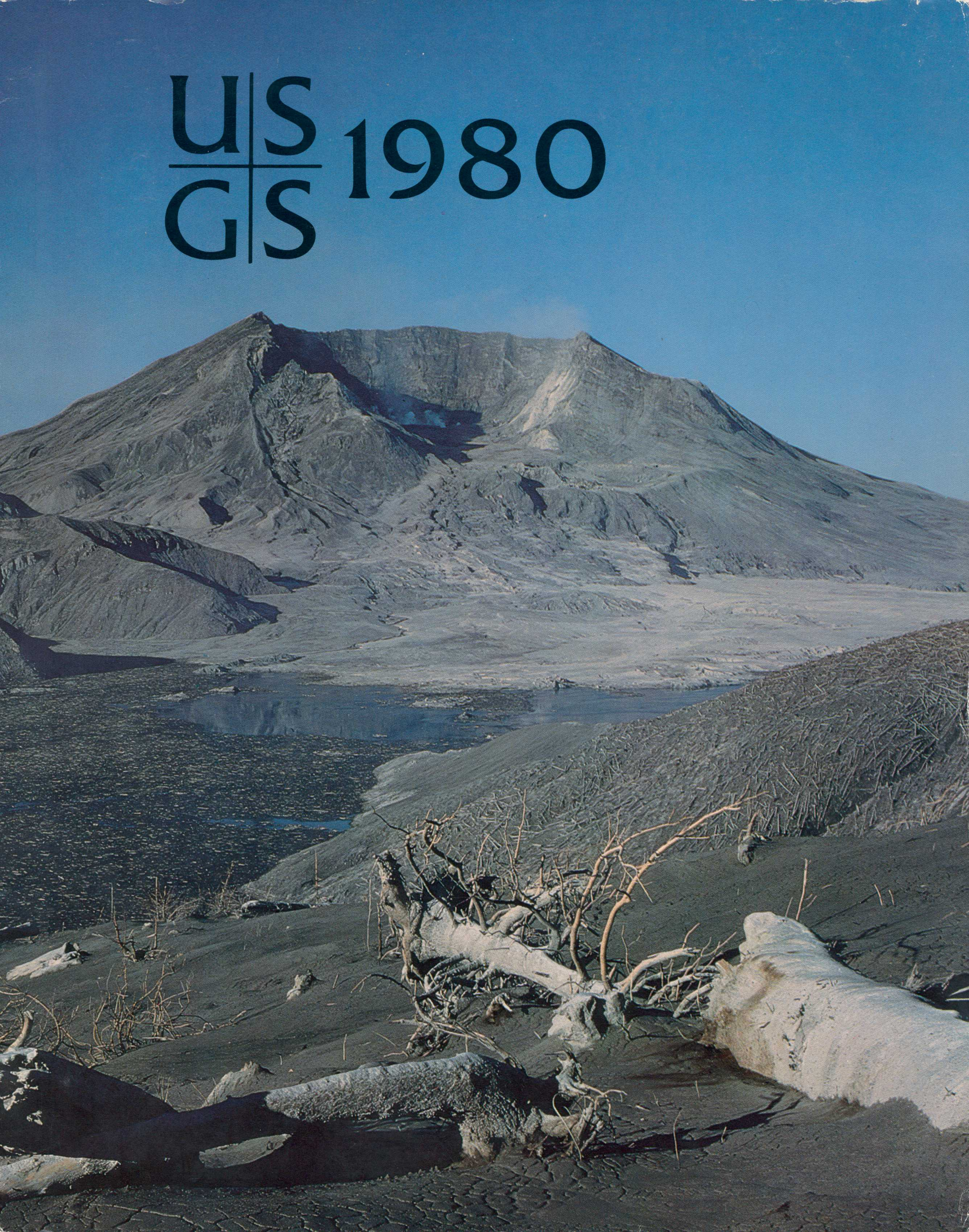
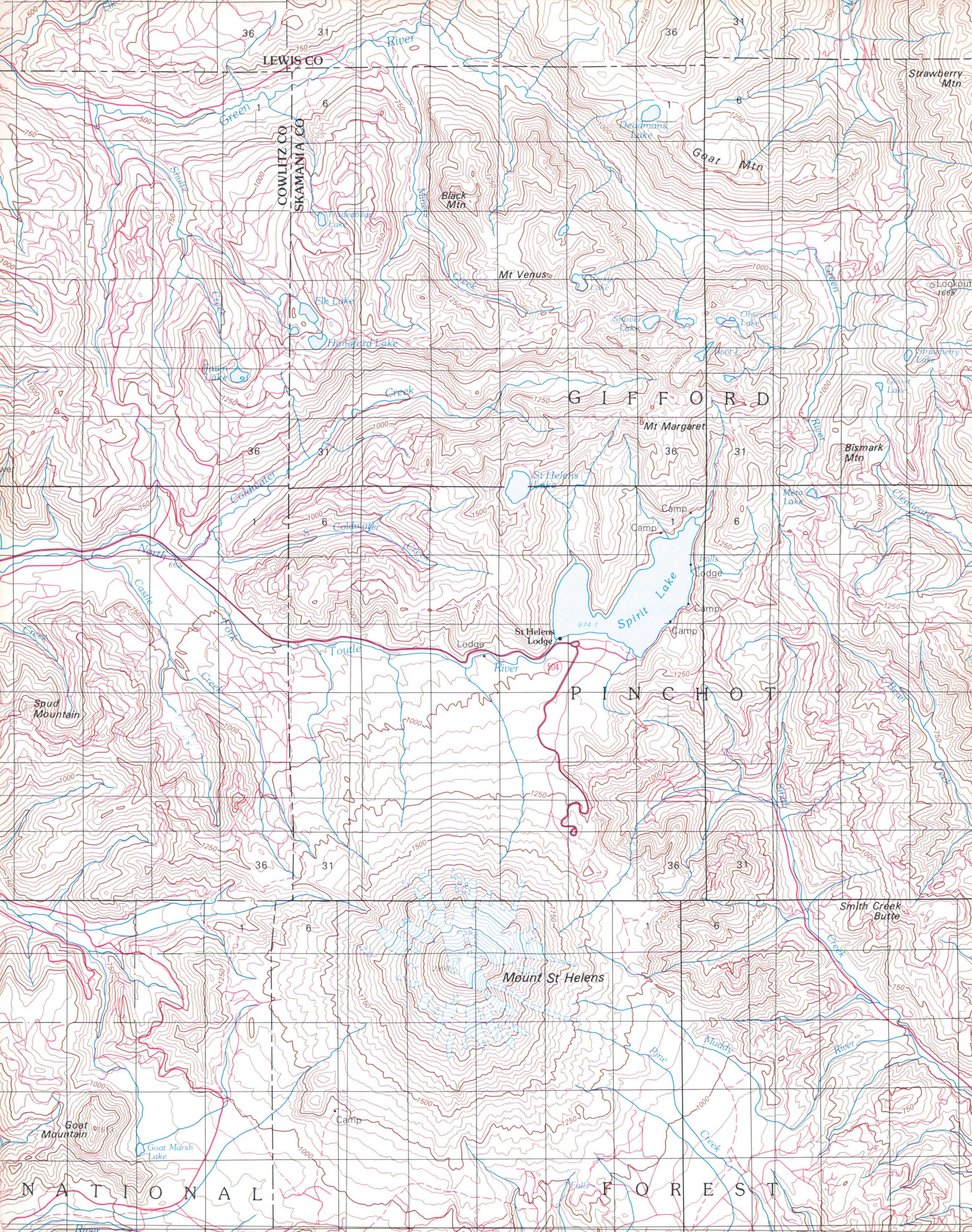
USGS 1980

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COWLITZ CO
SKAMANIA CO
Green River
Strawberry Mtn
Deadmans Lake
Goat Mtn
Black Mtn
Mt Venus
Elk Lake
Hanaford Lake
Lookout 1665
Strawberry Lake
GIFFORD
Mt Margaret
Bismark Mtn
St Helens Lake
Coldwater Creek
North Fork
Castle Creek
Spirit Lake
974.7
Camp
Falls
Lodge
St Helens Lodge
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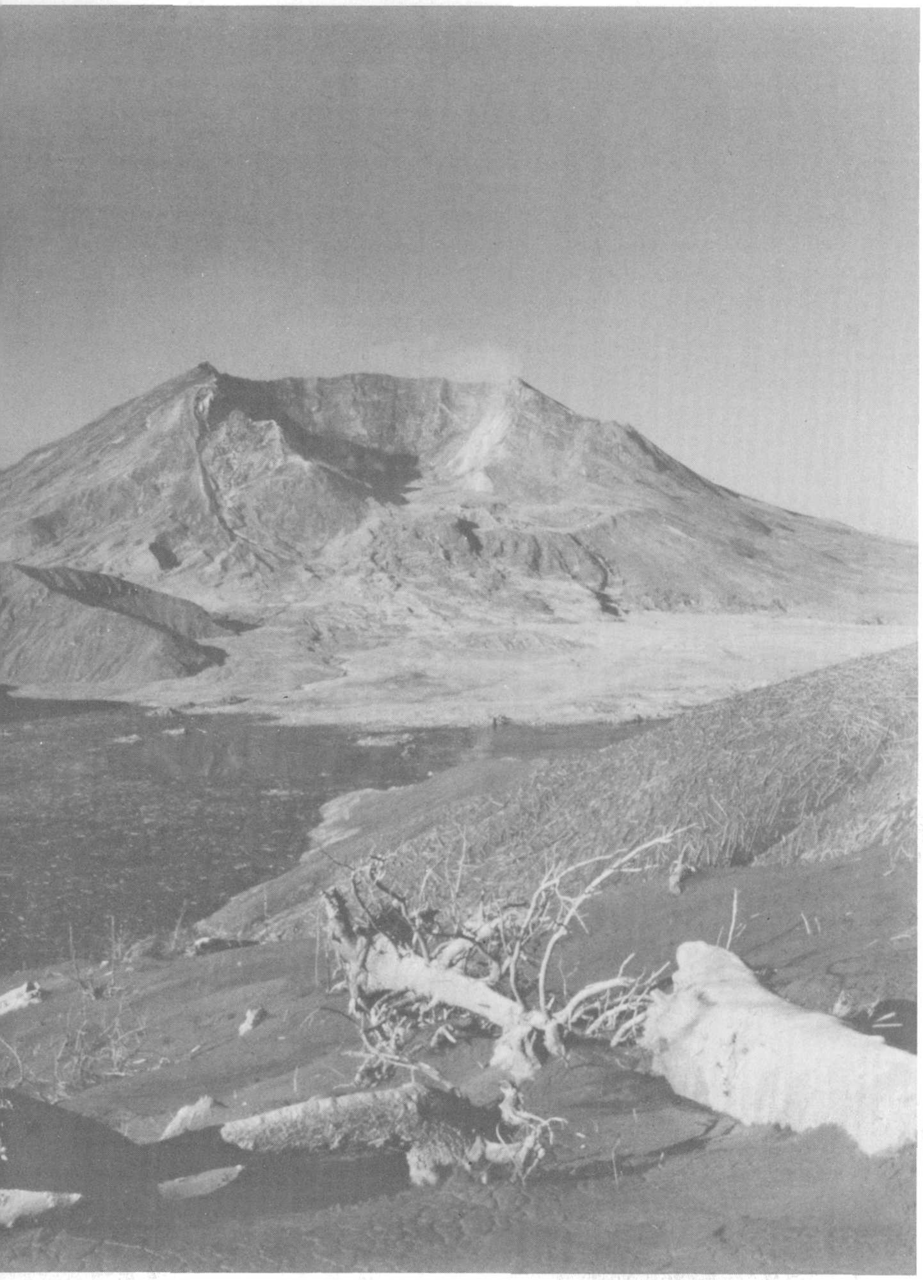
504
Spud Mountain
PINCHOT
Smith Creek
Bean Creek
Smith Creek Butte
Mount St Helens
Muddy River
Pine Creek
Goat Mountain
Goat Marsh Lake
NATIONAL
FOREST



United States Geological Survey Yearbook, Fiscal Year 1980

The two cover photographs, taken from approximately the same spot about 7 miles north-northeast of Mount St. Helens, graphically show the enormous change that the eruption caused. The photograph on the front cover depicts the crater created by the catastrophic eruption of May 18, 1980.

The eruption removed about 1,300 feet of the mountain top; the highest point is now 8,364 feet, compared to the former summit elevation of 9,677 feet. Spirit Lake (middle ground), formerly beautifully clear and bordered by lush forest, now is largely covered by a floating stinking mat of decaying downed trees and other debris.

The photograph on the back cover, taken in April 1980, shows minor steam venting. Spirit Lake (middle ground) has a light coating of ash from intermittent minor eruptions in March and April. (Photographs by John Marshall).

The cover maps show the Mount St. Helens area before and after the May 18 eruption. The pre- and posteruption maps were extracted from the Mount St. Helens and vicinity Washington-Oregon maps published at the 1:100,000 scale (1 centimeter=1 kilometer). The terrain is shown by contours at a 50-meter interval.

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For sale by the Superintendent of Documents
U.S. Government Printing Office
Washington, DC 20402

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Acknowledgments

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Photographs on pages 5, 21, 43, and 61 by Dawn Reed.
Photographs on page 97 by Alta Walker.
The photographs on pages 7 and 11 were taken by J. Friedman. The photographs on pages 8, 9, 12, and 15 were taken by C. Dan Miller.

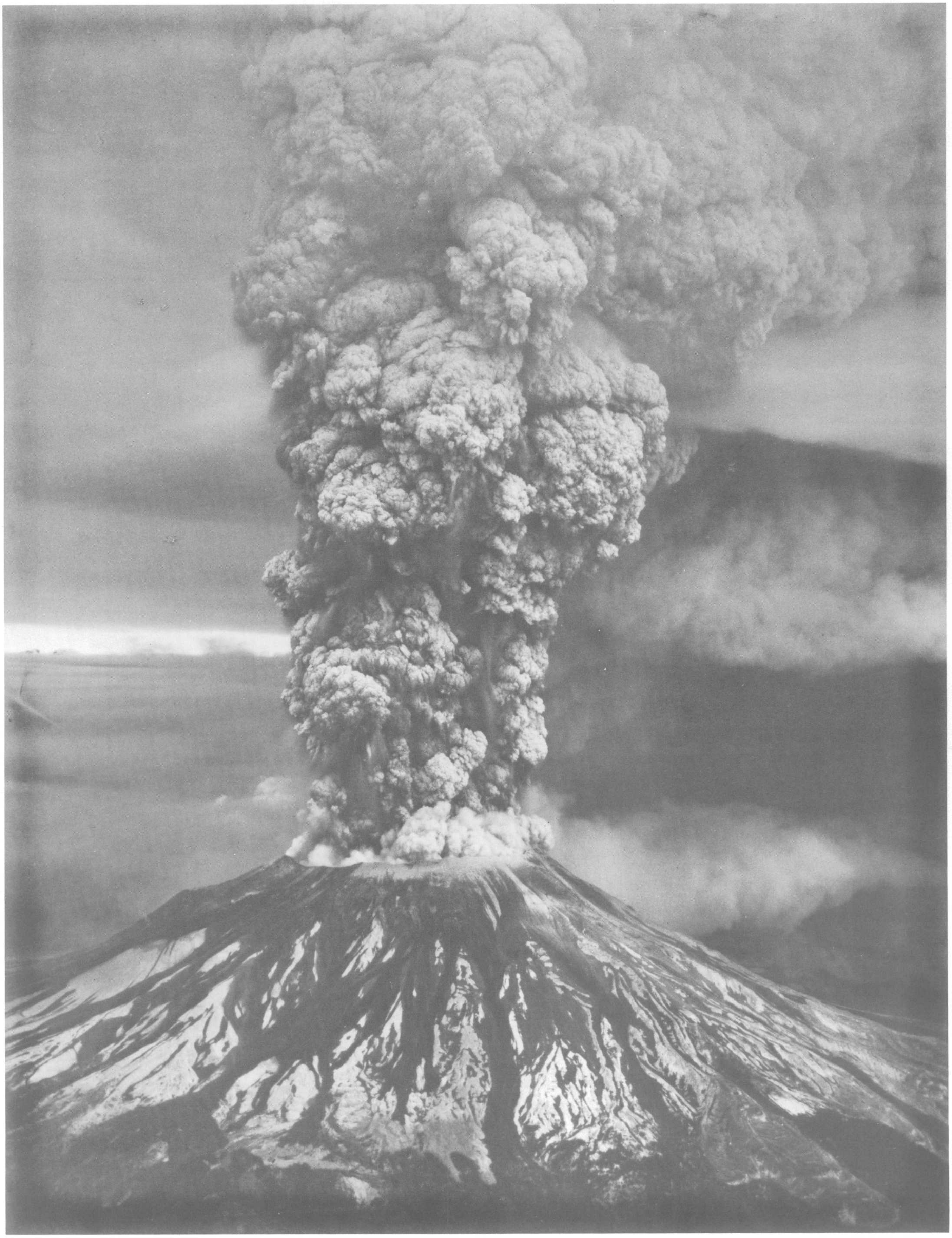
Preface

The fiscal year 1980 Yearbook summarizes the activities of the U.S. Geological Survey in response to its scientific and regulatory missions and its responsibility for exploration of the National Petroleum Reserve in Alaska.

The main sections of this Yearbook are:

- The Year in Review—a brief overview of the significant events of the Geological Survey during fiscal year 1980.
- Perspectives—essays focusing on specific events (rather than scientific topics) and programs involving multi-Division participation.
- Missions, Organization, and Budget—a description of the Geological Survey's major duties and assignments and of the organizational structure that supports its missions.
- Division Chapters—a description of the significant accomplishments (rather than a comprehensive program by program discussion) of each of the eight operating Divisions and Offices.
- Appendices—provide supplementary information regarding key personnel, cooperators, and selected summary budgetary tables and an index.

Professional Paper 1175, Geological Survey Research 1980, the latest in a series of annual reviews of technical results of the Geological Survey's research programs, supplements the Yearbook.



Year in Review

It is not very often that a single event is so overwhelming that it changes public perceptions of natural hazards for generations. Perhaps for the U.S. Geological Survey, the explosive volcanic activity of Mount St. Helens began such a change. After 101 years of careful science of the Earth's past and meticulous observations and assessments of the present, predictive earth science was in full public view. However vague and faint the glimpse of the future made possible by earth science, it was enough. Warnings were issued, thousands of lives were saved, and the age of real-time geology began.

The Survey's basic mission has not changed, but the power of our analytical tools has increased by several orders of magnitude. The Survey's efforts to understand Earth processes and hydrologic principles continued with the collection, during fiscal year 1980, of valuable new data on the geologic origin and framework, seismicity, and mineral and energy resources of the United States. The Survey is also responsible for classification of the leasable minerals on Federal lands and the regulation of mineral exploration and development activities on Federal and Indian lands. As the principal earth science fact-gathering agency, the Survey provides information for sound decisionmaking by government and private industry. Industry uses the Survey's information in exploring for energy and minerals and improving their efforts to make development of energy and minerals compatible with environmental protection standards. Government uses the Survey's information in conducting leasing operations on public lands, in regulating the safe design and siting of nuclear plants, and in establishing guidelines for determining and locating areas that are subject to geologic hazards such as landslides, earthquakes, and volcanic eruptions.

The *Yearbook* reports a broad range of the Survey's accomplishments during the past fiscal year and provides an overview of future directions. Many of the topics covered will continue to be important natural resource and earth science issues of the 1980's.

Energy

The Geological Survey provides the earth science information needed to support the Department of the Interior's energy leasing programs both on the Outer Continental Shelf and onshore. Providing the geologic-hydrologic and mining information to support the Federal Coal Management Program will make it possible for the Department of the Interior to carry out the Secretary's June 1979 decision to resume leasing Federal coal. Regulation of the private sector's development of the public's vast energy resources is also a Survey responsibility. During fiscal year 1980, $4.1 billion in bonuses and $2.7 billion in royalty payments were collected from all Federal oil and gas, coal, and other leases and deposited in the U.S. Treasury.

Aerial view of eruption of Mount St. Helens, May 18, 1980.

Outer Continental Shelf Oil and Gas

The Geological Survey conducted a variety of activities in support of the Department's Outer Continental Shelf (OCS) oil and gas leasing program. These activities included tract selection decisions for eight future sales and resource evaluations on 357 tracts involving four sales. In the course of these activities, over 66,000 line miles of high resolution and common depth point geophysical data were acquired and analyzed. Under Geological Survey supervision, an industry-financed deep stratigraphic test well was drilled in the Norton Basin of Alaska to provide potential private sector bidders and the government with down-hole data prior to OCS lease sale No. 57. The resource-evaluation processes were modified to include the consideration of net profit share bidding in sale A-62, Gulf of Mexico, according to the provisions of the Outer Continental Shelf Lands Act Amendments of 1978. Pursuant to those Amendments, a process was established to provide geological and geophysical data to the nearby coastal states.

The Survey's OCS regulatory workload also increased in the form of exploratory and production activities on 2,300 OCS leases in effect during fiscal year 1980, an increase of 6 percent over fiscal year 1979. These leases produced 9 percent of the Nation's oil and 23 percent of the gas in that year. A total of 1,040 new exploratory and development wells were started, and 8,856 inspections were conducted on both a scheduled basis and "random" unannounced basis. Royalties of $1.98 billion were collected from OCS production and were deposited in the U.S. Treasury.

Coal

Fiscal year 1980 saw a significant increase in the Survey's program efforts to better understand the Nation's coal resources. The Coal Folio Program was accelerated and now includes 27 folio studies in progress. These studies currently are focused on the identification and delineation of coal beds in the Western United States and on beds of low-sulphur coal in the central and southern Appalachian Basin. Investigations of coal stratigraphy and structure permit the projection of coal quality and quantity point-source information throughout a coal basin and enable a quantitative assessment of a basin's coal resources. Data generated by these investigations are incorporated in the National Coal Resources Data System. The Coal Folio Program is designed to provide geologic and resource information about Federal coal lands subject to the Federal Coal Leasing Amendments Act of 1975. The key elements of the program, in part accomplished cooperatively with State Geological Surveys, are core drilling on coal lands which are distant from coal bed outcrops, subsurface mapping of coal beds using well logs and geophysical exploration techniques, and geochemical analyses of core samples. These studies, compiled in loose-leaf folios, will assist (1) leasing and regulatory programs of the Department of the Interior, including the Bureau of Land Management, (2) national energy policy planning, (3) siting and technology development for coal energy-conservation programs of the Department of Energy, and (4) coal extraction technology development by the Bureau of Mines.

Another portion of the Coal Folio Program includes an evaluation of the geologic constraints to coal development on Federal lands such as the identification of geologic hazards. In addition, the Program aims to delineate alluvial valley floors in coal producing regions and to analyze chemical trace elements that might be released into the environment by mining. Analyses were prepared on 85 high-priority areas located in the Western States that are being considered by the Department for coal leasing. The data will be used to support land-use and socioeconomic planning efforts by other Federal, State, and local agencies and the private sector in addressing production targets and environmental consequences of mining.

The first in a series of 35 reports that provide information on existing hydrologic conditions and identify sources of hydrologic information about coal mine areas of the Eastern United States was prepared. The report, entitled *Hydrologic Assessment: Eastern Coal Province Area 23, Alabama,* is designed for use by mine owners, mine operators, and consulting engineers in evaluating the potential effects of surface coal mining operations on the hydrology of the area. Also prepared were three parts of a special five-volume index that will provide information on the availability of data on water resources in the several coal provinces of the United States. This index will help resource developers in obtaining data for evaluating the effects of coal mining on water resources and in developing plans for meeting water needs. The information also will assist agencies at all levels by identifying sources of data on quality and quantity of water supplies.

The Survey conducted a study to permit Department decisions on one land exchange on which Emergency Criteria Sales were held. The Survey also participated in the preparation of three environmental impact statements related to future coal lease sales. Development and coal mining was underway on 103 leases on Federal lands during fiscal year 1980. In addition, Geological Survey inspectors made 790 inspections of the 575 coal leases, and $28 million in royalties were collected on the 79 million tons (10 percent of U.S. production) of coal mined during the year. Investigations culminated in the publication of U.S. Geological Survey Professional Paper 1164 which documented results of environmental studies conducted in the Sheridan, Wyo., area. These studies suggest that modern surface mining of coal causes less damage than underground mining. The latter triggers subsidence depressions, pits, and underground fires, all of which pose serious hazards to the environment and to man's activities in the mined-out areas.

Oil and Gas Onshore

Onshore oil and gas leases were supervised by the Geological Survey and involved approvals on 4,539 wells, 23,106 field inspections, and the collection of $691 million in royalties. Operations on these leases resulted in more than 14 percent of the oil and roughly 29 percent of the gas produced in the United States.

The Geological Survey also implemented a number of provisions of the Natural Gas Policy Act (NGPA). Because the Act permits various higher prices to be charged for several different categories of gas (including newly discovered, stripper, and high-cost), the Geological Survey must approve or disapprove each application for a specific category, then collect the proper royalty on this increased price. The Survey made final determinations on 2,750 applications under NGPA in fiscal year 1980 for onshore Federal and Indian wells.

Petroleum exploration activities continued on the National Petroleum Reserve in Alaska (NPRA). Seven exploration wells were completed, including four that had been started in earlier years. Two geophysical parties acquired 1,110 line miles of seismic data. The Survey continued to operate and to maintain the South Barrow gas field that supplies natural gas to the village of Barrow and Federal installations in the vicinity of Barrow. One gas development well was completed by September 30, 1980. Husky Oil NPR Operations, Inc., continued as the principal contractor for all phases of the exploration program.

Geothermal Resources

Geothermal energy utilization for both electrical power generation and direct heat applications is increasing and will make a significant contribution to the Nation's energy supply in the next decade. During fiscal year 1980, the Survey started a major regional assessment of the geothermal potential of the Cascade Range in northern California, Oregon, and Washington. A quantitative evaluation of low-temperature geothermal waters was initiated which should encourage the use of these waters for direct heat applications.

During fiscal year 1980, five new geothermal projects were brought in to operation. Three of the projects involved use of geothermal power for the generation of electricity, and the remaining two used geothermal resources directly. Approximately 640 acres of land (1 square mile) are required to site each 50-megawatt electric plant. On the average, roughly 10 wells are needed to supply the required geothermal energy for operation of a typical generation plant.

During fiscal year 1980, 38 applications for permit to drill were approved. By year end, 4 leases covering 3,238 acres were actively producing, and a total of 2,546,304 acres of Federal and Indian lands, subject to 1,463 separate leases, was under supervision. Approximately 500,000 acres of these lands are classified in Known Geothermal Resource Areas. During the year, 34 geothermal wells were drilled on Federal lands, compared to 11 wells drilled during the previous year.

Nuclear Energy

A variety of geologic and hydrologic investigations is being conducted on behalf of the Department of Energy in regions where the Department of Energy is considering locating repository sites for high level nuclear wastes. These regions include the Nevada Test Site and vicinity; Waste Isolation Pilot Plant in southeastern New Mexico; Hanford Reservation Region in Washington; Paradox Basin in Utah; Gulf Coast Salt Dome region in north Louisiana, Mississippi, and northeast Texas; and Salinas Basin in New York and Ohio. The geohydrologic controls on the movement of waste solutes and the potential hazards from future volcanic activity are under study at the Idaho National Engineering Laboratory where transuranic wastes have been stored and disposed.

The Survey continued its efforts in support of the Department of Energy's National Uranium Resource Evaluation Program. These efforts are concentrated on conducting geologic studies in 24 selected $1° \times 2°$ quadrangles in the conterminous United States to assist the Department of Energy in assessing the uranium potential in each quadrangle and to develop uranium-resource assessment methodologies. Maps showing the results of these studies have been submitted to the Department of Energy.

Royalty Management

The present royalty collection system evolved over a period of years and was developed when mineral production was minimal, pricing structures simple, and workloads small. It relies entirely on monthly, manual, account reconciliation which requires long, labor-intensive, and costly procedures. Field personnel who are principally responsible for both offshore or onshore technical program activities currently try to keep up with the constantly growing demands of royalty collection. To correct the inadequacies of both the existing royalty management organization and the royalty collection system, it is planned to separate accounting operations from the Conservation Division's onshore and offshore field operations and consolidate them into a headquarters component located in Reston, Va., a national Accounting Center located in Lakewood, Colo., and four Review and Analysis Offices located at Albuquerque, N.M., Metairie, La., Tulsa, Okla., and Lakewood, Colo.

A Geological Survey Task Force aided by outside contractors finished a design for a new approach to royalty collection and management. This new system, which will be phased in over the next 2 years, will make greater use of computers; will centralize collection, partially to speed the deposit of royalty checks; and will emphasize financial analysis of accounts. By adopting this system, it is expected that the number of sales and collection reports now required from mineral companies will be reduced, erroneous billing account balances eliminated, and Survey royalty accounting operation costs minimized.

Minerals

Compilation of a bedrock geologic map of Massachusetts was completed, and the map is being processed for publication, culminating nearly 40 years of cooperative effort by the Geological Survey and the Department of Public Works, Commonwealth of Massachusetts, and augmented by geologists from various universities. A companion map showing the surficial geology of the State will be completed in early fiscal year 1981. Geologic maps for the States of Colorado and North Dakota (in cooperation with the North Dakota Geological Survey) were also published during fiscal year 1980.

Investigations of wildernesslike areas continued on two fronts during fiscal year 1980. In a significant increase over the fiscal year 1979 level, approximately 5 million acres of Forest Service land were surveyed for their mineral potential. On a reimbursable basis, the Survey also conducted mineral surveys on behalf of the Bureau of Land Management on 800,000 acres.

Research, demonstration projects, and production were underway on approximately 1,200 geology-related projects. These projects included basic geologic mapping, 15 2° quadrangles in the Conterminous United States Minerals Assessment Program, and 14 Alaska Minerals Resources Assessment Program quadrangles.

Water Resources

Water-quantity and water-quality data were collected at about 25,500 surface-water sites. Data on ground-water level and pumpage were collected at an additional 30,000 sites. A satellite data relay stream-gaging network was initiated in 1980, which will be operated by COMSAT General Corporation under contract to the Geological Survey. This "test" network will be in operation by February 1981 with a total of 105 stations located in Massachusetts, Vermont, New Hampshire, Maine, Pennsylvania, Colorado, Texas, and Arizona. The operating network will test the feasibility of establishing a full-scale system of collecting hydrologic data, such as stream stage and water quality, and of transmitting the data almost instantaneously to receiving stations by commercial satellite.

Three additional Regional Aquifer Systems Analyses were started: the Atlantic Coastal Plain, the Snake River Plain, and the Southeastern Coastal Plain. During the same period, work continued on six aquifer systems begun in previous years: the northern Great Plains, the High Plains, the California Central Valley, the Southeastern Carbonates, the Northern Midwest, and the Southwest Alluvial Basin. A number of interim reports were published or released to the Open File. A significant accomplishment in the Regional Aquifer-System Analysis Program has been the definition of the relationship between annual pumpage and irrigated crop acreage. Results from the High Plains study indicate that pumpage could be estimated by identifying irrigated acreage through use of imagery from the Landsat satellite.

The National Water-Use Data Program, which began in 1978 with 15 States participating, had 47 States cooperating by mid-1980. Water-use plans have been completed for all the participating States, and each State has begun a program of data collection. The National Water-Use Data System has been developed and implemented and is now part of the Survey's WATSTORE data system. A methods manual for the collection of irrigation water-use data has been developed by the South Florida Water Management District. This manual will serve to promote national consistency in the collection of such data. Additional manuals are being prepared by State cooperators for the collection of water-use data for municipal, domestic, commercial, industrial, and public uses.

The Hydrologic Instrumentation Facility in Bay St. Louis, Miss., was opened. The facility combines, under one roof, instrument development, supply, repair, quality assurance, and inventory control. The objective is to provide a more efficient supply and repair of instruments for the water field activities.

Studies conducted as part of the Climate Program provided new information on climatically induced erosion and deposition that have brought about geomorphic changes in the Earth's surface. Such changes have occurred primarily during times of rapid worldwide deglaciation. The most recent deglaciation occurred about 10,000 years ago, and glacial cycles appear to have a recurrence that ranges from a few thousand years to tens of thousands of years. Thus, such studies provide data critical to assessing and predicting the impact that future major climatic change will have on the United States.

Mapping and Earth Imagery

A number of steps were taken at the Earth Resources Observation System (EROS) Data Center in Sioux Falls, S. Dak., to permit the eventual processing of thematic mapper data from Landsat D, scheduled for launch in 1981. Changes were made to improve delivery time of multispectral data from the Landsat satellite as well as to increase the involvement of academic institutions and remote-sensing technology.

The EROS Data Center acquired 296,402 satellite images and frames of aerial photography, bringing the total to 6.4 million. The sales of both satellite data and aircraft photography increased in fiscal year 1980: satellite imagery and computer compatible tapes, $2.4 million (a 12-percent increase), and aerial photographs, $0.9 million (a 6-percent increase). Forty training courses were offered in remote-sensing technology with 402 people being trained.

Topographic map coverage of the Nation at 1:24,000 scale increased from 61.2 percent to 63.0 percent (excluding Alaska) with the publication of 1,139 new maps at that scale. An additional 1,355, mostly 1:24,000 scale, maps were revised. In total, 5,053 topographic maps at 12 different scales were printed, and 9 million copies were distributed.

Natural Hazards

Significant progress has been made in recent years in the development of techniques and systems to provide warnings of the possibility of impending natural disasters such as floods, landslides, and earthquakes. The Disaster Relief Act of 1974 gave the Geological Survey the responsibility for warning State and local officials of impending geologic hazards in their areas. To help meet this responsibility, a communications network for the transmission of technical information has been established in a majority of States.

During fiscal year 1980, the Survey made considerable progress in implementing the Earthquake Hazard Reduction Program; 151 earthquake hazards delineation studies were conducted.

Many years of careful earth science investigations enabled the Geological Survey to warn people of the impending Mount St. Helens hazard and to persuade other government agencies to enforce measures to keep people away. As a result, one estimate indicates that as many as 10,000 lives may have been saved from this special application of earth science in "real time."

During fiscal year 1980, the Survey prepared flood-prone-area maps in 222 areas subject to urban flooding. In response to the Flood Insurance Act of 1968, Housing and Urban Development flood-insurance studies were completed.

Management Initiatives

Several significant organizational changes were planned and (or) implemented during fiscal year 1980 that will have long-term implications for the ability of the Geological Survey to carry out its programs. The first of these involved forming a new National Mapping Division from the former Topographic Division, parts of the former Publications Division, and the Geography Program from the former Land Information and Analysis Office. During the last few years, demand from both governmental and nongovernmental users for specialized land-resource information has increased dramatically. Rapidly expanding technology in mapping, printing, automated data systems, and related equipment has required the installation of sophisticated equipment to satisfy ever-increasing user demands. Intensification of these efforts to supply clientele with the best products has led to an integrated research program in areas of data-base design; digital data preparation, analysis, and interpretation; remotely sensed data interpretation; and application with respect to geography and cartography. The new National Mapping Division provides an improved framework within which to accomplish these important objectives.

The second major reorganization involved the structure of the Conservation Division. During the last decade, the Conservation Division's responsibilities and prominence in implementing the Nation's energy policy on Federal and Indian lands have grown exponentially. The Division now regulates the production of over 28 percent of the Nation's natural gas, 14 percent of its oil, 10 percent of its coal, and significant percentages of other selected minerals. In parallel with the growth in the quantity of commodities it regulates, has been a growth in the range of its regulatory responsibilities for the environment, human health and safety, diligent development of resources, fair economic return to the Nation for public resources, and the conservation of resources. The Division has had to respond to a growing number of constituencies, including congressional committees, other Federal agencies, State and local governments, and a broad range of nongovernmental organizations and interests. All evidence indicates that the growth pattern of the last decade will continue, and it seems certain that interest in the efficient management of the energy and mineral resources of public and Indian lands will intensify in the future. The organizational structure of the Division was extensively modified; boundaries of the field offices were changed to provide for the following:

- Separation of onshore from offshore program management.
- Increase in the number of geographic service areas from 4 to 10 and realinement of service area boundaries to conform to State boundaries.
- Separation of royalty management functions from the onshore and offshore field operations and centralization of the royalty functions.
- Integration of technical disciplines to achieve a multidisciplinary approach to regulating industry mineral operations.
- Colocation of functions at regional and, where possible, at district locations of the organization.

The third organizational change involved the Office of the Director, specifically the various Assistant Directors and the former Land Information and Analysis Office. Evaluation of current and anticipated future Survey activities revealed a strong and continuing need to improve its capability to carry out high-priority multidisciplinary multidivision programs; coordinate programs of national significance, particularly mineral-, water-, and energy-resource programs; enhance its ability to strengthen cooperation among scientific disciplines; achieve a well-rounded approach to earth science problems; respond to increasing demands for earth science information and broaden the scope and utility of its information products; and strengthen the delivery of administrative and automatic data processing support services to its scientific programs.

Accordingly, the Land Information and Analysis Office was renamed the Office of Earth Sciences Applications and given more specific responsibilities to coordinate multidisciplinary multidivision programs and broaden its scope of activities to provide specialized staff support to the Directorate. Also, elements of the former Publications Division were added to that reorganized Office to strengthen the Survey's capability to transfer basic science products to planners, decisionmakers, and the public.

The position of Assistant Director for Mineral and Water Resources was renamed Assistant Director for Resource Programs, and the duties modified to reflect responsibilities broader than mineral and water resources. The position of Assistant Director for Land Resources was renamed the Assistant Director for Research with broader duties to recognize the need to provide a focal point at the Directorate level for research program planning, review and analysis, and coordination and monitoring of the Survey's research programs and projects. The functions of the Assistant Directors for Engineering Geology, Programs, and Administration were virtually unchanged.

Several key position vacancies were filled during the year. Doyle Frederick became the Associate Director (replacing Joseph Cragwall). At the Assistant Director level, Robert Wesson became Assistant Director for Research (replacing James Balsley); James Devine became Assistant Director for Engineering Geology (replacing Henry Coulter); and Betty Miller became Assistant Director for the Eastern Region (replacing William Overstreet). At the Division Chief level, Rupert Southard became Chief of the National Mapping Division, and Philip Cohen was designated the Chief of the Water Resources Division.

Equal Opportunity Office

Primary efforts of the Equal Opportunity Office (EEO) at the start of fiscal year 1980 were directed at fulfilling Affirmative Action Program planning requirements placed by Management Directive 702, issued by the Equal Employment Opportunity Commission. The directive, which targeted on determining the extent of underrepresentation for minorities and women and establishing hiring goals for the organization, was further supplemented by guidance from the Department of the Interior. Interaction and coordination between EEO specialists, personnelists, and managers brought about fruitful results in the form of realistic hiring and recruitment goals for the major occupations within the Survey.

Other efforts during fiscal year 1980 resulted in the resolution of 90 percent of the formal EEO complaints received, as well as a high percentage of resolutions of complaints at the informal stage. The Federal Women's Program and the Hispanic Employment Program established and trained Regional Committees which are made up of representatives of each of the Survey's operating divisions.

Lab technician Water Resources Division.

Perspectives

The Eruption of Mount St. Helens—Entering the Era of Real-Time Geology

By Robert L. Wesson

With sections by the Office of Earth Sciences Applications, the Geologic Division, the Water Resources Division, and the National Mapping Division.

Time generally means something different to geologists than it does to others. The geologists' common view of time is like looking through the wrong end of a pair of binoculars. All the myriad events that mark the passing of our daily lives—the passage of the seasons, rains and thaws, floods and droughts, growth and death—are tightly compressed into a murky record of mountain building and erosion, of the deposition of sediments and the weathering of exposed rocks, of evolution and extinction. The geologic history which has been pieced together by the investigations of geologists extends back 4.5 billion years to the origin of the Earth. This history is characterized by spatial changes on a grand scale—the movement of continents, the opening and filling of ocean basins. Generally, however, these movements take place so slowly as to be virtually imperceptible to man—without the aid of instruments developed only recently. The general uniformity and continuity of geologic processes through this 4.5 billion years are central to geologists' approach to understanding the Earth, its resources, and its hazards. However, not all geologic processes occur at continuous imperceptibly slow rates. Indeed major geologic changes can be accomplished in days or even minutes. No more powerful recent reminder of the Earth's capacity for sudden and catastrophic change can be cited than the explosive and disasterous eruption of Mount St. Helens on May 18, 1980.

U.S. Geological Survey scientists had their collective eye on Mount St. Helens over the years and, as a consequence, were able to advise local, State, and Federal officials about the threats from the volcano such that many hundreds, perhaps thousands, of lives were saved. This experience of warning vividly demonstrates the geologist's increasing capability to switch his geologic vision from the long view, thousands or millions of years, to the short view, days and weeks; from a history of Mount St. Helens over the last 40,000 years and especially the last 4,500 years to an estimate of what the mountain will do today—and tomorrow.

In the past, geologists—and the Geological Survey—have used their understanding of geologic history, and the processes which shape it, principally to answer "where" and "what" questions—questions about the location and physical description of geologic deposits or features, such as, where are mineral deposits or petroleum resources located? Increasingly, geologists are being asked "when" questions: When will the next major earthquake strike California? When will we run out of ground water in the high plains of the west? When will the next Cascade Range volcano erupt explosively? The new tenor of these questions presents serious challenges to the earth sciences, and to the Geological Survey in particular. The scientific challenges are severe, requiring answers to questions, many of which, so far, at least, are beyond our grasp: but no less difficult are the challenges to the Geological Survey, and to society, of how to use predictive information about geologic hazards.

What are these challenges? and how is the Geological Survey meeting them? The scientific challenges are the challenges of understanding; the institutional and societal challenges are of communication, education, and the understanding of risk.

Research and the Long View: Basis for Prediction

There can be no scientifically credible warning without a thorough understanding of the geologic history and of the geologic processes at work. The path leading to this understanding is not a straight one nor one which can be cut short. It is, in all likelihood, a circuitous and torturous path which must be followed step by step, flashes of insight followed by deadends and backtracking, each step whether forward or backward, adding some small bit to the total understanding. The investment of research does not always pay off immediately, nor is the final payoff always evident while the work is being done. With the eruption of Mount St. Helens, three long-term research efforts paid off handsomely. Only one of these was aimed directly at the volcanic hazards posed by Mount St. Helens. Perhaps even that was a long shot. What were these areas of research? and how did they come to pay off?

Hazard Studies of Mount St. Helens

Geologic studies of the volcanoes of the Cascade Range began in 1841 with Charles Wilkes' U.S. Exploring Expedition. However, the documentation of the hazards posed by them, and particularly by Mount St. Helens, was done by the career-long efforts of Geological Survey geologists Dwight R. Crandell, Donal R. Mullineaux, and their collaborators. The investigations of Crandell and Mullineaux included the construction of a detailed history of the activity of Mount St. Helens over the last 4,500 years. During this time, the volcano experienced several apparently dormant intervals of about 100 to 150 years and some dormant intervals as long as 400 to 500 years. Throughout this

Devastated area in the valley of the North Toutle River showing deforestation, reordered drainage, and the surface of debris flow and blast deposits of May 18.

4,500 year period, however, the dormant intervals were repeatedly interrupted with periods of activity which included numerous explosions, eruptions of ash, hot avalanches of rock debris, the building of domes, emission of lava and the flows of volcanic debris, and mud and ice off the glacier-mantled slopes of the volcano. This history led Crandell and Mullineaux to conclude in their hazards report, published in 1978, that, "Mount St. Helens has been more active and more explosive during the last 4,500 years than any other volcano in the conterminous United States . . . Mount St. Helens has had a long history of spasmodic explosive activity, and we believe it to be an especially dangerous volcano because of its past behavior and the relatively high frequency of its eruptions during the last 4,500 years. In the future, Mount St. Helens will probably erupt violently and intermittently just as it has in the recent geologic past, and these future eruptions will affect human life and health, property, agriculture, and general economic welfare over a broad area."

The record of Mount St. Helens history was deciphered by a combination of classical geologic mapping and stratigraphic studies with modern techniques. These studies included geochemical analysis to trace deposits from prehistoric falls of ash by their "mineralogical fingerprints" and to determine the age of deposits by radiocarbon analyses of pieces of wood found within them. Soils beneath the ferns and Douglas fir of the forests contain deposits of volcanic ash and hold the clues to determine the pattern of past eruptions of the volcano. Deposits of rock debris from prehistoric eruptions were examined in the area around the volcano to determine their origin, extent, and age. By mapping the distribution of these deposits and analyzing their mineral content and grain size, it is possible to trail them back to their source: the volcano from which they were spewn.

But how, from the record of past eruptions, can future hazards be estimated? A critical assumption was made that eruptions in the future will be of the same general type and have the same general effects as those in the past. Using this kind of approach, Crandell and Mullineaux described a set of "hazard zones," first, on the flanks of the volcano and along valleys leading from it, which would be endangered by lava flows, mudflows, pyroclastic flows (avalanches of hot rock debris ash), and floods and second, in the nearby and downwind areas which would be endangered by the ash fall. These zones were further differentiated by the frequency with which parts of the zone were affected by past eruptions. The potential for flooding caused by flows of mud into the reservoirs behind power dams on the Lewis River, which drains the south and east sides of the mountain, was viewed as a particularly serious problem. Finally, Crandell and Mullineaux concluded their analysis of potential hazards by indicating what hints might be given by the volcano if it were preparing for an eruption, such as the occurrence of numerous small earthquakes or swelling of the volcano, both caused by the underground movement of molten rock, and by listing actions that could reduce possible effects on people and property should warning signs appear or an eruption begin.

A seismologist installs monitoring equipment—April 12, 1980.

The published work of Crandell and Mullineaux was circulated in December 1978 to Federal, State, and local officials and was supplemented by a meeting with key officials and with personal discussions. But, understandably, concern about an event in a sparsely settled region—an event which might have localized impact and be of passing interest only every 100 years or so and have impacts distant from the volcano itself only every 500 to 3,000 years—was accorded relatively little attention. The probability of a catastrophic event was low compared to frequent floods, not to mention the day to day crises that affect us all.

Studies at the Hawaiian Volcano Observatory

Fountains, cascades, and rivers of glowing lava are images of the active volcanoes of Kilauea and Mauna Loa on the Island of Hawaii. Since 1912, Geological Survey scientists have studied, and been trained, in this unique natural laboratory of volcanic processes. The very fluid lava of Hawaii, as contrasted with the thick viscous lava of most Cascade Range volcanoes, is revealed by the smooth gently sloping forms of the Hawaiian volcanoes as compared with the steep, sometimes rugged character of the Cascade Range volcanoes. The difference in the fluidity of lava also accounts for the difference in the behavior of the volcanoes. The investigations at the Hawaiian Volcano Observatory have demonstrated that eruptions in Hawaii are preceded by systematic swelling of the volcano, swarms of small earthquakes, and a periodic trembling detected on seismographs called "harmonic tremor." Eruptions of Hawaiian-type volcanoes are rarely explosive but, nevertheless, have potentially serious impacts for residents on the island. Repeated successful warnings of impending eruptions based on swelling of the volcano and swarms of earthquakes gave a generation of Geological Survey scientists experience, not only with the active science of volcanology, albeit in quite a different geologic setting from Mount St. Helens, but also experience in dealing with officials, the press, and the public before, during, and after an eruption.

Earthquake and Geothermal Studies in the Cascade Range

The active geologic process in the Cascades—of which Mount St. Helens is a part—has other manifestations: earthquakes and geothermal energy. Since 1973, the scientists at the University of Washington, supported by and in cooperation with the Geological Survey, have studied the occurrence of earthquakes in the Puget Sound–Cascade region of Washington State. The core of these studies has been the establishment of a tool for basic research, a seismographic network. Studies of the potential for geothermal power associated with the active volcanic regions of the Cascade Range led to an expansion of the network, with the motive of using the occurrence of earthquakes—and studies of the propagation of seismic waves from them—for locating "hot" regions of the Earth's crust and of developing an understanding of the origin of these hot regions. As it turned out, this seismic network and the joint University of Washington–Geological Survey project were to give the first clues that Mount St. Helens was about to awaken from her 123-year sleep.

Earth Scientists Refocus From the Long View to the Short View

On March 20, 1980, the vicinity of Mount St. Helens was shaken by a magnitude-4 earthquake. The location of the earthquake, as determined by the seismograph network which included one station near the volcano, was at shallow depth immediately northwest of the summit. However, this earthquake was only the first of an intense sequence or swarm of earthquakes. Both the magnitude and number of these earthquakes were unusual for the Pacific Northwest, and their location directly beneath the volcano was immediately recognized as the possible symptoms of an impending eruption. What was the probability of an eruption? and, if the mountain did become active, what precisely would happen? No one knew. The possible scenarios for an eruption, or noneruption, were many, but no one knew how to assess the relative probabilities of the possible scenarios. Geological Survey and University of Washington scientists, working together, began to install portable seismograph equipment and to expand the permanent seismograph network, an exercise which has become commonplace following almost every significant earthquake or earthquake sequence in the United States. One of the principal aims of this effort was to try to determine whether this earthquake sequence was indeed symptomatic of molten rock moving beneath the volcano. As the days passed, the number of earthquakes increased, and the comparison with preeruptive sequences at other volcanoes became more compelling. Snow avalanches, triggered by the earthquakes, led to the closing of the upper slopes of the volcano by the U.S. Forest Service. By March 25, the frequency of magnitude-4 earthquakes reached a level of as many as eight per hour. Sightseers flocked to the area hoping for a glimpse of some activity. On March 26, the immediate vicinity of the volcano was closed on the basis of the potential hazards from an eruption.

On March 27, the Geological Survey issued a cautiously worded but formal "Hazards Watch," indicating that Survey scientists did not "have adequate hard information to determine whether an immediate volcanic eruption will or will not occur. Furthermore, it is not possible at this time to indicate which of the possible geologic effects of the eruption might take place or whether these effects might be experienced only very locally on the volcano or over a wider area." However, the Hazards Watch summarized potential dangers as indicated in the work of Crandell and Mullineaux.

That day the volcano began to erupt steam and ash. Following the actions recommended in the Survey publication, U.S. Forest Service and State and local and emergency officials evacuated people from the immediate area.

It was a chaotic time. The event captured the imagination of the Pacific Northwest and the Nation. No volcano

The "bulge"—May 5, 1980.

The hazards warning, preparedness, and technical assistance program is a relatively new responsibility of the U.S. Geological Survey stemming from the Federal Disaster Relief Act of 1974. The hazards warning activity is designed to develop public awareness of geologic-related hazards and encourage long-range mitigation measures. In addition, a hazards warning dissemination service has been developed to insure timely and effective warnings of geologic hazards to affected Federal, State, and local governments. Where possible, technical assistance and advice is made available also. The system for evaluating and transmitting notifications of hazards includes Notices of Potential Hazards, Hazard Watches, and Hazards Warnings (Predictions). The responsibility for the hazards warning, preparedness, and technical assistance program lies in the Office of Earth Sciences Applications, the Survey's unit involved in multidisciplinary projects concerned with the application of earth sciences information to natural resource planning and management.

When Mount St. Helens began showing signs of renewed activity in mid-March 1980, the Geologic and Water Resources Divisions began collecting and assessing data and, with the Office of Earth Sciences Applications, determined that the possibility of an eruption was great enough to issue a hazard announcement to State and local officials. The Office issued a Hazard Watch on March 31, 1980, the day of the initial eruption. Subsequently, the Office became the focal point for dissemination of information on the geologic and hydrologic activity at Mount St. Helens to Federal, State, and local authorities outside the immediate area of the volcano.

The May 18, 1980, eruption was, for most people, unexpectedly violent and damaging. The Geological Survey was overwhelmed by the need to assess the event and to meet the public and government needs for information and advice. This was particularly so for the Survey's field office in Vancouver, Wash. A representative of the Office of Earth Sciences Applications arrived in Vancouver on May 19, 1980, to assist as field liaison to Federal, State, and local governments and to help handle the extremely large demand for information. When the Federal Emergency Management Agency assumed leadership of the Federal Government's response to the eruption, the Office helped to establish and run the Mount St. Helens' technical information network. They also provided daily briefings to disaster-response officials and backed up the Survey press spokesman.

Representatives of the Office remained in the field through June 1980 when the Federal Government's response became sufficiently advanced to allow it to resume more "normal" operations. Since June 1980, the Office has been given the responsibility for coordinating the development of a Survey Emergency Response Plan for future volcanic eruptions of other Cascade Range and Alaskan volcanoes. This plan has been completed and is in effect.

Drawing upon its experience in issuing hazard warnings and assisting in coordinating emergency response activities, the Office has found that the public and the States could better be served by a more positive information program. Although the Office first issued a notice of the potential hazards from an eruption of Mount St. Helens in December 1978, the area was not as well prepared for the 1980 eruptions as it might have been. Therefore, the Office is developing plans for a series of workshops for Federal, State, and local emergency response officials which will help them to better understand and prepare for potential eruptions at the other Cascade Range volcanoes. In addition, the Office is working with public and private emergency management organizations to exchange, evaluate, and make use of information about how people and organizations respond to the threat of natural hazards and to document the many lessons to be learned from the 1980 eruptions of Mount St. Helens.

had been active in the contiguous United States since 1921. The pressure from the news media was intense. Demands for interviews were so great that scientists could not comply with all and still perform their work. Sightseers jammed the roads leading from the volcano and blocked possible evacuation routes. In addition, many sightseers evaded road blocks hoping to get a closer look.

