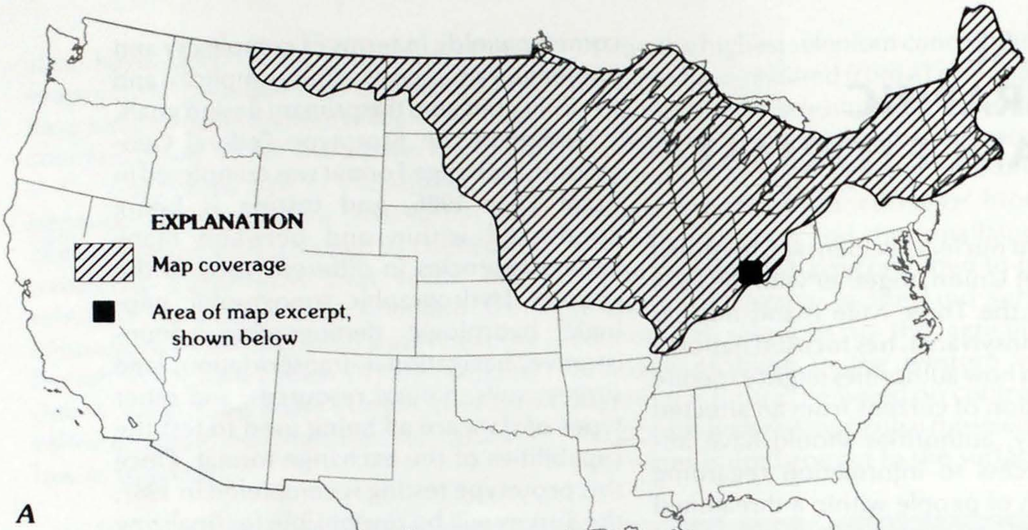
In developing the format, the committee had to keep in mind several major areas of concern. First, the format chosen would have to accommodate existing spatial and earth-science data bases as much as possible to avoid costly reentry of data. Second, the format would have to be flexible enough to handle future spatial data base developments. Finally, the format should not become unwieldy in terms of complexity and implementation costs. Thus, simplicity and flexibility became the primary design goals.

Design of the prototype Federal Geographic Exchange Format was completed in fiscal year 1986, and testing is being conducted within and between many Federal agencies in different parts of the country. Hydrographic, topographic, geologic, hydrologic, demographic, administrative, navigational, transportation, land survey, soils, natural resources, and other types of data are all being used to test the capabilities of the exchange format. Once this prototype testing is completed in 1987, the Survey will be responsible for finalizing an operational version of the Federal Geographic Exchange Format, the ultimate goal being to make the format a Federal Information Processing Standard for the exchange of digital spatial data.

Interest in the Federal Geographic Exchange Format has now gone beyond national bounds into the international arena, since the Federal Geographic Exchange Format might become the standard exchange format for a worldwide cartographic data base. Incidents such as the release of radiation that travels worldwide, unconstrained by political borders, strongly enforce the need for such an international data base and a standardized means of exchanging information.

NEW MAP OF GLACIAL DEPOSITS PROVIDES DATA FOR LAND PLANNING DECISIONS

A geologic map showing a three-dimensional perspective of both surficial and subsurface unconsolidated deposits over much of the northern conterminous United States has been completed by the U.S. Geological Survey and is being prepared for publication. The map area is the region once covered by the thick continental ice sheets in the United States east of the Rocky Mountains and in parts of Canada, the Great Lakes, and the Atlantic offshore (see fig. 2*A* for location of map coverage). The map shows the character of the surficial sediments, the total thickness of glacial, glacially related, and postglacial sediments, and certain well-mapped buried units.



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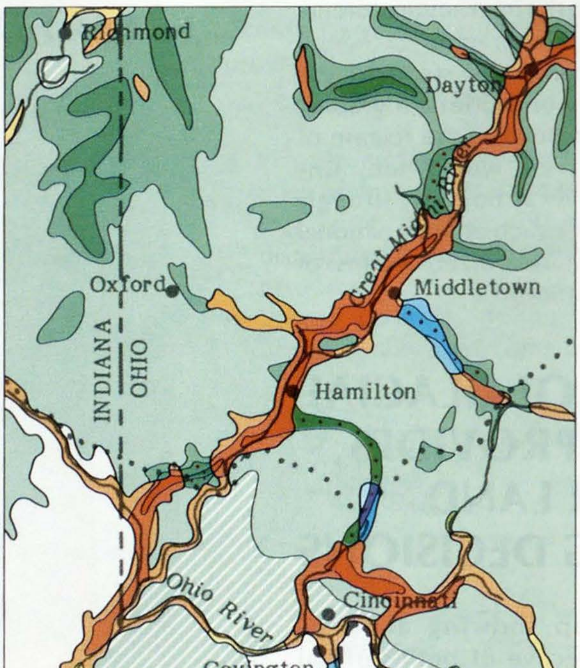


EXPLANATION

This map shows the character of surficial sediments, in colors, and the total thickness of Quaternary sediments, in shades of color. Where the location of buried sand and gravel aquifers is well known, they are shown diagrammatically.

Sediment Mapping

Till—Unsorted and unstratified ice-lain sediment ranging in size from clay to boulders

Coarse-grained, stratified sediment—Water-lain sand and gravel, with minor silt and clay

Fine-grained, stratified sediment—Water-lain clay, silt, and very fine sand, with minor coarser sediment

Areas where Quaternary sediment is patchy, and exposures of bedrock and residuum are common

Exposed bedrock and residuum

Location of sand and gravel aquifers buried beneath till or fine-grained, stratified sediment

Thickness Mapping

Character of the surficial sediment

Total thickness of Quaternary sediment (in feet)	TILL	COARSE	FINE
0–50			
50–100			
100–200			
200–400			

Symbols

Southernmost extent of Late Wisconsinan ice

Southernmost extent of pre-Late Wisconsinan ice

A part of the glacial sediments map, simplified

Scale 1:1,000,000

0 10 KILOMETERS

B

Figure 2. *Map area and format for the map of the glaciated United States east of the Rocky Mountains.* A, *Location of map area.* B, *Part of the map area, simplified.*

This map conveys, for the first time, the regional distribution and thickness of glacial and postglacial sediments, which previously had been shown in detail on local maps only. The data shown on the map were compiled and reinterpreted from approximately 850 existing maps, reports, and unpublished data sources. Discussions with geologic authorities for each State enhanced the quality of reinterpretation and map compilation. Most thickness data were taken from reports and drill hole logs and had not been published in map form before. Because a uniform classification system that could encompass differing styles of geologic mapping had to be developed for surficial units in the map area, many map patterns are different from those on existing maps. For example, the glacial history of New England is quite different from that of the Great Plains States, the result being contrasts in the glacial sediments and mapping emphases in the two regions. The uniform classification emphasizes similar aspects of the deposits in these areas and should, therefore, add to the effectiveness and accuracy of regional assessments.

Portraying not only the surficial geology but also the nature and extent of geologic units in the subsurface, this map is in essence a three-dimensional view of the outermost layer of the Earth. A small portion of the map is shown in figure 2*B*. This area, located in southwestern Ohio, was covered by ice during at least two major glacial episodes. Before and between glaciations, a network of streams and valleys existed; the major river in that network flowed past Hamilton and Dayton, Ohio, roughly where the Great Miami River flows today. This ancient valley and its tributaries contain a major aquifer system that serves the area's industrial centers. When the most recent (late Wisconsinan) glacier flowed over the area about 21,000 years ago, most of the valleys were covered over with till, a poorly sorted ice-lain sediment; in many valleys, sandy river sediments were not removed by the glacier and today serve as aquifers buried beneath the till (fig. 2*B*). Sandy sediments in the major river valley commonly occur from the land surface down to bedrock, because this valley was the course through which water from the melting, retreating glacier was channeled.

This map is the first regional approximation of the three-dimensional distribution of sediments over a very large area and is intended to supplement, not replace, the more detailed work on which it is based. Detailed mapping, particularly in populated areas, is necessary to address the site-specific geologic problems related to man's activities at and beneath the land surface. Detailed mapping is also required to interpret the geologic history and framework of sediments for a region. Regional maps such as the one discussed here place local detailed mapping in a regional context, permit the extrapolation of data into unmapped areas, and depict large-scale regional geologic features that are beyond the scope of detailed local mapping. A regional map in many cases will point out a problem or relationship that is not apparent on a detailed map and thus permits information from the detailed map to be used correctly to solve problems arising from site-specific activities.

Surficial geologic and sediment thickness mapping and the ability to predict where buried aquifers occur are vital tools for solving problems such as the siting of landfills and construction, the evaluation of mineral resources, and the evaluation of ground-water resources and their vulnerability to contamination. Approximately 40 percent of the population in the conterminous United States resides within the region covered by the map, which is less than 25 percent of the total area of the country. Population density this high necessitates regional cooperation, across State and other political boundaries, in planning and in assessing problems involving waste disposal and ground-water management, since the waste of one community can unintentionally contaminate the drinking water of another. Information on the map indicates the thickness of the unconsolidated sediments (which contain numerous aquifers) and also the extent of certain major aquifers; this information can be used to supplement detailed mapping in predicting contaminant movement through the unconsolidated sediments. The thickness and composition of these sediments may also influence the generation and migration of radon gas and mitigate the effect of acid rain.

In addition to its applications for resources and land planning, this new map should help to stimulate research and more detailed three-dimensional mapping. For example, research focusing on the creation of a digital geologic data base from the map is underway. Subsequent analysis of the digital data will permit the production of computer-generated derivative maps that will combine the geologic data base with hydrologic, cultural, and other data sets. These derivative maps will deal with a broad spectrum of topics including basic research into glacial mechanics and history, regional relations between glacial deposits and hydrology, and the need for applying geologic data to land use, waste disposal, and ground-water management decisions.

HYDROCHEMICAL RESPONSE OF A SMALL STREAM IN THE SOUTHEAST TO A RAINSTORM

The hydrologic response and the spatial and temporal patterns of stream chemistry were used to identify several key processes regulating stream acidification and major ion chemistry in a 100-acre research watershed (fig. 3*A*) at the Panola Mountain State Conservation Park near Stockbridge, Ga.,

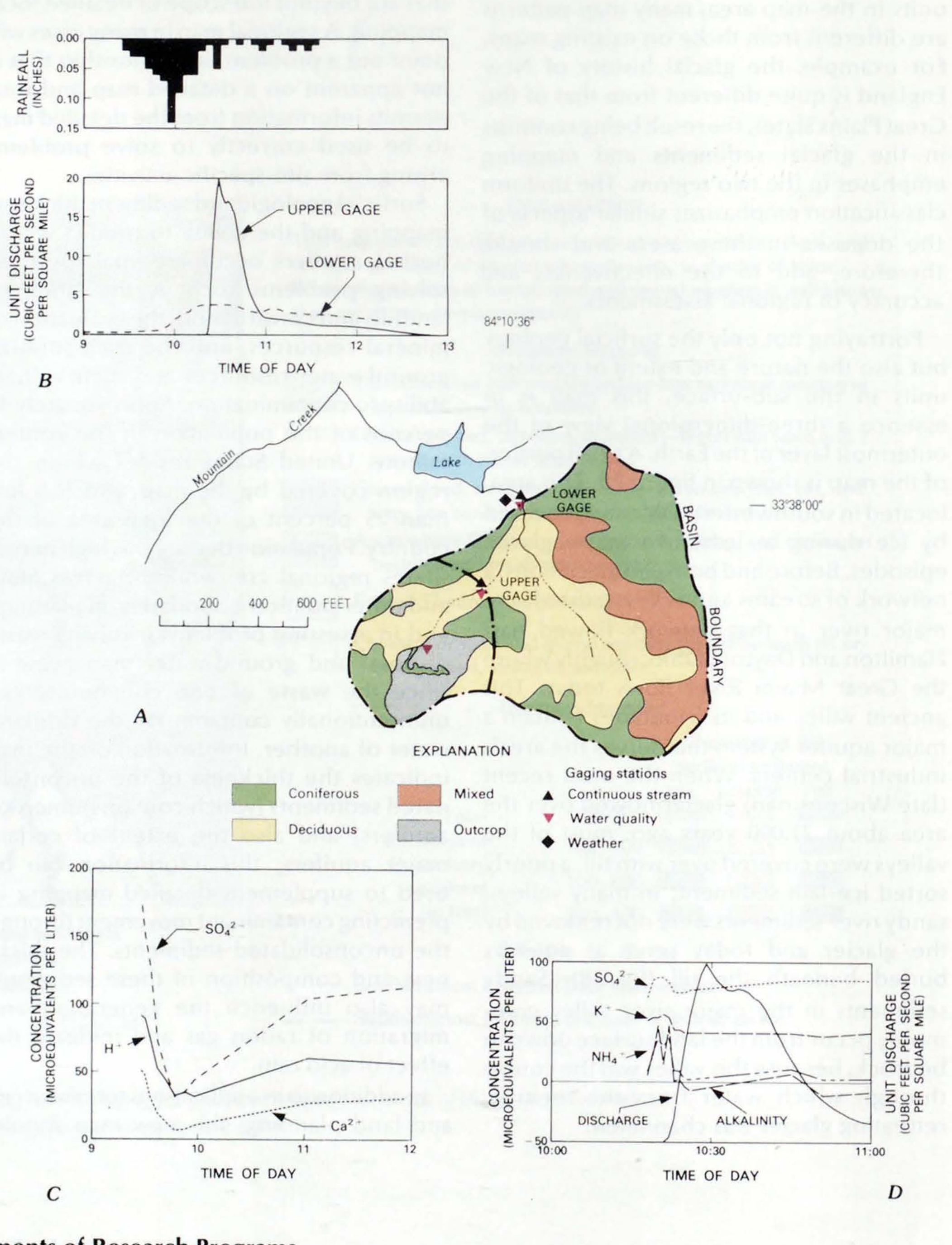


Figure 3. *Location map of the Panola Mountain research watershed and graphs showing variations in hydrology and chemistry of runoff and stream water in response to a rainstorm October 1, 1985.* A, *Distribution of major vegetation types and data collection stations.* B, *Discharge hydrograph and 5-minute rainfall rate at gaged sites.* C, *Temporal variability of SO_4^{2-}, H^+, and Ca^{2+} concentrations in runoff collected at the base of the granite outcrop.* D, *Temporal variability of discharge and the concentrations of NH_4^+, SO_4^{2-}, K^+, and alkalinity in the stream at the upstream gage.*

about 16 miles southeast of Atlanta. During a 2-hour period October 1, 1985, the forested watershed received a total of 1.30 inches of rain (fig. 3*B*). Runoff from a 7-acre granite outcrop was immediate and generated a wetting front that moved down the 1,480-foot stream channel at about 0.3 foot per second. The stream channel at the base of the granite outcrop was dry before the storm, and runoff from the granite outcrop soaking into the streambed caused the wetting front to move rather slowly down the channel. At a gage 656 feet downstream from the base of the granite outcrop, water arrived 17 minutes after the peak rainfall (fig. 3*B*), and flow peaked 12 minutes later. Streamflow at the basin outlet peaked twice; the first peak was coincident with the peak at the upstream gage, and the second occurred 35 minutes later. The basin, as a whole, responded like a giant sponge in that only 1 to 2 percent of the precipitation was transported out of the watershed by the stream within several hours of the storm. Overland flow did not occur except on bare rock areas, nor did water seep from the banks of the channel into the stream above the upstream gage. Despite the large retention of water in the watershed, large compositional variations of the runoff occurred spatially as the water moved down the stream channel and temporally in intervals as short as minutes.

Runoff that collected at the base of the granite outcrop generally was more acidic (pH 4.1-4.6) than the rain (pH 4.6). Sulfate, the dominant acid anion in precipitation, was the highest of any solute in the runoff and the rain. The decrease in acidity and sulfate concentrations from initial levels in the runoff to a minimum before peak rainfall intensity suggests that dry deposition of SO_2 during the previous 8-day period was a major source of acidity (fig. 3*C*). More than 50 percent of the runoff acidity was attributed to the dry deposition of SO_2 plus the wet deposition of sulfuric acid.

During the 12 minutes when the water level was rising at the upstream gage, the concentrations of several solutes (including K^+, SO_4^{2-}, and NH_4^+) and alkalinity increased and then decreased before flow peaked (fig. 3*D*). The NH_4^+ concentration and alkalinity changes were the most dramatic. Alkalinity increased from about 10 to 50 microequivalents per liter and then decreased to less than zero (positive acidity). Meanwhile, the ammonium concentration, which was highly correlated with the alkalinity, increased from about 6 to 40 microequivalents per liter and then decreased to levels that were lower than those of either the rain or the runoff from the granite. These variations are attributed to the differential release of solutes from organic material, consisting mainly of leaves, in the stream channel. These results also suggest that the stream alkalinity was partly controlled by nitrate reduction and the release of NH_4^+ from the organic material in the channel.

PRODUCTION OF SHADED-RELIEF PRODUCTS

Applications research in generating shaded-relief products using Digital Elevation Model data has seen many advances recently. Alternative methods for simulating illumination and shadowing on terrain features, including a convolution by wedge-filter technique and the cosine of the angle between slope-normal and the illumination direction method, have been investigated. The cosine approach has been selected as the more flexible and responsive technique because of greater control in positioning the illumination source, adding ambient light, and exaggerating elevation values.

A shaded-relief image for the entire State of South Dakota was generated by using the cosine technique; county boundaries were added to the final product to aid in identifying specific locations within the State (fig. 4). Work on the South Dakota shaded-relief image led to research on techniques to enhance standard products that include large areas of relatively low relief. Topographic detail in lowland areas can be enhanced by converting elevations to logarithmic values before the shaded-relief image is generated. This technique was used successfully on the Chattanooga, Tenn., 1:250,000-scale quadrangle to enhance the lowlands in the Valley and Ridge province.

Obtaining a correct impression of the relative relief of large areas from shaded-relief images can be difficult. To solve this problem, selected ranges of elevation are color coded by transforming the color elevation image to hue, intensity, and saturation separates. The color-coded

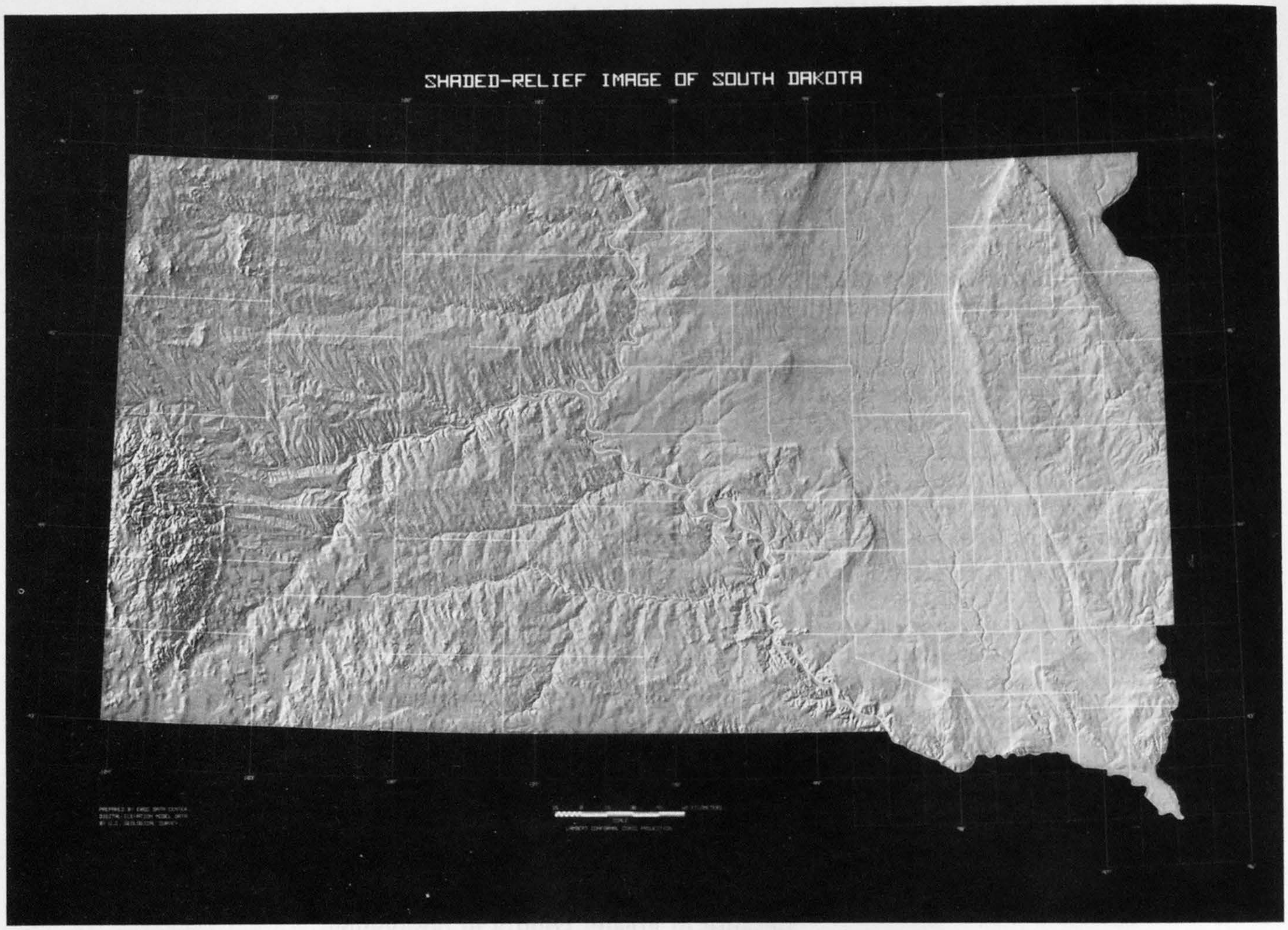


Figure 4. *This shaded-relief image of the State of South Dakota was created by mosaicking 40 Digital Elevation Model data blocks and simulating Sun illumination from the northwest at 10° above the horizon. State and county boundaries were extracted from Digital Line Graph data and added to the final shaded-relief image.*

shaded-relief image is then created by substituting the black-and-white relief image for the intensity separate and then retransforming back to standard red, green, and blue photographic separates for printing.

Under a cooperative agreement between the Geological Survey and the National Oceanic and Atmospheric Administration's National Ocean Service, shaded-relief images were created for the Anchorage, Alaska, 1:500,000-scale sectional air chart and the Los Angeles, Calif., 1:250,000-scale terminal air chart. Considerable research was conducted on 3 of the 60 1°x1° blocks of Digital Elevation Model data for Anchorage to improve the data cosmetically for input to the shaded-relief process. Improvements included (1) replacing localized anomalous elevation values, (2) matching terrain features geometrically within adjacent 1° blocks, and (3) generating a cosmetically improved terrain surface for a glacial plateau area. The National Ocean Service has printed prototype maps, which include the computer-derived shaded-relief information, for evaluation. On the basis of experience with the Anchorage prototype product, the shaded-relief product for Los Angeles was produced to meet the National Ocean Service's map requirements more closely.

Significant expertise was gained in producing and enhancing shaded-relief products to meet widely varying but very specific agency requirements.

RADON HAZARDS IN THE UNITED STATES: THE ROLE OF GEOLOGY

Indoor radon pollution has become recognized in the past few years as a leading cause of lung cancer, second only to smoking. The Environmental Protection Agency (EPA) estimates that 5,000 to 20,000 lung cancer deaths annually may be attributable to long-term exposure to radon and its radioactive decay products. The natural geologic environment plays a key role in the indoor radon problem because it is the original source of the uranium and thorium from which radon is derived. Under studies sponsored by the EPA (the congressionally designated lead Federal agency on the radon problem) and the U.S. Geological Survey's Uranium and Thorium Program, Survey scientists are investigating radon generation and migration in the ground and assessing the radon risk associated with soils and bedrock throughout the country. A large part of these investigations relies on past Survey studies that established the physical and chemical properties controlling radon availability in the ground and the distribution of uranium and its decay products in many rocks, soils, and waters across the country. Data recently transferred to the Survey from the U.S. Department of Energy's National Uranium Resource Evaluation program have also contributed to these investigations.

Investigators initially believed that indoor radon problems were largely created either by man's unintentional use of uranium or radium-rich building materials or by housing construction on sites that had been contaminated by disposed uranium wastes. More recent evidence, however, shows that elevated (greater than 4 picocuries per liter[1]) indoor radon gas concentrations are far more widespread nationally than previously thought and that the hazard is created by the entry of radon-rich soil gas through the foundation of a house. To a lesser degree, the gas can also enter households in the form of radon-rich ground water used in domestic water supplies. Most of the radon that exists in soils and bedrock below and adjacent to a house is derived from the element radium (which is in turn derived from uranium and thorium) included in the mineral grains that compose the soils and bedrock. A fraction of the radon that has formed from radium, which is known as the emanating power, seeps into the pore spaces among the mineral grains and subsequently is free to move either with the water or air in the pore spaces or by diffusion to other locations underground. The more permeable the soil or bedrock is, the more readily radon-bearing water or air contained in the pores will move. Because radon diffuses far more rapidly through air than it does through water and because convective flow of air through permeable materials is far more rapid than that of water, soil gas is the most likely source of indoor radon.

Rocks and soils enriched in uranium or radium, such as those found in areas underlain by granite or black shales, and the highly porous and permeable coarse sands and gravels overlying such geologic formations are first-order concerns with regard to indoor radon accumulations. A range of 50 to 200 picocuries per liter in indoor air is classified by the EPA as severe; levels greater than 200 picocuries per liter are considered extreme. Measured soil gas radon levels in the United States range from 10 to 40,000 picocuries per liter; however, most measurements fall within a range considered nonhazardous. Simple calculations of the amount of radon generated by soils having an "acceptable" range of radium content suggest that even these soils can generate radon in soil gases at levels well above those considered safe for indoor air (100-400 picocuries per liter of radon, in comparison with the safe level of 4 picocuries per liter). These data suggest that many soils can pose radon hazards if the mechanisms that permit large quantities of soil gas to enter a structure are present. Certain housing construction practices, such as unventilated crawl spaces, sump pumps, and the use of cinder block for foundation walls either create passageways for significant amounts of soil gas to enter a house or provide storage space for the radon. Increased concern about energy loss has led to improved insulation techniques, so that houses do not "breathe" as much as they did before, and indoor air is not vented readily to the outside. Thus, a certain percentage of homes, even in areas where radon levels in soils are average, is likely to have slightly elevated radon levels (4-20 picocuries per liter).

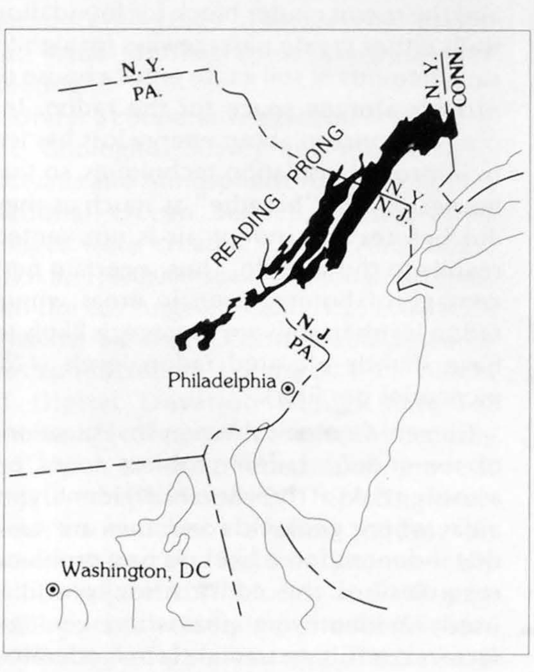
Current Geological Survey investigations of the indoor radon problem focus on assessing risks at three levels: (1) identifying areas where geologic conditions are such that indoor radon is likely to be a problem, regardless of the construction practices used; (2) identifying areas where geologic factors contribute to slightly to moderately elevated radon levels in soils and (or) water and where housing construction practices

[1]The average outdoor radon content is 0.2 picocuries per liter.

create conditions that allow moderate amounts of soil gas to enter; and (3) identifying areas where little or no risk exists, no matter what type of construction practices are used. To date, these investigations have produced a number of conclusions:

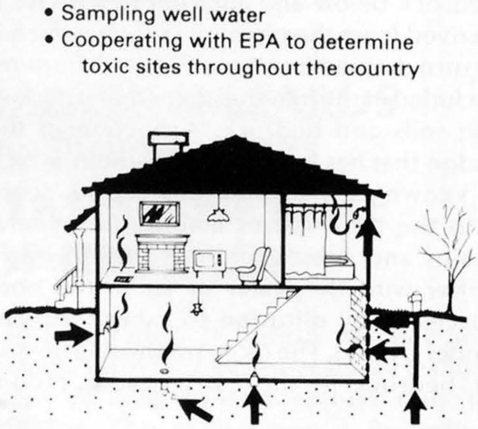
1. Uranium and thorium deposits will produce moderately (20-50 picocuries per liter) to extremely (>200 picocuries per liter) elevated indoor radon levels in homes sited thereon, unless extraordinary precautions are taken to prevent soil gas infiltration. Maps showing the locations of uranium and thorium concentrations should be a primary guide in assessing the radon hazards of a specific area.
2. Soils formed in areas where rainfall is abundant and where the bedrock is composed predominantly of basaltic volcanic rocks or of sediments derived from such rocks pose little or no hazard of elevated indoor radon levels.
3. Fractured bedrock increases the likelihood of radon seepage to the surface, probably in two ways. First, fractures provide conduits along which ground water containing uranium (ions) may have been transported in the past and in which trace amounts of uranium or radium may have precipitated. Second, fractured rocks can be permeable enough to permit the upward migration of radon-rich ground water or radon gas.
4. Granites and some metamorphic rocks commonly contain significant amounts of uranium and may be potential sources of radon. However, the uranium content of granites does vary, and the geologic nature of radon availability in granites is not well understood. Further study of this aspect would be useful, because decomposing granites often form permeable soils.
5. Black shales of marine origin, now found on land in various basins, contain moderately high to high concentrations of uranium (7 to as much as 170 parts per million). Persistent slightly to moderately elevated indoor radon levels seem to be associated with these rocks.
6. The mechanical grinding of rocks picked up and carried along by glaciers has enhanced the possibility for radon to escape from the sediments deposited by glaciers in the northern parts of the country.
7. Highly porous and permeable sediments provide conduits for large volumes of soil gas to migrate from one place to another in the subsurface. Because the length of the path that radon can travel through soil increases before decaying away, the volume of soil gas that accumulates increases by the cube of that length.
8. An impermeable soil layer above a permeable soil layer creates a significant

Figure 5. *Location of the Reading Prong area of Pennsylvania, New Jersey, New York, and Connecticut and an illustration showing how radon in soil gas and ground water infiltrates structures.*



-- Radon is a product of the natural decay of uranium. The indoor hazard was first discovered in the Reading Prong area.

-- The U.S. Geological Survey is
- Mapping deposits
- Sampling soil
- Sampling well water
- Cooperating with EPA to determine toxic sites throughout the country



-- Radon gas found in dwellings and water supply hazard if the bottom of the foundation of a structure is placed below the upper layer. Soil gases will be vented to the surface through the opening made in the impermeable soil. Indoor venting also becomes more pronounced when water saturates the surface soil layers during a rain or during snowmelt where the ground freezes and thaws seasonally.

9. A significant percentage of homes located in areas underlain by limestones and dolomites seems to have slightly to moderately elevated levels of indoor radon, and caverns in the carbonate rocks persistently accumulate moderately to extremely elevated levels of radon. Although these rocks are not known to have elevated uranium concentrations, they often produce soils that not only have a high capacity for absorbing any uranium and radium moving in shallow ground waters but also are well suited to emanate the radon that subsequently forms.

Since the indoor radon hazard was first discovered in the Reading Prong area of the Northeastern United States (see fig. 5), Geological Survey scientists have applied their expertise to understanding the geologic factors involved at five areas in the Reading Prong region of Pennsylvania, New Jersey, New York, and Connecticut and at several other sites designated for study by the EPA. A preliminary evaluation of 10 States, as part of EPA's State Assistance Program, will be completed in early 1987, and soil gas measurement techniques are being developed and tested.

WATER AND SEDIMENT IN THE ORINOCO RIVER

During the last 5 years, the U.S. Geological Survey has been studying the streamflow and sediment transport of the Orinoco River of Venezuela and Colombia. Proyecto Orinoco-Apure (Orinoco-Apure Project) is being conducted in collaboration with the Venezuelan Ministerio del Ambiente y de los Recursos Naturales Renovables (Ministry of the Environment and Renewable Natural Resources), which is interested in evaluating the river's potential for navigation, hydroelectric power generation, and other uses and in assessing the possible environmental consequences of these uses. Geological Survey research hydrologists welcomed the opportunity to develop new techniques for measuring and sampling large rivers and to study one of the world's great rivers, especially one that is largely unmodified and, in many parts of its basin, still unaffected by man's activities.

The Orinoco River ranks third in the world (after the Amazon and the Zaire) in water discharge to the oceans (equivalent to two Mississippi Rivers). Draining nearly 400,000 square miles of Colombia and Venezuela (fig. 6), it derives its water flow in approximately equal portions from the Guayana Shield on its eastern bank and from the Andes Mountains and pre-Andean plains on its western bank. Although equal in quantity, the waters entering from these two sides are markedly different in quality. Tributary waters that drain the Guayana Shield contain very little suspended sediment and, for rivers of this size, some of the lowest concentrations of dissolved elements. Tributaries that drain the Andes, on the other hand, contain much larger concentrations of dissolved elements and suspended sediment. Inflows from the major tributaries require 120 to 250 miles of downstream transport after entering the main stem before they are completely mixed with other waters of the Orinoco. Because the concentrations and compositions of suspended and dissolved material introduced by western bank tributaries are so markedly different from those introduced by eastern bank tributaries, downstream mixing of these tributary contributions to the main stem can be traced by their chemical and sedimentary signatures. At least 90 percent of the 150 to 200 million tons of suspended sediment carried annually by the Orinoco River to its mouth is derived from the Andes.

Distinctly different wet and dry seasons result in an annual fluctuation of 40 to 50 feet in the level of the river; large sand waves that form on the channel bed in response to high-water flow conditions are exposed during low-water conditions and are thus available for detailed study. These sand waves vary from 330 to 660 feet in length, stand 6.5 to over 13 feet high at their crests, and contain well-developed internal structures similar to those found in some ancient sandstones. One consequence of

Figure 6. *The 400,000-square-mile drainage basin of the Orinoco River in Venezuela and Colombia. The sand-dune area is shown in red.*

this exposure of the channel bed during the low-water season is the transport of these sediments upriver by the wind. Trade winds reach their greatest strength during the dry season and recycle upriver a visible fraction of the fine sand that the river transports downriver during the high-water season. A large area of sand dunes west of the Orinoco River (fig. 6), thousands of square miles in extent, attests to the persistence and importance of this process in recycling the sands of the Orinoco River.

DIGITAL CARTOGRAPHIC AND EARTH-SCIENCE DATA MERGE

In the last several years, the Geological Survey has made a substantial commitment to the production of digital cartographic data. The types of digital data being produced routinely include Digital Line Graphs and Digital Elevation Models, both of which originate from the Survey's standard topographic map series at various scales and projections. Data compiled by other Federal agencies also are becoming available in digital form as a result of the overall increase in automated data processing capabilities. Census information, geochemical data, and geophysical data are now typically disseminated on computer-compatible tapes, and a wide range of computer programs are available to support information processing needs. Some typical data bases include the U.S. Department of Energy's National Uranium Resources Evaluation Program and the Geological Survey's Rock Analysis and Storage System (RASS). A logical extension of digital data production and dissemination has been the development of techniques for merging data sets from these disparate data bases to generate thematic displays for various kinds of earth-science investigations.

Research is being conducted to define methodologies for merging and integrating digital data sets in response to the needs of the Survey and other Government agencies. This work has resulted in procedures that can be adapted to generate derivative products and graphic displays using a broad range of digital data to represent multidisciplinary information in cartographic form.

One example involved the generation of a geographically referenced display of the anomalous distribution of lithochemical data with reference to the topography and political boundaries within the State of Missouri (fig. 7). The lithochemical data were retrieved from the Survey's RASS data base, interpolated to a surface grid, transformed logarithmically, and processed to show the distribution of lead having logarithmic values above a certain level. The surface of anomalous distribution was color coded and merged with a shaded-relief image produced from 30-arc-second digital elevation data available from the National Oceanic and Atmospheric Administration. The outline of the State of Missouri was

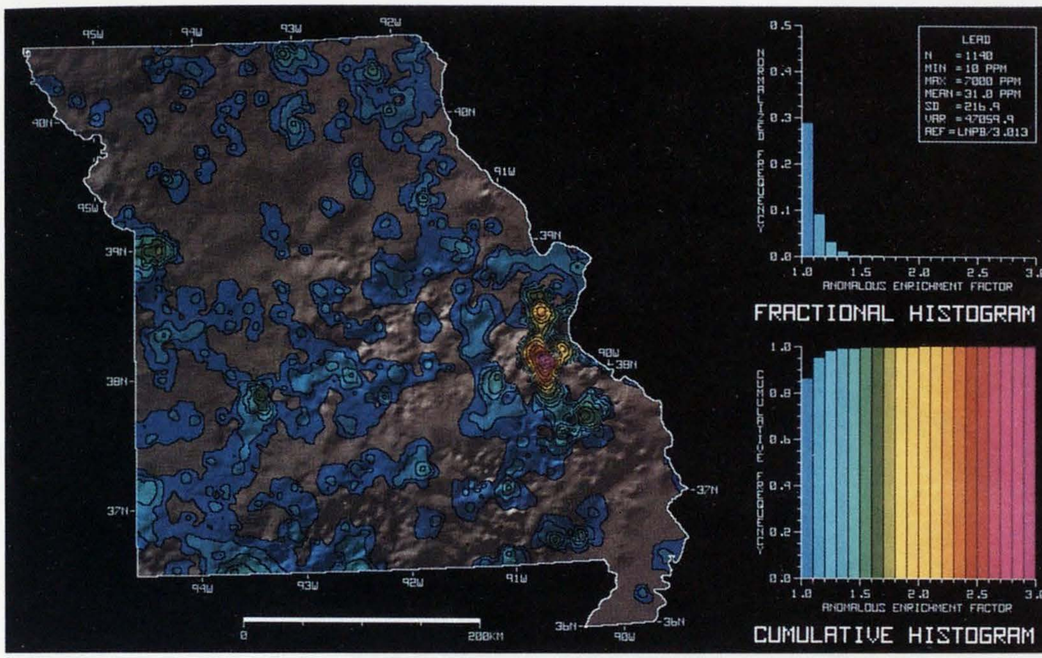


Figure 7. *Distribution of anomalous concentrations of lead, color coded and merged with a shaded-relief image (Albers equal-area conic projection), for the State of Missouri.*

created by using Digital Line Graph files from a 1:2,000,000-scale map base and was used to delimit the area of elevation and lithochemical data to be displayed. Digital processing techniques were used to generate graphic annotation (latitude, longitude, scale bar, and title) and descriptive information (color and distribution plot explanations).

The resulting product is an example of how multiple data sets can be processed, merged, and displayed to represent multivariate spatial relationships. As more tabular, statistical, and cartographic data become available in digital form, methods for effectively manipulating these data must be developed if their utility is to be fully realized.

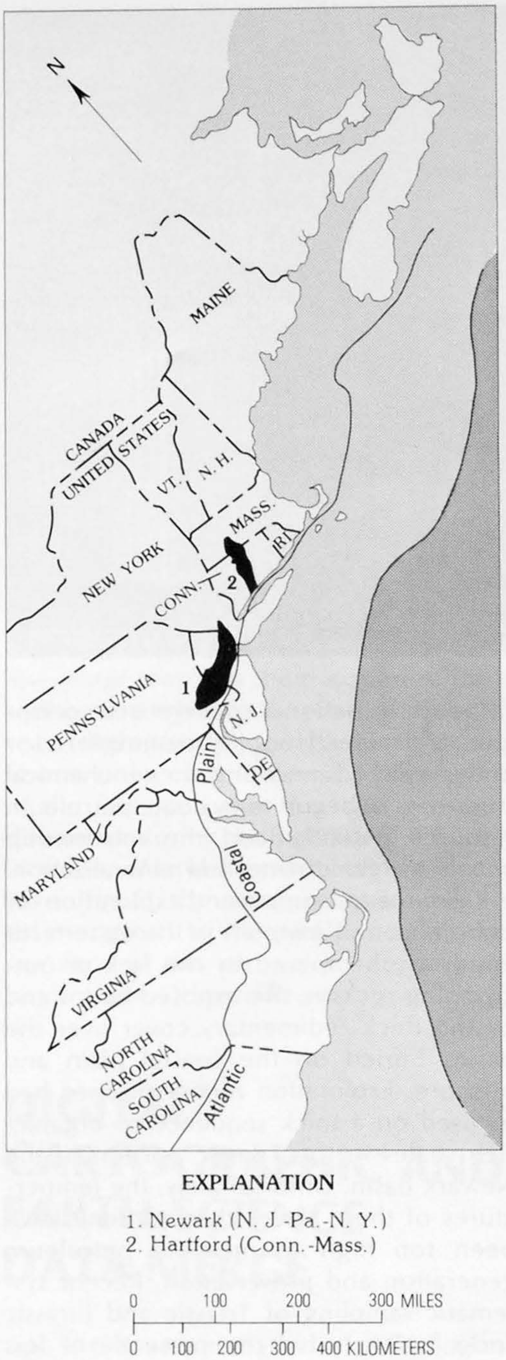
FRONTIER PETROLEUM PROVINCE IN THE EASTERN UNITED STATES

About 200 million years ago, in the Triassic and Jurassic geologic Periods, an extensive system of fault-bounded basins developed along the eastern margin of North America as a result of continental rifting and the formation of the Atlantic Ocean. Interdisciplinary study of these basins was undertaken by U.S. Geological Survey scientists in response to national concern over petroleum and mineral supplies in unexplored or underexplored areas. Organic geochemical studies were begun to evaluate petroleum resource potential and the relationship between organic matter and mineralization.

Resource assessment and exploration for petroleum and minerals in the eastern rift basins are hampered by the lack of outcropping rocks in the exposed basins and by the thick sedimentary cover over the basins buried on the coastal plain and offshore. Exploration reconnaissance had focused on a thick sequence of organic-rich shales in the Triassic portion of the Newark basin. Unfortunately, the temperatures of these shales through time have been too high to promote petroleum generation and preservation. Recent systematic sampling of Triassic and Jurassic rocks has revealed the presence of less thermally altered shales of Early Jurassic age in the Hartford (Connecticut and Massachusetts) and Newark (New Jersey, New York, and Pennsylvania) basins (fig. 8). A clear precursor-product relationship exists between indigenous organic matter in the Jurassic shales and migrated organic matter (liquid and solid) in overlying stained sandstones and vein fillings.

Mineralized veins crosscutting sedimentary and volcanic strata are a common feature of the Hartford and Newark basins. By studying the composition and texture of these veins, it is possible to reconstruct the history of fluid flow. Small bubbles trapped

Figure 8. *Locations of the Hartford and Newark basins.*



in the minerals (fluid inclusions) can be analyzed to determine the temperature and composition of migrating fluids. Results of these studies indicate that multiple generations of mineralizing fluids and petroleum fluids migrated through open fractures in these rocks.

The zone of source rocks having properties that permit the generation and migration of petroleum in the Hartford and Newark basins is inferred to be a little more than one-half mile thick and to encompass the Triassic-Jurassic boundary. A geologically brief episode of high flow during the earliest Jurassic is proposed to account for the narrow, shallow "oil window." Extensive Early Jurassic lava flows are consistent with the proposed high heat flow that occurred late in the sedimentary history of these basins.

Petroleum exploration targets in the exposed rift basins are limited by tilting and erosion that have stripped away most potential reservoirs. Where the upper portion of the section is preserved, however, exploration targets are shallow and relatively inexpensive to drill. The presence of thin but widespread organic-rich shales having moderate to excellent petroleum source potential indicates that reservoir properties rather than thermal history or source-rock quality have probably limited petroleum accumulation. The potential for petroleum accumulation in the buried basins is greater than that in the exposed basins because there has been less erosion of possible reservoirs. The regional geologic setting, the quality of potential source rocks, and the presence of migrated petroleum in the exposed basins are cause for optimism that the buried basins will become a major frontier area for petroleum exploration.

SEAWATER INTRUSION IN A COASTAL AQUIFER: A CASE STUDY OF PAJARO VALLEY, CALIFORNIA

Characterizing seawater intrusion into coastal aquifers is a continuing challenge for hydrogeologists because it is difficult to predict the behavior of the ground-water reservoirs undergoing encroachment. Most investigators have approached the problem by describing the landward movement of an interface between seawater and freshwater; this approach assumes that seawater infiltrates from an offshore outcrop of the aquifer. If a coastal aquifer is overlain by a leaky confining layer, however, the analysis is less clear cut, because seawater can migrate downward through this layer.

A recent U.S. Geological Survey investigation identified multiple pathways for seawater intrusion and attempted to quantify the individual contributions of these sources in Pajaro Valley, Calif., a coastal area of ground-water development. Application of a two-dimensional solute-transport model simulated the hydrodynamic interaction of lateral and vertical flow, along with the movement of seawater contamination.

An analysis of the source of ground water during the past decade of development indicates that, within the study area, approximately 60 percent of recharge to the aquifer comes from vertical leakage across confining beds. Of this 60 percent, two-thirds comes from the ocean and the water table through the overlying confining layers, and one-third comes from the deep aquifer through the underlying confining layers. Most of the remaining 40 percent of recharge comes from lateral boundary flow into the area of investigation; only 5 percent enters the aquifer from the offshore outcrop.

Hydrogeology indicates three principal pathways or sources for seawater contamination of the primary aquifer: (1) downward leakage from the water table, (2) downward leakage from the ocean, and (3) landward flow through the offshore outcrop. Onshore, brackish water in the sloughs and the Pajaro estuary contaminates the water table aquifer and can leak through the confining layers to the primary aquifer. Similarly, offshore, seawater can leak through the confining layers between the ocean floor and the primary aquifer and into the primary aquifer. In addition, the primary aquifer crops out in the northern wall of the Monterey Submarine Canyon; at this outcrop, seawater can flow horizontally into the aquifer.

To analyze the individual contribution of each of the three sources, three simulations were run. Each simulation examined the effect of only one source by eliminating the contamination from the other two.

Comparing the model-simulated onshore impacts of all three sources reveals interesting differences in the rates of contamination from each source. Onshore contamination caused by leakage from the ocean and the water table is relatively constant; leakage from these two sources will dominate onshore contamination until the year 2020. In contrast, contaminant inflow from the aquifer outcrop is slow and will be the last of the three sources to cause onshore contamination. Although contamination from the offshore outcrop is potentially larger than that from leakage, its effect in the simulation will not be felt onshore until the mid-1980's. This relation is believed to be typical for seawater intrusion of shallow stratified coastal aquifers. Analysis suggests that there will be a significant time interval, following the initial observation of seawater intrusion, in which to take remedial action to control future contamination.

FORMATION OF MISSISSIPPI VALLEY-TYPE LEAD AND ZINC DEPOSITS

"Mississippi Valley-type" lead and zinc deposits represent one of the world's major sources of these two metals as well as an important potential source of accessory cobalt, silver, copper, and nickel. Recent fluid inclusion research on the Mississippi Valley-type deposits of Missouri and Arkansas, together with a synthesis of geologic information from many other sources, has led to the development of a predictive model for the origin of these deposits. The model is based on a new understanding of the structural framework in which these deposits form and should serve as a guide to future exploration for lead and zinc. Until recently, little was known about the factors that localize ore deposition in Mississippi Valley-type deposits. Although much remains to be learned, it is now possible to identify structurally favorable exploration sites. More efficient assessment and development of both domestic and foreign resources of lead, zinc, and accessory metals should result.

The Ozark region of the midcontinent (Missouri, Arkansas, Kansas, and Oklahoma) hosts the highly productive Southeast Missouri and Tri-State districts as well as the smaller Northern Arkansas and Central Missouri districts. Studies of these Mississippi Valley-type lead and zinc districts indicate that they formed approximately contemporaneously from fluids originating in a sedimentary basin (Arkoma basin) to the south. Collision of the North and South American continental plates approximately 300 million years ago formed the Ouachita mountain belt in central Arkansas and played a major role in driving hot saline fluids from deep in the Arkoma basin northward, ultimately to form the ore deposits. New computer modeling of fluid systems has confirmed the viability of long-distance fluid migration through highly permeable sandstone and carbonate aquifers.

Evidence for the timing and the source of the fluids that formed the Ozark deposits is provided by fluid inclusions in ore-related minerals and by techniques for dating certain minerals. Tiny samples of the fluid from which the ore deposits formed are trapped in the ore minerals and provide information on the fluid's original temperature and chemistry. Strong similarities in the fluid chemistries of the deposits indicate a single fluid source, while an increasing temperature gradient to the south indicates a southern fluid source. Dating techniques based on the remanent magnetism in the rocks and on thermal annealing of fission tracks in the mineral zircon indicate the passage of hot fluid through regional aquifers approximately 300 million years ago. The timing of fluid migration is consistent with the timing of continental collision and formation of the Ouachita fold belt to the south. In addition, the age of ore formation in many of the Ozark deposits can be established as no greater than approximately 300 million years.

Combining fluid incision research with the results of research on regional structure, dating, and ground-water hydrology links Mississippi Valley-type lead and zinc occurrences with the margins of large, structurally deformed sedimentary basins. Deep-basin fluids are expelled as a result of basin margin deformation; if aquifers of adequate regional extent and porosity are present, hot brines capable of transporting metals in solution may reach distant ore-deposition sites.

This model applies to more than the Ozark deposits; it also describes the genesis and structural setting of Mississippi Valley-type deposits associated with the Appalachian basin and fold belt and Mississippi Valley-type deposits in Canada (for example, Pine Point, Robb Lake, Nanisivik, and others) and Sweden (Laisvall). Future investigations will probably show that other Mississippi Valley-type lead and zinc deposits worldwide can be described within the general framework of this model.

COMPUTER SIMULATION OF FLUID FLOW AND MOVEMENT OF DISSOLVED SUBSTANCES IN THE SUBSURFACE ENVIRONMENT

Advances in computer simulation are allowing sophisticated analysis of the subsurface environment as a multifaceted national resource for water supply, energy production, energy and materials storage, and waste isolation. U.S. Geological Survey research is developing computer technology to simulate the movement of fluids, heat, and dissolved substances in the subsurface and to display their behavior in numerical and graphic output. Using computers, hydrologists can study the nature of the subsurface environment in a scope and depth not previously possible and can develop methods for the optimal use and preservation of that environment.

Although the gradual development of this simulation modeling has taken place over the last 20 years, recent advances in the Geological Survey's research program allow both analysis of more realistic and complex processes and more detailed simulation of particular field areas. In analyzing subsurface chemical transport, for example, models now simulate the movement of multiple chemical solutes that undergo various chemical reactions with one another and with subsurface solids. These advances permit study of the dispersion of toxic and radioactive wastes in the subsurface, as well as study of natural hydrogeologic processes that affect the structure of the Earth's crust. In coastal aquifers where seawater intrusion into water supplies is a concern, new simulation methods allow detailed study of the hydrology of these systems, giving insight into the path of intruding saltwater and allowing schemes to be developed that minimize the impact of intrusion.

Simulation and optimization (mathematical) techniques are being applied by Geological Survey scientists to provide alternative designs and plans for policymakers and engineers concerned with the best use and (or) control of developments in the subsurface. This computer program carries out many simulations of a field system, readjusting the control variables (that is, the position and pumping rate of wells) on each simulation until an optimal development scheme is found under the desired conditions.

The goal of developing analytical hydrologic tools in the form of an intelligent simulator that automatically organizes itself to simulate a particular subsurface system from raw data is close to realization. This advance is based on significant developments in model identification and in model parameter-estimation methods. These developments also have direct application to the efficient design of networks for collecting the data on which the analysis of subsurface systems is based.

LAKE HYDROLOGY RESEARCH

Lakes are an important national resource used for water supply, for cooling water for industries and utilities, as a source for food, and for recreation. Lakes are hydrologically complex, and they are often mismanaged because their function within the hydrologic system is not well understood. To address this problem, the U.S. Geological Survey initiated a program of research on lakes in different climatic and geologic settings throughout the United States. A few recent results of that research follow.

Numerical modeling of ground-water movement near lakes indicates that seepage to and from lakes is highly dynamic and dependent on the timing and areal distribution of recharge to ground water. The common concentration of recharge directly adjacent to a lakeshore causes increased rates of seepage to the lake very quickly following, or even during, a period of rainfall. This process is particularly important along areas of a lakeshore that might ordinarily have seepage out of the lake, because the concentrated recharge reverses the direction of seepage and therefore causes ground water to seep into the lake. This phenomenon has been observed at many locations in the United States, such as Mirror Lake, N.H., Williams Lake, Minn., Cottonwood Lake, N. Dak., and Island Lake, Nebr.

In addition to being concentrated directly adjacent to lake shorelines, ground-water recharge is also frequently concentrated in depressions in upland areas between lakes. In the sand hills region in western Nebraska, for example, water table mounds occur in uplands characterized by many topographic depressions because of the greater opportunity for recharge in those depressions. In contrast, where there are no depressions in the upland, troughs on the water table surface occur because recharge is minimized. The normal seepage of water to and from lakes differs in this region in that water seeping from a lake usually does not move to adjacent lower lakes because of the presence of these water table mounds or troughs.

Knowledge of concentrated recharge near lakeshores or in topographic depressions is also important for understanding ground-water quality. For example, in the Cottonwood Lake area of North Dakota, frequent reversals of the direction of ground-water flow between adjacent wetlands increases the contact time of ground water with the rock matrix and results in increased salinity in local areas of the ground-water system. This increased salinity ultimately affects the quality of water in the wetlands that the ground water seeps into. Also, these differences in the quality of ground water seeping into a lake or wetland commonly affect the distribution of aquatic plants and microscopic animals living on the bottom of the lake or wetland. In some cases, the chemical quality of ground-water seepage is indicated by the presence of aquatic organisms in the lake or wetland.

Detailed study of seepage patterns in lakebeds has also resulted in a greater understanding of the impact of transpiration by nearshore upland plants. For example, during drier periods of the year, when ground-water levels are low, nearshore plants often lower ground-water levels to the point where lake water will seep into ground water, even if the regional gradient of the water table is toward the lake.

Research on the interaction of lakes and ground water is important for understanding the water balance of lakes, the chemical characteristics of lakes, and the distribution of aquatic plants and microscopic animals and plants in lakes, which in turn provide guidance for the successful management of lake ecosystems.

GEOLOGIC INVESTIGATIONS

MISSION AND OUTLOOK

During fiscal year 1986, the Geologic Division of the U.S. Geological Survey continued its programs to assess energy and mineral resources onshore and offshore, to identify and investigate geologic hazards, and to determine the Nation's geologic framework, the geologic processes that shaped it, and their relation to long-term climatic changes.

The articles in this chapter describe some of the most significant accomplishments of the Geologic Division during fiscal year 1986. Although these articles cover only a select few of the Division's activities, they show how basic geologic research simultaneously spurs new developments in the geosciences and provides the basic information required to conduct missions central to the needs of the Nation.

MAJOR PROGRAMS

The Geologic Division program is presented to Congress under five major program headings. A discussion of accomplishments under these subactivities during fiscal year 1986 and the outlook for the future follow.

Geologic Hazards Surveys

At 2:30 a.m. local time on March 27, 1986, Augustine volcano erupted in Cook Inlet, 180 miles southwest of Anchorage, Alaska. The Landsat 5 satellite acquired a Thematic Mapper image of the volcano at 10:46 a.m. Ash falling throughout the area curtailed air traffic, power usage, and business activities. The U.S. Geological Survey monitors Augustine and the 51 other active volcanoes in the United States. (Photograph courtesy of Earth Observation Satellite Company, Lanham, Md.)

A regional earthquake hazard assessment in the Provo-Salt Lake City-Ogden area of Utah was conducted in fiscal year 1986. Efforts with State and local officials to ensure that the results of this study are used to implement hazard reduction practices continue. A similar research effort in the Puget Sound region of Washington State is planned.

Installation of instrumentation for the prototype earthquake prediction experiment at Parkfield, Calif., was continued in fiscal year 1986; additional instruments will be installed and calibrated in fiscal year 1987. (See "Predicting the next major earthquake in the Parkfield area of California," p. 12, for more information.)

A study of the effects of recent earthquakes in Mexico and Chile provided data that can be applied to improving knowledge of similar seismic events that may occur in the United States. For example, the study greatly improved understanding of the devastating role that unconsolidated sediments can play in amplifying ground shaking.

Fiscal year 1986 was a year of unusual volcanic activity in Alaska and Hawaii (additional information regarding the Alaskan eruptions is found on p. 58). Monitoring and hazard assessments of all volcanically active regions of the Nation continue. Geologic Division scientists also assisted the Office of Foreign Disaster Assistance of the Agency for International Development during the eruption of Nevado del Ruiz in Colombia. (See "International activities," p. 105, for more information.)

Cooperative Federal-State landslide hazards assessment studies were established in fiscal year 1986 with the States of Arizona, Colorado, Idaho, Maine, Nevada, New Mexico, Ohio, Oregon, Utah, and the Commonwealth of Puerto Rico. Probability studies of landslide occurrence in the San Francisco Bay area of California and the Wasatch Front in Utah to identify dominant landslide processes amenable to low-cost landslide hazard reduction and a landslide hazards assessment of the Pittsburgh region of Pennsylvania are also planned.

Land Resource Surveys

A nationwide survey of geoscience information users conducted by the National Research Council indicated that large-scale general-purpose geologic maps are the products most in demand by private and public consumers. In response to this survey, the Geologic Framework and Synthesis Program will be redirected to become the National Geologic Mapping Program. Although most of the basic research functions of the former program will be preserved, its emphasis will be shifted to systematic, prioritized geologic mapping. The Federal-State Cooperative Geologic Mapping component of the Geologic Framework and Synthesis Program will be preserved as an element of the National Geologic Mapping Program. Thirty-one Federal-State cooperative projects were underway in fiscal year 1986.

Significant activities under the Deep Continental Studies component of the Geologic Framework and Synthesis Program are addressed in articles on the Trans-Alaska Crustal Transect and the Salton Sea Scientific Drilling Program (see p. 60, 55). Plans are underway to establish the Deep Continental Studies component as a separate program because of its close association with the Continental Lithosphere Program (conducted by the National Science Foundation) and with the Continental Scientific Drilling Program (conducted jointly by the Geological Survey, the U.S. Department of Energy, and the National Science Foundation).

Research under the Climate Change Program has established the long-term history of lake-level fluctuations in the United States. The geologic record indicates that historical lake levels are abnormally low and that the trend from natural variation indicates a long-term rise in lake levels. These studies illustrate that basic research can be useful in identifying and resolving environmental policy issues associated with potentially significant economic impacts. Geologic Division scientists continue to be directly involved with the U.S. Army Corps of Engineers and other concerned Federal and State agencies in addressing the hazards created by changing lake levels in areas such as the Great Lakes, including advising those agencies on the feasibility of mitigation strategies.

Mineral Resource Surveys

The National Mineral Resource Assessment Program is described in this chapter (see p. 53). Data previously gathered by programs within the Mineral Resource Survey's subactivity have been used to establish a national geochemical data base for identifying and monitoring areas where soil and water are contaminated. The first step in this plan was to compile existing data; areas where insufficient data exist are being identified, and plans are being developed to implement a schedule of sampling and resampling.

Fiscal year 1986 saw the acquisition of software to produce digital mineral resource assessment maps compatible with land use, census, and other geographic and water information maps produced in other information systems of the Geological Survey. This compatibility will facilitate comparisons of mineralized locations with other social and economic conditions within a geographic area.

Energy Resource Surveys

In fiscal year 1986, the Uranium and Thorium Investigations Program began using geologic data to identify areas having high potential for indoor radon hazards. Further information on this effort is contained in this chapter (see p. 38).

In cooperation with the Kentucky Geological Survey, a study to characterize the quantity, quality, and accessibility of low-sulfur coal in eastern Kentucky began. Included in that effort are an economic evaluation of the area's potential for coal production and computer modeling of the coal deposits. This type of study may be expanded to include other coal-bearing areas in the Appalachian region.

Offshore Geologic Surveys

The Coastal Erosion Program, established in fiscal year 1986, is designed to provide geologic information on the nature, extent, and cause of coastal erosion to the various Federal and State agencies that make decisions pertaining to the arrest and (or) mitigation of coastal retreat and land loss. The current focus of the program is the highly vulnerable coastal segments of the Louisiana barrier island system.

The results of sonar surveying of the sea floor of the Gulf of Mexico and of submarine massive sulfide deposits along the Juan de Fuca and Gorda Ridges, offshore Washington and Oregon, are addressed in this chapter (see p. 62, 51). Future plans include verification studies of potential mineral resources and previously unknown sea-floor features and hazards identified by the sonar surveys.

HIGHLIGHTS

Submarine Massive Sulfide Deposits

By William R. Normark

The U.S. Geological Survey began a program in 1980 to study hydrothermal processes associated with massive sulfide mineral deposits on the deep-sea floor. Through 1984, the field studies under this program were primarily concerned with the southern Juan de Fuca Ridge, an area 270 nautical miles west of Newport, Ore. (site A, fig. 1), that lies outside the Exclusive Economic Zone (EEZ) of the United States. The Juan de Fuca Ridge is a 12-mile-long segment of the axis of an oceanic spreading ridge characterized by voluminous young volcanic extrusions related to the growth of ocean crust. The massive sulfide deposits, which were discovered in 1981, occur within a narrow, approximately 100- to 165-foot-wide linear depression underlain by glassy sheet-flow lavas. The three largest sulfide deposits were examined by using the research submersible Alvin in September 1984, and extensive mineral, hydrothermal fluid, and biologic samples were recovered. Since 1984, researchers at the Pacific Marine Environmental Laboratory of the National Oceanic and Atmospheric Administration (NOAA) have worked closely with the Geological Survey to provide a jointly maintained acoustic transponder positioning net in the Juan de Fuca area. A joint diving program using the Alvin submersible is planned, as is development of a long-term effort to monitor the hydrothermal systems.

The focus of the program shifted in 1985 to the Gorda Ridge, which is southeast of the Juan de Fuca Ridge and lies entirely within the U.S. EEZ (fig. 1). Possible hydrothermal sulfide deposits were identified during the late summer of 1985 along the ridge and on related volcanic and transform fault zones. These studies were coordinated through the joint State-Federal Gorda Ridge Task Force, formed in 1984 to determine the extent of hydrothermal mineral deposits along the Gorda Ridge and to establish a baseline for environmental studies, should leasing of the deposits occur. The Survey-led cruises involved ancillary programs for scientists from Oregon State University (OSU), who were supported through the task force. These cruises focused on (1) the sediment-filled Escanaba Trough, which characterizes the southernmost part of Gorda Ridge; (2) the northern end of Gorda Ridge, in an area referred to as GR-14 (site B, fig. 1); (3) the Blanco Fracture Zone, which connects the Juan de Fuca and Gorda Ridges; and (4) the President Jackson Seamounts group (site C, fig. 1).

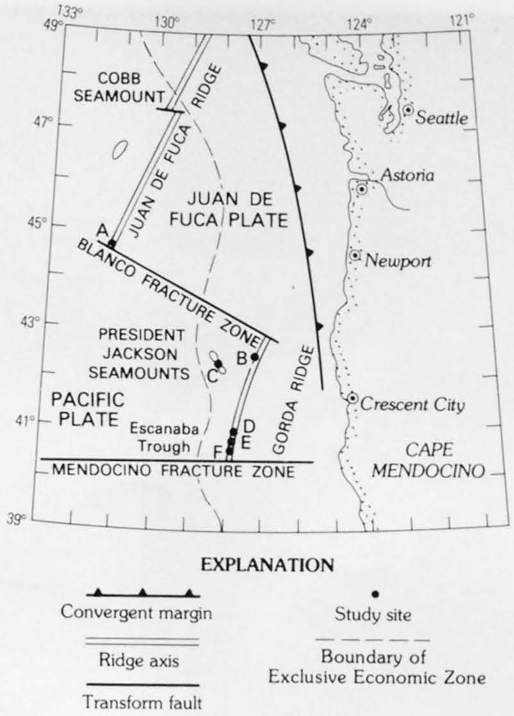


Figure 1. *Location map showing Juan de Fuca and Gorda Ridges and general work locations. Site A, Juan de Fuca study area; B, GR-14; C, President Jackson Seamounts; D and F, main 1985-86 work areas in the Escanaba Trough; E, additional dome explored in 1986.*

Escanaba Trough

In September 1985, Survey scientists led a research team, including geologists and geophysicists from OSU, that discovered massive sulfide and related petroleum deposits in the Escanaba Trough. After regional geophysical surveying of the Escanaba Trough was completed, two detailed study areas (D and F, fig. 1) were selected. Volcanic domelike intrusions pierce and uplift the 1,640-foot-thick faulted

Figure 2. *Hydrothermal mound. Small ledges of sulfide can be seen in sediment, and a constructional mound or chimney is visible in the foreground. Most of the animals shown are not specific to hydrothermal vents, but the greater-than-normal biologic density in this area may reflect hydrothermal activity. Width of photograph is approximately 9 feet.*

sediment fill of the trough in these two areas. High heat flow and microseismic activity characterized the volcanic centers. The southern study area (F, fig. 1) yielded a mudstone that has iron sulfides and interbedded petroleum-rich layers that contain as much as 5 percent organic carbon.

These two study areas were the main focus of fieldwork in July 1986. Detailed mapping indicated that the Escanaba Trough sediments have been uplifted locally (on fault systems that are not well understood) to expose massive sulfides and are cut by young volcanic peaks. In addition, small chimneylike deposits are found on top of the sediment cover in many areas (fig. 2). The sediment-hosted samples recovered from site F on figure 1 in 1985 consist mostly of iron sulfides; a single sample contains petroleum that precipitated from the hydrothermal fluid. Isotopic data demonstrate that the sulfides in the samples were derived from both oceanic crustal rocks and the sediments in the Escanaba Trough and that these deposits were apparently actively forming at the time that they were recovered.

Sulfide deposits were photographically mapped in 1986 at numerous locations in two areas (sites D and F, fig. 1); site F is the same area where sulfide was dredged in 1985. In addition, a gravity core from site E in figure 1 recovered sediment cut by sulfide veins, and massive sulfide was recovered in 11 dredges from the two main study areas. Unlike the samples dredged in 1985, most of the fragments recovered are rich in zinc, copper-iron, and lead sulfides, in addition to various iron-sulfide phases. Semiquantitative analyses of these samples demonstrate that some contain more than 1 percent of both copper and lead and more silver than had been previously reported for deep-sea polymetallic sulfide. Most of the deposits appear to be sediment hosted.

Northern Gorda Ridge

Detailed surveying and sampling along the northern axis of the Gorda Ridge (GR-14) (site B, fig. 1) indicated two potential targets for sulfide deposition. The first target is along the eastern wall of the axial valley and coincides with the inferred source of a hydrothermal plume mapped in the water column by NOAA and OSU scientists. The target zone is a ridge between the wall of the axial valley and a broad terrace at a depth of 9,500 feet. On the basis of a water chemistry anomaly, the target is thought to be a zone of active hydrothermal discharge. The second target is in the axial valley, where photographic surveys identified an area of high biologic density, and the rocks appear to be altered sulfide. No samples of hydrothermal material have been recovered from this target area, which is located within a zone of young basalt pillow and sheet flows.

Blanco Fracture Zone

Dredging during a cruise along the Blanco Fracture Zone recovered samples of basalt and gabbro generally altered to greenstone. These samples contain common pyrite and chalcopyrite that precipitated from hydrothermal fluids. The samples have complex textures resulting from several stages of hydrothermal precipitation and alteration and from brecciation due to deformation. These samples are now being analyzed at OSU.

President Jackson Seamounts

Dredging along the President Jackson Seamounts chain (site C, fig. 1) recovered pillow basalt, pillow breccia, and hyaloclastite (a deposit of small angular fragments formed when lava flows into water and causes granulation or shattering of the lava) encrusted with hydrothermal manganese oxides. The pillow breccia and hyaloclastite are cemented with iron oxides and quartz of hydrothermal origin. These deposits are similar to those recovered from the summit of the active Loihi Seamount off the coast of Hawaii and probably formed several million years ago when the seamounts were volcanically active.

1986 Sea Cliff Submersible Program

The work of Survey scientists on the Research Vessel *S.P. Lee* provided the geologic base maps and sample localities needed to carry out manned submersible operations in 1986 using the research submersible Sea Cliff. This submersible program was conducted by a team composed of personnel from the Survey, NOAA, the Minerals Management Service, and academia under a program directed by the Gorda Ridge Task Force.

Future Studies

Analytical results for the samples in hand will be used to select the most promising areas for further study. Plans for additional submersible surveys in fiscal year 1987 are being developed with the U.S. Navy.

The National Mineral Resource Assessment Program

By Frederick S. Fisher

Systematic mineral resource studies of the United States are conducted under the U.S. Geological Survey's National Mineral Resource Assessment Program (NAMRAP). NAMRAP provides comprehensive and timely assessments of the known and inferred mineral resources of the conterminous United States, Alaska, and the U.S. territories. The results of these mineral resource surveys are used for domestic and foreign policy decisions, resource management, land use planning by State and local governments, and identification of resources and target areas for industry exploration. The investigations are conducted at various scales, depending on legislative or administrative requirements.

NAMRAP consists of two program elements: the Alaska Mineral Resource Assessment Program (AMRAP) and the Conterminous United States Mineral Assessment Program (CUSMAP). Each element operates at four interconnected levels, each more detailed than its predecessor. Level I studies produce Statewide and regional syntheses of the mineral resources of the conterminous United States and Alaska from the published literature. Level II investigations are conducted at scales of 1:500,000 to 1:1,000,000 and are studies of mineral provinces based on the published literature and on completed level III projects. Level II studies include tabulations of the geologic characteristics of mineral resources and summary maps of favorable provinces. Level III studies are mostly of 1:250,000-scale (1°×2°) quadrangles and are carried out by teams of geologists, geochemists, geophysicists, and mineral economists. Level III studies also include regional mineral surveys of entire national forests, as requested by the U.S. Forest Service. Level IV studies are composed of detailed basic research projects on specific areas, including mining districts or particular mineral deposits, and on technical topics that will aid in determining the setting and character of mineral resources. They are also used when specific assessments of small tracts of land are needed under short deadlines (for example, when decisions regarding wilderness suitability are required). As concepts of ore-deposit formation evolve, as new data are generated by the regional level III studies, and as the mineral needs of the United States change, it is sometimes necessary to reexamine selected geologic terranes and ore deposits. These recurring mineral resource assessments are conducted as level IV studies.

The major emphasis of the NAMRAP program in 1986 was on level III and level IV projects. In fiscal year 1986, the Geological Survey coordinated its work on six 1°×2° quadrangles in the conterminous United States with the Geological Surveys of Arkansas, Georgia, Idaho, Kansas, Missouri, Minnesota, Nevada, South Carolina, and Utah. Coordination of work in two 1°×2° quadrangles in Alaska will continue with the Alaska Division of Mining and Geology. The Geological Survey is also conducting a mineral resource assessment of the Challis National Forest in Idaho. Level IV mineral surveys of 256 U.S. Bureau of Land Management wilderness study areas are underway in 10 Western States (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, and Wyoming).

Preliminary results of mineral resource assessments of the Glens Falls (New Hampshire, New York, and Vermont), Springfield (Missouri), and Tonopah (Nevada) 1°×2° quadrangles under the CUSMAP element were presented at three public meetings in fiscal year 1986 to representatives from the mining industry, universities, and various State and Federal government agencies. New CUSMAP mineral assessments were begun in the Delta (Utah) and Hailey (Idaho) 1°×2° quadrangles in formal cooperative programs with the Utah Geological and Mineral Survey and the Idaho Geological Survey, respectively. Final colored mineral resource assessment maps showing the resource potential for base, precious, and energy minerals have been published for the Wallace (Idaho) and Charlotte (North Carolina and South Carolina) 1°×2° quadrangles. Mineral resource potential in the Charlotte quadrangle is high for commodities that have been historically important (namely, construction materials, lithium, kyanite-sillimanite, and barite). New areas favorable for the occurrence of large lead, zinc, and silver deposits in the Wallace quadrangle were identified, as were occurrences of platinum-group metals, gold, molybdenum, and tungsten. Preliminary results of the Challis 1°×2° CUSMAP project have been published; new areas favorable for the occurrence of gold and silver were identified along the 160-mile length of the trans-Challis fault system, and potentially large resources of vanadium, silver, zinc, barite, and lead were also identified in a belt of rocks 9 to 27 miles wide and 50 miles long in central Idaho (fig. 3).

Figure 3. *The Triumph mine, one of Idaho's larger silver producers, is one of many mines located within a northwest-trending belt of highly mineralized black shales. This belt was first delineated and described by field studies of the Challis and Hailey CUSMAP projects. (Photograph courtesy of the Idaho Geological Survey.)*

To accelerate mineral resource surveys of the Steese and White Mountains areas of Alaska, the Geological Survey is coordinating its work in the Livengood and Circle 1°×2° quandrangles with the State of Alaska. The results of these surveys will provide the Bureau of Land Management with improved mineral information for developing land use plans for the two areas. In addition, level III field studies are underway in 11 other 1°×2° quandrangles in 1986 as part of the AMRAP element. A detailed level IV study is also being conducted on the Red Dog zinc-lead-silver deposit in the DeLong Mountains of northwestern Alaska and on similar deposits in nearby parts of the western Brooks Range (including analysis of cores that have been made available by cooperating industry scientists). Examples of other level IV studies include (1) evaluation of the unusual characteristics of the mineral deposits of the southern Ambler district, where the copper-base metal occurrences are rich in cobalt; (2) delineation of the tectonic environments of terranes that host numerous base- and precious-metal deposits of the Delta district in the eastern Alaska Range; and (3) analysis of geochemical environments and gold in streams of Alaska's numerous placer districts. In addition, the future importance of Alaska's apparently large resources of such critical commodities as tin and chromium is being addressed through detailed multidisciplinary studies in the Seward Peninsula, the southern Alaska Range, and the uplands of interior Alaska. Final mineral resource assessment maps were published for the Lake Clark, Petersburg, and Philip Smith Mountains 1°×2° quadrangles in the southern Alaska Range, the "panhandle" of southeastern Alaska, and the eastern Brooks Range. New areas favorable for the occurrence of tin lodes and large low-grade molybdenum deposits were identified in the Lake Clark quadrangle. New areas favorable for the occurrence of silver, barium, and base-metal deposits were identified in the Petersburg quadrangle. Promising new occurrences of gold and antimony were identified in the Philip Smith Mountains quadrangle.

In fiscal year 1986, the Geological Survey, in cooperation with the Forest Service, made a mineral resource assessment of the Black Hills National Forest to provide the mineral information necessary for forest planning. Deposits in the Black Hills National Forest are currently being mined for gold, silver, base metals, pegmatite products, limestone, oil and gas, sand and gravel, and dimension stone. Uranium, vanadium, tungsten, gypsum, and industrial sand have been produced within the forest in the past. These commodities, in addition to molybdenum, rare-earth elements, thorium, and fluorine, are still available for future development. Final results of this level III study have been published as U.S. Geological Survey Bulletin 1580.

The level IV mineral surveys of Bureau of Land Management wilderness study areas are multidisciplinary studies carried out on tracts ranging in size from 3 to 242,000 acres. This part of the program commenced with the passage of the Federal Land Management and Policy Act of 1976, which required the Geological Survey and the U.S. Bureau of Mines to conduct surveys to determine "the mineral values, if any," of areas recommended to Congress by the Secretary of the Department of the Interior as being suitable for inclusion in the National Wilderness Preservation System. By the end of fiscal year 1986, approximately 70 reports on the mineral resource potential of 106 wilderness study areas had been published; by the end of the wilderness study program in 1991, the Geological Survey will have examined approximately 400 separate areas covering about 11 million acres.

Over the next several decades, NAMRAP is scheduled to complete the mineral resource assessment of over one million square miles, more than one-fourth of the area of the entire United States. In Alaska, new geochemical and geophysical techniques are being developed and applied to look for concealed ore deposits in areas where the surficial cover of muskeg and glacial deposits is extensive. In the conterminous United States, clusters of completed CUSMAP quadrangles in the northern Rocky Mountains, the midcontinent, and the Great Basin are providing the basis for new concepts of the mineralization process and the description of new ore deposit models.

Salton Sea Scientific Drilling Program

By John H. Sass

The Salton Sea Scientific Drilling Program (SSSDP) is the first large-scale drilling project undertaken by the U.S. Continental Scientific Drilling Program. The objectives of the SSSDP were (1) to drill a deep well into the Salton Sea Geothermal Field in the Imperial Valley of California; (2) to retrieve a high percentage of core and cuttings along the entire depth of the well; (3) to obtain a comprehensive suite of geophysical logs; (4) to conduct flow tests at two depths (and to take fluid samples therefrom); and (5) to carry out several downhole experiments. These activities will enable the U.S. Geological Survey to study the physical and chemical processes involved in an active hydrothermal system driven by a molten-rock heat source. This program, originally conceived by Wilfred A. Elders, a faculty member at the University of California at Riverside, was coordinated under an interagency accord among the Geological Survey, the U.S. Department of Energy, and the National Science Foundation.

The Imperial Valley of California and the adjoining Mexicali Valley of Mexico (fig. 4)

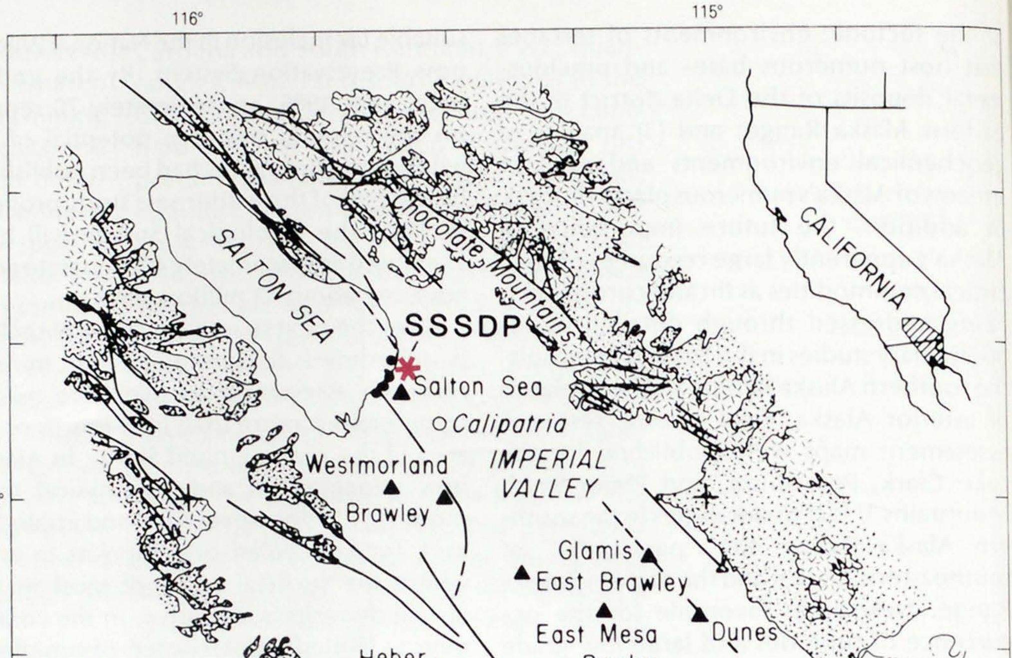


Figure 4. *The Imperial Valley of California and the Mexicali Valley of Mexico. Major faults are shown by solid and dashed lines, and volcanic centers are shown by solid circles. Major geothermal fields are indicated by solid triangles. The Salton Sea Scientific Drilling Program (SSSDP) site is marked by a red asterisk.*

are of great economic interest for geothermal energy development because of the large quantities of very hot brines (300 °C or hotter) that are accessible within a few thousand feet of the surface. These areas also are of scientific interest because the source of heat for the brines is molten rock that rises high into the Earth's crust (occasionally even being extruded as volcanoes). The occurrence of molten rock at relatively shallow depths results from the stretching and thinning of the crust caused by the relative motion of the Pacific and North American plates. The Imperial Valley is also the southern terminus of the San Andreas fault and the site of numerous earthquakes.

The Geological Survey was involved in many aspects of the SSSDP, including participation at all management levels, from the program's Executive Steering Committee through the Science Coordinating Committee to actual on-site management of all scientific activities. Most importantly, Survey scientists were active in several experiments, including collection and analyses of fluid samples, measurements of temperature and other properties, and analyses of rock samples taken from the well. Survey personnel also served on the Scientific

Experiments Committee that evaluated all proposals for downhole scientific experiments, mineralogic and petrographic studies of the drill core and cuttings, and geochemical analyses of fluids recovered from the well. In addition, the Survey's Water Resources Division provided a research logging vehicle and trained personnel to make physical measurements, aid in obtaining fluid samples from the well, and deploy downhole instrumentation.

The well was begun on October 23, 1985, and completed to a depth of 10,564 feet on March 17, 1986. The various stages of the drilling, coring, and scientific experiments are easily envisioned from the "time line" shown in figure 5. Where the line is nearly vertical, drilling was proceeding very rapidly. The more nearly horizontal the line, the less drilling progress was being made. In comparison with a conventional exploration well, the average rate of penetration for the SSSDP research well was slower because of the numerous core runs and the large amount of time devoted to other engineering and scientific activities (for example, logging, injectivity tests, flow tests). For a well of this depth in this environment, a normal amount of time was spent combating drilling problems and "fishing" for pieces of metal inadvertently left in the hole.

The eventual technological and scientific payoff from the SSSDP should be impressive, on the basis of the wealth of downhole information and samples obtained:

- The 36 cores recovered are unprecedented for a deep well in such a hostile regime. These cores provide a basis for a systematic study of (1) the gradual alteration and metamorphism of the near-surface unconsolidated lake and delta sediments of the Colorado River to dense metamorphosed crystalline rocks at depth and (2) the intrusion into these rocks of two diabase sills or dikes that were penetrated during coring.
- Technological advances in borehole instrumentation prompted by the project have allowed the accumulation of reliable temperature and pressure data above 270 °C through a combination of modifying conventional mechanical recording devices and providing thermal protection of sophisticated electronic memory for downhole recording.
- Geophysical measurements made in the well at high temperatures will be correlated with the corresponding physical properties of the cored rock and, in turn, will greatly aid the interpolation of diagnostic "signatures" between cored intervals.

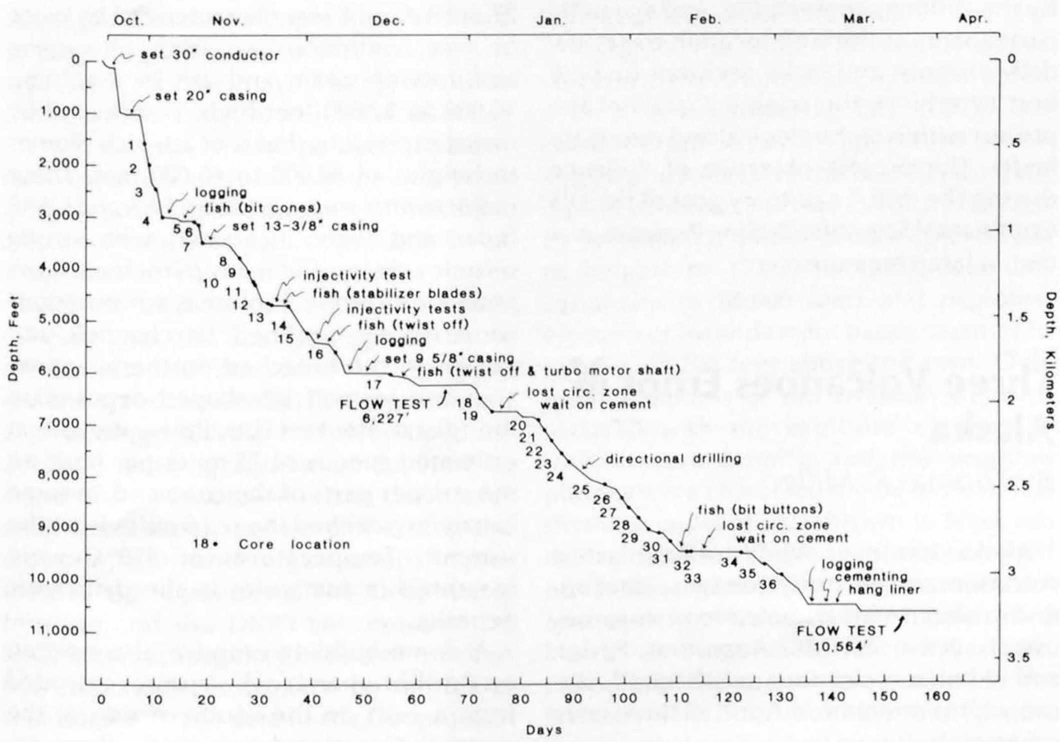


Figure 5. Depth of the Salton Sea Scientific Drilling Program well as a function of time. Numbered solid circles show depths at which cores were taken.

- Analyses of fluids and gases recovered during flow tests, combined with data from measurements of solid samples, will result in a better understanding of the processes that form ore minerals (many of which were abundant in the core samples).

The SSSDP exceeded its target depth of 10,000 feet, and a comprehensive set of cuttings, cores, and downhole logs was obtained. Two flow tests at different depths were successfully completed. Hydrologic connection between the different producing horizons, however, will make the data from the deeper test difficult to interpret. Temperature logging done by the Geological Survey to establish the equilibrium profile is continuing. A proposal to conduct further long-term flow tests and to deepen the well is now under consideration. If these activities are successful, they will greatly increase the scientific yield of the SSSDP.

The SSSDP provides a model for scientific cooperation among government agencies, universities, and private industry. The Geological Survey's on-site science management team provided coordination and liaison among Chief Scientist Elders, the prime contractor, the leaseholder, and participating scientists. The Survey team and the Chief Scientist were members of a Site Coordination Committee established by the drilling, engineering, and scientific participants at the well location to review daily progress and make decisions on how best to achieve the scientific goals of the project within technological and monetary limits. The project objective of "science driving the drill," a primary goal of the U.S Continental Scientific Drilling Program, was met in large measure.

Three Volcanoes Erupt in Alaska

By Thomas P. Miller

Alaska has over 40 historically active volcanoes and normally averages one eruption a year. Alaskan volcanoes were unusually active in 1986. Augustine, Pavlof, and Akutan volcanoes all erupted vigorously; at one time in April, all three were erupting.

Augustine Volcano

Augustine Volcano, located on an uninhabited island in lower Cook Inlet 180 miles southwest of Anchorage and 60 miles west of the Kenai Peninsula, went into major explosive eruption about 2:30 a.m. (Alaska standard time) on March 27, 1986. The eruption was not unexpected. An increase in very small earthquakes and in the amount of steam emitted from the summit area of the volcano beginning in mid-February were strong indications that Augustine was heading for an eruption. The principal hazards of a typical Augustine eruption are (1) dangers posed to aircraft by airborne ash and (2) the remote possibility that there will be a massive failure of the volcanic dome resulting in a landslide-induced tsunami similar to the one generated during an eruption in 1883. In the week before the eruption, the Federal Aviation Administration (FAA) and the U.S. Air Force (USAF) were briefed on the possibility of an eruption, the type of eruption to be expected, and the potential effects on aircraft and air traffic; information and liaison procedures were also established. The increased activity at Augustine and the potential hazards to the populace were discussed several times with the Alaska Division of Emergency in the month before the eruption.

Eruptive activity at Augustine from March 27 until April 8 was characterized by more or less continuous eruption of varying amounts of steam and ash in a column 10,000 to 12,000 feet high, punctuated by major explosions that sent ash-rich plumes to heights of 30,000 to 40,000 feet. These major events were visible on FAA and USAF radar and were associated with strong seismic activity. The many pyroclastic flows generated during explosive ash eruptions were largely confined to channels and gulleys in the breached northern summit area and formed fan-shaped deposits on the distal flanks. The flows moved at estimated speeds of 75 miles per hour on the steeper parts of the cone and, in some instances, reached the sea 5 miles from the summit. Temperatures of 550°C were measured in fumaroles in the pyroclastic deposits.

A dome-building eruptive phase began on April 23 when blocky lava was extruded from a vent on the southern side of the summit. Occasional pyroclastic flows accompanied the dome-building phase. This new lava began to move slowly down the northern flank of the volcano, and, by the afternoon of April 28 when this phase ended, the flow had descended to an elevation of about 2,000 feet. Augustine was in a quiescent state from April 28 until August 20, when apparently new dome-building activity began in the summit area.

During the first several days of the March eruption, airborne ash carried by southerly winds into the most densely populated parts of Alaska, including Anchorage, had severe effects on air traffic. Although Anchorage International Airport was never officially closed, most of the major interstate and international air carriers cancelled or diverted flights away from Anchorage.

Ash falling throughout the Cook Inlet area had a moderate to severe effect on commerce and the populace. Most of south-central Alaska derives its electricity from natural gas-powered generators located on the western side of upper Cook Inlet. Because these generators could have been damaged by ingesting airborne ash, public utility officials considered shutting them down and drawing on power generated from neighboring utilities outside the immediate area. A predicted shortfall in power supply led to requests to conserve power on March 27. Numerous companies, government agencies, retail outlets, restaurants, banks, and other establishments either closed or reduced their operations and sent employees home, and postal service was cancelled for the day. There was also considerable concern about the effect of the ash on machinery, particularly automobiles, and electronic equipment. Low-lying communities in the lower Cook Inlet area were concerned with the possibility of a tsunami.

As the result of extensive discussions over the past year, the U.S. Geological Survey, the Geophysical Institute of the University of Alaska, and the Alaska Division of Mining and Geology (DMG) had developed an informal working agreement on how to respond to an eruption in the Cook Inlet area. Immediately before and during the eruption, the three organizations implemented this agreement. The Geophysical Institute and the DMG concentrated on seismicity because they have a network of five seismometers in place on the island that telemeter the data to the Geophysical Institute in Fairbanks. The Survey concentrated on making daily observation flights, correlating visual reports from pilots, fishing boats, and other observers, and responding to inquiries from government agencies and the media. Between the main eruptive events, helicopter-supported teams from the Survey and the Geophysical Institute visited and studied the volcano. The pyroclastic flows were sampled, fumarole temperatures were measured, and seismic equipment was repaired. This close communication and cooperation between the Geological Survey in Anchorage and the DMG and the Geophysical Institute in Fairbanks resulted in an efficient flow of information to those State and Federal agencies concerned with public health and safety as well as to the media and the general public.