Analyses of ash indicated that so far only old rock fragments were involved; no new molten rock had been ejected. But, on April 1 and again on April 2, University of Washington and Geological Survey scientists recognized the first sign of harmonic tremor, which normally is associated with the movement of molten rock. On April 3, the Geological Survey updated its Hazards Watch, indicating that "the harmonic tremors . . . are the best indications so far that magma (molten rock) is involved and moving underground. We still cannot predict, however, whether this apparent subsurface movement of magma will break through the surface to produce an eruption of molten material." The Governor of Washington called out the National Guard to help maintain the closure of an area around the volcano to all but property owners and scientists. These moves were unpopular and contested, particularly by loggers excluded from the forest.

Following the first phase of the steam and ash eruption of March 27, a major system of cracks across the summit crater was observed, suggesting the spreading of the north flank of the mountain. Throughout the first 3 weeks of April, evidence of the bulging of the northern slope of the mountain accumulated; visual observations of the cracking and slumping of the glaciers and bedrock were substantiated by photogrammetric surveys and geodetic measurements. By April 25, instruments were in place to monitor the expansion of the bulge on a daily basis. The measurements carried on through early morning on May 18 indicated steady northward expansion of the bulge at rates of 0.5 to 2 meters per day. As the bulge grew, so did concern about the potential hazards it posed. On April 30, the Geological Survey again updated its Hazards Watch, indicating that the apparently unstable mass, if triggered by an eruption or earthquake, could lead to a massive avalanche, which in turn could lead to mudflows and floods in the valleys draining the north side of the mountain. "USGS scientists cannot pinpoint the exact cause of the bulge with the available data," the press release said, "but suspect that the bulging may reflect a combination of swelling from the upward movement of viscous (sticky) magma and gravitationally induced downward creep. . . ."

Did the U.S. Geological Survey tell—or indeed recognize—the whole story? In hindsight, it seems possible to say that the appearance and expansion of the bulge added substantial weight to the hypothesis that significant molten material was accumulating in the volcano and, consequently, that the odds of a significant eruption were substantially increased. However, the scientists could not reach a consensus. Although many individual geologists and geophysicists made this judgment, even aloud at the volcano, the Survey, through its institutional procedures of hazard warning, was not moved to reach this judgment. Why? Scientific uncertainty, institutional fear of being wrong, substitution of the more visible threat of a massive avalanche for the less visible threat of an eruption? Herein quantifiable uncertainty? Where does an established scientific interpretation stop and hunch begin?

Reacting to the advice from the Geological Survey, Governor Ray established two "hazard zones" around the volcano. A "red zone" included the area within a radius of approximately five miles from the mountain. Admission to this zone, which included the vacation community of Spirit Lake, was prohibited to all except law enforcement officials and scientists. A "blue zone," which extended 5 miles beyond the red zone in some places, was under the same prohibitions as the red zone except that logging operations and visits by property owners were permitted, but no overnight stays were permitted. The zones were unpopular. They were violated by journalists and scientists in helicopters and by curiosity seekers. Loggers and property owners, excluded from their homes, were particularly critical. The bulge, ominous as it was to geologists, did not seem to bother old timers of the region, who seemed unable to grasp the danger from a potentially explosive volcano, or even some of the scientists who worked in its shadow.

As scientists monitored the bulge and considered its implications, and as picnickers gathered at road blocks waiting for a view of a plume of steam or ash, owners of private property began to demand access to their cabins and houses to gather their possessions. Finally on May 17, property owners were allowed into the red zone by signing releases and agreements that they would be out before nightfall.

View to the south from vicinity of the north shore of Spirit Lake toward caldaralike amphitheatre of Mount St. Helens in background.

The Picnic Becomes a Nightmare

On the morning of May 18, the picnic became a nightmare. Mount St. Helens erupted catastrophically. The north side of the mountain collapsed in an avalanche, almost certainly triggered by a magnitude-5 earthquake, releasing the pent-up power of the magma with its gas under high pressure. The suddenly unconfined molten rock

Immediately following the first major earthquake on March 20, U.S. Geological Survey specialists in volcanic hazards assessment began intensive consultations and meeting with officials of the Gifford Pinchot National Forest, the land managers for Mount St. Helens, as well as many other Federal, State, and local officials involved in emergency preparedness and contingency planning. Throughout the week before the eruption, scientists from the Survey and the University of Washington arrived on the scene to increase surveillance and to assess volcanic hazards. Indeed, by the time the eruption entered its second week of activity, 25 to 30 scientists were on hand carrying out a wide variety of monitoring and volcanic hazards assessment investigations. By March 31, the onsite volcanic hazards assessment was presented at a major meeting of agencies responsible for public safety, and, on April 1, a large-scale volcanic hazards map was prepared for use by these agencies and the general public. Survey scientists participated in daily meetings and briefings with U.S. Forest Service and other officials and advised them on the locations of roadblocks to control access to hazardous areas around the volcano. Survey scientists contributed essential geotechnical and volcanic hazards information used in the preparation of the "Mount St. Helens Contingency Plan" issued by the U.S. Forest Service, Department of Agriculture, on April 9.

Since the devastating May 18 eruption, Mount St. Helens has continued to erupt intermittently. Significant eruptions occurred on May 25, June 2, July 22, August 7, August 15, and October 16–17. These eruptions produced steam and ash columns, pyroclastic and pumice flows, and small mudflows and were commonly followed by extrustions of bulbous volcanics composed of viscous pasty lava into the bottom of the crater. The first of these domes followed the June 12 eruption and was largely destroyed by the July 22 eruption. A second dome formed after the August 15 activity and was later obliterated by the October 16–17 eruptions. The third volcanic dome grew immediately after cessation of the October eruptions and persists (as of late November) as a muffin-shaped mound; incandescent rock can be observed at night through cracks in its crusted surface.

During the course of the 1980 eruptive activity of Mount St. Helens, significant advances in both the development and application of monitoring techniques, as well as in the understanding of Cascade Range volcanism, were made by both Survey and non-Federal scientists. Since the inception of activity in late March, nearly continuous gas-composition monitoring by Survey and Dartmouth College scientists indicates that the monitoring of sulphur dioxide, carbon dioxide, and hydrogen shows real potential as predictive tools, particularly for the lesser eruptions of June through August. Detailed analysis of the accompanying earthquake activity indicates that characteristic seismic patterns herald the close of each eruptive episode. Gradual changes in the ash and lava chemistry during the course of the 1980 activity provide a basis for anticipating the possible general character of future eruptions. Studies of the pumice-flow eruptions and deposits are providing new insights into the mechanisms of their emplacement and cooling history. Indeed, the 1980 Mount St. Helens activity has provided a veritable scientific workshop and laboratory that will undoubtedly yield important new advances in the field of volcanology and will provide new insights necessary for the prediction of future volcanic hazards in the Cascade Range.

and gas exploded like a bottle of warm champagne suddenly uncorked. The resulting blast devastated everything in a sector extending as far as 16 miles north of the volcano and nearly 20 miles wide. A massive debris avalanche filled the valley of the North Fork Toutle River for a distance of about 17 miles downstream. Mudflows continued on down the Toutle carrying extremely large loads of sediment, logs, and debris on to the Cowlitz and Columbia Rivers. The deposited sediments blocked the shipping channel in the Columbia and dangerously reduced the ability of the Cowlitz River to carry water within its banks, without flooding. Volcanic ash streamed higher than 12 miles into the atmosphere by the force of the explosion and was carried eastward by the wind to deposit ash in a plume across eastern Washington and into Idaho and beyond. What had formerly been a symmetrical cone—the "Mount Fuji of the United States"—was now a truncated cone, marred by a gaping north-facing amphitheater. The questions of "when" and "how big" had finally been answered. Geological Survey scientists, prior to the eruption, in describing the range of possibilities, had sometimes, in passing, mentioned the explosion of Mount Mazama, which formed the famous Crater Lake in Oregon, as an example of an eruption well beyond that which could reasonably be expected at Mount St. Helens. Indeed, the 6-mile-wide Crater Lake is a vivid example of raw destructive power of the explosive Cascade volcanoes. The eruption of Mount St. Helens was small by comparison, but closer than the public had seemed willing to believe was likely.

What was the most "expectable" size of the eruption and how did the May 18 eruption compare? So far, our understanding of the history of Cascade volcanoes is insufficient to answer the question of the *most* expectable size, either on the basis of statistics of past eruptions or on the basis of the kinds of premonitory phenomena observed; that is, the earthquakes, the bulge, the steam eruptions. But Crandell and Mullineaux did make some estimates about the range of possible eruptions and their relative probabilities based on their 4,500 year history of Mount St. Helens. They estimated that eruptions depositing an inch or less of ash within 50 miles or so of the volcano would have a frequency of 1 per 100 years. They estimated that eruptions depositing a few inches of ash at distances of 100 miles and more, as did the May 18 eruption, would have a frequency of 1 per 2,000 to 3,000 years or less. So the May 18 eruption was not a "common" event, but closer to the "worst case." Previous eruptions, however, have erupted much larger volumes of ash.

The course of potentially catastrophic geologic processes such as eruptions and earthquakes may depend on many random factors. Indeed, the most surprising aspect of the eruption was the magnitude of the disastrous lateral blast, which devastated the landscape north of the mountain. Although some evidence for much smaller prehistoric lateral blasts was available, geologists had expected the main force of an eruption to be directed vertically upward. Consequently, it may be very difficult, if not impossible, to know in advance from the symptoms of an impending event whether the event will be a "common one" or a "worst case." We would like to think we can solve this problem, perhaps by determining the volume of molten material available in a volcano or the size of the area over which anomalous phenomena are observed before an earthquake, but there is certainly no guarantee that these ideas will be right. Indeed, prior to May 18, some geologists began to feel that the molten rock, indicated inside the volcano by the bulge and the earthquakes, might solidify inside the volcano in a system of what geologists call "dikes" and, aside from the threat of avalanches and mudflows, be of no particular threat at all. Will the observed symptoms of a geologic process lead to a "worst case," a "common" event or a "nonevent?" This is another key dilemma facing the real-time geologist.

On May 18 and the days after, impacts of the eruption that had not been anticipated by the public were keenly felt by residents of the Pacific Northwest. Although Governor Ray, at the end of April, had declared the entire State an emergency area because of the possibility of widespread ash fall, the volume of the ash which settled like an ominous dark snow over eastern Washington and Idaho created problems of unexpected proportion and nature. Who had prepared for the problems of operating motor vehicles and machinery in an atmosphere of constant dust stirred up by wind or the movement of vehicles, an atmosphere in which the particles of ash are far more abrasive than common dust? And who in Portland, Oreg., where the spectacular plume of ash on May 18 had provided a thrilling display, expected that the mud and rocky debris carried down the Toutle and Cowlitz Rivers would block the shipping channel in the Columbia River, temporarily closing the important port facilities in Portland? Or who anticipated the added impact of the thousands of logs stacked at loading yards along the Toutle Valley which were picked up by the mudflows and swept away the bridges along the river as if they were made of paper? Because many of the phenomena dealt with by the real-time geologist occur so infrequently—from the perspective of man—the impacts are commonly unexpected. Preparations require preparing for the unexpected.

Dramatic before (April 1980) and after (May 24, 1980) photographs of the North Fork Toutle Bridge near Al Rought Park.

The devastation caused by rock, mud, ash, and other debris from the violent eruption of Mount St. Helens was highly publicized by the news media. Less attention was devoted to the potential flood hazards. This can be explained by the fact that many of the water problems which result from a volcanic eruption are not so dramatically or immediately obvious. Frequently, the effects on water resources require scientific investigation and the passage of time before their full implications are understood. When the Division combines its accumulated data of many years with its on-the-spot investigations at Mount St. Helens, it is anticipated there will be better understanding of the longer term effects of sediment transport and mudflows, chemical and biological changes in water quality, and changes in channel morphology.

When the major eruption occurred on May 18, the Water Resources Division was geared to provide immediate water information. Following the initial earthquakes of March 27, 1980, the Division installed 25 water-quality monitoring sites designed to detect changes in water quality that might result from volcanic activity. These sites provided data to supplement that already being obtained in the area from the U.S. Geological Survey's National Stream Quality Accounting Network and the cooperative programs with the Washington State Department of Ecology and the Tacoma City Light Department. At some of the sites, continuous water-quality monitors were installed which were equipped with GOES satellite telemetry to transmit temperature, specific conductance, and pH data eight times a day. Also, on March 27, after a small ash eruption, the Division selected tentative sites on streams draining Mount St. Helens for indirect measurements of floods and mudflows.

When the major eruption occurred, a variety of potential water-related hazards required immediate attention. The on-the-scene investigations of Division crews served many purposes, among them allaying fears of present danger and monitoring eruption-related phenomena which could present problems after a period of days, weeks, months, or perhaps even years.

In the area of the mountain, the field crews were able, in many instances, to provide assistance at once. They began discharge measurements at vital points on the afternoon of May 18 and furnished valuable data for the flood forecasting of the National Weather Service. A significant Division installation was GOES satellite telemetry at the North Fork of the Toutle River. It was able to transmit every 5 minutes if the gage exceeded a preset level. The data were automatically received by the National Weather Service River Forecast Center in Portland, Ore., and the National Weather Service office in Seattle, Wash.

Immediately after the eruption, it was also important to be able to conduct on-the-spot evaluations of the potential for disastrous floods caused by the destruction of glaciers, sediment accumulation, mudflows, and debris. Water Resources Division crews investigated the tremendous quantity of sediment deposited in rivers in the area. In the Cowlitz River, they estimated that about 25,000 acre-feet of sediment clogged the channel between the mouth of the Toutle River and the Columbia River. (This volume of sediment would cover 1 square mile to a depth of nearly 40 feet.)

Because the eruption destroyed the glaciers on the north slope of the volcano, the Survey's Glaciology Project office estimated that approximately 140,000 acre-feet of glacier and snowpack water was removed from the mountain. The snowpack and much of the glacier ice, probably mixed with rock and debris, produced massive mudflows in the Toutle River system and lower Cowlitz. Debris raised the level of Spirit Lake on the North Fork of the Toutle River by 200 feet.

Huge deposits of mud and debris in parts of the Cowlitz River made the available flood-plain delineation maps and river profiles obsolete. By May 26, the Division had completed the first up-to-date river profiles and flood delineation maps. Cooperation from the U.S. Army Corps of Engineers and private firms facilitated and expedited the field survey and mapping effort. New stream gaging stations were installed to provide flood-warning data.

The future Water Resources Division program has a dual purpose: to better understand the hydrologic and geomorphic processes involved in the devastation and recovery of the affected area and to provide sound information for hazard warning and resource planning. The program aims to define pre- and post-eruption conditions and to monitor hydrologic changes. This will involve new surveillance networks, additional gaging stations, glacier study by periodic aerial photography, calculations related to flood profiles and inundation maps, production of mathematical models to reflect improved knowledge related to mudflows, improvement of sediment transport models, investigation of the effects of ashfall on soil water and runoff, and the susceptibility of ground water to contamination. Advancement of knowledge from these studies, together with development of improved scientific techniques, will bring additional expertise to managing water problems caused by future volcanic eruptions.

As an example, the Cowlitz River channel was found to be clogged with sediment deposits following the floods of May 18—average flows would cause flooding. Meanwhile, snowmelt runoff from the higher elevations of the Cascades was rapidly filling upstream reservoirs. Any significant runoff either from accelerated snowmelt or rainfall would exceed reservoir capacity and result in flooding along the clogged reach of the lower river. Geological Survey hydrologists created a computer model of the river system using new channel surveys, parts of which were provided by the Corps of Engineers and private engineering firms. Output of the model allowed immediate assessment of inundation limits for any Cowlitz River flow rates and provided a realistic basis for warning and evacuating flood-threatened residents.

Hundreds, perhaps thousands, of lives were saved by the establishment of the hazard zones. Some of those who died were in the closed areas in defiance of the closure. However, people are skeptical about statements contrary to their common experience, particularly when their livelihood is at stake. Fortunately, the eruption occurred on Sunday when logging operations permitted in the "blue zone," much of which was devastated, were shut down. Real-time geologists must learn that they, like Dr. Stockmann of Henrik Ibsen's *An Enemy of the People,* will not always be either popular or even believed by segments of society.

Questions in the Aftermath

What would the volcano do next? Was the debris flow stable? Would the waters dammed behind it be released in further floods? Would the now clogged Cowlitz River be able to contain, without flooding, more water should the reservoir upstream become full? These were the questions asked immediately after May 18. The prospect of the volcano continuing to be active for 10 to 20 years, as it had in the 19th century, forms a background against which a whole new set of questions began to take shape. When could people go back in to salvage and rebuild? What should be rebuilt and what should be relocated? Would the volcano give a short-term warning of further eruptions as it seemed not to have done on May 18? Could the geologists predict subsequent eruptions in time for people to be evacuated safely from the hazard zones? What would be the effects of the ash on crops and on the health of animals and humans in the affected regions? Would the easily erodible mass of ash and debris in the tributaries of the Cowlitz be mobilized and eroded by winter rains, carrying yet more debris into the Cowlitz and Columbia?

As the months passed, some questions were answered, others deferred. Measurements were made in the clogged channels of the Cowlitz River, and computer models calculated to determine the amount of water which could be released safely from upstream reservoirs and to determine the inundation limits for potential floods. How long will the activity last? Will the volcano rebuild itself? The volcano, as expected from experience elsewhere, continued its activity, with eruptions on May 25, June 12, July 22 and 28, August 7 and 15, and October 16-17. Volcanic domes were erupted into the crater, then exploded during eruptions of ash. Varying patterns, of seismic activity have emerged which seem, so far, diagnostic of these continuing eruptions, enabling warning and evacuation of workers in endangered zones. Other possible precursors, such as gas emissions, seem promising. The debate about the efficacy of attempts to contain sediment in the Toutle Valley and to preserve the gains made by dredging in the Cowlitz and Columbia Rivers continues. Flash floods from new mudflows or the breach of dammed lakes were recognized as a threat. An elaborate system of stream and lake gages equipped with real-time data transmission systems has been installed to monitor the movement of water and sediment downstream. It is hoped that sufficient warning of floods can be given to communities along the Cowlitz.

Prior to the eruption, Geological Survey scientists worked closely with the U.S. Forest Service and, as the situation developed, with State and local officials. After the eruption, the number of individuals and entities needing contact with the Geological Survey scientists, elected officials, and their staffs grew rapidly—the Federal Emergency Management Agency, the Corps of Engineers, the Environmental Protection Agency, and many more. The real-time geologist works in a fish bowl. Important decisions must be made by a multitude of persons based upon individual interpretation. Commonly, the decisions must be made immediately, and, even more commonly, questioners must be given help the rephrase their questions so that meaningful answers are possible. The real-time geologist requires a capability for translation and public relations so that the results of his scientific investigations and interpretations can be used by people needing the answers.

Sharpening the Near Vision: Lessons and Challenges for the Real-Time Geologist

The eruption of Mount St. Helens bears many lessons for the Geological Survey—and for practitioners of real-time geology. Certainly some lessons are yet to be made clear. Implicit in each of these lessons is a challenge for the future. The lessons and challenges are not limited to the prediction of volcanic eruptions but have wide applicability to anyone who would try to forecast the future behavior of the Earth and the processes which shape it, the prediction of earthquakes, glacier surges or retreats, ground water exhaustion or contamination, or future climatic changes.

When something happens to the land, one of the first things people reach for is a good topographic map. When seismic tremors began to alert people of the potential for a volcanic eruption, maps of the area were "on-the-shelf" and ready for use. The area had been initially mapped by the National Mapping Division of the U.S. Geological Survey in the late 1950's when 15-minute maps at a scale of 1:62,500 were first published. Aerial photographs obtained in 1975 and 1979 had been processed into 7.5-minute orthophotoquads, which are scale-accurate photographic "maps" with minimal cartographic annotations showing the immediate mountain area at a scale of 1:24,000. These photographs were used to generate preeruptive digital elevation model data.

Surveying and mapping activities were directed from the Division's Western Mapping Center, which worked closely with the Washington State Department of Natural Resources and the U.S. Forest Service, Department of Agriculture.

Prior to the eruption, initial special mapping efforts involved compiling five "bulge" maps at the 1:24,000 scale to record the developing preeruption topographic changes. These maps showed the growth of the northernmost portion of the volcano and were used by geologists to monitor the rate of expansion leading to the eruption.

Immediately after the eruption, existing maps were used to prepare a special topographic vicinity map at a scale of 1:100,000 (1 inch equals about 1.6 miles) that provided coverage for about 3,000 square miles, showing parts of Clark, Cowlitz, Lewis, and Skamania Counties in Washington and Columbia County in Oregon. This map aided general planning in the devastated areas by scientists, land managers, law enforcement officers, and emergency support personnel. The map, published in four colors, was compiled and published within 3 weeks after the eruption of the volcano.

Division cartographers immediately ordered posteruption aerial photography to prepare new cartographic materials for the Mount St. Helens area. They included nine new 7.5-minute orthophotoquads at the 1:24,000 scale posteruption digital elevation model data and a 1:50,000-scale mosaic of the orthophotoquads to provide a base for compiling scientific and resource data. Additional 7.5-minute orthophotoquads for the Toutle and Cowlitz Rivers were prepared later for evaluations of drainage.

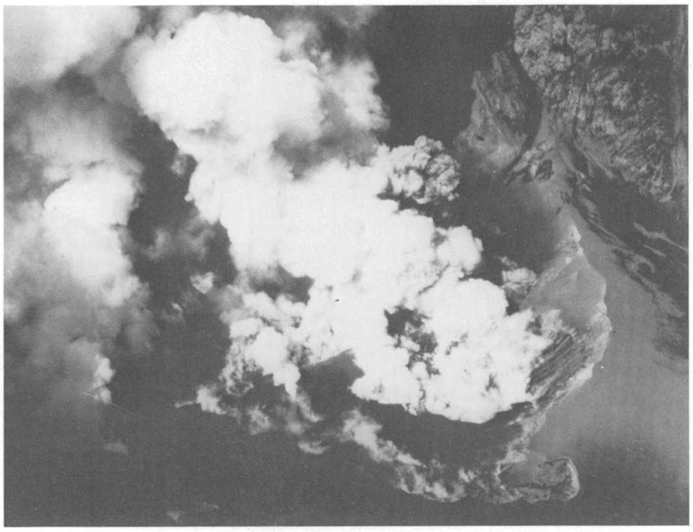
During July and August, two special crater maps were compiled at the 1:24,000 scale with 20-foot contour intervals to show the configuration. These maps portrayed development of a new volcanic cone within the erupted crater basin before and after its subsequent eruption.

Cartographers also used the new aerial photography to revise the special vicinity map published in early April to reflect surface changes that have occurred as a result of the eruption. The posteruption map will include extensive text, photographs, and diagrams on the reverse side and is expected to be published early in 1981.

Plans call for new 7.5-minute topographic quadrangle maps at the 1:24,000 scale to cover nearby or adjacent areas not yet mapped at that scale. Previously published maps of the series are being inspected and revised as needed to show changes brought about by the eruption.

Assistance is being provided to the Water Resources Division in preparation of large-scale, 4-foot contour-interval topographic channel maps at the 1:4,800 scale. Assistance involves establishing precise vertical control at nine gaging stations. The maps, which will meet stringent accuracy standards, will be compiled by the National Mapping Division with assistance from commercial firms.

Such a large aerial survey and mapping program involved substantial coordination by the National Mapping Division with other Survey units as well as a wide variety of other Federal, State, and local agencies which depend on the maps for planning and analysis work. To aid the effort, the National Mapping Division's Resident Cartographer in Washington served as the onsite aerial survey or mapping coordinator and liaison official.



Septum from northeast, Summit Crater—May 30, 1980.

The capability for looking into the future, even in an uncertain probabilistic way, will come from basic research into the nature of the geologic processes which may present future hazards; research to determine the history of past events, their nature, their frequency, and their effects; and research into the mechanics, the fundamental physics, and chemistry of the processes. Only through improved understanding can we improve our ability to take the Earth's pulse and estimate its future activity, benign or deadly. It will not be easy to know exactly what research to do, and the value of the research may not be obvious as it is being done. But the experience of Mount St. Helens emphasizes the value of combining the classical methods of investigation with the modern, of combining historical investigations with the process oriented, and of combining the geological, geophysical, and geochemical approaches. The real-time geologist must utilize the best of the classical methods along with the best of the most modern.

For a long time to come, problems of real-time geology will be at the leading edge of understanding in earth science. From a scientific point of view, this will make them fascinating. From the point of view of society, this will make these problems very difficult because uncertain scientific judgments will require flexible public policies, policies which may not always be as cost effective as they might be if their scientific basis were certain. The possibility must be faced squarely that a predicted event may fail to occur. The science of real-time geology is new. Little, if any, public policy is in place to utilize its results. Policy is exceedingly difficult to develop in advance, in the abstract. The challenge to the real-time geologist is that the public policy will be developed as we go along. Further, the real-time geologist will be asked to help make the policy, an area where geologists have little experience or expertise.

Many problems in real-time geology involve phenomena which pose substantial hazards to life and property. Consequently, the public pays much closer attention to studies in real-time geology than to classical investigations. This poses many problems for the earth scientist unaccustomed to doing his research under the bright lights of the television cameras. The pressures of the media can easily distort the perspectives of the scientists. In other cultures where less value is placed on openness, public attention need not be a problem, particularly if the impending phenomenon has few if any symptoms visible to the naked eye. But in the United States, the public is perceived as having "a right to know," even to know many things which at that moment may be unknowable or, at least, very uncertain. Emergency preparedness requires leadership. Preparations against an unseen hazard, such as earthquakes, rarely spring from enlightened self interest. So public attention to the scientific findings, uncertain as they may be, is required to motivate public action. At the same time, the public attention and discussion can magnify sometimes subtle differences in judgment among scientists, reducing credibility in the public eye. Intense public attention makes the job of the real-time geologist no easier.

The natural instinct of a scientist is to follow his intuition, wherever the scent of discovery may lead him. Commonly, this instinct creates a tension with the need to plan. Contingency plans, however, must be in place to respond quickly and effectively to the threat or occurrence of a potentially hazardous geologic event.

The list of scientific problems ahead for real-time geologists in the Geological Survey is immensely challenging. What does the future hold for the other potentially explosive volcanoes of the Cascade Range and Alaska? When and where will the next major earthquake strike California? When will the Ogallala aquifer supplying water to the High Plains be exhausted? How can systems be designed and monitored to assure that hazardous wastes do not reach ground water supplies? What is the future of our climate?

The eruption of Mount St. Helens is only the beginning. We have entered the era of real-time geology. The challenges before the U.S. Geological Survey will require the highest quality of geologic research. However, these challenges will also require substantial growth in our ability to communicate our results and to assist in their interpretation and implementation.

Devastated area in the valley of the North Toutle River showing deforestation, reordered drainage, and the surface of debris flow and blast deposits of May 18.

Ground-Water Contamination—No "Quick Fix" in Sight

The Problem in Perspective

The full magnitude of ground-water contamination in the United States is not known, and Federal and State efforts to assess and address the problem more fully are being mobilized. Health concerns aroused by the large number of contamination cases discovered in recent years and the spectre of a more widespread problem likely to be revealed by systematic areal inventory have accelerated policy, management, regulatory, investigative, and public information initiatives.

Additionally, the local and aggregate impacts of these unsettling underground discoveries have evoked greater recognition of the important role of ground water in the national water supply. Contamination events, which commonly lead to closure of supply wells and attendant hardships to users, are unhappy but vivid reminders that half the population of the Nation is served by ground water and 41 percent of agricultural irrigation water is pumped from ground-water reservoirs and that in many localities ground water is the only economical source of high-quality water. Contaminated ground water has limited utility, and, practically speaking, deterioration in quality constitutes a permanent loss of water resource because treatment of the water or rehabilitation of the aquifers is presently generally impractical.

The contamination situation has also brought under scrutiny the role of the land and underlying aquifers in the growing national waste-management predicament. Land-use practices have placed ground-water quality in jeopardy on a wider front than earlier perceived as the result of both deliberate and unintentional release of waste liquids into soils and rocks and subsequently into ground water (fig. 1). Several decades of vigorous and generally successful reduction in waste discharge into the atmosphere and into surface bodies of water have stimulated land disposal as an economically attractive and readily accessible alternative practice, which is sanctioned and encouraged by the Government with suitable precautions. However, as threats to water, environment, and health are recognized, stricter requirements are being imposed, and the door to the remaining waste-disposal domain—the land and the subsurface—is closing. The land has always been an inadvertent or deliberate recipient of human and animal wastes, and likely it always will be. Complete control of all sources of ground-water contamination will never be economically or physically possible. It is the levels of protection that must be decided.

In attempts to characterize the seriousness of the situation for legislators and the public, the known cases of underground hazardous waste contamination have been described collectively as "the tip of the iceberg," with the prediction that "this will become the environmental issue of the 1980's," or, more direly, "the environmental horror story of the eighties." And, indeed, the list of contaminated sites is lengthening as the intensity of search mounts.

What, then, can the earth scientist contribute to rational perspective and practicable solutions for this unwieldy perplexing public problem?

Earth scientists have established a record of contribution to public and governmental understanding of natural-resources and land-management issues. Much of the earth science information now produced by the U.S. Geological Survey is directly usable in planning for the management of the Nation's minerals, water, land, and environment. Also, the relevance of supporting programs of fundamental research to resource and environmental concerns is

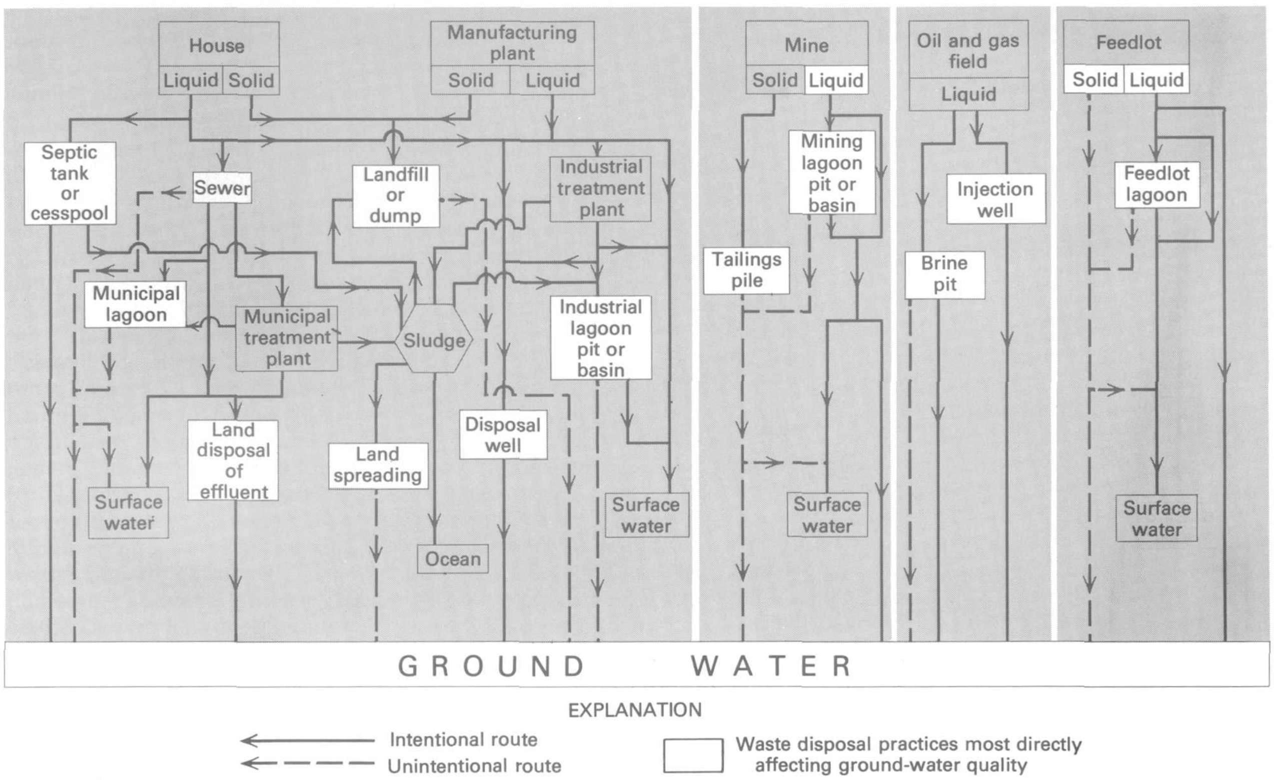


FIGURE 1.—*Waste disposal practices and the routes of contaminants from solid and liquid wastes. (Adapted from The Report to Congress: Waste Disposal Practices and Their Effects on Ground Water: U.S. Environmental Protection Agency, January 1977, p. 7, fig. 1.)*

readily demonstrable. The Geological Survey's hydrological and water-resources contributions, particularly, are commonly problem oriented or problem related, stemming from the intimate relations of water with human endeavors and the local and areal studies engendered by the long-standing cooperative water-resources program with State agencies. These "grass roots" investigations are especially compatible with the localized nature of waste-disposal contamination of ground water.

The ground-water contamination problem is rooted in our vigorous agroindustrial society, with accompanying population growth, urbanization, and increasing stress on land and water. In reality, at issue are a multitude of distinctive and overlapping problems, irregularly distributed throughout the country, for which future preventive actions are much more promising than remedial reclamation measures. New legal, institutional, and technical ground will need to be paved. Viewed by the scientist, then, ground-water contamination is deep seated and not amenable to "quick fixes" or nostrums. Instead, long-term, expensive, and complex protective, preventive, and corrective measures lie ahead which, to be effective and affordable, must be designed around a working knowledge of controlling field conditions—socioeconomic, hydrogeologic, and geographic.

Contamination of ground water by land practices and malpractices is not a new phenomenon in the United States. Events in the 1800's are on record. Two centuries of development undoubtedly invoked a significant cumulative toll on the quality of shallow ground water even before the advent of the exotic pernicious chemicals ushered into the environment in the post World War II period. Despite the resource's history of chemical and hydraulic stress, the volume of ground water significantly degraded can still be assumed to be extremely small compared to the enormous volumes of unaffected water in storage nationally. Intensified inventory may allow an estimate of the portion degraded, but it seems apparent that the resource historically has demonstrated resiliency except under the harshest treatment. Without minimizing the seriousness of cases of contamination recorded to date, these events have served to sound the alert at a relatively early stage that finds the overall safety and usefulness of the Nation's ground-water resources largely undiminished.

For much of the country, then, there is time for informed planning and program design. The following sections of this paper chronicle governmental programs, authorized, legislated, and implemented, including a comprehensive national strategy for ground-water protection now in preparation under the leadership of the U.S. Environmental Protection Agency that will set forth an organized countrywide rationale for systematic attention to ground-water quality.

Federal and State Programs

The Nation has made advances in the reduction of some sources of ground-water contamination, but the bulk of the effort lies ahead. Comprehensive management of the Nation's ground water is a pioneer enterprise. Policy, managerial, regulatory, and technical precedents are rare. Local and State management is uneven—effective in some States and in various stages of evolvement in others. The States now have environmental protection laws and water-quality legislation generally suitable at least for exercise of protective measures for ground-water quality, if not for more comprehensive management. Organizational and program improvements are in evidence; although similar to the Federal record, ground-water quality protection and management has been given second-class priority compared to surface water.

Recent State initiatives are identical to those spurring Federal efforts, concern for loss of usable water, endangerment of health and environment, and the compelling incentives imparted by publicized "horror stories." Specific "point sources" that lead to localized cases of ground-water contamination are receiving more attention initially than "nonpoint" areal and regional contamination originating from more widespread activities, including the collective diffused effects of large clusters of point-source contamination events. Nonpoint problems pose the greater managerial and technical challenge. By virtue of the localized occurrence of many ground-water quality problems, it can be anticipated that the national ground-water protection strategy now under development by the Environmental Protection Agency will install a prominent frontline role for the States.

Existing Federal water-quality legislation pertains primarily to the Nation's surface water; ground water is addressed rarely. A few statutes pertain specifically to ground water, and interpretative ingenuity has yielded others that, by intent or phraseology, are concluded to embrace the ground-water resource. The record of Federal legislation concerning water quality provides a chronicle of evolving programs that consider the ground-water resource and its protection.

The Refuse Act, one section of the River and Harbor Act of 1899, has been employed with success during the past decade as authority to regulate discharge of wastes to navigable streams. Though primarily focused on rivers, provisions of the act address land management as an influence on environmental and water quality and, therefore, have ground-water quality significance. Further progress toward national water-quality management is reflected in passage of the Water Pollution Control Act of 1948. Here, too, the primary emphasis is on stream-quality improvement, but, by a passing reference to ground water, the act was a precursor of broader amended legislation to follow in several decades.

The Nuclear Regulatory Commission, the Energy Research and Development Administration of the U.S. Department of Energy, and the Environmental Protection Agency share responsibilities and collaborate in the control of radioactive materials and emissions and in other actions necessary to protect the public health and environment from harmful radioactivity. The Atomic Energy Act of 1954 assigns principal regulatory responsibility to the Nuclear Regulatory Commission. The Environmental Protection Agency establishes standards for protection of the general environment from radioactivity. Water is the primary agent for transport of nuclear contaminants disposed of on the land. Disposal of radioactive waste materials without serious jeopardy to the environment and water resources is a societal and technical challenge.

Environmental impact analyses and statements required before initiation of certain Federal activities or construction under the National Environmental Policy Act of 1969 have drawn attention to the functions of water in the biosphere and to the susceptibility of the water resources to contamination. Water concerns and hydrologic investigations precipitated by the act undoubtedly have served to raise consciousness of the existence of the ground-water resource and its significant role in land and water management.

The Federal Water Pollution Control Act, which was amended in 1972 and which established a major nationwide program of waste management, pointed to surface-water quality improvement and protection. Ground-water relevance is left to inference in most of the act, but several sections clearly apply to that resource, and implementing programs are evolving. Section 208 is the most pertinent. It supports and encourages statewide and areal planning for waste management for the purposes of environmental and water-quality protection. The broad planning promoted by the act is especially appropriate to the solution of areally extensive ground-water contamination problems of nonpoint origin.

Two other sections of the amended act clearly apply to ground water. Section 304(e) requires that the Environmental Protection Agency issue guidelines to State and Federal agencies on how to deal with both nonpoint contamination and a long list of specific potential sources, including waste-disposal wells, surface impoundments, landfills, septic waste systems, saltwater intrusion, and the degradation of water quality attributable to pumping water from wells. Section 402 makes provision for issuance of permits by the States to regulate disposal of wastes in wells. However, the requirement is limited in both interpretation and application to deep waste-injection wells only.

The goal of the Safe Drinking Water Act of 1974 is evident in its name; it is intended to assure safe drinking water for all persons supplied by public water systems. It includes provisions intended specifically to protect aquifers utilized as sources of drinking water and to control and protect them from subsurface waste discharge (underground injection). Special protection is afforded to "sole-source" or "principal drinking-water-source" aquifers. Requirements of the act apply only to Federal and Federally supported activities that endanger drinking-water sources, but it serves as a base or model for parallel State controls. As of now, sole-source aquifers have been designated for the following localities: Fresno, Calif., Miami, Fla. (Biscayne aquifer), San Antonio, Tex. (Edwards Limestone), Spokane–Rathdrum Prairie, Wash.–Idaho, Passaic River Basin, N.J. (buried valley), Long Island, N.Y., and Ten Mile Creek, Md. Four others are being initiated: southwestern Missouri, karst aquifer system, Cape Cod, Mass., New Jersey coastal plain, and Scott Valley, Calif. A number of additional localities have been proposed.

The Resources Conservation and Recovery Act of 1976 regulates the management, storage, transportation, and disposal of hazardous wastes. The main thrust is improved land-disposal practices, which would have obvious potential benefits to ground-water quality protection.

These legislated programs do not constitute an exhaustive listing of Federal actions benefiting ground-water quality. The Environmental Protection Agency administers the Toxic Substances Control Act of 1976 and the Insecticide, Fungicide, and Rodenticide Act of 1972 as well as other programs whose broad purpose is to limit release of harmful chemicals to the environment, though they may not address the ground-water domain directly. And many Federal Departments carry mission-oriented responsibilities for land and resource management and environmental protection that include water-resources concerns. The Surface Mining Control and Reclamation Act of 1977 administered by the Department of the Interior is one example, and innumerable relevant activities can be identified in programs of the Department of Agriculture, the Army Corps of Engineers, and the Department of Commerce.

Thus, the array of Federal and State programs that deal with the environment and water contains some measure of ground-water quality protection, and, collectively, these programs constitute the foundation for expanded effort. However, it should be noted that fundamental policies concerning how the Nation should address this broad complex issue are yet to be formulated. The Environmental Protection Agency is engaged in development of a national ground-water protection strategy to define policies and national program goals. Because of the far-reaching effects of contamination, the strategy is being devised with State and broad public participation.

U.S. Geological Survey Investigations

Knowledge of the makeup and workings of the Earth is a basic requirement for the design of technically sound economic measures for the management of ground-water quality. Land usage determines the nature, source, and severity of contamination events in the subsurface, and management of the Nation's ground-water quality is tied to land-use practices. Figure 2 illustrates the hydrologic connection diagrammatically. Ground-water quality cannot be addressed in isolation.

The Water Resources Division of the Geological Survey addresses water-information requirements of the Nation through comprehensive programs of investigation, data collection, and research. Collaboration with the States and with a number of Federal agencies enables local, State, regional, and national levels of work. Multidiscipline technical teams pursue hydraulic, chemical quality, and geochemical investigations in tandem or integrally, and ground water is infused among these programs. The work of the Water Resources Division cannot be separated clearly into surface- and ground-water components, but ground water is estimated to constitute about 40 percent of the organization's total program.

The "grass roots" Cooperative Program with State geological and water agencies (see pages 120-129) is particularly conducive to ground-water investigation because a large share of the problems is of localized areal extent. These jointly funded investigations deal with an array of general and specific water concerns. The increasing number of investigations concerned specifically with ground-water contamination is a measure of the Cooperative Program's response to that growing problem. During the 1950's, 6 contamination reports were published; during the 1960's, there were 42 reports; and, during the 1970's, 121.

Broader programs of national scope, funded solely with Federal funds, include investigations of regional and national scale, systematic hydrologic observations, and research. "Thrust" programs address critical national water problems. In 1978, the Geological Survey initiated the major Regional Aquifer-System Analysis Program for the purpose of providing regional hydrologic descriptions for the 28 principal aquifer systems of the country. These regional studies complement the State cooperative investigations; together, they provide a foundation of technical information on flow systems and quality of water to aid all levels of planning and management. With regard to contamination problems, an effort is being made in the Regional Aquifer-System Analysis Program to interpret water-quality and geochemical information integrally with knowledge of the flow systems to predict large-area water-quality problems of the future and to aid in the design of preventive, management, and, where practicable, corrective measures.

A number of other national Geological Survey programs deal with critical water- and waste-management problems involving ground-water quality and contamination. The decade-old Subsurface Waste Storage Program addresses hydrologic principles and terrane suitability associated with practices of subsurface waste disposal, contamination, and ground-water-quality management. A major program concerned with nuclear energy hydrology is yielding scientific information required to manage, store, and

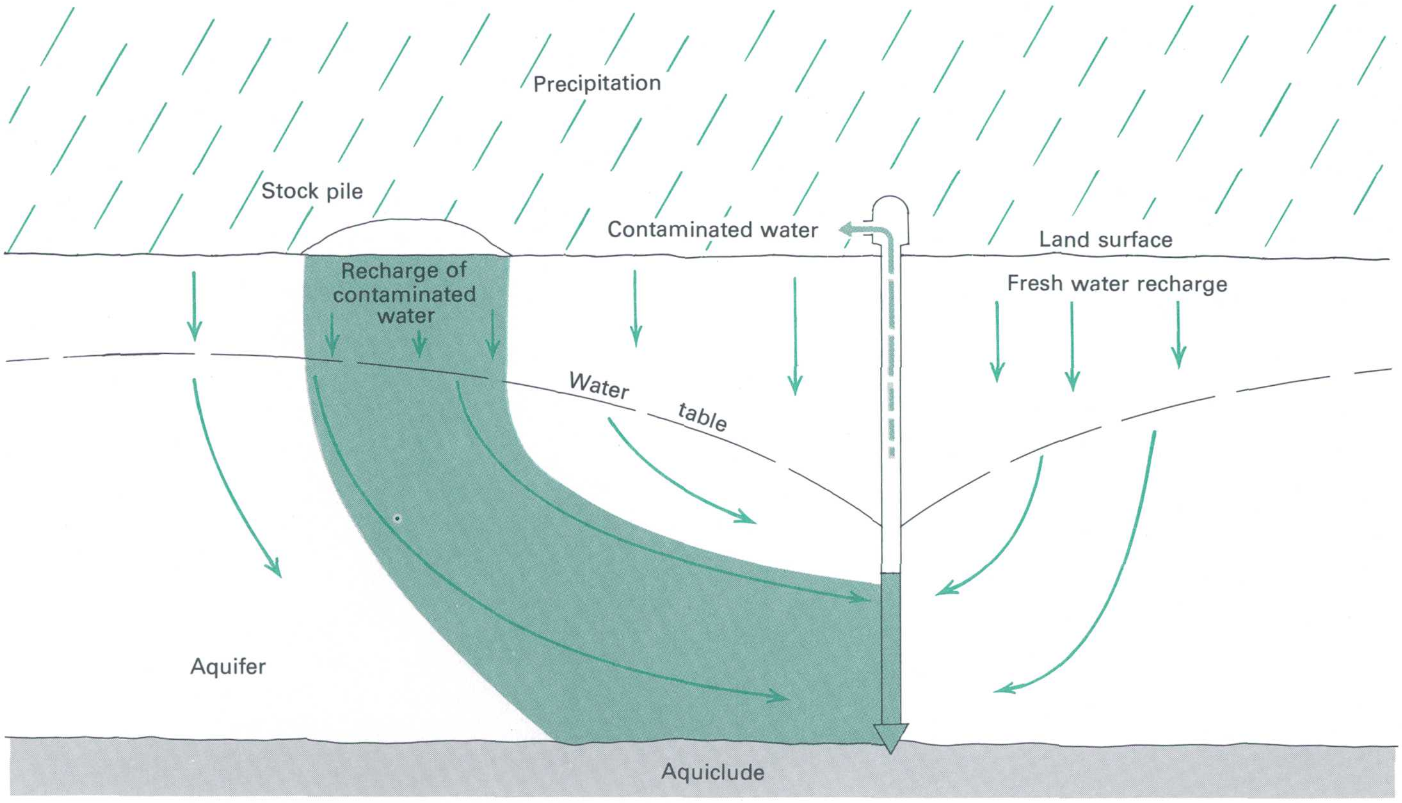


FIGURE 2.—*Diagram showing contamination of an aquifer by leaching of surface solids. (Adapted from Ground Water Contamination and Legal Controls in Michigan, by Morris Deutsch: U.S. Geological Survey Water-Supply Paper 1691, 1963, p. 35, fig. 14.)*

dispose of radioactive waste materials. These programs represent efforts of substantial proportions but are only a small version of the investigative and research effort likely to be required to provide adequate earth science information for management of ground-water quality.

The immensity of the Nation, the chemical and physical diversity of its terrane, and intensity of land usage pose major challenges for ground-water quality management, and much remains to be learned. Special challenges rest with geochemical hydrology and predictive methodologies. Simulation methods have become basic tools of ground-water hydrology, but only hydraulic flow models are well established and fully operational. Solute transport models that aid prediction of the movement of inorganic constituents in ground water are in hand, but additional field testing and verification are needed. Accuracy and reliability are dependent on improved methods for acquiring the physical and chemical data from study sites utilized in the mass transport equations. Transport models for organic solutes pose still additional difficulties that will entail more extensive laboratory and field study.

The Outlook

Ground-water contamination problems now attracting wide governmental and public concern in this country are rooted in land- and water-management practices. Solutions rest largely in changing these practices to take into account the susceptibility of the ground-water resources to degradation. Federal and State actions are now in evidence, and more comprehensive policies and programs are being devised. Although restoration of contaminated ground water is generally impractical, legal and physical means to limit further influx of contaminants are available and improving.

Seriously degraded ground water probably constitutes only a minor fraction of the total national ground-water supply. Local predicaments notwithstanding, the bulk of the resource remains unaffected, and there remains time for carefully conceived plans based, to the extent practicable, on adequate and accurate information. No "quick fixes" are likely. As the known dimensions of the problem expand, State and Federal geological and water agencies can expect accelerated demands for scientific and technical information to cope with site cases, areal nonpoint problems, and broader regional and national management measures.

Missions, Organization, and Budget

Missions

When the U.S. Geological Survey was established by an act of Congress in 1879, it was charged with the responsibility for the "classification of public lands and examination of the geological structure, mineral resources, and products of the national domain." Over the years, the evolution of the earth sciences, the need to carefully manage the Nation's nonrenewable resources and to find new sources of scarce energy and mineral commodities, and the mounting concern regarding the impact of man on the Nation's environment have added numerous other duties including topographic and geologic mapping, chemical and physical research, stream-gaging and water-resource assessments, and supervision of mineral exploration and development activities on Federal and Indian lands.

In general, the Survey's activities are oriented toward two basic missions, scientific and regulatory. The first mission is to collect, to analyze, and to publish information about the Nation's energy, mineral, land, and water resources; to conduct research to determine the geologic structure of the United States; and to develop an understanding of Earth processes and history. The second is to classify Federal lands as to their water and mineral potential and to supervise the activities of lessees who explore for and develop the mineral resources of Federal and Indian lands and the Outer Continental Shelf (OCS). Both missions and their supporting activities are directed towards the goal of assuring that the Nation's mineral resources are identified, conserved, and developed in an orderly, timely, and diligent fashion; that the American people receive a fair return on the value of their leased resources; and that mineral exploration and production activities on Federal and Indian lands are conducted with due regard for the interests of the communities directly affected and with minimum damage to other resource and environmental values.

Right Mitten, Monument Valley, Utah and Arizona.

Organization

The Geological Survey is headquartered at Reston, Va., and maintains a nationwide organization consisting of three Regions and more than 200 Offices located throughout the United States. The Survey is organized into four Program Divisions (National Mapping, Geologic, Water Resources, and Conservation), two major Offices (Earth Sciences Applications and National Petroleum Reserve in Alaska), and two support Divisions (Administrative and Computer Center), each reporting to the Director of the Survey as shown in the diagram appearing on pages 112 and 113 in the section entitled "Organizational and Statistical Data." Information on the reorganization of the Geological Survey during fiscal year 1980 appears in the "Year in Review" chapter.

A number of Assistant Directorships coordinate the activities and relations among the Divisions and the three Regional Offices and render staff services to the Director and Associate Director in certain specified areas such as program analysis; energy, mineral, and water resources and management; geologic engineering; and regulation.

The Geological Survey's field organization is made up of Regional Offices at Reston, Va., Denver, Colo., and Menlo Park, Calif., and a network of field and special-purpose offices. These offices coordinate and administer the work of the Survey's widely dispersed activities. The Water Resources Division, for example, has District Offices in 45 of the 50 States and 1 in Puerto Rico. The Conservation Division maintains 70 Area, District, and Inspection Offices close to its areas of work on the public lands and adjacent to areas of petroleum development on the Outer Continental Shelf. A directory of the Survey's National Center and selected field offices begins on page 114.

Budget

Total obligations incurred by the Geological Survey in fiscal year 1980 were $782 million, an increase of $17 million over those for the preceding year. Obligations for "Surveys, Investigations, and Research" were $469 million, an increase of $51 million over those for fiscal year 1979. Included in this increase were new or expanded programs for wilderness mineral surveys, coal programs, regional aquifer analyses, Earth Resources Observation Systems, volcano hazards, and onshore and Outer Continental Shelf oil and gas programs. Obligations for "Exploration of National Petroleum Reserve in Alaska" were $170 million in fiscal year 1980, a decrease of $47 million over those for the previous year.

Funds from other Federal agencies, States, and non-Federal sources amounted to $143 million, an increase of $13 million over those for fiscal year 1979. Included in this amount were $47 million from States, counties, and municipalities under the "Federal-State Cooperative Program," $3 million more than that for fiscal year 1979.

Just as the Survey performs services within its own field of expertise for other agencies by means of reimbursable agreements, outside sources are relied upon by the Survey for the accomplishment of an increasing share of its workload. Funds obligated for grants and contractual services have risen from less than $25 million in fiscal year 1973 (11.5 percent of total funds) to $150 million in fiscal year 1980 (24.5 percent of total funds, excluding National Petroleum Reserve in Alaska). The $170 million obligated under "Exploration of National Petroleum Reserve in Alaska" was almost entirely for contractual services.

The table shows a comparison of obligations in fiscal year 1979 and 1980 by major budget activity, and figure 1 depicts the annual obligations incurred by each activity from 1970 to 1980.