Pavlof Volcano

On April 16, 1986, Pavlof volcano, a 8,925-foot-high stratovolcano 600 miles southwest of Anchorage near the tip of the Alaska Peninsula, began erupting after 10 days of increased seismicity and continued to be active through August 21. A new vent on the eastern flank of the volcano, about 150 feet in diameter and 500 feet below the summit, was the source of much of the recent activity and marks the first change in vent geometry since the 1960's.

Pavlof is the most consistently active volcano in the Aleutian arc, having erupted over 30 times since the late 1700's. The current eruption, which appears to be the largest and longest in the past 30 years, is a typical strombolian eruption characterized by sporadic emissions of dark-colored ash to heights of 12,000 to 15,000 feet (occasionally to 50,000 feet) and explosive ejection of incandescent basaltic spatter to heights of 700 feet above the vent. Only minor amounts of ash emission were associated with the explosive ejection of incandescent bombs, and the eruption plumes were characterized by more or less rhythmic puffs of dark-brown to black ash that seldom rose above an estimated height of 10,000 to 12,000 feet. The incandescent spatter formed breadcrustlike blocks called bombs as much as 12 feet in diameter. Fallback of the spatter has resulted in the formation of hot, bouldery, mudflowlike features that are marked by abundant steam fumaroles on the northwestern and eastern flanks of the volcano. The eruptive explosions that occurred at closely spaced intervals of 5 to 15 seconds during the times when the vent was observed suggest a moderately high rate of magma rise in the conduit. Thunderlike noises could be heard downwind from the vent for 50 miles. The nearest towns, Cold Bay and King Cove 30 miles away, received light dustings of ash, but, because of its remote location and the nature of its eruptive activity, the volcano poses little threat to life.

Akutan Volcano

In the eastern Aleutian Islands, Akutan Volcano recorded its seventeenth reported eruption in the past 200 years in late April through early June 1986. The eruption was characterized by sporadic ejection of ash to heights of 15,000 feet from a 4,275-foot-high intracaldera cone. No ashfalls were recorded in the nearby villages of Dutch Harbor and Akutan, and the eruption was not considered a hazard.

A Deep Look at the Continent: The Trans-Alaska Crustal Transect

By Robert A. Page

Over the last decade and a half, geologists have learned that the Pacific edge of the North American continent comprises a collage of accreted crustal fragments, or terranes, each of which may be as large as a county or State. The rocks of adjacent terranes reflect different origins and histories. Many terranes are exotic, having been carried far from their point of origin by movement of the plates that compose the Earth's mobile geologic skin. These observations, many of which were made by Geological Survey geologists working in Alaska, led to the concept that continents grow by the accretion of terranes.

The accretionary character of the western North American continent has been reasonably well established by geologic studies of rocks exposed at the Earth's surface. However, the vertical extent and subsurface composition of the constituent terranes are largely unknown. In addition, understanding of the tectonic processes by which terranes are formed, transported, accreted, and deformed is primitive at best.

Geologists and geophysicists of the Geological Survey have embarked on the Trans-Alaska Crustal Transect (TACT) project, a major investigation of the structure, composition, and evolution of the Alaskan crust. Begun in 1984, this study is providing important insights into the process of accretion. In addition, TACT is furnishing the first precise information on the structure and composition of the Alaskan crust for a depth range of a few miles to 20 to 30 miles. Scientists from universities, Alaska's Geological Survey, and the petroleum industry are collaborating on various aspects of this investigation.

The TACT project focuses on the north-south trans-Alaska oil pipeline corridor (see inset map, fig. 6) and extends offshore across the Pacific and Arctic continental margins. The pipeline corridor traverses a number of major geologic structures, and the only highway crossing the State runs parallel to it. To decipher the deep structure of the crust and constrain models of its composition, TACT incorporates a wide range of geophysical techniques. One key technique involves the precise timing of explosion-generated seismic waves along 75-mile-long profiles to determine the configuration and velocities of rock layers within the Earth (fig. 7).

Investigations along the southern segment of the transect have identified two mechanisms by which the continent has grown. One is the accretion of terranes; the other is the pasting of layers of subducted oceanic crustal and upper mantle rocks onto the bottom of the continental crust.

The southern margin of Alaska is an active convergent plate boundary. The Pacific plate is moving northward along this margin relative to Alaska—part of the North American plate—at a rate of about 2 inches per year. Where the two plates collide at the Aleutian trench outboard of the continental margin, the denser rocks of the Pacific plate are thrust beneath the continent. As the oceanic plate is subducted beneath the continent, it deforms and is heated. The deformation is reflected in a landward-dipping inclined zone of earthquakes. Heating gives rise to the inland chain of volcanoes that roughly parallels

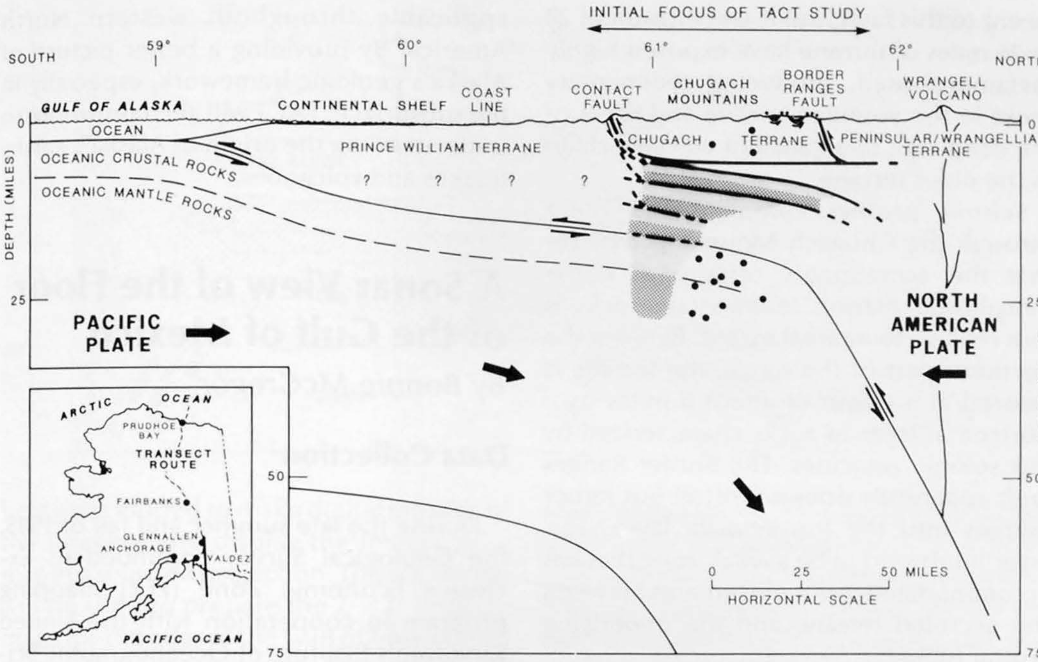


Figure 6. *Diagrammatic section through the margin of southern Alaska illustrating relations among surficial accreted terranes, subducted duplexes of oceanic rocks (stippled layers), and earthquakes (solid circles). Light stippling indicates relatively low seismic velocities; heavy stippling indicates high velocities. The continent has grown both by accretion and by underplating with subducted oceanic rocks. Inset shows the location of the section (heavy solid line) and the route of the Trans-Alaska Crustal Transect (dashed line).*

Figure 7. *Seismic reflection profiling along the Richardson Highway north of the Alaska Range. Vibrating the ground in unison, the trucks in the foreground generate seismic waves, reflections of which are used to detect boundaries between buried rock masses of contrasting velocity. This technique is one of two seismic profiling methods employed in the Trans-Alaska Crustal Transect.*

the trench. This chain includes Augustine Volcano, which erupted in March of 1986 (see article on Alaskan volcanic activity). The depth of the inclined earthquake zone beneath the volcanoes is typically 60 to 70 miles.

This type of compressional subduction tectonics has dominated the evolution of the southern margin of Alaska for the past 200 million years. The exposed rocks of the Chugach Mountains bordering the Pacific are predominantly of marine sedimentary origin. As a consequence of convergent plate motion, sediments deposited in the ocean adjacent to the continent have been transported and accreted to the continent. New geologic studies have documented major episodes of deformation and metamorphism associated with the process of accretion. At least 25 miles of shallow thrusting along the Border Ranges fault separating two major terranes causes the seaward accretionary terrane to be pushed northward beneath an older terrane. Adjacent to this fault, uplift and erosion of 20 to 25 miles of terrane have exposed highly metamorphosed, subducted sedimentary rocks in the younger terrane and rocks of the deep root of an ancient volcanic chain in the older terrane.

Seismic profiles completed by TACT through the Chugach Mountains indicate that the accretionary terrane of metamorphosed marine sedimentary rocks is thin relative to its areal extent. Beneath the northern part of the range, the terrane is floored at a depth of about 5 miles by a horizontal layer of rocks characterized by low seismic velocities. The Border Ranges fault apparently does not offset but rather merges into the low-velocity layer. This layer is inferred to be a weak zone that has accommodated major movements between the accreted terrane and the underlying crustal rocks.

Deeper within the Earth, the seismic profiles reveal a stack of north-dipping layers extending to depths of at least 25 miles. The seismic velocities are alternately low and high in successive layers. The observed velocities are similar to those measured in oceanic rocks of the lower crust and upper mantle. Thus, pairs of layers are possibly duplexes of subducted oceanic crustal and mantle rocks that have been emplaced beneath the edge of the continent; four such duplexes have been confirmed.

Earthquakes provide an additional dimension to the interpretation of inferred subduction duplexes. Along the transect corridor beneath the central Chugach Mountains, small shocks occur either at depths shallower than 5 miles, within the thin accreted terrane, or between depths of about 20 and 25 to 30 miles, within the deepest of the four duplexes. This pattern suggests that the deepest duplex is currently being subducted or at least was subducted more recently than the overlying duplexes. The lack of earthquakes at depths of between 5 and 20 miles suggests that the upper three duplexes are older and are now attached to the continent. Thus, initial results from TACT indicate that Alaska has grown by underplating as well as by accretion.

New insights into processes of continental growth stemming from the TACT project will stimulate ideas on how mineral and oil resources form and where they might be concentrated. Such insights are widely applicable throughout western North America. By providing a better picture of Alaska's geologic framework, especially in the subsurface, TACT will also contribute to understanding the origin of Alaska's earthquakes and volcanoes.

A Sonar View of the Floor of the Gulf of Mexico

By Bonnie McGregor

Data Collection

During the late summer and fall of 1985, the Geological Survey continued its Exclusive Economic Zone (EEZ) mapping program in cooperation with the United Kingdom's Institute of Oceanographic Sciences (IOS). A sidescan sonar survey of the Gulf of Mexico and the sea floor around Puerto Rico and the Virgin Islands was completed. The survey used a sonar system known as Geologic Long-Range Inclined Asdic (GLORIA) that was developed by the IOS. One hundred and twenty thousand square nautical miles of sea floor in the Gulf of Mexico were mapped in 71 days during three legs (fig. 8). Separated by port stops in New Orleans, La., and Tampa, Fla., the legs were punctuated by Hurricanes Danny and Elena.

A preliminary mosaic of sonar images of the gulf's sea floor was constructed at sea at a scale of 1:375,000. These data were merged with GLORIA data collected in 1982 on the continental slope in the northwestern gulf. This preliminary mosaic provides a real-time (as the data are being collected) reconnaissance-scale view of the sea floor from the shelf edge seaward to a water depth of more than 10,000 feet, the depth of the abyssal plains in the gulf.

Laboratory Analysis

The next step in the program is to use computers for image processing of the digital sonar data. In cooperation with the Survey's National Mapping Division (NMD), the sonar data are being radiometrically and geometrically corrected and improved by using the Mini-Image Processing System developed by NMD. Software is currently

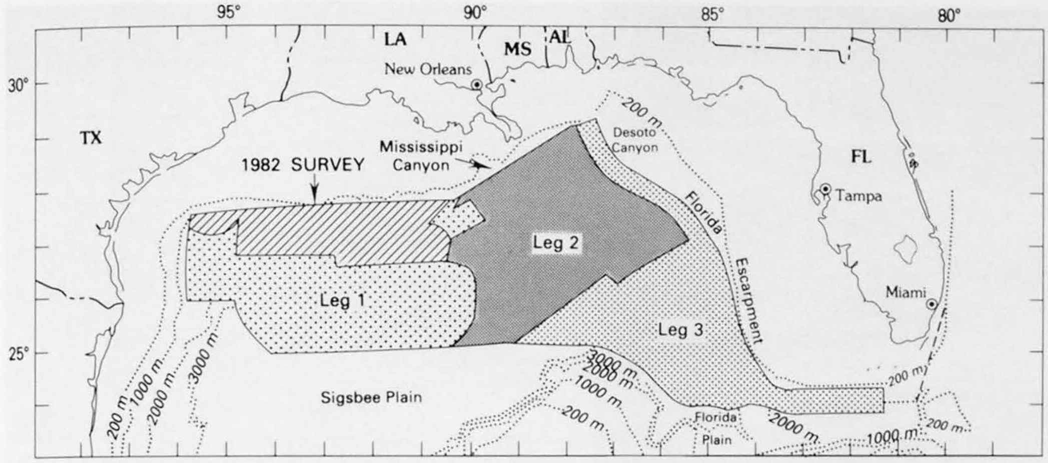


Figure 8. *Location of GLORIA surveys in the Gulf of Mexico.*

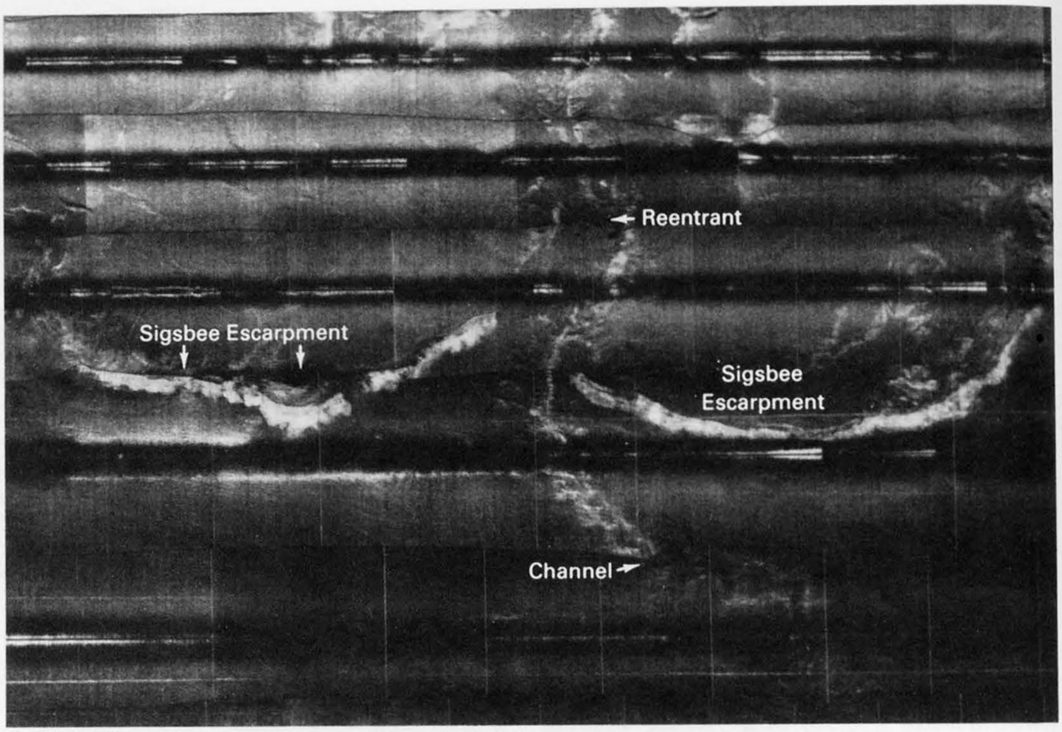
being developed to make digital mosaics of the imagery and display the images on a map at a selected projection. This technique will be used to prepare the 2°×2° imagery maps for the atlas of the Gulf of Mexico and Puerto Rico GLORIA data. This atlas, to be published in early 1987, will be the second in a series that displays the results of the Survey's EEZ mapping program.

Geologic Perspective of the Gulf of Mexico

The geologic setting of the EEZ in the Gulf of Mexico, a small ocean basin, is different than that of the EEZ off the west coast. The spreading ridge crests and cratered underwater volcanoes, which attest to the dynamics of formation of the Earth's crust and the floor of the Pacific, are not seen in the gulf. Instead, GLORIA imagery shows a sediment-carpeted sea floor that contains a record of the dynamic processes that have laid down and molded that muddy carpet. Features that have more than 650 feet of relief and sea-floor slopes of up to 1,312 feet are present in the gulf. These features are not volcanic, however, but were formed by processes such as erosion of the edge of the carbonate Florida Platform that formed the Florida Escarpment. Also, the weight of thick accumulations of sediment dumped into the gulf by rivers, such as the Rio Grande and the Mississippi, has caused a Jurassic-age layer of salt to flow upward and seaward and form domes and ridges that are flanked by basins, many of which are over 3,200 feet deep and filled with sediments. Movement of the salt controls the complex morphology of the continental slope seaward of Texas and Louisiana. Salt tectonics and thick accumulations of sediments in this region along the upper slope have contributed to an offshore oil and gas field called the Flexure Trend. Because this frontier area is located in deep water, advanced exploration and production technologies are required for the development currently underway in the Green Canyon area of the trend.

The complex morphology and dynamic movement of the salt have made the geology and evolution of the Texas-Louisiana slope difficult to unravel. The GLORIA imagery provides a new perspective on this problem because it allows identification of salt pinnacles more than one-half mile across and domes and basins 25 miles across. The seaward edge of the salt front is marked by the Sigsbee Escarpment, which is approximately 2,300 feet high. Piles of talus lying along the base of the escarpment suggest that erosion and deposition are occurring there. Three reentrants present in the salt front mark the locations of canyon systems that provided pathways for sediment transport from the Texas-Louisiana shelf edge to the deep water of the gulf. The sonar image shows one channel meandering on the sea floor from the escarpment southward toward the Sigsbee Abyssal Plains (fig. 9). Sediments that appear to have been reworked by bottom currents in this channel's levees suggest that this channel is no longer actively transporting sediment in the form of density flows. The presence of the channel, however, attests to the geologically recent movement of the salt blocking the path of this channel on the slope. Other remnant pathways that can be identified on the slope provide clues to the distribution of sediment deposition centers. These

Figure 9. *Sidescan sonar mosaic shows the Sigsbee Escarpment (bright band) seaward of Texas and Louisiana. A reentrant in the escarpment has a submarine channel associated with it. This channel can be traced over 80 miles meandering across the sea floor. For scale, the parallel stripes that are the ship's tracks are spaced approximately 12 miles apart.*



deposition centers may be the sites of additional oil and gas fields along the flexure trend.

Rivers and submarine canyons are an important clue to understanding the distribution of sediments in the gulf. The Mississippi Canyon and fan are striking features on the GLORIA imagery in the central and eastern gulf. The canyon and the channel that is its seaward extension (fig. 10) can be traced across almost 300 miles toward the southeast to a point due west of southern Florida. Another meandering channel is clearly visible in the northeastern gulf starting seaward of DeSoto Canyon and meandering for about 100 miles to the south parallel to the Florida Escarpment Canyons (fig. 11), whose deep-water meandering channels are important conduits for the transport of sediments by density currents. Like rivers on land, when these density currents are thick enough, they construct levees by overbank flow, depositing mud as they spread out away from the confines of the channel. The channel from DeSoto Canyon has built up its floor and levees above the surrounding sea floor. This type of channelized flow is a major means of distributing sediments in deep water. An understanding of canyon-fan systems is valuable for petroleum exploration and production, because many oil fields are associated with ancient submarine fans.

Besides channelized flow, submarine slides and debris flows make a significant contribution to the distribution of sediments in the deep gulf. GLORIA imagery shows that a series of massive debris flows has filled the Mississippi Canyon and buried parts of the Mississippi channel and the channel from the DeSoto Canyon area. These debris-flow deposits cover about 20,000 square miles (about one-third the area of the State of Florida). The very intricate flow patterns on the sea floor pose interesting questions about the dynamics of sediment movement across the sea floor where the gradient is 1° or less. Submarine slide deposits also cover areas ranging from 1,500 to 19,000 square miles in the DeSoto Canyon area and on the slope in the northwestern gulf. Mass wasting is also an important process in distributing sediments in the gulf. The trigger mechanisms for these submarine landslides, their relation to sea-level fluctuations, and whether they are synchronous are all questions to be addressed.

The Florida Escarpment, which flanks the gulf on the east, has approximately 6,500 feet of relief and a slope of about 40° and is composed of outcropping Cretaceous limestones. Because of the steep slope of the escarpment, its morphology could not be well defined by conventional profiling systems towed at the sea surface. For the first time, GLORIA images show the dis-

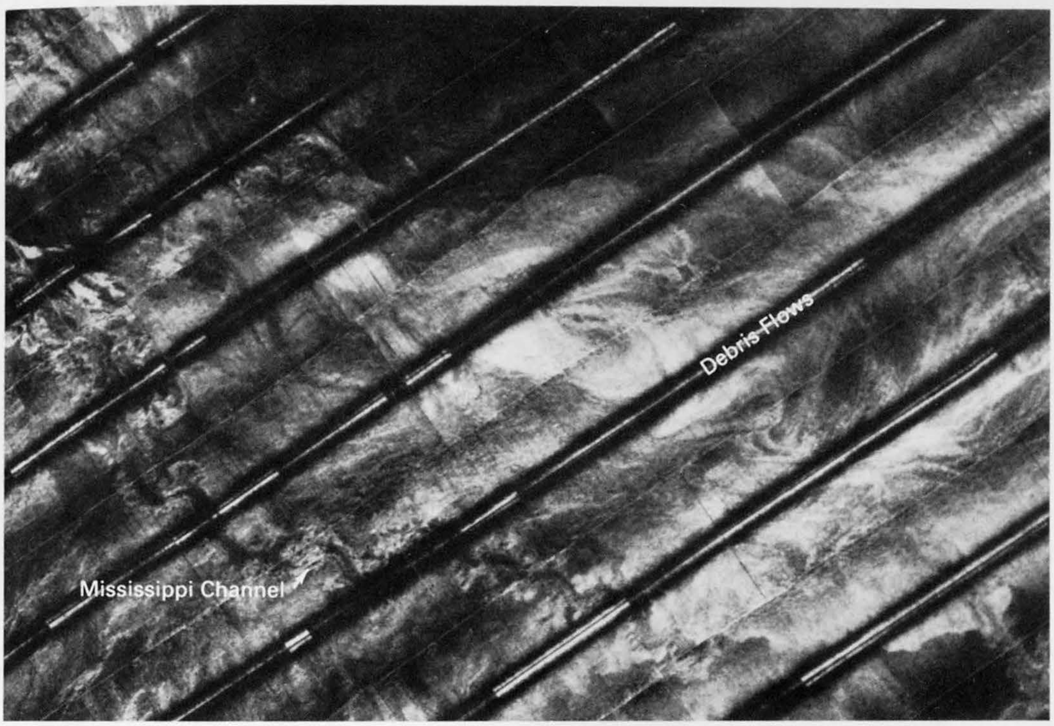


Figure 10. *The Mississippi channel can be seen on the sidescan mosaic meandering across its fan in approximately 8,000 feet of water. The bright areas marked by swirling patterns are the debris flows that also blanket the fan.*

sected morphology of the escarpment and how it changes along its length. Massive flat-floored box canyons cut the escarpment toward the south, and smaller dendritic canyons occur to the north. Studying the evolution of this carbonate cliff and the processes that shape it is an integral part of understanding the seascape of the floor of the Gulf of Mexico.

Continuing analysis of the GLORIA data will identify potential sites for detailed study aimed at solving the problems discussed above. The Geological Survey will be conducting GLORIA surveys of the Atlantic coast in fiscal year 1987 and planning additional GLORIA surveys of the Alaskan and Hawaiian EEZ's.

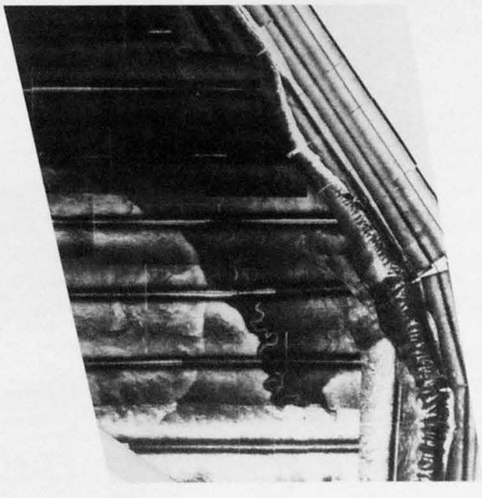


Figure 11. *Sidescan mosaic of the sea floor at a water depth of approximately 9,900 feet in the eastern Gulf of Mexico. The bright, billowy lobes are a continuation of the debris flows seen in figure 10. The debris flows terminate against the base of the Florida Escarpment, which is dissected by numerous small canyons. The channel from DeSoto Canyon meanders across the sea floor for 100 miles before being buried by the debris flows.*

WATER RESOURCES INVESTIGATIONS

MISSION

The mission of the U.S. Geological Survey's Water Resources Division is to provide the hydrologic information and understanding needed to best use and manage the Nation's water resources for the benefit of the people of the United States. To accomplish this mission, the Division, in cooperation with State and local governments and other Federal agencies:

- Systematically collects data needed to continually determine and evaluate the quantity, quality, and use of the Nation's water resources.
- Conducts analytical and interpretive water-resources appraisals to describe the occurrence and availability of and the physical, chemical, and biological characteristics of surface and ground water.
- Conducts supportive basic and problem-oriented research into hydraulics, hydrology, and related fields of science and engineering to improve the basis for field investigations and measurement techniques and to understand hydrologic systems in order to predict quantitatively their response to natural or manmade stress.
- Provides to the public the water resources data and the results of water resources investigations and research through reports, maps, computerized information services, and other forms of public releases.
- 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 hydrology to other Federal, State, and local agencies, to licensees of the Federal Energy Regulatory Commission, and, on behalf of the U.S. Department of State, to international agencies.

Parts of the Southeastern United States were hit by a severe hydrologic drought during the first 6 months of 1986. Indicative of the drought, the water level in the Rose River near Skyline Drive in the Shenandoah National Park, Va., was clearly far below normal on August 3, 1986. (Photographed by A. R. Powers, Water Resources Division, U.S. Geological Survey.)

PROGRAMS

The four Water Resources Division programs are the Federal Program, the Federal-State Cooperative Program, Assistance to Other Federal Agencies, and the Non-Federal Reimbursable Program.

Federal Program

The Federal program is specifically identified in annual congressional appropriations and provides for the collection of water-resources data, investigations of resources, and research activities in areas where the Federal interest is paramount. These interests include water resources in the public domain, river basins and aquifers that cross State boundaries, and other areas of international or interstate concern.

Federal-State Cooperative Program

The Federal-State cooperative program is based on the concept that Federal, State, and local governments have a mutual interest in evaluating, planning, developing, and managing the Nation's water resources. The Water Resources Division represents national interests, and the cooperating agencies represent State and local interests; the costs are shared 50-50, the Federal share coming from direct congressional appropriations. The Geological Survey has cooperative agreements with all 50 States. Projects generally respond to recognized problems or define a potential one. In emergency situations, such as drought or flood, events are monitored, and the data accumulated under the cooperative program are made available for use by the public.

Principal offices of the U.S. Geological Survey's Water Resources Division in the conterminous United States. Cities named are those where Regional and District Offices are located. Puerto Rico is included in the Southeastern Region, and Alaska and Hawaii are included in the Western Region.

Assistance to Other Federal Agencies

The Geological Survey performs a wide variety of water-resources investigations to meet the specific needs of other agencies. Investigations are funded by reimbursements to the Geological Survey from the agencies requesting the work.

Non-Federal Reimbursable Program

The non-Federal reimbursable program covers situations where there is both Federal and State interest in the investigation of water resources but where matching Federal funds are either unavailable or are not otherwise applicable to cost sharing. Unmatched funds are provided to the Geological Survey by State and local agencies for these studies.

HIGHLIGHTS

This section describes some significant accomplishments of the Water Resources Division's major programs during fiscal year 1986.

The Modification of San Francisco Bay, 1850 to 1986

By Samuel N. Luoma

Introduction

Estuaries have long been a focus for man's activities because of their wide variety of living and nonliving resources. Unfortunately, these activities alter the character of estuarine ecosystems. Tributary rivers are dammed and diverted, shorelines are modified, fish communities are endangered, and water quality is degraded by wastes. The San Francisco Bay estuary is no exception.

As the estuary of the Sacramento and San Joaquin Rivers, San Francisco Bay receives runoff from 40 percent of California's surface area. Human population around the estuary began to grow rapidly after the 1848 discovery of gold in the Sierra Nevada foothills, and that growth continues today. The accompanying socioeconomic development around the bay and in its watershed has caused physiographic alterations of the estuary, directly changed the species composition of its biota, altered freshwater inflows, and changed its water quality.

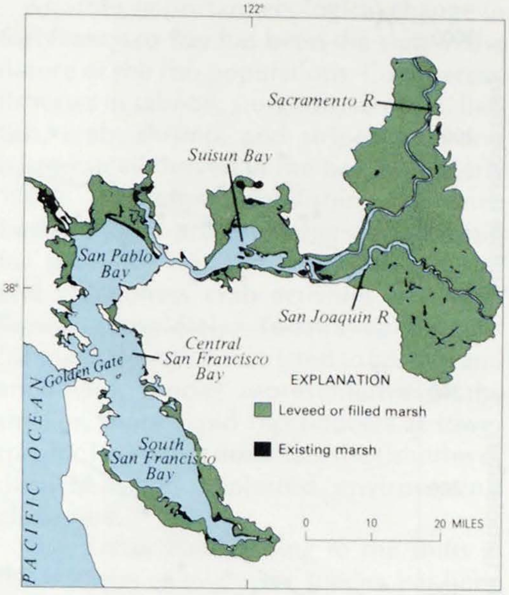


Figure 1. *Distribution of undiked tidal marshes around San Franscisco Bay before 1850 (leveed or filled marsh) and at present (existing marsh).*

Physical and Chemical Changes

Because a bay is a dynamic system, its physiography is in a continuous state of change. Changes in the physiography of San Francisco Bay accelerated during the late 1800's as a result of the gold mining, farming, and land development that accompanied population growth. Between 1853 and 1884, tens of millions of cubic yards of rock and earth were excavated in the gold fields of the Sierra Nevada by hydraulic mining (the use of water under high pressure to expose ore deposits). The debris from this process choked creeks and rivers throughout the drainage basin, and much of the mud and sand eventually reached San Francisco Bay. By 1900, from 1 foot to over 3 feet of this material had been deposited on the bottom of the bay, the result being a permanent reduction in the open-water area of the bay through shoaling and a reformation of bottom topography that reduced the water volume of the bay and altered tidal circulation patterns. The tidal marshes also were modified by land development around the bay. Marshes were filled and diked to create farm land, evaporation ponds for salt, and land for residential or industrial developments. Of the original 850 square miles of freshwater and saltwater marsh, less than 50 square miles remain undiked today (fig. 1).

Freshwater inflows into the bay have been continually reduced by the increase in irrigated agriculture in California's Central Valley and by the export of water to arid areas south of the bay. The dams, reservoirs, and canals used to manage the water that flows toward San Francisco Bay comprise the world's largest manmade water system, which has a storage capacity of about 16 million acre-feet. This water system removes 40 percent of the historic (1850) flow of the Sacramento and San Joaquin Rivers for consumption within the bay watershed. Another 24 percent of that flow is exported for municipal and agricultural use in central and southern California. The result is that freshwater flow into San Francisco Bay is presently less than 40 percent of historic levels. If water use continues to increase as projected, average freshwater flow into San Francisco Bay will drop to 30 percent of the historic average by the year 2000.

Disposal of the waste products from man's activities also has changed the quality of water in the bay and its tributaries. For example, U.S. Geological Survey studies have shown that, since 1950, the maximum annual concentration of sulfate has increased threefold and that of nitrate fivefold in the San Joaquin River (fig. 2). These changes reflect the increased use of fertilizers and soil amendments and (or) the fact that more and more soil is being exposed to weathering because of the expansion of irrigated agriculture.

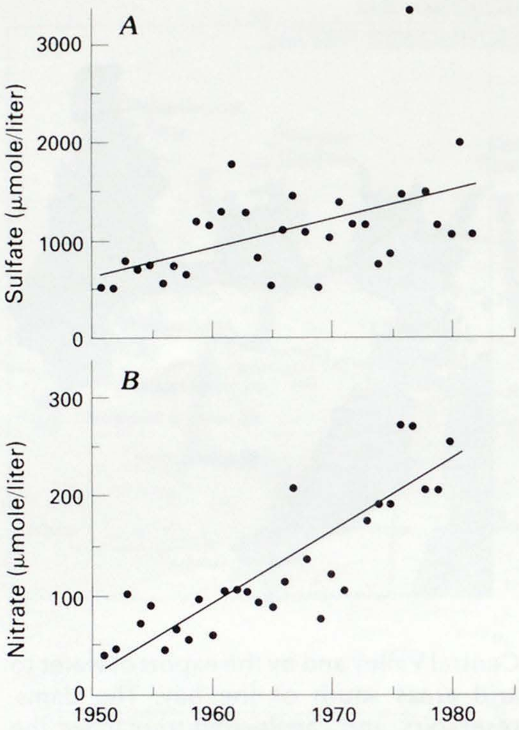


Figure 2. *Maximum annual concentrations of* (A) *dissolved sulfate and* (B) *nitrate in the San Joaquin River near its mouth. Lines are least-squares regressions.*

Industrial and domestic wastes, as well as urban runoff, are discharged at more than 100 locations within the bay itself. Additional contamination results from daily accidental spills of industrial chemicals and oil; small oil spills alone number 200 to 300 annually. Together, these wastes contain, among numerous constituents, more than 300 tons of trace metal contaminants annually and large quantities of trace organics included in the general category of oil and grease. Nutrients accumulate in South San Francisco Bay during the summer in concentrations more than twice those observed during the winter, apparently because discharges from waste treatment facilities combine with reduced natural flushing during the dry summer and autumn.

Ecological Changes

Scarce documentation of the historic condition of San Francisco Bay and its environs makes it difficult to assess how changes in physiography, freshwater inflows, and waste discharge have affected ecological interactions in the bay; however, the effects can be inferred. For example, half of the migratory birds on the Pacific flyway winter on or near San Francisco Bay. The loss of the food and habitat once provided by the original marshlands surrounding the bay has affected the size of the bird populations.

In other cases, ecological impacts caused by historic changes can be deduced from similar changes observed over shorter periods of time. For example, Geological Survey studies comparing ecological interactions during years of differing river-flow conditions have led to several conclusions about the effects that reduced river inflows have on the estuary.

Studies during the 1977 drought suggested that, in the northern bay, reduced summer flows (less than 3,500 cubic feet per second) caused reduced populations of phytoplankton (microscopic plants that are the ultimate food resource for the water-column food chain), which in turn reduced the production of zooplankton that fed on the plants and correspondingly reduced the number of striped bass that fed on the zooplankton. The studies suggested several different processes that might have contributed to such an effect. One is that low river flows physically move the zone of maximum phytoplankton productivity into a part of the estuary less suitable for plant growth. Another is that more phytoplankton are eaten by bottom-dwelling invertebrates at low flows, because these animals migrate upstream and grow to large populations when high salinities move upstream. Thus, food that is usually consumed by fish is transferred to commercially less valuable bottom-dwelling organisms when river flow is reduced.

Reduced freshwater inflow also reduces the estuary's capacity to dilute, transform, or flush contaminants that are discharged into the bay. Survey scientists measured trace-contaminant concentrations in bottom-dwelling invertebrates over a 7-year period to determine if freshwater inflow influenced contaminant dynamics in the semienclosed southern arm of the bay (South Bay). Measurements show that concentrations of the heavy metal silver are lower during years of high river flow than they are during years of low flow and that, in each year of the 7-year period, concentrations of silver in organisms living near a sewage outfall decreased after winter floods. Thus, freshwater inflow has a positive influence on the effectiveness of natural processes that help assimilate potentially toxic wastes in South Bay.

The ecological effects of waste discharge are especially difficult to determine, and conclusive documentation is complicated, especially in a system subject to as many different potential stressors as the San Francisco Bay is. Industrial wastes were implicated in the collapse of the bay's large oyster industry in the early 1900's, but the actual cause was never conclusively determined. Survey studies have shown that distribution of trace contaminants in the bay is patchy; localized areas exhibit intense enrichment, while other areas show little contamination. What has been established, however, is that improvements in sewage treatment that began in the 1960's have reduced some of the adverse effects of waste discharge. Summer depletion of dissolved oxygen in the extreme reach of South Bay, a typical occurrence two or three decades ago, no longer occurs, and concentrations of disease-causing bacteria in bay waters are greatly reduced from levels documented in the 1960's.

Although it is difficult to directly link specific human activities with most specific ecological changes, it is clear that the San Francisco Bay ecosystem is very different today from what it was before 1850. The single most important factor in that change has been the successful invasion of the bay by species that are not native to the system, and man's activities are without question the primary source of those invading species. Between 1869 and the early 1900's, large quantities (up to 100 carloads per year) of live eastern oysters were shipped from the east coast to California for maturing on bay mudflats. The eastern oyster never naturalized, but large numbers of east coast invertebrates that were unintentionally shipped with the oysters did become established. Additional species that bored into ship hulls or collected in ship ballast also were released into the bay. In all, approximately 100 new invertebrate species successfully invaded the bay. Nearly all common bottom-dwelling macroinvertebrates now present in shallow mudflat zones and a number of the important invertebrate and plant species living in the water column are introduced. A large number of introduced fish species also has become established. Of the 42 fish species inhabiting the sloughs of Suisun Bay, 20 are introduced. The striped bass, which at one point yielded annual commercial catches of 450 tons per year and which remains a primary sport fishery, was intentionally introduced in 1879.

Another important ecological change in San Francisco Bay has been the shift in the nature of the fish populations. Commercial fisheries in salmon, sturgeon, sardines, flatfish, crab, shrimp, and striped bass and oystering all thrived in the bay in the early 1900's. All commercial fishing has since been halted to preserve what stocks remain for sport fishing, and commercial oyster and Dungeness crab activities have collapsed completely. Today's commercial fishing in the bay is restricted to herring and anchovies, species representative of the smaller, more rapid reproducers at lower trophic levels that dominate the fisheries of disturbed and exploited environments elsewhere.

One factor contributing to the shifts in the fisheries of migratory species has been the management and disruption of the natural flow of river water into the bay. Construction of Shasta Dam in 1944, for example, eliminated half of the salmonid spawning habitat in the Sacramento River system. During the summer, when water moves upstream in the channels of the San Joaquin Delta system because of pumping for water diversion, hundreds of millions of juvenile salmon and striped bass (as much as 25 to 30 percent of a typical year class) are drawn into the water diversion pumps and killed. Equal numbers appear to be lost to numerous small siphons and pumps that locally collect irrigation water in the delta. Overfishing, elimination of essential habitats, changes in water quality, and, perhaps, some shifts in natural factors, such as ocean temperature, also may have contributed to changes in the fisheries, although the specific contributions of any of these factors are difficult to demonstrate.

Conclusions

Studies by the Geological Survey have shown that the future well-being of San Francisco Bay depends on better understanding its interacting physical, chemical, and biologic processes. Such understanding is best achieved by multidisciplinary research having long-term objectives focused on understanding the estuary as a natural entity but within the historic context imposed by the onset of intense human activities a century ago. Because San Francisco Bay is similar to other estuaries, such studies will help in understanding and preserving valuable estuarine ecosystems elsewhere.

Drought Conditions in the Southeastern United States

By Harold G. Golden

Parts of the Southeastern United States were hit by a severe drought during the first 8 months of 1986. Rainfall during winter and spring was much below normal everywhere in the Southeast except Arkansas, Florida, and Louisiana. As of September 1, a significant long-term drought seemed likely to occur throughout much of this area unless rainfall were to be substantially above normal during the last 4 months of the year.

Climatologic Conditions Associated with the Drought

The conditions that produced the record dryness in the Southeast are closely linked with general atmospheric circulation. The jet stream, for example, did not penetrate as deeply or as frequently into the Southeast as it commonly does during the winter months. As a result, cyclonic storms, which typically form in and move through the Gulf and Southeastern Atlantic States, were displaced farther north and west. This displacement effectively deprived much of the Southeast of its usual abundant winter moisture. During the spring months, when the track of the jet stream and surface storm systems seasonally migrate northward in response to weakened temperature gradients across the midlatitudes of the Northern Hemisphere, the pattern of frequent northward displacement persisted. The relatively weak atmospheric flow over the Eastern United States produced little precipitation; thus, the moisture problem was aggravated by the increased seasonal demand for water for evapotranspiration, agriculture, and domestic use. Whereas much of the usual spring and early summer precipitation is associated with warm fronts and a moist southwesterly wind flow, the Southeast mainly experienced more scattered precipitation along cold fronts. Also, dry westerly and northwesterly winds were common over the region and tended to suppress the normally widespread and abundant thundershowers.

The severity of the situation in the Southeast was further complicated by the fact that similar atmospheric conditions had persisted since autumn 1984. Although the water deficit was producing the "drought of the century" by summer 1986, precipitation from December 1985 through July 1986 was one of the lowest of record for that 8-month period. Precipitation was in the normal to above-normal range across most of the Southeast during August and early September, but drought conditions still persisted. Since 1875, extreme dryness in the Southeast has not typically occurred as a single-year event. Rather, droughts frequently tend to persist or recur seasonally over 2- to 4-year periods. Further, unusually dry years are rarely followed by abnormally wet years. The general pattern during the past century has been for very dry years to be followed by either less dry conditions or near-normal precipitation.

Hydrologic Conditions Associated with the Drought

Precipitation.—For the first 8 months of 1986, precipitation ranged from 48 to 100 percent of normal. The percentage of normal precipitation for January through August at key stations in eight States in the Southeast is shown in figure 3. Also shown is the monthly precipitation for the current year, the normal monthly precipitation, and the previous minimum of record for Atlanta, Ga., Raleigh. N.C., Nashville, Tenn., and Jackson, Miss. Precipitation at Atlanta during the first half of 1986 set a new record low and was the second lowest for the 6-month period of record at Raleigh and Nashville. The hydrographs in figure 1 indicate that, during years of deficient rainfall, little significant precipitation occurred during the period August through October. The graphs also show that, during years of normal precipitation, significant rainfall occurred during July and August. Because of high evapotranspiration rates during the summer, however, runoff and groundwater recharge are lower than those from equivalent precipitation in the winter and spring. Consequently, the return of normal precipitation for the remainder of the year would do little to alleviate the drought.

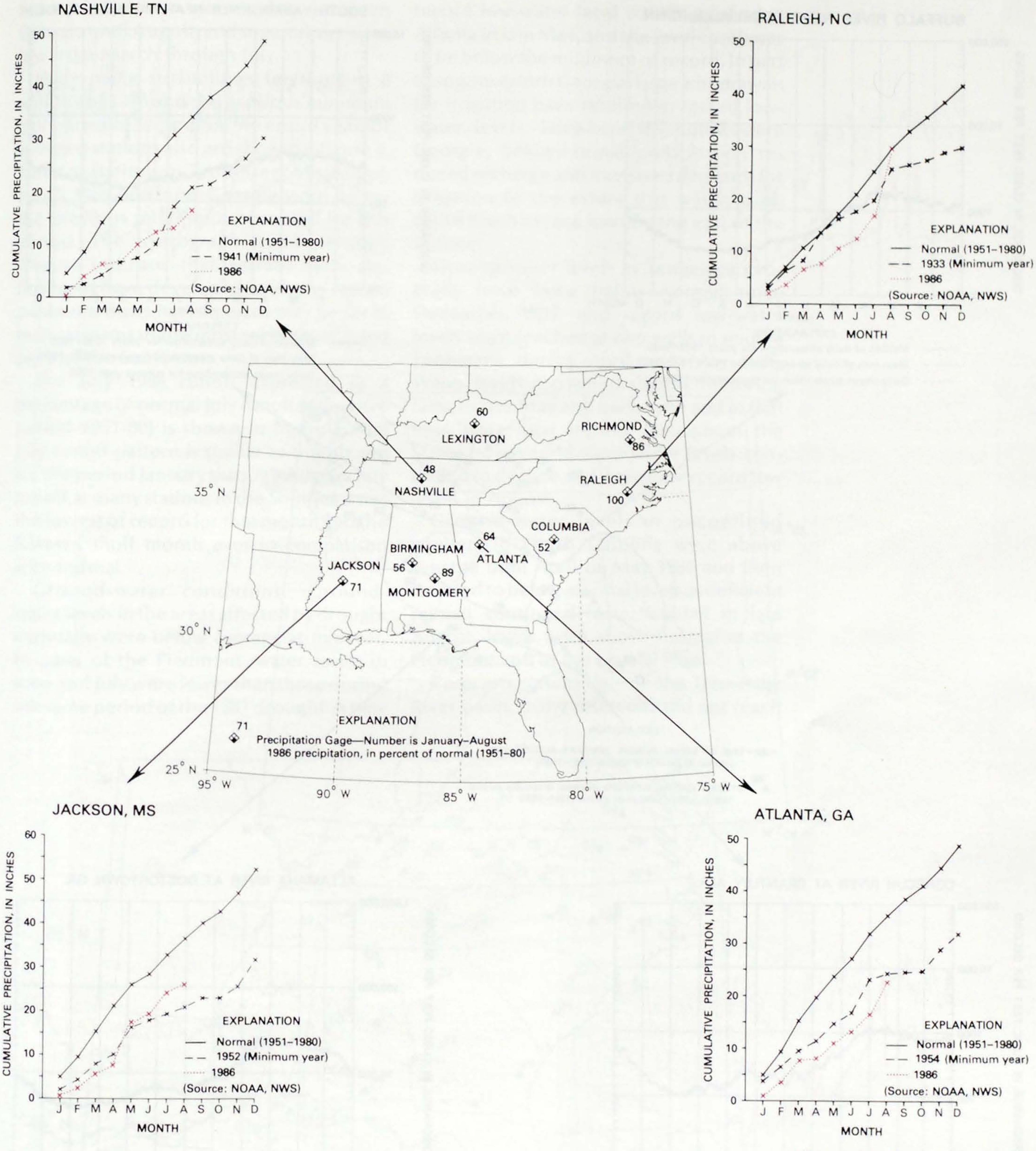


Figure 3. *January-August 1986 precipitation as a percentage of normal precipitation at selected sites in the Southeastern United States.*

Streamflow.—Reduced streamflow was evident in 1985, when the flow of many streams was only 50 to 80 percent of normal for the year. The reduced flows continued into the first 8 months of 1986, when many streams had the lowest flows of record for the season. Figure 4 shows the cumulative runoff as a percentage of normal. Flows through August 1986 were less than 40 percent of normal from Mississippi to North Carolina (fig. 4). Flows in other parts of the drought area were less than 80 percent of normal, except for southern Georgia, where heavy rains fell in late February. However,

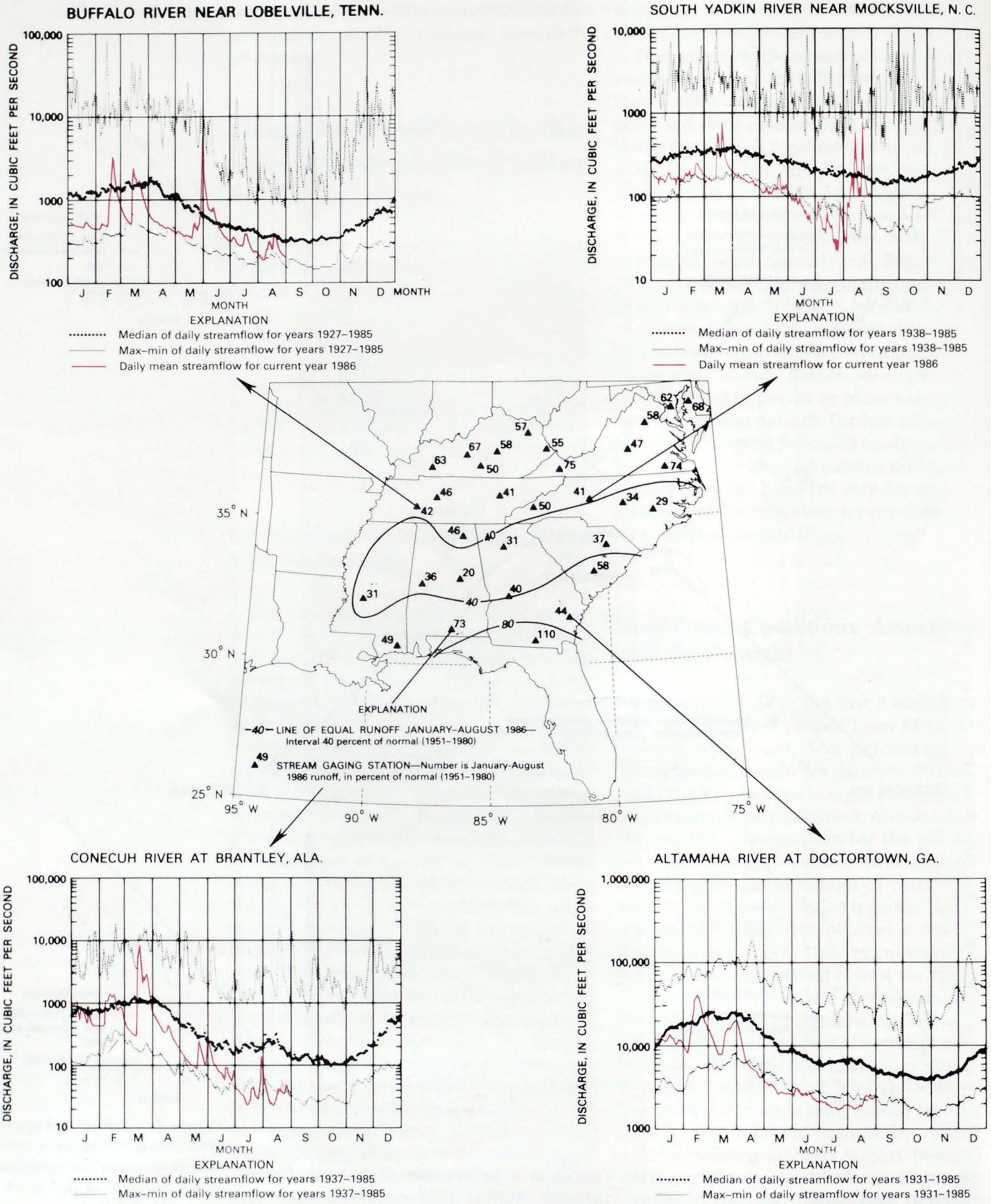


Figure 4. *January-August 1986 runoff as a percentage of normal runoff at selected sites in the Southeastern United States.*

little precipitation occurred in southern Georgia until August, and streamflows were low from March through July.

Daily mean streamflows for the first 8 months of 1986 and the previous minimum daily flows of record for the entire year for selected stations also are shown in figure 4. Flows at stations in Tennessee, Mississippi, North Carolina, and Georgia were below the previous minimums of record for this period. The hydrograph trends through August indicate that serious flow deficiencies have developed, and new record minimum flows have been or may be set in many streams in the most severely affected parts of the Southeast.

The July 1986 runoff expressed as a percentage of normal July runoff (reference period 1951-80) is shown in figure 5. The July runoff pattern is similar to that shown for the period January through August. July runoff at many stations in the Southeast was the lowest of record for that month and the lowest runoff month ever in comparison with normal.

Ground-water conditions.—Ground-water levels in the areas affected by drought generally were below average at midyear. In parts of the Piedmont, water levels in June and July were lower than those during the same period of the 1981 drought. A new record low-water level was established at Atlanta in late May, and the level continues to be below the minimum of record. In part of southwestern Georgia, large withdrawals for irrigation have resulted in record low-water levels. Elsewhere in southwestern Georgia, below-normal precipitation reduced recharge and increased demands for irrigation to the extent that water levels could reach record lows by the end of the summer.

Ground-water levels in Tennessee generally have been below normal since December 1985, and record low-water levels were reached at two wells in middle Tennessee during April and May 1986. Water levels recovered slightly following rains in late May and early June and at that time were near normal throughout the State; however, ground-water levels continued to decline and were near record low levels in August.

Ground-water levels in unconfined aquifers in North Carolina were above average until April or May 1986 and then receded to below-normal levels as deficient rainfall continued. After rainfall in late August, levels were above normal in the Piedmont and in the Coastal Plain.

Reservoir conditions.—In the Tennessee River basin, many reservoirs did not reach

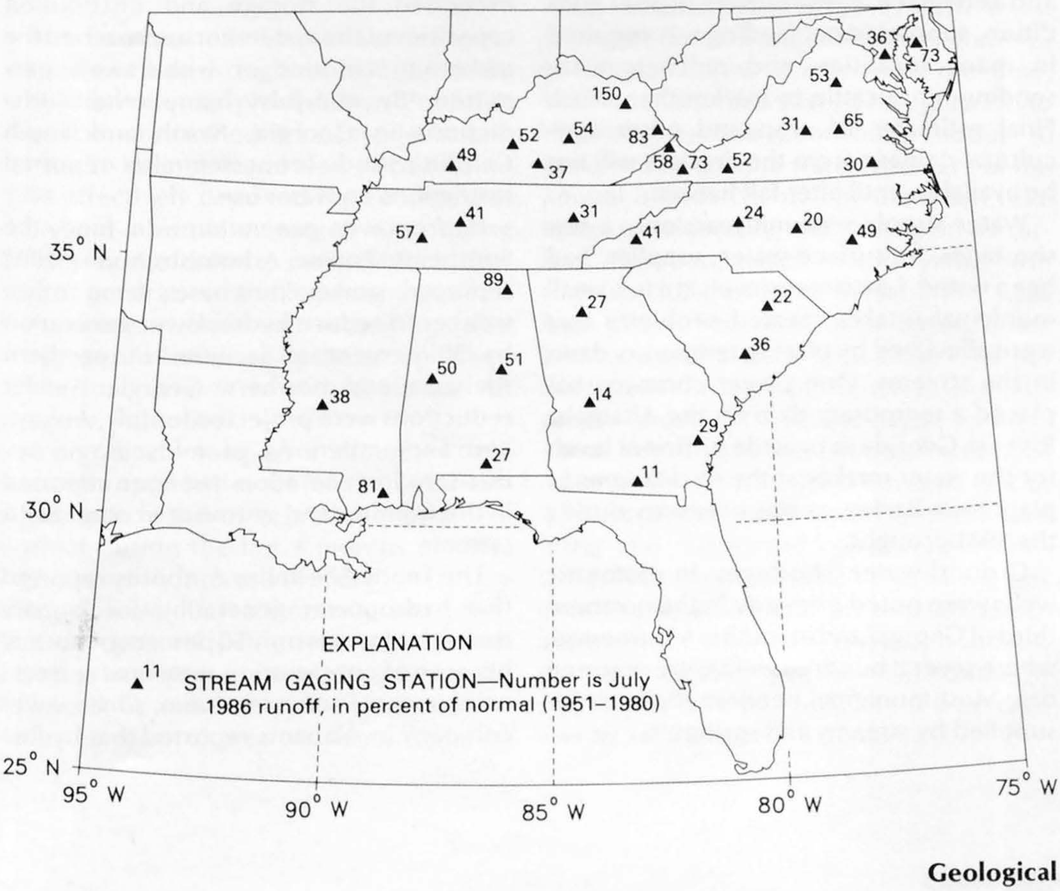


Figure 5. *July 1986 runoff as a percentage of normal runoff at selected stream-gaging sites in the Southeastern United States.*

normal summer levels in 1985 and have remained below normal through June 1986. These low reservoir levels are having a negative impact on hydropower generation, recreation, water quality, navigation, and legal commitments for minimum flows on some regulated streams.

Lake Lanier in northern Georgia is the primary water supply for metropolitan Atlanta and is the most popular recreation lake of all the U.S. Army Corps of Engineers reservoirs nationwide. In early September, Lake Lanier was at the lowest level (15 feet below normal pool level) recorded for that time of year, and boaters were warned to watch for submerged objects.

Impact of the Drought

Agriculture.—According to weekly State weather and crop reports from the U.S. Department of Agriculture, soybeans, corn, peanuts, cotton, and peaches were generally rated in the fair to poor range and in many areas were under stress in early July. South Carolina reported that winter wheat yields were down 50 percent in the midlands of the State. Soil moisture was rated very low in more than 50 percent of Georgia, South Carolina, North Carolina, and Tennessee. Pastures were in poor condition, supplemental feeding was required in many localities, and ranchers were sending more cattle to market than usual. Final estimates of crop and other agricultural damage from the drought will not be available until after fall harvest.

Water supply.—At midyear, only a few shortages in surface-water supplies had been noted. Low stream levels at a few small municipal intakes created problems that were alleviated by placing temporary dams in the streams. One power company has placed a temporary dam on the Altamaha River in Georgia to provide sufficient levels for the water intakes at the nuclear energy plant near Baxley, as was necessary during the 1981 drought.

Ground-water shortages in domestic wells were noted primarily in the northern third of Georgia and in southern Tennessee, where several hundred wells were reported dry. Most municipal needs in this area are supplied by streams and springs.

Water quality.—At midyear, several reservoirs in the Southeast had low dissolved oxygen concentrations that could be harmful to some types of fish and reduce the capacity of lake water to assimilate waste released into streams. As streamflows continue to decline and temperatures remain in the high nineties, more water-quality problems could develop. Contingency plans are available whereby the regulatory agencies of several States can curtail the disposal of waste into streams if conditions warrant.

Irrigation.—Irrigation withdrawals in southwestern Georgia will exceed the withdrawals made during the 1980-81 drought if the present trend continues. Irrigation use in other areas, although not as large, is following the same pattern. Water shortages have occurred as some irrigation ponds in North Carolina have gone dry.

Management Actions

Restrictions on water use.—The first major restrictions on water use in the region were in the Atlanta metropolitan area, where several water authorities limited or banned all outdoor water use. Heavy demands caused by the drought either exceeded the storage and distribution capacities of the systems or approached the maximum amount of withdrawals permitted. By mid-July, many other jurisdictions in Georgia, North and South Carolina, and Tennessee also reported restrictions on water use.

Hydropower generation.—In June, the Southeast Power Administration (SEPA) reported power purchases from other sources to reduce hydropower generation by 50 percent at facilities in northern Alabama and northern Georgia. Similar reductions were projected for July, August, and September. As of midyear, no reductions in generation had been reported in the Cumberland system or in other SEPA systems.

The Tennessee Valley Authority reported that hydropower generation for January through May was only 50 percent of normal because of conservation measures at reservoirs in the Tennessee basin. One power company in Alabama reported that hydropower generation was about 70 percent below average in May and about 60 percent below average in June because of conservation measures. The South Carolina Electric and Gas Company ceased hydropower generation at Lake Murray on June 13, and generation had been minimal before that time.

Reduction in waste releases.—The South Carolina Department of Health and Environmental Control reported that at least one industrial facility curtailed its waste release because of low streamflow.

State actions.—Tennessee considered declaring a drought emergency; however, rainfall in May and June postponed that action. Kentucky has instituted a Water Watch Program designed to encourage citizens' groups to adopt a local water resource and promote its natural and cultural benefits. Efforts are underway to use this program to monitor drought conditions and promote conservation during drought periods. Georgia has instructed water authorities in northern Georgia to implement water conservation measures in each jurisdiction as dictated by local conditions.

Summary

The Southeastern United States experienced a severe drought in 1986 caused by well-below-normal precipitation. Persistent displacement of the track of the jet stream farther to the north and west since autumn 1984 effectively deprived the Southeast of its usual abundant winter and spring moisture. Agriculture, navigation, hydropower generation, and legal commitments for minimum flows on some regulated streams are all affected by the drought, and some jurisdictions have had to ban all outdoor water use.

A significant long-term drought could occur throughout much of the Southeast unless precipitation is substantially above normal during the last 4 months of 1986. Unfortunately, unusually dry years are rarely followed by abnormally wet years, and the general pattern during the past century has been for very dry years to be followed by either less dry conditions or only near-normal precipitation.

Great Salt Lake: An Expanding Sea in the Utah Desert

By Doyle Stephens

Background

The western part of Utah is desert having an annual precipitation of about 5 inches, whereas precipitation is about 20 inches along the central, densely populated part of the State. Although precipitation in the mountains east of the population corridor is as much as 60 inches annually, Utah is an arid State overall. In the midst of this dryness is Great Salt Lake, the country's largest lake outside of the Great Lakes region. However, because its salinity ranges from 1.5 to 5 times that of seawater, it is actually America's largest inland sea. Although a large lake has occupied the same area for the last 32,000 years, only in relatively recent times have the contraction and expansion of the lake caused concern for the inhabitants of its shorelines.

Great Salt Lake is unique among lakes of the Western Hemisphere because of its size and salt content. It is a terminal lake (that is, it has no outlet to the sea), the fourth largest such lake in the world. About two-thirds of its annual inflow comes from the Bear, Weber, and Jordan Rivers. Precipitation to the lake surface contributes about 30 percent and ground water 3 percent of the annual inflow. The size of Great Salt Lake varies considerably, depending on its surface elevation, which in turn varies with climatic changes. At an elevation of 4,200 feet above sea level (the approximate average level around which the lake has fluctuated during historic time), the lake covers about 1,700 square miles; its maximum depth is 34 feet. At an elevation of 4,209.25 feet, the lake covered about 2,300 square miles. The salinity of the lake brine also has varied considerably, both temporally and aerially. The brine has contained as much as 27 percent salt, about eight times more than ocean water; in 1984, however, the salinity of the main (southern) part of the lake was only about 6 percent and by 1986 was near 5 percent.

Large and rapid changes in the level of the lake have had a profound effect on roads, railroads, recreational facilities, wildlife management areas, and industrial installations around the lake. Excessive dilution of the brine also affects recreation and industry based on the brine. The record-breaking 12.2-foot rise in the southern part of the lake from September 18, 1982, to June 6, 1986, coupled with the dilution of that part of the lake to its smallest known historic salinity, resulted in severe economic impacts on all of man's installations and activities on the lake.

Lake Levels

Prehistoric.—Great Salt Lake is a remnant of a much larger water body (Lake Bonneville) that had a maximum depth of about 1,000 feet and covered about 20,000 square miles in Utah, Nevada, and Idaho during the latter part of the Pleistocene Epoch. The lake rose in a series of three major steps to reach its freshest water conditions and highest elevation of approximately 5,200 feet about 17,000 years ago and then overflowed into the Columbia River drainage. Great Salt Lake, as the remnant of this prehistoric lake, declined to below historic levels from about 14,500 to 12,700 years ago; for about 8,000 years, the lake has fluctuated near its present elevation of about 4,200 feet.

Historic.—The earliest known measurement of the surface level of Great Salt Lake was made in 1843 by John C. Fremont, who reported that the lake was 4,200 feet above sea level on the basis of barometric readings. No actual measurements are available for the period 1844-74, but G.K. Gilbert, the first Chief Geologist of the U.S. Geological Survey, indirectly determined the lake level for that period by using reported observations of the depth of water over the sandbars between the mainland and Antelope and Stansbury Islands.

The rapid rise of the lake during the period 1862-73 and the continued high levels of the lake for several years after 1873 were of considerable concern to the settlers in Salt Lake City. They feared that the city and adjacent farm lands might be flooded if the lake rose further. The newspaper *Latter-Day Saints' Millenial Star* reported that, on September 8, 1876, "a party of gentlemen, accompanied by a surveyor, left for the north-west shore of the Salt Lake, with a view to determining the feasibility of cutting an outlet for the waters in that direction, and thereby greatly reducing the body of waters of the Lake. They coasted the west shore to the extreme northwest, a distance of forty miles, finding no point where an outlet was possible, there being an average incline of the desert, from the present water line, of four to six inches to the mile." The decline of the lake during ensuing years ended the concern at that time.

During the 31 years following the historic high level of 1873, the lake declined almost 16 feet and, in November 1905, reached a then-historic low level of 4,195.8 feet. From 1907 to 1910, the lake rose almost 7 feet, the steepest rise during a 5-year period since the beginning of record keeping. During the next 14 years, the lake rose an additional foot to peak at 4,205.1 feet in May 1924. The lake gradually declined to a low of 4,193.7 feet in November 1940 and then rose again to a peak of 4,200.95 feet in June 1952. Another lengthy period of decline followed, and, in October 1963, the lake reached an all-time historic low level of 4,191.35 feet and covered only about 1,000 square miles.

Because the overall trend of the lake level had been downward for the 90 years preceding 1963, many people thought that the lake would never rise again and would actually become dry. With that notion, railroads, interstate highways and other roads, wildfowl management areas, recreational facilities, and industrial installations for the processing of lake brine were established on the exposed lakebed. In 1964, however, the lake began to rise again; by June 1976, it had risen approximately 11 feet to 4,202.25 feet. Again, concerns grew about a potential calamity for facilities and installations around the lake, and the feasibility of pumping water out of the lake into the desert to the west was studied. In 1977, however, the lake began to decline because of unusually light snowfall during the preceding winter, and thus the concern ended once again. On September 15, 1982, the lake surface elevation was at 4,199.65 feet, approximately the same as it had been 135 years earlier when the pioneers arrived.

Dramatic rises of 1982-86.—The lake began to rise on September 18, 1982, in response to a series of storms earlier in the month. Then, on September 26, a recordbreaking 2.27 inches of rain was recorded at Salt Lake City International Airport, the most precipitation ever measured for a single day during the 108 years for which records have been kept for the city. The total precipitation (7.04 inches) for the month made it the wettest September on record for the city. The total annual precipitation at Salt Lake City during 1982 was 22.86 inches, in comparison with an annual average of 15.63 inches.

The unusually intense rainfall resulted in unseasonably large inflow to Great Salt Lake, both from precipitation directly on the lake and from surface streams. The flows in the Bear, Weber, and Jordan Rivers from October to December 1982 were 2 to 3.8 times greater than average. Great Salt Lake continued to rise rapidly throughout the autumn in response to the immense surface inflow and to the cool weather and extensive cloud cover that greatly reduced evaporation. Snowfall in the drainage basin of Great Salt Lake was greatly above average from autumn 1982 through spring 1983 and thus provided potentially enormous quantities of water for the lake. The largest reported snowfall was 845 inches at Alta, about 20 miles southeast of Salt Lake City. On June 1, the snow cover in the basins draining into the lake ranged from about 2.4 to 5.2 times greater than average.

Snowmelt in 1983 began about a month later than usual, and the snowwater content increased until mid-May. Because soil moisture in the drainage basin was considerably greater than average, the potential for water to infiltrate into the ground was diminished. The major snowmelt began at the end of May, and recordbreaking quantities of water flowed into the lake. From January to May, streamflow was 1.7 times greater than average in the Bear River, 3.6 times greater in the Jordan River, and 1.6 times greater in the Weber River, and new record flows were recorded for the Bear and Jordan Rivers.

The large streamflows continued for many weeks; the lake continued to rise until June 30, when losses by evaporation finally exceeded the inflow, and the lake level peaked at 4,204.75 feet. The rise from September 18, 1982, to June 30, 1983, was 5.1 feet, the greatest seasonal rise ever recorded. This rise represented a net increase in the volume of the lake of about 6 million acre-feet, equivalent to the volume of water used by the combined populations of California and New York in 1 year.

During summer 1983, precipitation was above average, and evaporation was relatively small because the cloud cover was greater than usual. These conditions resulted in a decline of only 0.5 foot in the lake level. Excessive precipitation continued throughout the fall and culminated in the wettest December ever recorded at Salt Lake City. By yearend, Salt Lake City had received 24.26 inches of precipitation during 1983, about 1.6 times the average. Snowfall from January to June 1984 also was above average, and, by May 1, the snow cover ranged from near normal to about two times greater than average.

The lake rose steadily from October 1983 through June 1984, primarily in response to

The Bear River National Wildlife Refuge was inundated by Great Salt Lake in 1983 and remained underwater through 1986. (June 19, 1986, photograph by Doyle Stephens, Water Resources Division, U.S. Geological Survey.)

surface inflow that resulted from the excessive precipitation. The precipitation at the Salt Lake City International Airport was about 1.5 times greater than average for the 9-month period, and the resultant inflow from the three major surface tributaries to the lake during that period greatly exceeded their average flows. The Bear River flow was 2.7 times greater, the Weber River flow was 2.1 times greater, and the Jordan River flow was 5.2 times greater. The flow in the Bear River during water year 1984 was the greatest measured during 95 years of record. When the lake level peaked on July 1, 1984, it was at an altitude of 4,209.25 feet above sea level and covered an area of about 2,300 square miles.

The lake started to decline during July 1984 and reached a seasonal low of 4,207.85 feet on October 1, 1984. It then rose to 4,209.95 feet by May 21, 1985, the highest level since 1877. The precipitation at Salt Lake City International Airport during 1984 was 21.55 inches, the third successive year in which precipitation exceeded the average by more than 40 percent.

Between May 21 and November 1, 1985, the lake level declined 1.55 feet because of evaporation during a warm summer. The lake then began its autumnal rise during the wettest and snowiest November on record, when more than 27 inches of snowfall was recorded at Salt Lake City International Airport. January through March 1986 were characterized by unusually warm temperatures and less-than-average precipitation. On February 19, 1986, the lake rose an unprecedented 1.5 to 2 inches in response to a week of storm activity in northern Utah. This rise represented a 1-day inflow of 36 billion gallons, or 7 gallons for every person on Earth. April precipitation exceeded 150 percent of normal in most of northern Utah, and both April and May were the third wettest on record at Salt Lake City International Airport. On May 12, 1986, the lake reached 4,211.65 feet, surpassing the recognized historic peak of 4,211.6 feet set in June 1863. By the end of May, the water content of the snowpack in the drainage to Great Salt Lake ranged from 144 to 264 percent of normal.

The lake continued to rise during the first week of June in response to record inflows from the Bear, Weber, and Jordan Rivers. Inflow to the lake since October 1985 was 4 million acre-feet, surpassing the 1983 record of 3.5 million acre-feet during an equivalent time period. On June 6, the lake peaked at 4,211.85 feet. The 30 million acre-feet of water in the lake on June 6 was about equal to the usable storage capacity of all the freshwater lakes and reservoirs in Utah and, if spread evenly, would have covered the State to a depth of 6.5 inches.

The 1986 peak elevation was short lived, however; on June 7, 5-foot waves on the lake caused a breach in the Amax Magnesium Corporation dike at the southwestern end of the lake. By June 10, the level of the southern part of the lake had declined 5 inches; the flow of water from the lake into the previously shallow brine ponds was estimated at 370,000 acre-feet. The net rise of the lake from September 18, 1982, to June 6, 1986, was 12.2 feet. By comparison, the previously recorded maximum net rise during a 4-year period was 6.8 feet from 1906 to 1910.

Economic Costs

In 1983, the State of Utah began studying various methods of controlling the level of the lake. The three methods that appeared to have the most merit were (1) pumping water out of the lake into the desert to the west, (2) impounding water on the Bear River for diversions that would decrease inflow to the lake, and (3) breaching the Southern Pacific Transportation Company railroad causeway and thereby decreasing the water level in the southern part of the lake where most of the damage was occurring. The first two methods involved extensive construction and a considerable delay before their effects on the level of the lake would be felt. The third method promised relatively quick results and was approved in 1984 by the Utah Legislature. A 300-foot-wide breach was completed at the western end of the causeway on August 3, 1984, at a total cost to the State of $3 million.

In spite of all control efforts, the surface area of the lake rose 12.2 feet and increased its size 640 square miles between 1982 and 1984. These increases caused approximately $285 million in damages to roads, railroads, wildfowl management areas, recreational facilities, and industrial installations that had been established on the exposed lakebed.

Continued economic losses through 1985 prompted the Utah Legislature to appropriate an additional $71.7 million on May 14, 1986, for dikes and pumps designed to contain the lake and reduce its volume. Water would be pumped from near the western end of the Southern Pacific Transportation Company causeway over a land ridge and then allowed to flow into the western desert to create a new lake about 500 square miles in area and an average of 2.5 feet deep. Evaporation would reduce the water volume, and the concentrated brine would then be recycled back into Great Salt Lake.

Declining Salinity

Before the Southern Pacific Transportation Company railroad causeway dividing the lake was completed in 1959, mineral concentrations in the lake probably were fairly uniform, and salinity was dependent on lake volume. In 1869, for example, when the lake was within a few feet of its historic high level, the lake water contained 15 percent brine minerals by weight. In 1930, however, when the lake level was about 10 feet lower, the mineral content was 21 percent.

The railroad causeway was constructed mostly of gravel and sand capped with boulder-sized riprap and was originally breached by two box culverts, each 15 feet wide. The causeway separates the lake into two parts; about two-thirds of the lake is south of the causeway, and about one-third is north of it. The southern part of the lake receives most of the freshwater inflow, whereas the northern part receives most of its water in the form of brine that moves through the culverts and causeway from the southern part. These factors, in conjunction with the restriction of flow by the causeway, have caused differences in the salinities and water levels of the two parts of the lake. These differences increased steadily throughout the 1960's. Since 1966, when measurements of the water level in the northern part were begun, the water level in the southern part has been consistently higher; the difference reached a maximum of 3.7 feet on July 1, 1984.

The causeway was breached with a 300-foot-wide opening on August 3, 1984, to provide flood relief to areas along the southern shore of the lake. Within 2 months, the difference in water levels north and south of the causeway had decreased to 0.75 foot; within 1 year, it had decreased to 0.5 foot.

Waves lash at the tracks of the Southern Pacific Transportation Company causeway across Great Salt Lake on June 19, 1986, shortly after the lake peaked at 4,211.85 feet. (Photograph by Doyle Stephens, Water Resources Division, U.S. Geological Survey.)

The brine north of the causeway remained relatively constant and near saturation from 1919 to 1982; dissolved mineral content was about 27 percent, regardless of changes in lake levels. The concentration decreased somewhat, however, during the large lake-level rises of 1983 and 1984, and a slight but steady decrease continued after the breach of the causeway and as the lake continued to rise through May 1986. By June 1986, the salinity north of the causeway had decreased to about 17 percent; south of the causeway, it was only 4.8 percent. At this salinity, which is about 1.5 times that of seawater, the famed buoyancy of Great Salt Lake is considerably diminished.

Can the salinity of Great Salt Lake ever decrease to that of the ocean? The lake would have to be diluted by a volume of freshwater sufficient to raise its elevation to about 4,218 feet, which is 6 feet higher than the 1986 peak. At this elevation, the lake would be so shallow and expansive on the western shore that evaporation would quickly concentrate the salts; it is thus very doubtful that seawater-level salinity will occur in the near future.

Cyclic Patterns in Lake Levels

The lake reacts to complex annual and long-term cycles in climatic patterns. The difficulty in determining the exact cause of the recent rise (and consequently in predicting future levels) is due to a series of these cycles superimposed on one another. As expected, the lake rises when large quantities of precipitation are received within its basin; however, this pattern is modified by the quantity of moisture in the soil and by the time of onset of the evaporation season. Analysis of historic precipitation and drought patterns for the area indicate a 118- to 146-year return period for large quantities of precipitation. Some climatologists predict that it is more likely than not that, in the next 100 years, another period of excessive precipitation will result in the expansion of this unique inland sea. The question then becomes, "Will this occur before the lake has fully receded from its most recent expansion?"

Water-Quality Trends in the Nation's Rivers

By Richard A. Smith

A comprehensive Federal program for nationwide collection of water-quality data was established by the U.S. Geological Survey in the early 1970's in response to a growing interest in monitoring trends in water quality. The program, the National Stream Quality Accounting Network (NASQAN), maintains a network of about 500 water-quality stations located near the junctions of major U.S. rivers. Although the network represents only a small fraction of the Nation's monitoring capability (State and local governments monitor various aspects of water quality at more than 60,000 locations), the fact that sampling and laboratory methods have remained essentially the same at all stations makes the program unique in the picture that it provides of long-term changes in water quality at the national level.

Using data from the NASQAN program, Geological Survey scientists recently conducted a nationwide analysis of water-quality trends for the years 1974-81, a period of major change in a number of factors influencing the water quality of rivers in the United States. The following four key factors—point- and nonpoint-source pollution, salinity, and toxic trace elements—are noteworthy.

Effects of Point-Source Pollution Controls on Water Quality

Point-source pollution control has been a major water-quality improvement effort for several decades, and the effectiveness of such control has been a longstanding issue. In the decade following passage of the Clean Water Act in 1972, discharge of oxygen-demanding wastes from municipal sewage treatment plants declined an estimated 46 percent nationally, and similar discharge from industrial sources decreased at least 70 percent. Reductions of this magnitude in point-source pollution would be expected to produce improvements in two water-quality variables in particular—dissolved oxygen concentration and fecal bacteria counts. In fact, changes in only one of these variables were clearly visible in the records from water-quality networks for the 8-year period 1974-81. Widespread decreases in fecal coliform and fecal *streptococcus* bacteria (fig. 6) during the study period correlated with areas of improved waste treatment. In contrast, increases in dissolved oxygen concentrations occurred with only moderate frequency and were only weakly correlated with changes in pollution loads occurring upstream of the sampling stations during the same period, although concentrations were most noticeable within 30 miles of sampling stations.

Trends in Nonpoint-Source Pollution

Nonpoint-source pollution may prevent the attainment of national water-quality goals even after complete implementation of planned point-source controls. Suspended sediment and nutrients from agricultural sources are usually cited as the most damaging nonpoint-source pollutants nationally. Damages caused by soil erosion and related nutrient impacts on aquatic ecosystems have been roughly estimated to equal $3.5 billion annually. Despite the widely acknowledged severity of nonpoint-source pollution, there have been few studies of long-term trends in the specific aspects of water quality most affected by nonpoint sources.

Of particular interest are the effects of changes in agricultural activity on suspended sediment and nutrient concentrations. Because of rapidly rising farm production, fertilizer application rates increased 68 percent between 1970 and 1981, continuing the long-term history of fertilizer use as one of nearly continuous increase. Analysis of national network data indicates that, from 1974 to 1981, nitrogen concentrations in rivers followed a distinctly different trend, both in frequency and in geographic distribution, from those followed by phosphorus and suspended sediment concentrations. Increases in phosphorus and suspended sediment concentrations occurred with only moderate frequency and were largely confined to the major midcontinent basins. In contrast, nitrate concentrations increased with great frequency and were widely distributed from the Farm Belt eastward (fig. 7).

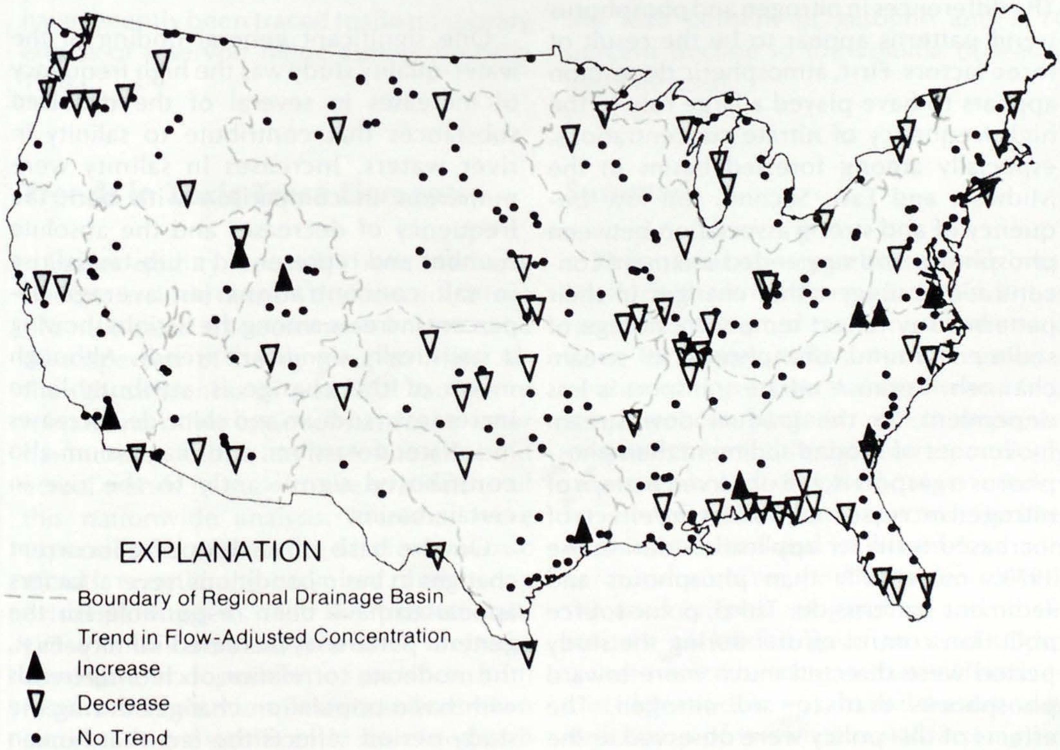
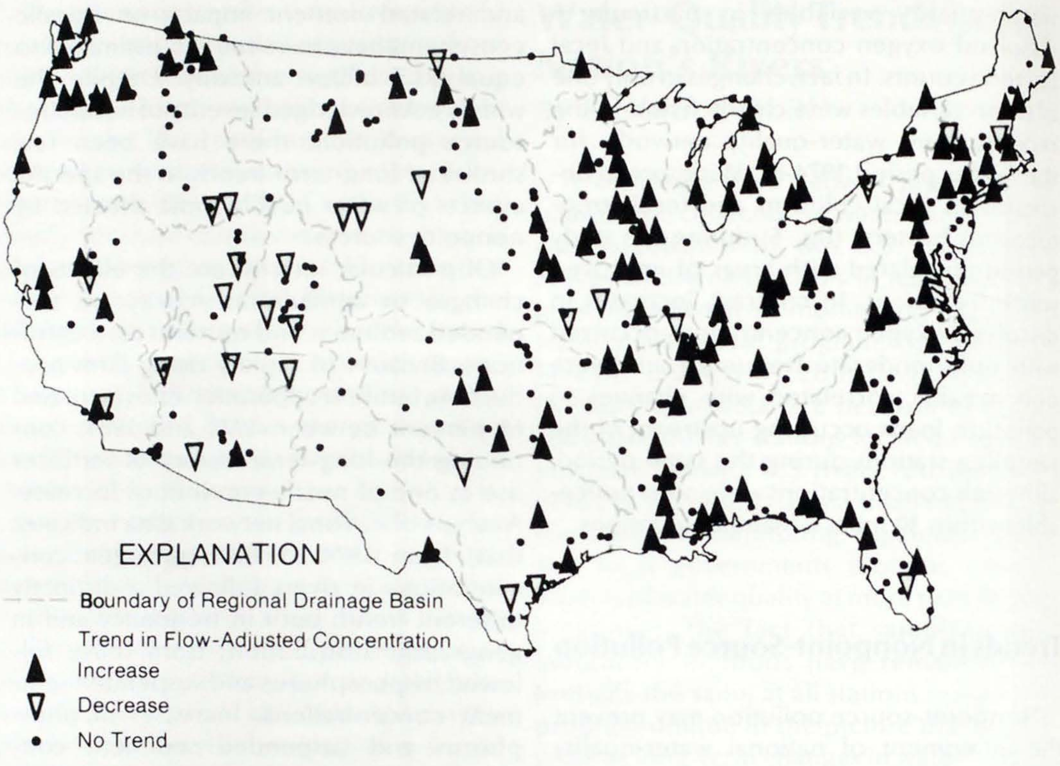


Figure 6. *Trend in flow-adjusted concentration of fecal* streptococcus *bacteria at water-quality network stations, 1974-81.*

Figure 7. *Trend in flow-adjusted concentration of nitrate at water-quality network stations, 1974-81.*



The major causes of the trends in suspended sediment and nutrient concentrations were determined by correlating the trend patterns with data pertaining to sources of sediment and nutrients in the basins upstream of the sampling stations. The differences in nitrogen and phosphorus trend patterns appear to be the result of three factors. First, atmospheric deposition appears to have played a large role in the high frequency of nitrate concentrations, especially among forested basins in the Midwest and East. Second, the low frequency of and strong association between phosphorus and suspended sediment concentrations suggest that changes in their patterns may reflect temporary storage of sediment-bound phosphorus in stream channels. Because nitrate transport is less dependent on the gradual downstream movement of eroded sediment than phosphorus transport is, the observed pattern of nitrogen increases may reflect the effects of increased fertilizer application during the 1970's more fully than phosphorus and sediment patterns do. Third, point-source pollution control efforts during the study period were directed much more toward phosphorus than toward nitrogen. The effects of this policy were observed in the greater ratio of phosphorus decreases to increases and in the significant correlation between phosphorus decreases and point-source loads.

Trends in Salinity

One significant general finding of the water-quality study was the high frequency of increases in several of the dissolved substances that contribute to salinity in river waters. Increases in salinity were numerous in comparison with both the frequency of decreases and the absolute number and represented a substantial rise in salt concentrations (an average 30-percent increase among the stations showing a statistically significant trend). Although much of the change is attributable to increases in sodium and chloride, increases in sulfate, potassium, and magnesium also contributed significantly to the rise in certain basins.

On the basis of analysis of concurrent changes in basin conditions, several factors appear to have been responsible for the general pattern of increased salinity. First, the moderate correlation of chloride trends with basin population changes during the study period reflects the fact that human wastes are a major source of chloride in many of the basins. Second, the use of highway salt increased nationally by a factor of more than 12 between 1950 and 1980 and thus stands out as a significant contributor to total stream salinity. Increasing chloride concentrations were significantly correlated with high rates of and large increases in the use of highway salt, especially in the Ohio, Tennessee, lower Missouri, and Arkansas-Red River basins. Finally, increases in sulfate were especially frequent in the Missouri, Arkansas, and Tennessee River basins and were highly correlated with changes in surface coal production during the 1974-81 period. Sulfate increases were not significantly correlated with underground coal production in the basins, however. Also, despite the fact that irrigated agriculture is known to have a large influence on the salinity of certain Western rivers, chloride increases were not significantly correlated nationally with changes in acreage under irrigation in the basins.

One interesting aspect of the geographic salinity pattern is that salinity clearly decreased in the upper Colorado River basin during the 1974-81 period, in contrast to the pattern observed in much of the rest of the Nation. Decreases in chloride concentrations in the Colorado drainage are noteworthy in view of the history of salinity problems in the basin, and the decreases have recently been traced to the temporary effects of reservoir filling during the early 1970's.

Trends in Toxic Trace Elements

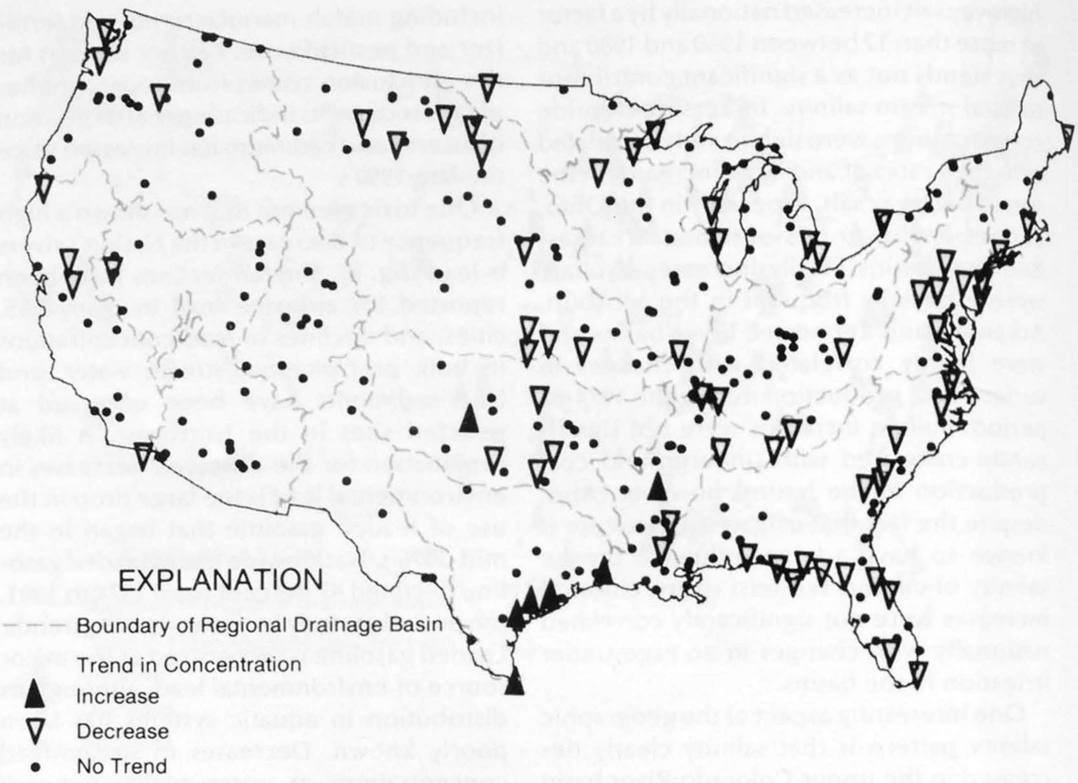
Water-quality records from network stations include data on the concentrations of a number of trace elements known to be or suspected of being toxic to man. Although awareness of potential sources of metals and other toxic substances in water has increased, little has been known about actual trends in their concentrations until this nationwide analysis. Increases were especially frequent in the data for two toxic metals, arsenic and cadmium, and strong evidence suggests that the predominant cause of this trend was the same for both: atmospheric deposition of products from fossil fuel combustion. Arsenic and cadmium increases were significantly correlated with estimated atmospheric deposition rates but not with measures of other known sources, including metals manufacturing and fertilizer and pesticide use. Further support for this conclusion comes from recent studies of lake sediments indicating that deposition of arsenic and cadmium has increased since the late 1950's.

One toxic element that has shown a high frequency of decrease in the Nation's rivers is lead (fig. 8). Similar declines have been reported for airborne lead in many U.S. cities, and declines in lead concentrations in bulk precipitation, stream water, and lake sediments have been observed at selected sites in the Northeast. A likely explanation for the observed decreases in environmental lead is the large drop in the use of leaded gasoline that began in the mid-1970's. Nationwide use of leaded gasoline declined 47 percent from 1974 to 1981, the period of study for water-quality trends. Leaded gasoline is recognized as the major source of environmental lead, although its distribution in aquatic systems has been poorly known. Decreases in stream-lead concentrations at water-quality network stations were highly correlated with both the level and rate of decline in the use of leaded gasoline in the basins during the study period. The steepest rate of decline in lead in both streams and gasoline occurred during 1980, which saw a 32-percent drop in the lead content of gasoline and a 14-percent decline in the volume of leaded gasoline used.