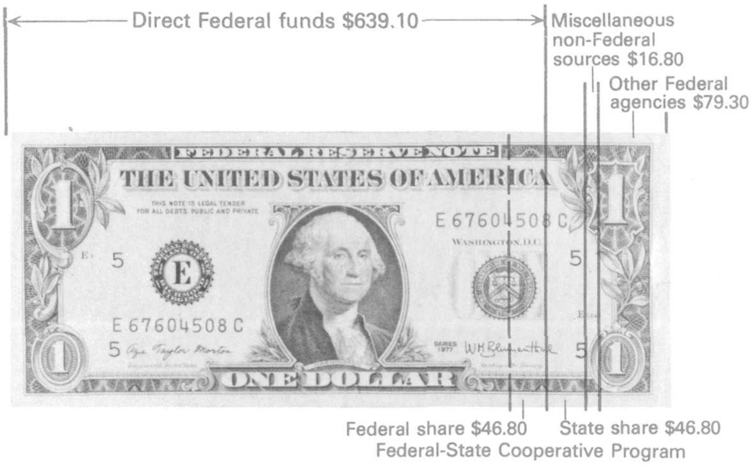
A 10-year comparative analysis of obligations incurred under direct and reimbursable program activities is presented in figure 2.

Detailed supplementary budget and statistical tables are available upon request from the Program Office, U.S. Geological Survey, 105 National Center, Reston, VA 22092.

U.S. Geological Survey obligations for fiscal years 1979 and 1980, by activity

[Dollars in millions. Data may differ from that in statistical tables because of rounding]

Activity	Fiscal year 1979	Fiscal year 1980
Total	**$764.72**	**$782.12**
Direct programs	634.89	639.13
Reimbursable programs	129.83	142.99
Alaska Pipeline Related Investigations	----	----
National Mapping Geography and Surveys	**74.56**	**82.68**
Direct programs	65.58	72.76
Reimbursable programs	8.98	9.92
Geologic and Mineral Resource Surveys and Mapping	**178.56**	**193.65**
Direct programs	134.85	146.96
Reimbursable programs	43.71	46.69
Water Resources Investigations	**168.60**	**184.87**
Direct programs	96.85	108.66
Reimbursable programs	71.75	76.21
Conservation of Lands and Minerals	**85.48**	**106.40**
Direct programs	85.36	105.93
Reimbursable programs	.12	.47
Office of Earth Sciences Applications	**23.96**	**23.73**
Direct programs	19.96	18.93
Reimbursable programs	4.00	4.80
General administration	**3.66**	**3.77**
Facilities	**11.74**	**12.27**
Miscellaneous services to other accounts	**1.26**	**4.91**
National Petroleum Reserve in Alaska	**216.89**	**169.85**
Direct programs	216.89	169.85
Allocation transfer	----	----



SOURCE OF FUNDS

TOTAL $782.10 MILLION

USE OF FUNDS

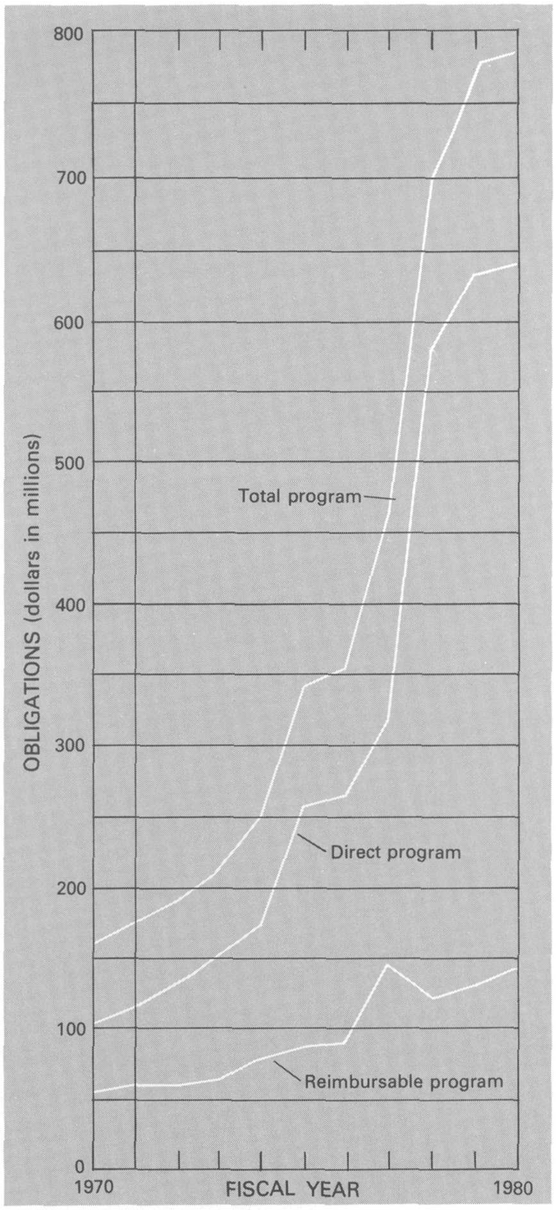
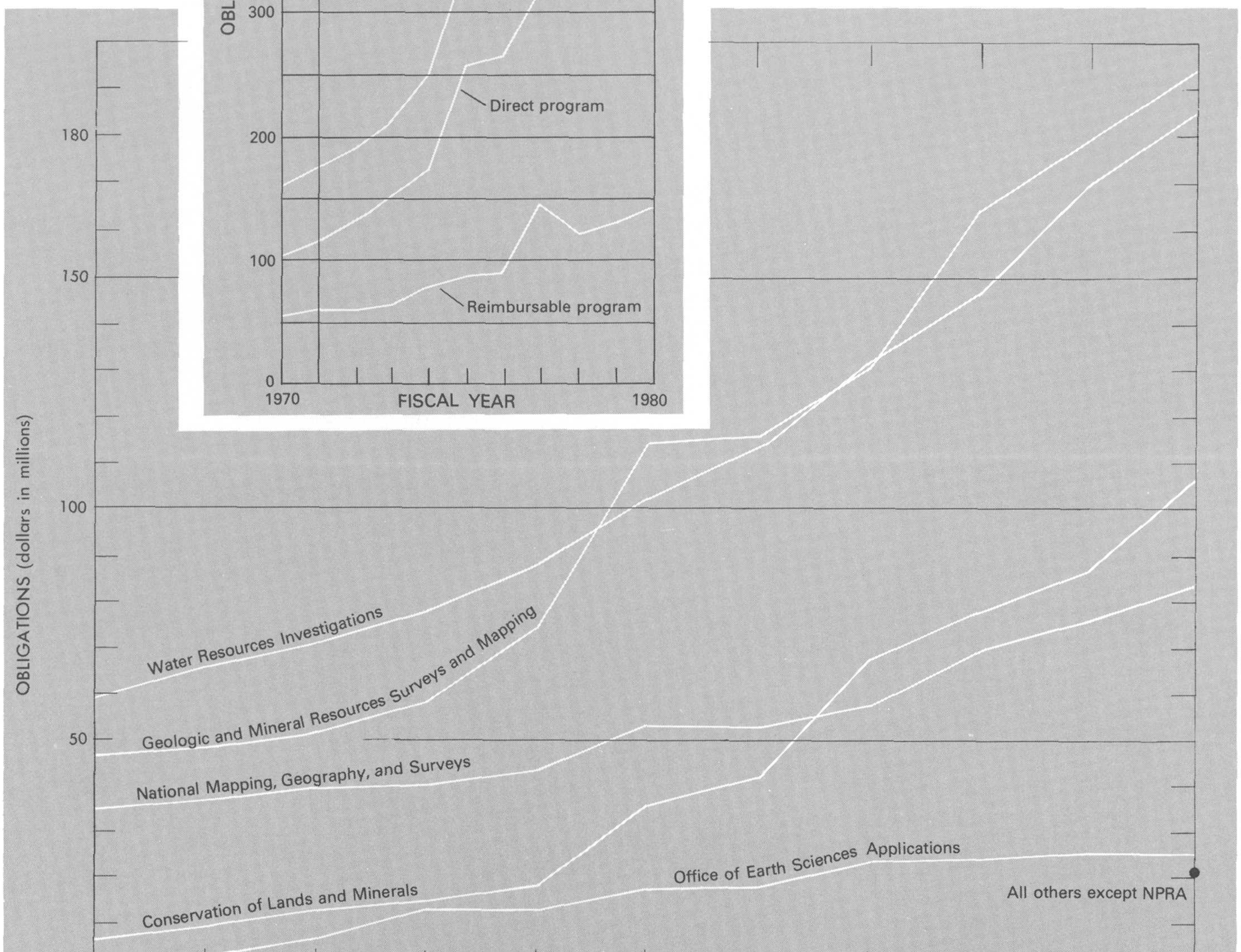


FIGURE 2.—U.S. Geological Survey budget for fiscal years 1970 to 1980, by source of funds.

FIGURE 1.—U.S. Geological Survey budget for fiscal year 1970 to 1980, by activity.



Personnel

Although the workload of the Survey has grown dramatically during the past 6 years, its permanent employment has risen very little from 8,357 at the end of fiscal year 1974 to 9,309 at the end of fiscal year 1980, an increase of 11 percent. The increased responsibilities related to the Survey's scientific activities have been accomplished with an essentially level full-time work force; virtually all of the increases in full-time personnel have been directed to the rapid increases in regulatory activities. These are principally related to energy exploration and development on Federal lands. Although much of the nonregulatory program increases have been "contracted out" as described in the preceding section, a substantial share of the additional work is being performed by the Survey's other-than-permanent employees. The number of these part-time positions has more than doubled since fiscal year 1973, as shown in figure 1. The Survey has profited greatly from its utilization of other-than-permanent employees. Many eminent specialists have been employeed on a part-time basis and have afforded the Survey great flexibility in meeting surges in the workload. The arrangement also has unique advantages in bringing the academic community into close and continuing contact with government on a personal level.

Staff distribution among the several Divisions is shown in figure 2. Scientists, engineers, and other professionals comprise roughly one-half of the Survey's total permanent staff, and technical specialists account for an additional 22 percent Hydrologists and geologists predominate among the professional corps, 17 percent of whom have doctoral degrees. These and other aspects of the Survey's permanent work force are presented graphically in figure 3.

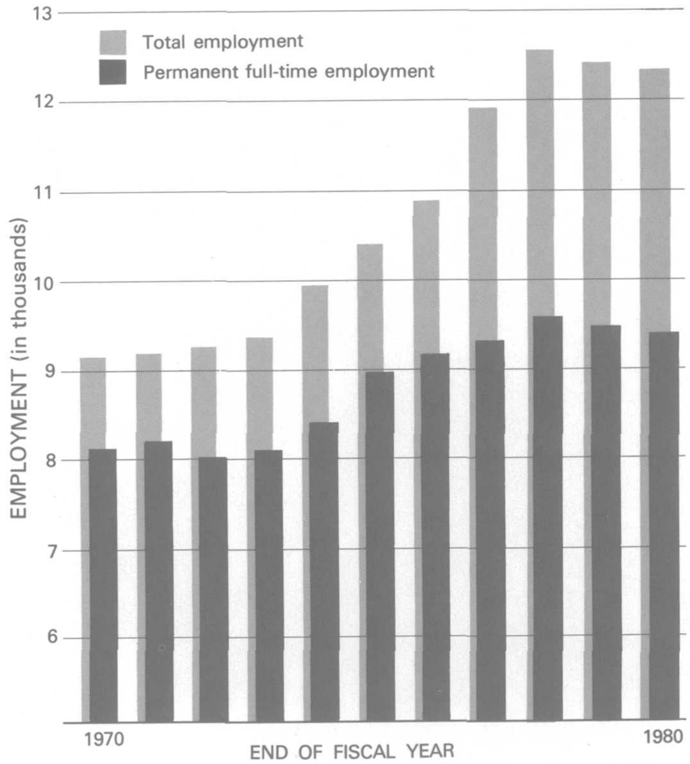


FIGURE 1.—U.S. Geological Survey end-of-year employment for fiscal year 1970 to 1980.

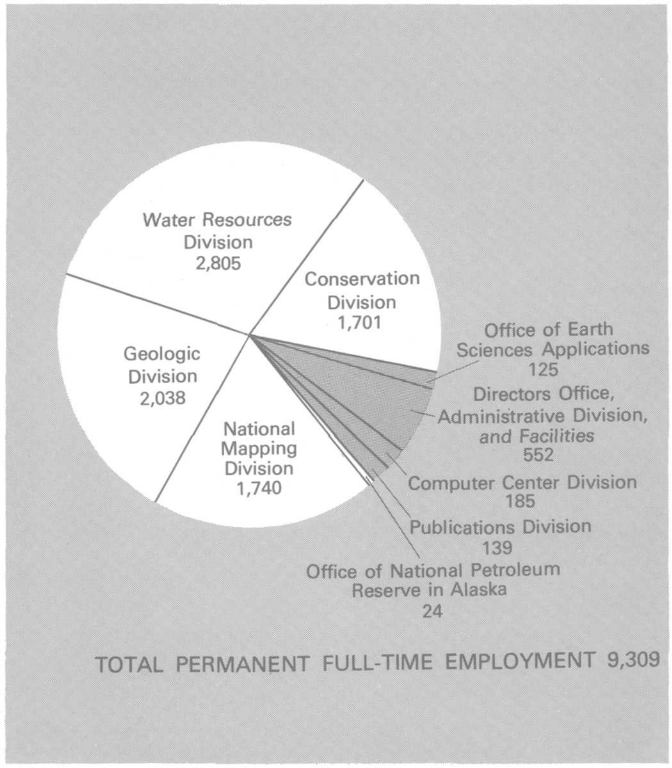


Figure 2.—Distribution of permanent full-time U.S. Geological Survey employees as of the end of fiscal year 1980, by organization. (Publications Division number represents remainder of personnel to be reassigned to other organizational units.)

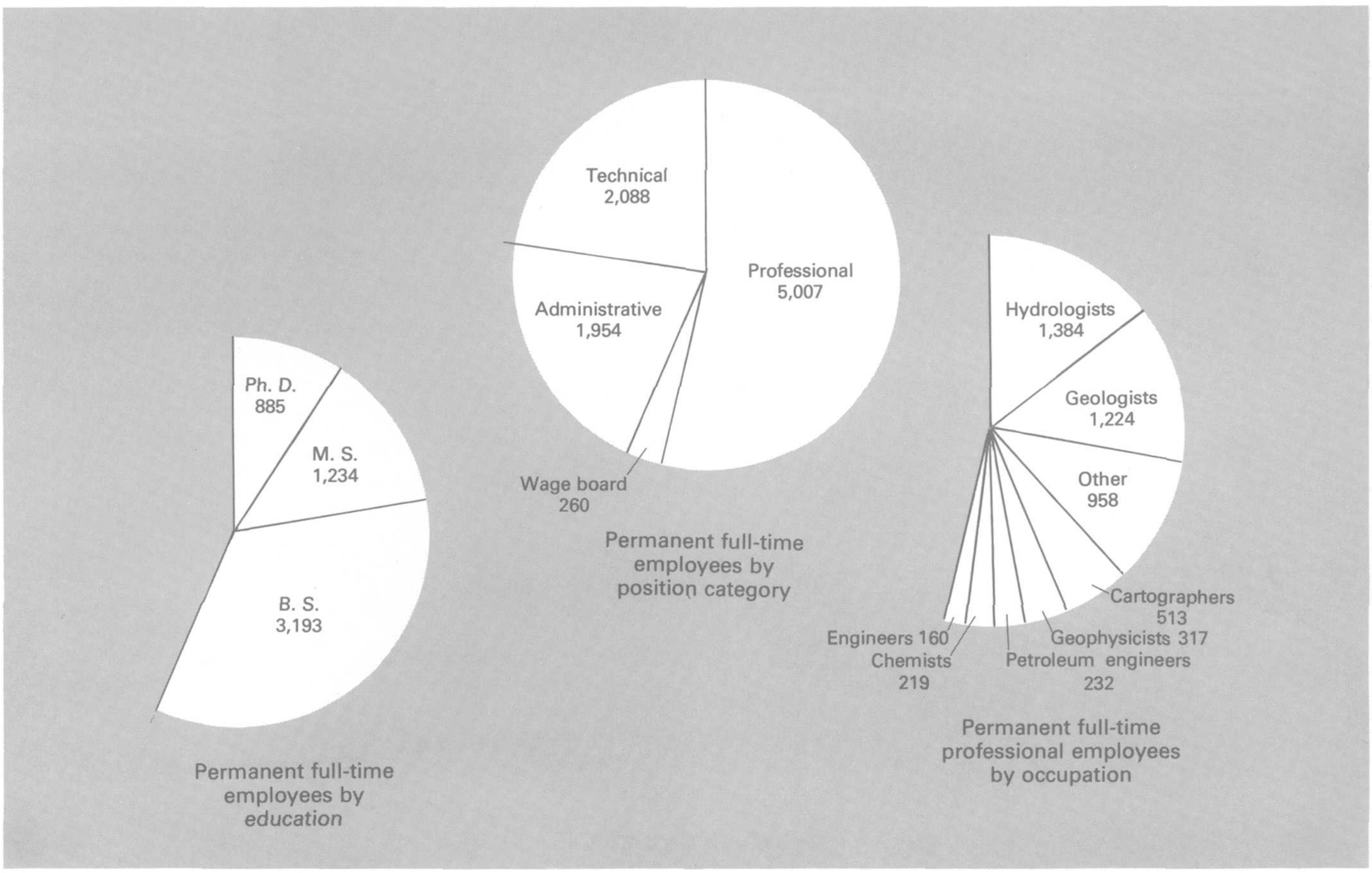
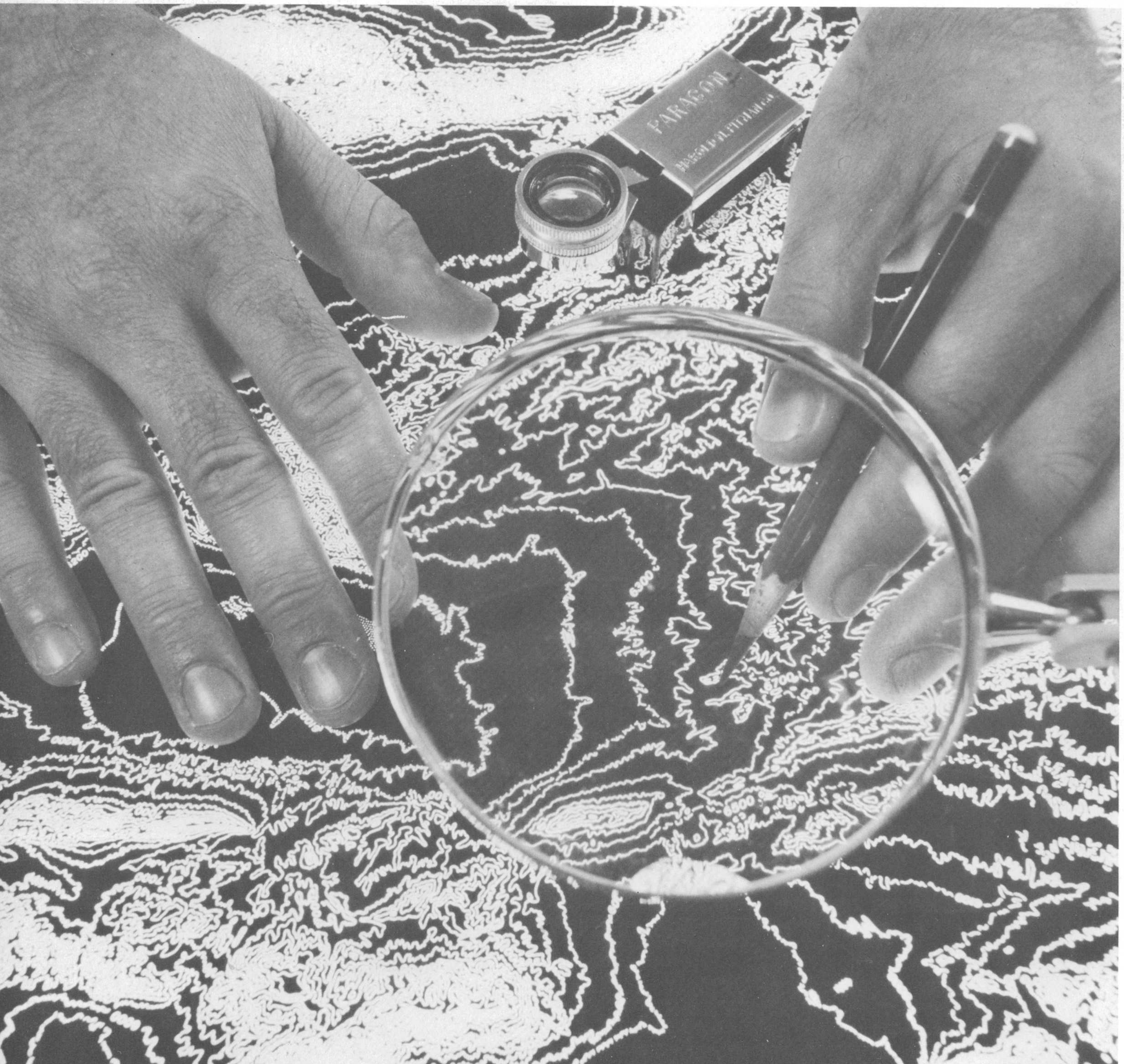


FIGURE 3.—Permanent full-time U.S. Geological Survey employees, by type.


PARAGON

National Mapping, Geography, and Surveys

A New Era

Perhaps not since application of aerial photography to mapping has the science and technology of portraying the things of the Earth been in such a state of change. Growing and more sophisticated demands for earth science information and the opportunities for handling the information through computer technology have created a new era in cartography and geography.

The U.S. Geological Survey is acutely aware of changes in public expectations and technology related to mapping. As the Nation's principal earth sciences agency, it has led many of the developments and, in fiscal year 1980, brought into being a new National Mapping Division to continue that leadership role through the remaining years of the 20th century.

In fall 1979, the Department of the Interior approved a Geological Survey recommendation establishing a National Mapping Division from units within the agency. The proposal brought together Survey components with mapping and map-related responsibilities, including the Topographic Division, most elements of the Publications Division, and the Survey's Geography Program. The purpose was to form a broad-based mapping organization built on the scientific disciplines of cartography and geography, incorporating related technical and physical resources of map printing and distribution. The new Division also included an important new component for managing and disseminating cartographic and geographic information.

The National Mapping Division was established on an interim basis in January 1980. Work has since proceeded on details of the organization and personnel and financial arrangements necessary to bring the unit into formal operation by the start of fiscal year 1981.

Organization Highlights

There are several significant organizational developments for the new Division.

The Research staff has undergone perhaps the most substantial change. It was previously organized into major functions associated with mapping—field surveys, cartography, and photogrammetry. It is now composed of three major offices, two of which are for basic and applied research in cartography and geography and the third of which is primarily designed for providing engineering and technical assistance for production activities. Research activities are being strengthened and more clearly separated from on-going production needs.

A central Plans and Operations staff plans and budgets the Division's programs, oversees accomplishments, manages international activities, and coordinates and manages various management information systems.

Previously separate components have been brought together into a single organization responsible for planning and developing policies and procedures for scientific information and product distribution services. It consists of a new product distribution policy office, a National Cartographic and Geographic Information Service, an Office of Publications Liaison and Review, and the Geological Survey's Public Inquiries Offices. The organization reflects the Survey's desire to improve the flow of earth sciences information to the public. Particular emphasis is being placed on complete information programs, such as digital spatial data (geographic and cartographic data in computer formats).

Field Units

The National Mapping Division's field organization carries forward the former Topographic Division's four mapping centers as principal locations for map production. These centers continue to be points of contact and coordination for mapping on a regional basis, working with other Federal agencies and coordinating joint mapping activities with the States.

A fifth center includes the printing and distribution units of the former Publications Division and is situated in Reston, Va. It is also responsible for warehouses in Arlington, Va., Denver, Colo., and Anchorage, Alaska, as well as the Survey's printing plant at the National Center, Reston.

The Survey's mapping centers are situated in Reston, Va., Rolla, Mo., Denver, Colo., and Menlo Park, Calif.

Major Activities

The National Mapping Division conducts the National Mapping Program of the United States, which includes the following major activities:

- Quadrangle mapping and revision, including production and revision of 7.5-minute maps at 1:24,000 scale in Inch-Pound System Units and 1:25,000 scale in metric units for the conterminous United States, Hawaii, and developing areas in Alaska, and maps at 1:63,360 scale (Inch-Pound System Units) and 1:50,000 scale (metric units) for Alaska.
- Small-scale and special mapping, including preparation of maps and map products from the intermediate scale (1:50,000 and 1:100,000) series to the small-scale U.S. base maps (1:250,000).
- Information and data services, which include acquisition and dissemination of information about the Nation's maps, charts, aerial and space photographs; geodetic control, cartographic and geographic (spatial) data, and other related information; distribution of earth science information to the public; and sale of map and map-related products through nearly 2,000 private retailers.
- Advanced development and engineering, including modernization of mapping to improve the quality of standard products; to provide new products, such as digital cartographic data, that make maps and map-related information more useful to people; to reduce costs and to increase productivity of mapping activities; to acquire innovative and more useful equipment; and to design and develop new techniques and systems, such as building and testing components for an advanced airborne system designed to speed surveying important areas of the Nation.
- Digital cartographic and geographic research with particular emphasis on spatial data techniques for multidisciplinary studies employing methods of modern geographic analysis and to develop new and improved cartographic concepts and techniques.
- Digital mapping is a program to produce base categories of cartographic data in standard scales, accuracies, and formats suitable for computer-based analysis in response to high-priority Federal requirements.

Budget and Personnel

For fiscal year 1980, National Mapping Division obligations amounted to $82.68 million, an increase of about 7 percent over fiscal year 1979. Included are funds from 40 States, which, when matched by Federal funds, amounted to more than $6.4 million for cooperative mapping. The cooperative projects mutually benefit the State and national program by ensuring completion of map coverage sooner than would otherwise be possible.

The National Mapping Program of the Geological Survey is carried out through a combination of in-house and cooperative efforts and contracts. The in-house effort involves about 1,994 career employees, many with special training in geography, cartography, data processing, engineering, photographic technology, and the physical sciences. About 254 additional employees, many on work-study programs, serve as temporary aids.

SOURCE OF FUNDS

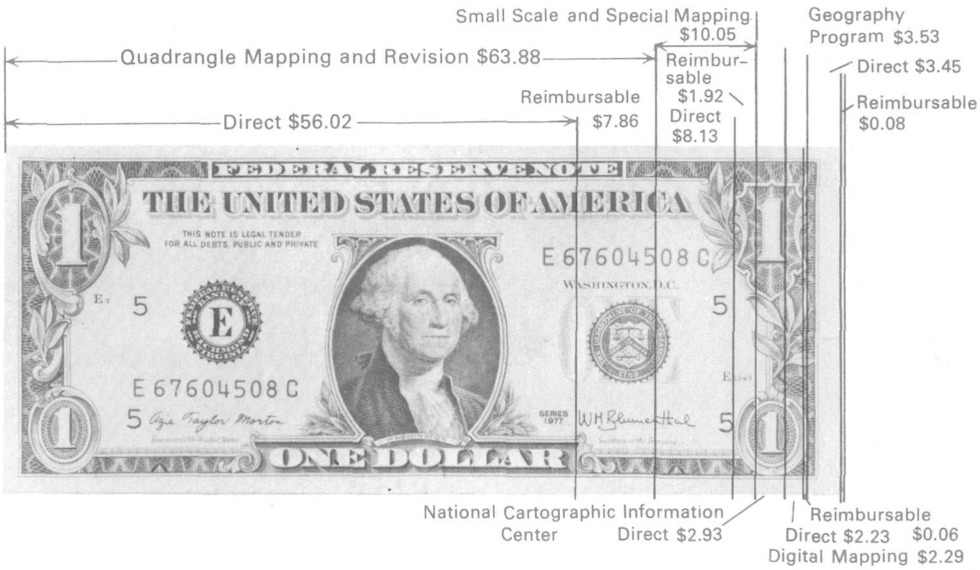
TOTAL $82.68 MILLION

National Mapping Division activity obligations for fiscal years 1979 and 1980, by subactivity

[Dollars in millions. Data may differ from that in statistical tables because of rounding]

Program	Fiscal year 1979	Fiscal year 1980
Total	**$74.57**	**$82.68**
Quadrangle Mapping and Revision	**60.53**	**63.88**
Direct programs	54.52	56.02
Reimbursable programs	6.01	7.86
States, counties, and municipalities	2.83	2.70
Miscellaneous non-Federal sources	.24	.42
Other Federal agencies	2.94	4.74
Small-Scale and Special Mapping	**11.02**	**10.05**
Direct programs	8.05	8.13
Reimbursable programs	2.97	1.92
States, counties, and municipalities	.54	.38
Miscellaneous non-Federal sources	.36	.16
Other Federal agencies	2.07	1.38
National Cartographic Information Center	**3.02**	**2.93**
Direct programs	3.02	2.93
Digital Mapping	------	**2.29**
Direct programs	------	2.23
Reimbursement programs	------	.06
States, counties and municipalities	------	0
Miscellaneous non-Federal sources	------	.02
Other Federal agencies	------	.04
Geography program	------	**3.53**
Direct programs	------	3.45
Reimburseable programs	------	.08
States, counties, and municipalities	------	0
Miscellaneous non-Federal sources	------	0
Other Federal agencies	------	08

USE OF FUNDS



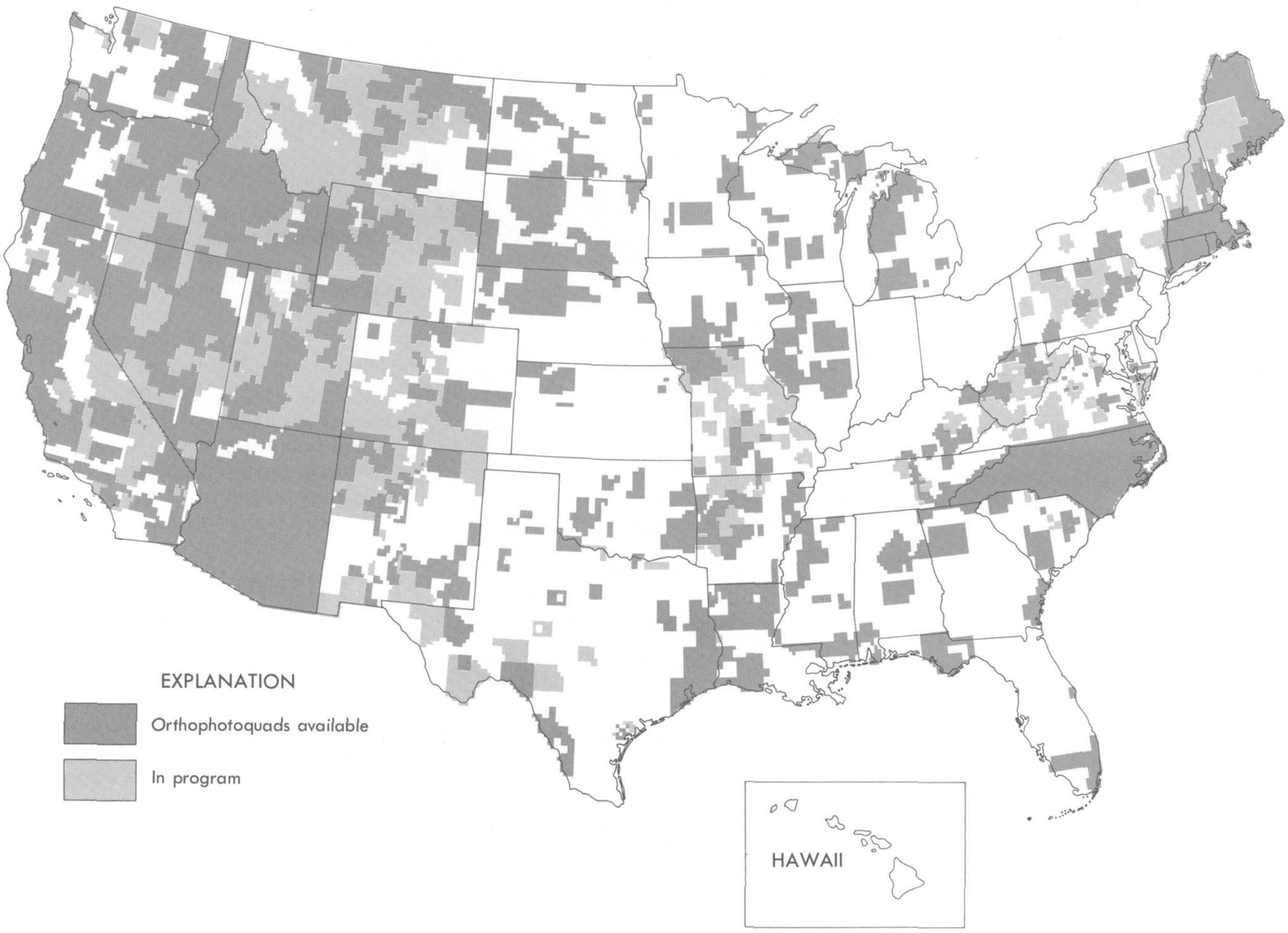
Quadrangle Mapping and Revision

During the fiscal year, 1,111 new standard topographic maps were published, covering 63,327 square miles. Most of the maps were in the 7.5-minute 1:24,000-scale series (1:63,360-scale series in Alaska). There are 16 States with complete published topographic map coverage at 1:24,000 scale. These maps also are used to prepare small-scale and special maps.

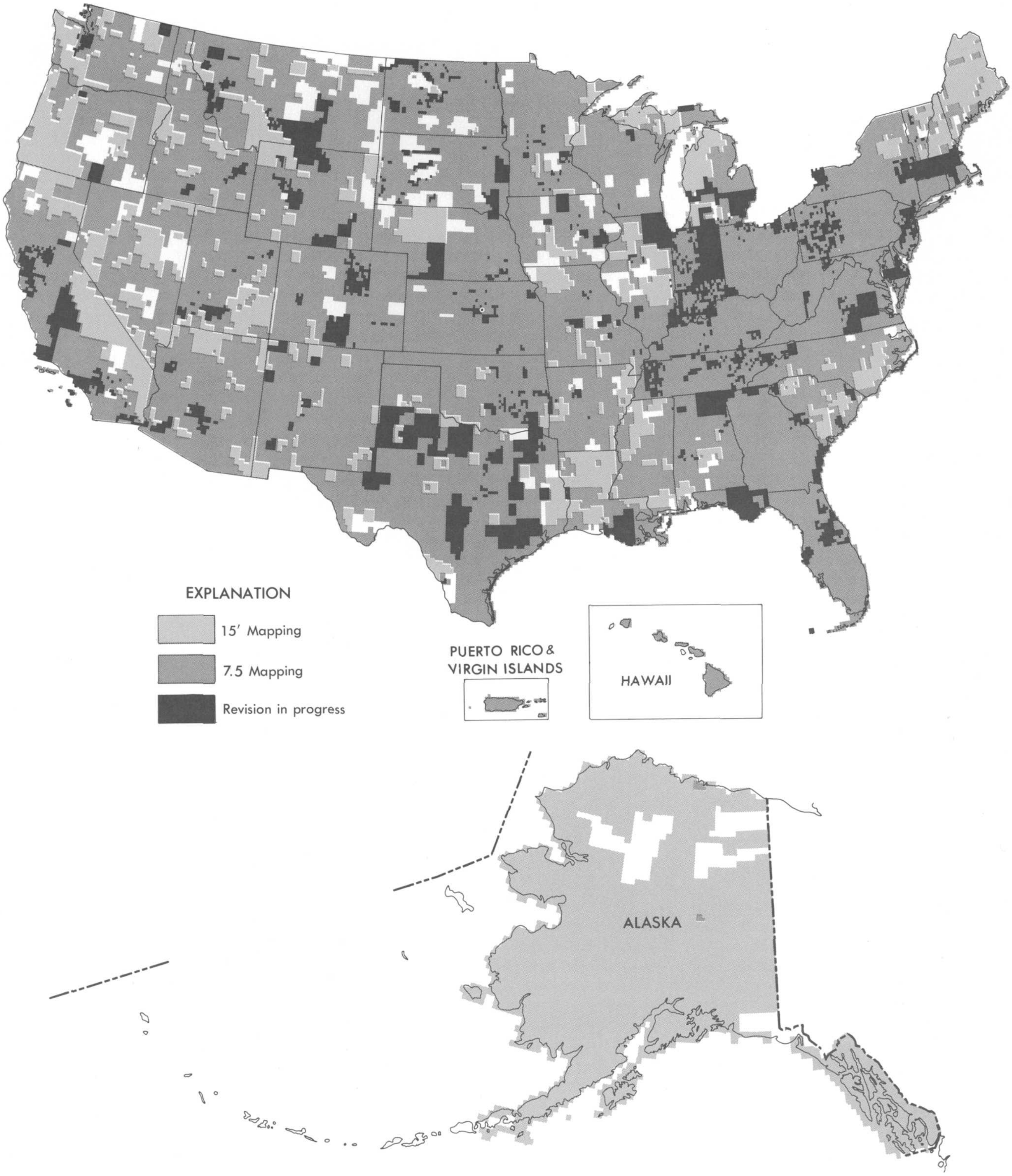
As national coverage in the 7.5-minute series increases, the map revision workload grows. The need for revision of individual maps is set by the amount of change detected when published maps are compared to new aerial photographs. Maps are reviewed cyclically with emphasis on urban areas, coastal zones, airports, major transportation corridors, and other areas of high national interest. During the fiscal year, 2,919 7.5-minute maps were reviewed, and 1,355 revised maps were published.

Orthophotographs are produced by processing aerial photographs to correct image displacement caused by camera tilt and terrain variations. In a standard quadrangle format with grid and name information superimposed, orthophotographs become orthophotoquads, which have many applications as a map substitute or as companions to published line maps. In fiscal year 1980, 2,579 orthophotoquads were prepared. Copies produced by printing are available for a limited number with the bulk available in nonlithographic form (diazo print) on request to regional mapping centers.

The orthophotoquad program was undertaken by the U.S. Geological Survey to produce rapidly a minimal cartographic product covering areas of the Nation yet to be mapped at 1:24,000 scale. The program, started in 1973, is now virtually complete in terms of initial coverage. Orthophotoquads continue to be made, though, from new aerial photography to meet substantial public demand for these scale-accurate and distortion-free map complements.



Status of orthophotoquad production.



Status of standard topographic mapping and revision.

Mapping production for fiscal year 1980
[In square miles]

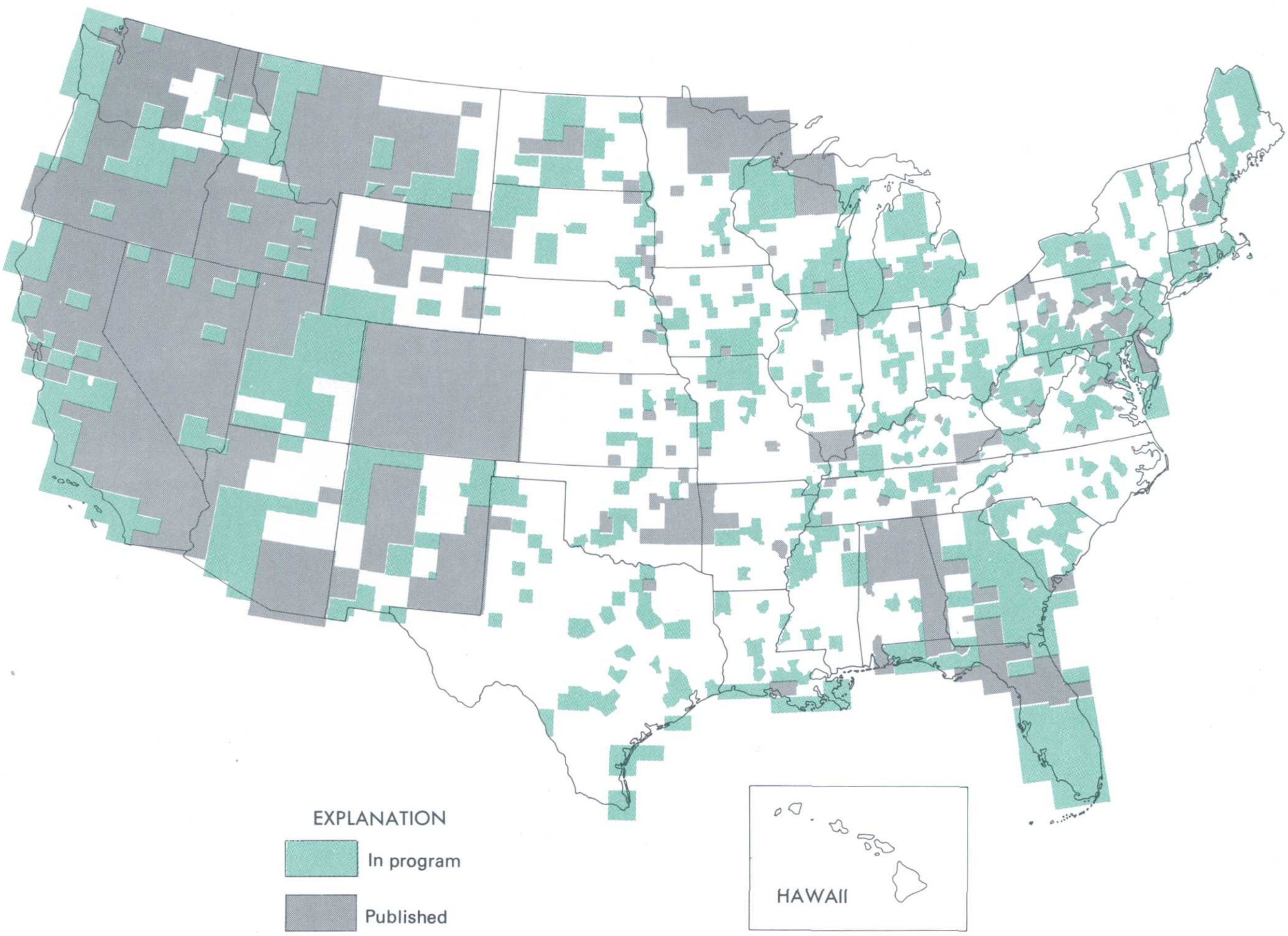
State	1:24,000-scale topographic	1:24,000-scale orthophotoquads	1:24,000-scale revisions	Intermediate scale
Alabama	3,701	—	1,008	3,913
Alaska	948	262	—	—
Arizona	4,155	—	1,178	—
Arkansas	490	1,998	1,281	954
California	3,852	16,471	5,499	1,592
Colorado	2,085	16,655	4,466	51,735
Connecticut	—	—	—	—
Delaware	—	—	—	—
District of Columbia	—	—	58	—
Florida	—	—	—	4,848
Georgia	—	321	1,827	5,871
Hawaii	—	1,167	—	—
Idaho	2,203	1,000	2,322	5,200
Illinois	1,152	—	855	7,876
Indiana	—	—	1,653	6,986
Iowa	2,673	—	389	53
Kansas	5,808	—	3,920	27,342
Kentucky	—	708	1,357	6,737
Louisiana	630	—	3,648	11,435
Maine	377	6,612	—	1,174
Maryland	—	—	2,088	4,029
Massachusetts	—	1,848	2,200	154
Michigan	—	—	486	5,107
Minnesota	—	—	1,820	447
Mississippi	64	—	1,323	1,264
Missouri	3,562	906	1,580	7,152
Montana	3,682	24,533	765	22,913
Nebraska	1,287	—	952	3,234
Nevada	4,563	11,165	—	6,996
New Hampshire	104	1,816	108	187
New Jersey	—	—	—	139
New Mexico	1,316	5,516	4,674	49,391
New York	1,182	581	2,090	4,027
North Carolina	303	—	1,513	1,722
North Dakota	1,588	—	2,576	7,448
Ohio	—	—	2,964	6,872
Oklahoma	1,220	280	3,757	—
Oregon	2,351	2,065	486	6,402
Pennsylvania	—	2,348	2,034	7,084
Rhode Island	—	—	56	2,390
South Carolina	2,112	561	1,550	3,957
South Dakota	1,186	—	1,284	5,900
Tennessee	48	1,256	2,904	2,059
Texas	6,104	5,455	3,904	15,306
Utah	1,033	14,555	406	14,827
Vermont	4	325	—	—
Virginia	—	184	4,425	5,812
Washington	247	2,326	354	3,009
West Virginia	—	886	116	3,557
Wisconsin	2,233	—	159	16,438
Wyoming	108	18,256	3,325	32,149
Guam	—	—	—	—
Puerto Rico	—	—	—	—
Samoa	—	—	—	—
Virgin Islands	—	—	—	—

Intermediate-Scale Mapping

The U.S. Geological Survey publishes an intermediate-scale series of maps at scales of 1:50,000 and 1:100,000 to meet a variety of customer requirements for formats and detail that cannot be met with the 1:24,000- and 1:250,000-scale series.

These intermediates have a number of innovative features, including multiple feature-separation drawings that can be combined in various ways to produce special maps with varying levels of content. Feature symbolization has been designed for data capture, computer storage, and output. By the end of the fiscal year, intermediate-scale maps for approximately 60 percent of the conterminous United States were completed, an increase of 50 percent from those of fiscal year 1979.

Under a joint agreement with the Defense Mapping Agency, the Geological Survey produced an additional 89 15-minute 1:50,000-scale metric topographic maps, compared to 87 the prior year. Total program goal is completion of about 2,100 maps, prepared in accordance with jointly developed specifications and yielding map materials that are being used directly in preparation of other intermediate-scale maps. Of the 2,100 maps in the program, 193 have been published to date.



Status of the Intermediate-Scale Mapping Program.

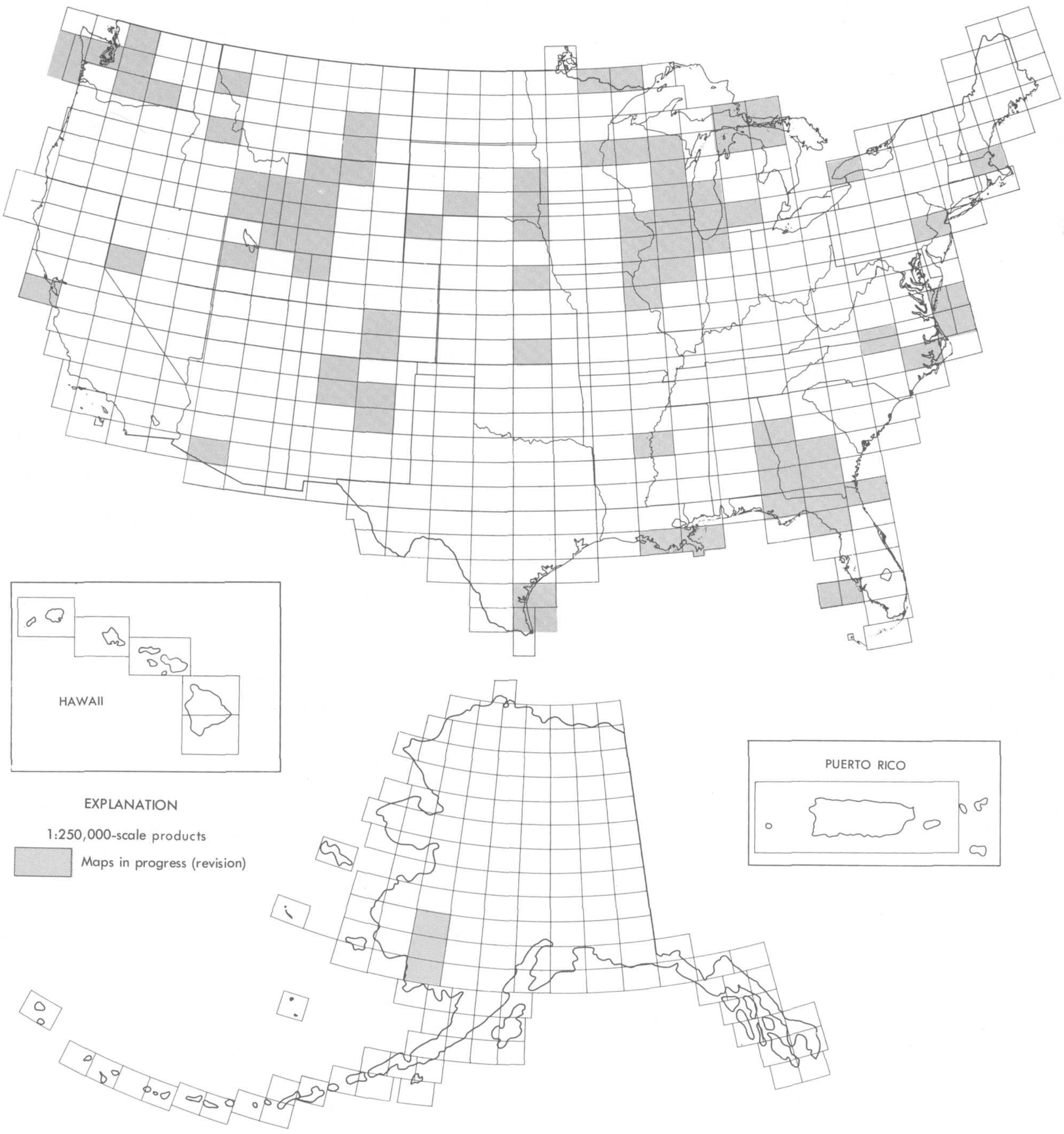
Small-Scale and Special-Purpose Mapping

Small-Scale Mapping

The 1:250,000-scale map series provides the largest scale of complete topographic coverage available for the United States. These maps are widely used by Federal and State agencies as well as by the U.S. Geological Survey for preparing State base maps, various geologic maps, and special-purpose maps, such as those showing land-use and land-cover information. During the fiscal year, 25 revisions were published, compared to 48 the prior year. Terrain data digitized from contours on the 1:250,000-scale maps are available on magnetic tape from the National Cartographic Information Center, Reston, Va.

Topographic and Bathymetric Mapping

The joint Geological Survey–National Ocean Survey program for producing coastal area maps combining topography of the land with bathymetry of the ocean floor continued to progress during the year. The series includes maps at the Survey's three basic scales: 1:24,000, 1:100,000, and 1:250,000. By fiscal year's end, two, zero, and four maps at those respective scales had been published. The maps, used by State as well as Federal agencies, are a valuable tool for coastal area planning.



Status of 1:250,000-scale mapping production.

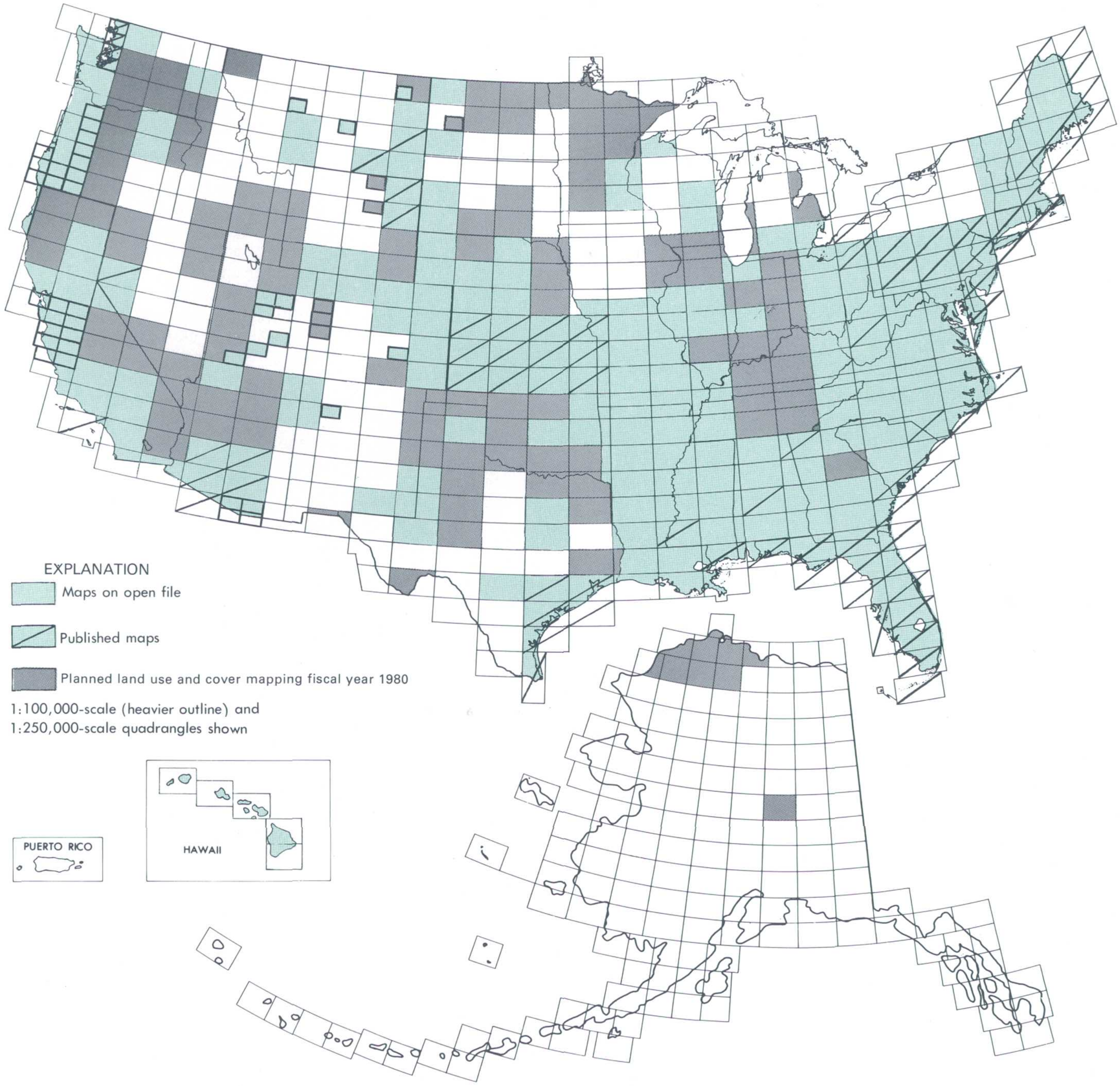
Land-Use and Land-Cover Mapping

Land-use and land-cover maps for more than 250,000 square miles of the United States were completed by the end of the fiscal year, bringing total coverage to 1.5 million square miles. By 1982, maps will be completed for the entire Nation, except Alaska, for which maps are to be completed by 1984.