Summary

The analysis of water-quality trends in the Natifor's rivers for the period 1974-81 has, for the most part, shown improved conditions for many pollutants. Decreases in contamination by fecal coliform and fecal *streptococcus* bacteria reflect improved waste treatment, although, correspondingly, improvements in dissolved oxygen content have been slower than expected. Declines in airborne lead and in stream-lead concentrations correspond with decreases in the lead content of gasoline and in the volume of leaded gasoline used. Other trends reflect the increased use of fertilizers and highway deicing salts and the increased deposition of the toxic metals arsenic and cadmium, both products of fossil fuel combustion.

Figure 8. *Trend in concentration of dissolved lead at water-quality network stations, 1974-81.*



Measurement, Movement, and Fate of Contaminants: Research on Organic Substances in Water

By Jerry A. Leenheer

The movement and fate of most contaminants introduced into surface and ground waters are frequently related to the presence and nature of organic substances of natural and contaminant origin. The binding of insoluble contaminants with soluble or colloidal (a fine-grained material suspended in a liquid) organic substances greatly increases the mobility of the contaminant. The binding of contaminants with organic constituents of bed sediments provides a reservoir for the slow release of contaminants to the water column, and these sediments are a direct source of contamination for benthic (bottom-dwelling) organisms. Contaminants bound to sediment are frequently difficult to extract for laboratory analyses, and assessing the extent of sediment contamination becomes impossible. Binding of contaminants to organic substances may either enhance or retard the degradation of organic contaminants. The presence of natural organic solutes in water, for example, enhances the photolytic degradation of certain organic contaminants, but the binding of contaminants to organic substances can retard the rate of biological degradation of the contaminant.

The U.S. Geological Survey has established a comprehensive research program to study the chemistry of both organic contaminants and natural organic substances in water. The first method of determining pesticides in water was established in the late 1960's. Research expertise in natural organic substances in soil, sediment, and water led to the establishment of the International Humic Substances Society in 1982. The U.S. Geological Survey's research program, which is balanced between studies of natural organic substances and organic contaminants, has achieved new and valuable insights on the binding mechanisms (processes that cause humic substances to attach to contaminants) that affect the movement and fate of contaminants in water.

The measurement of binding constants, which is the ratio of bound contaminant to free contaminant, is being investigated for a variety of organic contaminants bound with different types of humic substances under varying chemical and physical conditions in water. Binding-constant data are required for mathematical models that predict contaminant transport in water under varying environmental conditions.

An example of the binding of organic contaminants with humic substances (partially degraded organic materials of natural origin) in soils and sediments is illustrated by the molecular model in figure 9. This model shows that humic substances are comprised of complex mixtures of molecules that associate to form semi-ordered membrane structures having polar exteriors that associate with water and non-polar interiors that associate with nonpolar organic contaminants. Insoluble organic contaminants may be "solubilized" by humic substances if the humic aggregate structure is small enough to be transported with dissolved constituents in water. If the humic aggregate structure is larger or if it exists as a surface coating on a mineral surface, the contaminant will be absorbed by the soil or sediment and will not be dissolved in water in transport processes. Changing chemical and physical conditions in water, such as variations in pH, salinity, temperature, and suspended sediment, can cause changes in the molecular configuration of the humic aggregate structure that result in the release or absorption of organic contaminants in water.

Studies of contaminant transport in water require accurate and very sensitive analytical methods. To follow specific contaminants over a long flow path, the methods used must have a wide range of measurement, because contaminant concentrations are diluted several orders of magnitude during transport. An example of applying improved analytical methods to the assessment of ground-water contamination to obtain a better understanding of contaminant transport processes is provided by a study of ground-water contamination by domestic sewage at Otis Air Force Base on Cape Cod, Mass. This study was conducted in cooperation with the Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control. A portion of the study involved measuring the areal extent and rate of transport of trichloroethylene (TCE) and perchloroethylene (PCE) in ground water. TCE and PCE are the most common contaminants found in ground water because they are widely used as cleaning solvents, because they are moderately soluble in water, and because they are not readily degraded by sewage treatment processes. The volatility of these contaminants permits them to be purged from water by passing air through the water; an adsorbent trap recovers the contaminants from the air for subsequent analytical determination.

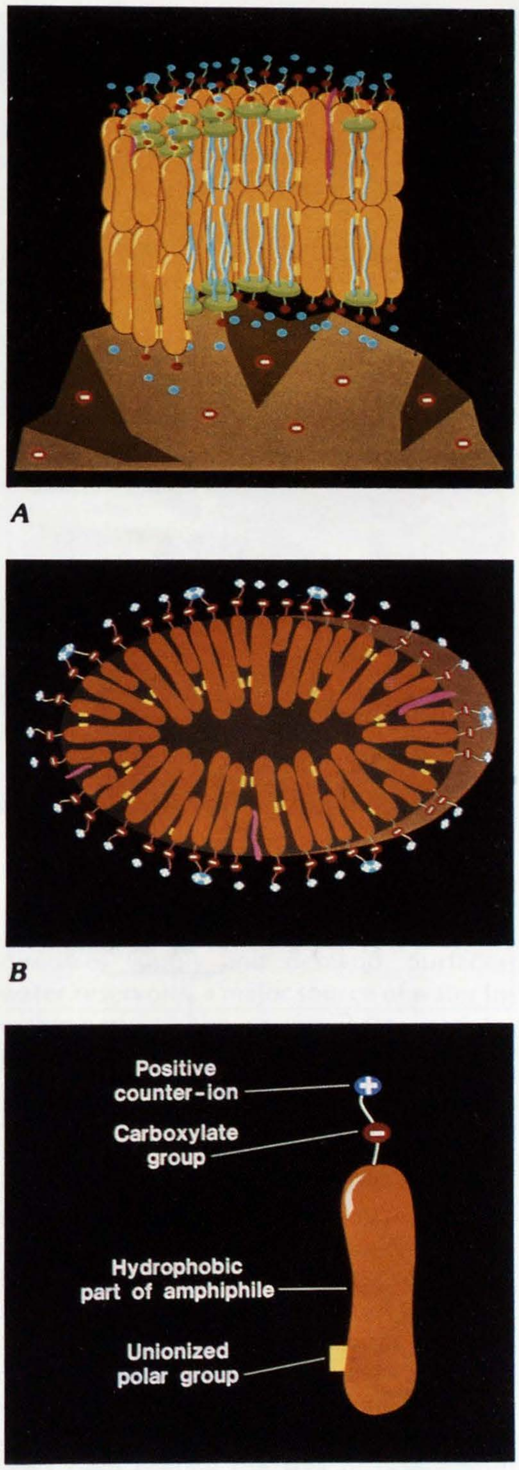


Figure 9. *Conceptual models illustrating the binding of nonpolar organic contaminants with humic substances in soils and sediment.* A, *Humic acid molecule. Amphiphiles are molecules consisting of a polar (hydrophilic) part (the carboxylate group) and a nonpolar (hydrophobic) part. The carboxylate group is an acid group that gives the molecule polar properties and that binds positively charged metal ions (positive counter-ions). The unionized polar group is a hydroloxyl group (for example, alcohol or phenol).* B, *Humic acid aggregate structure that exists in soil, sediment, and water as colloids or larger particles. Purple units represent nonpolar organic contaminants that partition into the nonpolar portion of the aggregate structure.* C, *Organic coating on a mineral surface of humic acids and natural lipids oriented into a membrane-type structure. The green and blue units represent diglyceride lipids, and the purple units represent organic contaminants. The two surfaces of the membrane are polar, and the interior is nonpolar. The organic membrane is attached to the mineral surface by polar interactions.*

The first analytical method developed for measuring TCE and PCE in water is known as the "sparge and trap" procedure. This method has a lower limit of detection of 1 microgram per liter and an upper limit of 100 micrograms per liter. The areal extent of TCE- and PCE-contaminated ground water determined by the "sparge and trap" procedure is shown in figure 10. Only three compounds, including TCE and PCE, were detected by this procedure.

A more sensitive method for detecting volatile organic contaminants is the Grob closed-loop-stripping procedure, which is based on recycling air through a water sample and isolating the volatile contaminants on a 1-milligram carbon trap. The method has a detection range from 0.01 to 20 micrograms per liter. The areal extent of ground-water contamination by TCE and PCE, as determined by the Grob closed-loop-stripping procedure and shown in figure 11, is significantly greater than that shown in figure 10. More importantly, over 50 contaminants were detected by the Grob closed-loop-stripping procedure.

The contrast between figures 10 and 11 illustrates that the definition of contaminated water depends on the ability to measure contaminants at very low concentrations. The most sensitive method of detecting organic contaminants is to measure volatile contaminants in water. Nonvolatile organic contaminants cannot presently be measured at trace concentrations, and many nonvolatile organic contaminants are discharged in significant quantities into water resources without detection.

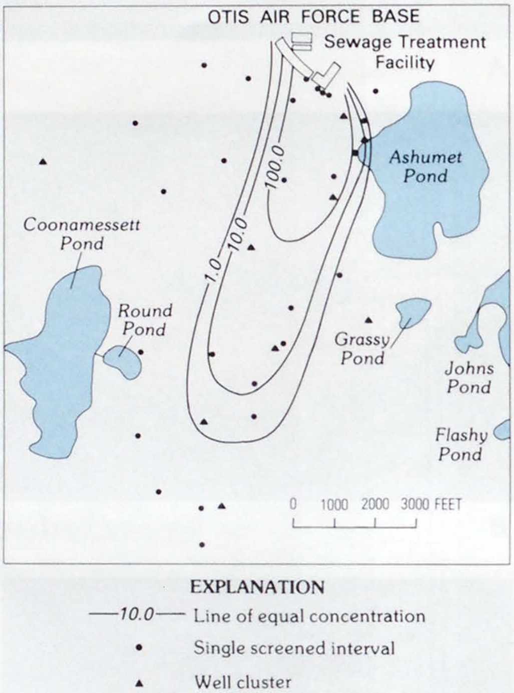


Figure 10. *Concentration of trichloroethylene plus perchloroethylene in a contaminant plume determined by the "sparge and trap" procedure at Otis Air Force Base on Cape Cod, Mass.*

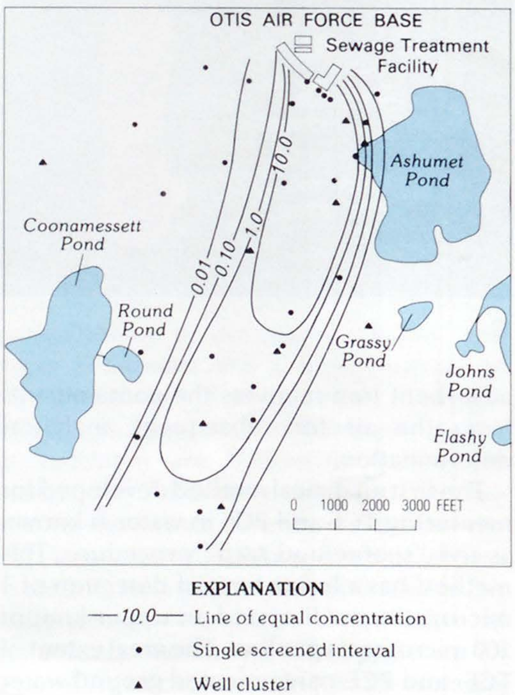


Figure 11. *Concentration of trichloroethylene plus perchloroethylene in a contaminant plume determined by the Grob closed-loop-stripping procedure at Otis Air Force Base on Cape Cod, Mass.*

National Water Summary 1985

By Edith B. Chase

The *National Water Summary 1985—Hydrologic Events and Surface-Water Resources*,, Water-Supply Paper 2300, focuses on the surface-water resources of the United States. Surface water is extensively developed and managed to provide water for public drinking supplies, irrigation, industries, hydroelectric power, navigation, and recreation and to ensure sufficient streamflows to maintain fish and wildlife habitats and adequate water quality. Surface water represents 77 percent of the Nation's total freshwater withdrawals; in only 10 States does surface water provide less than half of the total withdrawals.

The first part of the *National Water Summary 1985*, "Hydrologic Conditions and Water-Related Events," relates variability of precipitation to streamflow in water year 1985 (a water year begins October 1 and ends September 30 of the following year). Below-normal precipitation resulted in deficient streamflows and drought along much of the west coast, in the northern Rocky Mountains and northern High Plains, in central Texas, and along the entire east coast. These hydrologic conditions mark a significant change from the normal to above-normal pattern of precipitation and streamflows that have prevailed during the

Persistent deficient streamflow due to prolonged below-normal precipitation is indicated by the intrusion of wood ferns and maple saplings into the flood plain of the Rose River in the Shenandoah National Park, Va., on August 3, 1986. (Photograph by A. Ryan Powers, Water Resources Division, U.S. Geological Survey.)

previous two water years. Above-normal precipitation and streamflow patterns did persist in some parts of the country; for example, record-high water levels continued in Great Salt Lake, and, at the end of the water year, the Colorado River at Cisco, Utah, recorded its twenty-ninth consecutive month of above-normal flow. Record-high monthly mean water levels in Lakes Michigan, Huron, St. Clair, and Erie also were recorded. Despite the extreme dryness in some areas of the country, the combined yearly average flow of the Nation's three largest rivers—the Mississippi, the St. Lawrence, and the Columbia—was 9 percent above normal.

During 1985, six hurricanes struck the U.S. mainland, the largest number to make landfall since 1916. Although the effects were more socioeconomic than hydrologic, these hurricanes did provide considerable relief to the drought-plagued east coast by replenishing soil moisture, increasing runoff, and restoring reservoir levels. In September 1985, for example, Hurricane Gloria contributed enough rainfall to bring Delaware River basin reservoirs to near-normal levels and to end water-use restrictions and reduced diversions for the New York City and northern New Jersey area that had been in effect since May 1985.

"Hydrologic Perspectives on Water Issues," the second part of the report, discusses supply and demand. Surface-water reservoirs, a major source of water in many parts of the country, are used to provide reliable water supplies and to help smooth out the seasonal or annual variations in streamflows. In the United States, 2,654 reservoirs and controlled natural lakes having capacities of over 5,000 acre-feet provide about 480 million acre-feet of storage. Storage capacity is dominated by large reservoirs—the 574 largest reservoirs account for almost 90 percent of the total. In addition, there are perhaps as many as 50,000 smaller reservoirs having capacities ranging from 50 to 5,000 acre-feet and about 2 million smaller farm ponds. Reservoirs help reduce the size of floods and increase the amount of water in river channels during low flow; they also trap the sediment carried by rivers. Consequently, river channels downstream from dams will change in response to new patterns of streamflow by releases from reservoirs.

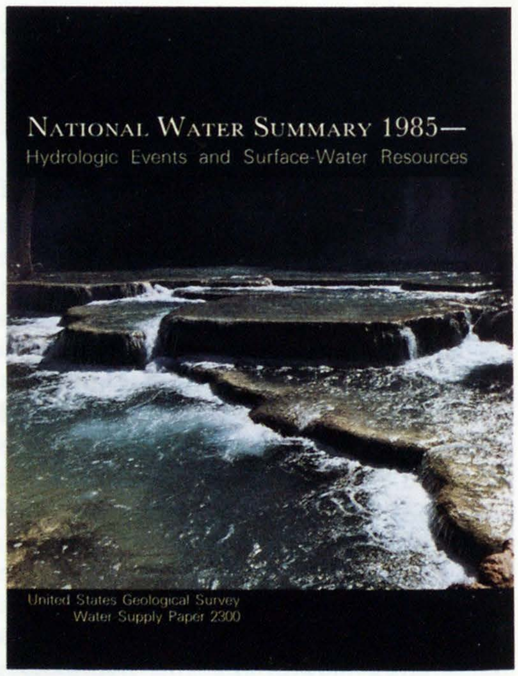
High construction costs for major water projects, environmental concerns, legal constraints, economic considerations, and increasing competition for water all point to an urgent need for better management of existing water supplies. New projects generally are designed and developed independently of existing projects, and some limited attempts are made to operate water-supply projects as integrated regional systems. In several parts of the country, water supply has been improved by implementing coordinated management techniques for existing systems.

In the Washington, D.C., metropolitan area, water supplies were increased by implementing better management procedures instead of by major new construction. Suppliers coordinated operation by adopting flexible operating rules that call for "saving" water in local reservoirs when Potomac River flows are high and taking water from local reservoirs at a rate higher than that normally allowed under a safe-yield (the amount of water that can be continuously withdrawn from storage at an acceptably small risk of interrupting the supply) constraint on withdrawals for short periods of time during low Potomac flows. The joint operation of supplies has solved a water-supply problem of almost 30 years' standing and is between $200 million and $1 billion less expensive than previously evaluated alternatives.

Water is a valuable economic commodity. Water transactions, which can be a change in the location of or in the type of water use that is undertaken voluntarily for the mutual benefit of the involved parties, are becoming more commonplace. For example, water previously used for irrigation in the U.S. Bureau of Reclamation's Emery County Project in Utah has been leased by the Utah Power and Light Company for cooling in a coal-fired thermoelectric powerplant.

Water banks are becoming more common. During the 1976-77 drought in California, the Federal Water Bank purchased water from the California State Water Project and the U.S. Bureau of Reclamation's Central Valley Project and sold 42,544 acre-feet, at an average price of $61 per acre-foot, to water users who would suffer the greatest damage from the drought. In 1984, Idaho's Water Supply Bank, under legislative authority to operate 1-year leases, leased 276,167 acre-feet on the upper Snake River to 13 lessees for $2.50 per acre-foot. Members of the Northern Colorado Water Conservancy District frequently trade water at fair market prices.

Water transactions are easier when suppliers and buyers have accurate estimates of the amount of water available. Likewise, timely knowledge of hydrologic conditions is a key element in improving water management. Data on floods and other extreme hydrologic events must be collected and transmitted without delay. Some water-resources agencies have begun to implement very sophisticated communications and data-processing technologies to collect and analyze up-to-date hydrologic data, so that management decisions can be made on a day-by-day or even an hour-by-hour basis. Hydrologic data-collection instruments automatically collect and communicate data from hydrologic gaging stations to the Geostationary Operational Environmental Satellites (GOES). Relay of environmental data by these satellites can be accomplished at any time from almost any point in the Western Hemisphere. In 1985, about 1,500 hydrologic stations reported through GOES. These stations are connected through the U.S. Geological Survey's Distributed Information System network of approximately 70 minicomputers.



The final part of the report, "State Summaries of Surface-Water Resources," reemphasizes the importance of surface water to the Nation by portraying the availability, use, and development of surface-water resources and related management activities in each State, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, the Trust Territory of the Pacific

Islands, Saipan, Guam, and American Samoa. These summaries point out the many similarities as well as the differences in surface-water resources among the States and Territories. Multicolored maps show river basins, reservoirs, and hydropower plants, graphs present seasonal variations in precipitation and streamflow, and tables depict statistics on streamflow and surface-water use.

The adequacy of the Nation's water supplies depends, in part, on future demands and types of water use and on the legal, institutional, and managerial arrangements that are used by the States to manage and allocate water. But whatever specific techniques are adopted by each State to manage and develop its water resources, increasing competition for available supplies will increase the demand and underscore the need for water information and knowledge about the hydrologic processes that control the availability, quantity, and quality of the Nation's water supplies. With the publication in September 1985 of the third *National Water Summary,* the U.S. Geological Survey continues its effort to make water information available to a wide audience.

Cartographer Douglas E. Clark performs a semiautomatic line-following procedure at a Lasertrac station. (Photograph by National Mapping Division.)

NATIONAL MAPPING PROGRAM

MISSION

The U.S. Geological Survey, through the National Mapping Division, provides cartographic and geographic products and information for the United States, territories, and U.S. possessions. The products include several series of topographic maps in both graphic and digital form, photoimage maps, land use and land cover maps and associated data, geographic names information, geodetic control data, and remotely sensed data.

The products are generated by four regional mapping centers in Reston, Va., Rolla, Mo., Denver, Colo., and Menlo Park, Calif., and by the Earth Resources Observation Systems Data Center in Sioux Falls, S. Dak. The Division's Printing and Distribution Center, headquartered in Reston, Va., prints, stores, and distributes all Geological Survey maps and related texts. The Division also operates Public Inquiries Offices and National Cartographic Information Centers throughout the country; along with the Earth Resources Observation Systems Data Center, these outlets provide information about and fill orders for cartographic, geographic, earth-science, and remotely sensed data.

MAJOR PROGRAMS AND ACTIVITIES

Major programs and activities of the Division in support of the National Mapping Program are:

- Primary mapping and revision, which include the production and revision of 7.5-minute 1:24,000-scale topographic maps in the conterminous United States and Hawaii and 15-minute 1:63,360- scale topographic maps in Alaska. A few maps have been prepared at 1:25,000 scale in specific States. During fiscal year 1986, about 925 revised and 1,250 new primary quadrangle maps were published. Published topographic maps are available for about 92 percent of Alaska and for 90 percent of the other 49-State area (fig. 1). Twenty-four States have complete 7.5-minute series map coverage.

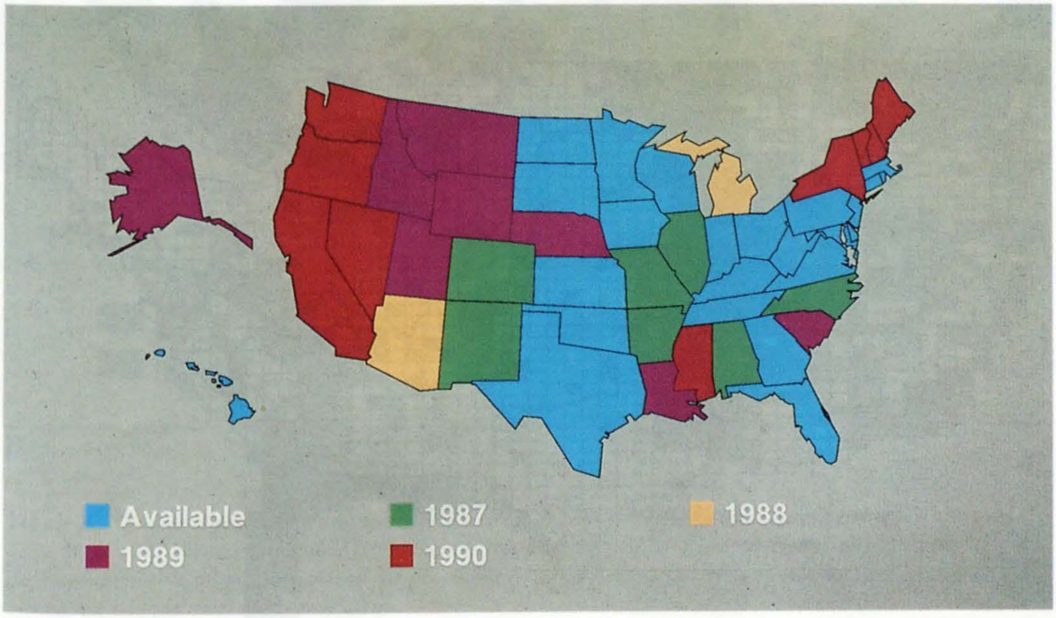


Figure 1. *Status of availability of primary quadrangle maps. Some maps will initially be available in manuscript form only.*

- Intermediate-scale, small-scale, and special mapping, which includes the preparation of maps and map products from the intermediate-scale (1:50,000 and 1:100,000) series to the small-scale (1:250,000) series and other smaller scale U.S. base maps. Complete topographic coverage of the United States is available at 1:250,000 scale. The Division completed planimetric coverage of the United States at 1:100,000 scale in 1986, 5 years ahead of the original completion date. Topographic coverage of the conterminous United States is more than 50 percent complete in one or more of the following intermediate-scale series: 1:50,000-scale quadrangle maps, 1:50,000- or 1:100,000-scale county maps, and 1:100,000-scale quadrangle maps (fig. 2). More than 200 topographic-bathymetric maps have been published for coastal area planning. Land use and land cover maps are complete for 3 million square miles and are available in the 1:250,000-scale or, in selected areas, in the 1:100,000-scale quadrangle format.
- Digital cartography, which includes the production of base categories of cartographic data at standard scales, accuracies, and formats suitable for computer-based analyses (fig. 3). Categories include the Public Land Survey System, boundaries, hydrography, transportation, and elevation data from 7.5-minute quadrangle maps; hydrography and transportation data from 1:100,000-scale quadrangle maps; boundaries, Census tracts, hydrologic units, Federal land ownership, land use and land cover, and elevation data compiled at 1:250,000 scale; and boundaries, transportation, and hydrography data from 1:2,000,000-scale National Atlas sectional maps.
- Information and data services, which include the acquisition and dissemination of information about U.S. maps, charts, aerial and space photographs and images, geodetic control, cartographic and geographic digital data, and other related information; distribution of earth-science information to the public; and sale of maps and map-related products directly and through commercial map dealers.
- Cartographic and geographic research and development, which include efforts to improve the quality of standard products, to provide new products, to reduce costs and increase productivity, to acquire innovative and more useful equipment, and to design and develop techniques and systems to advance the mapping of high-priority areas of the country.
- International activities, which include the coordination of Division participation in international cartographic, geographic, surveying, remote sensing, and other map-related activities.

BUDGET AND PERSONNEL

Funding for the National Mapping Division for fiscal year 1986 totaled approxi-

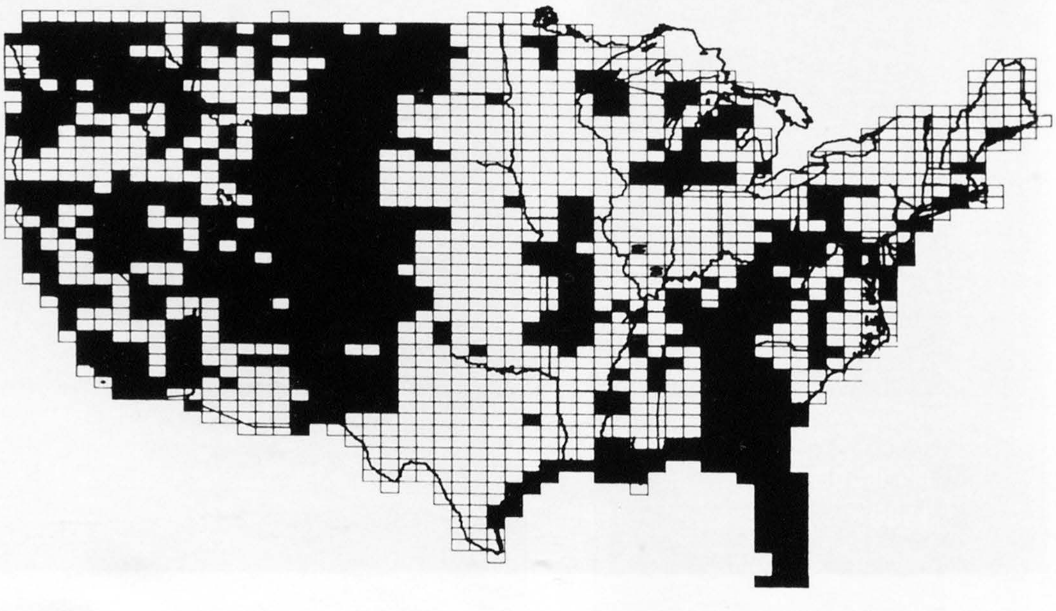
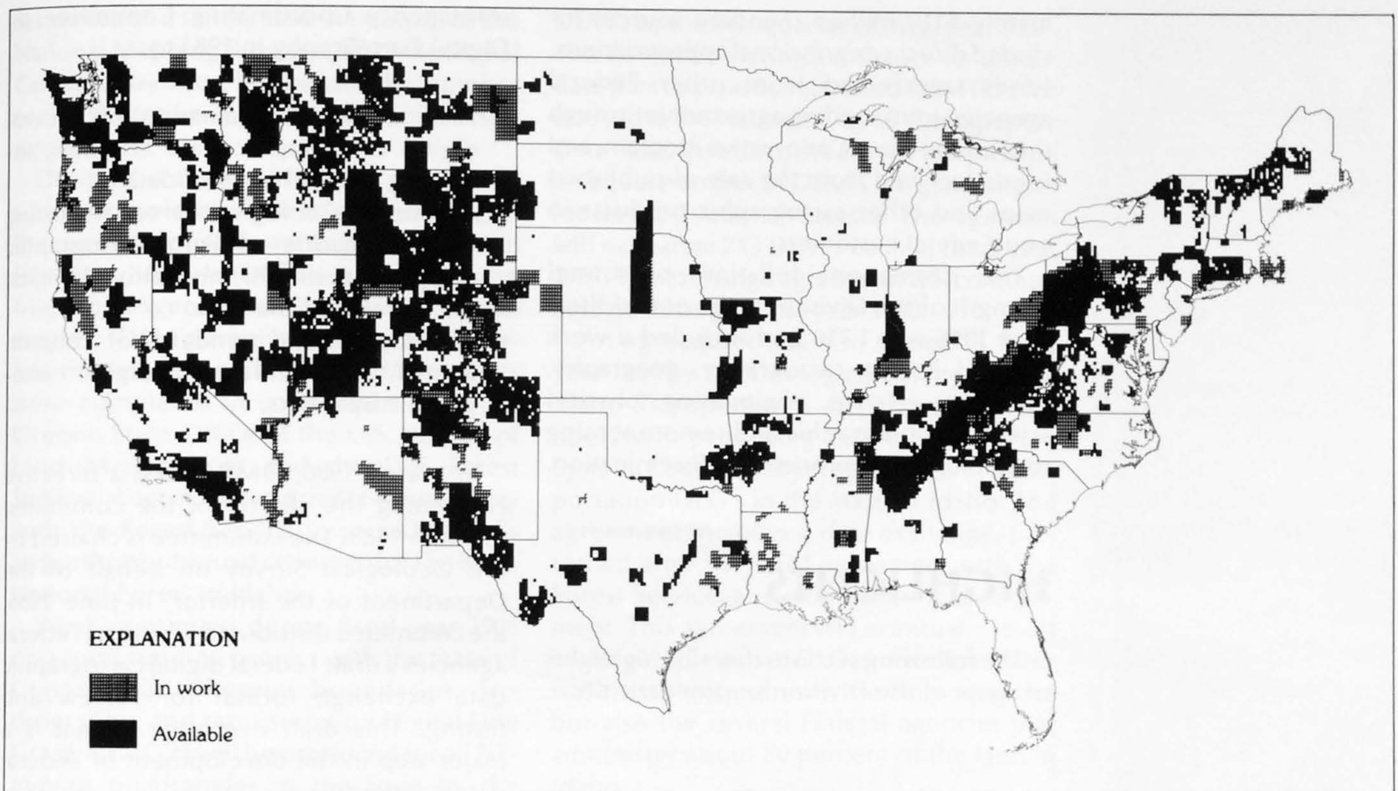


Figure 2. *Status of 1:100,000-scale topographic mapping program. Alaska, Hawaii, and Puerto Rico are not currently included in the 1:100,000-scale quadrangle mapping program.*



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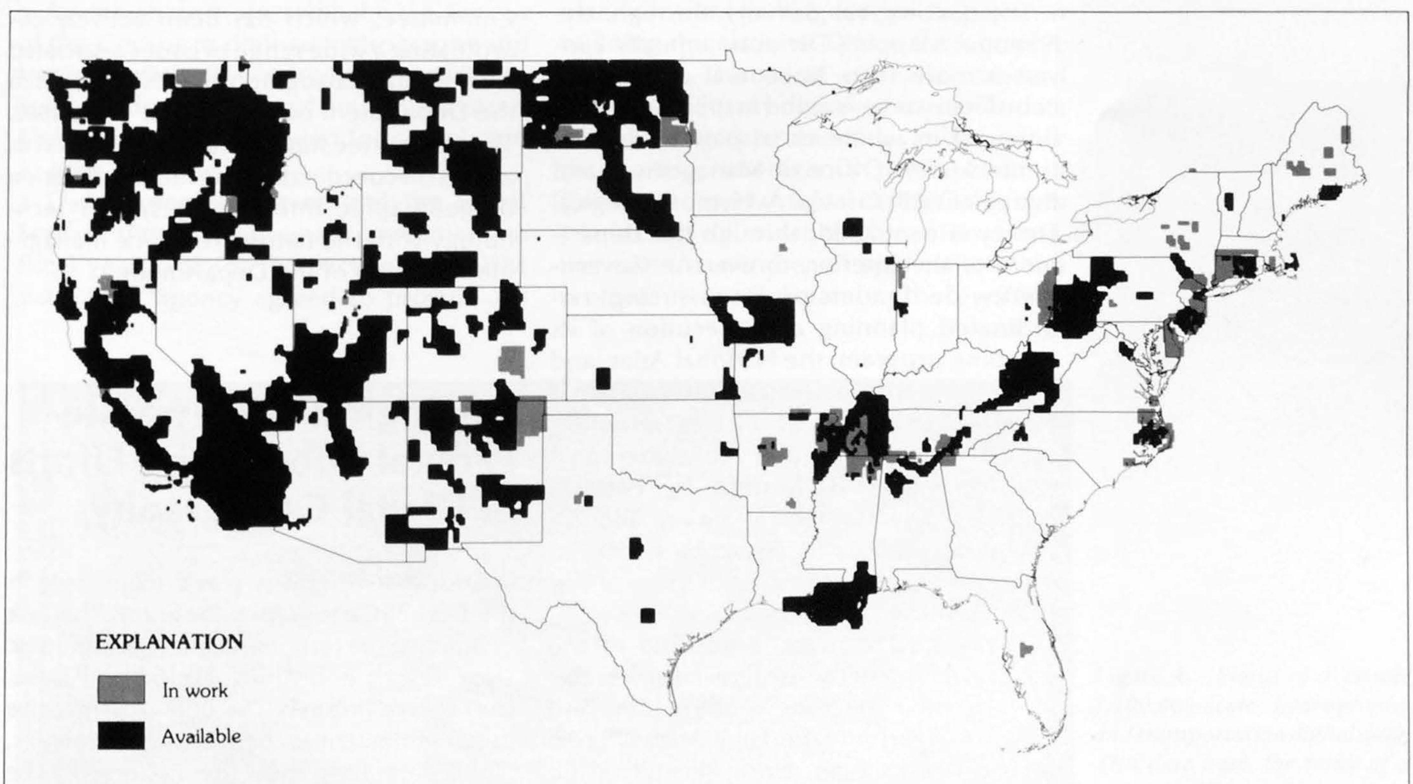


B

Figure 3. *Status of digital cartographic production.* A, *Digital Line Graphs from primary-scale data.* B, *Digital Elevation Models from high-altitude photographs. Limited digital cartographic data are available or are authorized for production in the Anchorage area of Alaska and on the Hawaiian islands of Hawaii and Oahu.*

mately $110 million. Funding sources included direct congressional appropriations, funds transferred from other Federal agencies, joint funding agreements through the Federal-State Cooperative Program, and funds received from the sale of published maps and other cartographic products to non-Federal customers.

The permanent full-time personnel strength of the Division at the end of fiscal year 1986 was 1,710 and included a work force skilled in cartography, geography, computer science, engineering, physical science, photographic and remote sensing technology, and information dissemination.

HIGHLIGHTS

The following sections describe highlights of some of the Division's major activities.

Mapping Coordination

The Geological Survey, through the National Mapping Division, annually canvasses more than 30 Federal agencies to coordinate surveying and mapping activities financed in whole or in part by Federal funds. Under Office of Management and Budget (OMB) Circular A-16, the Geological Survey is mandated, through the Department of the Interior, to exercise Governmentwide leadership in assuring coordinated planning and execution of its mapping program, the National Atlas, and map information activities. This mandate is extended to State and local government agencies whose programs and cartographic requirements are funded by Federal agencies. The Geological Survey also arranges for Federal agencies to exchange information concerning technological developments in cartographic activities.

The annual canvass is initiated in the second quarter of the fiscal year. Participants identify their mapping requirements and give them priority ranking according to their program goals. Upon receipt of the Federal requirements, the Geological Survey plans its upcoming year's production in accordance with capacity and funding levels.

As the use of digital cartographic data began to spread throughout the Federal Government, OMB established the Federal Interagency Coordinating Committee on Digital Cartography in 1983 to:

- Facilitate the coordination of Federal digital cartographic data activities, including the exchange of data.
- Advise the Geological Survey regarding which categories of digital cartographic data are needed in the National Digital Cartographic Data Base.
- Develop Federal standards of content, format, and accuracy for digital cartographic base data.

In March 1986, OMB issued a directive continuing the charter of the committee through 1989. The committee is chaired by the Geological Survey on behalf of the Department of the Interior. In June 1986, the committee distributed to several Federal agencies a draft Federal digital cartographic data exchange format for review and testing. This draft exchange format is a major step in the development of Federal data standards.

The Geological Survey also chairs the Interior Digital Cartography Coordinating Committee, which has been actively coordinating a wide range of issues associated with digital cartographic activities within the Department of the Interior since 1982. The committee has increasingly focused its efforts on coordinating the implementation of geographic information system technology with the natural resource management mission of the Department.

Geological Survey-State-Federal Cooperative Efforts in Digital Cartography

Cooperative efforts play a major role in the Digital Cartography Program. The task of building the National Digital Cartographic Data Base is enormous. Excluding Alaska, there are nearly 54,000 7.5-minute quadranqles. For each of these quadrangles, eight data files must be collected. The Survey cannot digitize this amount of data within a reasonable time without the assistance of Federal and State agencies.

Traditionally, the Geological Survey has cooperated with Federal and State agencies to augment its financial and production resources and to increase the output of the National Mapping Program. Since the Digital Cartography Program began, the number of cooperative projects has increased significantly.

During fiscal year 1986, the Geological Survey completed work on a project begun the preceding fiscal year to provide Digital Elevation Models (DEM's) to the Defense Mapping Agency for about 1,600 quadrangles. (DEM's are three-dimensional terrain models.) Several smaller DEM projects were completed in cooperation with the Oregon State Office of the U.S. Bureau of Land Management and the U.S. Forest Service. A work-share project is underway with the Forest Service to provide DEM's and orthophotoquad coverage for the Boise National Forest in Idaho.

Work continued during fiscal year 1986 on a joint funding project with the State of Connecticut whereby boundaries, hydrography, and transportation Digital Line Graphs (DLG's) will be produced for all 7.5-minute quadrangles in the State by the beginning of calendar year 1988. (DLG's represent linear map features.)

A work-share project with the U.S. Bureau of the Census to digitize hydrography and transportation DLG's from the 1:100,000-scale quadrangle maps of the conterminous United States is scheduled for completion in June 1987 (fig. 4).

The Geological Survey and the Forest Service signed a landmark agreement in fiscal year 1986 for the exchange of DEM data. Each agency agreed to provide 208 DEM's by the first quarter of fiscal year 1987. The Forest Service will enhance its terrain data files to produce standard DEM files for entry into the National Digital Cartographic Data Base. In return, the Survey will provide an equal number of DEM's for quadrangles located in national forests. The agencies will exchange 713 DEM's each in fiscal year 1987. The exchange agreement will continue at least through fiscal year 1989.

An agreement was also signed in fiscal year 1986 by the Geological Survey and the Idaho Transportation Department to cooperate in producing Public Land Survey System, boundary, hydrography, and transportation DLG's in the State of Idaho. The agreement includes a data exchange, patterned after the DEM agreement with the Forest Service, and a cost sharing arrangement. This agreement will eventually result in the completion of DLG production statewide, assisting not only the State agencies but also the several Federal agencies that administer about 80 percent of the land in Idaho.

The agreements with the Forest Service and the State of Idaho are the beginning of a trend toward multiagency participation in building the National Digital Cartographic Data Base. This trend will make standard Geological Survey digital cartographic data available in greater quantities and at earlier dates. Also, interagency participation in Geological Survey digital cartographic data production will widen the use of those data, increase the number of applications, and promote compatibility among those systems.

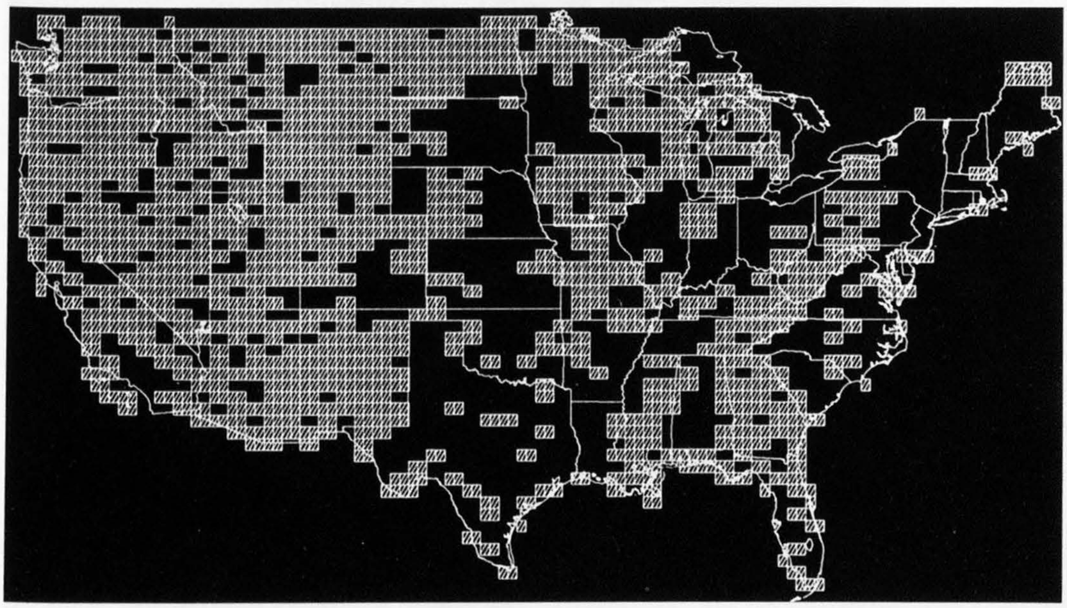


Figure 4. *Status of available 1:100,000-scale hydrography and transportation digital data. This data base, the result of a Geological Survey-Bureau of the Census project, is expected to be completed during fiscal year 1987. The data will be considered preliminary until final processing through edge-matching software.*

Earth-Science Data Base Archive and Distribution

As the Nation's principal earth-science research agency, the Survey has acquired vast amounts of scientific data, which are used to study, analyze, and provide information about the Earth. The data cover both natural and human-induced phenomena, as well as detailed mapping information and measurements of the Earth's resources. In many cases, these data are scattered or unavailable to a broad sector of natural resource scientists and managers and lack the ease of access and organization necessary for widespread use.

To make valuable earth-science data more readily available to Federal and State agencies and the general public, the National Mapping Division has accepted the responsibility for acquiring, archiving, and distributing select earth-science digital data sets originally compiled by the Survey or its cooperators. This activity is generally limited to those data sets that are national in character and geographically referenced, contain relevant data of significant general interest and applicability, and are suitable for use with existing spatial data bases and (or) geographic information systems. The decision to archive and distribute a data set takes into account its compatibility with data sets already archived, the merits of preparing merged data sets, the need for user-specified products (digital, graphic, or tabular) derived from the data set, and the need for reformatting the data set to make it more useful.

For example, the Division's Earth Resources Observation Systems Data Center currently archives and distributes digital earth-science data collected by the National Uranium Resources Evaluation (NURE) Program of the U.S. Department of Energy. From 1974 to 1980, the Federal Government systematically evaluated the uranium resources of the conterminous United States and Alaska. Earth-science research in the NURE Program included geochemical and stream-sediment reconnaissance sampling, coordinated rock sampling and analyses, airborne radiometric and magnetic surveys, geologic mapping and ore-deposit studies, subsurface geologic investigations (borehole drilling), technology application studies, development of resource estimation methodologies, and uranium resource evaluations incorporating research results. Several years of data collection generated substantial geologic, geophysical, and geochemical data that can be used in other earth-science research.

Nearly all data from the NURE Program are organized and retrievable by reference to a rectangular grid system that corresponds to the 1:250,000-scale topographic quadrangle system used by the Survey. In this system, a total of 621 quadrangles cover the conterminous United States and Alaska (468 for the conterminous States and 153 for Alaska). However, not all categories of NURE data are available for all quadrangles.

The NURE data are only the first of many earth-science data sets that might eventually be archived and distributed.

Satellite Radiometer Data Acquisition and Product Generation

The Geological Survey, in cooperation with the National Oceanic and Atmospheric Administration (NOAA), is building a reception and processing system for NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite data at the Earth Resources Observation Systems Data Center. The system, planned to be operational by May 1987, will ensure that limited quantities of geographically referenced AVHRR data for the conterminous United States, needed to support Federal earth-science research and land management programs, are routinely available within 24 hours of a satellite overpass. The system will have the capability to receive and process as many as six daytime data swaths daily and to collect predawn passes on request. All data will be screened and categorized in terms of quality and cloud cover. A researcher will be able to obtain a digital tape of original or processed (georeferenced) data and a floppy disk and (or) a photographic product of the processed data and to have the data merged with line data from the Survey's 1:2,000,000-scale Digital Line Graph or other map files.

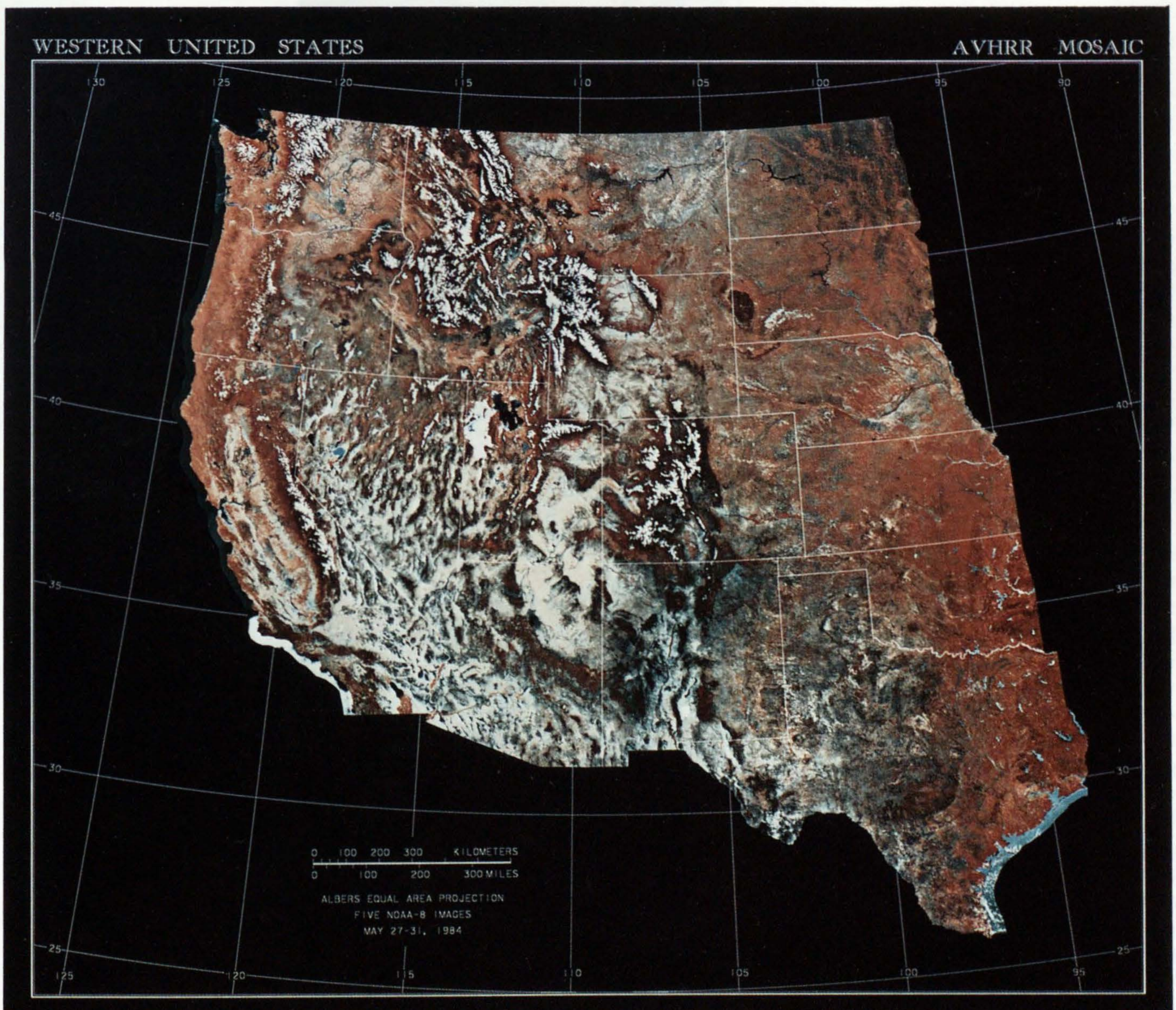
The Survey has investigated using AVHRR data to supply the information needs of selected Department of the Interior bureaus. A few obvious land science applications include fire-fuels mapping, image mapping, rainfall distribution monitoring, and vegetation monitoring. A cooperative research effort between the Survey and the U.S. Bureau of Land Management (USBLM) illustrates one application of AVHRR data.

The USBLM operates an Initial Attack Management System for fire management in the Western United States. The data base and model for predicting the probability of fire ignition from lightning strikes contain weather, terrain, and fire-fuel (vegetation) information, all at 1-km resolution. Fire-fuel types, suitable for inclusion in the Initial Attack Management System, can be determined from vegetation cover types identified by digital processing of time-series AVHRR data. The USBLM is now using AVHRR data operationally.

In another example, image mapping of entire countries and continents is becoming increasingly important for the study and monitoring of limited global resources. Research on advanced image mapping techniques has demonstrated that AVHRR data are suitable for producing image maps at scales of 1:4,000,000 and smaller. An image map for the entire conterminous United States is being prepared for a fraction of the cost and time that would be required if data from other sensors, such as Landsat multispectral scanners, were used (fig. 5).

Monitoring requires repetitive coverage, and the monitoring of vegetation may require weekly, or even daily, acquisitions. Monitoring of annual vegetation growth and decay provides useful information to the resource scientist and land manager. The frequency of overpasses and the collec-

Figure 5. *A mosaic of five color-composite Advanced Very High Resolution Radiometer (AVHRR) images of the Western United States. State boundaries from Geological Survey 1:2,000,000-scale Digital Line Graph data were digitally superimposed on the mosaic.*



tion of midday thermal infrared data provided by the AVHRR data offer a unique opportunity to observe and measure moisture-related anomalies. Also, using AVHRR data for repetitive mapping of snow cover, changes in water areas or apparent turbidity, thermal mixing within water bodies, and vegetation conditions on a watershed provides the research hydrologist with synoptic repetitive coverage from which to derive information for use in hydrologic models.

These examples address only a few areas in which AVHRR data have been applied. The prospects for broader application of AVHRR data will increase when the reception and processing system becomes fully operational in 1987.

Global Positioning System Applications in the Geological Survey

The scope and varied nature of the Geological Survey's programs are reflected in the surveying demands that these programs generate. Because positioning requirements for activities such as mapping control, iceflow studies, fault monitoring, marine gravity, and airborne laser profiling vary enormously, a multiplicity of equipment and techniques is necessary. However, the Geological Survey has recently begun applications testing of a new geodetic surveying system that is expected to substantially replace existing methods.

The Global Positioning System was designed by the U.S. Department of Defense to provide a continuous, worldwide navigation capability. The system will comprise 18 Earth-orbiting satellites, a network of ground-control stations to monitor and update the satellite orbits, and user equipment to track the satellites and determine the user's position in three dimensions. At present, only six satellites are operational; consequently, effective use of the system is limited to a few hours a day. An 18-satellite system providing round-the-clock navigational and positioning capabilities is scheduled to be in operation by 1990.

The Global Positioning System can be used for real-time navigation or precise surveying. Real-time navigation accuracy is about 15 meters. Survey accuracy obtainable by using relative positioning techniques is better than 1 centimeter ±1 part per million over distances of a few meters to a few thousand kilometers. Relative positioning requires two receivers, one at each end of the survey line, tracking the same satellites simultaneously. First-order accuracy is possible with as little as 30 minutes of observational data.

The Survey now has five Texas Instruments TI-4100 Global Positioning System survey units (fig. 6). The Geologic Division in

Figure 6. *Cartographer Edward Cyran operates a Texas Instruments TI-4100 Global Positioning System survey unit (top). Commands are entered through a hand-held control display unit, and data are logged onto magnetic-tape cassettes. The dual-cassette drives are shown in the foreground on top of the receiver-processor unit. Because the lead on the tripod-mounted antenna (bottom) is 100 feet long, the survey unit can be left in the vehicle at many survey sites.*

Menlo Park, Calif., is using three of the units to test and develop the system's application for crustal motion studies. The National Mapping Division is using the other two units to establish a Global Positioning System surveying capability in its mapping centers and to develop applications such as mapping control, subsidence monitoring, and dynamic positioning of airborne systems. Several pilot projects are in progress, including one to test the Global Positioning System's ability to provide vertical mapping control and another comprising a 50-station subsidence survey for the Water Resources Division in the Sacramento District of California. A new dynamic relative positioning technique that promises to yield decimeter accuracy will soon be tested.

The Denali Image Map

Mount McKinley in Denali National Park, Alaska, has perhaps the greatest relief of any land mountain in the world; it rises over 5,000 meters (17,000 feet) above its surrounding base. As such, it challenges the mapmaker to produce a satellite image map that will not be badly distorted by relief displacement. Moreover, the area presents a stark contrast between the snow and ice and the summer vegetation coverage.

Scene selection for any image mosaic project is difficult, and the snow, cloud cover, and short summer season in the northern latitudes combine to restrict the usable number of images to a select few. Thus, the Denali National Park and Preserve Satellite Image Map (fig. 7) is a mosaic of nine separate Landsat multispectral scanner scenes acquired over a 5-year period. Two of the images were recorded by Landsat 5, and their orbital and image characteristics are different from those of the other seven images recorded by Landsat 3. The mosaic involves three of the four wavebands recorded by the Landsat multispectral scanner.

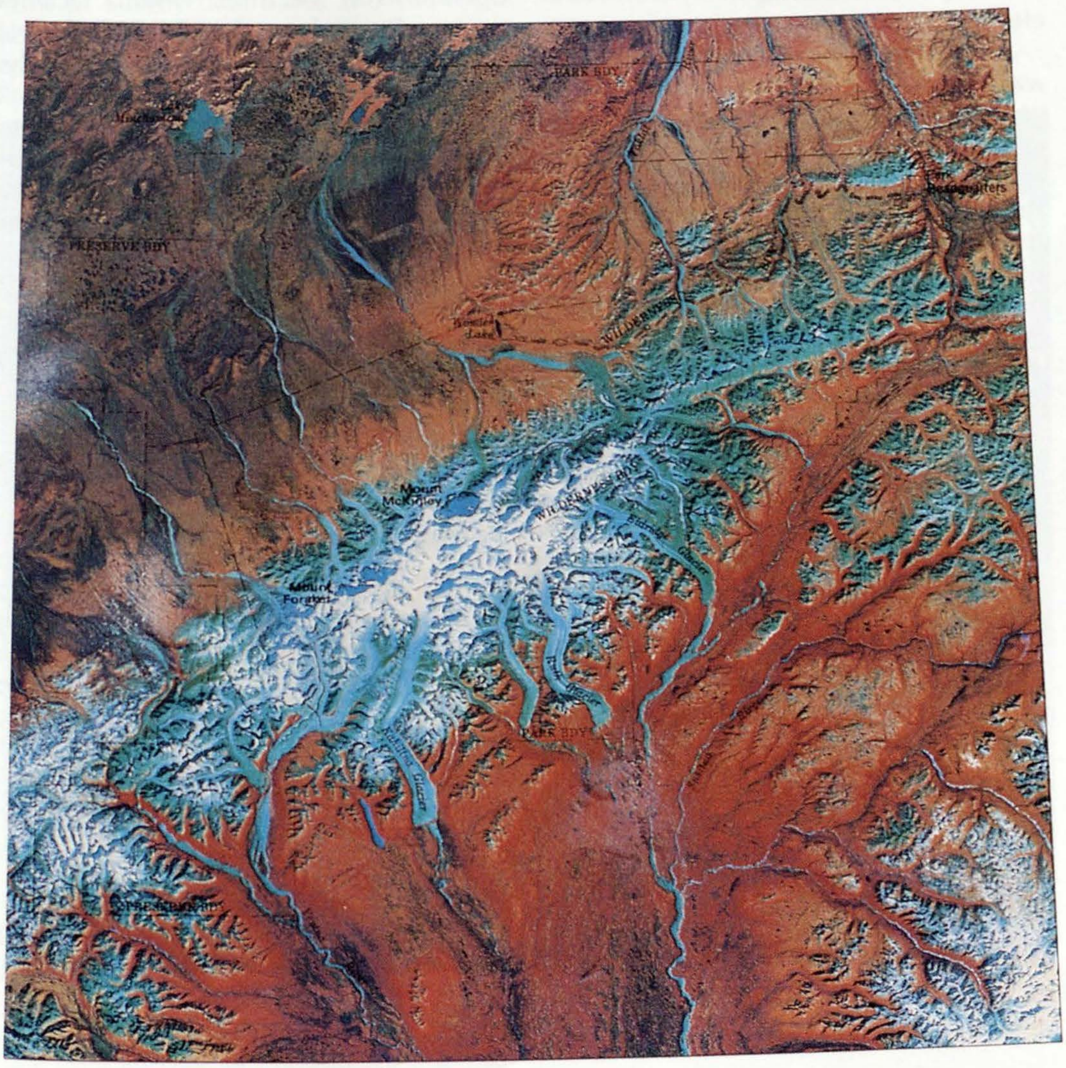


Figure 7. *Reduced-scale mosaic of the Denali National Park and Preserve Satellite Image Map prepared from nine Landsat multispectral scanner scenes. Mount McKinley is in the center of the mosaic.*

The geometry of each image is digitally corrected during the mosaicking process through the use of ground-control points and seam-control (tie) points between adjacent images. Such corrections reduce internal geometric problems and permit the mosaicking of adjacent scenes without appreciable alignment errors.

The digital data as received contained a considerable number of missing elements and lines of data. To produce an optimum image, these missing data bits were artificially created. In addition, the radiance differences between adjacent images were minimized by computer to create a scene that appeared to be continuous.

An area such as Denali has only a limited number of identifiable control points in addition to its high relief. Because Mount McKinley is near one of the satellite groundtracks (orbital paths), relief displacement is much less than it would be if the mountain were nearer the image edge. This positioning was of particular importance, since usable control points were found only at the lower elevations.

A line map of the Mount McKinley area was originally produced in 1958 as the "Mount McKinley National Park" and revised in 1972. When the park area was expanded and renamed Denali National Park and Preserve in 1980, additional map revisions were made. The 1986 revised map, portraying a special-interest area, contains portions of six standard 1:250,000-scale maps. The revised line map and the satellite image map, both covering the identical area, were printed back-to-back on a durable plastic-coated material suitable for outdoor use.

The Denali image map demonstrates that Landsat data can be converted into highly usable image maps even under such adverse conditions as extreme relief, cloud cover, and high scene contrast.

Consolidation of Product Distribution Operations

For many years, the maps, books, and reports of the Geological Survey have been distributed by the National Mapping Division through three facilities in Arlington and Alexandria, Va., a facility in Denver, Colo., and a facility in Fairbanks, Alaska.

As part of an overall effort to reduce costs and improve operations, the Geological Survey is consolidating the four distribution facilities in the conterminous United States into one major facility located in Building 810 of the Denver Federal Center (the Fairbanks facility will remain in operation). Elimination of duplicate map inventories and recordkeeping systems, streamlining of inventory and order-processing systems, improvement of current warehouse practices, and reduction of transportation costs through expanded use of full-carload shipments are just a few of the anticipated improvements.

An estimated annual savings of about $1.1 million will result. The total cost of the consolidation will be about $2.9 million, which includes moving costs, new equipment, and renovation of Building 810 (primarily to add office space).

During fiscal year 1986, all distribution operations in the three Virginia facilities were relocated to the Denver Federal Center. Distribution operations in the present Denver facility (Building 41) will continue during a phased relocation to Building 810. Complete consolidation is scheduled for the end of fiscal year 1988, when the necessary building modifications are expected to be finished.

Geographic Information System Development

To enhance Geological Survey activities in collecting and disseminating earth-science information, part of the National Mapping Division's research efforts during fiscal year 1986 was devoted to improving access to and exchange of data among varying cartographic and thematic data bases, improving the capabilities of existing geographic information systems (GIS's), implementing advanced GIS concepts, and developing and encouraging new or improved applications of GIS technology within the Department of the Interior. Specific areas of research were:

- Data structure—To facilitate horizontal and vertical integration, to improve storage and processing, and to define a format for data exchange between GIS's.

- Data capture—To improve data collection and editing capabilities, to evaluate and implement automatic line-following systems for collecting certain kinds of data, and to improve procedures for collecting and tagging attribute and textual data.
- Data query and analysis—To provide storage for large volumes of data, to maintain topology between spatial, textual, and attribute data, and to facilitate query and retrieval of data for analysis.
- Data output—To provide a flexible and diverse ability to produce user-customized products.

The National Mapping Division also conducted numerous projects with other Survey divisions, Department bureaus and offices, and Federal and State agencies. These projects demonstrated the applications of Survey data bases and GIS technology to ongoing programs and provided feedback for design of the National Digital Cartographic Data Base. Conterminous United States Mineral Assessment Program and Alaska Mineral Resource Assessment Program activities with the Geologic Division required predictive model development and application to multiple spatial categories. The Federal Land Information System (fig. 8) required coordination with the Geologic Division, the U.S. Bureau of Land Management, the U.S. Bureau of Mines, and others to investigate a nationwide data base using data categories derived by other agencies, together with data from the Survey's National Digital Cartographic Data Base. The John Day River Basin Project with the Water Resources Division and the State of Oregon required the merging of numerous data categories into a GIS for analysis and application to land and water resources policy planning.

Projects with other Federal agencies, such as the Soil Conservation Service, will define how products can be better used and implemented through digital spatial analysis techniques for specific agency responsibilities.

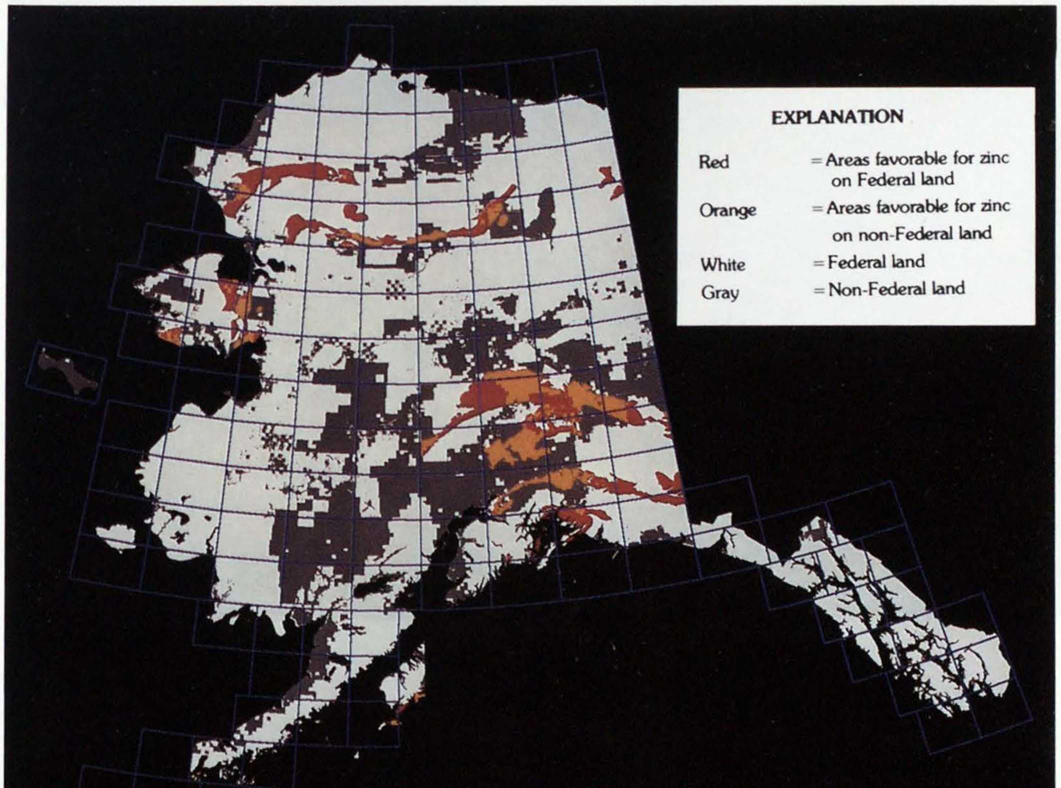


Figure 8. *Federal Land Information System data showing areas favorable for zinc on Federal and non-Federal land in Alaska. Land ownership data are from the U.S. Bureau of Land Management's Alaska Automated Land and Mineral Record System. Data resolution is one township. Mineral favorability data are from the Geological Survey's Regional Alaska Mineral Resource Assessment Program (data for southeastern Alaska were not available). Data were digitized from 1:1,000,000-scale maps. Blue lines are Geological Survey 1:250,000-scale quadrangle boundaries.*

INTERNATIONAL ACTIVITIES

MISSION

Under the Organic Act, as revised, and the Foreign Assistance Act and related legislation, the U.S. Geological Survey is authorized to conduct investigations in foreign countries when such studies are deemed by the Departments of the Interior and State to be in the interests of the U.S. Government. These international activities, a part of the Survey's program for more than 40 years, are undertaken on the basis of these principal objectives:

- To expand the scope of and help achieve domestic research objectives through the comparative study of scientific phenomena abroad and in the United States.
- To obtain information about existing and potential foreign resources of interest to the United States.
- To develop and maintain relations with counterpart institutions and programs that will facilitate scientific cooperation and exchange.
- To provide support for the international programs of other Federal agencies, including those of the U.S. Department of State, that contribute to foreign policy objectives.

MAJOR PROGRAMS AND ACTIVITIES

Colombia's Nevado del Ruiz volcano seven weeks before its devastating November 13, 1985, eruption. (Photograph by Darrell Herd, U.S. Geological Survey.)

Two general types of activities comprise the Survey's major international programs. Technical assistance to foreign countries or international organizations is funded by other Federal agencies, international organizations, or foreign governments as authorized under the Foreign Assistance Act. Some programs involve transferring technology to foreign nationals through advice, training, and demonstration; some require Survey personnel to accomplish all project tasks alone. Bilateral or multilateral cooperative ventures with foreign counterpart organizations under Government-approved cooperative agreements to achieve common research objectives use both funds appropriated for Survey research and funds or other financial resources made available by the cooperating countries or organizations. Participants in such cooperative research activities pay their own expenses. Activities in this category range from informal scientist-to-scientist discussions and correspondence, through formal, jointly staffed research projects, to multinational projects focusing on particular problems or topics and coordinated internationally. Related activities include institutional development, exchange of scientists, training of foreign nationals, and representation of the Survey or the U.S. Government in international organizations, commissions, or associations.

Sixty-eight foreign nationals from 45 countries participated in training programs at the Geological Survey during fiscal year 1986. Twenty-nine attended Survey-scheduled training courses, and 39 received on-the-job training at various Survey facilities in the United States. The Survey also provided cooperative research opportunities to 45 exchange foreign scientists.

Countries where the Geological Survey carried on international activities in fiscal year 1986 are shown in figure 1, and types of activities are listed in table 1. The following summaries more fully describe various aspects of the programs.

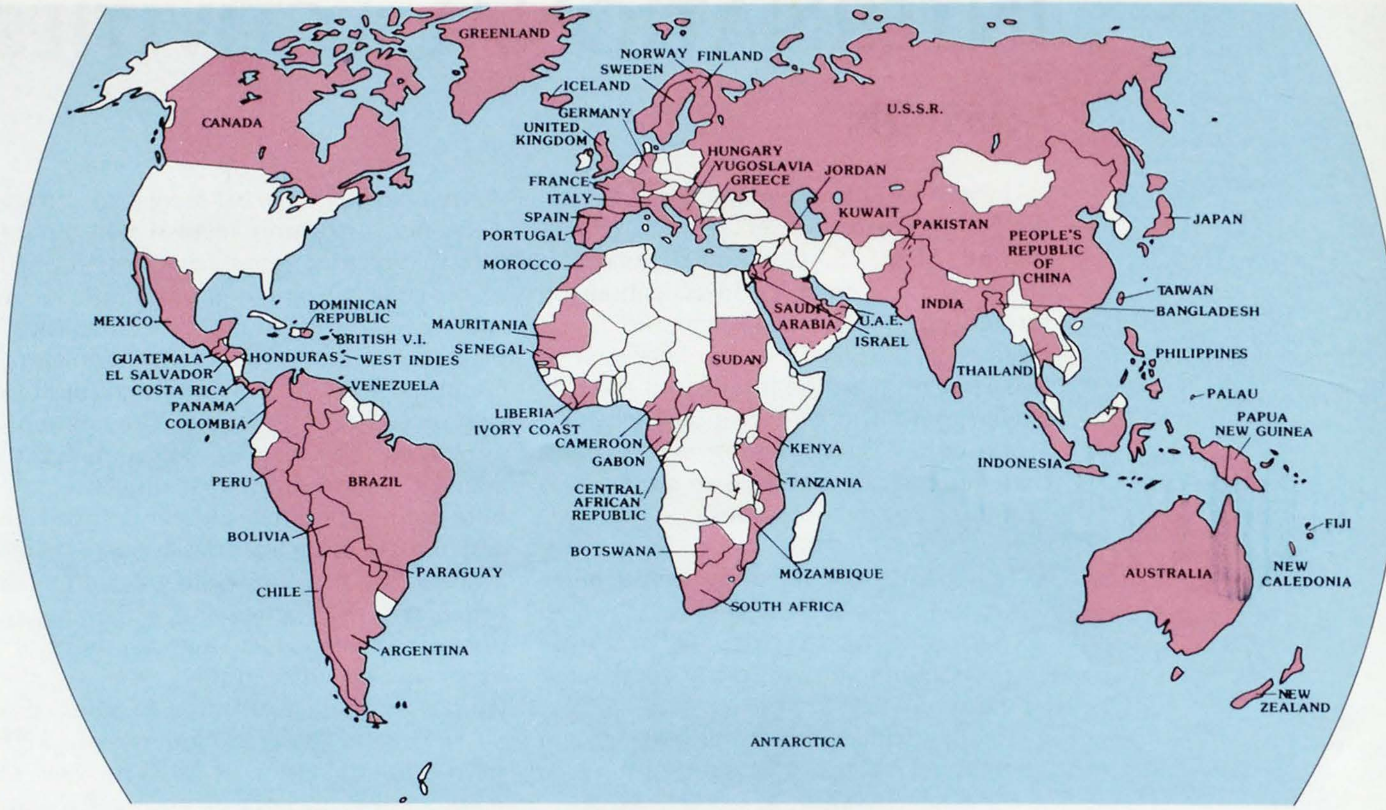


Figure 1. *Countries with whom the U.S. Geological Survey carried on international programs in fiscal year 1986.*

Table 1. *International scientific activities conducted by the U.S. Geological Survey in fiscal year 1986*

Country or region	Activity
	Technical Assistance Activities
Bangladesh	Planning for institutional modernization in the Geological Survey of Bangladesh; training of chemists.
Cameroon	Geologic program review and recommendations; investigation of toxic gas explosion of Lake Nyos.
Circum-Pacific	Earthquake and tsunami potential
Colombia	Nevado del Ruiz volcano disaster response; earthquake monitoring and hazards mitigation; Orinoco River sediment studies.
Costa Rica	Coal, mineral, and geothermal energy resources assessments; transport and bioavailability of toxic metals in rivers.
East Asia	U.S. Government representation at United Nations (U.N.) regional meetings in Thailand and China; participation in volcanological hazards course in Indonesia sponsored by the U.N. Educational, Scientific and Cultural Organization; participation in U.N. course in Indonesia on economic aspects of coal exploration, evaluation, and exploitation; participation in petroleum resources assessment workshop in Malaysia; participation in U.N. workshop in Thailand on fertilizer minerals; earthquake hazard mitigation program for Southeast Asia.
El Salvador	Earthquake hazards reduction
Fiji	Study of coastal sediment distribution
Gabon	Geologic investigation of Moanda manganese mine
Guatemala	Earthquake hazards reduction

Table 1. *International scientific activities conducted by the U.S. Geological Survey in fiscal year 1986*—Continued

Country or region	Activity
Technical Assistance Activities	
Honduras	Geothermal energy resources assessment
Hungary	Basin analysis and petroleum exploration research
Indonesia	Volcanic monitoring and research; marine geology and geophysics; proposal for national coal resources management system.
Italy	Seismic and volcanic monitoring
Jordan	Seismic network; computer systems; oil shale assessment; ground-water modeling
Kenya	Regional remote sensing facility; Landsat imagery; map publication
Kuwait	Sand and gravel resources assessment project definition
Latin America	Organization and participation in workshop on gold deposit modeling, Brazil; volcano early warning disaster assistance.
Liberia	Gold and diamond resources assessment project definition
Mauritania	Mineral and energy resources assessment project definition
Mexico	Cerro Prieto geothermal energy program
Morocco	Landsat base-map compilation; mineral deposit assessment; geophysical investigations
Mozambique	Mineral resources assessment review and recommendation; geologic and cartographic program definition; training and institutional development.
Pakistan	Coal resources assessment; national planning for coal exploration, geodata center, and coal analytical laboratory system; participation in First Pakistan National Coal Conference.
Palau	Gold resources assessment
Panama	Earthquake mitigation; geologic mapping, mineral resources exploration, and training program definition.
Papua New Guinea	Mineral resources data systems and assessment; Bairaman River landslide dam consultancy.
Paraguay	Hydrologic hazards related to floods
Peru	Mineral resources assessment
Philippines	Mineral deposit modeling workshop and symposium
Saudi Arabia	Geologic mapping and mineral resources assessment; hydrologic studies; Landsat image base maps; seismic studies.
South Pacific	Hydrocarbon resources studies of cruise data from Tonga, Vanuatu, Solomon Islands, and Papua New Guinea; U.S. Government representation at U.N. regional meeting in Solomon Islands; coastal mapping workshop.
Sudan	Landsat base-map compilation; map publications
Taiwan	Land subsidence investigations
Thailand	Coal resources assessment program definition
United Arab Emirates	Water resources reconnaissance of Abu Dhabi; marine geology and environmental geochemistry program definition.
Venezuela	Sediment studies of Orinoco River; mineral resources assessment project definition; seismic consultancy.
West Indies	Streamflow and stream-sediment studies
Worldwide	Global Seismic Network; hydrologic training course; remote sensing workshop
Scientific Cooperative Activities	
Antarctica	Topographic and satellite image mapping; marine geologic and geophysical surveys; mineral resources studies; seismic studies; geodesy; glaciology.
Argentina	Seismic studies
Australia	Antarctic research; tectonics and resources studies of South Pacific
Bolivia	Seismic studies
Botswana	Seismic studies
Brazil	Technology transfer in remote sensing; mineral resources assessment workshop; seismic studies; sink-hole studies.
British Virgin Islands	Geologic examinations and geochemical sampling

Table 1. *International scientific activities conducted by the U.S. Geological Survey in fiscal year 1986*—Continued

	Scientific Cooperative Activities
Canada	Strategic minerals inventory; deep-ocean sulfide mineral deposit studies; deep crustal studies; Great Lakes seismic reflection profiles; borehole geophysics; cartographic data exchange; thematic mapping; geographic information systems; remote sensing; water resources studies; strong-motion studies; geomagnetic studies; acid rain studies; lake eutrophication; sea ice studies.
Central African Republic	Seismic studies
Chile	Earthquake studies
Circum-Pacific	Coordination of compilations for geologic, tectonic, mineral resources, and energy resources maps; cartographic and thematic design, drafting, and preparation of maps for publication.
Costa Rica	Limnology of high-altitude tropical forest lakes
Dominican Republic	Offshore insular shelf studies
East Asia	Preparation of base map at 1:2,000,000 scale in eight sheets covering a total area of approximately 12 million square miles; pilot study of circum-Borneo sedimentary basin analysis.
Federal Republic of Germany	Strategic minerals inventory; marine seismic studies of continental margins; radioactive waste; petroleum resources assessment; Antarctic research; marine minerals research; sea ice studies.
Finland	Mineral resources data systems exchange
France	Marine hydrothermal mineralogy; geophysical and geochemical studies; sediment transport studies; radioactive waste studies; marine data-base software development; sea ice studies; remote sensing in polar regions.
Greece	Geochemistry of petroleum; structural geology studies
Greenland	Airborne radar soundings
Hungary	Seismic stratigraphy; seismic modeling; electromagnetic, mineralogic, paleomagnetic, and paleoenvironmental studies.
Iceland	Volcanic, geothermal, and glacial studies
India	Science and technology review for possible cooperative program development; coal basin analysis and coal resources assessment workshop; seismic studies.
Indonesia	Pilot study of peat resources potential in Sumatra; study of chromite sands
Israel	Stable isotope geochemistry of sedimentary phosphate deposits
Italy	Volcanology; marine geology; mathematical modeling of estuarine flow
Ivory Coast	Seismic studies
Japan	Joint panels on earthquake prediction, wind and seismic effects, marine geology, and marine mining; ore deposit research; seismically induced landslide studies; debris flow and mudflow studies; digital cartographic development exchange.
Latin America	Technical support for Pan American Institute of Geography and History; satellite mapping project definition; mapping standards and multilingual terms.
Mexico	Seismology and seismic risk assessment; base-map compilation of U.S. border area
New Caledonia	Study of chromite sands
New Zealand	Antarctic research
Norway	Watershed geochemistry; fulvic and humic acid research; sea ice studies
Paraguay	Seismic studies
People's Republic of China	Surveying, mapping, and geographic information systems; surface-water hydrologic studies; isotope hydrology; China digital seismic network; Beijing digital seismic network computer system; magnetic and deformation observations; crustal stress measurements; intraplate active faults and earthquakes; fault zone xenoliths; landslide and debris flow studies; ophiolites; Paleozoic-Mesozoic boundary; paleomagnetism of Proterozoic rocks of China; strata-bound copper deposits; geochronology of minerals of China; geochronology of mineral deposits; antimony and mercury deposits; pyrophyllite deposits.
Philippines	Study of chromite sands
Portugal	Massive sulfide studies; remote sensing
Senegal	Paleontologic studies
South Africa	Strategic minerals inventory; seismic studies
Spain	Ground-water geochemistry and flow systems; remote sensing for mineral deposits; earthquake research; marine geology and oceanography of continental margins; water resources management for reducing environmental pollution; epithermal gold-alunite deposits; hydrogeochemical processes in the Canary Islands; sampling and observation networks; Almaden-type mercury deposits.

Table 1. *International scientific activities conducted by the U.S. Geological Survey in fiscal year 1986*—Continued

	Scientific Cooperative Activities
Sweden	Subsurface contaminant migration
Tanzania	Seismic studies; testing of local fertilizer materials
United Kingdom	Marine geology, GLORIA sonar mapping; world coal resources; strategic minerals inventory; digital cartographic development exchange; Antarctic research; sea ice studies.
U.S.S.R.	Joint committee on earthquake prediction
Yugoslavia	Soil condition and soil structure; seismology and earthquake hazards; geochemical surveys; granite-metamorphic complexes; ground-water modeling project definition; soil sciences project definition; mineral nitrogen in ground water, soils, and plants; coal resources project definition; agrohydrology; geophysical research in coal mines.
Worldwide	International Strategic Minerals Inventory; World Energy Resources Program; Global Seismic Network.

International Agrogeology Activities

The "green revolution" now taking place in many developing countries has placed new importance on the field of agrogeology. In recognition of this importance, the Geological Survey has begun field studies and seminars on discovering agricultural minerals such as phosphate and zeolite and research on economical direct applications of those minerals as fertilizer. Although new hybrid crops can provide the increased productivity needed to break the cycles of famine brought on by continued population growth and climatic variability, most farmers in developing countries cannot afford the fertilizers needed to maintain those crops. To be affordable, fertilizers must be produced locally or at least regionally. Geological Survey researchers have devised a method of applying locally available unprocessed rock phosphate directly as fertilizer. Rapid plant growth is supported by the sustained release of phosphorous, and the quick solution and flushing from the soil common to chemical fertilizers do not occur. Tests show that applying ammoniated zeolite with rock phosphate results in greater plant productivity and reduced costs; the method is thus very attractive to developing countries. Results of this research into a generally neglected aspect of the "green revolution" were presented at a meeting on "Agrogeology in Eastern and Southern Africa," held June 23 through 27, 1986, in Zomba, Malawi.

In a related study, Geological Survey and Yugoslav scientists are evaluating a method whereby the large amounts of liquid waste generated in commercial hog-feeding lots in Slovenia can be absorbed by natural zeolite and then used as fertilizer. At present, these wastes have no use and constitute a major environmental problem. Also in Yugoslavia, the Geological Survey and the U.S. Department of Agriculture are participating in an interdisciplinary study of the possible relation between high levels of nitrate and nitrite in ground water and the occurrence of endemic kidney disease. Similar high levels of nitrate and nitrite occur locally in the United States, apparently caused by the flushing of ammonia from chemical fertilizer.

Geological Survey scientists advised the Government of Mauritania on agricultural minerals as part of a review of a national plan to combat the advance of the desert. Field agricultural trials used local rock phosphate as fertilizer and peat to increase the organic content of the soil; agricultural lime and gypsum resources were also evaluated.

Geologic Hazards

Colombia

On November 13, 1985, Nevado del Ruiz volcano in central Colombia erupted, killing an estimated 22,000 people. The volcanic eruption triggered numerous mudflows, one of which inundated the town of Armero, about 50 miles west of Bogota.

The Geological Survey was requested by the Government of Colombia and the Office of Foreign Disaster Assistance (OFDA) of the U.S. Agency for International Development (AID) to provide technical assistance in response to this disaster; within 3 days, a seven-man team and volcano monitoring equipment were at the site. Within a week, the Survey team had deployed telemetered seismographs to relay immediate readings to the scientists and several electronic distance-measuring (EDM) reflectors to measure deformation of the volcano's shape. Ten days after the eruption, a team of three Survey scientists evaluated the debris flow hazard at the volcano and installed a telemetered detector to help provide early warning of flood waters or mudflows moving downstream.

Survey and Colombian scientists and university teams from the United States and other countries had seismic and ground networks operating effectively within 1 month; five telemetered seismograph stations, four telemetered tiltmeters, and several EDM lines were also installed. The Survey provided continous staffing and additional equipment until early February 1986, when the Survey agreed with AID/OFDA to effect an orderly transfer of equipment to the Colombians and to provide training and guidance to ensure its optimum use. The Survey assisted the Colombians in establishing a volcanological observatory at Manizales, which now serves as a focal point for monitoring Ruiz and other volcanoes. Japan, Canada, and Switzerland also provided monitoring equipment and staffing support to the observatory.

As an outgrowth of the Colombia disaster response, an agreement was signed by the Survey and AID/OFDA in August 1986 to establish the five-year Interagency Volcano Early Warning Disaster Assistance Program. Assisted during the first phase by technical services and support from the Smithsonian Institution, the Survey will establish a program capable of providing rapid, cost-effective technical emergency repsonse and assistance for actual or potential volcano crises in Latin America. The need for such a program has been demonstrated by recent volcano disasters at Tacana and El Chichon in Mexico, Ruiz in Colombia, Rabaul in Papua New Guinea, and Mayon in the Philippines.

Cameroon

More than 1,500 people were killed and 300 injured on August 21, 1986, when a lethal gas burst occurred in Lake Nyos in northwestern Cameroon. A cloud of carbon dioxide containing apparently minor amounts of hydrogen sulfide and related compounds infiltrated at least three villages (Nyos, Subum, and Cha). A gas cloud of similar origin killed 37 people at nearby Lake Manous on August 15, 1984.

Lake Nyos, approximately 200 miles northwest of the capitol of Yaounde, is in a basaltic maar crater of prehistoric but Holocene age (10,000 years ago), one of at least 30 volcanic crater lakes in the 1-million- to 10,000-year-old Cameroon volcanic line. These volcanoes are part of a chain of vents that follows a tectonically active zone of crustal weakness extending from the island of Pagalu in the Atlantic Ocean northeastward through Cameroon and part of Nigeria.

The Geological Survey, at the request of AID/OFDA, sent one volcanologist and two geochemists to evaluate the disaster. Two limnologists from Brown and Duke Universities, two representatives from the Environmental Protection Agency, and two forensic medical experts from the United States also investigated the disaster. Geological Survey scientists are analyzing field information and samples to determine the cause of the gas ebullition and to recommend methods for assessing the risks of such a disaster recurring at Lake Nyos, at similar lakes in Cameroon, or elsewhere.

Energy and Mineral Resources Studies

The Geological Survey conducts research on foreign energy and mineral resources to expand the basis for assessing domestic energy and mineral resource potential and to determine the availability of foreign resources for satisfying U.S. and world needs. During 1986, Survey scientists:

- Continued studies of foreign petroleum resources through the World Energy Resources Program and reported on the petroleum potential of the Baltic Basin and several basins in China and South Asia.
- Continued to coordinate the International Strategic Mineral Inventory (ISMI) and published ISMI reports on nickel and platinum. Geoscience organ-

izations from Canada, the United Kingdom, West Germany, Australia, and South Africa provide data and collaborate in this worldwide compilation of the major sources for strategic minerals.

- At the request of local governments, the Department of State, and AID and in support of U.S. foreign policy objectives, conducted reconnaissance studies of manganese in Gabon, titanium sands in Mozambique and Mauritania, nickel and platinum in Morocco, sulfide deposits in Japan, and gold and other minerals in Costa Rica, Liberia, Palau, and Papua New Guinea.
- In cooperation with the U.S. Bureau of Mines, provided field training and orientation consultations in the United States and in foreign countries for Regional Resources Officers and Minerals Reporting Officers from U.S. Embassies around the world and advised and assisted various offices in the Department of State that are the principal users of this mineral and energy resources information.
- Undertook an assessment of the coal resources potential in Pakistan under an agreement with AID and in cooperation with the Geological Survey of Pakistan. A National Coal Exploration Plan, which summarized known resources both locally and regionally and evaluated present and projected coal demands, use, and exploration requirements, was developed and presented to the Government of Pakistan for use in formulating the Pakistan Seventh Five-Year Plan. An in-depth review of the coal analytical laboratory system recommended that it be extensively upgraded and strengthened to ensure accurate, reliable, and internationally comparable analytical results. A similar review of the national geodata center recommended its regeneration and overall strengthening to function as a repository for data nationwide. First-year activities in the assessment of coal resources in southern Sind Province produced a project work plan, a coal exploration drilling plan, specifications of contract for a coal exploration drilling company, compilation of base maps and available coal resources data, collection of 40 coal samples for laboratory analyses, preliminary geologic mapping, and stratigraphic and geophysical records of three exploratory core holes that indicate basin-edge interfingering of marine and continental environments.
- Conducted a mineral resource assessment in Costa Rica, supported financially by AID and in cooperation with the Central American School of Geology of the University of Costa Rica, the General Directorate of Geology, Mines, and Hydrocarbons in the Ministry of Industry, Energy, and Mines of Costa Rica, and the Los Alamos National Laboratory. Maps produced during the investigations show gravity, aeromagnetics, terrane, volcanic framework, vein-sample locations, known mineral localities, and domains favorable for mineral deposits. On the basis of domain maps and tonnage and grade models, additional investigations are recommended to search for undiscovered mineral deposits in a number of areas. Detailed and regional geologic mapping integrated with available geologic, geophysical, and geochemical information and newly derived modeling studies in the Cordillera de Tilaran-Montes de Aguacate gold area improved understanding of the overall controls for the origin of gold ore. This knowledge can be used to search for extensions of the known gold district as well as for concealed gold deposits in areas of similar geology.
- Also funded by AID and in cooperation with Los Alamos National Laboratory, evaluated geothermal areas in Costa Rica and Honduras with counterparts from the respective national electric companies. Additional studies have been recommended for two volcanic areas in Costa Rica—Rincon de la Vieja and El Tenorio—that have the potential for geothermal development. Geochemical study of thermal fluids having temperatures of 120 °C in the St. Ignacio area of Honduras indicates that the site is favorable for geothermal development, even though the fluids are from a sedimentary rock reservoir rather than being associated with a recent volcano.

Hydrology and Hydrogeology Studies

Technical assistance in hydrology was extended by Water Resources Division personnel in fiscal year 1986 to 13 foreign nations, primarily in Africa, the Mideast, and the Caribbean region. Activities ranged from hydrologic hazards evaluations (toxic gases from Lake Nyos in Cameroon, mudflows from Nevado del Ruiz volcano in Colombia, and flooding on the Parana and Paraguay Rivers in Paraguay) to consultation and assistance in water resources data collection and analysis (water-quality modeling in the People's Republic of China, sediment studies in the Orinoco River in Venezuela, and water resources reconnaissance of Abu Dhabi in the United Arab Emirates).

Scientific cooperation with scientists from at least 15 nations included studies of hydrologic systems or conditions not readily available in the United States, the scientific results of which contribute directly to the understanding and resolution of domestic water resources problems (for example, mudflow studies in Japan, geochemistry of regional ground-water flow systems in Spain, and lake eutrophication in Canada). Other cooperative projects were undertaken to support the missions of other Federal agencies (for example, airborne radar ice sounding in Greenland, evaluation of nitrogen in ground water in Yugoslavia, and marginal sea ice studies in the Arctic).

Visiting scientists from New Zealand and China also participated in year-long hydrologic research projects in the United States, including studies on the effect of fluid production from hot-water wells on thermal features and mathematical modeling of sediment transport in harbors and estuaries.

U.S. domestic water programs have and will continue to accrue significant benefits from the scientific knowledge gained from these cooperative efforts. In particular, the availability of a unique 2,500-year record of extreme hydrologic events in China and the opportunity to study sediment transport in the Yellow River, the world's most sediment-laden river, will significantly enhance our hydrologic knowledge and ability to resolve domestic water problems.

Topographic and Geographic Mapping

A protocol on scientific and technical cooperation in surveying and mapping studies was signed by the Geological Survey and the National Bureau of Surveying and Mapping (NBSM) of the People's Republic of China in April 1985. The first meeting of a Joint Working Group was held in Beijing in August 1985 to develop work plans. In 1986, the NBSM conducted a functional requirements study for a geographic information system design and sent five people to the United States to study geographic information systems at the Geological Survey and other Federal agencies. The NBSM subsequently drafted a requirements document showing the planned system configuration that was reviewed by the NBSM and the USGS. Appropriate computer equipment and programs were evaluated, and personnel were exchanged to study data acquisition, map feature classification, and data-base management.