Land-use and land-cover maps are a relatively new base map product of the U.S. Geological Survey. In 1975, the Survey undertook to publish current reliable land-use and land-cover maps in standard formats compiled from high-altitude aerial photographs as primary source materials. The maps use a land-use and land-cover classification system developed by the Survey that is becoming the standard for the Nation.

The maps are being published in a new "L" series. The land-use and land-cover and associated maps are also available from the Survey's Open-File Services Section, Box 25425, Federal Center, Denver, CO 80225. Published versions are available through normal map ordering channels of the Survey.

The land-use and land-cover maps are also being digitized and placed in a Geographic Information Retrieval and Analysis System. Digital data products include statistical summaries by counties, hydrologic units, and Census county subdivisions and for Federally owned land. Analysis of such data to determine land-use trends and patterns helps solve land-resource problems. The digital formats are essential for efficient use and multipurpose applications of the information.



Status of land-use and land-cover mapping production.

Research and Development

An active research and development program is conducted by the National Mapping Division to improve the quality and efficiency of map production and to evolve new technology supporting national earth science needs. During the year, major emphasis continued in areas applying computer technology to production of cartographic and geographic data, materials, and information.

- *Geographic Information Retrieval and Analysis System.*—The Geographic Information Retrieval and Analysis System (GIRAS) is used to manipulate land-use, land-cover, and associated map information as digital data. During the fiscal year, a total of 580,000 square miles of land-use and land-cover map data was processed and included in GIRAS. Using the data bank, people can quickly produce statistical summaries for counties, hydrologic units, Census county subdivisions, and Federally owned land and computer-plot variable-scale black-and-white or color-shaded graphic summaries of the information. GIRAS is becoming an important tool for people who must determine land-use trends and patterns to aid resource analyses.
- *Land-use map and data applications.*—Cooperative research efforts continued with the Survey's Water Resources Division on a 5-year study to estimate the extent of irrigated cropland and pasture in the High Plains aquifer area of the United States using Landsat digital image data. A major purpose of the study is to develop ways to estimate the rate at which the High Plains aquifer is being depleted by irrigation. Data from the continuing tests provide information on irrigated cropland in map, statistical, and digital formats for direct input into a ground-water model. Techniques developed in this research effort can be applied to update the irrigated cropland information and ground-water data base in the future, as well as to serve as an example of similar studies elsewhere.
- *Landsat remote-sensing applications.*—Landsat 3 return beam vidicon (RBV) imagery has been used in two specific remote sensing applications: for production of an image-base-controlled map and as an intermediate-scale map revision tool.

  In the first application, the National Mapping Division experimented with the production of a precisely controlled Landsat 3 RBV map of the Cape Cod, Mass., area at 1:100,000 scale. To determine the feasibility of using RBV imagery as a map revision tool, images of specific mapped areas were examined to determine what map information could be seen. The selected scenes were enlarged without rectification to 1:100,000 scale and registered to maps for the correction of cartographic detail. Current map revision policies guided the revision. At this scale, results indicate that the RBV imagery can be used successfully to update specific features such as highways, streams, and woodland in a timely and cost-effective manner.
- *Interactive compilation and editing.*—The National Mapping Division has been evaluating the compilation and revision potential of using a stereoplotter online with an interactive editing system. Two objectives were pursued: to develop procedures for an interactive (online) digital map compilation and editing system and to evaluate the potential of the interactive system for new map compilation and for photorevision of existing digital files.

  Online digitization-compilation resulted in a 31-percent reduction in the time needed to compile and edit a quadrangle as compared to offline compilation methods. Online digitization-revision by digital methods proved to be technically feasible as well as cost effective when compared to manual photorevision methods.
- *Computer-assisted map symbol placement.*—The placement of letters and symbols on topographic and thematic maps represents a significant activity in the map-finishing operation. In a continuing effort to reduce these labor requirements, a digitizer, in a single step, is assigning the x and y coordinates of a symbol with 0.003-inch accuracy, their identification, and their correct orientation within 0.5 degree precision at least five times faster than by manual methods. A flatbed plotter uses a custom photohead symbol disk with 70 of the most frequently used Survey map symbols. Operational speed is in excess of 50 times the rate of manual symbol placement methods.
- *Screenless printing.*—Orthophotoquads are monocolor photographic image maps in standard quadrangle format without topographic detail. They contain extensive image detail at National Map Accuracy Standards. However, the standard halftone lithographic process degrades the image into a grid structure of dots.

  The screenless lithographic method structures the image as random dots equivalent to the very fine chemical grain structure of a commercially presensitized anodized aluminum lithographic plate. The screenless plates are used on conventional offset lithographic presses at the Survey's National Center in Reston, Va. In addition to the improved resolution of image detail, the monocolor screenless orthophotoquad gives the impression that the image is printed with two ink colors rather than one. The combination of an apparent two-color (duotone) process and the fine random-dot structure results in a significantly more usable product.
- *Aerial Profiling of Terrain System.*—The Geological Survey is developing the concept of measuring accurate terrain profiles from low-flying aircraft using a laser altimeter and inertial guidance technology—the Aerial Profiling of Terrain (APT) System. The system-design accuracy of 6 inches vertically and 24 inches horizontally can be achieved for extended missions if positional updates are provided at 3-minute time intervals. The project has progressed from a development phase beginning in 1974, through completion of system design, to the midpoint of fabrication of a prototype system.

  Along with the fabrication effort is the effort to obtain an aircraft suitably modified to carry the APT System. A Twin Otter already in the fleet of the Office of Aircraft Services has been selected for the project and will be made available in June 1981 when extensive aircraft modifications will begin.
- *Seasat.*—A study to analyze the performance of the Seasat radar altimeter in overland tracking was completed under a contract jointly funded and monitored by the National Geodetic Survey and the National Mapping Division. Although the Seasat altimeter had been designed for open-ocean tracking with little consideration given to overland data acquisition, it was noted that the altimeter acquired meaningful data over smooth terrain and large ice sheets.

The altimeter acquired topographic profiles agreeing within a few feet with large-scale topographic maps or Doppler satellite positioning (geoceiver) elevations. Comparison with GEOS–3 profile intersections, however, indicated that improvement approaching 4-inch precision could be obtained by additional analysis of the recorded radar waveform data.

Another contract has been awarded to study the waveform retracking that may provide geodetic quality terrain profiles. Initial results indicate that a radar altimeter optimized for overland tracking from a near-polar-orbiting satellite could provide terrain profiles of mapping quality over most nonmountainous areas at relatively low cost.

Cartographer operates computer system used for transferring geographic and cartographic images into digital spatial data for earth science analyses and modeling.

Computer processing of Landsat image data produced this map showing extent and type of irrigation for two counties in Nebraska in studies on the rate of depletion of the High Plains aquifer, a major source of irrigation water.

Digital Cartography

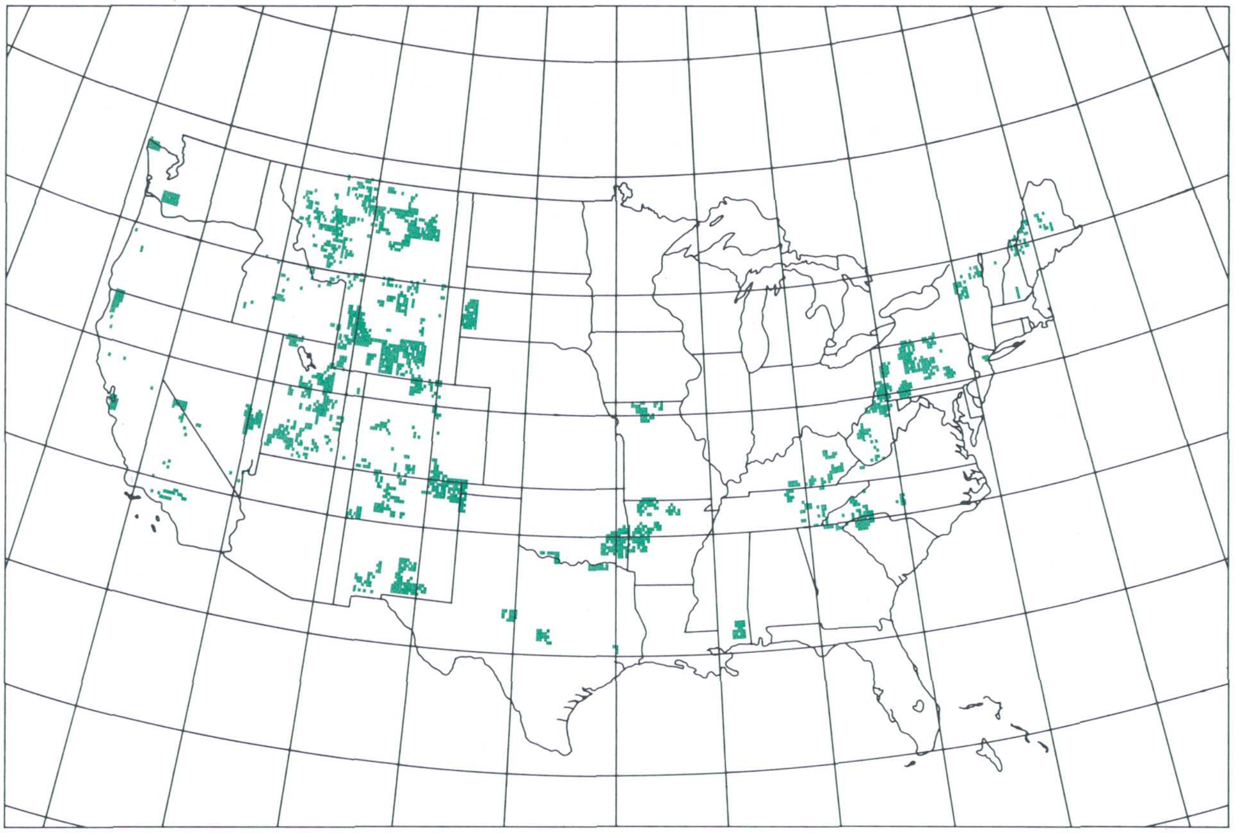
A major fundamental change is occurring in the cartographic sciences. The wealth of information portrayed since antiquity only on maps is now being ingested by computers, and the capability for applying the data has multiplied severalfold. Many public and private organizations involved in land and resource planning and management are making increased use of cartographic data in computer-based analyses to weigh the complex alternatives they face. The U.S. Geological Survey is collecting, organizing, and disseminating digital cartographic data in such a way that a common data base will serve a wide range of applications and users. Following are several examples of applications of digital cartographic data:

- The Bureau of Land Management is developing systems to determine rapidly which areas of the public lands are appropriate for grazing, to discern the best ways to manage timber resources, and to identify areas appropriate for specific recreational uses. These analyses require the combination of various types of data: slope of the land, location of water, transportation routes, soil types, and vegetation types. Digital cartographic data produced as part of the National Mapping Program describe the elevation of the ground, the surface hydrography network, public land survey net, and transportation routes. The various Bureau of Land Management State Offices produce digital thematic resource data within their resource management programs for use in preparing environmental impact statements on lands managed by the Bureau of Land Management. Essentially, all public lands are subject to this type of analysis.
- The Bureau of Land Management is also developing a land-records information system to replace the current paper-oriented systems that are very awkward and difficult to work with. The new system requires digital positions of public land survey section corners and political boundaries as a framework to which land status information can be added. These data (land net and boundaries) will be digitized as part of the National Mapping Program's digital cartographic mapping for the use of the Bureau of Land Management. This information will be added to the digital cartographic data base. All lands managed by the Bureau of Land Management will ultimately be included in this land records information system.
- The Geological Survey's National Coal Resources Data System combines digital elevation data, boundaries, and public land survey section corners with data regarding subsurface coal deposits. This information will be used to compute overburden and to evaluate the economic feasibility of developing these resources in different areas.
- The National Park Service is developing a computer-based analysis system to monitor and evaluate air quality as part of their program to assure preservation of resources as prescribed by the Clean Air Act. Information about air flow, velocity, and direction are combined with digital terrain data provided by the Survey to model regions in and around parks and other areas to determine the effect of air pollution sources. All Class I Federal areas are subject to this type of analysis.
- The U.S. Fish and Wildlife Service has a computer-based analysis system which requires digital cartographic data. Wildlife management activities require thorough analysis of habitat to include requirements for water sources, range availability, and cover and concealment to develop location criteria (site location of dams for water source and habitat for aquatic species). Predators, development, encroachment, hunting, and pollution are all factors entering into analysis. Currently identified major areas requiring digital cartographic data include the Columbia River mouth, the San Francisco Bay region, the Mississippi River Delta, the Dakota Pothole region, and many other coastal regions.
- The U.S. Forest Service has also developed several systems that require digital cartographic data. Timber management activities require analysis of the best routes for locating logging roads, projections of optimum management sites, vegetative growth on different locations, environmental considerations, and preservation of scenic and recreational opportunities especially in "clear cutting" areas. Digital cartographic data such as elevation models, boundaries, public land survey nets, transportation networks, and surface hydrography are necessary to do the analysis required for effective timber management. Digital cartographic data are needed over all national forests to support this system.
- The Tennessee Valley Authority needs digital terrain data to conduct air pollution studies as part of their effort to reduce the effects of pollution from coal-fired electric generating plants. Immediate requirements include areas surrounding 12 powerplants with long-range requirements covering the whole Tennessee Valley Authority Service Area.

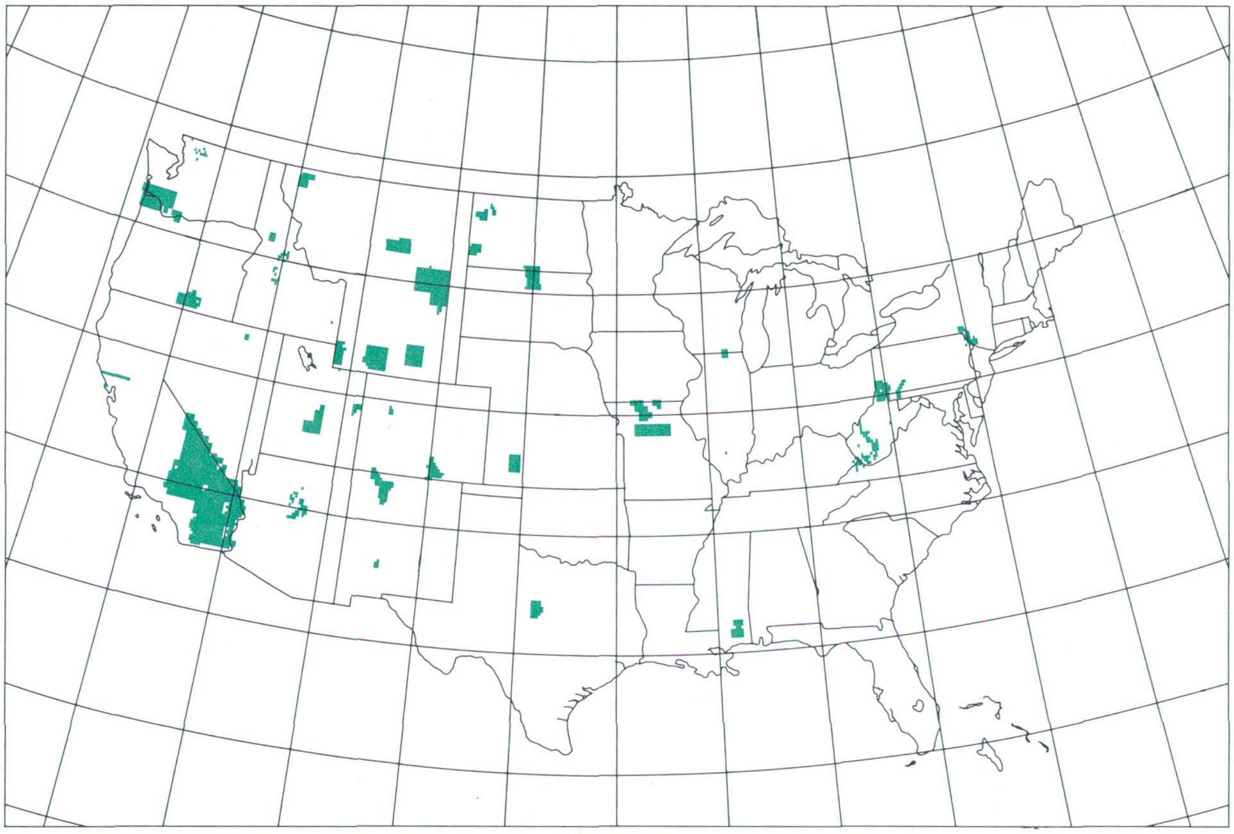
The primary objective of the digital mapping program is to provide digital cartographic data at the equivalent scale of 1:24,000 for those major data categories shown on 7.5-minute topographic maps. Fiscal year 1980 efforts were directed at meeting the immediate requirements of Federal agencies.

Digital cartographic data files are grouped into two categories, Digital Elevation Models (DEM's) and Digital Line Graphs (DLG's) (see figures). DEM's consist of a sampled array of elevations for a number of grouped positions that are usually at regularly spaced intervals. In fiscal year 1980, DEM's were produced for 568 7.5-minute quadrangles. DLG's consist of line map information in digital form and include such linear features as streams, boundaries, and transportation systems. In fiscal year 1980, 3903 DLG's were produced. The categories of map data digitized on most quadrangles were land net (section lines) and political boundaries.

In a related effort, work neared completion on a small-scale data base containing digital data from the 1:2,000,000-scale National Atlas sectional maps to meet the need for a digital data base at that scale covering the entire United States. This project, initiated in 1979, will be completed in 1981, and the data will be available for distribution. Included will be political boundaries, Federal lands, transportation networks (roads and railroads), hydrographic features (streams and water bodies), populated places and miscellaneous cultural features (airports and so forth).



A Digital Elevation Model is a digitized file of ground position elevations normally at 30-meter intervals over a 7.5-minute quadrangle.



A Digital Line Graphic is line map information in digital form. This status map shows 7.5-minute quadrangles where at least one category, such as transportation, hydrography, or boundaries, has been digitized.

Public Services

The amount of earth science information required by the Nation is enormous. Managing it, maintaining it, and disseminating it in all of its variety—data tapes, maps, books, leaflets, scientific and technical reports—is a major undertaking.

National Cartographic Information Center

Cartographic and geographic information represent a wide variety of products and services, virtually the entire range of items that either go into or are produced by the process of compiling and publishing maps. It is the role of the National Cartographic Information Center (NCIC) to make cartographic and geographic data available to the public. NCIC also makes available information about cartographic and geographic holdings of other public agencies and private organizations.

NCIC offices handled more than 200,000 requests for information and assistance during the year. Key centers are operated by the four mapping centers and two Federal affiliates at the National Space Technology Laboratories, Bay St. Louis, Miss., and the Tennessee Valley Authority in Chattanooga, Tenn.

There are also affiliated offices operated by agencies of State governments. Agreements with the States were signed for six new NCIC offices during the year, bringing the total to 27.

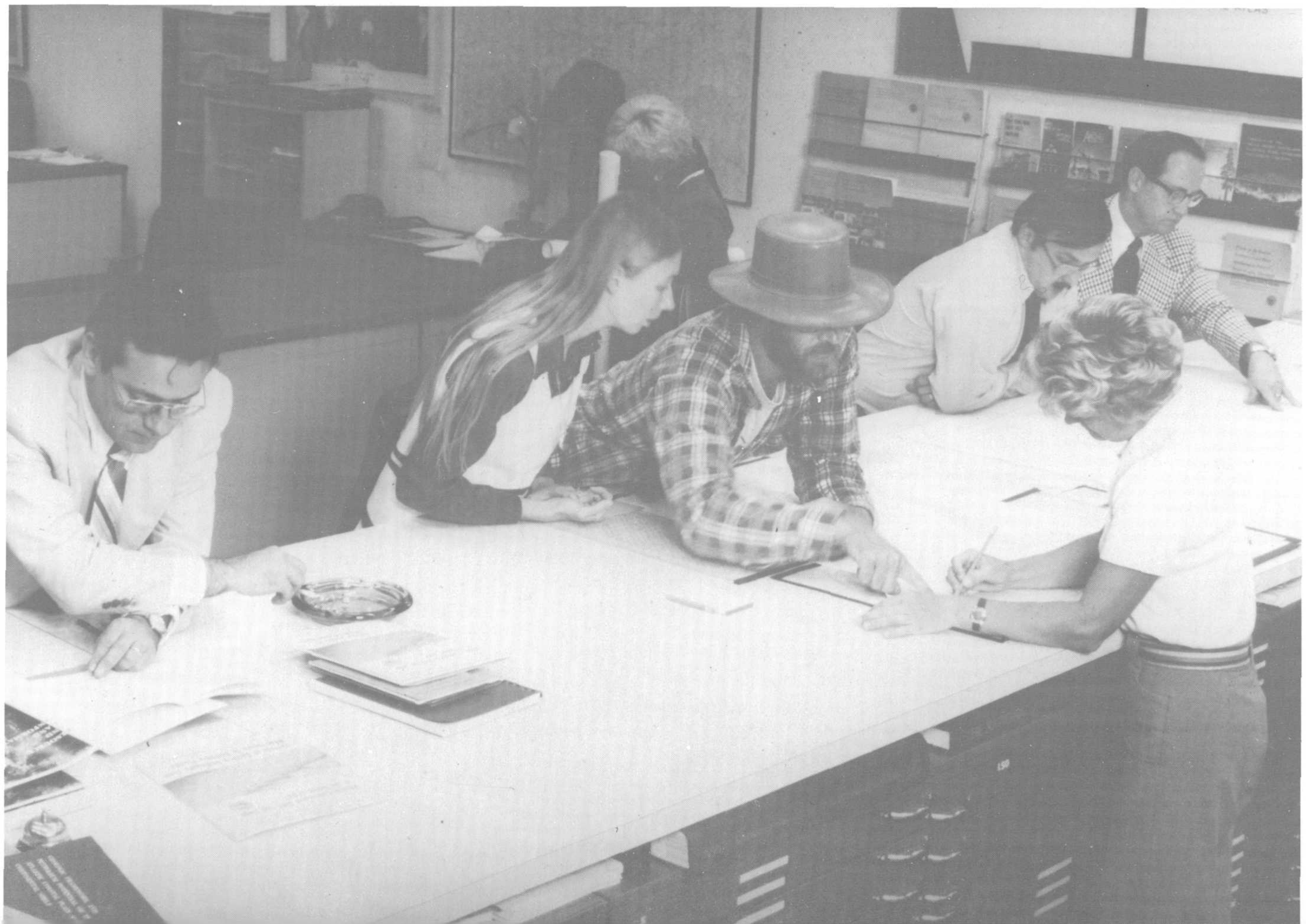
Public Inquiries Offices

Maps and reports of the Geological Survey are available to the public through Public Inquiries Offices. Office personnel also provide general assistance to the public in locating Survey earth science information.

Private Retailers

Nearly 2,000 private retailers are authorized map dealers of the Survey and account for about one-third of agency map sales in the Nation. During the year, the Survey's map dealer program included various point-of-purchase promotional items. A special effort was undertaken to inform college and university book stores of the benefits of becoming authorized map dealers.

Customers purchase maps over-the-counter from one of 10 Survey Public Inquiries Offices.



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 1980, the Survey produced over 10,783 new and revised topographic, hydrologic, and geologic maps; printed 14,975,712 copies of 5,984 different maps; distributed 9,295,804 copies of maps; and sold 6,210,878 copies for $5,790,792. The number of reports approved for publication by the Geological Survey continues to increase—4,799 reports prepared in fiscal year 1980 with 54 percent designated for publication in professional journals and monographs outside the Survey with the remainder scheduled for publication by the Survey. In addition, 452,165 copies of technical reports were distributed of which 79,874 copies were sold for $146,869, and 1,640 open-file reports were released of which 39,924 copies were sold for $293,844.

To buy Survey book publications or to request Survey circulars, catalogs, pamphlets, and leaflets (limited quantities free), write or visit:
U.S. Geological Survey
Branch of Distribution
604 S. Pickett St.
Alexandria, VA 22304

To buy maps of areas east of the Mississippi River, write or visit:
U.S. Geological Survey
Eastern Distribution Branch
1200 S. Eads St.
Arlington, VA 22202

To buy maps of areas west of the Mississippi River and to request Survey catalogs, pamphlets, and leaflets (limited quantities free), write or visit:

U.S. Geological Survey
Western Distribution Branch
Box 25286, Bldg. 41, Federal Center
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 obtain information on the availability of microfiche or paper-duplicate copies of open-file reports, write:

U.S. Geological Survey
Open-File Services Section
Box 25425, Federal Center
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
Mailing List Unit
329 National Center
12201 Sunrise Valley Drive
Reston, VA 22092

To subscribe to the *Earthquake Information Bulletin*, 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:
108 Skyline Bldg.
508 2nd Avenue
Anchorage, AK 99501

California:
7638 Federal Bldg.
300 No. Los Angeles St.
Los Angeles, CA 90012

122 Bldg. 3
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 Bldg.
19th and F Sts., N.W.
Washington, DC 20244

To obtain information on cartographic data, write or visit the U.S. Geological Survey, National Cartographic Information Centers (NCIC), in the following States:

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 501
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:
Midcontinent 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

Eastern Mapping Center
National Cartographic Information Center
536 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

To obtain information on satellite and space photography, 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
Water Information Group
420 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 22091

Geologic and Mineral Resource Surveys and Mapping

Mission

The Geologic Division conducts programs to assess energy and mineral resources, to identify and to predict geologic hazards, and to investigate the effects of climate. The assessments resulting from these programs are vital to planning for the wise use and management of our natural resources and to mitigating the disastrous effects from geologic hazards.

In the last several years, the Survey's responsibility in assessing the Nation's resources has increased markedly, especially in the areas of energy—oil and gas, coal, geothermal, and uranium. Large areas designated by Congress for inclusion as Wilderness Areas have required mineral assessments, and additional areas are likely to be designated in the future. Studies are being done to evaluate the energy-resource potential of offshore areas and the environmental hazards that pose problems to the development of that energy. In addition, a major program for earthquake hazard mitigation and prediction is now well underway. Geologic hazards related to nuclear reactor siting are being investigated.

In support of these extremely important mission programs, extensive basic research is done continually on geologic processes and events. Basic research continues to be an important and strong part of the Division's programs and provides the capability needed to respond to emerging national problems.

The Geologic Division budget is presented to Congress under four subactivities that fulfill the above programs. A brief description of these subactivities is given below.

Spider Rock, a monolith composed of the De Chelly Sandstone of Permian age, Canyon De Chelly National Monument, Ariz.

Land Resource Surveys supply basic data in the form of geologic, geophysical, and geochemical maps and reports. Research is conducted to predict and to delineate earthquake and volcano hazards, to identify environmental problems related to coal development and nuclear reactor siting, and to identify, to map, to report on, and to date geologic processes and historical natural events, including climatic changes and landslides.

Mineral Resource Surveys provide an assessment of the distribution, quantity, and quality of the mineral resources of the United States. During fiscal year 1980, these surveys were concentrated in Alaska, Wilderness Areas, and other public and Indian lands. Research is also conducted on the fundamental geologic processes that result in mineral formation.

Energy Resource Surveys provide assessments of the distribution, quantity, and quality of the Nation's coal, oil and gas, oil shale, uranium and thorium, and geothermal resources. Assessments of these resources are continually updated so that information is kept current.

Offshore Geologic Surveys investigate the continental margins of the United States and its territories to assess the potential mineral and energy resources and to identify environmental hazards that must be considered when siting offshore drilling platforms and pipelines.

The following eight articles describe some of the research and assessments done by the Geologic Division in fiscal year 1980. Although they reflect only a small portion of the current programs, these articles represent typical ongoing activities of the Division.

Budget and Personnel

In fiscal year 1980, obligations of the Geologic and Mineral Resources Surveys and Mapping activity were $193.66 million. This amount was supplemented by approximately $640,000 from 11 States and $46 million from other Federal agencies and non-Federal sources.

At the end of fiscal year 1980, the Geologic Division had 2,038 permanent full-time employees and 951 temporary or part-time employees.

SOURCE OF FUNDS

TOTAL $193.66 MILLION

USE OF FUNDS

Geological and Mineral Resource Surveys and Mapping activity obligations for fiscal years 1979 and 1980, by subactivity

[Dollars in millions. Data may differ from that in statistical tables because of rounding]

Subactivity	Fiscal year 1979	Fiscal year 1980
Total	**$178.55**	**$193.66**
Land Resource Surveys	**69.50**	**72.91**
Direct programs	57.50	56.85
Reimbursable programs	12.00	16.06
States, counties, and municipalities	.22	.24
Miscellaneous non-Federal sources	.10	.06
Other Federal agencies	11.68	15.76
Mineral Resource Surveys	**54.32**	**49.95**
Direct programs	31.81	34.28
Reimbursable programs	22.51	15.67
States, counties, and municipalities	.20	.14
Miscellaneous non-Federal sources	10.71	13.20
Other Federal agencies	11.60	2.33
Energy Resource Surveys	**36.57**	**43.19**
Direct programs	30.18	35.68
Reimbursable programs	6.39	7.51
States, counties, and municipalities	.02	.03
Miscellaneous non-Federal sources	.02	---
Other Federal agencies	6.35	7.48
Offshore Geologic Surveys	**18.16**	**27.61**
Direct programs	15.36	20.15
Reimbursable programs	2.80	7.46
States, counties, and municipalities	.14	.23
Miscellaneous non-Federal sources	.09	---
Other Federal agencies	2.57	7.23

Scouting for Minerals on Indian Lands

In recent years, Indian tribes have become increasingly aware of the economic importance of the mineral resources on their reservations. With this increased awareness, the Indians recognized the necessity of knowing the nature and the extent of these resources. Optimum planning, leasing, and development that will assure a fair-market-value return to the tribes for these resources depend on knowledge of the resources. In response to the Indians' "need-to-know," the U.S. Geological Survey developed a two-phase program of inventorying mineral resources on Indian lands. Both phases are sponsored and funded by the Bureau of Indian Affairs.

The intent of the program is to provide a level of geological information that, should the tribes decide to do so, can be used to encourage exploration companies to conduct more detailed studies of specific sites, which, in turn, could lead to actual exploration and mining. Indian tribes are greatly interested in knowing the amount of their resources, so that they can do long-range planning, and the Bureau of Indian Affairs believes that the Survey's studies will aid them.

The first phase of this minerals inventory, which is conducted jointly with the Bureau of Mines, consists of gathering existing information from the literature and from files. Phase I is designed to produce reports on mineral resources, known and potential, of each Indian reservation in the conterminous United States. These reports are excellent starting points for further work because they summarize what is already known and contain good bibliographies. Some of these Phase I reports conclude that a reservation has few or no resources; however, even such negative information is useful. Initially, Phase I reports are administratively released to the tribal council of each reservation studied and to the Bureau of Indian Affairs; any other release must be authorized by the tribal council.

Phase I of the Indian lands program is nearing completion, and all reports should be released administratively by the end of fiscal year 1981. A complete set of these reports will constitute a convenient reference to what is presently known about the geology and mineral resources of all Indian reservations in the conterminous United States. Those reservations determined to have good mineral-resource potential become candidates for further study through geological field investigations.

The objectives of Phase II of the Geological Survey's inventorying program on Indian lands, which consists of field investigations, are to assess actual resources, such as coal, and to evaluate the potential for other mineral resources. These other resources include uranium, metals, industrial minerals, and geothermal. The Survey not only tries to provide the tribe with a wide variety of geological and geophysical data but, whenever possible, also provides advice on how to use it. Additionally, for reservations, such as the Papago and the Navajo, where a large amount of data has been collected, the Survey is developing a computerized mineral- and energy-information system.

The decision as to whether further studies of a particular reservation will be done is based on several factors, which include determination of resource potential in a Phase I study, the willingness of a tribe to have such an investigation, and the availability of funding from the Bureau of Indian Affairs. All the field studies contribute to the broader scale objectives of the Geologic Division of the Survey, which are the geological mapping and mineral-resource evaluation of the United States.

The Phase II geological field studies began in 1976 with a $150,000 program on the Papago Reservation, and, in 1980, the Geological Survey had a $4-million-per-year program, funded by the Bureau of Indian Affairs involving about 57 man years of effort. The program includes studies on 18 reservations in the Western States (50,000 square miles) and on 18 smaller reservations in the Great Lakes region (3,000 square miles). Coal-resource studies are underway on 11 reservations—Blackfoot, Crow, Ft. Peck, Wind River, Acoma, Canoncito, Ramah, Alamo, Jicarilla, Zuni, and Navajo. Studies of metallic mineral deposits are underway on four—Papago, Flathead, Colville, and Mescalero. Studies concerning metals and uranium are being conducted on several small reservations in the Great Lakes region. A report on the mineral occurrences in the Ft. Belknap Reservation has been completed, as have reports on zeolites in the Rosebud and Pine Ridge Reservations.

As a part of the Survey's program, a special effort is being made to involve young tribal members in each of these projects by offering on-the-job training when possible (see figure) and by fostering an interest in the earth sciences among the young Indians. It is hoped that these young Indians will seek higher education in the earth science field; therefore, a high-school-level descriptive text of the geology of the Navajo Nation is being prepared. If successful in attracting their attention and interest, it will be followed by similar geologic descriptions for other reservations and will help foster interest and, in turn, will accelerate the availability of inhouse expertise for future inventories of mineral resources on Indian lands.

Indian student working for the U.S. Geological Survey on the Navajo Reservation. (Photograph courtesy of Cheryl Kyllonen, a geologist employed by the Navajo Tribe.)

Minerals for the 21st Century—Where They Are

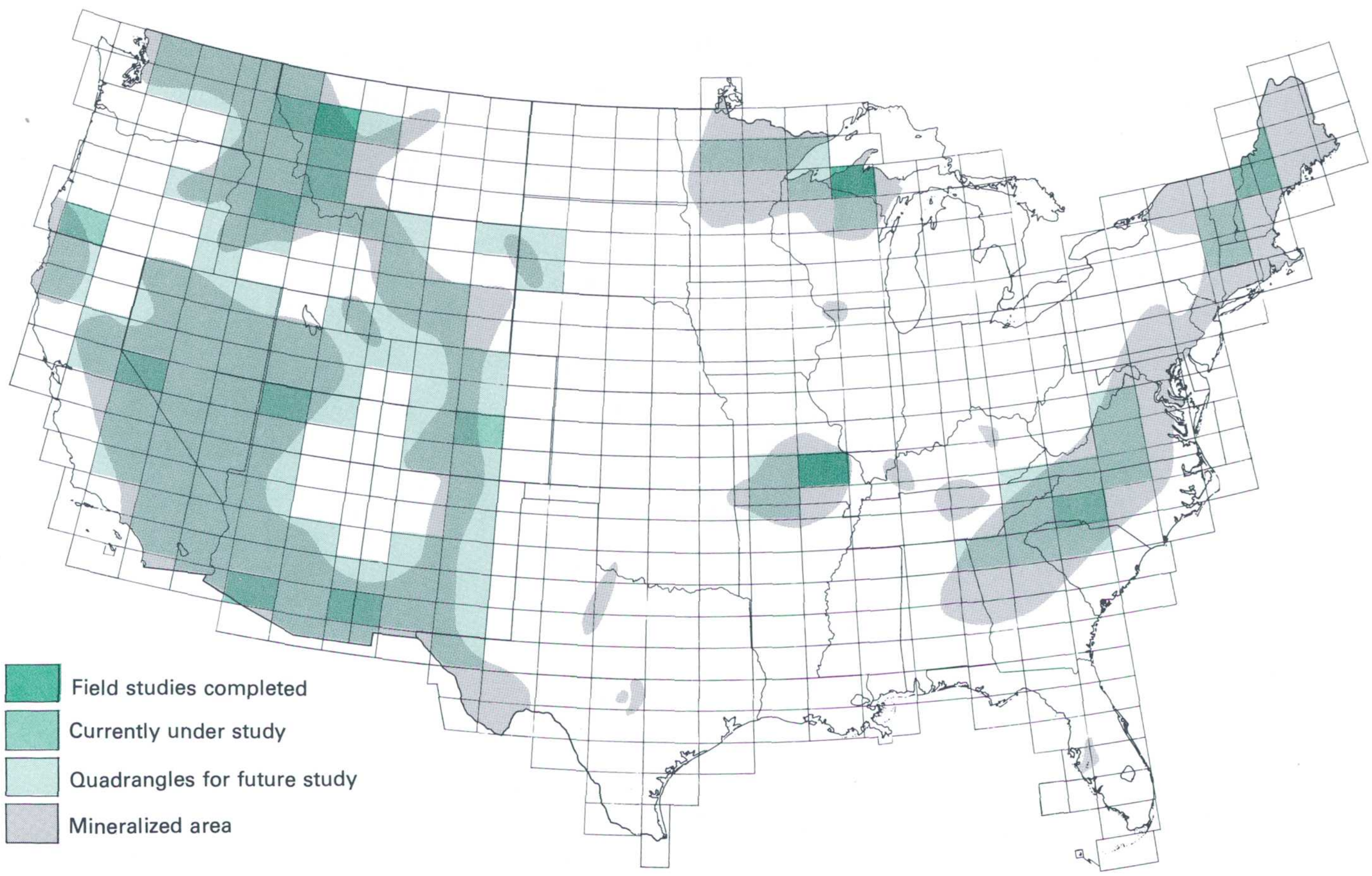
The United States is beginning to realize that it is facing a period of decreasing metal reserves and a growing dependence on foreign sources for such critical metals as chromium, nickel, tin, cobalt, manganese, aluminum, titanium, mercury, and platinum. Many of these foreign sources are in parts of the world that are politically unstable and that most likely will remian so in the foreseeable future; thus, reliance on foreign imports may be in jeopardy.

To update and increase the mineral inventory of the United States, the U.S. Geological Survey initiated the Conterminous United States Mineral Resource Assessment Program (CUSMAP) in 1978 as a companion to the Alaska Mineral Resource Assessment Program, which was initiated in 1974. This program is unique because it is the first in which systematic regional studies are being made of the mineral resources of the conterminous United States. CUSMAP is providing new informatioin on present and potential mineral supplies nationwide and is producing important data to guide our national minerals policy and for land-use planning by Federal, State, and local governments. The program also provides a regional geological and mineral-resource framework for site-specific studies such as wilderness projects.

The goal of this program is to complete, by the year 2000, a mineral resource inventory of the 125 most mineralized 1:250,000-scale quadrangles that contain significant amounts of Federal land in the conterminous United States. The results of these inventories will be published in folio format. The main components of the folios are a mineral-resource map and report that outline and describe mineral occurrences of significant size. Where possible, the report includes probabilistic estimates of tł number, size, and grade of deposits that may occur within the given quadrangle. The folios also contain detailed geological, geochemical, geophysical, and remote sensing maps and reports as well as a short report that summarizes the different elements of the folio. The folios for the Choteau, Mont., Iron River, Mich., and Rolla, Mo., quadrangles will be published in early 1981, and field studies will be completed in seven additional quadrangles during fiscal year 1981 and submitted for publication (see figure). In all, 16 quadrangles have been studied or are under study at the present time.

Some highlights of the program in fiscal year 1980 as follows:

- Geological and geochemical studies in the Dillion quadrangle, Montana, revealed a previously undiscovered molybdenum occurrence in the east Pioneer Mountains and several possible occurrences in the west Pioneer Mountains, the Hecla district, the Beaverhead Mountains, the southern Highland Mountains, the Anaconda Range, and the Tobacco Root Mountains. These discoveries possibly could augment our reserves of molybdenum, an important metal used in strengthening and hardening steel.
- Studies within and southwest of the Rolla quadrangle, Missouri, have defined a possible new and previously unknown and untested belt for mineral occurrences in an area just southwest of the Rolla quadrangle. Analyses of drill cores from widely spaced drill holes show that there are anomalous amounts of molybdenum, arsenic, lead, copper, nickel, cobalt, and silver in the Potosi and the Eminence Formations in this area.
- Three major mineralized shear zones have been identified in and adjacent to the Kings Mountain belt in the southern part of the Charlotte, N.C., quadrangle. One of the zones, informally named the Kings Mountain shear zone, influenced the location of a belt of spodumene pegmatites that constitute the most important source of lithium in the world. Two major potential energy uses for lithium are as a primary constituent in batteries to power electric automobiles and as a direct energy source to breed tritium for more efficient use of nuclear energy.
- New gold occurrences have been discovered in Tertiary gravels in the Sapphire Range in the western part of the Butte, Mont., quadrangle. Gold, largely associated with sapphires, is distributed through thicknesses ranging from 30 to more than 90 feet of gravel veneer in the Sapphire Range. The gravels had not been prospected previously because they are on the flanks of ridges where no water was easily available for washing them.



Quadrangles being investigated under the Conterminous United States Mineral Resource Assessment Programs.

Anatomy of an Ore Deposit: Case History From Creede, Colorado

Most of the world's operating mines were found by prospectors who diligently pursued indications of mineralization they found at the surface until they located an ore body. (Unfortunately, the prospectors usually went broke.) In the central San Juan Mountain region of Colorado, prospectors in the early 1890's found high-grade silver veins (the Amethyst vein system) high in the walls of the canyons of Willow Creek (figs. 1, 2) just north of the present town of Creede. Development and mining proceeded quickly in a typical boom town-ghost town cycle. The best high-grade silver ran out early in this century, but persistent exploration encouraged by occasional additional finds eventually lead to the discovery of two new veins (the OH and P veins) that were mined for lead, zinc, copper, and gold, as well as silver. Production along these veins ceased by the middle to late 1970's, and mining in the Creede district would have ended except for a new factor—detailed studies of the geology.

In the early 1950's, the U.S. Geological Survey initiated a detailed study of the mineralization in the central San Juan Mountains to relate the mineralization to the volcanic and structural evolution of these mountains. In 1960, investigations revealed that a system of fractures similar to that containing the highly productive Amethyst system also was present less than a mile west of the old mines but had been covered by younger deposits and thus was never adequately prospected. Industry moved quickly to discover and to develop the Bulldog Mountain Mine which for the past 15 years has produced 1.5 million to 2 million ounces of silver annually.

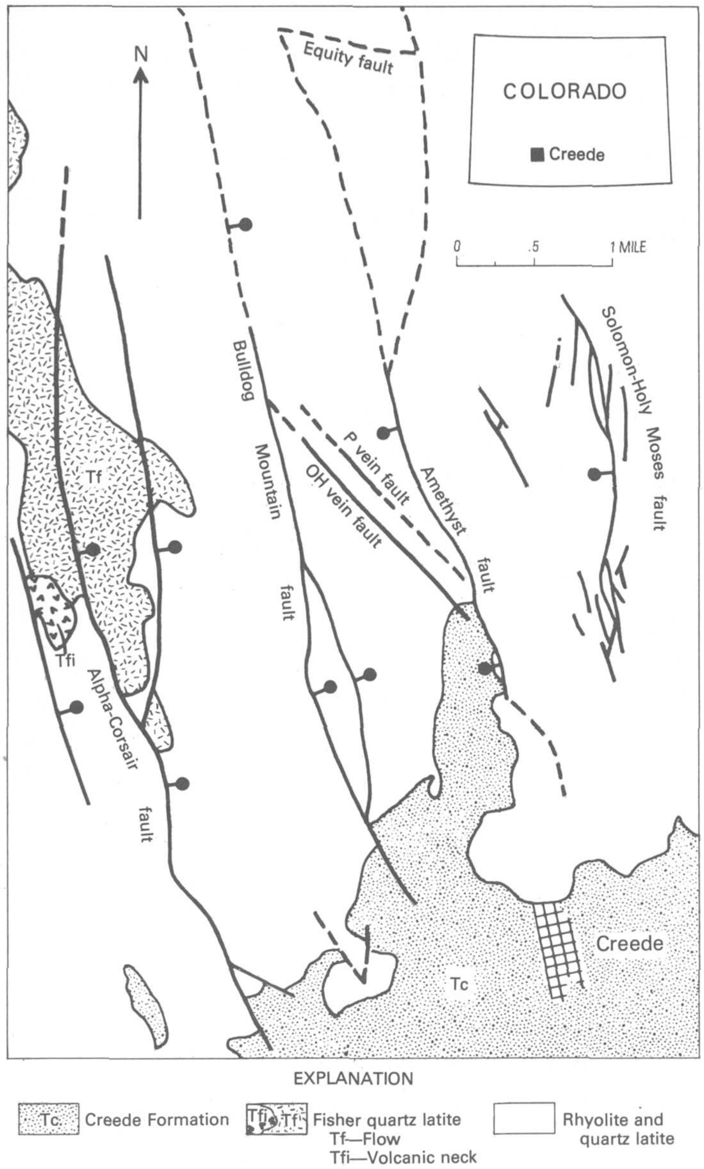
Because of exceptionally good exposures of the mineralization in the district, the OH vein at Creede was chosen by the Survey in the late 1950's as a site for additional detailed topical studies to attempt to understand the "anatomy and physiology" of a typical ore deposit. These studies were pursued intermittently due to periodic manpower limitations, but, by 1975, studies of the vein and wallrock minerals revealed that the known ore deposit was merely the top of a former huge circulating geothermal system that had "lived" about 25 million years ago during the dying stages of the intensive volcanism that created the rocks of the San Juan Mountains. Much of the geothermal system was apparently barren of valuable minerals. As shown in figure 3, the geothermal system involved southward-flowing waters from higher land in the vicinity of the Continental Divide to the north, and northward-circulating waters from the sediment-filled volcanic basin of the Creede caldera to the south. The waters boiled at the top of the system where they deposited metals and subsequently discharged to the south through a gravel-filled old stream valley. This model induced renewed interest by industry explorationists who, within the last 5 years, have discovered large silver resources that are now under development for possible production.

The current focus of the Creede studies is on fluid inclusion (fig. 4) measurements that document the evolution of this old geothermal system. When a crystal forms in a geothermal system such as this, some of the fluid may be trapped within. When fluid inclusions cool from their original temperature of formation, the fluid in the inclusions contracts more than the crystal itself, thereby forming a bubble in the inclusion. When such inclusions are heated under the microscope, the expanding fluid once again eventually completely fills the inclusion; the temperature of this complete filling indicates the temperature at which the crystal grew around some of its "mother" fluid, thereby trapping the fluid in the inclusion. By computing the freezing point of the fluid to that for pure water, a fairly accurate measure of the total salinity of the fluid may be obtained. Fluid inclusions from the Creede ore deposit show that the ores formed at about 250°C from brines containing common salt about twice as concentrated as sea water. Some groups of fluid inclusions that obviously represent a single stage of growth of the host crystal show drastically different bubble sizes and homogenize (the gas bubble disappears) over a wide temperature range. Such inclusions grew in a boiling environment where they trapped liquid and gas in variable relative amounts. This evidence of boiling is particularly useful because it permits fairly accurate calculation of the pressure (and, therefore, the depth) at the time of mineralization. At Creede, this depth was about 1,500 feet below the land surface at the time of mineralization. Isotope studies of the inclusions have shown thus far that the fluids in the ore-forming system were dominantly surface waters, as is the case in present-day geothermal systems.

The Creede studies have accelerated understanding the mechanisms that form vein-type ore deposits and have served as a critical test for the application of laboratory studies to field problems. Creede has become an almost unique field laboratory in which to examine such topics as (1) the variations of the physical and chemical environment of ore deposition with both time and space, (2) the sources and migration routes of the ore-forming fluids and the metals contained therein, and (3) why one part of the system deposited rich silver ore, while another part produced mainly base metals, and while still another produced only barren veins. Comparative studies of modern geothermal systems with the no-longer-active Creede geothermal system has provided valuable information. Ore-deposit studies can document the detailed evolution in time and space of a small part of a fossil geothermal system, whereas studies of modern geothermal systems reveal the "instantaneous" near-surface patterns of active systems analogous to those that have produced ores. It is clearly recognized that the ore deposit represents only a small part of the entire geothermal system that was responsible for its formation. An attempt is being made to devise and sharpen concepts and techniques that will permit the explorationist to recognize whether the prospect he is examining is the promising top, the unpromising bottom, or some distal fringe of a former circulating system; or, perhaps, whether elsewhere in the same system one might anticipate additional concentrations of valuable materials.

Creede is a good example of the appropriate and effective role of the Survey with respect to industry. The Survey is not in the business of finding ore; that role properly belongs to industry. However, the Survey does perform broad-scale technical investigations that may result in the identification of opportunities for the private sector to engage in exploration. As more and more of the easily located mineral deposits are discovered and mined out, more intensive and imaginative searches for the resources necessary to maintain the economy must be made. Knowledge of the processes by which mineral deposits form and application of that information to exploration and mineral-resource appraisal will assure that society can make the optimum use of the resources at its disposal.

It is usually difficult to calculate precisely the potential monetary benefits of a scientific program with as broad a range as that of the Creede district. The central San Juan Mountain studies, which have also contributed significantly to fundamental information on volcanism and ore genesis in many other deposits besides Creede, have cost on the order of $2 million to $3 million (1980); the recently identified silver resources alone range well into several billions of 1980 dollars. Even allowing for the fact that industry has invested many times the Government's expenditure, the present and potential return on the taxpayer's dollar is very appreciable in dollars, in materials added to the economy, in resources developed, and in productive employment within the mining industry.



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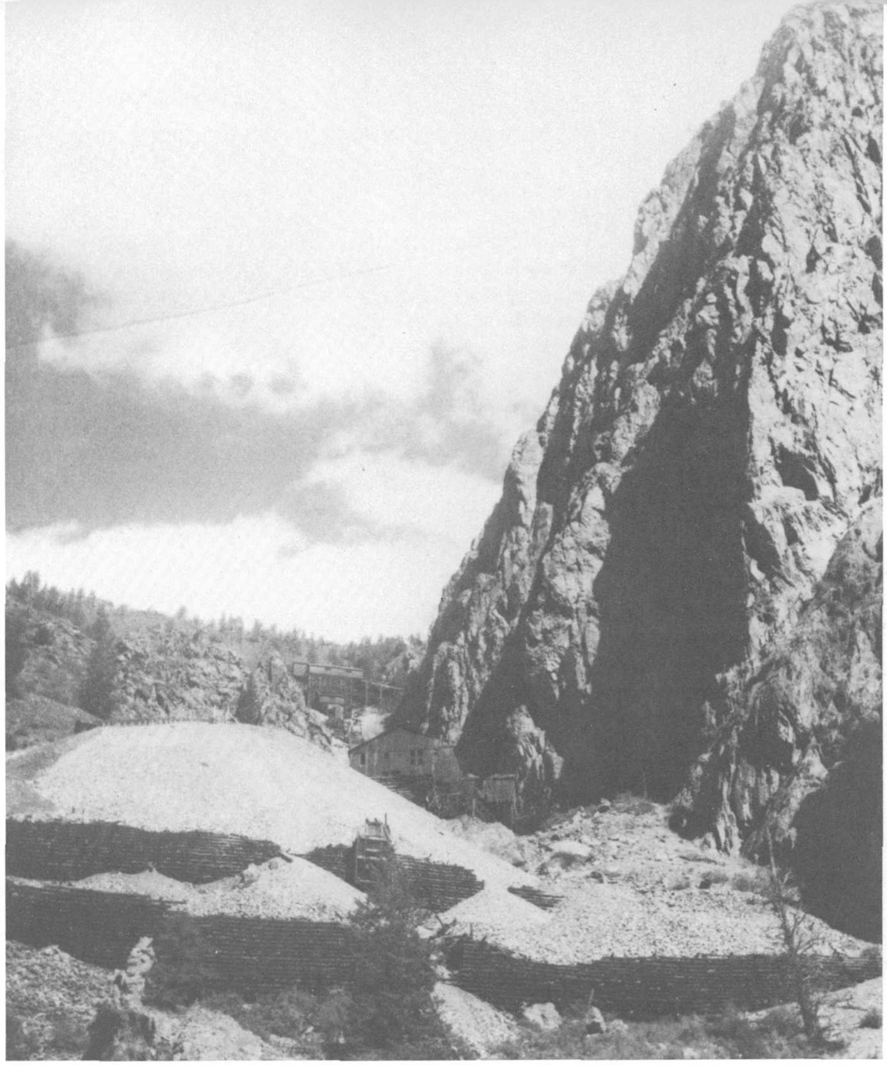


1.