The NBSM also sent experts to the United States to study remote sensing equipment, facilities, and operations, and the Survey sent representatives to China to discuss project implementation techniques and equipment requirements. Comparative projects using the Black Hills area in the United States and the Ningxiang area in China were also begun. The project work emphasized applications of digital image processing for mapping, map revision, and thematic maps.

Antarctic Surveying and Mapping

Surveying and mapping are two of the many activities necessary for the National Science Foundation's successful operation of its multifaceted scientific and exploration effort in Antarctica. For the twentieth year, Survey personnel performed seasonal fieldwork to obtain geodetic control data and aerial photography in support of earth, biologic, and mapping sciences. Year-round data acquisition, cataloging, and data dissemination activities continued in the Scientific Committee for Antarctic Research Library for Geodesy and Cartography, which is maintained by the Survey. A topographic reconnaissance map covering 25,000 square miles was published during the fiscal year and provides a base for displaying scientific information in a spatially accurate manner, for planning future expeditions, and for conducting search and rescue missions.

Application of Remote Sensing Techniques

The Geological Survey has expanded its mapping program in Antarctica to include the use of colored, digitally enhanced Landsat multispectral scanner (MSS) images to increase existing map coverage and to improve upon previously published Landsat maps. The first product—a digitally enhanced mosaic image of the McMurdo Sound region (fig. 2)—covers four complete and two partial 1:250,000-scale topographic quadrangles and shows rock and ice in much more detail than previously compiled black-and-white paper-print mosaics of the region do.

In addition to providing maps, digitally processed Landsat images should play an important part in solving a variety of Antarctic research problems. Special-purpose images have been prepared showing bedrock or ice features only (fig. 3); maps made from such images will be used to locate specific types of ice or rock for research purposes. Identifying these features in remote areas saves time and money because of the difficulties in reaching these areas on the ground. Special-purpose images may also show blue ice areas, which are significant because most of the approximately

Figure 2. *False-color multispectral digital mosaic of the McMurdo Sound region in Lambert conformal conic projection. Ross Island (A) is topped by Mount Erebus (B), an active volcano. McMurdo Station on the island is located at the tip of a fingerlike peninsula extending toward the southwest (C). Ice-free valleys in the center of image are the Dry Valleys (D).*

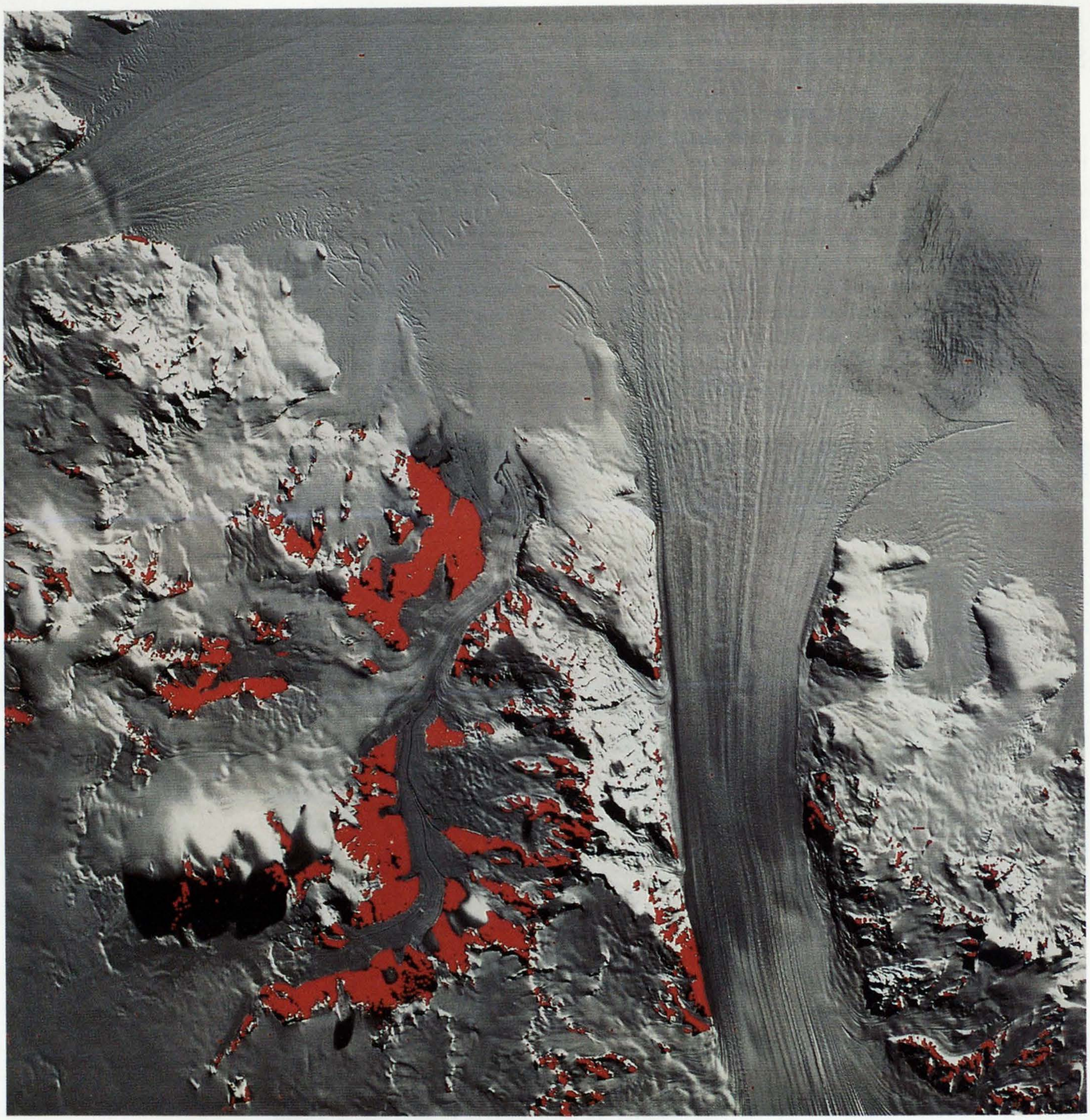


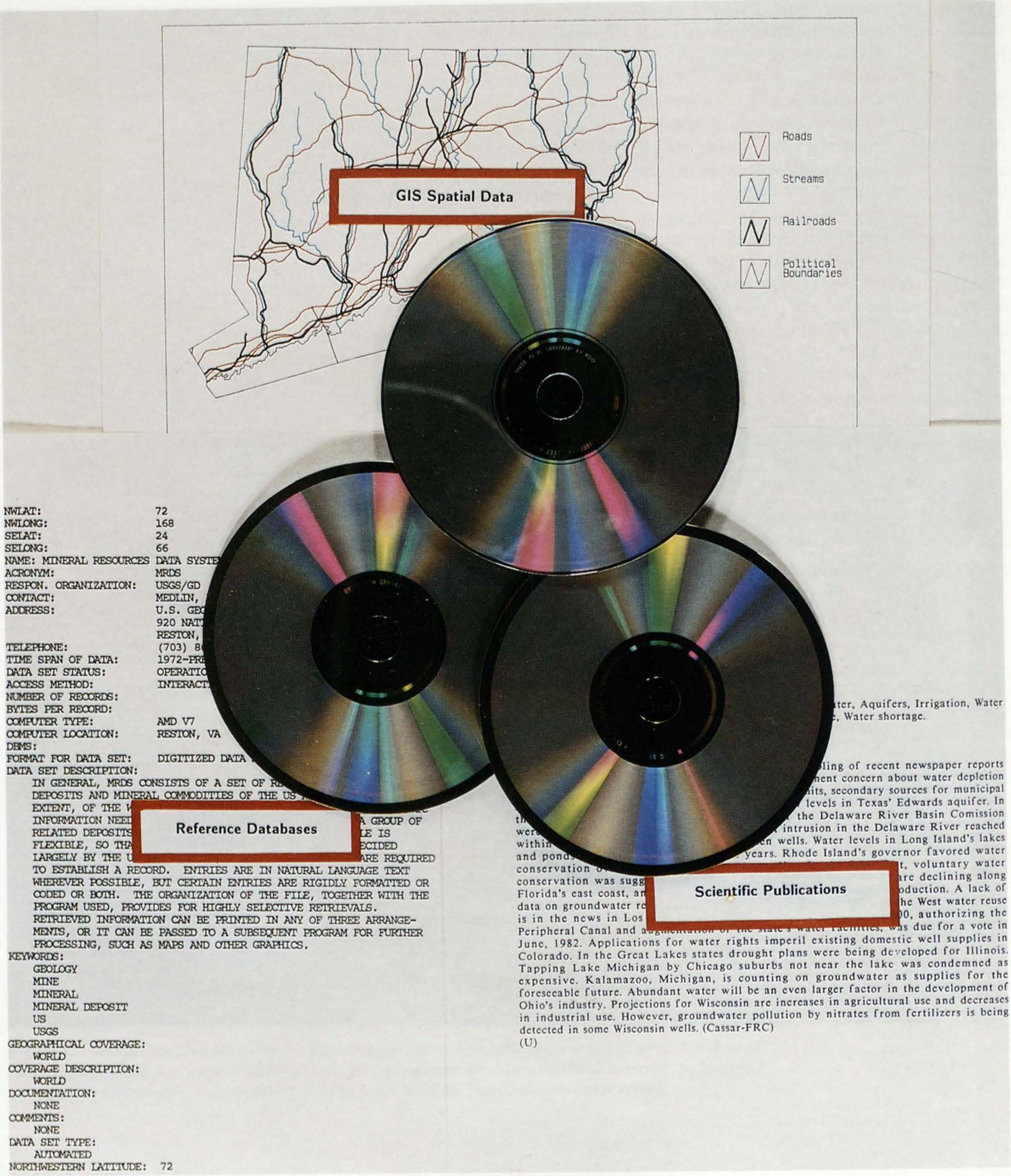
Figure 3. *Special-purpose image of the Byrd Glacier region highlighting areas of soil or rock exposure (red). Diffused light and dark areas in the top right of the image are clouds and their shadows. Isolated red spots on the glaciers (the smooth-looking upper portion of the image) are computer errors.*

6,000 meteorite fragments (25 percent of the total found on Earth) found in Antarctica have been in blue ice areas.

Digitally enhanced images show ice rises, flow lines on ice streams and ice shelves, and buried mountain ranges more clearly than previous images do, and linear scarps and ancient valleys are clearly reflected on ice surfaces in places.

Because distinctive flow and crevasse features in floating parts of ice streams and outlet glaciers remain visible just below their grounding zones for many years, imaging the same area twice over an interval of several years yields time-lapse measurements of glacier velocity to a first order of accuracy. This technique offers a rapid, cost-effective method of obtaining average velocities of many ice streams and outlet glaciers near their termini.

A cooperative project with the Norsk Polarinstitutt of Norway was set up to analyze digitally enhanced Thematic Mapper (TM) images of an area in Queen Maud Land. These images have a ground resolution of about 100 feet, three times better than the resolution of MSS images. Discrimination between clouds and snow is also better in TM near-medium infrared-wavelength bands than it is in bands of MSS, which are in visible and near-infrared wavelengths. These TM bands also reveal splotchy markings on the snow, which are not observed in visible wavelengths and which may be caused by variations in grain size. The excellent resolution of these images makes them a valuble tool for expeditions doing traverse planning.



CD ROM technology, a revolutionary new way to distribute earth-science data. (Design by Marti Quigley and E.J. McFaul, U.S. Geological Survey; photograph by William Dize, U.S. Geological Survey.)

INFORMATION SYSTEMS DIVISION

MISSION

The Information Systems Division provides support and advice to the Director of the U.S. Geological Survey, the Divisions of the Geological Survey, the Department of the Interior, and other Government agencies on matters relating to information technology and automated data processing (ADP). It provides these computer services for users of large-scale general-purpose computers and smaller special-purpose computers. The Division assists users in acquiring ADP and telecommunications equipment and software, coordinates and improves information systems through system analysis and design, and conducts research into better ways to use data-processing technology to solve mission-related problems. The Division is responsible for managing all voice, data, and radio communications in the Geological Survey.

BUDGET AND PERSONNEL

The Division had a budget of $15.9 million for fiscal year 1986, which was funded by providing services to other Geological Survey Divisions, to the Department of the Interior, and to other Federal agencies. Division staffing consisted of 148 full-time employees, primarily computer specialists, computer analysts, mathematicians, computer scientists, systems programmers, and computer technicians. Part-time and intermittent employees and contract computer operations personnel assisted in fulfilling the mission of the Division. These employees served customers through four ADP service centers located in Denver, Colo., Menlo Park, Calif., Flagstaff, Ariz., and Reston, Va.

CURRENT ACTIVITIES

In fiscal year 1986, the Division, assisted by other Divisions of the Geological Survey, substantially enlarged the Earth Science Data Directory, an automated system for improving access to earth-science information. The directory contains information about earth-science data bases maintained by State and Federal agencies and nongovernmental entities.

The Division assisted in establishing a telecommunications plan that provides a comprehensive, cost-effective, unified approach to voice and data telecommunications services within the Geological Survey. The plan supports and links diverse program elements through the management of a nationwide data communications network called GEONET.

In addition, the Division was involved in other activities such as the Reston Service Center, geographic information systems, and bureauwide personnel administrative systems.

HIGHLIGHTS

Earth Science Data Directory

By C.R. Baskin

The Earth Science Data Directory is a computerized catalog of approximately 800 references for sources of earth-science and natural resources data. Maintained on a mainframe computer in Reston, Va., the directory is accessible through a variety of computer terminals and is extremely easy to use. A number of search routines can be used to locate references.

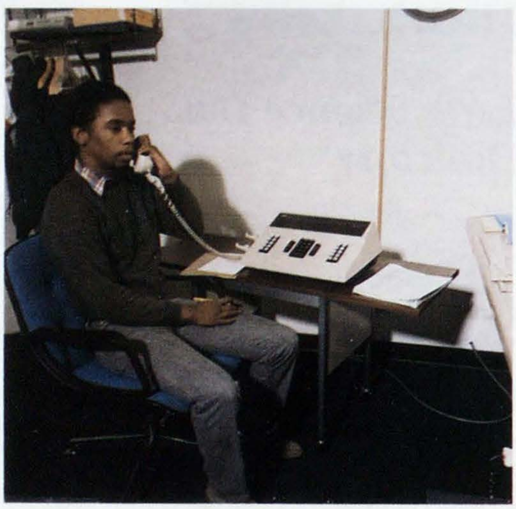
During fiscal year 1986, agencies from 36 States either entered or agreed to enter references to their data into the directory. In addition to the Geological Survey, 13 Federal agencies provided directory references, and some references were received from nongovernmental sources. Users of the directory included people from 20 Geological Survey sites, 24 State agencies, several other Federal agencies, other State and local agencies, and the private sector.

Telecommunications

By Telecommunications Services

The Geological Survey implemented a telecommunications system to meet the growing demand for voice and data communications. A computerized voice/data telephone system was installed in Reston,

Ambidextrous skills helped at the Geological Survey's old switchboard.



The new answering console: simplified yet superior.

Va.; installation of a similar system was begun in Menlo Park, Calif.; and a nationwide communications network called GEONET was acquired. These changes in the telecommunications system have significantly affected the way in which the Geological Survey performs its mission.

Installation of the new telephone system, called the computerized branch exchange, involved rewiring the Reston and Menlo Park facilities, installing more than 5,000 telephones, training employees to use the system, and testing to ensure that the system fulfilled the needs of its users. Features available on the system include speed dialing, call forwarding, automatic call back, call pickup, call waiting, phone mail, and conference calling. The standard black telephones were replaced by multifunction touch-tone telephones, but the more striking change took place in the communication center, where electronic switches replaced mechanical relays.

The new system is a fully automatic digital telephone switching system that has access to the Federal Telecommunications System (FTS), Division service centers, and GEONET, the Department of the Interior's nationwide data communications network. GEONET provides ready access to more than 100 Geological Survey computers throughout the United States and to several public networks. GEONET links computers of the Geological Survey with those operated by the Fish and Wildlife Service, the National Park Service, the Minerals Management Service, the Bureau of Mines, the Bureau of Reclamation, and the Department's Office of the Solicitor. The network is also used by the Bureau of Land Management and the Office of Surface Mining.

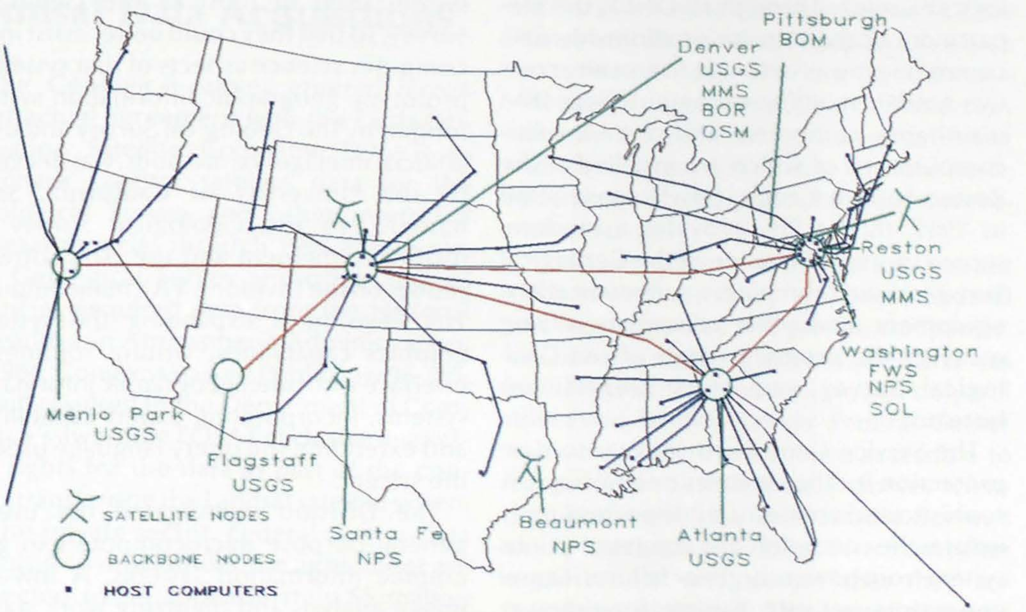
More than 4,000 people use GEONET each month, initiating a quarter of a million computer sessions, transmitting about 2 billion characters of data, and logging approximately 46,000 hours of network time.

GEONET operation is monitored around the clock by a vendor-owned, vendor-operated network control center, which is responsible for keeping GEONET in an operational status 24 hours a day, 7 days a week. That responsibility includes maintaining GEONET hardware and coordinating with local telephone companies to keep telephone circuits in an operating condition.

Reston Service Center

By Theodore J. Herrman and Thomas J. Faulds

The Information Systems Division Service Center in Reston, Va., provides large-scale computing resources for the scientific, technical, and administrative staffs of the Geo-



GEONET, the Department of Interior-Geological Survey telecommunications service using state-of-the-art packet switching technology. Blue lines indicate links between host computer locations and backbone nodes. Red lines indicate backbone node links. SOL, Office of the Solicitor; FWS, Fish and Wildlife Service; MMS, Minerals Management Service; NPS, National Park Service; BOM, Bureau of Mines; BOR, Bureau of Reclamation; OSM, Office of Surface Mining; USGS, U.S. Geological Survey.

Network Control Center in Malvern, Pa., is manned 24 hours a day by Tymnet technicians in support of GEONET.

logical Survey. Through GEONET, the Department of the Interior's nationwide data communications network, users can access two Amdahl mainframe computers, an IBM mainframe computer, and a VAX minicomputer, all of which are installed at the Reston Service Center. Newly constructed in 1985, this facility provides a modern, secure location for some of the Geological Survey's shared computers, communications equipment, and other computers serving many of the program needs of the Geological Survey and other Department bureaus.

The Service Center provides up-to-date protection for the electronic equipment. A sophisticated uninterruptible power supply isolates the computers and communications system from power surges or failures. Diesel generators activate during long power failures to ensure stable, continuous operation. During fiscal year 1986, the Amdahl computers were upgraded and are now controlled by new operating systems. Fiber-optic cables connect the computers to high-speed laser printers that can produce quality graphics, and modern magnetic disk technology provides 50 billion bytes of online storage. Comprehensive security software protects the computers and the data from unauthorized access; the tape library is automatically controlled to provide protection against accidental erasure; and new communications links permit easy and reliable transmission of data between mainframes and microcomputers. Large volumes of printed output can be directed to high-speed printers, while higher quality printing can be handled by laser printers.

Contributions to Geographic Information Systems

By Richard A. MacDonald

A geographic information system is an integrated set of computer hardware and software that is used to acquire, store, analyze, and display digital spatial data. The Division assisted the program Divisions in geographic information system activities and undertook some initiatives of its own in fiscal year 1986. Division personnel were trained to use the geographic information system used in most of the Geological Survey, so that they could better assist in the computer science aspects of that system. A prototype geographic information system, funded by the Geological Survey and using artificial intelligence methods, was delivered by the University of California, Santa Barbara, to the Geological Survey for further refinement and use. This software resides on the Division's VAX minicomputer. The Division is expanding the system's graphics capabilities, writing routines to interface with other geographic information systems, incorporating expert capabilities, and extending the query language used by the system.

The Division investigated the use of general-purpose microcomputers in geographic information systems. A low-cost image analysis and digitizing work station was assembled from hardware and software components generally available in the marketplace. Principal elements of the system were a microcomputer having an expansion interface, a digitizing tablet, a video scanner, a high-resolution color monitor, and software for image enhancement and analysis.

Because geographic information systems perform many calculations, they function poorly on conventional computer systems. The Division investigated the use of concurrent processors as possible candidates for processing geographic information system data. During fiscal year 1986, Division employees received training and spent time processing a Geological Survey system on a parallel processor. Tests indicated that this technology is promising for use in geographic information systems.

Working with microcomputers and various software systems led to investigating data exchange capabilities among software packages and among data bases. Translation programs were developed to allow transfer of data from one processing system to another. One set of programs translates data from the source system to a common file format, while a second set translates data to a target system format from the common file format.

The Division continued to research new technologies to support the massive storage requirements of geographic information systems. Two promising systems using optical storage devices were developed as prototypes. Compact Disc-Read Only Memory was tested as a low-cost method of distributing geographic information systems data. An inexpensive reader similar to the audio compact disc players used in music systems is connected to a personal computer and used to access a disc containing up to 540 megabytes of data. Readers were distributed to a number of offices in the Geological Survey, along with a prototype disc containing files of earth-science data.

The second prototype system used a different technology. A Write Once Read Many optical disc system can record data as well as read it. The prototype study examined the efficiency and economics of using optical storage devices for archiving data. The optical storage unit was connected to the Division minicomputer in Denver, Colo. Seismic data stored on magnetic tapes were written into the Write Once Read Many system to ensure more accurate data for greater periods of time and faster retrieval of data kept in a smaller storage area.

Personnel Administrative Systems

By Larry C. Harms

The Division began several prototype bureauwide personnel administrative systems in fiscal year 1986. The Automated SF-52 system, the Vacancy Announcement system, and the Paypers Query system were all developed on the Amdahl computer system by using the Model 204 Data Base Management system. The SF-52 system will allow Geological Survey Divisions and personnel offices to electronically create, approve, and route personnel actions nationwide. The Vacancy Announcement system will enable the Survey to electronically create and mail vacancy announcements nationwide. The Paypers Query system will provide a central source of personnel information for the entire bureau. The success of these activities will facilitate the automation of other personnel activities such as position descriptions.

ADMINISTRATION

MISSION

The Administrative Division provides administrative direction and coordination for the support service aspects of the scientific, research, and technical programs of the U.S. Geological Survey. The administrative services include financial management, personnel services, procurement, property and space management, management analysis and improvement, safety and occupational health, and administrative systems management.

BUDGET AND PERSONNEL

The cost of the central administrative services provided by the Administrative Division totaled about $26 million in fiscal year 1986. Division staffing consisted of about 430 employees, located primarily at the Reston, Va., headquarters and at two Regional Management Offices in Denver, Colo., and Menlo Park, Calif.

HIGHLIGHTS

Volunteer for Science Program

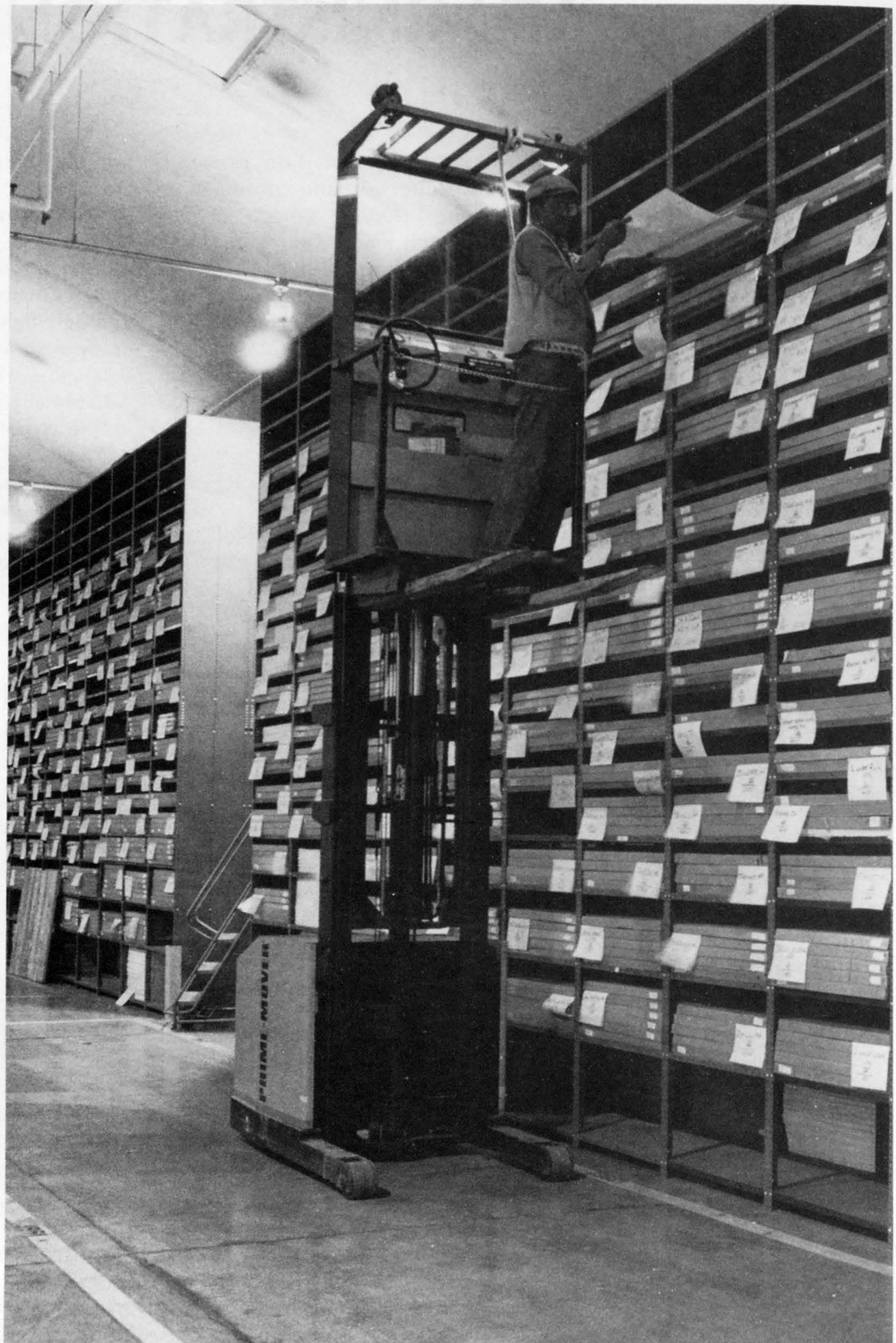
During fiscal year 1986, the Geological Survey launched its Volunteer for Science Program, a service-oriented program designed to accept volunteer services from individuals or groups interested in science and public service. The Volunteer for Science Program relates directly to the national "Take Pride in America" campaign, which, among other things, encourages citizens to become more knowledgeable and careful about public land use and fosters responsibility and respect for the Nation's natural resources.

The Geological Survey's Volunteer for Science Program received immediate bureau, academic, and community support and interest. During the program's first three months, program coordinators and a bureauwide network of key individuals enlisted about 55 volunteers, who provided services in library research, hydrologic and geologic field assistance, laboratory work, computer assistance, procurement assistance, and administrative clerical support. Additionally, over 300 citizens, concentrated in the San Francisco area of California, volunteered to collect rainfall data for landslide hazard studies. The Geological Survey expects increased participation during fiscal year 1987 and development of a quality corps of volunteers, who will make significant contributions to our mission.

Streamlined Personnel Processing

As part of a continuing effort to improve administrative practices, the Geological Survey reviewed its personnel processing system and identified actions that could streamline those processes and save manpower and dollars. Efforts are now underway to increase automation, eliminate duplication, increase delegations of authority to managers, and increase standardization in personnel documentation. In support of the President's Management Improvement Program and the Department of the Interior's Reform 88 management initiatives, action has been taken to automate Personnel Action Requests and vacancy announcements in fiscal year 1986. The automated Personnel Action Request system will be a prototype for application throughout the Department of the Interior. Efforts are also in progress to increase the use of standardized position descriptions, performance standards, and job selection factors and to identify and eliminate duplication of personnel recordkeeping and systems through expanded direct access to the integrated payroll-personnel system.

U.S. Geological Survey National Center in Reston, Va. (Photograph by William Dize, U.S. Geological Survey.)



Consolidation of warehouse activities at Building 810 in Denver has allowed the Geological Survey to increase the efficiency of map and book distribution. The new facility offers more space, a more centralized distribution point, and the opportunity to use improved storage and shipping techniques.

Landsat Data Acquisitions

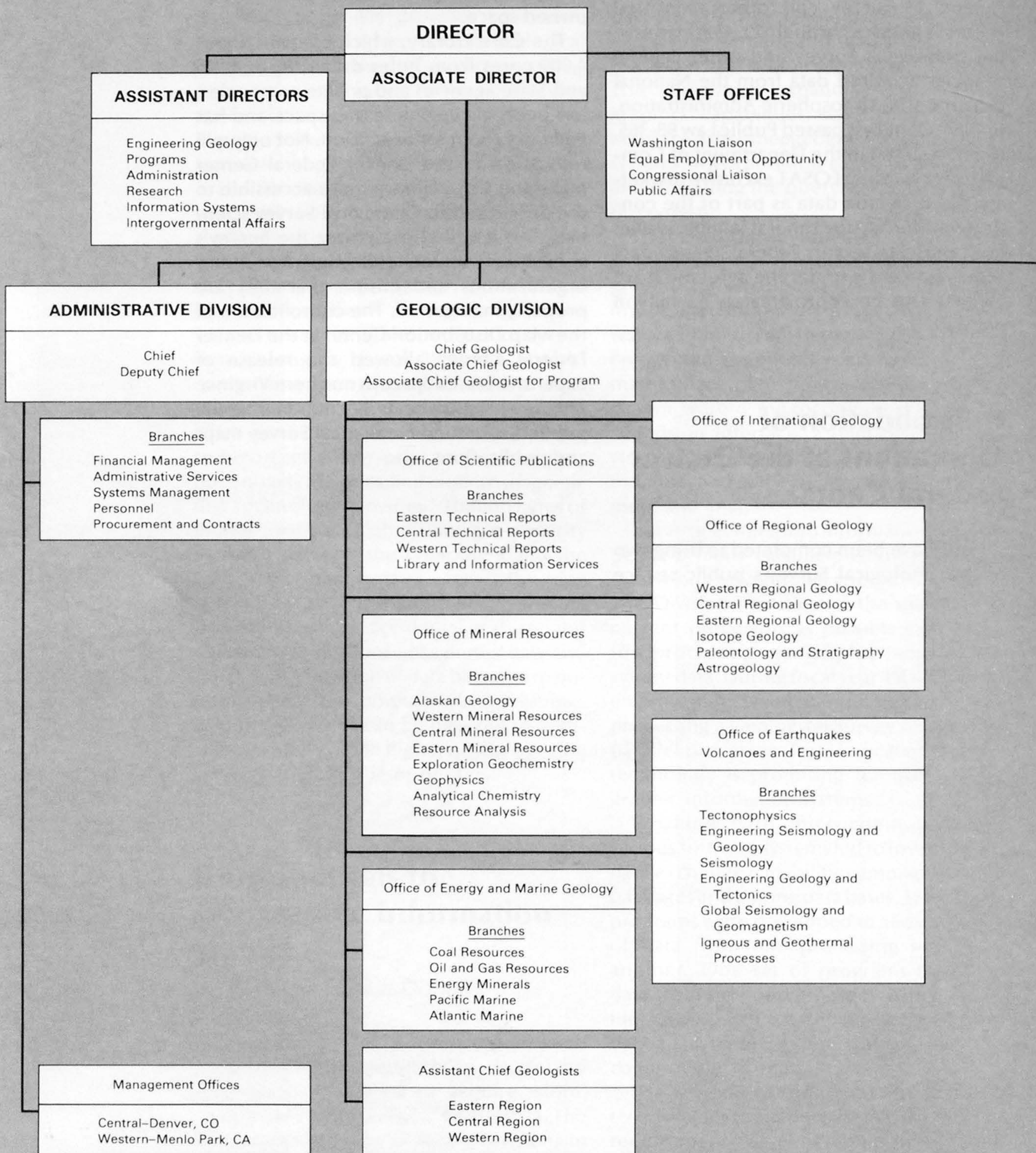
The Geological Survey entered into a contractual agreement with the Earth Observation Satellite Company (EOSAT) to purchase Landsat satellite data for the Geological Survey and other interested Federal agencies through 1994. Previously, the Geological Survey and other Federal agencies acquired data from the National Oceanic and Atmospheric Administration. In 1984, Congress passed Public Law 98-365, which resulted in the Department of Commerce's awarding EOSAT exclusive marketing rights for the data as part of the contract transferring the Landsat satellite system to the private sector. Federal agency data acquisition costs under the agreement are expected to be approximately $5 million per year.

Consolidation of Operations at the Denver Federal Center

Plans have been completed to bring two of the Geological Survey's public service organizations—the Geologic Division's Core Library and the National Mapping Division's consolidated Map Distribution Center—into the Denver Federal Center. This action not only reduces costs but also is consistent with Government initiatives to move more Federal agency operations into Government-owned space.

The Core Library, which contains about 4,900 cores from holes drilled by Federal and State agencies and private companies, has been occupying leased space and has had little room for expansion. Not only will relocation to the Denver Federal Center make the Core Library more accessible to the public and to Geological Survey scientists, but it will also increase the Survey's ability to accept rock collections from other organizations and ensure that they are properly maintained. The consolidation of the Map Distribution Center at the Denver Federal Center allowed the release of expensive leased space in northern Virginia. The newly consolidated center will be the public's source of Geological Survey maps and publications.

ORGANIZATION OF THE GEOLOGICAL SURVEY
U.S. Department of the Interior



Organizational Data

INFORMATION SYSTEMS DIVISION

Chief
Associate Chief

Policy Planning and Coordination

Office of Management Services

Branches
- Management Information
- Budget and Administration

Office of Customer Services

Branches
- Applied Technology
- Acquisition Support
- Technology Assessment
- Technology Information

Office of Computer and Communication Services

Branches
- Communication Services
- Computer Services

Office of Field Services

- Denver Service Center
- Menlo Service Center
- Flagstaff Service Center

NATIONAL MAPPING DIVISION

Chief
Associate Chief

Assistant Division Chief for Research

Offices
- Geographic and Cartographic Research
- Systems and Techniques Development

Assistant Division Chief for Plans and Operations

Offices
- Program Management
- Plans and Coordination
- International Activities

Assistant Division Chief for Information and Data Services

Offices
- Product Distribution Policy
- Publications Liaison and Review
- National Cartographic and Geographic Information Service
- Public Inquiries

Field Centers

- Eastern Mapping–Reston, VA
- Mid-Continent Mapping–Rolla, MO
- Printing and Distribution–Reston, VA
- Rocky Mountain Mapping–Denver, CO
- Western Mapping–Menlo Park, CA
- EROS Data –Sioux Falls, SD

WATER RESOURCES DIVISION

Chief Hydrologist
Associate Chief Hydrologist

Assistant Chief Hydrologist for Scientific Information Management

Assistant Chief Hydrologist for Operations

Assistant Chief Hydrologist for Research and External Coordination

Offices
- Hydrologic Research
- External Research
- Water Data Coordination

Assistant Chief Hydrologist for Program Coordination and Technical Support

Offices
- Ground Water
- Water Quality
- Surface Water
- Atmospheric Deposition Analysis
- National Water Summary and Long-Range Planning

Regional Offices

- Northeastern–Reston, VA
- Southeastern–Atlanta, GA
- Central–Denver, CO
- Western–Menlo Park, CA

District Offices

U.S. Geological Survey Offices

Headquarters Offices
12201 Sunrise Valley Drive
National Center, Reston, VA 22092

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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. 7343, 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 Management Applications	Edmund J. Grant	(703) 648-4191	National Center, Stop 107
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	Box 25046, Stop 406, Denver Federal Center, Denver, CO 80225
Director's Representative—Western Region	George Gryc	(415) 323-8111 ext. 2711	345 Middlefield Rd., Stop 144, Menlo Park, CA 94025
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
Staff Assistant (Special Issues)	Harold Mattraw	(703) 648-7413	National Center, Stop 121
Special Assistant to the Director for Alaska	Philip A. Emery	(907) 271-4398 or (907) 263-7429	Gould Hall—APU Campus, University Drive, Anchorage, AK 99504
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
Geologic Division			
Chief Geologist	Robert M. Hamilton	(703) 648-6600	National Center, Stop 911
Associate Chief Geologist	William F. Cannon	(703) 648-6601	National Center, Stop 911
Assistant Chief Geologist for Program	Benjamin A. Morgan	(703) 648-6640	National Center, Stop 911
Deputy Chief Geologist for Scientific Personnel	Penelope M. Hanshaw	(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	Eugene H. Roseboom, Jr.	(703) 648-6959	National Center, Stop 908
Office of Earthquakes, Volcanoes, and Engineering, Chief	John R. Filson	(703) 648-6714	National Center, Stop 905
Office of Energy and Marine Geology, Chief	Gary W. Hill, Acting	(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

Office	Name	Telephone Number	Address
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Chief Hydrologist	Philip Cohen	(703) 648-5215	National Center, Stop 409
Associate Chief Hydrologist	Robert C. Averett	(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 Research and External Coordination	Marshall M. Moss	(703) 648-5041	National Center, Stop 436
Assistant Chief Hydrologist for Program Coordination and Technical Support	John N. Fischer	(703) 648-5229	National Center, Stop 414
Assistant Chief Hydrologist for Operations	William B. Mann IV	(703) 648-5031	National Center, Stop 441
Office of Hydrologic Research, Chief	Roger G. Wolff	(703) 648-5043	National Center, Stop 436
Office of Water Data Coordination, Chief, Acting	Donald K. Leifeste	(703) 648-5016	National Center, Stop 417
Office of External Research, Chief, Acting	Marshall M. Moss	(703) 648-5042	National Center, Stop 436
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	Verne R. Schneider	(703) 648-5301	National Center, Stop 415
Office of Water Quality, Chief, Acting	David A. Rickert	(703) 648-6862	National Center, Stop 412
Office of National Water Summary and Long-Range Planning, Chief	David W. Moody	(703) 648-6856	National Center, Stop 407
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, Acting	Virginia L. Ross	(703) 648-7178	National Center, Stop 805
Office of Computer and Communications Services	Vacant	(703) 648-7157	National Center, Stop 807
Office of Management Services	Wendy A. Budd	(703) 648-7103	National Center, Stop 802
Office of Field Services	Fred B. Sower	(303) 236-4944	Denver Federal Center
Administrative Division			
Chief	Jack J. Stassi	(703) 648-7200	National Center, Stop 201
Administrative Operations Officer	Timothy Calkins	(703) 648-7204	National Center, Stop 203
Branch of Personnel, Chief	Maxine C. Millard	(703) 648-7442	National Center, Stop 215
Branch of Procurement and Contracts, Chief	Paul A. Denett	(703) 648-7373	National Center, Stop 205
Branch of Financial Management, Chief	Roy Heinbuch	(703) 648-7604	National Center, Stop 270
Branch of Administrative Services, Chief	William F. Gossman, Jr.	(703) 648-7338	National Center, Stop 207
Branch of Systems Management, Chief	Phillip L. McKinney	(703) 648-7256	National Center, Stop 206
Selected Field Offices			
National Mapping Division			
Regional Centers			
Eastern	K. Eric Anderson	(703) 648-6002	National Center, Stop 567
Mid-Continent	Lawrence H. Borgerding	(314) 341-0880	1400 Independence Rd., Rolla, MO 65401
Rocky Mountain	Merle E. Southern	(303) 844-5825	Box 25046, Stop 510, Federal Center, Denver, CO 80225
Western	John R. Swinnerton	(415) 323-8111, ext. 2411	345 Middlefield Rd., Menlo Park, CA 94025
Printing and Distribution	Vacant	(703) 648-5181	National Center, Stop 580
Public Inquiries Offices			
Alaska	Elizabeth C. Behrendt	(907) 561-5555	Room 101, 4230 University Dr., Anchorage, AK 99508-4664
		(907) 271-4307	E-146 Federal Bldg., Box 53, 701 C St., Anchorage, AK 99513

Office	Name	Telephone Number	Address
California:			
Los Angeles	Lucy E. Birdsall	(213) 894-2850	7638 Federal Bldg., 300 N. Los Angeles St., Los Angeles, CA 90012
Menlo Park	Bruce S. Deam	(415) 323-8111, ext. 2817	345 Middlefield Rd., Stop 533, Bldg. 3, Menlo Park, CA 94025
San Francisco	Patricia A. Shiffer	(415) 556-5627	504 Customhouse, 555 Battery St., San Francisco, CA 94111
Colorado	Irene V. Shy	(303) 844-4169	169 Federal Bldg., 1961 Stout St., Denver, CO 80294
District of Columbia	Bruce A. Hubbard	(202) 343-8073	1028 GSA Bldg., 18th and F Sts., NW., Washington, DC 20405
Texas	John P. Donnelly	(214) 767-0198	1C45 Federal Bldg., 1100 Commerce St., Dallas, TX 75242
Utah	Wendy R. Hassibe	(801) 524-5652	8105 Federal Bldg., 125 S. State St., Salt Lake City, UT 84138
Virginia	Margaret E. Counce	(703) 648-6892	1C402, National Center, Stop 503
Washington	Jean E. Flechel	(509) 456-2524	678 U.S. Courthouse, W. 920 Riverside Ave., Spokane, WA 99201
Distribution Branch Offices			
Alaska	Natalie Cornforth	(907) 456-0244	101 12th Ave., Box 12, Fairbanks, AK 99701
Colorado	Dwight F. Canfield	(303) 236-7477	Box 25286, Stop 306, Denver Federal Center, Denver, CO 80225
Earth Resources Observation Systems Data Center			
South Dakota	Allen H. Watkins	(605) 594-6123	EROS Data Center, Sioux Falls, SD 57198

Geologic Division

Regional Offices

Office	Name	Telephone Number	Address
Eastern	Jack H. Medlin	(703) 648-6660	National Center, Stop 953
Central	Harry A. Tourtelot	(303) 236-5438	Box 25046, Stop 911, Denver Federal Center, Denver, CO 80225
Western	Carroll A. Hodges	(415) 323-8111 ext. 2214	345 Middlefield Rd., Stop 19, Menlo Park, CA 94025

Water Resources Division

Regional Offices

Office	Name	Telephone Number	Address
Northeastern	Stanley P. Sauer	(703) 648-5817	National Center, Stop 433
Southeastern	James L. Cook	(404) 221-5174	Richard B. Russell Federal Bldg., 75 Spring St., SW., Suite 772, Atlanta, GA 30303
Central	James F. Blakely	(303) 236-5920	Box 25046, Stop 406, Denver Federal Center, Denver, CO 80225

Office	Name	Telephone Number	Address
Western	John T. Conomos	(415) 323-8111, ext. 2337	345 Middlefield Rd., Stop 470, Menlo Park, CA 94025
District Offices			
Alabama	Vacant	(205) 752-8104	520 19th Ave., Tuscaloosa, AL 35401
Alaska	Philip A. Emery	(907) 271-4138	4320 University Dr., Suite 201, Anchorage, AK 99508
Arizona	Robert D. Mac Nish	(602) 629-6671	Federal Bldg., 300 W. Congress St., Tucson, AZ 85701
Arkansas	Ector E. Gann	(501) 378-6391	2301 Federal Office Bldg., 700 W. Capital Ave., Little Rock, AR 72201
California	John M. Klein	(916) 978-4633	Room W-2235, Federal Bldg., 2800 Cottage Way, Sacramento, CA 95825
Colorado	Charles A. Pascale	(303) 236-4882	Box 25046, Stop 415, Denver Federal Center, Denver, CO 80225
Connecticut (*See* Massachusetts)			
Delaware (*See* Maryland)			
District of Columbia (*See* Maryland)			
Florida	Irwin H. Kantrowitz	(904) 681-7620	227 North Bronough St., Suite 3015, Tallahassee, FL 32301
Georgia	Jeffrey T. Armbruster	(404) 221-4858	6481 Peachtree Industrial Blvd., Suite B, Doraville, GA 30360
Hawaii	J. David Camp, Acting	(808) 541-2653	P.O. Box 50166, 300 Ala Moana Blvd., Rm 6110, Honolulu, HI 96850
Idaho	Ernest F. Hubbard, Jr.	(208) 334-1750	230 Collins Rd., Boise, ID 83702
Illinois	Larry G. Toler	(217) 398-5353	Champaign County Bank Plaza, 102 E. Main St., 4th Floor, Urbana, IL 61801
Indiana	Dennis K. Stewart	(317) 927-8640	6023 Guion Rd., Suite 201, Indianapolis, IN 46254
Iowa	Richard A. Engberg	(319) 337-4191	P.O. Box 1230, Room 269, Federal Bldg., 400 S. Clinton St., Iowa City, IA 52244
Kansas	Joseph S. Rosenshein	(913) 864-4321	1950 Constant Ave., Campus West, University of Kansas, Lawrence, KS 66044
Kentucky	Alfred L. Knight	(502) 582-5241	572 Federal Bldg., 600 Federal Pl., Louisville, KY 40202
Louisiana	Darwin D. Knochenmus	(504) 389-0281	P.O. Box 66492, 6554 Florida Blvd., Baton Rouge, LA 70806
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) 223-2822	150 Causeway St., Suite 1309, Boston, MA 02114
Michigan	T. Ray Cummings	(517) 377-1608	6520 Mercantile Way, Suite 5, Lansing, MI 48910
Minnesota	Donald R. Albin	(612) 725-7841	702 Post Office Bldg., St. Paul, MN 55101

Office	Name	Telephone Number	Address
Mississippi	Andrew G. Lamonds, Acting	(601) 960-4600	Suite 710 Federal Bldg., 100 West Capitol St., Jackson, MS 39269
Missouri	Daniel P. Bauer	(314) 341-0824	1400 Independence Rd., Stop 200, Rolla, MO 65401
Montana	Joe A. Moreland	(406) 449-5302	428 Federal Bldg., 301 South Park Ave., Drawer 10076, Helena, MT 59626
Nebraska	William M. Kastner	(402) 471-5082	406 Federal Bldg., 100 Centennial Mall, North, Lincoln, NE 68508
Nevada (*See* Idaho)			
New Hampshire (*See* Massachusetts)			
New Jersey	Donald E. Vaupel	(609) 771-0065	Suite 206, Mountain View Office Park, 810 Bear Tavern Rd., West Trenton, NJ 08628
New Mexico	Robert L. Knutilla	(505) 766-2246	Western Bank Bldg., Rm. 720, 505 Marquette, NW., Albuquerque, NM 87102
New York	Lawrence A. Martens	(518) 472-3107	P.O. 1669, 343 U.S. Post Office and Courthouse, Albany, NY 12201
North Carolina	James F. Turner	(919) 856-4510	P.O. Box 2857, Rm. 436, Century Postal Station, 300 Fayetteville Street Mall, Raleigh, NC 27602
North Dakota	L. Grady Moore	(701) 255-4011, ext. 601	821 East Interstate Ave., Bismarck, ND 58501
Ohio	Steven M. Hindall	(614) 469-5553	975 West 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	Ferdinand Quinones-Marquez	(809) 783-4660	GPO Box 4424, Bldg. 652, GSA Center, San Juan, PR 00936
Rhode Island (*See* Massachusetts)			
South Carolina	Rodney N. Cherry	(803) 765-5966	Suite 658, 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	Larry R. Hayes	(615) 251-5424	A-413 Federal Bldg., U.S. Courthouse, Nashville, TN 37203
Texas	Charles W. Boning	(512) 482-5766	649 Federal Bldg., 300 E. 8th St., Austin, TX 78701
Utah	Russell W. Cruff, Acting	(801) 524-5663	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

Office	Name	Telephone Number	Address
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	Richard M. Bloyd	(307) 772-2153	P.O. Box 1125, 2120 Capital Ave., Rm. 4004, Cheyenne, WY 82003

Administrative Division

Regional Management Offices

Central	George A. Honold	(303) 236-5900	Box 25046, Stop 201, Denver Federal Center, Denver, CO 80225
Western	George F. Hargrove, Jr.	(415) 323-8111	345 Middlefield Rd., Stop 211, Menlo Park, CA 94025

Guide to Information and Publications

Throughout this report, reference has been made to information services and publications of the U.S. Geological Survey. During fiscal year 1986, the Survey produced over 6,078 new and revised topographic, hydrologic, and geologic maps; printed 15,043,050 copies of 6,078 different maps; distributed 6,346,266 copies of maps; and sold 5,285,320 copies for $8,567,898. The number of reports approved for publication by the Geological Survey in fiscal year 1986 was 4,698, with 68 percent designated for publication in professional journals and monographs outside the Survey and the remainder scheduled for publication by the Survey. In addition, 154,900 copies of technical reports were distributed, of which 50,360 copies were sold for $198,261, and 1,025 open-file reports were released, of which 27,606 copies were sold for $269,439.