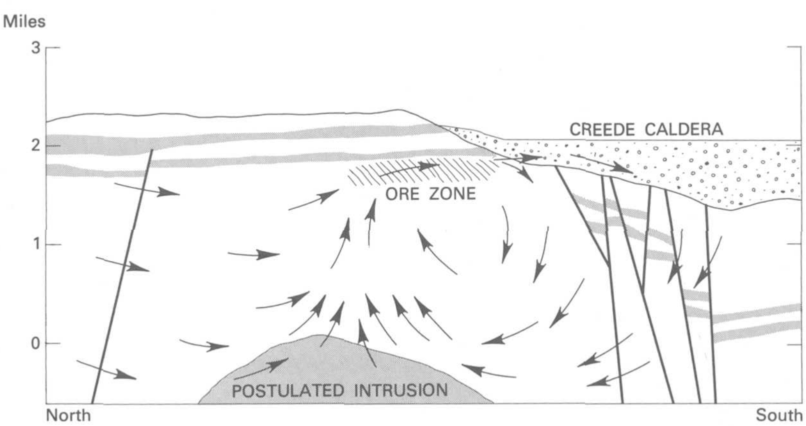
FIGURE 1.—Abandoned portals of the Commodore Mine. The Amethyst vein crops out along the edge of the hillside just beyond the prominent rocky knob to the right.

FIGURE 2.—Location of Creede and diagram showing the major veins of the district

FIGURE 3.—Generalized geologic and hydrologic model showing the circulation and mixing of fluids in response to local heating by an igneous intrusion. This model is strongly supported by isotopic studies of hydrogen and oxygen in fluid inclusions in vein minerals which indicate the former presence of different waters from several sources.

FIGURE 4.—Fluid inclusions in sphalerite (zinc sulfide) form the OH vein, Creede. The largest inclusion is about 0.2 inch long, is filled with a saline solution, and shows a gas bubble. Some irregularities of the walls of the inclusion are also visible.

3.



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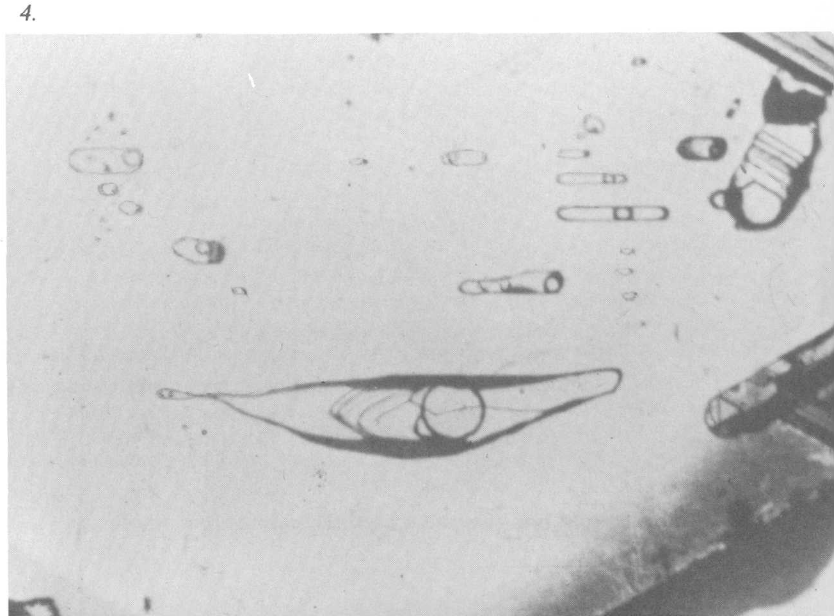


Anatomy of a Basin— The Exploration of Navarin Basin

In 1970, a geophysical reconnaissance cruise in the Northern Bering Sea led to the discovery of the Navarin Basin (see figure). The initial mapping was conducted by the U.S. Geological Survey and the Department of the Navy; subsequently, surveys by the Geological Survey and by private industry have revealed that the Navarin Basin province is of exceptional size, encompassing more than 11 million acres. Even more important in terms of potential petroleum resources is the fact that the basin contains 6 to 9 miles of sediment which is comparable to that of the Gulf of Mexico. These investigations have led to the inclusion of the Navarin Basin in the current Outer Continental Shelf (OCS) lease sale schedule (sale date December 1984).

Resource Potential

The Navarin Basin is one of the most favorable offshore U.S. basins for future oil and gas discoveries. The undiscovered recoverable oil and gas potential ranges from 0 to 11.8 billion barrels of oil and 0 to 38.3 trillion cubic feet of gas with a mean estimate of 3.8 billion barrels and 14.2 trillion cubic feet, respectively. For comparison, the United States consumes about 6 billion barrels of oil and 20 trillion cubic feet of gas per year.

The Navarin Basin province comprises a series of northwest-trending basins and ridges with 6 to 9 miles of sediment fill. Although Mesozoic (the Mesozoic Era ranges from 280 million–70 million years before present) rocks may form part of the basin fill, the greater part of the sequence is probably of Cenozoic age (the Cenozoic Era ranges from 70 million years to the present).

Numerous possible traps for hydrocarbons exist in the Narvarin Basin. Geophy sical data indicate that large anticlinal structures 6 to 9 miles across occur in the northern half of the province. Growth faults flank the basins, and stratigraphic pinch-outs and unconformities are present throughout the basins.

The geologic evolution of the basin suggests that it has adequate oil and gas reservoir rocks. In early Cenozoic time, the infant basins were flanked by coastal mountains, peninsulas, and islands. Those relatively high land masses probably shed coarse debris to the adjacent basins. Reservoir rocks of shallow-water origin are likely to be present because the basins were fed sediment by major Alaskan and Siberian rivers, including the Yukon, Kiskokwim, and Anadyr. The shelf was swept by numerous marine transgressions and regressions. All these factors suggest the likely deposition of good reservoir rocks; because the Navarin province has not been drilled or sampled yet, little is known about possible source rocks.

Tertiary (65 million–1 million years before present) mudstone dredged from the continental slope adjacent to the Navarin Basin averages more than 0.25 percent organic carbon (0.50 percent is commonly considered potential source rock), and Mesozoic mudstone along the nearby continental slope in Pribilof Canyon contains as much as 1 percent organic carbon.

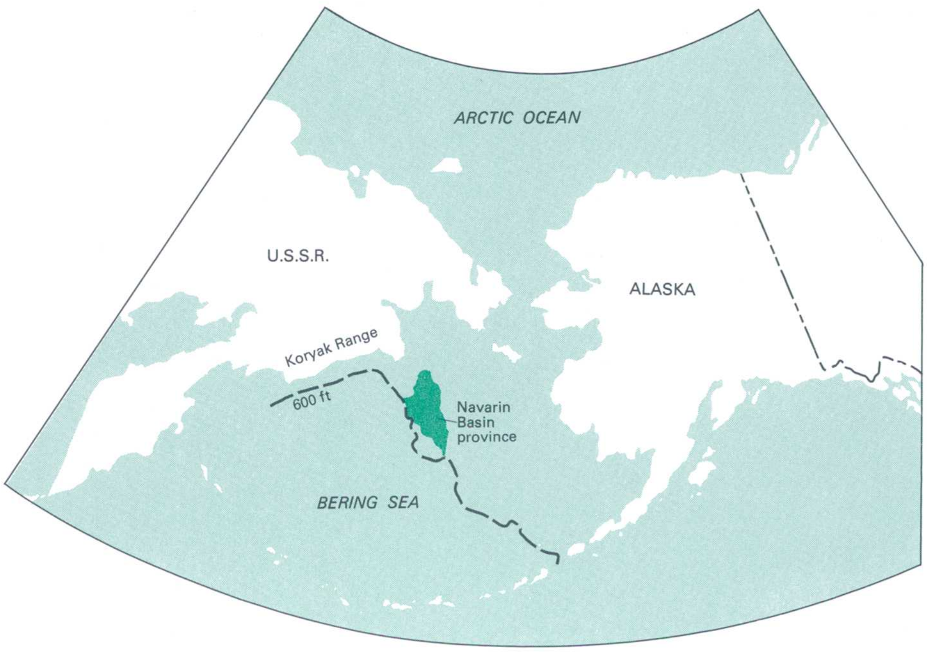
Onshore Soviet Exploration

The U.S.S.R. has drilled about 25 onshore wells in the Anadyr Basin in eastern Siberia, which is adjacent to the Navarin Basin. In the Anadyr Basin, gas was found in Miocene (25 million–10 million years before present) sandstone, and oil shows were present in lower Tertiary strata. A single well drilled in the Khatyrka Basin, northwest of the Navarin province, flowed commercial quantities of gas as high as 1.06 million cubic feet per day from three Oligocene (40 million–25 million years before present) sandstone units. Our geophysical data indicate that the Anadyr, Khatyrka, and Navarin Basins are juxtaposed features and probably share a common geologic history.

Further exploration is needed to define the province and to provide deep stratigraphic samples for analyses. The first major step will be a stratigraphic test well and then leasing which is scheduled for 1984.

Environmental Hazards

Numerous features that are potentially hazardous to development exist in the Navarin Basin province, including near-surface faults, submarine slumps, shallow zones of gas-charged sediment, and extensive fields of large sand waves. The province is covered by ice during the winter months. During 1980, about 2,160 miles of high-resolution geophysical data as well as 115 seafloor sediment samples were collected during a cooperative cruise with the Department of Commerce and the Bureau of Land Management. These data will be combined with previously collected data to make a preliminary map of the geologic hazards within the province. This environmental information will be utilized, along with information on the resource base, by the Secretary of the Department of the Interior in making decisions on the selection of tracts to be offered to industry under the December 1984 OCS lease sale.



Map showing location of Navarin Basin province. Heavy dashed line indicates 600-foot water depth.

"Mudslides" in Southern California

Floods and "mudslides" once again struck southern and central California with disastrous results during a series of severe rainstorms from January through March 1980. The storm damage extended south into northern Baja California, Mexico, and east into central Arizona. In southern California alone, damage from the several kinds of slope movements, popularly called mudslides, is estimated at several hundred million dollars; and, even months after the storms ceased, losses have increased from the continuing movement of landslides activated when infiltrating storm water raised the ground-water table in sensitive slope areas. Storm-triggered landslides are natural events that pose recurring hazards in southern California. The winter rainy seasons of 1961-62, 1965-66, 1968-69, 1977-78, and 1979-80 each triggered tens of thousands of mudslides that took lives, caused injuries, and wreaked damage on structures, roads, and terranes. Large financial losses were incurred during each of these events; each event involved natural earth processes that are being studied from both a scientific and an engineering viewpoint.

Assessing the potential for hazard, forecasting or predicting the areas and times of greatest risk, and undertaking specific mitigating measures require the recognition that significantly different processes have been lumped under such commonly used terms as landslide, mudslide, and slump. For example, the events usually reported as mudslides in southern California have included such diverse types of sloped movement as:

- Rockfalls and rock topples from road cuts and bedrock cliffs (fig. 1);
- Rotational slumps in both bedrock and unconsolidated materials;
- Debris slides from steep slopes covered with colluvium, talus, or old landslide deposits;
- Debris flows and mud flows generated by rapid runoff and sheetwash from drainage basins denuded by brush and grass fires (fig. 2) or generated by soil slips (small debris slides) on unburned slopes (fig. 3); and
- Earth and debris falls and topples from stream banks (fig. 4) and coastal bluffs in unconsolidated sedimentary deposits.

The foregoing examples include only a few of the large number of different kinds of slope movements, each with a distinctly different mechanism. The hazards posed by different kinds of slope movements are also significantly different. The principal danger from falls and some topples derives from high speed and their potential for crushing impact. The principal hazard from slumps, lateral spreads, and creep is from differential displacements in the upper surfaces, which can tear apart the foundations of structures. Potential hazards from slope movements can be described under four general headings:

- *High-speed impact.*—Individual rocks or masses of debris are directed downward or laterally and strike structures and roads on or below steep slopes. Falls, topples, debris slides, and debris flows generated by soil slips are principal contributors to hazards from high-speed impact.
- *Differential movement of ground beneath foundations.*—Structures built on the upper surfaces of slumps, lateral spreads, low-angle block slides, and some topples are endangered by this type of slope movement (fig. 5). Structures built on flat lands subject to ground failures caused by quick clay flows or liquefaction also are susceptible to foundation damage from this type of hazard.

FIGURE 1.—A rock topple and fall halted traffic on this highway in the central Santa Monica Mountains of southern California. The sequence of failures began at the left with a small block slide on bedding surfaces dipping out of the roadcut. This slide removed support that resisted overturning of joint-bounded blocks higher in the roadcut, which then tumbled one after another onto the road. (Photograph courtesy of the Department of the County Engineer, Los Angeles County, Calif.)

FIGURE 2.—An area in the San Bernardino Mountains, southern California, that was burned over in fall 1979. The view shows rilling and other features typical of sheetwash surface erosion resulting from the heavy rainstorms; but no landslide scars occur. Mud flows and mud floods from this area were responsible for such inundation and burial effects as are seen in figure 7.

- *Lateral pressure.*—Large landslide masses moving at slow or moderate speeds tend to push erect structures over and shear them off at their bases (fig. 6).
- *Inundation and burial.*—Debris flows, mud flows, and mud floods commonly inundate and bury structures in their paths; such buried structures are sometimes unusable even if no structural damage occurs. Inundation and burial by debris flows or mud flows can be difficult to distinguish from the similar effects of debris-laden flood flows (fig. 6). Of course, in a broad sense *all* kinds of slope movements result in deposits that bury some older surface downslope. The need for removal of these deposits from roadways is the most widely visible cleanup requirement (figs. 1 and 7).

Landslide activity is not confined to southern California nor are severe rainstorms the sole triggers. Landslide activity is commonly clustered in time around some external triggering event such as a rainstorm, an earthquake, or construction activity. The large number of landslides that can occur in the short durations of some triggering events is impressive. In California's San Gabriel Mountains, more than 1,000 rock falls and debris slides were triggered within minutes of the 1971 San Fernando earthquake. The tens of thousands of southern California debris slides, soil slips, and debris flows triggered by rainstorms in 1969, 1978, and 1980 occurred within a few hours to a few days. Most falls, topples, debris slides, and debris flows cease activity within days or even minutes after a triggering event ends. In contrast, rotational slumps and many block slides move slowly and continue to move long after a triggering event ends. Many rotational slumps in southern Calfornia, apparently triggered by the rainfalls from January through March 1980, continued to move throughout the spring and summer. As long as displacement of material continues, its buttressing effect on adjacent slope materials at the head and upper sides is reduced, and the area of potential hazard commonly enlarges to include structures not threatened during or immediately after the triggering rainstorm (fig. 4).

Southern California is only a small part of the total area of our Nation in which slope movements are serious natural hazards. Major landslide hazard areas in the conterminous United States are indicated in figure 8.

Large parts of the Pacific Northwest, the Rocky Mountains, and the Appalachian Mountains lose millions of dollars annually to slope movements. Current research by the U.S. Geological Survey includes efforts to improve the instrumental quantifications of engineering properties of slope materials and the identification and probability of occurrence of external events that have a potential for triggering slope movements and to provide more precise techniques for the evaluation of regional distributions of the various kinds of potential slope-stability hazards. Future research will attempt, using reliable and comprehensive regional data, to develop predictive models that will provide the basis for evaluating the relative risk in different parts of a region and to determine the most appropriate means to avoid selected levels of risk or to identify the most economical engineering methods that will minimize the potential hazards.

The Survey's research on slope movement, geologic hazards, and engineering geology paid two large dividends during fiscal year 1980. First, the compilation of a set of maps showing areas in the conterminous United States where different types of geologic constraints to construction exist and areas where construction could adversely affect the environment (for example, construction could increase an area's susceptibility to problems such as landslide and erosion) was completed. Second, the Survey was able to provide swift, competent, and effective guidance to the governmental authorities responsible for public safety and disaster relief during the Mount St. Helens eruptions and their associated debris flows because the potential hazards from such an event had been previously recognized and evaluated in the Survey's ongoing research.

FIGURE 3.—An area of unburned natural vegetation in the eastern Santa Monica Mountains shows numerous soil-slip scars formed during the heavy rainstorms. Contrast this view with features of the burned area in figure 2. Shallow landslides can cause significant mud flows and mud floods to issue from unburned areas.

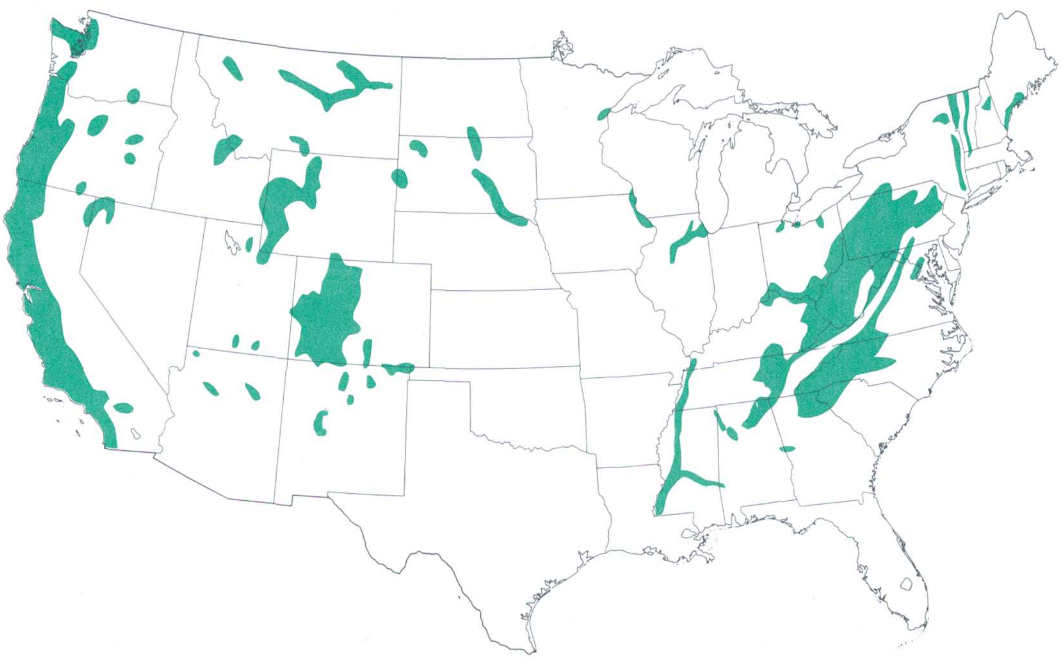
FIGURE 4.—Undercutting of the unconsolidated deposits by stream flow has resulted in debris falls. Mixed with flood waters, these falls can cause surges of debris-flow consistency to be interspersed with the flood flow.

FIGURE 5.—Scarps (S) and tension cracks (T) in the surface of a rock slump, Summit Road, Topanga area, Los Angeles County, that is undergoing headward enlargement, showing the kinds of stresses imposed on buildings founded on such a deforming surface. (Photograph courtesy of the Department of the County Engineer, Los Angeles County, Calif.) ▶

FIGURE 6.—Deformation of a house in the Repetto Hills of southern California from ◀*lateral pressure and partial burial by a debris flow originating from a small debris slide.*

FIGURE 7.—Inundation by a mud flood along the southside of the San Bernardino Mountains. Houses have been buried nearly to their eaves by sand and silt mud deposited from mud floods. (Clearing of roads in the view has already taken place.) High-water marks no more than a few inches above the top of the deposits indicate that most of the material was emplaced by a flowing slurry.
X *Approximately 6 to 8 feet of sand, gravel, and silt accumulation.*

FIGURE 8.—Major areas where slope stability presents serious problems in the conterminous United States. (Map by W. E. Davies, based on U.S. Geological Survey Map MF-771, 1976.)



Evidence of Ancient Rifting Discovered in the New Madrid, Missouri, Earthquake Zone

Earth scientists and the general public are becoming increasingly aware of the damage and loss of life that would be caused by a repetition of the major earthquakes that occurred near New Madrid, Mo., in 1811 and 1812. The intensities of these events ranged between X and XII on the Modified Mercalli Intensity Scale. Because of the greater thickness of the Earth's crust in the Central United States, the geographic area that would be affected by such earthquakes is much larger than that of the Western States. This unique characteristic of the Central United States is of critical importance in evaluating the seismic hazards of that area. A measure of the effects of this characteristic in the Central United States relative to the Western United States is to compare the population within the areas of damage for the New Madrid earthquake of February 7, 1812, and the San Francisco earthquake of 1906. Census information for 1975 indicates that more than 12 million people live within the damage area for the New Madrid earthquake compared to about 4 million people for the area of the San Francisco earthquake. A major difficulty in evaluating potential seismic hazards in the Central United States is that, until recently, few adequate geologic and seismologic criteria were available. Application of criteria commonly used for seismic hazard assessments for earthquakes in the Western United States are not suitable for earthquakes in the area that is generally assumed to be the stable continental interior of the United States.

A multidisciplinary effort that was started on a small scale in 1974 to investigate earthquakes in the New Madrid region has resulted in information that has greatly advanced understanding of the New Madrid earthquakes and has provided rational concepts useful for seismic hazard evaluation. The effort includes participation of Federal, State, and academic scientific communities funded largely under the Earthquake Hazard Reduction Program of the U.S. Geological Survey. In addition, the Nuclear Regulatory Commission has provided funding to States and academic organizations under a seven-State (Alabama, Arkansas, Illinois, Indiana, Kentucky, Missouri, and Tennessee) cooperative program whose principal objective is to provide earth science information useful for the assessment of seismic hazards to nuclear powerplants in the region. The multidisciplinary effort has included acquisition of seismic, aeromagnetic, gravity, geomorphic, tectonic, seismic refraction, and seismic reflection data. Analysis of these data indicates that most earthquakes in the region are associated with an ancient intraplate rift in the Earth's crust, which may be similar to interplate rifts in East Africa or the Rhine River region in Germany. Major rifting in the New Madrid region appears to have occurred 500 million to 700 million years ago. Intrusive igneous activity and faulting in or near the rift has occurred periodically at least three times since the initial major rifting.

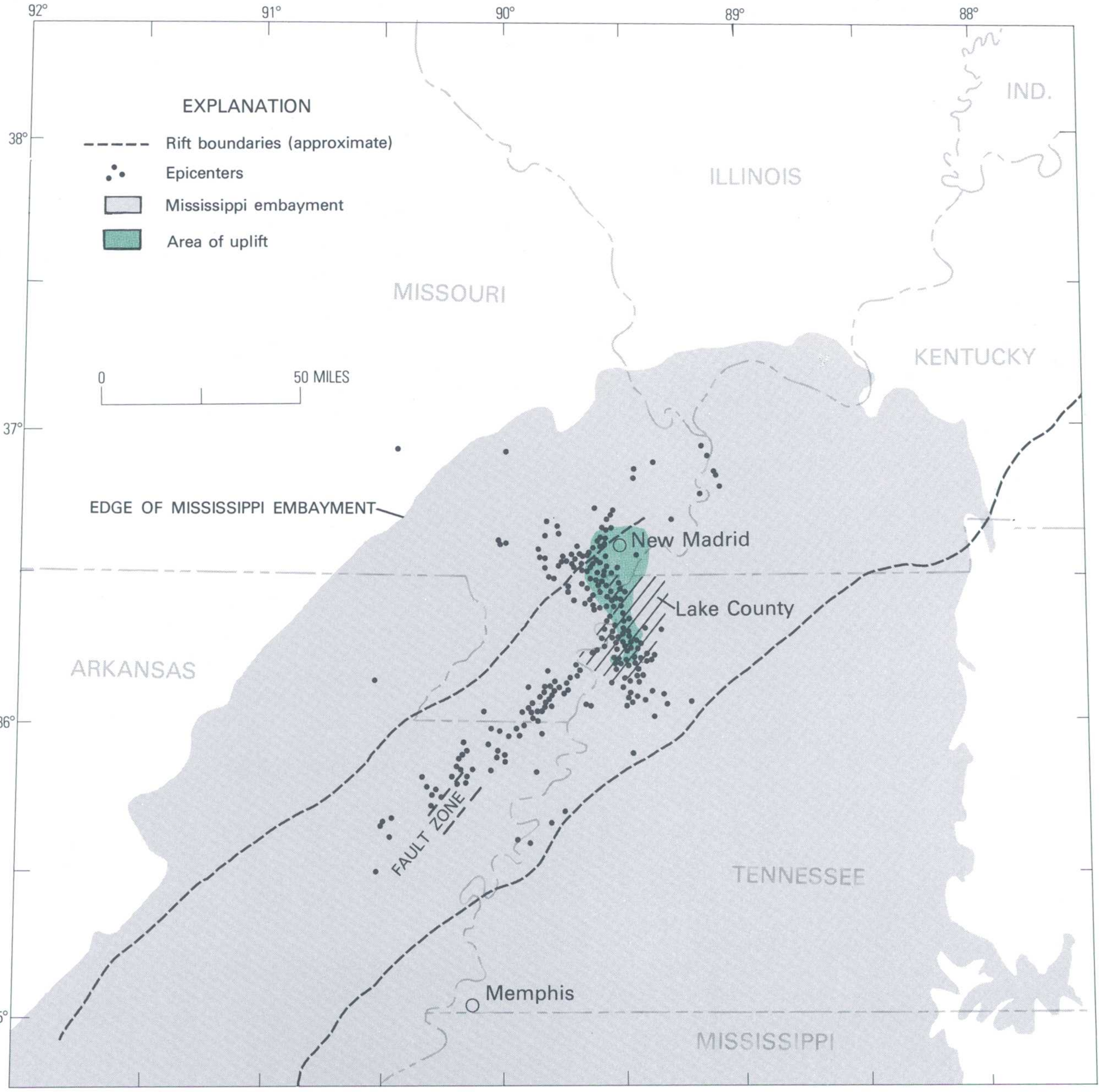
The seismic data have provided the first subsurface indication of the approximate location of seismically active fault zones. Alinements of epicenters (surface location of earthquakes) have a prominent northeast trend; less prominent trends are north-northwest and west (see figure). Approximate delimitation of the buried rift is most evident in aeromagnetic data. These data indicate a trough in the magnetic basement that trends northeast and is about 42 miles wide and more than 120 miles long. The bottom of the trough is at a depth of about 3 miles, which is a little over 1 mile deeper than the flanks of the trough. The aeromagnetic data, along with evidence from exploratory drill holes and abundant outcrops of alkalic rocks commonly found in rifts all over the world, are the principal basis for inferring that the trough in the New Madrid region is an intraplate rift. Interpretation of seismic reflection profile data shows a fault zone with an aggregate vertical displacement of about 0.6 mile, which appears to be associated with the longest trend of seismic activity. This faulting occurred prior to the deposition of most Paleozoic (about 240 million–570 million years old) rocks. The location of the fault zone and longest trend of seismicity is along the axis of the inferred rift. All post-Paleozoic faults in the reflection profiles have less than 300 feet of vertical offset. The reflection profiles also indicate that some faults and slight bending of sedimentary rocks are associated with small masses of volcanic rocks which did not reach the surface of the Earth.

Subtle uplift (see green-shaded outline in the figure) of the alluvial flood plain in the New Madrid area has been identified, and uplift of subsurface rock units has also been identified. Analysis of the seismic reflection profile data shows that the Paleozoic rocks are uplifted conformably with the surface uplift. This correspondence clearly indicates that the geologic processes that deformed the subsurface strata are on-going today.

Mapping of a trench dug into a low-sloping scarp within the uplifted area resulted in the discovery of a number of faults with displacements ranging from several inches to 1 to 2 feet; one fault had a displacement of more than 9 feet. In this trench, crosscutting relations of sand-blow deposits (inferred to be associated with earthquakes) and age dating of sampled strata indicate a recurrence interval of about 600 years for earthquakes during the last 2,000 years. This geologic evidence of a 600-year recurrence interval for major earthquakes is an independent confirmation of estimates of recurrence intervals derived from extrapolation of seismic data. The subsurface and surface deformation is the first evidence of very young tectonic activity observable at ground level in the Central United States.

Discovery of an association of earthquakes with an ancient intraplate rift that has had periodic volcanic and tectonic activity has broad implications. By comparison with tectonically active rifts studied in other parts of the world, the structural and seismologic characteristics of the rift in the New Madrid region may be inferred. Accurately identifying the exact extent of the rift is a basis for delineating the area in which earthquakes associated with the rift may occur. Because the three largest earthquakes during historic time in the Central United States occurred within the rift, areal constraints on their location have a large impact on earthquake-hazard evaluations.

Although the objectives of the investigations of the New Madrid region were designed to acquire an understanding of earthquakes, the results of the investigations have been advantageous to other geologic interests. The discovery of a trough a little over 1 mile deep raises the possibility that there may be thick sections of sedimentary rocks which may contain reservoirs of oil. Several oil companies, which are already using this information, are exploring the area. Chemical and mineralogical data have been obtained from samples collected by the Geological Survey from an exploratory hole drilled to measure in situ stress. These data confirm the presence of elements and mineralization similar to that at Magnet Cove, Ark., where commercial and potentially commercial deposits of vanadium, titanium, molybdenum, and other minerals are currently being extracted or investigated. Thus, a 6-year multidisciplinary effort in basic earth science research has once again led to the discovery of previously unknown energy and mineral resources.



Map showing the approximate boundaries of the rift as dashed line, the location of a subsurface fault zone, the area of uplift (green), and epicenters within the Mississippi embayment.

The 1979 Imperial Valley, California, Earthquake

On October 15, 1979, the largest earthquake in California in the last quarter century occurred on the Imperial fault near the international boundary between the United States and Mexico. The earthquake measured 6.6 on the Richter scale and was felt from Las Vegas, Nev., to northern Mexico. Surface movement on four fault zones accompanied the earthquake and caused approximately $30 million in damage. From a scientific point of view, the earthquake is unprecedented. It generated the most comprehensive set of data on ground shaking and structural response yet recorded from a damaging earthquake anywhere in the world. It is also the first damaging earthquake in California's history for which the actual surface rupture zones had been defined by careful fault mapping prior to the seismic event.

The earthquake and its aftershocks were distributed along the Imperial and Brawley faults (fig. 1) which form part of the tectonic boundary between the North American and Pacific crustal plates. As the Pacific plate drifts slowly northwestward with respect to the North American plate, some of the crustal strain is released suddenly during moderately large earthquakes. The remaining strain is released gradually in the form of fault creep, which is often associated with small earthquakes. In the case of the 1979 earthquake, the ground surface ruptured suddenly along a 19.3-mile segment of the Imperial fault, with additional surface movement along approximately 8 miles of the Brawley fault, as shown in figure 1. The maximum horizontal displacements reached 31 inches near the southern end of the rupture (10 miles from the main-shock epicenter) and decreased to 0.6 inch near the northern end of the fault.

Because of the frequent occurrence of seismic activity in the region and the possibility of a repeat of the magnitude 7.1 Imperial Valley earthquake of May 18, 1940, the region has been under intensive study by scientists and engineers from the U.S. Geological Survey and other research institutions. In anticipation of strong earthquakes in the area, Survey engineers had devoted considerable attention to the design and installation of comprehensive accelerograph networks capable of recording strong shaking in the ground and in buildings and other structures. Such data are essential for establishing engineering design criteria for structures in seismically active areas. When the 1979 Imperial Valley earthquake occurred, significant ground-motion and structural response records were obtained from 32 sites [4 of which are maintained by the California Division of Mines and Geology (CDMG)] located near the surface rupture zone. In addition, ground-motion data were also obtained from nine stations in Mexico installed under a cooperative program by the University of California, San Diego, and the National University of Mexico, Mexico City. The records from both countries are of considerable interest in the scientific and earthquake-engineering research community because they provide new and highly important information on ground motion and the response of structures.

The El Centro, Calif., ground-motion array, a 13-accelerograph 28-mile-long array oriented perpendicular to and crossing the Imperial fault near El Centro, obtained data of particular interest. Strong-motion data from this array (fig. 2) show that the horizontal velocity of the ground decreased with distance from the fault trace and that the velocity of ground shaking was greatest toward the northern end of the fault. Indepth studies of the data also indicate that the Earth's crust started to slip at a depth of about 5 miles below the surface east of Calexico, Baja California, Mexico, with the rupture breaking the surface 6 miles northwest of the epicenter and then continuing to the northwest along the fault to an area near Brawley. As the Earth's crust ruptured in a northwestward direction, it generated at station VO6, which is within 0.6 mile of the fault trace, the largest amplitude of shaking yet recorded anywhere in the world, a vertical peak motion of 1.74 times the force of gravity. This peak acceleration is of special interest in the engineering community because it is expected to have an impact on design criteria for critical structures such as nuclear powerplants. Overall, the data acquired from the El Centro ground-motion array during the October 15, 1979, earthquake are expected to be of immense value in predicting the characteristics of strong ground shaking in future damaging earthquakes.

From an engineering point of view, by far the most significant data from this earthquake are those obtained from the heavily damaged six-story Imperial County Services Building (fig. 3), which is the tallest building in El Centro and in the surrounding region. Though the extent of damage was so severe that it is now likely that the building, designed in 1968 and constructed in 1971 at a cost of $1.9 million, will have to be demolished; the fact that the building was instrumented with state-of-the-art earthquake recording instrumentation makes it a unique case study. The 13-channel strong-motion instrumentation network, designed by Survey personnel and installed and maintained by CDMG, accurately documented the partial collapse of the four reinforced-concrete columns at the east end between the second and ground floors, as well as the damage that was caused by the subsequent settlement (8 inches during the main shock). The data, plotted on the accompanying schematic of the building (fig. 4) provide a complete description of the response of the building to ground motion before, during, and after damage occurred. Moreover, these records are unprecedented, not only because this is the first occasion on which an extensively instrumented building has sustained earthquake-induced structural damage but because the time and mechanism of damage can be inferred from the recorded data. Already the subject of numerous research efforts, the data are expected to provide important information for improving building design and construction practice.

Since the October 15 earthquake, extensive geological and seismological investigations and monitoring efforts have been undertaken by scientists from the Survey and a number of other institutions. These investigations have yielded a number of new findings. Since the main shock, the fault has continued to creep with displacements increasing by as much as 1 foot, and surface faulting also occurred along the San Andreas and Superstition Hills faults located far to the north and west of the Imperial fault. The latter displacements, much smaller than those observed on the Imperial and Brawley faults nearer the shock epicenter, were probably "sympathetic" creep movements triggered by the earthquake or some of its aftershocks. Postearthquake studies also have shown that the 1979 surface rupture coincided with those of earlier historic and prehistoric offsets on the Imperial fault and that the surface rupture was confined to the fault segment northwest of the segment where exceptionally large horizontal shifts (up to 18 feet) occurred during the 1940 earthquake.

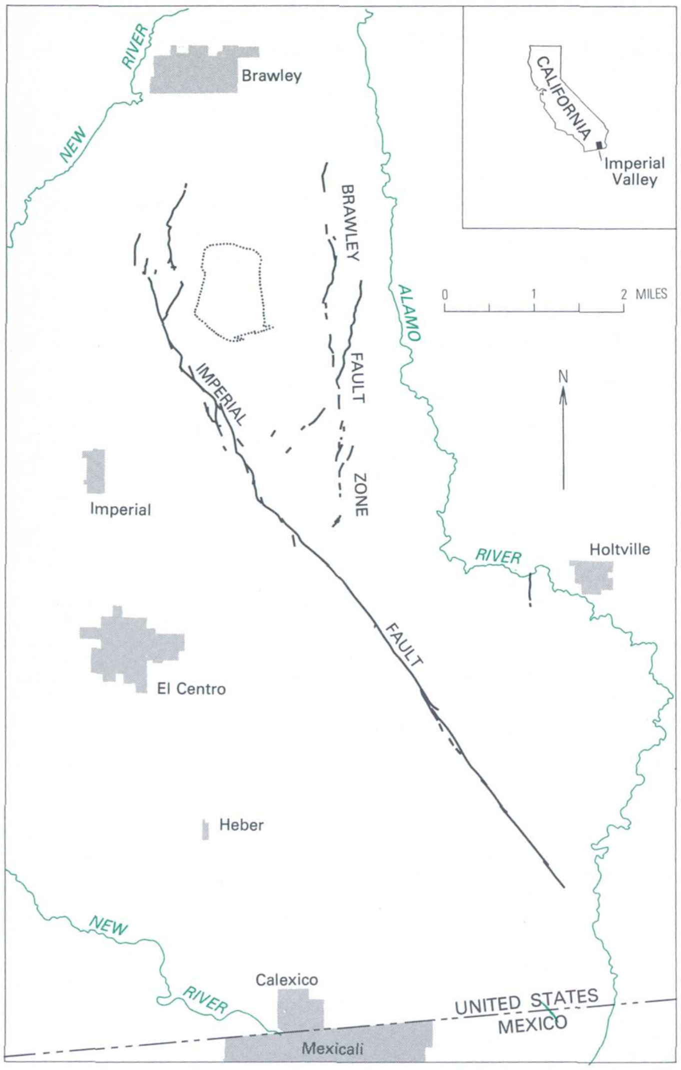
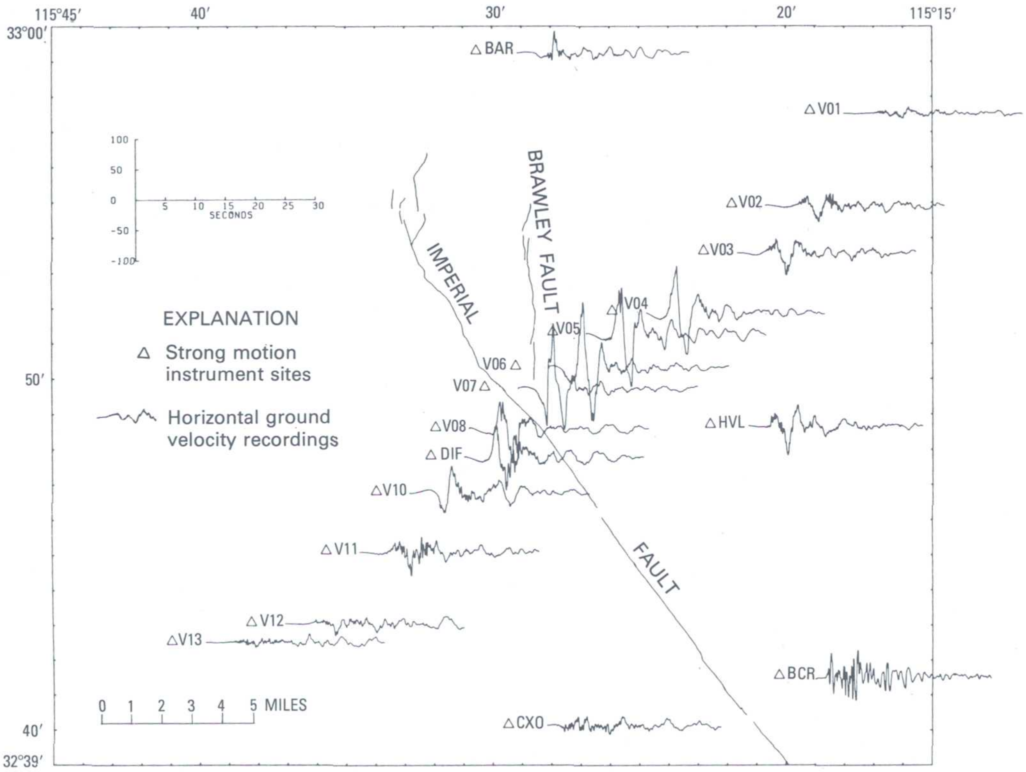


FIGURE 1.—Heavy black line shows location of surface ruptures that occurred during the October 15, 1979, Imperial Valley, Calif., earthquake.

FIGURE 2.—Recordings of horizontal ground velocity from the U.S. Geological Survey El Centro, Calif., ground-motion array and four other strong-motion accelerograph sites in the Imperial Valley.



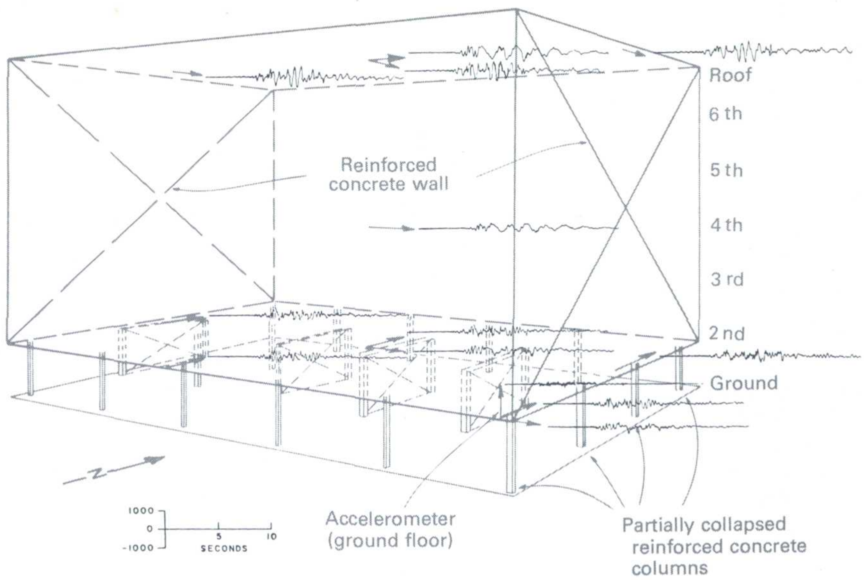


FIGURE 4.—Schematic of the Imperial County Services Building showing strong-motion accelerograph data recorded during the 1979 earthquake.

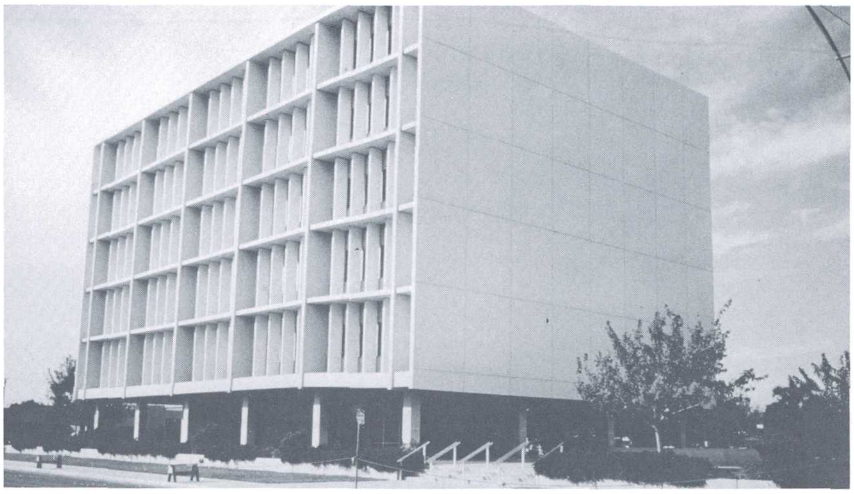
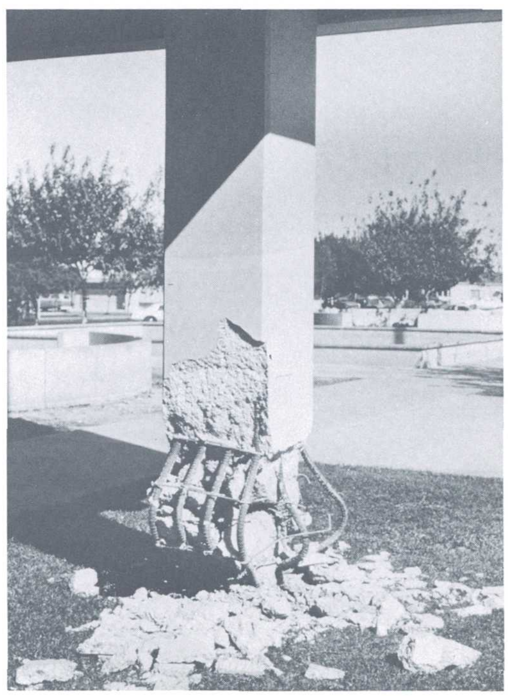


FIGURE 3.—Southeast view of heavily damaged six-story Imperial County Services Building ▲ located near the center of El Centro, Calif. One of four partially collapsed reinforced-concrete columns at the east end between the ground and second floors is shown. ▼



The U.S. Geological Survey Overseas—In Saudi Arabia

The U.S. Geological Survey's present program with the Saudi Arabian Ministry of Petroleum and Mineral Resources began in 1963 as a 3-year reconnaissance mineral-exploration and geologic mapping program in cooperation with the Ministry's Directorate General of Mineral Resources (DGMR). It has continued to the present without interruption through a series of extensions to the original work agreement, and a sixth extension, recently negotiated, will continue the program into 1985. The entire cost of the Survey Mission and all of its activities is borne by the Ministry of Petroleum and Mineral Resources.

As many as 35 full-time Survey personnel are stationed at the Jiddah Headquarters, supplemented by a large counterpart staff of the DGMR, and annually by as many as 17 Survey specialists who are detailed to Jiddah on short-term assignments. In contrast to the facilities available in the small port of Jiddah in 1963, the scientists and their families now live in comfortable air-conditioned homes in the midst of a modern seaport city that is rapidly growing in size and population. The Ministry also has work agreements with Missions from France and the United Kingdom to carry out other phases of mineral exploration and evaluation. Those Missions have been established in a campuslike center in the foothills of the Hijaz Mountains at the eastern edge of Jiddah. A new headquarters complex is under construction at the campus area that will concentrate Survey offices, laboratories, living quarters, and recreational facilities all in one compound, in contrast to the present widely scattered homes and offices; this will facilitate cooperation with the other Missions.

To assist in accomplishing the DGMR objective of becoming a viable independent scientific organization capable of assessing and developing the Kingdom of Saudi Arabia's mineral resources, the Survey's Mission work is divided into several programs that run the gamut from administration to highly specialized scientific investigations:

Program I, Management and administration.—This program is responsible for management and technical administration of activities of the Survey Mission.

Program II, Study of basic geology of the Arabian Shield.—This program includes geologic mapping and compilation at 1:100,000 scale (fig. 1) and synthesis and recompilation of geology at 1:250,000 scale; studies of layered rocks; igneous rock geochronology, genesis, structure, and economic potential; Phanerozoic sedimentary and volcanic rocks in relation to water supplies and industrial materials; geomorphology studies; and Red Sea coastal geology.

Program III, Mineral exploration.—All activities are directed toward three projects: regional evaluation of economic mineral potential of 1:100,000-scale quadrangles, regional and detailed evaluation of the economic potential of the plutonic igneous rocks of the Arabian Shield, and the identification and assessment of the evaporite deposits of the Kingdom.

Program IV, Geophysics and geochemistry.—This program includes regional geophysics of the Earth's crust, preparation of a gravity anomaly map of the Kingdom, ground and airborne geophysical surveys for regional mineral exploration, and seismic studies in the western part of the Arabian Shield to assess seismic risk, particularly for settled areas.

Program V, Technical support.—The Survey has helped to establish facilities capable of supporting a modern earth science institution, including laboratories specializing in geochemistry, petrology, mineralogy, and geophysics; a computer center; a remote sensing center; a library; a publications department consisting of editorial and cartographic sections and a photolaboratory; a data-processing system; a complete topographic service; and an exploration drilling service.

Program VI, Logistic support.—The Mission manages and acquires facilities for field support, vehicles, special equipment, and housing accomodations for its members.

Program VII, Training.—Training is emphasized in all phases of work of the Mission by on-the-job assignments or by specialized training in Saudi Arabia or in the United States to build up a staff of qualified Saudi Arabian scientists and technicians.

More than 430 reports and maps by Survey and counterpart authors describing the work of the Survey Mission have been published since 1963 (see fig. 1 for status of geologic mapping); all the recent reports and multicolor geologic maps are now being published by the DGMR Publications Department, which has been built up largely under Survey guidance.

In the area of mineral resources, prospecting in igneous rocks has revealed a belt of tin-bearing granites in the southeastern part of the shield. One at Jabal al Gharra has been investigated, and three others will be studied for economic potential. Anomalous tungsten and molybdenite have been identified at several places, and these sites are being investigated. Some granites and related igneous rocks mapped in the Jizan-Abha area are possible host rocks for niobium, tantalum, and rare elements. The granites and associated rocks show geochemical anomalies and indications of radiometric anomalies, and some may be potential sources of uranium.

Over the past few years, the Survey has investigated large phosphate deposits at Turayf-Sakakah, large pyrite deposits overlain by a cover of iron-bearing weathered material at Wadi Wassat and Wadi Qatan, silver deposits at the Samrah mine, and gold at the ancient Mahd adh Dhahab mine, which had been abandoned in 1954 when mining was no longer profitable. Through an extensive sampling and drilling program, the Survey discovered extensive areas of additional gold-bearing rock. Consolidated Gold Fields, Ltd., acquired an exploration license in 1975, has confirmed the Survey discovery, and found additional mineralized areas—as much as 1.2 million tons of ore containing 0.86 ounce of gold per ton may be recoverable.

In 1980, the Survey completed a special edition of the Landsat mosaic of the Arabian Peninsula and multicolor aeromagnetic maps of the Arabian Shield at scales of 1:2,000,000 and 1:1,000,000 for display at the International Geological Congress in Paris. The Band-7 near-infrared channel was selected for superior delineation of geologic and geographic features of interest, and computer processed at the Survey Field Station at Flagstaff, Ariz. A digital filter was used to subdue extremely high contrasts between very dark lava and basaltic rock formations and the bright desert sands and to enhance lineaments and other fine details of structure. Figure 2 is the scene covering the area around the seaport of Jiddah on the Red Sea.

The eastern Red Sea margin and coastal plain is an area where large industrial and development projects are being constructed. This will inevitably lead to population expansion and urban growth. Because many small earthquakes were recorded during the shooting of an experimental seismic refraction profile in this supposedly seismically inactive area, the Survey has been asked to install a seismic and magnetic observatory at a site near At Ta'if (fig. 2) that will become

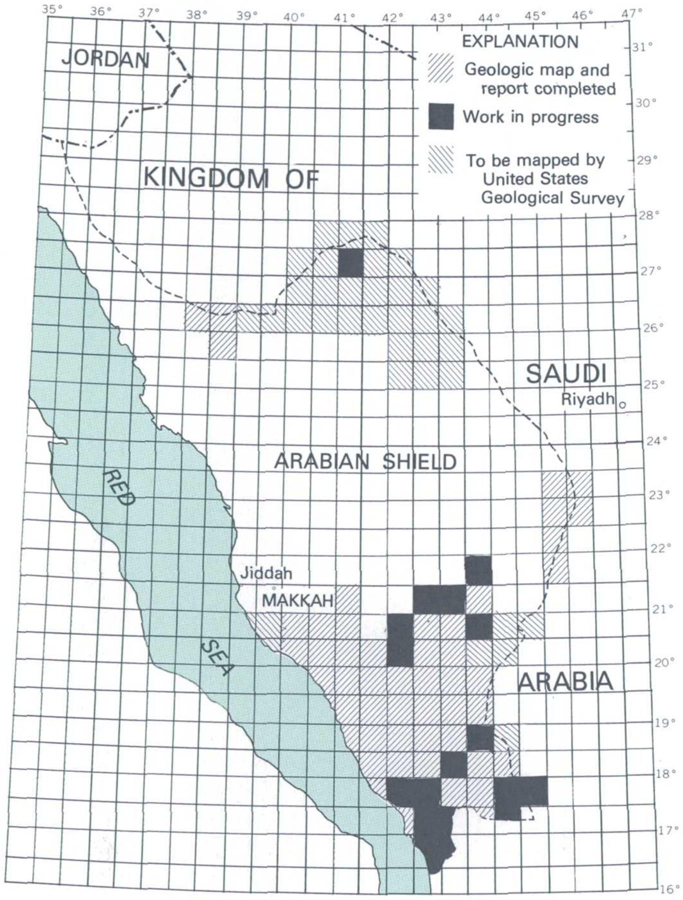
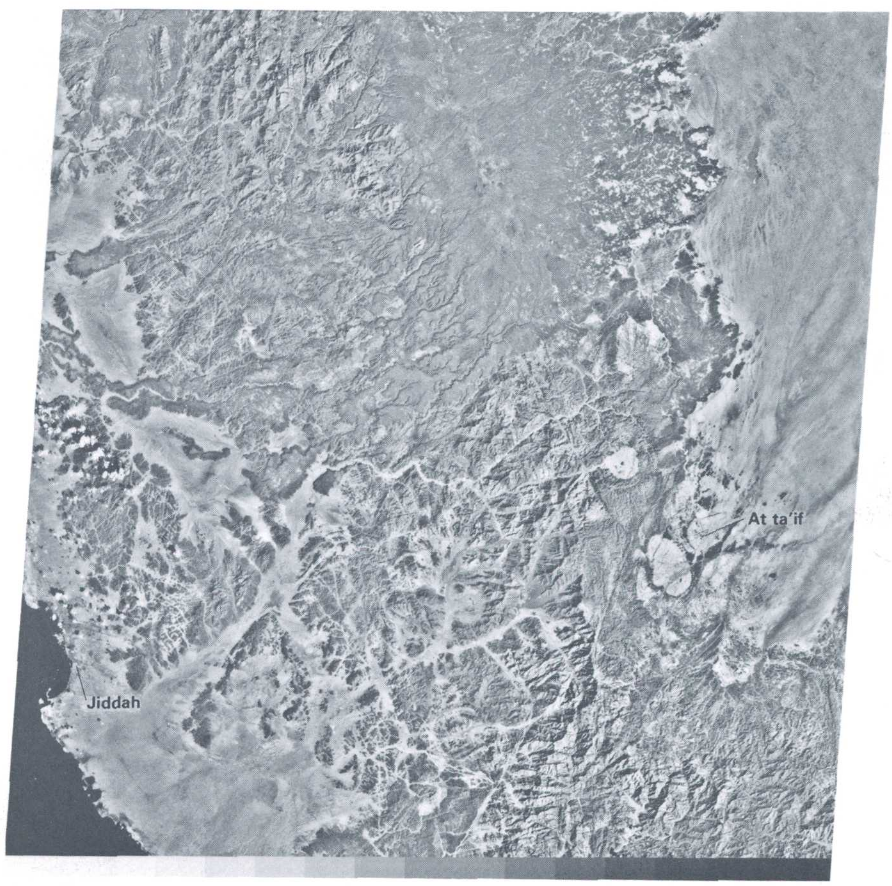


Figure 1.—The status of U.S. Geological Survey 1:100,000-scale geologic quadrangle mapping in the Arabian Shield, Kingdom of Saudi Arabia.

a modified Worldwide Standardized Seismograph Network station. This station will locate all seismic activity in the region and, in combination with stations in surrounding areas, will locate earthquakes throughout the peninsula. Data acquired by this station will indicate the amount of seismic risk involved and will allow building codes and construction practices to be appropriately modified, thus demonstrating the value of this cooperative program in relation to changing needs.

Figure 2.—Landsat image of the seaport of Jiddah on the Red Sea.



Water Resources Investigations

Mission and Organization

"... in the past decade significant achievements have been made in preserving water and harnessing its power. Although interest in water conservation and environmental protection is growing, still greater efforts are needed. Without intensified dedication to careful management of water resources, pressures from our technological society will continue to deplete and degrade the Nation's water supply."
Second National Assessment, 1979
Water Resources Council

The necessity for "careful management of water resources" as stated by the Water Resources Council is dependent upon the ready availablility of up-to-date scientific hydrologic information. Such information is an imperative for planners and managers if they are to initiate programs to ameliorate serious water problems throughout the country. The Water Resources Division has the principal responsibility within the Federal Government for providing water-resources information. It conducts investigations and presents impartial data and scientific analyses of its findings.

The Federal Program

The water-data collection, resource investigation, and research activities of this program are carried out in areas where the Federal interest is paramount. These include bodies of water in the public domain, river basins and aquifers that cross State boundaries, and other areas of international or inter-State concern. Activities include operation of surface- and ground-water quantity and quality measurement stations throughout the country, the Survey's Central Laboratories System, hydrologic research and analytical studies, and a variety of supporting services.

Support of Missions of Other Federal Agencies

With funds transferred from other Federal agencies, the Geological Survey performs work related to specific needs of each agency. Examples of work done in cooperation with several of these agencies are as follows:

Department of Agriculture
- Hydrologic studies on small watersheds, sediment studies, stream discharge and quality.

Department of Defense—Corps of Engineers
- Tidal flows in estuaries, subsidence studies, streamflow data, ground-water studies, sedimentation and water-quality studies.

Department of Energy
- Hydrologic and water-supply exploration studies at nuclear-explosion sites and at both operating and potential nuclear-waste sites; research in field of radiohydrology related to interaction between radioactive materials and various geohydrologic environments, both above and below ground; hydrologic modeling.

Department of Housing and Urban Development
- Flood-plain delineation, flood profiles, flood-frequency studies related to flood-insurance programs.

Department of the Interior:
- Bureau of Indian Affairs
  - Hydrologic data collection, water resources appraisal studies, water-supply investigations on reservations.
- Bureau of Land Management
  - Collection of hydrologic data, water-supply studies on public lands, effects of coal mining on hydrology.
- Bureau of Mines
  - Collection of hydrologic data, hydrologic studies of abandoned coal mines.
- Bureau of Reclamation
  - Collection of hydrologic data, ground-water-resources, reservoir, and land-subsidence studies.
- Fish and Wildlife Service
  - Collection of hydrologic data, ground-water recharge, water supply for fish hatcheries, in-stream flow evaluations, relation of ground water to lakes.
- National Park Service
  - Collection of hydrologic data, water-resources appraisals of National Parks and Monuments, flood-hazard, forest-geomorphology, and ground-water studies.

Environmental Protection Agency
- Studies related to energy research and development, municipal waste-disposal-site studies, relationship of ground water to lakes, collection of water-quality information.

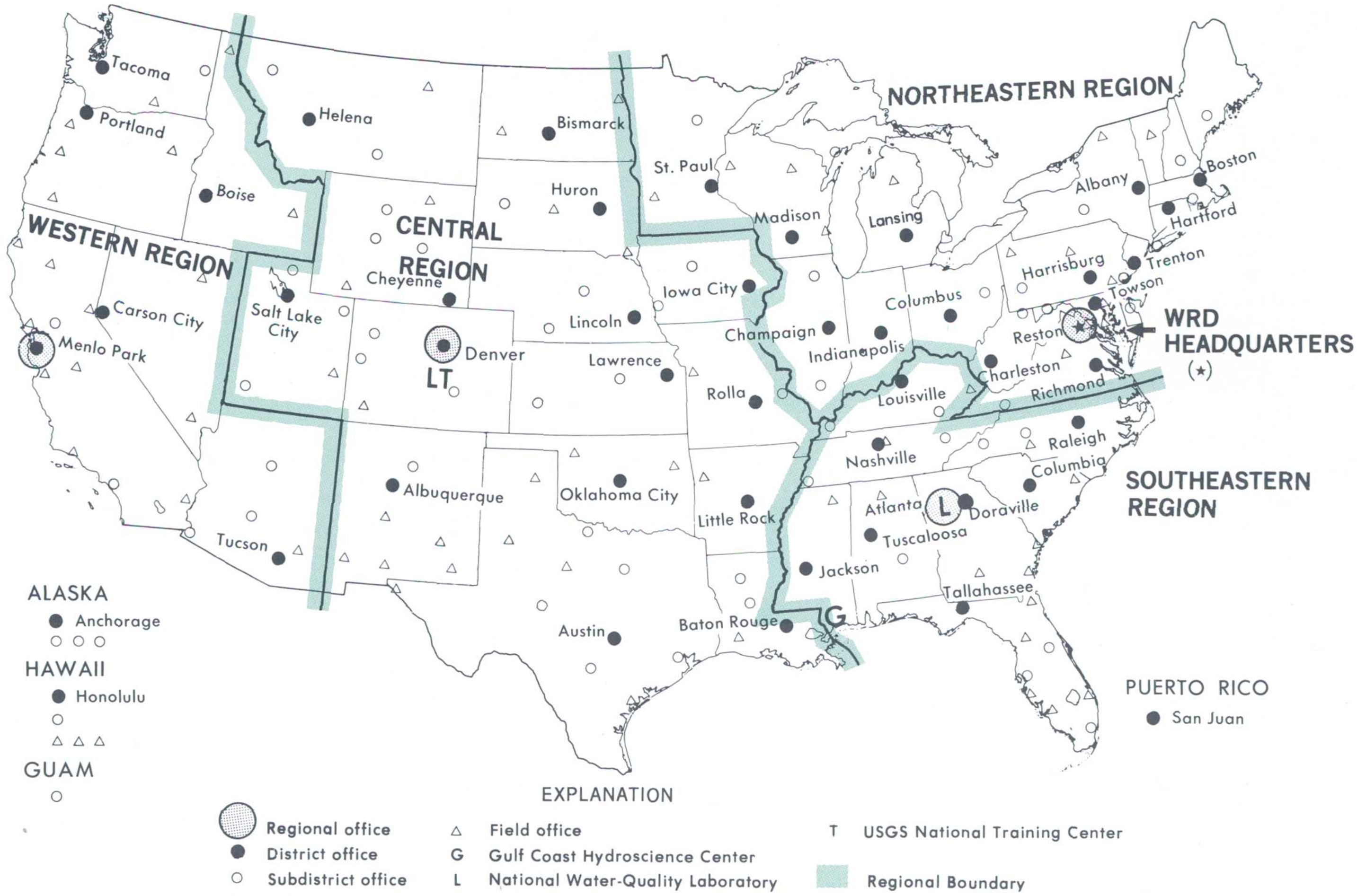
Office of Surface Mining
- Collection of hydrologic data in coal mining areas, hydrologic modeling, developments of methods for assessing hydrologic impacts.

Federal-State Cooperative Program

Under the Federal-State Cooperative Program, the Division works with State and local agencies as described in the essay beginning on page 16.

The breadth of the Division's activities results in an awareness of water-information needs at all levels of government and provides a background to develop programs responsive to those needs. Through a network of offices in 50 States and in Puerto Rico and Guam (see figure), the Division works closely with State and local agencies. Addresses of District Offices are listed in the "Organizational and Statistical Data" chapter.

In addition a major responsibility was assigned to the Survey in 1964 when it was designated the lead agency for coordinating water-data acquisition activities of all Federal agencies, including information on streams, lakes, reservoirs, estuaries, and ground water. This coordination effort minimizes duplication of data collection among Federal agencies and strengthens the overall data base and its accessibility.



Location of 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, Guam, and Hawaii are included in the Western Region.

Budget and Personnel

In 1979, the Water Resources Division employed 1,701 full-time personnel. They included scientists and engineers representing all fields of hydrology and related sciences, technical specialists, and administrative, secretarial, and clerical employees. An additional 1,382 permanent part-time and intermittent employees assisted in the work of the Division.

The $184.9 million available in 1980 for the water resources investigations activities came from the following sources:

1. Direct congressional appropriations.
2. Congressional, State, and local appropriations for 50-50 funding in the Federal-State Cooperative Program.
3. Funds transferred from other Federal agencies.
4. Funds transferred from State and local agencies.

Water Resources Investigations activity obligations for fiscal years 1979 and 1980, by subactivity

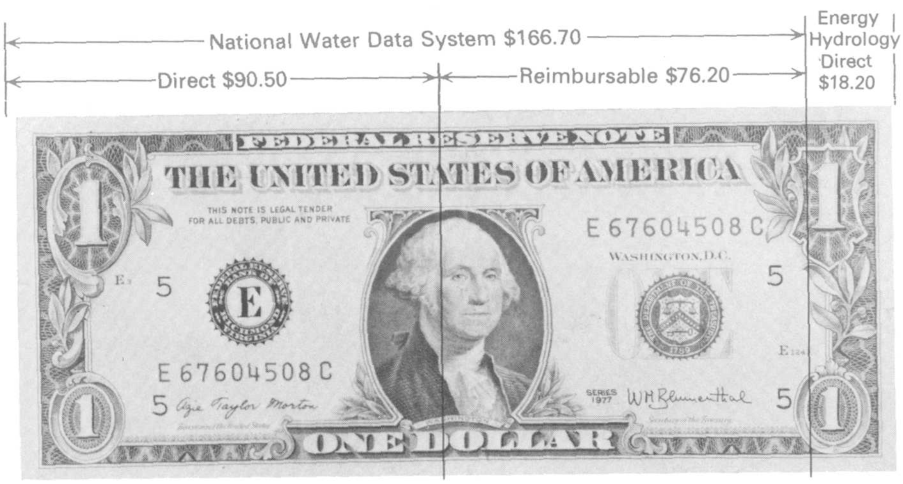
[Dollars in millions. Data may differ from that in statistical tables because of rounding]

Subactivity	Fiscal year 1979	Fiscal year 1980
Total	**$168.6**	**184.9**
National Water Data System	**153.3**	**166.7**
Direct programs	81.5	90.5
Federal program	42.7	50.7
Federal share of Federal-State Cooperative Program	38.8	39.8
Reimbursable programs	71.8	76.2
States, counties, and municipalities	40.2	43.1
Miscellaneous non-Federal sources	1.7	1.8
Other Federal agencies	29.9	31.3
Energy Hydrology	**15.3**	**18.2**
Direct program	15.3	18.2

SOURCE OF FUNDS

TOTAL $184.90 MILLION

USE OF FUNDS



The National Stream Quality Accounting Network

At each of 518 stations of the National Stream Quality Accounting Network (NASQAN) (fig. 1.), systematic and continuing streamflow and baseline water-quality measurements are made to determine the quality of the Nation's streams. NASQAN is designed to provide balanced large-scale national and regional assessments of water quality that can be used to evaluate the effectiveness of programs implemented to control and improve water quality. The primary objectives are (1) to account for the quantity and quality of water moving within and from the United States, (2) to depict areal variability, (3) to detect changes in stream quality, and (4) to lay the groundwork for future assessments of changes in stream quality.

Prior to the implementation of NASQAN, it had not been possible, on a nationwide basis, to determine areal differences or changes in water quality over time. Areal coverage of the Nation's surface water displayed an uneven geographic distribution, and the majority of sampling sites were not long term (8 or more years of record). Many sites had measured only a limited number of characteristics and were sampled at a variety of intervals.

To counteract these shortcomings, NASQAN was created to form a nationwide network in which station location was based on a relatively uniform hydrologic subdivision of river basins. This design used the 21 hydrologic regions and 222 subregions established by the Water Resources Council as well as the U.S. Geological Survey's breakdown of the subregions into 352 accounting units. Starting with 50 stations in 1973, NASQAN reached its present complement of 518 stations in 1979, with at least 1 stations in each of the 352 accounting units; streamflow is measured at all stations. On the water-quality side, an extensive suite of constituents was selected to meet general assessment needs. These included inorganic, organic, biologic, pesticide, and radiochemical parameters. The water quality characteristics and their frequency of measurement at NASQAN stations are shown in the table.

All data collected are published annually by each Water Resources Division district. Data also are available in a machine-readable format from the Survey's WATSTORE computer storage and retrieval system. Published summary reports for 1974 through 1976 provide annual statistics for each station and also show areal distribution of selected constituents in the Nation's surface water through the use of shaded maps and histograms.

NASQAN is a unique program for several reasons. The network is designed around a system of subdivided river basins so that the data generated can be related to conditions within a known area upstream and compared with that from adjacent or nearby areas. Stations or sites are operated uniformly, and analyses are performed by Survey Laboratories; therefore, results obtained can be compared because the same methods are used to collect and analyze the data at all stations in the network. Stations are committed to long-term objectives, so the length of record, the frequency of sampling, and the sampling locations will remain constant for extended periods of time. This uniformity allows for valid comparisons between stations and provides an opportunity to look for long-term changes.

In 1980, monthly water-quality data from more than 300 NASQAN stations with 5 to 8 years of record were studied for trends, using a recently developed test, the Seasonal Kendall Test. This test was applied to time series of concentration values, instantaneous transport (load) values, and flow-adjusted concentration.

A recently published report based on the trend study, "A Study of Trends in Total Phosphorus Measurements at Stations in the NASQAN Network," indicated that flow-adjusted phosphorus concentrations show an increasing trend at 40 stations, a decreasing trend at 45 stations, and no trend at 218 stations. These trends, considered on a nationwide basis (fig. 2) show that phosphorus increases occupy a region extending from the Midwest to the Southeast, while most of the decreasing trends occur in States in the west, north, and northeast.

Characteristics currently measured at National Stream Quality Network stations
[Frequencies: C, continuous; D, daily; M, monthly; Q, quarterly; T, twice per year]

Characteristics	Frequency
Field measurements:	
Discharge	C
Water temperature	C, D, or M[1]
pH	M
Specific conductance	C, D, or M
Dissolved oxygen	M
Bacteria:	
Fecal coliform and fecal streptococci	M
Common constituents:	
Dissolved[2] calcium, magnesium, sodium, potassium chloride, sulfate, flouride, silica, dissolved solids, hardness, and noncarbonate hardness; total[3] alkalinity.	M
Turbidity	M
Major nutrients:	
Phosphorus:	
Total as P	M
Dissolved as P	M
Nitrogen:	
Total ammonia plus organic as N	M
Dissolved ammonia plus organic as N	M
Total organic as N	M
Total ammonia as N	M
Dissolved ammonia as N	M
Nitrite plus nitrate, total as N	M
Suspended sediment:	
Concentration	M
Percent finer than 0.062-millimeter sieve diameter	M
Trace constituents (total and dissolved):	
Arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, silver, zinc.	Q
Organics and biological:	
Organic carbon, total	Q
Phytoplankton:	
Total, cells/mL	M
Identification of three codominants	M
Three codominants, percent of total	M
Periphyton:	
Biomass, dry weight g/m^2	Q
Biomass, ash weight g/m^2	Q
Chlorophyll a	Q
Chlorophyll b	Q
Pesticides:	
Chlorophenoxy acid herbicides, organochlorine and organophosphorus insecticides, PCB, PCN.	
Total	Q[4]
Bottom material	T[4]
Radiochemical:	
Gross alpha, gross beta, radium-226, uranium	T[5]

[1] Continuous or daily, depending upon whether the station is equipped with a monitor or whether daily observations are made. Monthly measurements made at stations where a long-term record is available.

[2] Dissolved constituents in water are those remaining after filtering samples through 0.45-micrometer membrane filters.

[3] Total concentrations are those determined by analysis of unfiltered samples. They include both dissolved and suspended materials.

[4] Collected at 151 selected NASQAN stations. Cooperative program with U.S. Environmental Protection Agency.

[5] Collected at 53 selected NASQAN stations.

Figure 1.—National Stream Quality Accounting Network stations in the United States and Puerto Rico, 1979.

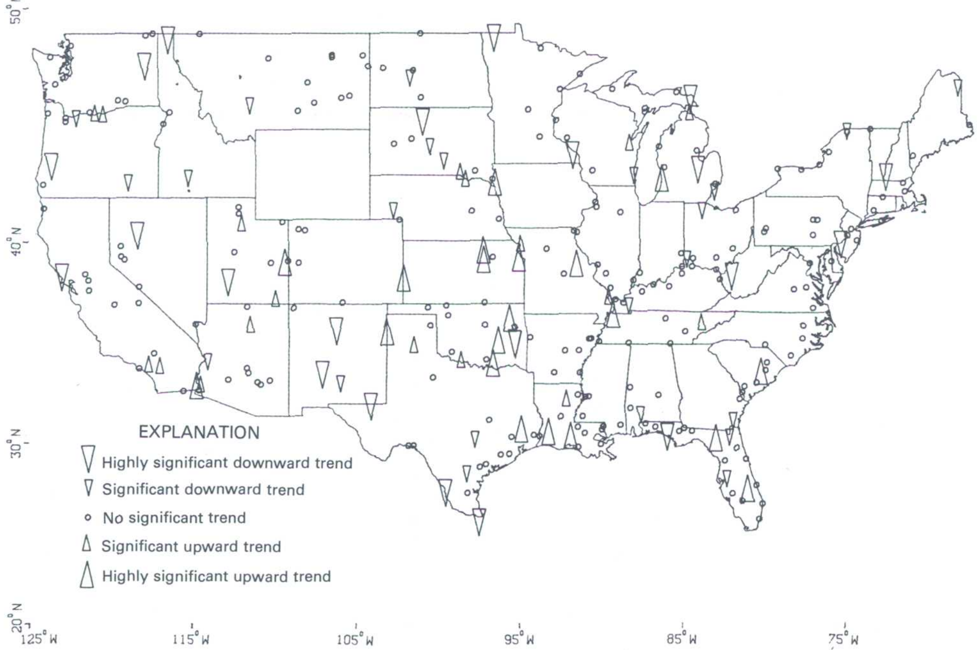


Figure 2.—Results of tests for trends in total phosphorus transport.

Icebergs and Oil Tankers: Predicting the Drastic Retreat of Columbia Glacier, Alaska

A new phenomenon has recently been added to the list of natural hazards that can be predicted—the drastic retreat of a tidewater glacier. Glacial retreat normally would be considered of only academic interest, but the drastic retreat of Columbia Glacier, near Valdez, Alaska, will be accompanied by a large increase in the calving (the breaking away of a mass of ice from a glacier or ice shelf) of icebergs. Many of these icebergs will drift into Valdez Arm and cause increased hazards to shipping. Tankers carrying 1.6 million barrels of oil per day from the Trans-Alaska Pipeline pass only 8 nautical miles down the line of iceberg drift from the terminus of this immense glacier. Icebergs and smaller pieces of ice (bergy bits or growlers) now drift toward, and occasionally across, the navigation lanes but have not yet seriously impeded shipping. However, U.S. Geological Survey glaciologists predict that the drastic retreat of Columbia Glacier will soon begin and will cause a large increase in the annual discharge of icebergs. Consequently, the Survey is carefully monitoring this glacier.

Nearly all grounded iceberg-calving glaciers have exhibited large-scale advances and retreats that are unrelated to climatic changes. Survey glaciologists have determined that the reason for this unusual pattern of behavior lies in the relative stability or instability of the terminus; the critical factor is water depth. If the ice at the terminus is in shallow water, the glacier is generally stable; however, instability results when the glacier retreats into a deep fiord or basin. The glacier may then retreat very rapidly and irreversibly as unusual volumes of ice break away. The attention of glaciologists became focused on the Columbia Glacier because it appears to be on the verge of such instability.

The Columbia Glacier is a large calving glacier, 42 miles in length, 430 square miles in area, and up to 3,700 feet in thickness. It now ends on a moraine shoal (a shoal consisting of rock materials deposited at the terminus of the melting glacier) in shallow water (not more than 75 feet deep), but, upglacier from the terminus, the bed is about 1,300 feet below sea level. To determine when and how fast the glacier might retreat and how much the iceberg discharge would be increased, an intensive study was begun by the Geological Survey in 1977. Thickness, velocity, slope, mass balance, and other variables were measured in the field, and these data were used in computer flow models. Studies made at other calving glaciers in Alaska led to an empirical relation for calculating the rate of iceberg calving, and a calving model was developed that uses these results to provide specific predictions.

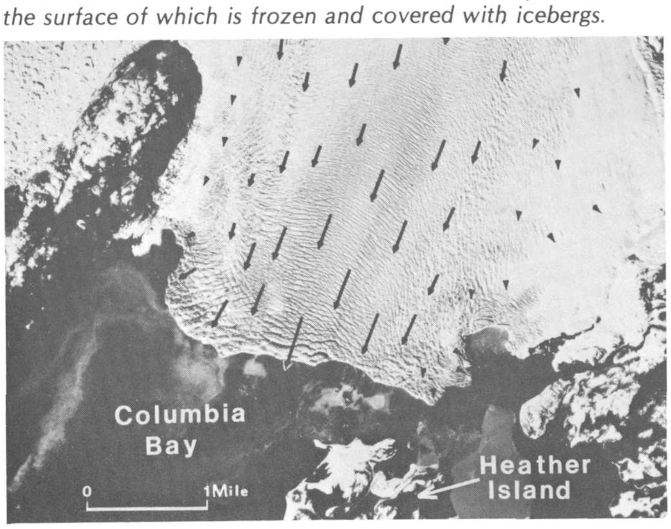
Studies of the 52 calving glaciers in Alaska show that:

- All glaciers with stationary, slowly advancing, or slowly retreating termini end in shallow water (less than 260 feet deep). This shallow-water position is either at the head of a fiord or on an advanced terminal moraine shoal. Most glaciers have retreated back from an advanced position attained, in many cases, during the "Little Ice Age" (about 3,000 years before the present time).Only one glacier still remains in an advanced position—the Columbia Glacier.
- All glaciers undergoing rapid retreat (0.5 to 6 miles per year) terminate or terminated in deep water, and, in general, the deeper the water, the faster the retreat.
- No calving glaciers have been observed advancing rapidly.
- Advances or retreats of calving glaciers show no consistent or apparent relationship to changes in climate.
- Calving speed (the volumetric discharge of icebergs per year divided by the area of the terminus face) is simply proportional to water depth at the terminus.

These observations are consistent because the rate of advance or retreat is equal to the difference between the ice flow speed to the terminus and the calving speed of ice away from the terminus. In shallow water, the ice speed is increased because a given ice discharge must flow through a section of reduced thickness and, thus, must flow faster, and the calving speed is reduced to about the same as the ice speed. As ice flow approximately balances calving, the position of the terminus changes very little. If, on the other hand, the glacier were to retreat off a shoal into deeper water, the rate of ice movement down valley would be reduced, but calving speed would be increased. This is because the greater ice thickness requires less velocity to handle a given ice discharge. Calving then would exceed flow, the terminus would retreat into even deeper water, and instability would result.

In early 1980, Columbia Glacier still terminated on the moraine shoal, although it was becoming thinner at an accelerating rate near the terminus and was retreating at the rate of about 190 feet per year. Using the new calving model, Survey glaciologists have calculated that the rate of retreat is expected to increase at an ever-faster rate during the next few years and that, from 1982 to 1985, the iceberg discharge rate will also increase to a peak of 6 to 8 times the present level. Now the main effort is on monitoring—comparing observed flow and recession data with computer predictions to better calibrate the ice flow and calving models and, thus, to further define the timing and the amount of the large increase of iceberg discharge that is to come.

FIGURE 1.—*Vertical aerial photograph of the terminus of Columbia Glacier, taken on February 29, 1980. Superimposed on the photograph are velocity vectors, determined for October 20, 1979, to February 29, 1980. The length of each arrow on this figure is equivalent to the motion over 100 days. For a glacier, these speeds are very fast; the motion at midstream close to the terminus was 23 feet per day, whereas further upglacier it was only half as much. The glacier terminus retreated from Heather Island in December 1978 for the first time in recorded history. The gray shapes between Heather Island and the mainland are sea ice floes. In the upper left corner, an arm of Columbia Glacier dams and flows into the basin of Terentiey Lake, the surface of which is frozen and covered with icebergs.*



◄ *FIGURE 4.—Columbia Glacier (background) and its iceberg plume. The water body in the foreground, dotted with icebergs, is Valdez Arm.*

FIGURE 2.—This unusual map, which shows the altitude of the bedrock surface beneath Columbia Glacier, is based on measurements made by a specially designed glacier radar and computer analysis which combined these measurements with velocity and other measured data and calculated the most likely ice thickness at 2,056 points. Although the bed of the glacier is more than a thousand feet below sea level in some areas, the glacier is not floating because it is very thick. The area where the bed is below sea level is indicated by vertical lining. The deep new fiord, that will result after 30-50 years of drastic retreat will be several miles wide and about 26 miles long, rivaling Port Valdez in size. The direction of ice flow is shown by solid arrows; the direction of iceberg drift is shown by open arrows. ▼

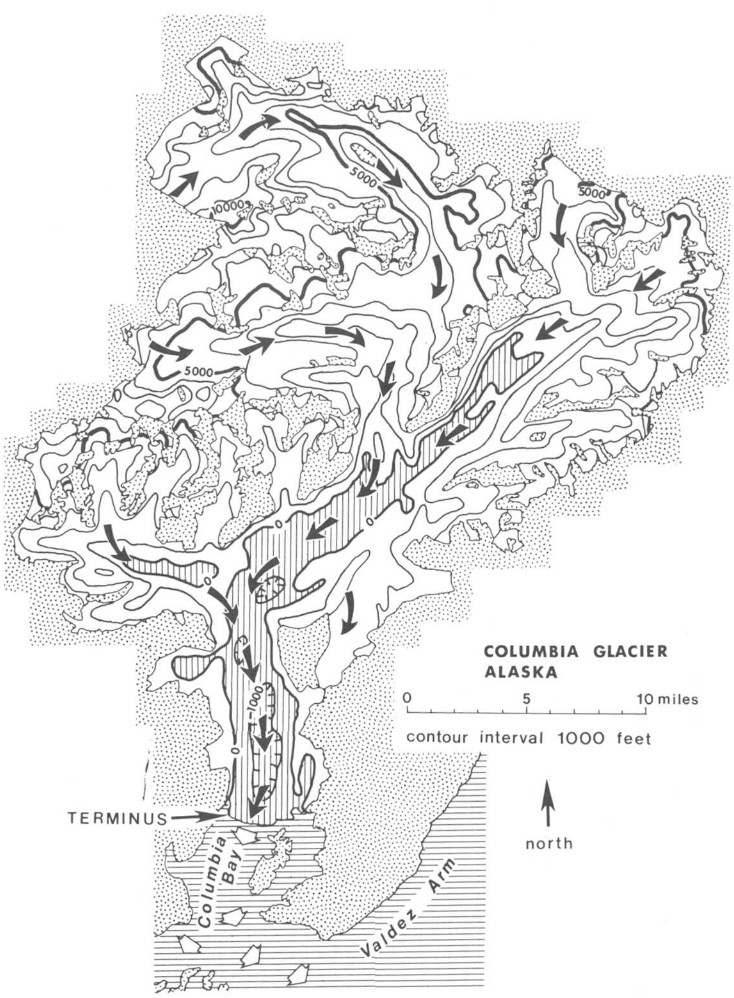
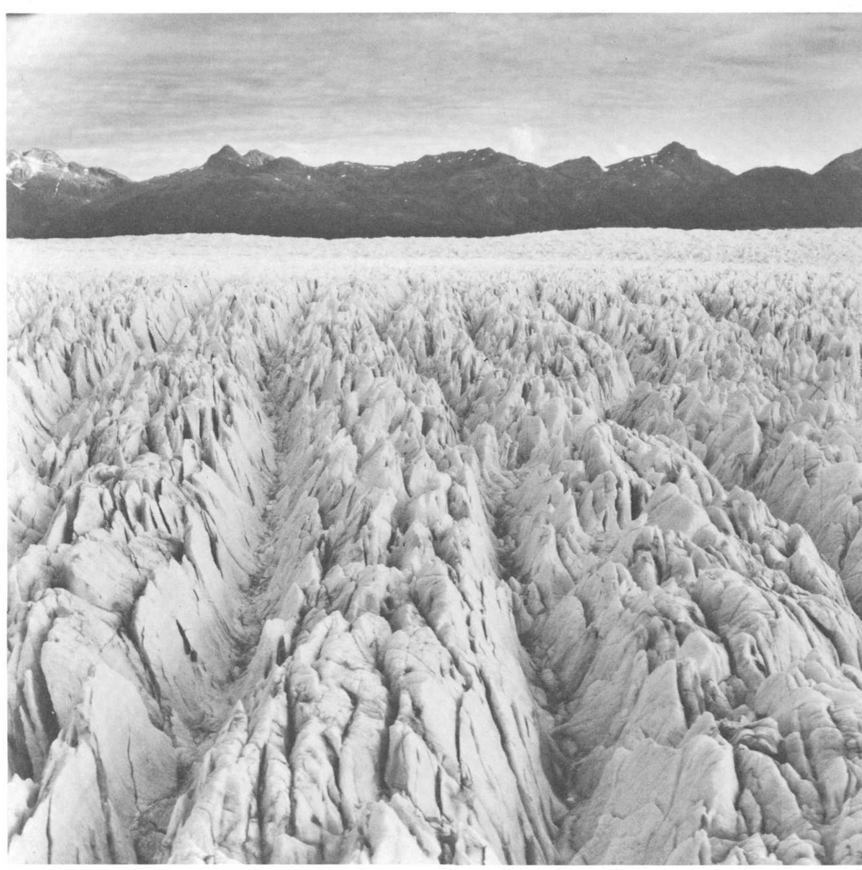


FIGURE 5.—Aerial photograph looking down Columbia Glacier to Columbia Bay and just beyond Valdez Arm. ▲

FIGURE 3.—The surface of Columbia Glacier is severely shattered, due to its relatively high rate of flow. Geological Survey photogrammetrists were able to identify distinct crevasse patterns, even in winter photography, to measure the motion. These interesting crevasse "streets" are not yet explained. ▼



Research on Using the Geohydrologic Environment for Isolating High-Level Radioactive Wastes

Although the world entered the Atomic Age nearly 40 years ago, none of the resulting high-level radioactive wastes[1] has been disposed in a manner that can be regarded as permanent. One disposal method considered to be feasible is burial in a mined repository. Many scientists agree, however, that elements of the geohydrologic environment, particularly ground-water flow, can result in undesirably rapid dissolution and release of radioactive wastes from some burial sites. Likewise, they agree that the diversity of environments makes it likely that suitable sites can be found whose geohydrologic characteristics could effectively isolate the wastes with very low risk of exposure to man.

Part of the U.S. Geological Survey's research on high-level waste disposal is concerned with locating areas where the geologic and hydrologic conditions provide a series of natural, relatively independent, multiple barriers to radioactive waste transport (see figure). This concept was adopted to overcome deficiencies in the ability to characterize adequately the masses of rock around a respository and to predict waste-rock-water reactions, natural events, and radioactive waste transport. Another aspect of the research is to improve our knowledge in the areas of these deficiencies.

The topical nature of the Survey's research in high-level waste disposal is influenced significantly by the fact that the responsibility for selection and design of waste repository sites rests with the Department of Energy. The Nuclear Regulatory Commission and Environmental Protection Agency are responsible for licensing proposed facilities and establishing criteria for determining environmental acceptability. The Survey's research on high-level wastes, a joint effort of the Water Resources and Geologic Divisions, is designed to complement and augment the Department of Energy's research programs with needed information from an agency that has neither operational nor regulatory responsibility for waste disposal.

The initial effort to identify potential respository sites involved analyzing alternative approaches to the systematic screening of broad geohydrologic environments. One approach under consideration was developed jointly with the Department of Energy. It is a nationwide screening process that begins with broad provinces which are subdivided into successively smaller land units. The screening would be done with the substantial participation of scientists from State agencies concerned with natural resources and earth sciences. An alternative approach would consider a very limited area, would involve a small number of Survey personnel, and would focus primarily on Federal lands in the West. Work has started on assembling a data base to support whichever regional screening process is ultimately selected and on identifying ways of recording and processing the large amount of data needed for the screening.

[1] Includes fission products that initially have a high level of beta and gamma radiation; also transuranic elements with a long toxic life. Transuranic waste contains long-lived alpha emitters at concentrations greater than 10 nanocuries per gram.

Research on the nature of critical geologic and hydrologic properties and processes involved in radionuclide migration from a waste repository falls into three categories: studies of rock types and geohydrologic environments for emplacing wastes, methods for characterizing environments for emplacing the waste, and investigations and modeling of geologic and hydrologic processes.

The rock types and environments under study as possible host media for the wastes include shales of Cretaceous age in the West, the unsaturated zones beneath some western deserts, granite and related crystalline rocks, and anhydrite.

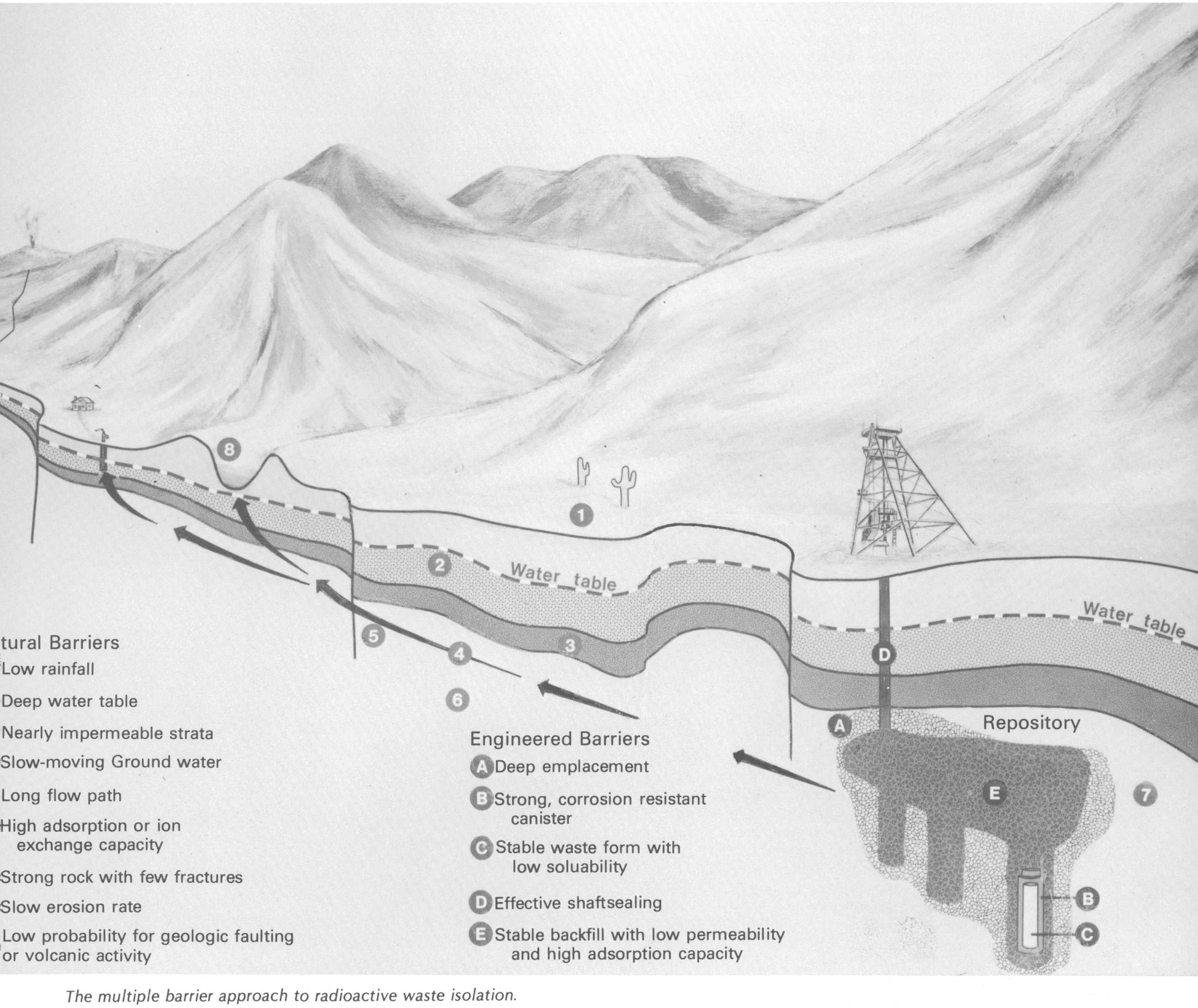
Several geophysical and geochemical methods are under study to improve our ability to characterize the geohydrologic environment of a potential waste repository. The emphasis in geophysics is on so-called nondestructive methods that will not compromise the containment properties of the site. Included are studies of surface seismic methods, acoustic and electric techniques, borehole geophysical logging, remote sensing, and neutron activation methods to measure the water content of salt deposits. In the area of geochemistry, efforts are directed to the improvement of carbon-14 techniques for dating ground water and carbonaceous materials and the extension of the capability for dating old ground water and sediments using the isotope techniques. Improvements in the accuracy of dating geologic events and features will help to refine our knowledge of the geologic history of an area and to improve our ability to make extrapolations into the future.

Among the studies of geologic and hydrologic properties and processes is a group related specifically to the thermal and mechanical stresses imposed on the surrounding rocks by the emplacement of high-level wastes. The effects of these stresses on the underground flow of fluids and heat cannot be modeled at present for fractured rocks and unsaturated alluvium. To accurately describe the flow of fluids in these media requires an understanding of rock mechanics, heat transport, saturated ground-water flow (fractured rock), water movement in the unsaturated zone under nonisothermal conditions, and combined unsaturated-saturated zone flow in thick alluvium. Except for heat transport, studies are under way on some aspects of all these topics. In addition, research is being done to define the chemical and hydrologic behavior of the transuranium elements (particularly plutonium) in ground waters, to determine oxidation-reduction potentials and reactions in ground water and the response of the transuranium elements to these potentials, to describe solute transport in the unsaturated zone, to develop radionuclide transport models in ground-water systems, and to synthesize information on recent tectonic conditions in the United States.

A variety of geologic and hydrologic investigations is being conducted on behalf of the Department of Energy in regions where the Department of Energy is considering locating respository sites. These regions include the Nevada Test Site and vicinity; the Waste Isolation Pilot Plant in southeastern New Mexico; Hanford Reservation Region in Washington; Paradox Basin in Utah; Gulf Coast Salt Dome Region in north Louisiana, Mississippi, and northeast Texas; and the Salina Basin in New York and Ohio. The geohydrologic controls on the movement of waste solutes and the potential hazards from future volcanic activity are under study at the Department of Energy's Idaho National Engineering Laboratory where transuranic wastes have been stored and disposed.

The following are a few significant results of the research:

- Detailed geologic mapping combined with surface geophysical studies on the eastern edge of the Jackass Flats area of the Nevada Test Site showed that the underlying intrusive body of granodiorite was highly fractured and altered at the depths where a repository could be constructed. Consequently, the decision was made by the Department of Energy to discontinue additional exploration.
- Test drilling, surface geologic mapping, and regional and borehole geophysical surveys in the north-central part of Jackass Flats indicated that the depth to a suitable host rock for the wastes, inferred to be an intrusive body, was too great; also, the overlying rocks apparently were extensively faulted and mineralized. On the basis of the Survey's research, the Department of Energy discontinued exploration.
- The acoustic televiewer log (a sonic geophysical borehole log) was used to demonstrate that unfractured rocks are very rare even at depths of thousands of feet. This finding is of significance with regard to the search for repository sites in rocks of low hydraulic conductivity.
- Hole-to-surface direct-current resistivity measurements at Salt Valley in the Paradox Basin, Utah, clearly defined relative variaitons in depth of the salt-caprock interface. Similar measurements in volcanics at the Nevada Test Site clearly defined fracture zones a few hundred feet laterally from a borehole.



The multiple barrier approach to radioactive waste isolation.

Coal Hydrology Program

The Water Resources Division of the U.S. Geological Survey began work in coal hydrology in fiscal year 1974 in response to a request from the Bureau of Land Management for assistance in assessing hydrologic problems associated with coal mining, particularly surface mining and reclamation. Such studies were needed for the environmental impact statements required for leasing Federal coal and for the management needs of the Bureau of Land Management. In fiscal year 1975, $1.2 million was appropriated directly to the Survey to investigate the relationships between coal development and water resources, primarily on Federal lands. Since then the Federal program has grown to more than $12 million. Much of the growth in the program, particularly in the East, is attributed to the enactment of Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977. The coal hydrology program in support of the act is nationwide in scope and is designed to acquire, interpret, and disseminate information on the hydrology of the areas where mining exists or is likely to develop. Program emphasis is on water availability and the assessment of the impacts of mining on water resources. Accordingly, the Survey has expanded its data-collection programs on both Federal and non-Federal lands and has implemented research on a number of water-related subjects concerned with cause-and-effect relations of mining. In addition, studies to develop techniques for discriminating between the impacts of various types of land use have been started.

The above funding was provided, in part, to meet the stipulation in the act that a Federal agency would supply the hydrologic information necessary to describe the hydrology of the general area of mining. This, along with permittee-site data, would permit an assessment to be made of the probable consequences of a proposed mining operation. It would also allow the regulatory authority to appraise the cumulative impacts of a given mine in conjunction with other land uses that might cause impacts in what is referred to as the "general area."

The most coal mines exist in the Eastern and Interior coal provinces; hence, this is where there is the greatest need for hydrologic information for permitting purposes. The map shows these two provinces and the major subbasin delineations chosen for intensive hydrologic data collection and reporting. The first hydrology report on Area 23 in Alabama has been published. This report and the remaining 34 have been designed to summarize all pertinent hydrologic data on the areas in question. Approximately one-half of these reports will be published by early 1981, and the balance will be published in 1982.

Coal hydrology is also an element of the Federal-State Cooperative Program. Federal and State shares, which amount to $2.9 million each, support efforts to evaluate site-specific mining related hydrologic problems such as acid mine drainage, subsidence, impacts on local water supplies, excessive sediment in streams and reservoirs, pollution from coal washing and loading facilities, and impacts of dewatering identified by State and local governments. Federal-State cooperative projects number 77 in 31 States, but, at present, many of the projects are not designed specifically to provide the hydrologic data needs that may result when State regulatory surface mining programs are put into effect. However, much of this data will be useful to the State surface mining program.

Much of the existing Federally funded coal hydrology network of the Water Resources Division is possible only because a broad network of hydrologic data monitoring sites and water-resources investigation programs has existed for many years. These efforts have been funded through the Federal-State Cooperative Program and by other Federal agencies.

Agencies that have provided funds for the Water Resources Division coal program are principally the Bureau of Land Management, the Office of Surface Mining, the Bureau of Mines, and the Environmental Protection Agency. The Office of Surface Mining and the Bureau of Mines currently contribute $179,450 each for the study of flooding characteristics of the Big Sandy-Tug Fork basin in West Virginia and Kentucky. The Office of Surface Mining is also providing $100,000 to the Water Resources Division to develop the techniques for assessing cumulative impacts of mining. The Bureau of Land Management is the largest contributor of funds for coal hydrology, providing $3.8 million in fiscal year 1980 for studies on Federal lands in eight States. A number of studies assist the Bureau of Land Management in their coal tract delineations and in planning and managing the Federal coal reserves. Hydrologic modeling is being done to aid the Bureau of Land Management in determining hydrologic characteristics of selected basins and the effects of coal mining on areal hydrology. Presently, hydrologic data is being organized in 33 small basins to develop and calibrate the models; these studies are in Montana, North Dakota, Colorado, New Mexico, Alabama, Tennessee, Indiana, and Illinois.

Semino mine, Wyoming. (Photograph courtesy of the Bureau of Land Management.)

The principal use of coal is for steam generation for large-scale electric power generation. In recent months, much emphasis has been placed on synthetic fuels, and coal is expected to play a major role in the development of these fuels and oil shale. Plans are to convert solid coal into gaseous and liquid phases which would provide clean energy for applications now using large quantities of petroleum products.

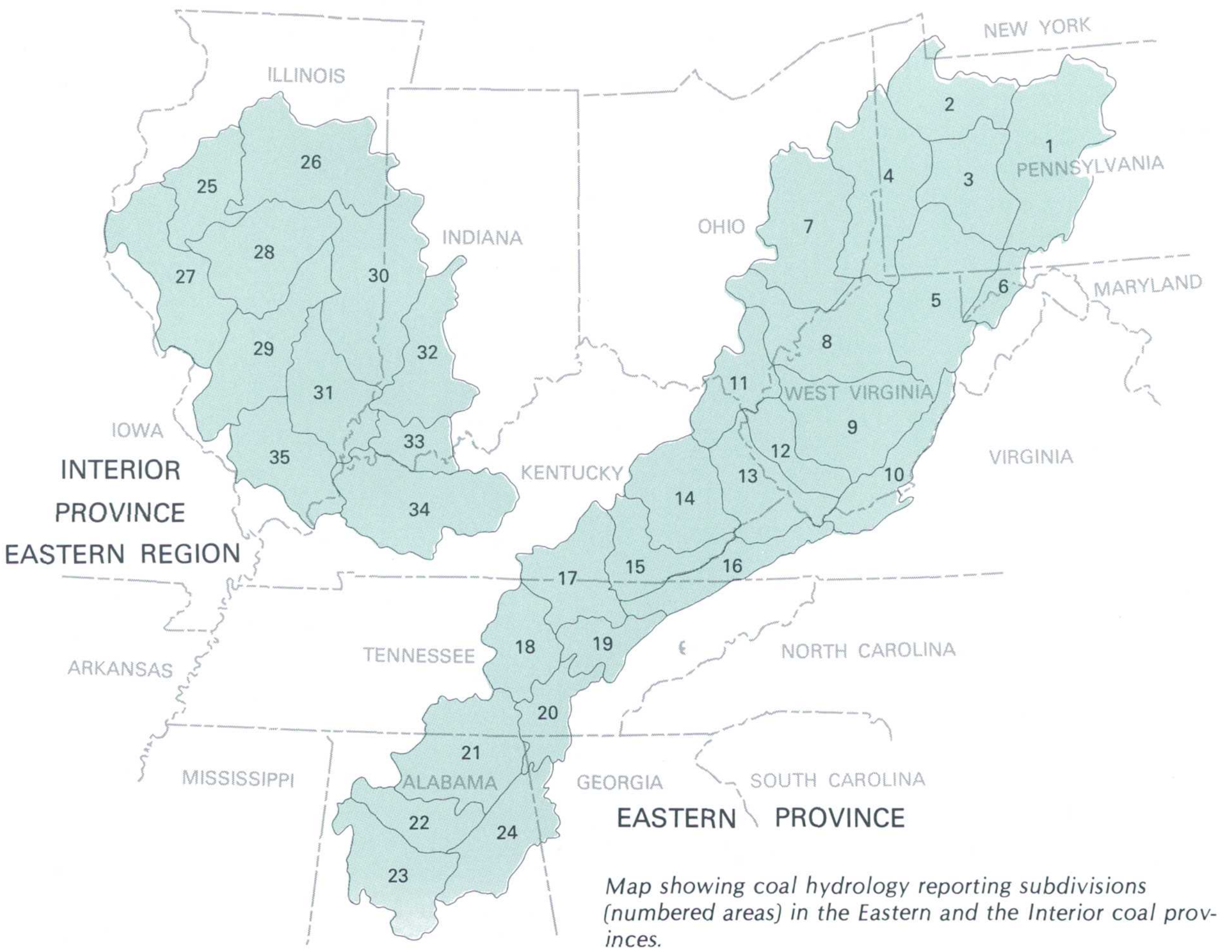
The development of synthetic fuels from coal potentially will affect water resources in two basic ways: the various fuel conversion processes require large amounts of water and the handling of raw materials and the waste residuals from the extraction and conversion processes will produce major waste-disposal problems that may have long-term adverse impacts on the quantity and quality of water supplies.

The water requirements for fuels development and the demands of the increased population for the industry will be superimposed on existing, and largely agricultural, water use. Competition for the available water resources will increase, and, although, in the aggregate, sufficient water does exist for the various uses, the required amount may not always be available at a particular site. This is especially true in the Western States where major coal deposits are suitable for surface mining and plans are being developed for leasing large tracts for coal extraction.

All extraction and surface processes for development of synthetic fuels require large volumes of water, particularly for cooling. The wastes produced by the processes are disposed of by various techniques, all of which affect some element of the environment. For example, heated waters discharged to surface streams may change the ecological regimes of the streams and have major impacts on the biota; spoil piles commonly result from the residual disposal of mining operations and are potential sources of toxic materials that may be leached by rainfall and introduced into either surface streams or underground waters; other forms of waste disposal include storage in lagoons and injection underground. The last, especially, has a tendency to produce temporary complacency in that "out of sight" results in "out of mind." Major impacts on fresh-water resources may occur as a result of improper well construction and completion, inadequate waste containment, and potential waste-aquifer reactions that would make injection hazardous.

Unique problems are associated with in situ developments of synthetic fuels. Although this approach would lessen the coal-handling and waste-disposal problems and lessen surface-pollution effects for air and water, other considerations arise concerning the impacts on ground-water systems and whether or not potential wastes will be contained and not reach surface sources. In situ coal gasification poses many questions related to impacts on ground-water systems such as subsidence, dewatering, movement and fate of residuals, and disruption of aquifers. The heat, pressure, and fracturing caused by in situ processes are likely to change aquifer characteristics affecting flow and transport of dissolved substances.

Extraction of energy from coal may have long-term adverse impacts, and it behooves government and scientists to establish a better understanding of natural conditions and of the potential effects of fuel development. With such understanding, problems can be addressed before they occur or before they have so adversely affected the environment that little remedial action can be taken.



Map showing coal hydrology reporting subdivisions (numbered areas) in the Eastern and the Interior coal provinces.

Aerial view showing surface mining operations underway. (Photograph courtesy of the Bureau of Land Management.)

The Federal-State Cooperative Program

The Water Resources Division's Federal-State Cooperative Program is the foundation of much of the water-resources management and planning activity in the country. In addition, it provides an early-warning system for the detection of emerging water problems.

How did this important program come into existence? and where is it headed? The Cooperative Program is rooted in the concept that Federal, State, and local governments have a mutual interest in evaluating, planning, developing, and managing the Nation's water resources. This concept dates back to the late 1800's when problems associated with inland navigation, irrigation, and flood protection drew attention to the fact that water is a joint responsibility of all levels of government. The realization that many water problems begin locally led to the establishment of the Federal-State Cooperative Program as a major component to fulfill the U.S. Geological Survey's responsibilities to assess the Nation's water resources. In 1928, Congress established the principle of 50-50 matching funds within the program (Public Law 70-100), and the Survey's relationship with the States became a partnership of equals and led to the initiation of the cooperative stream-gaging program.

The enormity and complexity of this task of appraising the Nation's water resources preclude accomplishing the task by Federal efforts alone. Similarly, State and local agencies working independently cannot relate to the larger regional aspects of the hydrologic system. Therefore, cooperation through the Federal-State Cooperative Program provides an economical means of assessing water resources. The Cooperative Program promotes the National interest by providing information and expertise to its clients. It is supportive of other Federal agency missions, of States' needs to meet Federal regulatory requirements, of interstate compacts and international treaties, and of Congressionally mandated programs. An ongoing exchange of ideas, data, and results between the Geological Survey and State water agencies aids State agencies in implementing planning, management, and regulatory activities and programs and assures that the Geological Survey's attention is directed towards significant water problems.