To buy maps of all areas of the United States and to request Survey catalogs, pamphlets, and leaflets (limited quantities free), write or visit:

U.S. Geological Survey
Office and Customer Services Section
Federal Center, Box 25286
Denver, CO 80225

To buy Alaskan 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 Survey book publications, to request Survey circulars, or to obtain information on the availability of microfiche or paper-duplicate copies of open-file reports, write:

Publications and Open-File Services Section
Federal Center, Box 25425
Denver, CO 80225

To get on the mailing list for the monthly list of New Publications of the Geological Survey (free), write:

U.S. Geological Survey
Computer Operations Office
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.
Box 53
701 C St.
Anchorage, AK 99513

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

Bldg. 3, Stop 533
345 Middlefield Rd.
Menlo Park, CA 94025

504 Customhouse
555 Battery St.
San Francisco, CA 94111

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

Texas:
1C45 Federal Bldg.
1100 Commerce St.
Dallas, TX 75242

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

Washington, DC:
1028 General Services Admin. Bldg.
18th and F Sts., NW.
Washington, DC 20405

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:
Western Mapping Center
National Cartographic Information Center
345 Middlefield Rd.
Menlo Park, CA 94025

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

Mississippi:
National Space Technology Laboratories
National Cartographic Information Center
U.S. Geological Survey
Bldg. 3101
NSTL Station, MS 39529

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

Virginia:
National Cartographic Information Center

507 National Center
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 specific data, write:

U.S. Geological Survey
National Water Data Exchange
421 National Center
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
417 National Center
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
419 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

To obtain information on geology topics such as earthquakes, energy and mineral resources, the geology of specific areas, and geologic maps and mapping, write:

U.S. Geological Survey
Geologic Inquiries Group
907 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

Cooperators and Other Financial Contributors

Cooperators listed are those with whom the U.S. Geological Survey had a written agreement cosigned by Survey officials and the cooperating agency for financial cooperation in fiscal year 1986. 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 with whom the Geological Survey has research contracts and to whom it supplied research funds are not listed.

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

State, County, and Local Cooperators

Alabama:

Alabama Department of—Environmental Management (w), Highways (w); Alabama Surface Mining Commission (w); Autauga County Commission (w); Birmingham, City of (w); Coffee County Commission (w); Dauphin Island (w); Geological Survey of Alabama (g,n,w); Heflin, City of (w); Huntsville, City of (w); Jefferson County Commission (w); Montgomery, City of (w); Tuscaloosa, City of (w); University of Alabama (w)

Alaska:

Alaska Department of—Fish and Game (w), Natural Resources (n), Division of—Geological and Geophysical Surveys (w), Mining and Geology (g), 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 Community Planning (w), Department of Solid Waste Services (w), Water and Wastewater Service (w); Dillingham, 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); Wasilla, City of (w)

American Samoa: (See Hawaii)

Arizona:

Arizona Bureau of Geology and Mineral Technology (g); Arizona Department of—Health Services, Bureau of Water Quality Control (w), Water Resources (w); Arizona Stateland Dept. (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); Salt River Valley Water Users Association (w); San Carlos Irrigation and Drainage District (w); Show Low Irrigation Company (w); Tucson, City of (w); University of Arizona Board of Regents (w); Arizona Municipal Water Users Association (w)

Arkansas:

Arkansas Department of—Parks and Tourism (w), Pollution Control and Ecology (w); Arkansas Soil and Water Conservation Commission (w); Arkansas Geological Commission (g,n,w); Arkansas State Highway and Transportation Department (w); Arkansas-Oklahoma: Arkansas River Compact Commission (w)

California:

Alameda County—Flood Control and Water Conservation District (Hayward) (w), Flood Control and Water Conservation District, Zone 7 (Pleasanton) (w), Water District (w); Antelope Valley—East Kern Water Agency (w); Calaveras County Water District (w); California Coastal Conservancy (w); California Department of—Boating and Waterways (g,w), Conservation (g), Health Services (w), Parks and Recreation (w), Water Resources—Central District (Sacramento) (w), Northern District (Red Bluff) (w), San Joaquin District (Fresno) (w); California Office of Emergency Services (n); California Water Resources Control Board (w); Carpinteria County Water District (w); Casitas Municipal Water District (w); Coachella Valley Water District (w); Contra Costa County 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); El Dorado, County of (w); Fresno Metropolitan Flood Control District (w); Georgetown Divide Public Utility District (w); Goleta County 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); Jurupa Community SVCS District (w); Kern County Water Agency (w); Kings River Conservation District (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); Modoc County Department of Public Works (w); Mojave Water Agency (w); Montecito County Water District (w); Monterey County Flood Control and Water Conservation District (w); Nevada Irrigation District (w); Newport Beach, City of (w); Oakdale-South San Joaquin Irrigation District (w); Orange County—Environmental Management Agency (w), Water District (w); Oroville-Wyandotte Irrigation District (w); Pacheo Pass Water District (w); Pacific Gas and Electric Company (w); Pacific Power and Light Company (w); Paradise Irrigation District (w); Placer County Water Agency (Foresthill) (w); Rainbow Municipal Water District (w); Rancho California Water District (w); Regional Water Quality—Lahonton Region (w); Riverside County Flood Control and Water Conservation District (w); Rock Creek Limited Partnership (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 Diego County Water Authority (w); San Francisco, City and County of, Hetch Hetchy Water and Power (w); San Francisco Water Department (w); San Luis Obispo County Engineering Department (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 County Flood Control and Water Conservation District (w); Santa Maria Valley Water Conservation District (w); Scotts Valley Water District (w); Shape Energy Development Corporation (w); Siskiyou County Flood Control and Water Conservation District (w); Sonoma County—Planning Department (w), Water Agency (w); Southern California Edison Company (w); Tahoe Regional Planning (w); Terra Bella Irrigation District (w); Tulare County Flood Control District (w); Tuolumne, County of (w); Turlock Irrigation District (w); United Water Conservation District (w); University of California—Berkeley (g), Cooperative Extension (w); Ventura County Public Works Agency (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); Boulder, County of, Department of Public Works (w); Breckenridge, Town of (w); Castle Rock, Town of (w); Cherokee Water and Sanitation District (w);

Cherry Creek Basin Authority (w); Colorado Department of—Health (w), Highways (g), Natural Resources (w); Colorado Division of—Mined Land Reclamation (w), Water Resources, Office of the State Engineer (w); Colorado Geological Survey (w); Colorado River Water Conservation District (w); Colorado Springs, City of—Department of Public Utilities (w), Office of the City Manager (w); Delta County Board of County Commissioners (w); Denver, City and County, Board of Water Commissioners (w); Denver Regional Council of Governments (w); Dolores Water Conservancy District (w); Douglas, County of (w); Eagle County Board of Commissioners (w); Englewood, City of, Bi-City Wastewater Treatment Plant (w); Evergreen Metro 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); Kiowa-Bijou Ground Water Management District (w); Larimer-Weld Regional Council of Governments (w); Longmont, City of (w); Lost Creek Ground Water Management District (w); Lower Fountain Water-Quality Management Association (w); Metropolitan Denver Sewage Disposal District No. 1 (w); Mineral, County of (w); Moffat County Commissioners (w); Northern Colorado Water Conservancy 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 West Metropolitan District (w); Purgatoire River Water Conservancy District (w); Rio Blanco County Board of County Commissioners (w); Rio Grande Water Conservation District (w); St.Charles Mesa Water District (w); Southeastern Colorado Water Conservancy District (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 Yampa Water Conservancy District (w); Urban Drainage and Flood Control District (w); Water Users No. 1 (Rangely) (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); Simsbury, Town of (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)

Florida:

Big Cypress Basin Board (w); Boca Raton, City of (w); Bradenton, City of (w); Brevard County, Board of County Commissioners (w); Broward County—Environmental Quality Control Board (w), Utility Division (w), Water Resources Management Division (w); Cape Coral, City of (w); Clearwater, City of (w); Collier, County of (w); Collier Mosquito Control District (w); Cocoa, City of (w); Coordinating Council on the Restoration of Kissimmee River Valley and Taylor Creek-Nubbins Slough Basin (w); Daytona Beach, City of (w); Englewood Water District Board of Supervisors (w); Escambia County Board of County Commissioners (w); Flagler County Board of County Commissioners (w); Florida Department of—Environmental Regulation, Bureau of Water Resources Management (w), Division of Recreation and Parks (Hope Sound) (w), Division of Recreation and Parks (Tallahassee) (w), Natural Resources (n), Division of Marine Resources (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); Gainesville, City of (w); Hallandale, City of (w); Henory, County of (w); Highland Beach, Town of (w); Hillsborough, County of (w); Hollywood, City of (w); Indian River, County of (w); Jacksonville, City of (w); Jacksonville, Consolidated City of, Department of Health and Environmental Services (w); Jacksonville Electric Authority—Production Engineering Division (w), Research and Environmental Affairs (w); Jacksonville Plan Department (w); Jacksonville Beach, City of (w); Juno Beach, Town of (w); Jupiter Inlet District (w); Lake County—Board of County Commissioners (w), Pollution Control Department (w); Lee County, Board of County Commissioners (w); Leon County—Courthouse (w), Department of Public Works (w); Manatee County Board of County Commissioners (w); Marion County Board of County Commissioners (w); Metropolitan Dade County Department of Environment Resources Management (w); Miami-Dade Water and Sewer Authority (w); Northwest Florida Water Management District (w); Old Plantation Water Control District (w); Orange County Board of County Commissioners (w); Palm Beach County—Board of County Commissioners (w), Solid Waste Authority (w); Pasco, County of, Utilities Department (w); Perry, City of (w); Pinellas, County of (w); Plant City, City 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); Sanibel, City of (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); Stuart, City of (w); Sumter County Recreation and Water Conservation and Control Authority (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); Tampa, City of (w); University of Central Florida (w); University of Florida, Center for Wetlands (w); Walton, County of (w); West Coast Regional Water Supply Authority (w); Winter Park, City of (w)

Georgia:

Albany, City of, Water, Gas, and Light Commission (w); Bibb County Board of County Commissioners (w); Brunswick, City of (w); Clayton County Water Authority (w); Consolidated Government of Columbus (w); Covington, City of (w); Georgia Department of—Natural Resources—Environmental Protection Division, Water Management Branch (w), Geological Survey (n,w); Transportation (w)—Materials and Research (w); Helena, City of (w); Macon-Bibb County Water and Sewage Authority (w); Moultree, City of (w); Thomaston, City of (w); Thomasville, City of (w); Valdosta, City of (w)

Guam: (See Hawaii)

Hawaii:

American Samoa, Government of (g,n,w); Guam, Government of (w); Hawaii Department of—Health (w), Land and Natural Resources, Division of Water and Land Development (g,w), Transportation (w); Honolulu, City and County of, Board of Water Supply (w); Trust Territory of the Pacific Islands—Federated States of Micronesia (w)—State of Kosrae (w), State of Ponape (w), State of Truk (w), State of Yap (w); Northern Mariana Islands, Government of (w); Republic of Palau (w)

Idaho:

Idaho Department of—Fish and Game (w), Health and Welfare (w), Lands (n), Natural Resources (n), Water Resources (w); Idaho Geological Survey (g); Middleton, City of (w); Orofino, City of (w); Shoshone, County of (w); Sun Valley Water and Sewer District (w); Teton County Board of Commissioners (w); The Shoshone-Bannock

Tribes, Fort Hall Indian Reservation (w); University of Idaho (w); Water District No. 01 (Idaho Falls) (w); West Cassia Soil and Water Conservation District (w)

Illinois:
AVM Lockport Division of Water Resources (w); Bloomington and Normal Sanitary District (w); Cook County Forest Preserve District (w); Decatur, City of (w); DuPage County Public Works (w); Illinois Department of—Energy and Natural Resources, State Water Survey Division (w), Nuclear Safety (w), Transportation, Division of Highways (n), Division of Water Resources (n,w); Illinois Environmental Protection Agency (w); Illinois State Geological Survey (g,n), Water Survey Division (w); Metropolitan Sanitary District of Greater Chicago (w); Springfield, City of (w); University of Chicago (g)

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

Iowa:
Carroll, County of, Health Department (w); Cedar Rapids, City of (w); Charles, City of (w); Clear Lake, City of (w); Des Moines, City of (w), Water Works (w); Fort Dodge, City of (w); Gutherie, County of, 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), Hygenic Laboratory (w), Physical Plant (w); Sioux City, City of (w); Union Electric Company (w); Waterloo, City of (w)

Kansas:
Arkansas River Compact Administration (w); Hays, City of (w); Kansas Department of—Health and Environment (w), Transportation (w); Kansas Geological Survey (n,w); Kansas State Board of Agriculture, Division of Water Resources (w); Kansas Water Office (w); Sedgwick, County of (w); Southwest Kansas Ground Water Management District No. 3 (w); Western Kansas Ground Water Management District No. I (w); Wichita, City of (w)

Kentucky:
Elizabethtown, City of (w); Jefferson, County of, Department of Public Works and Transportation (w); Kentucky Department of—Natural Resources and Environmental Protection Cabinet (w), Transportation Cabinet, Division of Design (w); Louisville, City of (w); University of Kentucky, Kentucky Geological Survey (n,w); University of Louisville (w); Western Kentucky University (w)

Louisiana:
Capital-Area Groundwater Conservation Commission (w); East Baton Rouge Parish (w); Jefferson Parish Department of Public Utilities (w); Louisiana Department of—Natural Resources—Geological Survey (g,w), Environmental Quality (w), Office of Conservation (w); Transportation and Development—Office of Highways (w), Office of Public Works (n,w); Sabine River Compact Administration (w); Slidell, City of (w)

Maine:
Androscoggin Valley Regional Planning Commission (w); Cobbossee Watershed District (w); Maine Department of—Conservation, Geological Survey (g,n,w), Environmental Protection (w), Transportation (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 of (w); Caroline, County of (w); Carroll County Board of County Commissioners (w); Howard County Department of Public Works (w); Maryland Department of—Health and Mental Hygiene, Office of Environmental Programs (w), Transportation, State Highway Administration (w); Maryland Geological Survey (g,n,w); Maryland Water Resources Administration (w); Montgomery County—Department of Environmental Protection, Office of Environmental and Energy Planning (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); Cape Cod Planning and Economic Development Commission (w); Harwich, Town of (w); Massachusetts Department of—Environmental Management, Division of Water Resources (w), Environmental Quality Engineering, Division of Water Pollution Control (w), Fisheries, Wildlife, and Environmental Law Enforcement, Division of Fisheries and Wildlife (w); Public Works, Hazardous Waste Facility (w); Metropolitan District Commission, Water Division (w)

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 of (w); Huron-Clinton Metropolitan Authority (w); Imlay, City of (w); Kalamazoo, City of, Department of Public Utilities (w); Lansing, City of, Board of Water and Light, Water and Stream Division (w); Macomb, County of (w); Mason, City of (w); Michigan Department of—Agriculture (w), Natural Resources (w), Transportation (w); Oakland County Drain Commission (w); Otsego County Road Commission (w); Portage, City of (w); Van Buren County Board of Commissioners (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); Lower Red River Watershed Management District (w); Metropolitan Waste Control Commission (w); Minnesota Department of—Natural Resources, Division of Waters (w), Transportation (w); Minnesota Geological Survey (g); Red Lake Tribal Reservation Business Committee (w); St. Paul, City of (w), Water Utility (w); University of Minnesota (w); Wesmin Resource, Conservation and Development Association (w); White Earth Reservation Business Community (w)

Mississippi:
Gulf Regional Planning Commission (w); 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); Mississippi Research and Development Center (n,w); Pat Harrison Waterway District (w); Pearl River Basin Development District (w); Pearl River Valley Water Supply District (w)

Missouri:

Little River Drainage District (w); Missouri Department of—Conservation (w), Health (w), Natural Resources—Division of Environmental Quality (w), Division of Geology and Land Survey (n,w), Land Reclamation Commission (w); Missouri Highway and Transportation Commission (n,w); Springfield, City of, City Utilities, Engineering Department (w)

Montana:

Daniels, County of (w); Helena, City of (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); State of Montana, Governor's Office (w); Salish and Kootenai Tribes of Flathead Reservation (w); University of Montana (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); Nebraska Department of—Environmental Control (w), Water Resources (w); Nebraska Natural Resources Commission (w); University of Nebraska, Conservation and Survey Division (w)

Nevada:

Carson City Department of Public Works (w); Clark County Department of Public Works (w); Douglas County Department of Public Works (w); Elko, County of (w); Las Vegas Valley Water District (w); Legislative Counsel Bureau (g); Makay School of Mines (w); Nevada Bureau of Mines and Geology (g,n,w); Nevada Department of—Conservation and Natural Resources—Division of Environmental Protection (w), Division of Water Resources (w), Transportation (w); Nevada Senate Interim Finance Committee (w); Nye, County of (w); Reno, City of (w); Tahoe Regional Planning Agency (w); University of Nevada—Reno (w)

New Hampshire:

Conway, Town of (w); New Hampshire Department of Resources and Economic Development (g); New Hampshire Water Resources Board (w)

New Jersey:

Camden County Board of Chosen Freeholders (w); Cranford, Township of (w); Delaware River Basin Commission (w); Greenwich, Township of (w); Logan, Township of (w); Morris County Municipal Utilities Authority (w); New Jersey Department of 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 Environmental Commission (w)

New Mexico:

Alamogordo, City of (w); Alamo Navajo Chapter (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); Highlands University (w); Jemez River Indian Water Authority (w); Las Cruces, City 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); 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); Santa Fe Metropolitan Water Board (w); Veremejo Conservancy District (w)

New York:

Amherst, Town of, Engineering Department (w); Auburn, City of (w); Brookhaven, Town of (w); Chautauqua, County of, Department of Planning and Development (w); Cheektowaga, Town of (w); Cornell University—Department of Natural Resources (w), Department of Utilities (w); Council of Great Lakes Governors (w); Dutchess, County of, Environmental Management (w); Heritage Task Force (w); Hudson-Black River Regulating District (w); Irondequoit Bay Pure Waters (w); Kiryas Joel, Village of (w); Long Island Regional Planning Board (w); Monroe, County of, Department of Health (w); Montgomery, County of, Planning Department (w); Nassau, County of—Department of Health (w), Department of Public Works (w); New York City Department of Environmental Protection, Air Resources-Water Resources-Energy (w); New York State Department of—Environmental Conservation, Division of Water (w), Transportation, Bridge and Construction Bureau (w); New York State Power Authority (w); Nyack, Village of, Board of Water Commissioners (w); Oneida, County of, Planning Department (w); Onondaga, County of—Department of Drainage (w), Water Authority (w); Orange, County of, Department of Public Works (w); Oswego, County of, Department of Health (w); Putnam, County of, Department of Health (w); Suffolk, County of—Department of Health Sciences (w), Water Authority (w); Sullivan, County of, Planning Department (w); Temporary State Commission on Tug Hill (w); Ulster, County of, County Legislators (w); Westchester, County of—Department of Planning (w), Department of Public Works (w)

North Carolina:

Ayden, Town of (w); Charlotte, City of (w); Durham, City of, Department of Water Resources (w); Farmville, Town of (w); Greene, County of (w); Greensboro, City of (w); Greenville, City of, Utilities (w); Guilford County S.W.C.D. (w); Jacksonville, City of (w); Jones, County of (w); Kinston, City of (w); LaGrange, Town of (w); New Bern, City of (w); North Carolina State Department of—Human Resources (w), Natural Resources and Community Development (g,n,w), Transportation, Division of Highways (w); North Carolina State University (w); Onslow, County of (w); Orange, County of (w), Water and Sewer Authority (w); Pinetops, Town of (w); Raleigh, City of (w); Rocky Mount, City of (w); Snow Hill, Town of (w); Stantonsburg, Town of (w)

North Dakota:

Burleigh County Water Resources District (w); Dickinson, City of (w); Lower Heart Water Resources District (w); North Dakota State University (w); Oliver County Board of Commissioners (w); Public Service Commission (w); State Department of Health (w); State Water Commission (w);

Northern Mariana Islands: (See Hawaii)

Ohio:

Akron, City of (w); Canton, City of, Water Department (w); Columbus, City of (w); Freemont, City of (w); Geauga, County of (w); Lucas, County of (w); Miami Conservancy District (w); Northwood, City of (w); Ohio Department of—Natural Resources (w), Transportation (n,w); Ohio Environmental Protection Agency (w); Richwood, City of (w); Ross, County of (w); Sandusky, County of (w); Seneca Soil and Water District (w); Wood County of (w); Williams, County of (w)

Oklahoma:

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

Oregon:

Benton County Board of Commissioners (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); Lane Council of Governments (w); McMinnville, City of, Water and Light Department (w); Oregon Department of—Fish and Wildlife (w), Geology and Mineral Industries (g,n), Transportation, Highway Division (w), Water Resources (w); Portland, City of, Bureau of Water Works (w)

Pennsylvania:

Allentown, City 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); Millcreek, Township of (w); Neshaminy Water Resources Authority (w); New York State Department of Environmental Conservation (w); Philadelphia, City of, Water Department (w); Pennsylvania Department of—Environmental Resources (Padar)—Bureau of Abandoned Mines Reclamation (w), Bureau of Mining and Reclamation (w), Bureau of Oil and Gas Management (w), Bureau of Waste Management (w), Bureau of State Parks (w), Bureau of Topographic and Geologic Survey (g,n,w), Bureau of Water Quality Management (w), Office of Resources Management (w); Susquehanna River Basin Commission (w); University Area Joint Authority (w); Warren County Commissioners (w); Washington, County of—Conservation District (w), Supervisors (w); Williamsport, City of (w)

Puerto Rico:

Puerto Rico Aqueduct and Sewer Authority (w); Puerto Rico Department of—Agriculture (w), Health (w), Natural Resources (g,w), Transportation and Public Works (w); Puerto Rico Electric Power Authority (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)

Rhode Island:

Narragansett Bay Water Quality Commission (w); Rhode Island State Department of Environmental Management, Division of Water Resources (w); State Water Resources Board (w)

South Carolina:

Charleston Commission of Public Works (w); Cooper River Water Users Association (w); Grand Strand Water and Sewer Authority (w); Myrtle Beach, City of (w); South Carolina State—Department of Highways and Public Transportation (w), Geological Survey (w), Health and Environmental Control (w), Public Service Authority (w), Water Resources Commission (w); Spartanburg Water Works, Commissioners of Public Works (w); Waccamaw Regional Planning and Development Commission (w)

South Dakota:

East Dakota Water Development District (w); Lower James Conservancy Subdistrict (w); Ogallala Sioux Tribe (w); Rapid City, City of (w); Sioux Falls, City of (w); South Dakota Department of—Game, Fish and Parks (w), Transportation (w), Water and Natural Resources—Geological Survey Science Center (g,w), Water Quality Division (w); South Dakota School of Mines and Technology (w); Watertown, City of (w); West Dakota Water Development District (w)

Tennessee:

Alcoa, City of (w); Bartlett, City of (w); Dickson, City of (w); Eastside Utility District (w); Lawrenceburg, City of (w); Lincoln, County of, Board of Public Utilities (w); Memphis, City of—Light, Gas, and Water Division (w), Public Works Division (w); Metropolitan Government of Nashville and Davidson County (w); Murfreesboro Water and Sewer Department (w); North Stewart Utility District (w); Safe Growth Team (w); Shelby, County of (w); Tennessee Department of—Conservation, Geology Division (g,w), Health and Environment (w)—Division of Superfund (w), Office of Groundwater Protection (w), Office of Surface Mining and Reclamation (w), Transportation (w); Tennessee Wildlife Resources Agency (w); Tennessee Technological University (w); University of Tennessee, Water Resources Research Center (w)

Texas:

Abilene, City of (w); Alice, City of (w); Arlington, City of (w); Athens Municipal Water Authority (w); Austin, City of (w); Bexar-Medina-Atascosa Counties, Water Improvement District No. 1 (w); Bistone Municipal Water Supply District (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 (w); Dallas, County of (w), Public Works Department (w); Dallas-Fort Worth Airport (w); Edwards Underground Water District (w); El Paso, City of, Public Service Board (w); Fort Bend, County 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); Lower Colorado River Authority (w); Lower Neches Valley Authority (w); Lubbock, City of (w); Mackenzie Municipal Water Authority (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); Reeves, County of, Water Improvement District No. 1 (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—Engineering Department (w), Public Service Board (w), Waste Water Management Department (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 A & M Research Foundation (g); Texas Bureau of Economic Geology (g); Texas Parks and Wildlife Department (w); Texas Water Commission (n,w); Texas Water Development Board (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); Willas Fork Drainage District (w); Wood, County of (w)

Trust Territory of the Pacific Islands: (See Hawaii)

Utah:

Bear River Commission (w); Salt Lake, County of—Board of County Commissioners (w), Division of Flood Control and Water Quality (w); Utah Department of—Natural Resources—Geological and Mineral Survey (g,n,w), Oil, Gas and Mining Division (w), State Lands and Forestry Division (n), Water Resources Division (w), Water Rights Division (w), Wildlife Resources Division (w); Transportation (w); Utah Health Department, Division of Environmental Health (w)

Vermont:
Agency of Environmental Conservation (n); Office of the State Geologist (g); Vermont Department of Water Resources and Environmental Engineering (w)

Virginia:
Alexandria, City of, Department of Transportation and Environmental Services (w); Charles City, County of (w); Hanover, County of (w); James City, County of, Department of Public Works (w); James City Service Authority (w); New Kent, County of (w); Newport News, City of, Department of Public Utilities (w); Northern Virginia Planning District Commission (w); Roanoke, City of, Utilities and Operations (w); Southeastern Public Service Authority of Virginia (w); University of Virginia, Department of Environmental Sciences (w); Virginia Department of—Conservation and Economic Development, Division of Mineral Resources (g,n), Highways and Transportation (w); Virginia Polytechnic and State University (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); Cowlitz County Board of Commissioners (w); Douglas, County of, Public Utility District No. 1 (w); Hoh Indian Tribe (w); Kitsap County Board of Commissioners (w); King, County of (w), Department of Public Works (w); Lewis, County of, Board of Commissioners (w); Municipality of Metropolitan Seattle (w); Pend Orielle, County of (w); Pierce, County of (w); Pullman, City of (w); Puyallup Indian Nation (w); Quinault Business Committee (w); San Juan County Board of Commissioners (w); Seattle, City of—Department of Lighting (w), Department of Parks and Recreation (w); Skagit, County of (w), Department of Public Works (w); Snohomish, County of (w); South King, County of, Regional Water Association (w); Tacoma, City of—Public Utilities Department (w), Public Works Department (w); Yakima Tribal Council (w); Washington Department of—Ecology (w), Emergency Management (w), Fisheries (w), Natural Resources (g,n,w), Transportation (w); University of Washington (g); Whatcom, County of, Department of Public Works (w)

West Virginia:
Marshall County Commission (w); Morgantown, City of, Water Commission (w); Washington Public Service District (w); West Virginia Department of—Highways (w), Natural Resources, Division of Water Resources (w); West Virginia Geological and Economic Survey (g,w)

Wisconsin:
Bad River Tribal Council (w); Beaver Dam, City of (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); Forest County Potawatomi Community (w); Fox Valley Water Quality Planning Agency (w); Green Lake Sanitary District (w); Lac du Flambeau Indian Reservation (w); Madison Metropolitan Sewage District (w); Medford, City of (w); Menominee Indian Tribe of Wisconsin (w); Middleton, City of (w); Morris Lake Management District (w); Norway, Town of (w); Okauchee Lake Management District (w); Oneida Tribe of Indians (w); Park Lake Management District (w); St. Croix Tribal Council (w); Southeastern Wisconsin Regional Planning Commission (w); Stockbridge-Munsee Tribal Council (w); The District of Powers Lake (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); Wisconsin Department of—Natural Resources (w), Transportation (n), Division of Highways (w); Wolf Lake Management District (w); Wood, County of (w)

Wyoming:
Afton, Town of (w); Attorney General (w); Cheyenne, City of (w); Lincoln, County of (w); Sullette, County of (w); Uinta, County of (w); Water Development Commission (w); Wyoming Department of—Agriculture (w), Economic Planning and Stabilization Board (w), Environmental Quality (w), Highways (w); Wyoming Geological Survey (g); Wyoming State Engineer (n,w)

Federal Cooperators

Central Intelligence Agency (g)

Department of Agriculture:
Agricultural Stabilization and Conservation Service (n); Forest Service (n,w); Agricultural Research Service (w); Soil Conservation Service (g,n,w); Statistical Reporting Service (n)

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

Department of the Army:
Aberdeen Proving Ground (w); Avionics R and D Activity (g); Coastal Engineering Research Center (g); Corps of Engineers (g,w); Fort Bliss (w); Fort Carson Military Reservation (w); Jefferson Proving Ground (w); Mobility Equipment Research and Development Command (g); Picatinny Arsenal (w); Research Office, Triangle Park, N.C. (g); Waterways Experiment Station (g); White Sands Missile Range (w)

Department of Commerce:
Census (n); Coastal Plains Regional Action Planning Commission (g); National Bureau of Standards (g); National Ocean Survey (n); National Oceanic and Atmospheric Administration (g,n); National Marine Fisheries Service (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:
Albuquerque Operations Office (g,w); Bonneville Power Administration (n,w); Chicago Operations Office (g,w); Idaho Operations Office (w); Los Alamos National Laboratory (g); Lawrence Livermore Laboratory (g); Nevada Operations Office (g,n,w); Oak Ridge Operations Office (w); Office of Energy Research (g); Procurement Operations Office (g,w); 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,w)

Department of Health and Human Services (w)

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

Department of Justice (w)

Department of the Navy:
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 Air Ground Combat Center

(w); U.S. Marine Corps Air Station, Cherry Point (w); U.S. Marine Corps, Camp Lejeune (w); U.S. Marine Corps, Camp Pendleton (w)

Department of State:
Agency for International Development (g); International Boundary and Water Commission, U.S. and Canada (n,w); International Boundary and Water Commission, U.S. and Mexico (n,w); International Joint Commission, U.S. and Canada (w)

Department of Transportation:
Federal Highway Administration (g,n,w); St. Lawrence Seaway (w); U.S. Coast Guard (g,w)

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

Environmental Protection Agency (n):
Corvallis Environmental Research Laboratory (w); Environmental Monitoring Systems Laboratory (g,w); Environmental Research Laboratory (w); Office of Administration and Resources Management (n,w); Office of Environmental Engineering and Technology (g); Office of Pesticides Programs (w); Office of Waste Programs Enforcement (w); Robert S. Kerr Environmental Research Laboratory, (w)

Federal Emergency Management Agency (g,w)

Federal Energy Regulating Commission Licensees (w)

General Services Administration (w)

National Aeronautics and Space Administration (g,w)

National Research Council (n)

National Science Foundation (g,n,w)

Navajo and Hopi Indian Relocation Commission (w)

Nuclear Regulatory Commission (g,n)

Tennessee Valley Authority (n,w)

Veterans Administration (g,w)

Other Cooperators and Contributors

Government of Peru (g)

Government of Saudi Arabia (g,n,w)

People's Republic of China (g,w)

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

Budget Data

Geological Survey budget for fiscal years 1981 to 1986, by activity and sources of funds [1]

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

Budget activity	1981	1982	1983	1984	1985	1986
Total	**$769,757**	**$661,842**	**$556,054**	**$596,177**	**$604,664**	**$600,852**
Direct program	623,057	509,983	396,909	423,885	417,021	412,667[2]
Reimbursable program	146,700	151,859	159,145	172,292	187,643	188,185
States, counties, and municipalities	48,700	50,418	51,972	55,801	59,454	59,945
Miscellaneous non-Federal sources	19,605	24,376	21,215	21,142	26,075	12,111
Other Federal agencies	78,395	77,065	85,958	95,349	102,114	116,129
National Mapping, Geography, and Surveys	**89,177**	**88,133**	**91,611**	**112,447**	**115,155**	**112,562**
Direct program	77,449	77,687	81,138	90,985	85,469	84,117
Reimbursable program	11,727	10,446	10,473	21,462	29,686	28,445
States, counties, and municipalities	2,985	3,000	2,700	27,000	1,937	1,975
Miscellaneous non-Federal sources	1,095	1,100	1,204	2,362	9,450	9,568[3]
Other Federal agencies	7,648	6,346	6,569	16,400	18,299	16,902
Geologic and Mineral Resource Surveys and Mapping	**208,287**	**212,355**	**206,517**	**217,584**	**216,921**	**206,463**
Direct program	162,756	163,731	159,190	164,354	169,851	165,585
Reimbursable program	45,531	48,624	47,327	53,230	47,070	40,878
States, counties, and municipalities	758	480	490	988	1,016	1,320
Miscellaneous non-Federal sources	13,192	16,844	14,293	15,030	13,261	348
Other Federal agencies	31,761	31,300	32,544	37,212	32,793	39,210
Water Resources Investigations	**194,016**	**190,096**	**199,697**	**220,390**	**238,131**	**248,598**
Direct program	115,458	108,637	115,096	129,441	133,408	135,152
Reimbursable program	78,558	81,459	84,601	90,949	104,723	113,446
States, counties, and municipalities	45,138	46,938	48,782	52,113	56,500	56,650
Miscellaneous non-Federal sources	2,088	2,679	3,914	3,600	3,327	2,161
Other Federal agencies	31,332	31,842	31,905	35,236	44,896	54,635
Conservation of Lands and Minerals	**127,001**	**130,468**	....	....	....	....
Direct program	125,739	129,868	....	....	....	....
Reimbursable program	1,262	600	....	....	....	....
Miscellaneous non-Federal sources	29	210	....	....	....	....
Other Federal agencies	1,233	390	....	....	....	....
Office of Earth Sciences Applications	**23,205**	**20,853**	**18,452**	......	....	....
Direct program	18,849	14,359	11,132	....	....	....
Reimbursable program	4,356	6,494	7,320	....	....	....
States, counties, and municipalities	....	....	....	....	....	....
Miscellaneous non-Federal sources	3,139	3,482	1,728	....	....	....
Other Federal agencies	1,217	3,012	5,592	....	....	....
National Petroleum Reserve in Alaska						
Direct program	107,001	2,196	....	....	....	....
Allocation transfer	....	....	....	....	....	....
Reimbursable program (Federal)	....	....	....	....	....	....
General Administration	**3,896**	**3,407**	**16,313**	**15,962**	**15,354**	**14,515**
Direct program	3,896	3,407	14,931	15,642	15,244	14,246
Reimbursable program (Federal)	....	....	1,382	320	110	269
Miscellaneous non-Federal sources	....	....	....	....	....	1
Other Federal agencies	....	....	1,382	320	110	268
Facilities	**11,909**	**10,093**	**9,167**	**10,608**	**13,089**	**13,615**
Direct program	11,909	10,093	9,022	10,463	13,049	13,567
Reimbursable program	....	....	145	145	40	48
Miscellaneous services to other accounts	**5,266**	**4,236**	**7,917**	**6,186**	**6,014**	**5,099**
Reimbursable program	5,266	4,236	7,917	6,186	6,014	5,099
Miscellaneous non-Federal sources	62	61	96	150	37	33
Other Federal agencies	5,204	4,175	7,821	6,036	5,977	5,066
Barrow Area Gas Operations	....	....	**6,400**	**13,000**	....	....
Direct program	....	....	6,400	13,000	....	....

[1] Includes 1982 appropriation for Minerals Management Service.

[2] Direct program includes $412,306 for current year, $11 for indefinite appropriation, and $350 for last year's unobligated balance.

[3] Includes $8,568 for map receipts previously shown under direct program column.

U.S. Geological Survey budget authority for fiscal year 1986, by appropriation

[Dollars in thousands]

Activity/Subactivity/Program Element	Fiscal year 1986[1] enacted
Surveys, Investigations, and Research	
National Mapping, Geography, and Surveys	**$84,117**
Primary Mapping and Revision	**36,018**
Digital Cartography	**12,871**
Small, Intermediate, and Special Mapping	**13,903**
Intermediate-Scale Mapping	5,441
Small-Scale and Other Special Mapping	2,005
Federal Mineral Land Information	1,441
Land Use and Land Cover Mapping	3,751
Image Mapping	1,265
Advanced Cartographic Systems	7,088
Earth Resources Observation Systems	**8,965**
Data Production and Dissemination	4,556
Applications and Research	4,409
Cartographic and Geographic Information	**3,371**
Side-Looking Airborne Radar	**1,901**
Geologic and Mineral Resource Surveys and Mapping	**165,574**
Geologic Hazards Surveys	**47,347**
Earthquake Hazards Reduction	34,332
Volcano Hazards	10,161
Landslide Hazards	2,854
Land Resource Surveys	**21,634**
Geologic Framework	18,634
Geomagnetism	2,054
Climate Change	946
Mineral Resource Surveys	44,575
Alaska	9,467
Conterminous States	5,782
Mineral Resources of Public Lands	7,600
Strategic and Critical Minerals	9,188
Development of Assessment Techniques	12,538
Energy Geologic Surveys	**26,725**
Evolution of Sedimentary Basins	4,669
Coal Investigations	7,604
Onshore Oil and Gas Investigations	4,617
Oil Shale Investigations	557
Geothermal Investigations	3,139
Uranium-Thorium Investigations	5,642
World Energy Resource Assessment	497
Offshore Geologic Surveys	25,293
Offshore Geologic Framework	23,802
Coastal Erosion	1,491
Water Resources Investigations	**$134,802**
National Water Resources Research and Information System—Federal Program	**72,875**
Data Collection and Analysis	19,492
National Water Data and Information Access Program	2,090
Coordination of National Water Data Activities	903
Regional Aquifer System Analysis	13,474
Core Program Hydrologic Research	8,082
Improved Instrumentation	1,888
Water Resources Assessment	1,287
Toxic Substances Hydrology	11,182
Nuclear Waste Hydrology	7,020
Acid Rain	2,998
Scientific and Technical Publications	2,081
National Water-Quality Assessment Program	2,378
National Water Resources Research and Information System—Federal-State Cooperative Program	**49,774**
Data Collection and Analysis, Areal Appraisals, and Special Hydrological Studies	41,956
Water Use	3,670
Coal Hydrology	4,148
National Water Resources Research and Information System—State Research Institute and Research Grants Program	**12,153**
State Water Resources Research Institutes	6,159
National Water Resources Research Grants Program	4,767
Program Administration	1,227
General Administration	**14,246**
Executive Direction	5,790
Administrative Operations	6,818
Reimbursements to the Department of Labor	1,638
Facilities	**13,567**
National Center—Standard Level User's Charge	**11,329**
National Center—Facilities Management	**2,238**
TOTAL, Surveys, Investigations, and Research	**412,306**

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

Geological Survey reimbursable program funds from other Federal agencies for fiscal years 1981 to 1986, by agency

[Dollars in thousands]

Budget activity	1981	1982	1983	1984	1985	1986
Total	**$78,395**	**$76,675**	**$85,958**	**$95,349**	**$102,114**	**$116,129**
Department of Agriculture	3,567	2,675	2,774	2,770	3,066	2,756
Department of Commerce	....	....	111	910	617	104
National Oceanic and Atmospheric Administration	823	1,781	5,750	6,139	6,876	8,675
Ozarks Regional Commission	....	....	....	....	....	....
Department of Defense	18,490	21,459	25,429	33,707	31,883	27,343
Department of Energy	10,885	10,529	5,858	13,828	15,893	24,341
Bonneville Power Administration	81	75	103	120	132	170
Department of Housing and Urban Development	188	....	....	....	....	....
Department of the Interior	22,553	20,328	23,955	16,167	19,859	18,852
Bureau of Indian Affairs	3,999	5,001	4,796	4,299	5,530	5,033
Bureau of Land Management	13,800	10,551	7,150	3,446	2,900	2,447
Bureau of Mines	299	275	200	56	54	122
Bureau of Reclamation	2,231	1,800	3,411	3,524	8,510	8,734
Minerals Management Service	....	....	5,284	2,347	744	342
National Park Service	1,121	1,015	1,957	1,037	1,122	1,043
Office of the Secretary	154	100	223	244	17	701
Office of Surface Mining	469	1,176	606	95	90	129
Fish and Wildlife Service	480	410	328	1,119	892	301
Department of State	2,272	3,445	573	700	619	8,625
Department of Transportation	273	500	483	600	458	133
Environmental Protection Agency	1,259	675	883	1,012	1,476	1,878
National Aeronautics and Space Administration	5,065	3,885	3,716	3,999	3,979	4,340
National Science Foundation	2,001	1,958	1,300	774	242	162
Nuclear Regulatory Commission	1,781	1,544	2,272	2,003	1,236	1,154
Tennessee Valley Authority	317	290	151	250	247	264
Miscellaneous Federal agencies	3,717	3,431	4,882	6,334	9,554	12,264
Miscellaneous services to other accounts	5,204	4,175	7,821	6,036	5,977	5,066

Yearbook Staff

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Sandye Holmes	Water Resources Division Coordinator
Eloise Byrd	National Mapping Division Coordinator
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John Cordyack	Administrative Division Coordinator

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.