The Current Progam

The current Cooperative Program consists of a diverse mix of activities. In fiscal year 1980, it included over 2,000 projects in cooperation with more than 800 agencies. In addition to data collection, the program focuses on water use and availability, the impact of man's activities on the hydrologic environment, the definition of hazards, and energy-related water issues which may strain available water supplies as a result of new energy development.

Hydrologic data collection within the Cooperative Program remains a very significant aspect of the program. The Geological Survey is the Nation's principal water-data collection agency, and its reputation for accurate impartial data makes the Survey's data bases an important source of water information for other agencies. For example, the National Weather Service uses data from about 2,000 gaging stations operated by the Survey for their river forecasting program.

Of considerable significance is the role that the Cooperative Program plays in emergency situations. It is the foundation of the Geological Survey's rapid response capability to water-related crises. During the drought of 1976–77, the Water Resources Division was able to gather information with which the Congress and the Executive Branch could monitor events. When the drought began to affect west coast water supplies, Congress and the Executive Branch received requests for emergency assistance. Because it was difficult to assess the seriousness and validity of these requests, the White House established a task force of agencies to monitor the drought situation and to brief White House and Congressional Committee staffs on developments. The Water Resources Division provided the task force with daily reports on streamflow, reservoir storage, and other vital information associated with the drought. The Congress and the White House made use of these reports to allocate emergency funds. The Division's rapid response and assistance would not have been possible without the data accumulated by the Cooperative Program.

A more recent example of rapid response capability was the eruption at Mount St. Helens on May 18, 1980. For many years, the Survey has collected hydrologic data from stations in the vicinity of the volcano. Moreover, for several months before the major eruption, Survey Field Offices increased the number of stations and the sampling frequency for water-quality samples throughout the State of Washington. When the major eruption occurred, the Survey was well prepared to begin immediate studies of the impact of ash falls on water quality, the impact of mudflows and other deposits on river flow, and the measurement of other types of hydrologic data. As with the drought, it would not have been possible to mount new data-collection programs in the northwest had not a sizable network of stations and a cadre of experienced personnel already been present. Perhaps more important, the program provided good hydrologic records before the event, so the preeruption hydrologic conditions were well established as a basis for determining the effects of the eruptions.

Program Planning— A Continuous Process

How is such a large program with so many different facets effectively managed in the context of societal needs? A unique aspect of the program is the continuous nature of the planning process that permits the program to adjust to the changing world.

Each fiscal year, the Director of the Geological Survey reviews the priorities of the Department of Interior and issues a policy guidance statement for all programs. The Chief Hydrologist integrates the Director's policy guidance statement with local problem priority statements from the Regional Hydrologists. Program guidelines are then established and communicated to each Division District through the Regional Hydrologists. At the State level, the Districts and their Cooperating Agencies are constantly developing new project proposals to meet emerging problems and needs. The heads of State agencies are guided in their planning by the nature and severity of the water-management problems facing them.

All project proposals are first screened at the District level. Next, the proposals are reviewed at regional headquarters on the basis of technical merit, contribution to the hydrologic knowledge of the region, and consistency with National priorities. All proposals received by a Regional Hydrologist are supported by Cooperators. Priorities are assigned to all acceptable proposals within a region, and the proposals are funded until the Cooperative allocation to each region has been committed.

Nature of the Program

Perhaps most important to those working with water policy is the fact that the Cooperative Program is "policy relevant," in that most projects provide interpretive hydrologic information necessary for developing guidelines for making decisions or for formulating plans. Most projects are responding to a recognized problem or are working to define a potential problem, as shown by the following examples:

- Ground-water management in the High Plains of Colorado—regulation of ground-water pumping. (Colorado State Circular 34-1976.)
- Hydrology of the Piceance Creek Basin, Colorado—simulation of the effects of oil shale development. (Professional Paper 908-1974.)
- Ground-water model of the closed basin area of the San Luis Valley, Colorado—lead to interstate compact. (Colorado State Circular 29-1975.)
- Water-resources investigations of the Cook Inlet Hydrologic Unit, Alaska—land-use planning, waste emplacement, and supply development.
- Evaluation of the Edwards Limestone Aquifer, Texas—the study created interest in drafting legislation dealing with the protection of aquifers which are the only source of public water supply.
- Beaver Creek Study, Kentucky—pioneering work on the environmental impacts of surface mining. Surface mining laws and regulations based on this study. (Professional Paper 427-A, B, C; 1963, 1964, 1970.)
- Indianapolis Ground-water Study—controversy over water-supply availability and need for Highland Reservoir. The study appears to have saved the taxpayers over $100 million.
- Highway Bridge Studies—to avoid over and under design of bridges. Studies have saved taxpayers millions of dollars in construction.

The program directly contributes to earth science knowledge by fostering the advancement of hydrologic science and by providing a major part of the Survey's water data base. As illustrated in table 1, many major advancements in ground-water science have been made within the Cooperative Program. The information in table 2 shows the importance of the Cooperative Program to the Survey's water-data base.

Finally, the Cooperative Program is a source of stability and strength for the total water-resources investigations program of the Division. Without the extensive and detailed knowledge of the hydrology of each State that has been accumulated over the years, the Geological Survey's goal of providing the Nation needed water information would be nearly impossible.

TABLE 1.—*Major advancements in hydrology supported by Cooperative Program*

1890's	G. K. Gilbert, N. H. Darton, W. D. Johnson: Qualitative description of major aquifers; established geology as the cornerstone of ground-water hydrology.
1899–1930's	C. S. Slichter: Applied the mathematics of potential theory of ground-water flow and devised methods for measuring ratio of ground-water movement.
	W. C. Mendenhall: Developed quantitative technique for appraisal of ground-water resource.
	O. E. Meinzer and V. C. Fishel: Experimentally established the validity of Darcy's law for low ground-water gradients and introduced the Thiem equation for steady-state analysis of aquifer tests.
1920's	F. W. Clarke: *Compiled Data of Geochemistry,* which was instrumental in guiding geochemical research and data collection through the next two decades.
1923	O. E. Meinzer: The classic paper, *The Occurrence of Ground-Water in the United States, With a Discussion of Principles,* established ground-water hydrology as a scientific discipline.
1935	C. V. Theis: Developed a mathematical equation describing the nonsteady flow of ground water to a well and opened the door to the modern era of quantitative ground-water hydrology.
1940's	C. E. Jacob: Developed the physical foundation of the ground-water flow equations and extended mathematical basis for analyzing aquifer-test data.
	B. R. Colby: Advancement of use of Oden Theory as a standard technique for determining particle-sized distribution of fluvial sediment.
	P. C. Benedict: Development and advancement of the standardization of suspended-sediment samplers.
	G. E. Ferguson: Development and use of crest-stage gages of peak-stage measurement.
1940–1950's	H. B. Kinnison, B. R. Colby, R. W. Carter, T. Dalrymple, W. B. Langbein, M. A. Benson: Development of techniques for the regionalization of flood-frequency information.
1950's	H. E. Skibitzke, R. R. Bennett, R. W. Stallman: Introduced the use of numerical methods to analyze ground-water flow and develop concepts and techniques of simulating ground-water systems with 2- and 3-dimensional electrical networks.
	R. W. Carter and C. E. Kindsvater: Development of contracted-opening methods of flow measurement.
	J. S. Gatewood, T. W. Robinson, B. R. Colby, J. D. Hem, L. C. Halpenney: Documented water use by phreatophytes.
	H. Wires, G. F. Smoot, and others: Development of the bubble gage for the measurement of stage.
	B. R. Colby and C. H. Hembree: Development of Modified Einstein Theory for computing total sediment discharge.
	B. R. Colby: Development of Visual-Accumulation-Tube analytical method for determining particle-sized distribution of fluvial sediment.

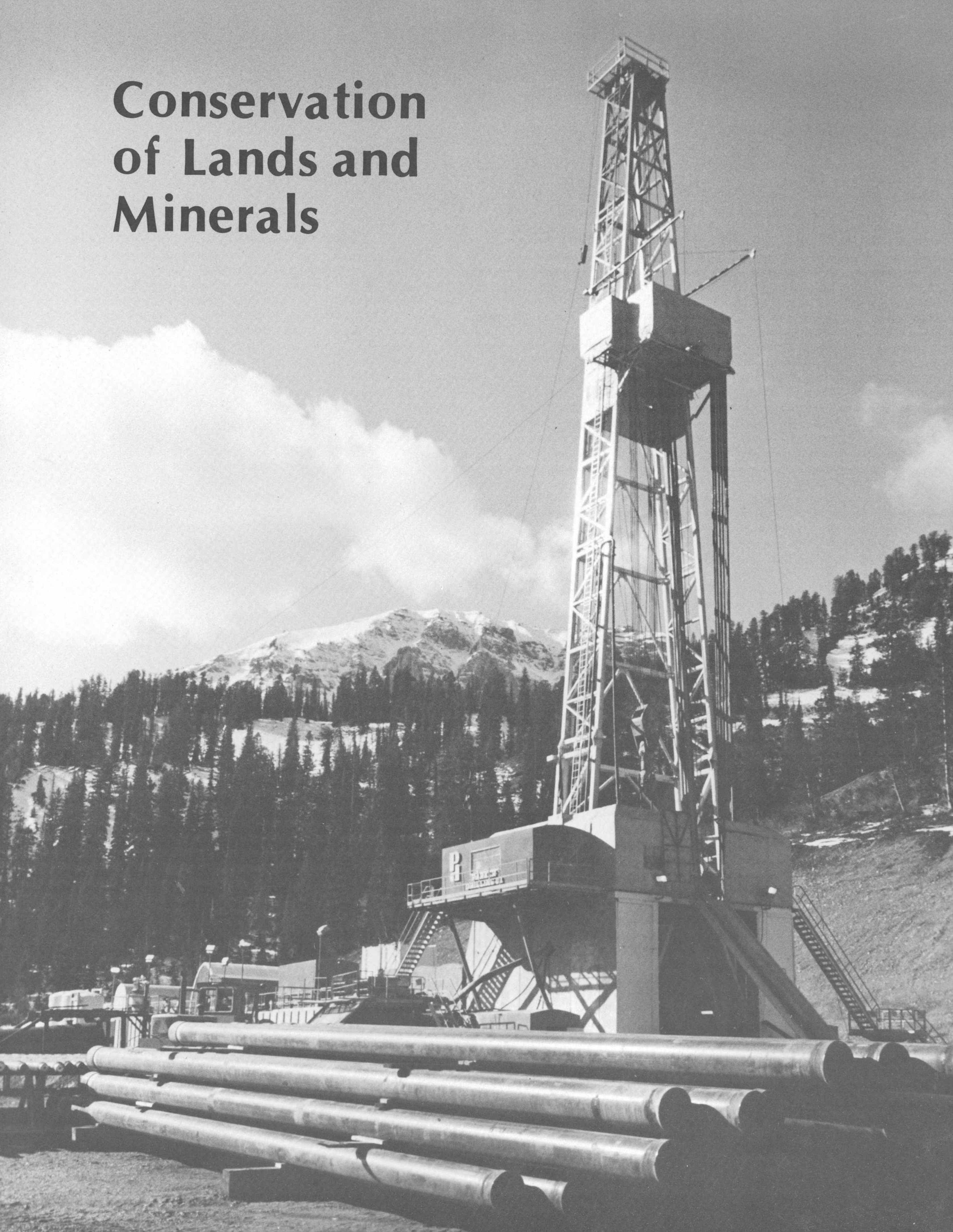
TABLE 1.—*Major advancements in hydrology supported by Cooperative Program*—Continued

	J. D. Hem: Developed simultaneously with other researchers of Eh-pH stability field concepts, systematized several thermodynamic relations for solid-dissolved phase interactions of several minerals and techniques for similar interpretation of other minerals.
1950–1960's	J. F. Poland, G. E. Davis, B. E. Lofgren: Investigated and described the mechanical deformation (subsidence) of earth material caused by the withdrawal of water by wells.
	B. R. Colby and D. R. Dawdy: Documented the influence of streambed forms on stage-discharge relation.
1950–1970's	W. B. Langbein, D. O. Moore, R. E. Hedman, H. C. Riggs: Development of techniques for relating channel and flow characteristics.
1960's	N. J. Luscynski, H. H. Cooper, Jr., F. A. Kohout: Developed variable density concepts and applications to saltwater intrusion in coastal aquifers.
	D. R. Dawdy: Advancement of rainfall-runoff modeling.
	G. F. Smoot: Development of the moving-boat method of flow measurement.
1960–1970's	J. D. Bredenhoeft, G. Pinder, P. C. Trescott: Developed and encouraged the use of computer-based numerical models of complex ground-water flow systems.
	N. C. Matalas, C. H. Hardison, R. W. Carter, M. E. Moss: Development of methods for streamflow network design.
	J. F. Wilson, Jr., F. A. Kilpatrick, N. Yotsukura, E. D. Cobb: Development of time-of-travel techniques for the transport and diffusion of solutes in river estuaries.
	N. Yotsukura and W. Sayre: Development of stream-mixing concepts.

TABLE 2.—*Type of hydrologic data collection stations in the Water Resources Division*

Type of station	Total number of collection sites	Percentage supported by Federal-State Cooperative Program
Surface-water:		
Continuous discharge	8,200	65
Intermittent discharge	7,400	90
Lake-reservoir sites	900	60
Water-quality:		
Surface-water sites	5,200	70
Ground-water sites	8,250	95
Sediment stations	1,400	60
Ground-water levels	27,900	55

Conservation of Lands and Minerals



Mission

The Conservation Division performs several functions concerning the leasing, classification, and use of mineral and water resources on Federal and Indian lands. These functions have been delegated to the U.S. Geological Survey by the Secretary of the Interior and are accomplished through two major missions:

- Evaluation of resources, which includes the classification of public lands to identify areas containing potentially valuable leasable minerals and areas valuable for waterpower and water-storage purposes. Also included is the evaluation of mineral resources on tracts of public land that are exchanged, sold, or made available for development and production through a competitive leasing process.
- Supervision of operations associated with the exploration, development, and production of minerals from leased Federal, Indian, and Outer Continental Shelf (OCS) lands. A significant element of this mission is the collection of certain rentals and royalties for minerals produced.

The Geological Survey collects and analyzes data for the sound development of mineral resources, for protection of the environmental characteristics of public lands and to support the programs of other Federal agencies. Within the Department of the Interior, the Geological Survey supports the missions of the Bureau of Land Management, the Bureau of Indian Affairs, and the National Park Service, the Fish and Wildlife Service, and the Water and Power Resources Service. Outside the Department, the Survey provides information to the Department of Defense, the Forest Service, the Department of Agriculture, the General Services Administration, the Environmental Protection Agency, and the Department of Energy. In addition, data from minerals production on Federal and Indian lands are compiled on a calendar year basis to be compatible with statistics published by the Department of Energy, State governments, and private industry. This information is helpful in gauging production performance and developing planning strategies.

In fiscal year 1980, minerals from Federal and Indian lands produced a significant portion of the Nation's mineral supplies. More than 13 percent of the oil, 31 percent of all natural gas, and 12 percent of the Nation's coal were produced from leases on Indian and Federal lands onshore and offshore. These production levels clearly demonstrate the value of Federal mineral deposits to the Nation's economy. In fiscal year 1980, the value of all mineral commodities produced from leased Federal and Indian lands exceeded $19.5 billion. Lease rentals and royalties resulting from production of minerals, combined with bonus payments from lease sales, provided roughly $6.9 billion in revenue for the Federal Government.

The authority to classify public lands and to regulate mineral development on Federal and Indian lands, to protect the environment, and to collect a fair return from extracted resources lies in a complex array of mineral and land laws, some dating back to the 1870's.

Congress stipulated in the Act of March 3, 1879, which created the Geological Survey, that the agency should study the Nation's mineral wealth, classify the public lands, and identify various land values. In 1906, the President directed the Secretary of the Interior to immediately withhold from other uses all valuable coal lands on the public domain. Federal coal lands in Alabama, Arkansas, and Wyoming were withdrawn and later classified under this directive. Subsequently, Congress passed the Withdrawal Act of 1910 which authorized the President to reserve public lands from settlement, location, or sale. This act resulted in the immediate withdrawal of about 100 million acres of public lands and the preservation of their potential coal reserves. The Geological Survey began to examine and classify these lands. Lands found to have no coal were made available for other uses, and those found to contain potentially workable coal beds were appraised and priced at varying amounts per acre. Because the lands withdrawn included many areas that were valuable for farming, Congress passed the Separation Acts of 1909 and 1910 that provided for the separation of surface and subsurface ownership rights. This permitted the public to purchase or use surface areas, but guaranteed U.S. ownership of subsurface mineral deposits and the right to prospect and mine them.

Parker Rig No. 163, operated under contract to Sun Oil Company, explores for oil and gas at a site more than 8,000 feet up the side of Prater Mountain, near Jackson, Wyo. U.S. Geological Survey personnel frequently inspect drilling activities to assure that operations conform with the requirements of the approved plan of operations. (Photograph by James Cook, Wide World.)

The Mineral Leasing Act of 1920 ended the practice of selling public coal lands at appraised values and instead provided for the leasing of coal and other mineral commodities. Other minerals now produced from public and Indain lands include oil, gas, uranium, potash, sodium, phosphate, oil shale, asphaltic minerals, sulphur (only in New Mexico and Louisiana), and geothermal resources. Under the various provisions of the act, a permit may be obtained to explore public lands for minerals other than oil, gas, oil shale, and geothermal resources. If the land is determined by the Geological Survey to contain a known leasable mineral deposit, however, it becomes subject to a competitive bidding process. All minerals on acquired and Indian lands are leasable. After required permits are obtained and production begins, each lessee is required to pay the Federal Government a stipulated royalty based on the quantity or value of the minerals produced. Other laws authorize the leasing and management of metallic and nonmetallic minerals on Indian lands, railroad and other rights-of-way across public lands, acquired lands, and OCS lands.

In a manner consistent with these various statuatory authorities, the Secretary of the Interior has promulgated numerous rules and procedures pertaining to the development of minerals on the Federal and Indian lands. The principal laws governing operations on Federal mineral leases are contained in the *Code of Federal Regulations* and include:

- Outer Continental Shelf Leasing Regulations—Part 3300 of Title 43.
- Outer Continental Shelf Operating Regulations—Parts 225a, 250, and 260 (Proposed) of Title 30.
- Onshore Federal Lands Leasing Regulations—Parts 3100, 3200, and 3500 of Title 43.
- Onshore Federal Lands Operating Regulations—Parts 211, 221, 223, 225, 226, 231, 270, and 271 of Title 30.
- Indian Lands Leasing and Operating Regulations—Parts 171, 172, 173, 174, 176, and 177 of Title 25 and the pertinent onshore Federal operating regulations contained in Title 30.

Leasing regulations are issued by the Bureau of Land Management and the Bureau of Indian Affairs. Some provisions of leasing regulations and all provisions of operating regulations are implemented and enforced by the Geological Survey.

The Reorganization of the Conservation Division

During the last decade, the Conservation Division's responsibilities for implementation of the Nation's energy policies have grown exponentially. The Division now regulates production of almost one-third of the Nation's natural gas, 13 percent of its oil, more than 12 percent of its coal, and significant portions of other minerals. Paralleling the growth in the variety and quantity of commodities it regulates, there has been a growth in the array of the Division's regulatory responsibilities. In addition to the traditional mineral evaluation and operations management role, a growing number of responsibilities for protection or enhancement of the environment, human health, and safety; land-use planning coordination; and social values impacted by mineral production have been added. Finally, the Division has increased corrdination with a growing number of specialized constituencies, including Congressional committees, other Federal agencies, State and local governments, and a broad range of nongovernmental organizations and interest.

In this period, the Division experienced dynamic growth in the budget and number of personnel required to perform its mission. Over the past 5 years alone, employment rose from roughly 600 to nearly 2,000. In the same period, the annual budget grew from $18 million to more than $106 million. This rapid growth placed intense pressures on an organizational structure established when the regulatory environment was less diverse and dynamic. Although periodic adjustments were made in the structure and methods of operation, the Division lacked sufficient ability to perceive and respond to the massive escalation of responsibilities created by rapidly changing energy and environmental conditions. It was imperative that an entirely new organizational structure be divised.

During 1978-79, a new organizational structure was developed. This new framework had two principal goals:

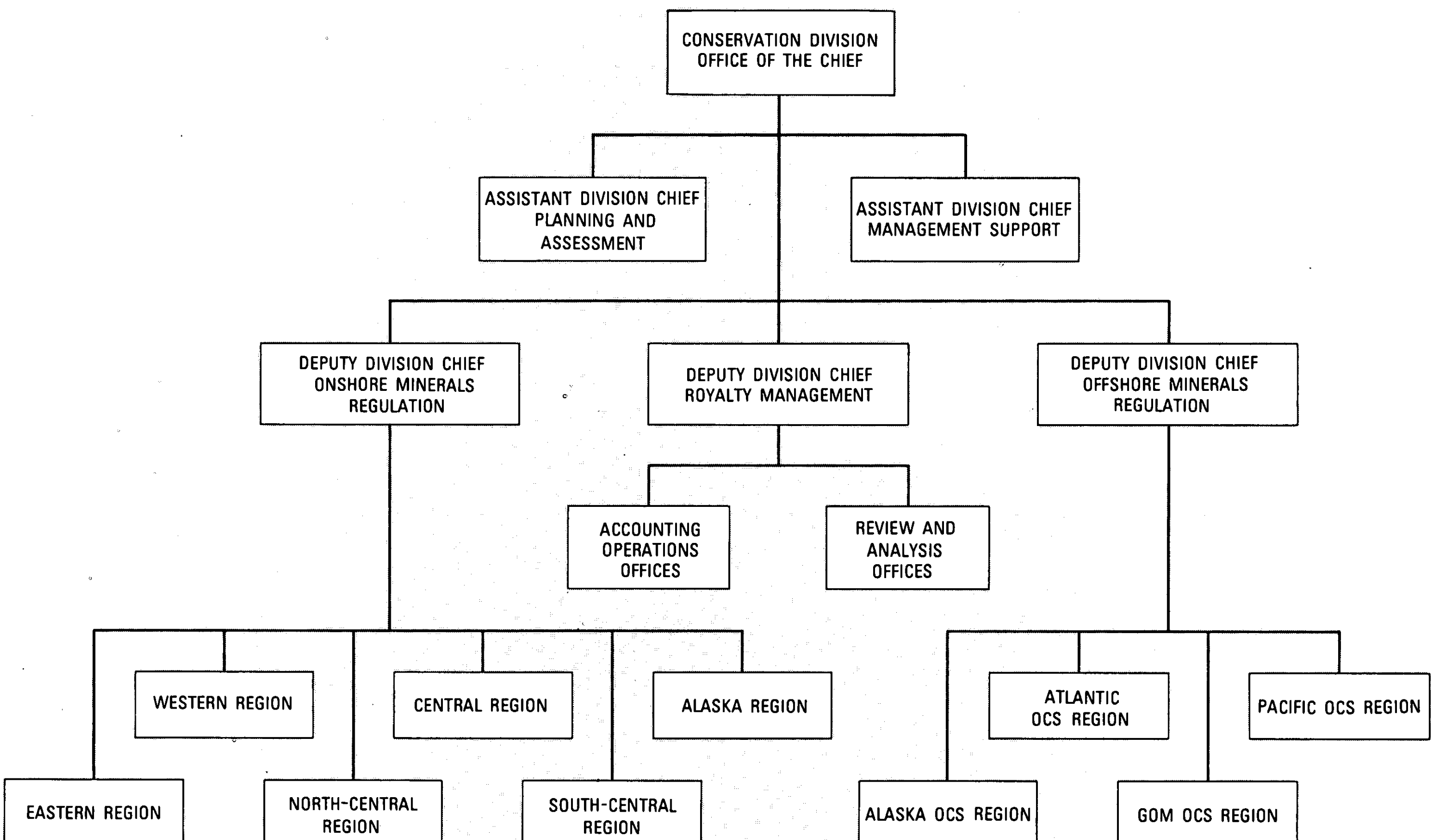
1. To improve the day-to-day performance of resource evaluation and lease management activities.
2. To provide a substantially enhanced ability to conduct continuing analyses of changing regulatory and energy-demand conditions, to carry out longer range program planning, and to provide systematic ongoing program anlaysis.

Procedures developed with the new organization structure established clearer more functional lines of authority for managers at all levels; provided means to recruit, develop, and maintain a workforce with a much broader range of expertise and experience; and provided greater flexibility for accomodating dynamic, often sudden, changes in the nature and extent of mission responsibilities. For example, the traditional separation of resource evaluation and lease operations management responsibilities along functional lines has been eliminated. Geophysical and environmental evaluation activities are now directly coordinated with day-to-day offshore and onshore lease management. In addition, stronger provision has been made for the downward delegation of decisionmaking authority through the designation of three Deputy Division Chiefs for onshore, offshore, and royalty management functions. Efforts to improve the contact with principal lessees have resulted in the establishment of three new regional offices in Casper, Wyo., Albuquerque, N. Mex., and Anchorage, Alaska, which has brought the Division total to 10. Regional Managers in 10 locations have been delegated significant authority and decisionmaking responsibility for all aspects of mineral evaluation and lease management. The new organizational procedures also will improve communication and coordination of functions with State and local governments, Federal agencies, and other constituencies and will enhance the collection, processing, and accounting of royalty payments to the Federal Government.

The aspect of personnel recruitment and training traditionally has been difficult because of intense industry-government competition for limited qualified personnel. Higher salaries and more favorable benefits offered by industry have hampered the ability of the Government to attract a sufficient number of geologists, geophysicists, engineers, and technicians. To counter this problem, a new broadly based recruitment and training program has been designed and centralized in Denver, Colo. Efforts are being redoubled to attract highly qualified personnel from other agencies and the private sector, as well as to upgrade and retrain existing personnel to meet Division mission needs.

The Division also is incorporating more advanced systems and procedures to improve worker productivity and general information management. A new data-base management system, greater use of word processing, and planned implementation of a Divisionwide records management system all promise to reduce labor intensiveness and increase the ability of personnel to perform their jobs.

All evidence indicates the growth patterns of the previous decade will intensify in the future. Congress and various Presidental Administrations continually consider new legislative initiatives and changes in current energy policies as world affairs, changing economic conditions, and scientific advancements dictate. In another spectrum, State and local governments, Indian tribes, and the public are demanding better more detailed information about the impacts of energy development on society so that potential resource and land-use conflicts can be avoided. The improved management system now in the final stages of development should provide the means to meet these challenges.


CONSERVATION DIVISION OFFICE OF THE CHIEF
ASSISTANT DIVISION CHIEF PLANNING AND ASSESSMENT
ASSISTANT DIVISION CHIEF MANAGEMENT SUPPORT
DEPUTY DIVISION CHIEF ONSHORE MINERALS REGULATION
DEPUTY DIVISION CHIEF ROYALTY MANAGEMENT
DEPUTY DIVISION CHIEF OFFSHORE MINERALS REGULATION
ACCOUNTING OPERATIONS OFFICES
REVIEW AND ANALYSIS OFFICES
WESTERN REGION
CENTRAL REGION
ALASKA REGION
EASTERN REGION
NORTH-CENTRAL REGION
SOUTH-CENTRAL REGION
ATLANTIC OCS REGION
PACIFIC OCS REGION
ALASKA OCS REGION
GOM OCS REGION

Budget and Personnel

During fiscal year 1980, the Conservation Division of the U.S. Geological Survey broadened its personnel base and range of programs to more effectively manage responsibilities for administration of mineral leases on public lands. These programs in fiscal year 1980 required an expenditure of $106.4 million, a budget rise of 24.2 percent over the previous year.

More than one-half of all 1980 expenditures were dedicated to administration of leasing activities on Outer Continental Shelf (OCS) lands. This subactivity accounted for $66.1 million—a 35-percent rise from the $49.1 million authorized in fiscal year 1979. This increase in budget authority was due to the implementation of additional programmatic requirements specified in the Outer Continental Shelf Lands Act Amendments of 1978 simultaneously with the acceleration of the rate of OCS leasing. Management of onshore leasing activities on Federal and Indian lands required $40.3 million, an increase of nearly 11 percent over the $36.4 million spent the previous year.

Significant personnel changes also occurred in 1980. Virtually all top management chose to convert their status from career civil servants to senior executives under the new Senior Executive Service Program of the Office of Personnel Management. Many tenured managers opted to retire. As a result, by the end of the fiscal year, 7 of the Division's 10 Regional Managers were new because of personnel changes and the creation of new offices. Because of the Division reorganization and expanded program management activities, the number of personnel employed increased to 1,807 during fiscal year 1980, a rise of 117 over the preceding year. Although hiring was constrained by provisions of a freeze, the Division was able to acquire badly needed skills through the addition of persons in special exempted categories. More aggressive recruitment of experienced employees, combined with an intensive retraining program for already employed personnel, promises to ease the short-term demand for qualified people to staff expanding programs.

Barbara Harris, a U.S. Geological Survey geologist, inspects samples from a contract rig doing exploratory drilling on potential coal fields near Sheridan, Wyo. Analyses of rock cuttings found in the samples provide information on the type and composition of mineral deposits at various depths beneath the surface. (Photograph by James Cook, Wide World.)

Conservation of Lands and Minerals activity obligations for fiscal years 1979 and 1980, by subactivity

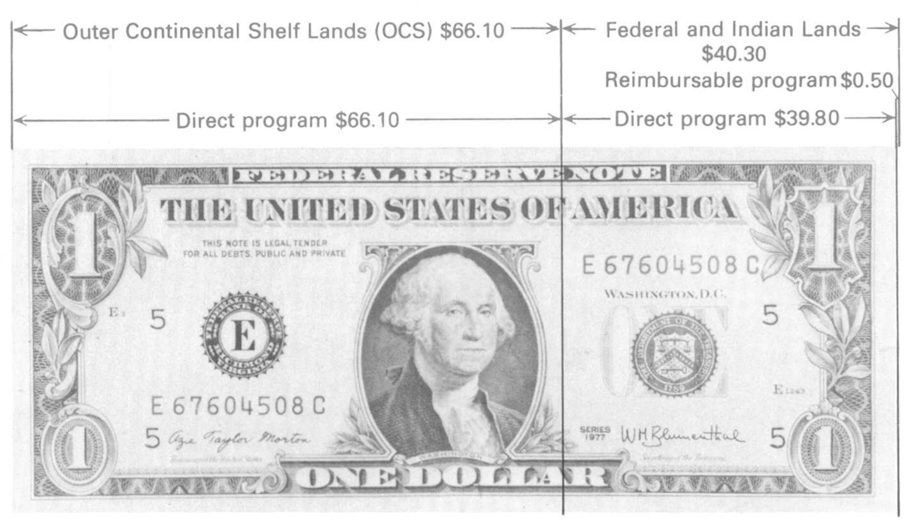
[Dollars in millions. Data may differ from that in statistical tables because of rounding.]

Subactivity	Fiscal year 1979	Fiscal year 1980
Total	**$85.5**	**106.4**
Outer Continental Shelf (OCS) lands	**49.1**	**66.1**
Direct programs	49.1	66.1
Reimbursable programs	—	—
States, counties, and municipalities	—	—
Miscellaneous non-Federal	—	—
Other Federal agencies	—	—
Federal and Indian lands	**36.4**	**40.3**
Direct programs	36.3	39.8
Reimbursable programs	.2	.5
States, counties, and municipalities	—	—
Miscellaneous non-Federal	—	—
Other Federal agencies	.2	.5

SOURCE OF FUNDS

TOTAL $106.40 MILLION

USE OF FUNDS



Oil and Gas From Federal and Indian Lands

The number of leases on Federal and Indian lands, the total wells on those leases, and the royalties collected from oil production have continued to increase, even though the total domestic onshore production of oil has been declining since 1969. Although onshore gas production has continued to increase gradually, royalties stemming from gas well operations have risen sharply since 1975 because of higher market prices. Private companies are attempting to offset the decline in oil production by stepping up exploration activities in frontier areas, including the western overthrust belt of Utah, Wyoming, Idaho, and Montana and the eastern overthrust belt located along the Appalachian Mountains. They are also conducting research aimed at discovering ways of increasing the amount of oil and gas recovered from older now declining reservoirs. Production from onshore Federal and Indian lands provided roughly 6.4 percent of the oil and 6.5 percent of the gas produced in the United States last year.

The U.S. Geological Survey conducted geological investigations, environmental analyses, and other studies related to the many aspects of exploration and development, safety of operations, collection and processing of royalties, and protection of the environment. During fiscal year 1980, the Geological Survey approved 3,830 applications for drilling permits to provide exploration and development wells on Federal leases. More than 3,840 environmental analyses of the potential impacts of oil and gas development operations on Federal lands were also prepared. In the same period, 3,095 new wells were started on Federal leases. Roughly 2,150 of those wells were completed as usable holes for the production of oil and gas, or for the injection or disposal of various fluids.

Other sources of oil and gas, like the "tight gas sands" and tar sands that occur in northwestern Colorado, eastern Utah, and northern Montana, have become more attractive prospects now that present market prices have made drilling and production from these deposits economically feasible. Exploration and development in newer more remote regions provide new challenges. Terrain—especially in wilderness areas—often is rugged; cold winters with deep snows can hamper drilling and supply operations, and the distance from existing pipelines limits delivery of new supplies to the marketplace. Some producible wells completed in these remote areas will likely be "shut-in" until pipelines or local processing facilities are built to serve them.

The development and use of enhanced recovery processes has been instrumental in the restoration of production at many oil fields formerly developed through natural production methods. Advanced secondary recovery procedures include the use of gas or water or the injection of steam into oil-bearing formations to separate the oil from sand or rock and move it toward recovery wells. Tertiary methods include flooding with chemical solvents or stimulation with heat to support continued production after secondary recovery becomes uneconomic. In addition, well completion techniques and formation stimulation processes constantly are being improved and will continue to add to the supplies of oil and gas produced.

U.S. Geological Survey petroleum engineering technician David Little inspects a daily operations report while visiting a Sun Oil Company rig conducting exploratory drilling on a portion of the overthrust belt near Jackson, Wyo. (Photograph by James Cook, Wide World.)

Improved Royalty Management

During the past decade, a number of factors led to a reexamination of the procedures used by the Conservation Division to collect, process, and audit royalty payments resulting from minerals production on Federal and Indian lands. This review, completed in 1979, resulted in a proposal for a total restructuring of the royalty accounting system and has become the most critical element of the Division reorganization effort.

The traditional system for collecting and processing royalties proved to be inadequate when confronted by major increases in lease accounts and more complexity in the requirements for lease account administration. In the past decade, the number of producing leases administered by the Division grew by 66 percent. Royalty payments from those leases, however, rose by nearly 600 percent as a result of an increase in the number of producing wells combined with much higher market prices for mineral products, particularly oil and gas. Frequent continuing changes in lease ownership and an increase in multicompany joint development of leases added stress to the tracking ability of the system. Departmental establishment of variable royalty pricing schemes and recent additional requirements to collect windfall profits tax payments and compute royalties on the basis of net profits also provided complicated new requirements for accounting.

The existing system, based on a decentralized accounting scheme, placed the responsibility for account management and auditing in 14 separate offices. This was done to maintain accounting files along with other associated lease management information. Each office operated with independent procedures, using largely manual accounting methods which were partially supported by automated systems. With the responsibility to process 300,000 reports involving more than 2 million entries annually, paperwork delays increased and check processing slowed. The Government was frustrated by an inability to force timely payment because of inadequate reporting requirements and the enormous records management load.

An intensive study by several Federal agencies, with industry cooperation, revealed many areas where improvements could be made. As a result of these efforts, an improved royalty management program is being developed and will be implemented beginning in 1981.

The new system will centralize all royalty collection and accounting functions for minerals in Lakewood, Colo. Substantial automated data processing capability will replace a major share of the manual tasks associated with the accounting process. Based on reports from the system, field review and analysis units, situated primarily in regional offices located close to major mineral royalty payors, will administer the royalty verification processes. Total royalty management staffing will rise from 200 to roughly 300 personnel, with additional outside support coming from private contractors.

Transition to the new program will occur over an 18-month period to provide adequate system testing under actual operating conditions and proper training of personnel. The Division expects to derive several significant operational benefits from the new program, including standardized policies and operating procedures, increased income from properly managed royalty accounts, timely availability and processing of funds, dramatic increases in personnel productivity, and a substantially reduced regulatory burden on private industry. From the control standpoint, the new system will assure greater security for information collected, will reduce the potential for fraud and abuse in royalty reporting, and will provide a better level of administrative control over activities and funds.

The royalty accounting study also revealed that royalty revenues may have been understated by as much as 10 percent. If predictions of a 670-percent rise in royalty collection levels in the next 15 years—to the level of $20 billion annually by 1995—are correct, then timely installation of this new system will assure that the Conservation Division is prepared to properly manage the rapid increase of royalty management workload resulting from expanded domestic mineral production.

Cognac Platform, Gulf of Mexico. Heaviest, deepest water production platform in the world. (Photograph courtesy of Shell Oil Company.)

New Coal Program Efforts

During the period from 1973 to 1980, dramatic rises in oil prices and sudden shifts in energy-resource use patterns impacted domestic coal production. Because many of the known reserves of coal are found on Federal lands, pressures for leasing these resources have intensified. The Department of the Interior has responded by announcing a program to streamline and expand Federal coal leasing through a carefully monitored competitive leasing process.

The U.S. Geological Survey—with its sister bureaus, the Bureau of Land Management and the Office of Surface Mining—share the responsibility to support the Department's coal-management program in two ways: by issuing new coal development leases and by managing new and existing leases. The Geological Survey responsibilities are carried out in two phases: prelease identification and evaluation of the location, extent, and production potential of Federal coal resources and postlease management of certain exploration and mining activities. The Survey carries out these functions of providing geologic, engineering, and economic evaluation input during both phases of leasing.

Proper identification of Federal coal land areas with a high or moderate potential for coal mining is a critical component of effective land-use planning. Only these areas are considered for competitive leasing. The Survey personnel, using interrelated geologic and mineral economic criteria, classify coal areas according to their development potential and identify lands with minable coal as "Known Recoverable Coal Resource Areas" (KRCRA's). Under the Coal Resource Occurrence/Coal Development Potential (CRO/CDP) Assessment Program, these areas are mapped, using data from public, private, and industry sources, and tracts having minable coal are delineated.

Coal deposits located in the Green River–Hams Fork Coal Regions of Colorado and Wyoming and the Uinta Region of Colorado and southwest Utah and in the State of Alabama were delineated and appraised during 1980 in preparation for lease sales planned for the 1981–82 period. Other studies, covering known coal deposits in the Powder River Region of Wyoming and Montana, the Fort Union Region of Montana and North Dakota, and Mid-Continent (Oklahoma) regions, which began last year, are still underway. Detailed tract profile reports prepared by the Division provided extensive data on expected geologic, engineering, environmental, social, and economic impacts of mining in each area identified. Final tract selection, ranking,and detailed regional environmental impact assessments will follow these preliminary analyses, and tonnage goals for each sale will be determined from energy production goals established by the Department of Energy.

The Survey also has responsibility for establishing estimated fair market values for all lease tracts prior to sale through a variety of appraisal procedures. This process assures that the Government receives a fair price for resources produced.

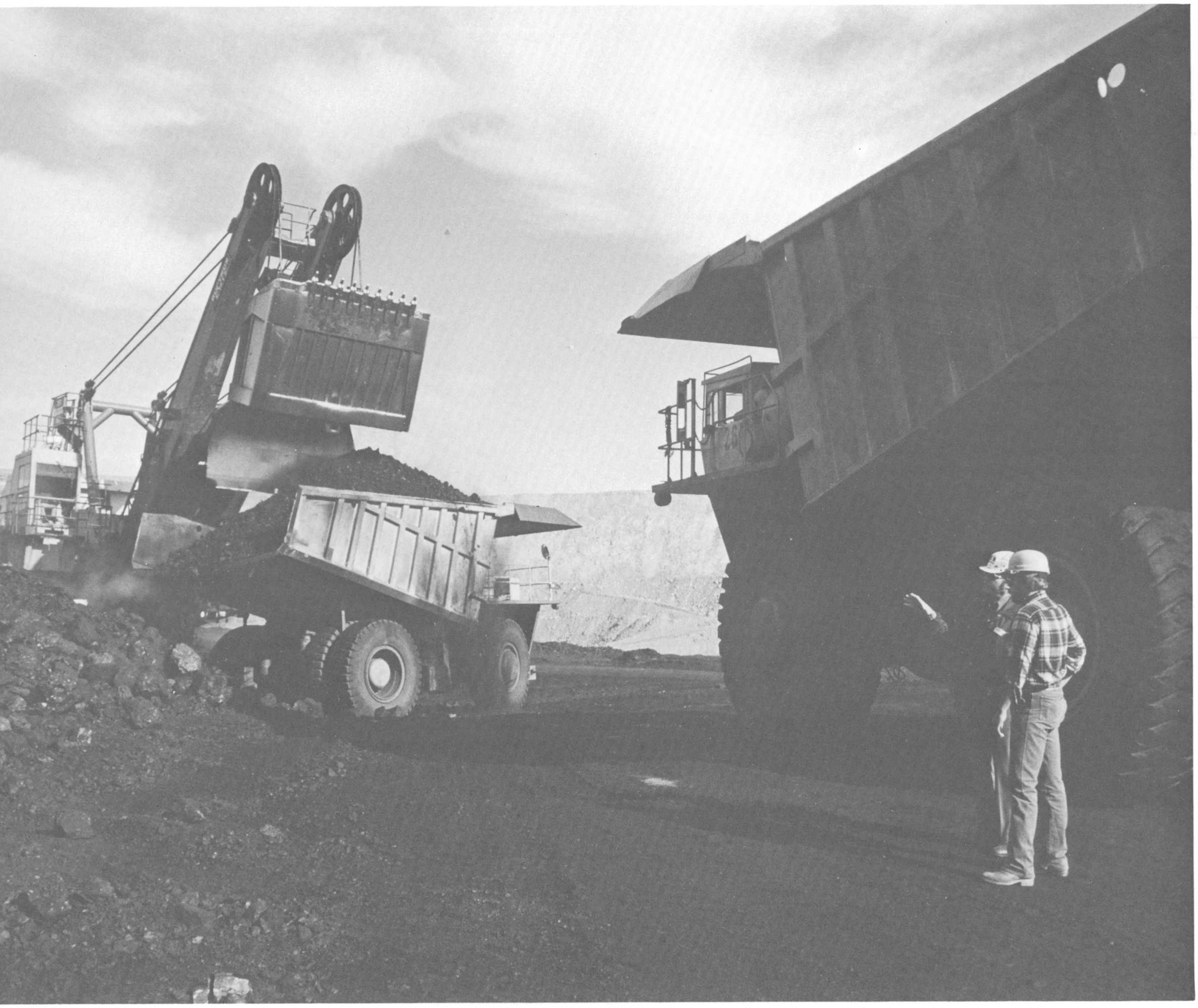
In fiscal year 1980, the Survey performed 28 economic evaluations of coal deposits, completed mapping for 276 quadrangles under the CRO/CDP Program, classified more than 1.8 million acres of coal as KRCRA's, completed administrative work on several land exchanges, and managed the drilling of more than 421 holes having a total depth of 218,000 feet to determine the extent, quality, and economic development potential of various coal deposits.

The Survey also provided review and recommendations for approval of proposed mining plans for Federal and Indian lands and carried out inspections and enforcement of activities consistent with the mandated requirements of the Mineral Leasing Act. Those regulations promulgated under the mineral leasing laws concern the formation of logical mining units, diligent development and maximum economic recovery of coal resources, protection of other resources from damage due to mining operations, and systematic collection of royalties, which totaled $21.7 million in fiscal year 1980 from Federal coal leases.

The Survey also provided the Bureau of Land Management with data and information required for the periodic adjustment of terms and conditions of leases, including land exchanges and changes in royalty rates. Although principal responsibilities for the environmental protection and land reclamation aspects of coal mining were transferred from the Geological Survey to the Office of Surface Mining in 1977, the Survey, the Bureau of Land Management, and the Office of Surface Mining coordinate all lease management activities to assure consistency and diligent supervision.

As part of the Survey's new emphasis on total resource management, several new coal program initiatives are underway. These include greater research into the use of geophysical modeling, supported by expanded drilling data, in economic evaluations, as well as more extensive use of computer systems for tract delineation, resource evaluation, lease management, royalty accounting and collection, and tactical planning for future coal development. Other new and important programs are aimed at identifying coal resources most suitable for use by the emerging synthetic fuels industry and at finding new ways to resolve land-use planning conflicts for areas having multiple potentially produceable or currently used resources.

These coal program adjustments and new initiatives, developed during 1980, provided mechanisms that will assist the Survey and other bureaus in the Department of the Interior in meeting the challenges of increasing domestic coal production in the coming years.



U.S. Geological Survey mining engineer Harvey Gloe (plaid shirt) and a foreman from the AMAX Coal Company inspect operations at the Belle Ayr surface mine near Gillette, Wyo. (Photograph by James Cook, Wide World.)

Oil and Gas From the Outer Continental Shelf

One industry estimate recently indicated that more than one-half of the still-undiscovered oil and gas resources in the Nation lie in offshore areas. Despite the greater expense and difficulty in establishing production in the offshore environment, there seems to be little doubt that oil and gas production from the Outer Continental Shelf (OCS) will continue to contribute a major portion of the Nation's energy supplies in the years ahead, especially as new deposits are located and developed. During fiscal year 1980, a total of 4 lease sales were held in which 293 Federally managed tracts covering more than 1.2 million acres were leased by industry for exploration. Sale of these leases brought $5.94 billion to the Treasury.

The Gulf of Mexico (OCS) area continues to provide the majority of oil and gas production offshore. In 1980, more than 264.6 million barrels of oil and 4.6 trillion cubic feet of natural gas flowed into the Nation's energy system from this prolific region. The Gulf alone accounts for virtually 9 percent of all oil and 24 percent of all U.S. domestic natural gas production.

Efforts started in fiscal year 1978 to explore the Mid-Atlantic OCS (Baltimore Canyon) area, off the coast of southern New Jersey, and, in fiscal year 1979, exploration began in the South Atlantic region off the coast of southern Georgia. Rigs operating in more than 450 feet of water roughly 100 miles offshore drilled several wells in the Baltimore Canyon. This effort resulted in encouraging indications of significant natural gas desposits. After formations in the area are further tested and defined, gas from the Mid-Atlantic OCS may provide an important new source of fuel for the industrialized East Coast. Results in the South Atlantic have not been as encouraging. Despite the existence of several promising geological formations in the area, only minor traces of oil and gas have been found.

Exploration activities also are continuing in the OCS areas of Alaska. One lease sale was held during fiscal year 1980 in which 24 Federally managed tracts covering 85,776 acres were leased in the Beaufort Sea off the State's northern coast. Promising geological characteristics make the Alaska OCS one of the brightest areas for potential major finds.

Additional leasing off the southern California coast is proceeding more slowly. Widely varying water depths and locally sensitive environmental conditions require sophisticated hardware and great diligence in drilling to assure that exploration and production occur in a safe manner.

New initiatives for exploration in OCS frontier areas, in the vicinity of densely populated coastal regions and other areas with sensitive environmental characteristics, have created new concerns among Federal, State, and local governments; the environmental constituency; and the public. Section 26 of the Outer Continental Shelf Lands Act Amendments called for the establishment of a program to assemble information about OCS mineral developments and their onshore impacts and to make such information widely available. As a result, in 1978, the Outer Continental Shelf Oil and Gas Information Program was established. Five *Summary Reports* have been published covering the Mid-Atlantic and South Atlantic Regions, Gulf of Mexico, Pacific (South California), and Gulf of Alaska (including Lower Cook Inlet). In addition, four *Indexes* covering Federal reports and documents used by the Government in the OCS decisionmaking process have been published for the Atlantic, Gulf of Mexico, Pacific, and Alaska regions.

Each *Summary Report* is an anthology of currently known information about a particular region. When a significant event occurs, a new report is published to supercede a preceeding document. *Indexes* are revised annually. Compiling information available from a variety of Federal, State, and private sources into single regionally specific documents has provided a timely and valuable new source of information for planners at all levels. There has been a heavy demand for this series of reports among State and local governments and other constituency groups interested in planning for future onshore and offshore impacts of OCS exploration, development and production.

Section 102 of the Outer Continental Shelf Lands Act Amendments, clarifies the intent "to balance orderly energy resource development with protection of the human, marine, and coastal environments." The amendments called for development of a program to meet this basic requirement and those of other emerging legislative mandates. A comprehensive geologic hazards program has been established to identify and evaluate geologic hazards prior to any oil and gas exploration and development activities.

The U.S. Geological Survey obtains geologic hazards information through a three-phase program. In the first phase, geologic data and high-resolution geophysical data are collected through reconnaissance surveys on a broad scale. Information derived from these regional surveys is used in preliminary tract selection and for an assessment of regional geologic hazards for the draft environmental statement.

The second phase consists of collecting high-resolution geophysical data for specific tracts tentatively selected for a proposed lease sale. These data are generally acquired under exclusive contract. Information is obtained by using a grid on a selective basis over those proposed tract areas where professional judgment indicates the presence of geologic hazards could preclude exploration and development activities. These geohazards are identified, mapped, and carefully evaluated. Recommendations are then made for withdrawal of specific tracts from a sale or, if necessary, for addition of appropriate lease stipulations. This assures the Secretary of the Interior and the public that any resources discovered can be developed without undue risk. The results of these more detailed examinations are included in the final environmental statement in response to the mandate of Title II of National Environmental Protection Act for agencies to consult with the Council on Environmental Quality "to insure that environmental information is available to public officials and citizens before decisions are made and before actions are taken."

The third phase consists of requiring lessees to obtain detailed site-specific geologic hazards information for those locations on leased tracts where exploration and development activities are proposed. These data are reviewed in detail by the Survey to assure the safety of operations before approval of exploration and development plans.

During preparation of a Geologic Hazards Report for proposed Lease Sale No. 52, a supervisory geologist confers with two geophysicists in the Outer Continental Shelf Regional Office in Washington, D.C., to correlate and analyze seismic and bathymetric data.

Subsea hazards information becomes part of a prelease issue document used by the Secretary of the Interior in the selection of tracts to be offered for eventual leasing. Lease Sale No. 52, scheduled for October 1982, involves acreage proposed for leasing on the Georges Bank, in water ranging in depth from 171 to 9,285 feet, located between 81 and 164 statute miles off the New England coast.

Office of Earth Sciences Applications

Mission

The Office of Earth Sciences Applications plans, develops, coordinates, directs evaluates, and implements the land-resources and environmental impact programs of the U.S. Geological Survey. This office was created in 1980 primarily from the principal functional units of the Land Information and Analysis Office.

Increased public interest in environmental quality and public awareness of the limited supply of nonrenewable resources has created a need for the communication of scientific and engineering data in a manner readily understandable to the general public. The communication of earth science information to the general public and to decisionmakers is an important goal of the Survey.

The Office of Earth Sciences Applications is composed of earth scientists as well as specialists in such diverse fields as urban planning, economics, and remote sensing. This Office manages multidisciplinary programs directly concerned with the techniques and methodologies that can be used to apply earth science information to land and resource planning. The major functions of the Office include:

- Developing resource planning methods to enhance the use of earth science information in the planning-decisionmaking process;
- Overseeing implementation of and compliance with environmental laws, including the preparation and review of environmental impact statements within the Survey;
- Providing earth science information for land-resources decisionmaking;
- Collecting, processing, and distributing remotely sensed data and applying remote-sensing technology in support of land-resource and environmental analyses;
- Developing visual products and services designed to inform both the scientific and nonscientific communities about applications of earth science information.

The task of achieving these objectives is carried on by the following offices:

- Resource Planning Analysis Office (RPAO)
- Environmental Affairs Office (EAO)
- Earth Sciences Assistance Office (ESAO)
- Earth Resources Observation Systems Office (EROS)
- Visual Information Services Office (VISO)

Mount St. Helens, before and after. Viewed from space, the snow-capped peak of Mount St. Helens was a typical small bright volcanic feature in a September 11, 1979, Landsat image (21693-18095). An August 19, 1980, Landsat image (22036-18201) of the same area shows the extent of devastation caused by the May 18 and subsequent eruptions. Note the elongated crater, the blasted area where forested slopes had stood, and the extent of debris and mudflow along stream channels. The different tone of Swift Reservoir, to the southeast, is caused by deposition of 11 million acre-feet of water, mud, and debris. (Photograph courtesy of the EROS Data Center and the National Aeronautics and Space Administration.)

Budget and Personnel

Obligations for Office of Earth Sciences Applications activities in fiscal year 1980 amounted to $23.74 million, a decrease of 1 percent from fiscal year 1979 (see table).

The objectives of the Office of Earth Sciences Applications are accomplished partly through contracts to private industry and research grants. During fiscal year 1980, $10.65 million (45 percent) was expended on contracts. Contract services were the major source of operational support at the EROS Data Center in Sioux Falls, S. Dak. The Office of Earth Sciences Applications employed 213 full-time career employees in 1980, of which 149 positions were assigned to the Office's programs and 64 were assigned to other Survey Divisions for supportive work. There were also 72 temporary or part-time employees. In addition, contract support services at the EROS Data Center amounted to 315 person years.

Office of Earth Sciences Applications obligations for fiscal years 1979 and 1980, by subactivity

[Dollars in millions. Data may differ from that in statistical tables because of rounding]

Subactivity	Fiscal year 1979	Fiscal year 1980
Total	**$23.96**	**$23.74**
Earth Resources Observation Systems Office	**12.87**	**15.28**
Direct program	9.91	11.78
Reimbursable program	2.96	3.50
Miscellaneous non-Federal sources	2.36	2.80
Other Federal agencies	.60	.70
Environmental Affairs Office	**5.21**	**5.90**
Direct Program	4.29	4.70
Reimbursable program	.92	1.20
Other Federal agencies	.92	1.20
Land Resource Data Applications Program (ESAO and RPAO)	**2.41**	**2.56**
Direct Program	2.36	2.46
Reimbursable program	.05	.10
Other Federal agencies	.05	.10

SOURCE OF FUNDS

TOTAL $23.74 MILLION

USE OF FUNDS

Geologic Hazards Movie

It is human nature to look at damage from earthquakes, volcanoes, floods, landslides, and other geologic hazards and to say, "They can't happen to me," or "They can't happen here." But they can and do. A new motion picture, entitled *When the Earth Moves* and produced by the U.S. Geological Survey, describes both the geologic hazards prevalent in the United States and the measures and methods to reduce the damage they cause.

In uninhabited areas, some geologic processes are merely interesting phenomena; but when they take place where people live, they become hazards. Human suffering and financial loss result—unless effective measures are taken beforehand to assess potential threats and to enact methods to limit the damage. *When the Earth Moves* describes how appropriate land uses, engineering techniques, and land-use and building regulations are being used in communities throughout the country to avoid or lessen the effects of geologic events.

The film uses animation and scenes from actual events to describe the hazards, associated dangers, and probable locations. In interviews, land-use planners, government officials, engineers, and geologists explain various ways now being used to cope with geologic hazards.

The film is especially useful for land-use planners, government officials, and members of the building industry. However, the film is also of interest to the general public, particularly high-school and college students and teachers.

The 26 minute, sound, color film can be borrowed or purchased from:
U.S. Geological Survey
303 National Center
Reston, VA 22092
Telephone (703) 860-6171

The May 18, 1980, eruption of Mount St. Helens caused flooding and sedimentation along the Cowlitz River, Wash.

COOPERATIVE PROJECTS: APPLICATIONS OF REMOTELY SENSED DATA

The U.S. Geological Survey has ongoing cooperative projects with many Federal, State, and local government agencies; with colleges and universities; and with foreign governments and international organizations. These projects involve applications of data about the Earth gathered by several remote-sensing systems, including the Landsat satellites. During fiscal year 1980, Survey scientists were working on several such projects including preparing a satellite image poster of Cape Cod National Seashore with the National Park Service, monitoring and managing water resources in the Everglades National Park with the National Park Service, inventorying and mapping wildland vegetation in Arizona with the Bureau of Land Management, and improving petroleum exploration techniques and applying advanced remote sensing to arid land evaluation with the People's Republic of China.

Everglades National Park

The ecological balance of the Shark River Slough, a freshwater marsh in the Everglades National Park, depends on the flow of surface waters from north and east of the park. The Survey and the National Park Service are using Landsat data to monitor hydrologic conditions in the park, especially the spatial and temporal components of the surface water flow, and, thus, to improve the management of the water resources by providing more quantitative and timely measurements of the distribution of water.

The work has involved selecting a set of Landsat images that represent the wide range of hydrologic conditions in the park. Using computerized analysis techniques, the areal extent of the different hydrobiological zones, the space and time distribution of water inundation, and the variations in the volume of water stored within the slough were determined. This information was registered geometrically to a base map of the park for correlation with the 75 monitoring stations within the slough. Subsequent Landsat images were then used to monitor the conditions in the slough through sophisticated data manipulation and analysis techniques.

The results of the project show that Landsat data can be used to monitor hydrological conditions in a freshwater marsh ecosystem and to determine the relationships between water deliveries to the Everglades National Park and the interactions of sheet surface-water movement through the slough. Landsat data can be applied to delineate the extent of Shark Slough's hydrobiological zones and the expansion and contraction of the slough's margins throughout "wet" and "dry" seasons. When combined with gaging station data, estimates of the volume of water stored in the slough can be made. This information obtained through the analysis and interpretation of Landsat data is being used to formulate a sound water-resources management program for Everglades National Park.

Cape Cod Project

Since 1973, the Survey has been working with National Park Service personnel from the Cape Cod National Seashore and evaluating the use of Landsat data on the park. One project in which Landsat data are being used to monitor changes in the coastline is vividly demonstrated by a public exhibit at the Salt Pond Visitor Center at Eastham, Mass. The exhibit shows the effects of a severe winter storm in February 1978. During the storm, a 5,000-ft-wide breach opened on Monomy Island south of the cape's "elbow." Because of the interest generated by the exhibit, a poster showing a Landsat image of the cape was prepared and placed on sale at the Visitor Center to evaluate public response to using Landsat images to compliment more traditional topographic and thematic maps of the cape and the National Seashore. The idea was so well received that, during the first 3 months that the poster was available, 1,200 copies were distributed to visitors.

Oblique aerial photograph looking north at the breach in Monomy Island caused by the February 1978 northeast storm.

Arizona Wildland Vegetation Inventory

The Bureau of Land Management requires a low-cost, quick, and accurate means of inventorying vegetation on thousands of acres of arid public land in the Southwest. The Federal Land Policy and Management Act of 1976 requires the Bureau of Land Management to maintain an inventory of resources on public lands.

In fiscal year 1980 the Survey and the Bureau of Land Management completed a cooperative demonstration project in Mojave County, Ariz. The objective was to determine the usefulness of Landsat data, combined with conventional aerial photography and data from ground surveys, for mapping and inventorying wildland vegetation. To achieve this objective, the project had to:

1. Determine to what extent vegetation classes could be mapped from Landsat data using a vegetation classification system supplied by the Bureau of Land Management, and
2. Evaluate the utility of Landsat-derived vegetation maps in combination with other information such as ter-

rain data, soils data, ownership, and so forth.

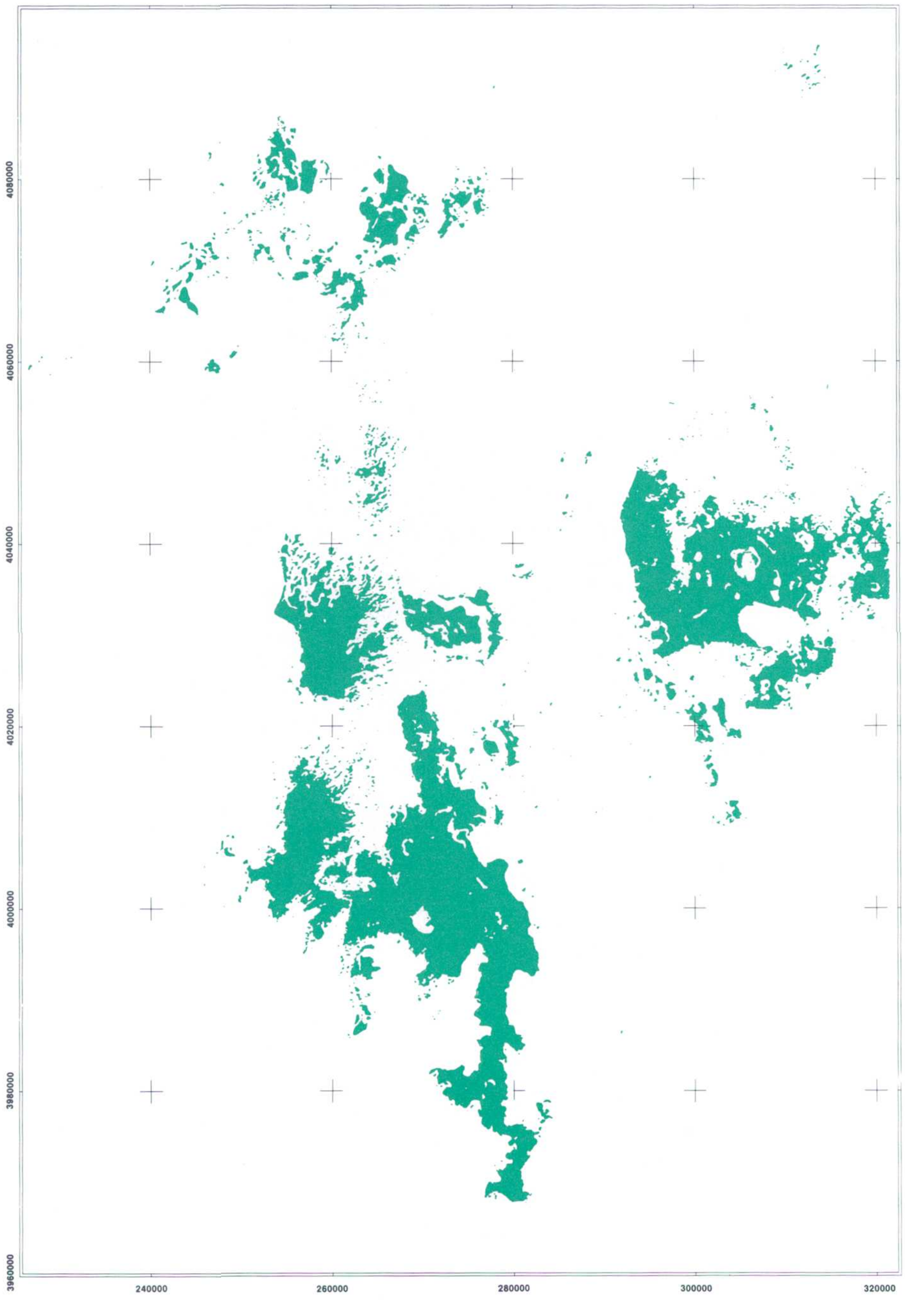
To map the vegetation, Landsat digital data were used to classify 1,000,900 acres of land into 76 classes according to the spectral response of the vegetation cover.

When terrain data for the area (elevation, slope, and aspect) were combined with the Landsat data, digital manipulations of the data were possible, and the accuracy was 73 percent.

Combining the terrain data with the Landsat data produced a data base that could be used to produce map overlays that will be effective tools for managing land resources. Providing the location of suitable areas for different types of grazing, areas of mule deer summer and winter ranges, antelope and Desert Bighorn sheep habitats, and areas having a potential for pinyon-juniper clearing to improve grazing potential. The map overlays are geometrically correct and can be used with standard maps.

POTENTIAL PINYON / JUNIPER CHAINING AREAS

ARIZONA STRIP DISTRICT, ARIZONA



MAPPING CRITERIA*

(a) VEGETATION — EVERGREEN WOODLAND

(b) ELEVATION — 5,000 ft. — 7,800 ft. (1,524 m — 2,377 m)

(c) SLOPE — <10%

(d) MAPPING UNIT — 10 ACRES (4 HECTARES)

*Vegetation data derived from Landsat vegetation classification of scene I.D. 2947 - 17074 acquired August 26, 1977. Elevation, slope and aspect were derived from NCIC digital terrain data.

Area mapped as potential pinyon-juniper chaining areas: 264,204 acres (106,923 hectares)

COVER TYPE DESCRIPTION BASED ON PHOTO DATA

Total Photo Plots: **689**

Coniferous forest	Evergreen woodland	Great Basin desert shrub	Mountain shrub
Ponderosa pine - sagebrush <1%	Pinyon-juniper 3%	Big sagebrush - perennial grass 3%	Mixed chaparral 2%
Ponderosa pine - pinyon - juniper 6%	Pinyon-juniper - shrub 82%	Big sagebrush - mixed shrub <1%	
Ponderosa pine 1%		Big sagebrush - tree 2%	
		Snakeweed <1%	
Total 7%	85%	6%	2%

GRID NUMBERS INDICATE THE UNIVERSAL TRANSVERSE MERCATOR GRID, ZONE 12

WILDLAND VEGETATION RESOURCE INVENTORY SYSTEM
NASA/BLM ASVT PHASE II
ANALYSIS COMPLETED MAY, 1979
BY U.S. GEOLOGICAL SURVEY, EROS DATA CENTER

Reduced print of map overlay depicting potential pinyon-juniper chaining areas. The overlay was prepared from a digital data base that included Landsat-derived vegetation cover type, elevation, slope, and aspect. The mapping criteria were specified by Bureau of Land Management personnel.

Techniques for Petroleum Exploration in the People's Republic of China

As part of a formal agreement between the United States and the People's Republic of China, scientific and technical geologists of the EROS Data Center and the Office of Energy Resources of the U.S. Geological Survey are cooperating with geologists from China on the use of remotely sensed data (different types of Landsat data, aerial photography, and radar data) to improve techniques for oil exploration.

The relationships between various geological parameters, especially regional structure and the occurrence of petroleum, are being studied in the Quidam Basin, a large sedimentary basin in a remote part of northwestern China. Using Landsat data and other available data and applying the current principles and techniques of the earth sciences (including remote sensing, sedimentation, structural geology, nonmarine biostratigraphy, organic geochemistry, geophysics, and mineral diagenesis) geologic models of the basin will be constructed. The models will be useful in studying the relationships between the occurrence of petroleum and the physical characteristics of the Earth's crust.

The effectiveness of existing Landsat image-analysis and other remote-sensing techniques will be evaluated in the studies of the Quidam Basin and will probably result in the development of new remote sensing techniques and applications specifically aimed at improving petroleum exploration capabilities.

These formal studies will carry on the work of informal projects begun in 1978. Structural geologic interpretations and models based on the study of Landsat data have been made for the western part of the basin. A predictive geologic structure model will help to determine the geologic features in the eastern part of the basin.

The interpretation of four Landsat images of the western Quidam Basin were checked in the field by American and Chinese geologists in June 1979 and were found to be in close agreement with actual field conditions. In fiscal year 1980, the Survey enlarged the mosaic to 16 images which include the entire basin for which they made an interpretation overlay. Chinese counterparts purchased computer-compatible tapes of the region. The joint project is planned to have a duration of 4 years during which 2 years each will be devoted to studies of the Quidam Basin and the Tibetan Plateau.

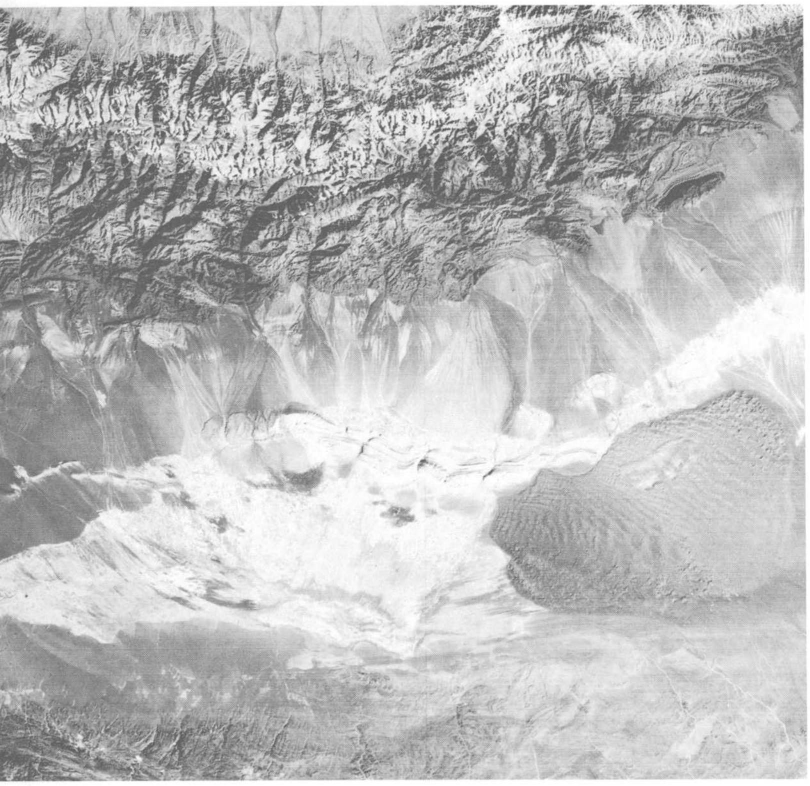
Deserts and Desertification in the People's Republic of China

Using Landsat and field data, geologists of the U.S. Geological Survey, in a project initially sponsored by the National Academy of Sciences Committee on Scholarly Communication with the People's Republic of China, are working with Chinese geologists and geographers of the Institute of Desert Research, at Lanzhou, Gausu Province, and of the Institutes of Geography and of Remote Sensing Application, at Beijing, to map and classify the deserts, to study desertification processes and land-reclamation methods, and to assess the feasibility of upgrading arid lands for agriculture.

During the project, western scientists for the first time have access to previously inaccessible field data. Quantitative information on eolian materials, including analysis of grain size, fabric, texture and mineralogic composition, and reflectivity will be compared with information acquired from analysis of Landsat imagery for three different types of deserts found in China. The size and composition of surficial sand material will be compared with the composition of atmospheric dust in major Chinese cities in a wind-pattern study. Knowledge and understanding of Chinese deserts and the processes that occur within these deserts will contribute to a better understanding of global arid ecosystems. Some desert borders and other semiarid lands are subject to desertification, which is the encroachment of desertlike conditions on formerly productive land due to human activity. Desertification currently affects more than 600 million people worldwide and one-third of the Earth's surface. Some Chinese scientists believe that entire deserts have been created in historical times by human misuse of the land. Although historical information on this subject is not readily available, a comparison of early (1972–73) Landsat images with more recent images can indicate where deserts are presently advancing and where recent human intervention to reclaim damaged land has been successful.

Analysis of Landsat imagery can rapidly locate fragile arid ecosystems and can monitor these areas to note both positive and negative changes. This technique is being used in three test areas in the People's Republic of China to assess the effectiveness of selected land-upgrading processes. The use of Landsat data provides a synoptic view of these areas where rapid detection of the encroachment of deserts can lead to the application of preventative measures.

Photographs from the People's Republic of China. A, The Turpan Depression, south of the Tien Shan Mountains in Xinjiang Province, is one of the lowest areas in China. By comparing this 1972 Landsat image with more recent images, changes in the dune field east of the depression and in land-use patterns in the black gobi may be studied. B, Scientists at the Institute of Desert Research, Lanzhou, examine Landsat images as a potential tool for monitoring arid-land reclamation techniques. C, The line of trees, irrigated vegetation, and checkerboard dunal pattern are three methods used to halt the advancing Tengri Desert near the Shapotou Desert Research Station in Mingxia Province. D, Sand dune advancing on an alluvial plain north of the Tien Shan Mountains, Gurbantunggut Desert. E, A balloon captures a new heart.



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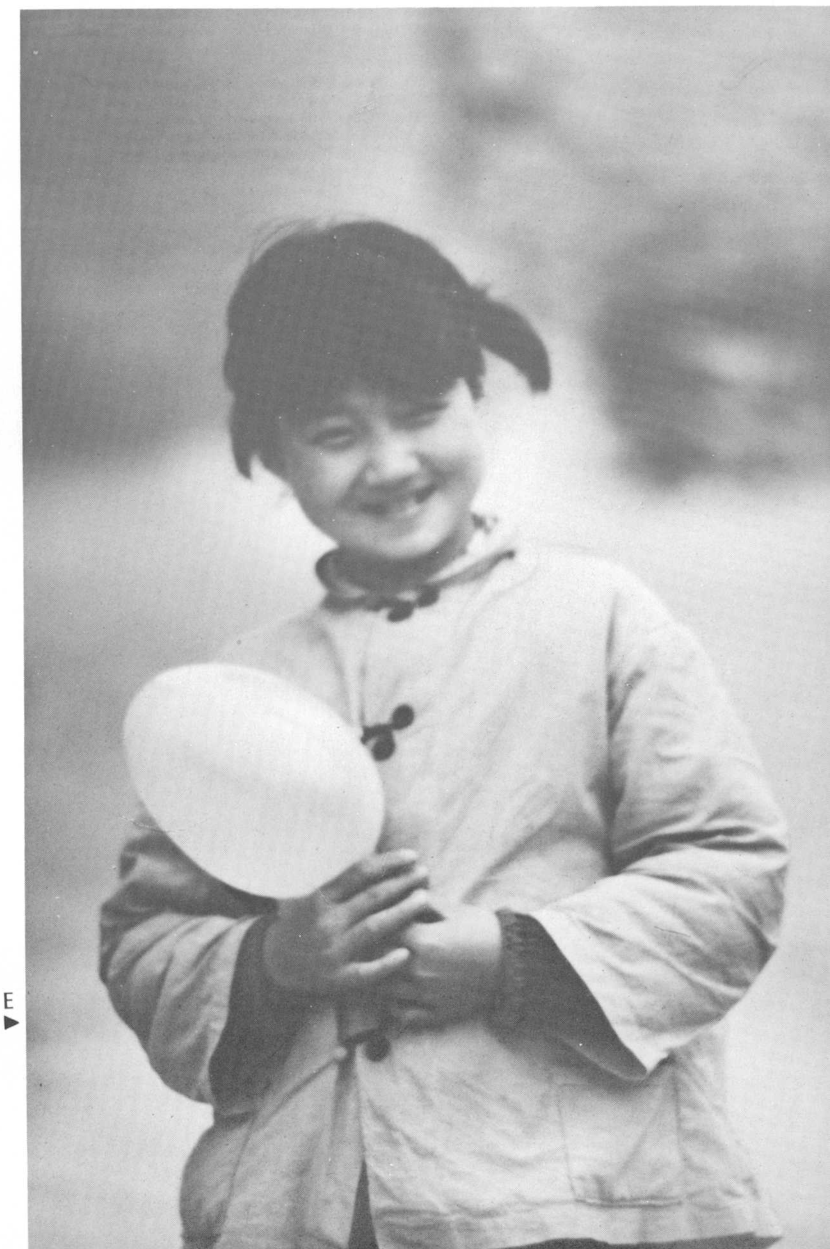


Environmental Conflict Resolution: Powerplant Siting in New England

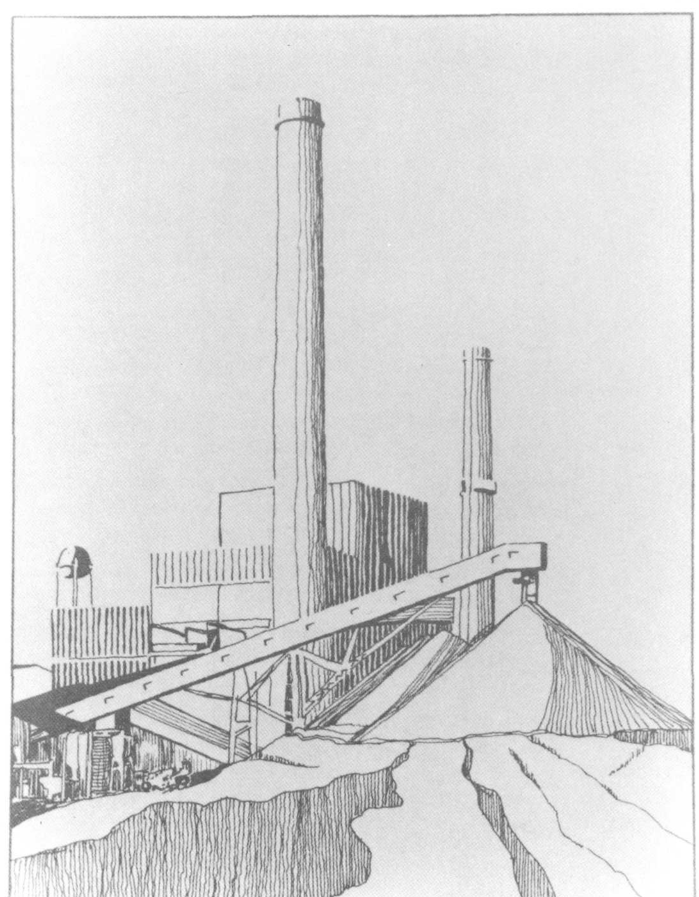
Conflicts over economic, energy, and environmental issues have become widespread in our society. These conflicts may relate to the leasing of minerals on the public lands, to the siting of hazardous-waste disposal facilities or powerplants, or to similar issues. Disputes among government, developers, and public interest groups can also occur over the adequacy or interpretation of earth science information. The U.S. Geological Survey is working with Federal, State, and local planners and decisionmakers to develop and apply methods for anticipating and mitigating environmental disputes.

The New England River Basins Commission is cosponsoring a powerplant siting project under this program. A Task Force, composed of people from public and private sectors, was convened in July 1979 to study four aspects of the site selection process: reconnaissance-level studies, alternative site identification, preferred site selection, and review and approval of the site and design of the station. Emphasis is on the water resource and related land-resource aspects.

The Task Force is run by a facilitator, a neutral third party who has no stake in the outcome but is a specialist in group problem-solving dynamics. This arrangement is designed to overcome difficulties encountered in the normal public participation process. Some of these difficulties are:

- The public has no opportunity to participate in early planning decisions.
- Those who may be affected ty the proposals feel that the range of siting alternatives are constrained by conditions and tradeoffs of which they are unaware of or do not understand.
- The hearing process predisposes people to polarization and hostility.
- Duplication of effort in the review and approval process causes delays and frustration and invites disruption.
- Most government agencies have been placed in reactive postures and lack impact on the planning process.

The Task Force has developed standards against which solutions can be measured and has identified additional major improvements in the public–government regional planning process. These techniques and standards will be refined and applied in the New England area and the methodology and results made available to other regional planning activities nationwide.



Coal Development Planning

Illinois Coal Basin

The U.S. Geological Survey is cooperating with the Indiana, Illinois, and Kentucky Geological Surveys and with the Indiana University School of Public and Environmental Affairs to assist planners and managers in meeting problems generated by coal development in the Illinois Coal Basin. The State Geological Surveys have assembled relevant earth science information for those areas affected and have provided these data in an understandable and usable form for planners and managers. The Indiana University School of Public and Environmental Affairs, through its Environmental Applications Center, is providing socioeconomic and related information to be used with the earth science information as a basis for conducting workshops for planners and managers in the three States. The workshops will demonstrate the use of earth science and other environmental, social, economic, and fiscal information in developing scenarios, identifying and assessing impacts, considering alternatives and consequences, and arriving at decisions.

Western Coal Planning Assistance Project

The Western Coal Planning Assistance Project, a cooperative program involving the Survey and the Missouri River Basin Commission, was designed to assist State and local government planners and decisionmakers to deal more effectively with problems associated with coal-energy development.

The project focussed on the major coal areas of Montana, North Dakota, and Wyoming and consisted of two major phases: (1) the development of a four-volume Planning Reference System comprising a coal factbook, a guide to impact assessment methods, forecasts for Western coal development , and a sourcebook identifying funding and technical assistance sources and (2) the conduct of four participatory workshops to introduce the Planning Reference System and other similar information sources and to involve participants in case studies and simulation games patterned after actual problem situations. The workshops were held during the summer of 1980 in Billings, Mont., Bismarck, N. Dak., Jackson, Wyo., and Omaha, Neb. An average of 65 participants attended each session.

Surface mining at the Absaloka mine in southeastern Montana.

The Puget Sound Regional Study

Since 1977, the U.S. Geological Survey has been making a multidisciplinary study of the wide range of geologic and hydrologic conditions in the 15,800-square-mile Puget Sound region. The objective of the study was to gather, analyze, and interpret earth science data for use by planners and decisionmakers confronted by an equally wide range of problems including management of land use in the coastal zone, ensuring energy supplies, avoidance or mitigation of natural geologic hazards, and safeguarding the quantity and quality of the water, mineral, and other resources of this region—especially its unique environmental qualities. Because of the diversity of conditions and planning problems, the results of the project will be applicable to many other areas in the country where any similar conditions and problems exist.

The main thrust of the Survey's Puget Sound project is to produce maps and reports that interpret basic earth science information for use by the planning and decisionmaking community and to assist that community in applying the information to resolve current and future land-use conflicts.

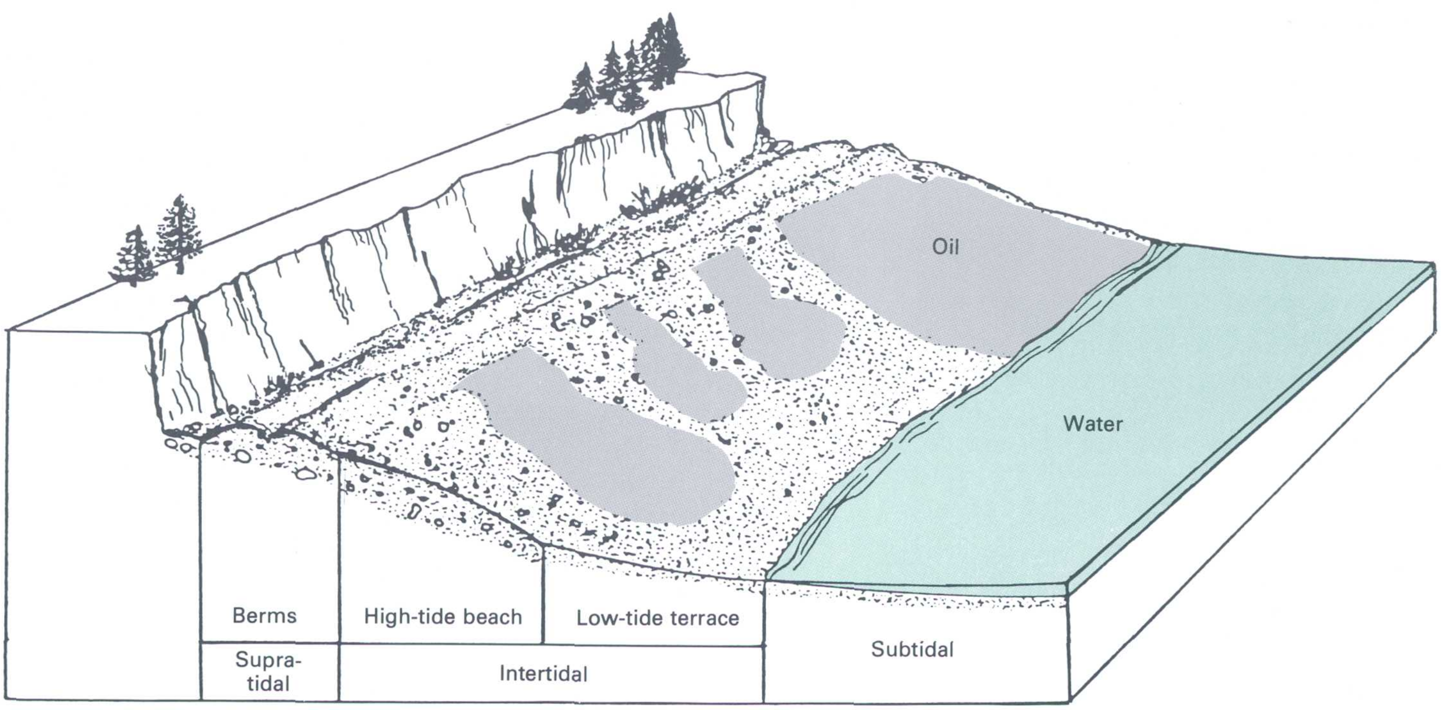
In addition to increasing understanding of the region, the Puget Sound project:

- Promotes an understanding of the need for and advantages of using earth science information for planning land and resource development, hazard mitigation, resource conservation, and environmental protection;
- Increases the familiarity of planners, decisionmakers, and other citizens with geologic and hydrologic hazards and resources;
- Increases the availability and uses of the scientific, engineering, and planning information produced by the Geological Survey;
- Expedites the dissemination of information needed for urgent regional decisions;
- Helps ensure the correct and appropriate application of earth science information; and
- Helps supply the data needed by users to comply with Federal and State statutes and regulations.

Some of the significant interpretive reports produced by the study in fiscal year 1980 illustrate the wide variety of information being made available to achieve these objectives:

- A report on the availability of ground-water data and its uses (U.S. Geological Survey Open-File Report 80-430 by David Frank).
- A study of the phosphorus (a pollutant) concentrations in the lakes of the region (U.S. Geological Survey Open-File Report 80-328 by R.J. Gillion).
- A study of landsliding and slope stability in a part of the Cascade Mountains and map of the surficial geology of the same area (U.S. Geological Survey Open-File Reports 79-963 and 79-964 by P.L. Heller).
- A study of the potential effects of an oilspill on the shoreline near Port Townsend (U.S. Geological Survey Open-File Report 80-724 by R.F. Keuler).

Diagrammatic view illustrating beach features and distribution of petroleum. Oil is deposited not only on the highest part of the beach face but can be deposited across the intertidal zone as the tide falls. At low tide, oil can flow down the beach and collect on the low-tide terrace.



The "Circuit-Rider" Geologist

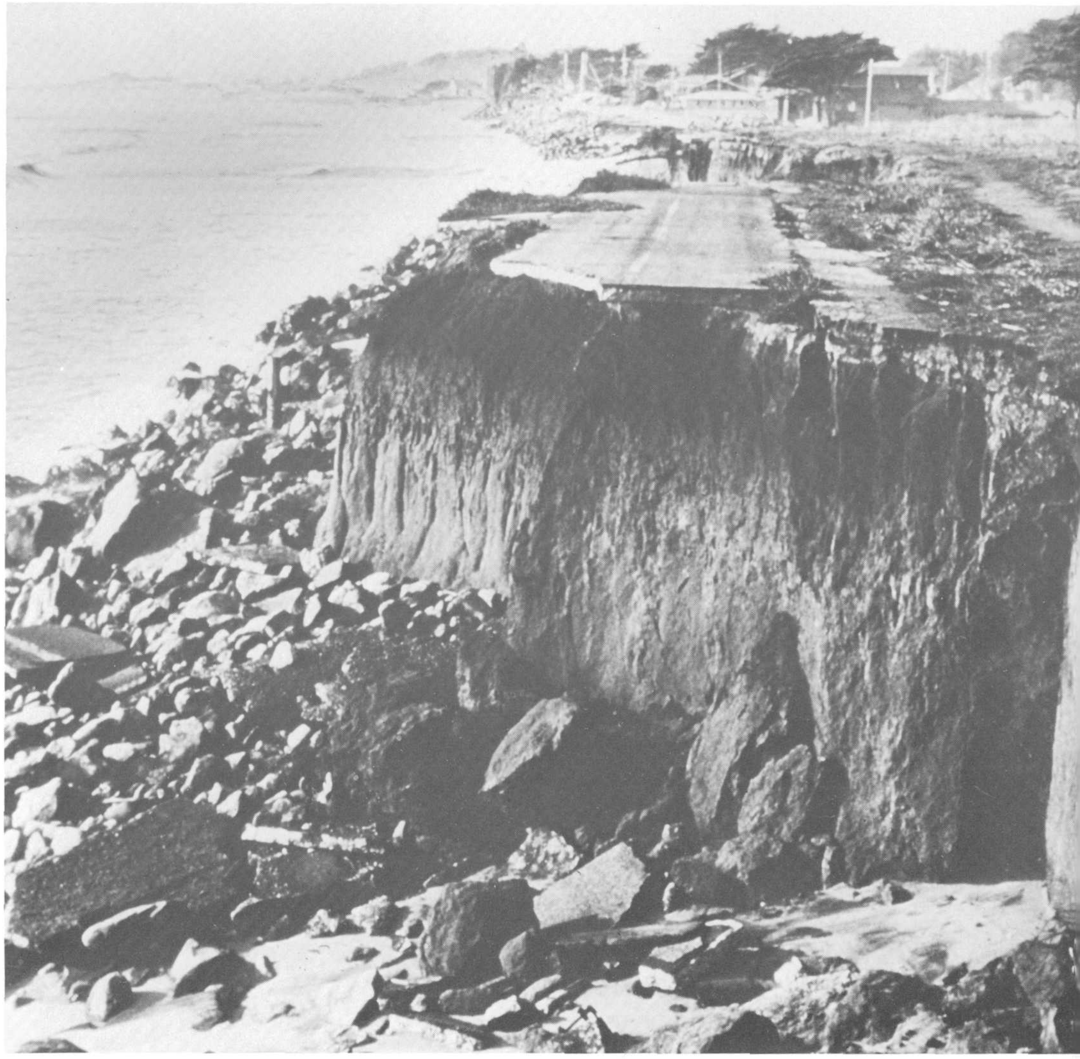
The occurence of coastal erosion, landslides in steep terrain, and other geologic factors within Clallam, Jefferson, and Island Counties, Wash., makes them difficult areas to develop. In most other regions of the country where geologic factors are important considerations in land-use decisions, such as the San Francisco Bay and the Denver areas, local governments have staff geologists. These "county geologists" develop a knowledge of the specific local geology and geologic processes not generally attained by the traditional geologists. As a result, they are in a position to understand and apply their expertise to the local needs of the community. Equally important, they become personally acquainted with local officials, policy-making processes, and problems. The local orientation of the county geologist enables earth science to become an important aspect in local land-use decision-making. Unfortunately, there are no "county geologists" in Washington State.

Last year, the U.S. Geological Survey initiated a cooperative program with the Washington Department of Natural Resources to increase the understanding and use of earth science information by providing the services of a part-time "county geologist" or "circuit-rider" geologist. The circuit rider is an employee of the State's Division of Geology and Earth Resources and assists local governments of the three Puget Sound lowland counties in using earth science information to plan and regulate development.

The circuit-rider geologist performs many functions. He is teacher, consultant, and geologic mapper. As teacher, he may find himself discussing the principles of ground-water occurrence with local planners or explaining how to use a slope stability map. As consultant, he may be asked to review the hydrogeologic aspects of a development plan before the issuance of a building permit. At the same time, the circuit-rider geologist is preparing a geologic map of Whidbey Island County and identifying the natural hazards of the area.

The circuit-rider geologist has been able to bring much-needed earth science information to localities that are in a position to apply it. However, the real value of this project will depend on whether these and other counties continue to obtain and properly apply earth science data in the decisionmaking process after the project is completed.

Homes damaged by landslides.



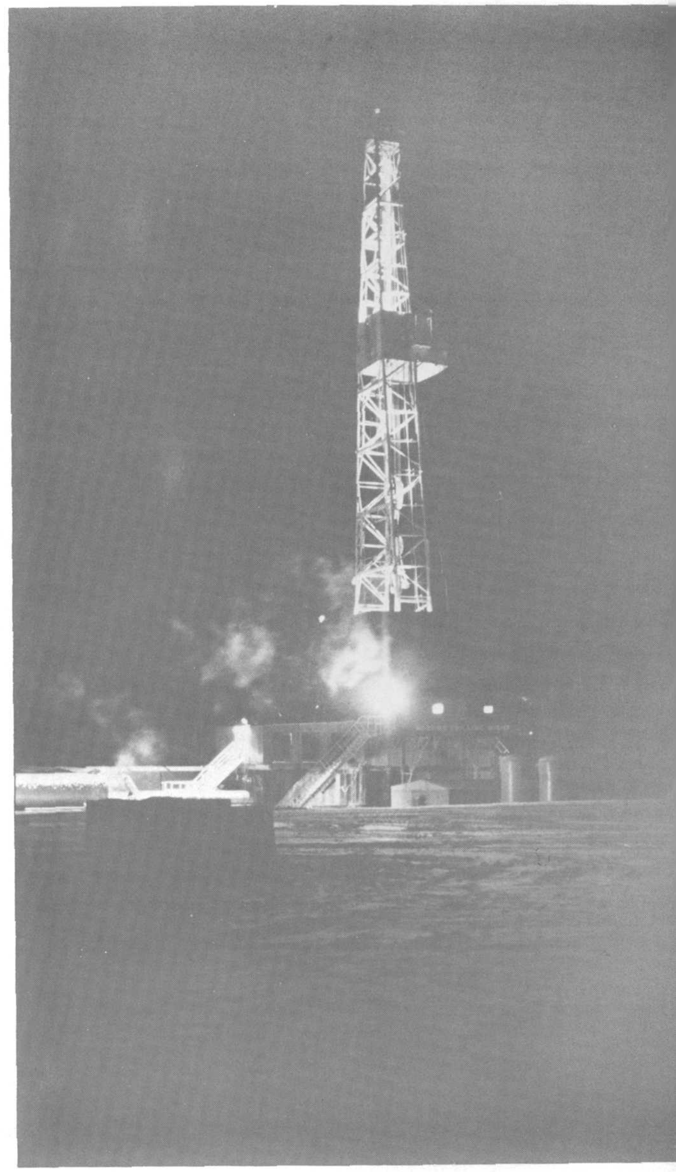
Road damaged by coastal erosion.

National Petroleum Reserve in Alaska

Mission

The U.S. Geological Survey continued petroleum exploration activities on the National Petroleum Reserve in Alaska (NPRA), which was transferred from the Department of the Navy to the Department of the Interior on June 1, 1977, under the Naval Petroleum Reserves Production Act of 1976 (90 Stat. 305; 42 U.S.C. 650 4(d)(3)). In accordance with the Act, the Survey was assigned the responsibility to explore and to evaluate the petroleum resources by drilling and geological and geophysical investigations, to build an information base to assist Congress in determining the best use of the land within the Reserve, to continue to develop and to produce natural gas from the South Barrow gas field or other fields as may be necessary and to supply gas at reasonable and equitable rates to the Native village of Barrow and other communities and installations of the Federal Government in the vicinity of Barrow, and to continue environmental rehabilitation of parts of the Reserve disturbed by previous exploration and construction activities.

Seven exploration wells were completed, including four that had been started in earlier years. Two geophysical parties acquired 1,110 line miles of seismic data. In addition, the Geological Survey continued to operate and to maintain the South Barrow gas field which supplies natural gas to the village of Barrow and Federal installations in the vicinity of Barrow. Three gas development wells were drilled in the East Barrow field. A pressure-reducing station was constructed at the East Barrow gas field to allow East Barrow wells to begin production during the winter of 1980–81. Husky Oil NPR Operations, Inc., continued as the principal contractor for all phases of the exploration program during fiscal year 1980.



Drilling at night at Lisburne Test Well No. 1, February 1980.

Budget and Personnel

$169.8 million was appropriated for drilling and related activities within the National Petroleum Reserve in Alaska. Of this amount, $138.6 million was allocated to continue the ongoing evaluation and assessment of the Reserve; $28.4 million, to operate the South Barrow gas field and to explore for and to develop additional gas reserves in the Barrow area; and $2.4 million, for the Environmental Rehabilitation Program which consists of the normal cleanup of current exploration drilling sites and rehabilitation of areas of the Reserve disturbed during previous petroleum exploration and construction activities.

The Office of National Petroleum Reserve in Alaska was allocated 24 permanent full-time positions and 6 part-time positions for the fiscal year. Of the 24 permanent full-time positions, 3 have been staffed by the Administrative Division in the Geological Survey to provide dedicated contract support to the program and to upgrade National Petroleum Reserve in Alaska petroleum-resource data as new information is acquired from the ongoing exploration program. The remaining 21 positions comprise the Operations, Exploration Strategy, and Liaison elements of the Office.

National Petroleum Reserve in Alaska activity obligations for fiscal years 1979 and 1980, by subactivity

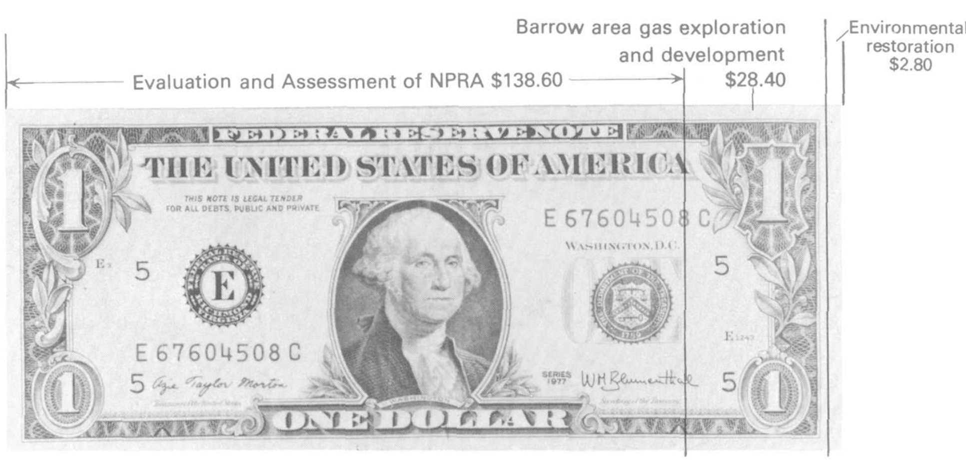
[Dollars in millions. Data may differ from that in statistical tables because of rounding.]

Subactivity	Fiscal year 1979	Fiscal year 1980
Total	**$216.9**	**$169.8**
Evaluation and Assessment of NPRA	**194.1**	**138.6**
Direct programs	194.1	138.6
Reimbursable programs	--	--
Barrow Area Gas Exploration and Development	**20.2**	**28.4**
Direct programs	20.2	28.4
Reimbursable programs	--	--
Environmental Restoration	**2.6**	**2.8**
Direct programs	2.6	2.8
Reimbursable programs	--	--

SOURCE OF FUNDS

TOTAL $169.80 MILLION

USE OF FUNDS



Status of Exploratory Drilling

Tunalik Test Well No. 1, located 22 miles southeast of Icy Cape, was started in November 1978 as a deep test in the western part of the National Petroleum Reserve in Alaska. Numerous gas shows were encountered at both shallow and moderate depths in sandstones which had low porosity. High-pressure gas, which was encountered at about 12,550 and at 14,725 feet, created severe drilling problems. The heavy drilling mud and barite used to control the high-pressure gas flow damaged the formation, and attempts to test the sand were unsuccessful. An unexpected and geologically significant sequence of igneous rocks was drilled within sedimentary rocks. Most stratigraphic units pentrated by this well were found to be thicker than equivalent strata in wells to the east. The well was drilled to 20,335 feet and was plugged and abandoned in January 1980.

Ikpikpuk Test Well No. 1 was completed on February 28, 1980, at 15,481 feet in "argillite" basement. The well was drilled to test the Lisburne and pre-Lisburne plays at their wedgeout on the north flank of the Ikpikpuk Basin. Nearly 4,000 feet of tight nonprospective Lisburne and Endicott beds were drilled with scattered minor gas shows. Two of the shallow sands, the pebble shale sand and a Torok sand, were tested primarily for productive capacity and fluid content. Some gas was recovered on each test.

Lisburne Well No. 1 was completed on June 2, 1980, at 17,000 feet in the fifth penetration of the Lisburne limestone. The well was located on a seismic closure in the disturbed belt play, which borders the Brooks Range and is at least partly analogous to the overthrust play in the Western United States. The well drilled about 7,000 feet of highly deformed rocks before reaching the Jurassic to Mississippian prospective section exposed at the surface, immediately south of the well site. Ubiquitous dead oil occurrences demonstrate generation of hydrocarbons. Tests in two different Lisburne plates recovered only very small amounts of gas and some relatively fresh formation water.

Seabee Well No. 1 was completed on April 15, 1980, in the lower Cretaceous "pebble shale" at a total depth of 15,611 feet. The well was drilled on the flank of the Umiat anticline, which contains the Umiat oil field discovered in 1950. The objective was to test for possible deeper hydrocarbon reservoirs in Early Cretaceous (Fortress Mountain) strata. Good oil and gas shows were encountered in the shallow Umiat oil zone, but testing was not possible because of the large-sized borehole. Minor oil and gas shows were found in the Nanushuk and upper Torok, and a significant show was found at 5,340 feet in the Torok. Tests of this zone gave flows of 2 million to 6 million cubic feet per day, but detailed analyses of the test data indicate a limited depleting reservoir. Minor gas shows were found in deeper thin nonporous sandstones.

Walakpa Well No. 1 was completed on February 7, 1980, at a depth of 3,660 feet in "argillite" basement. The objective of the well was a large structural-stratigraphic trap in the Jurassic Simpson sand. The Jurassic sand was not present, but a pebble shale-type sand tested gas in amounts significant to the local Barrow market.

West Dease Test Well No. 1 was completed on March 26, 1980, at a depth of 4,170 feet in "argillite" basement. The well was drilled to test a seismic structural-stratigraphic trap in the Sag River sandstone. The Jurassic Barrow and the Triassic Sag River sands were cored with good oil and gas shows and fair porosity but with very poor permeability. A test in the Barrow sand recovered only mud with an oil sheen. Minor gas and oil shows were found in the Torok and pebble shale.

East Simpson Test Well No. 2 was completed on March 15, 1980, at a depth of 7,505 feet in "argillite" basement. Drilled 4 miles from the East Simpson No. 1, the objective was a seismically sensed thickened section of the porous and oil-stained Sadlerochit strata found in that well. Minor oil and gas shows were found in the Torok and Sag River Formations. A thin section of Sadlerochit was cored with a good oil show, but a test of the sand recovered 161 barrels of formation water with a sheen of oil. Small-scale faulting is indicated between the wells in the area and may account for the thin Sadlerochit section. Sandstones of probably Endicott age were cored with poor to fair porosity and with dead oil shows. An Endicott play similar to that in the Prudhoe Bay area may lie updip from the East Simpson No. 2.

Awuna Test Well No. 1, located approximately 152 miles south-southwest of Barrow in the central part of the Reserve, was started on March 1, 1980, to test for potential oil and gas accumulations on one of the highest structural positions along the prominent Carbon Creek-Awuna anticline which extends across much of the Reserve. The well will test sands of the Fortress Mountain and Torok Formations of Cretaceous age and the Upper Kingak Formation of Jurassic age. The projected depth is 15,000 feet. The well was suspended for the summer on May 8, 1980, at a depth of 5,300 feet before encountering the potential reservoir horizons.

Geophysical studies in the National Petroleum Reserve in Alaska continued during fiscal year 1980 with the acquisition, processing, and interpretation of 1,110 line miles of fill-in and detailed seismic surveys in various parts of the Reserve using two field geophysical crews, one in the Southern Foothills area and one in the northern coastal area. Approximately 1,000 miles of previously acquired seismic data were processed for special stratigraphic evaluation. To date, 12,517 line miles of seismic data have been collected and processed. In addition, various geologic studies are underway by the U.S. Geological Survey and by contractors to support oil exploration activities, which include structural and stratigraphic studies, geochemical investigations, and hydrologic and engineering studies.

The petroleum exploration activities in the National Petroleum Reserve in Alaska have been coordinated with two related studies mandated by Public Law 94–258. One study completed in December 1979 relates to the best overall procedure to be used in the development, production, transportation, and distribution of the petroleum resources in the reserve. This study is referred to as the Presidential Study or the 105(b) Study. It consists of an economic analysis by the Office of Minerals Policy and Research Analysis in the Department of the Interior and an environmental analysis by the U.S. Geological Survey. The second study, conducted by the Bureau of Land Management, is to determine the values of and best uses for the lands contained in the Reserve, taking into consideration (1) the Natives who live or depend upon such lands, (2) the scenic, historical, recreational, fish and wildlife, and wilderness values, (3) mineral potential, and (4) other values of such lands. This study, referred to as the 105(c) Study, was compiled by the Bureau of Land Management and was submitted to Congress in April 1979.

The table lists wells drilled by the Navy between 1975 and 1977; wells drilled in fiscal years 1978, 1979, and 1980; exploration wells planned for fiscal year 1981 by the Geological Survey; and development wells drilled in the Barrow gas fields in fiscal years 1977, 1978, and 1980.

Summary of exploration drilling by the Department of the Navy and the U.S. Geological Survey

Name	Location	Date spudded[1]	Date completed	Total depth, in feet	Deepest horizon attained	Remarks
Cape Halkett No. 1.	18 miles ESE of Lonely.	3-24-75	5-23-75	9,900	Argillite basement (Devonian or older).	Dry; plugged and abandoned.
East Teshekpuk No. 1	25 miles of Lonely.	3-12-76	5-11-76	10,664	Granite basement	Do.
South Harrison Bay No. 1.	50 miles SE of Barrow.	11-21-76	1-27-77	11,290	Lisburne Group (Mississippian).	Poor oil shows; plugged and abandoned.
Atigaru Point No. 1.	44 miles SE of Lonely.	1-12-77	3-10-77	11,535	Argillite basement (Devonian or older).	Do.
West Fish Creek No. 1.	51 miles SE of Lonely.	2-14-77	4-21-77	11,427	Kayak Shale (Mississippian).	Poor oil shows; plugged and abandoned.
South Simpson No. 1.	41 miles WSW of Lonely.	3- 9-77	4-18-77	8,805	Argillite basement (Devonian or older).	Dry; plugged and abandoned.
W. T. Foran No. 1.	23 miles ESE of Lonely.	3- 7-77	4-16-77	8,864	----do----	Oil and gas shows; plugged and abandoned.
Drew Point Test Well No. 1.	14 miles W of Lonely.	1-13-78	3-13-78	7,946	----do----	Poor oil and gas shows; plugged and abandoned.
North Kalikpuk Test Well No. 1.	37 miles SE of Lonely.	2-27-78	4-14-78	7,395	Kingak Shale (Jurassic).	Do.
South Meade Test Well No. 1.	45 miles S of Barrow. (Reentered 12-1-78).	2- 8-78	1-22-79	9,945	Argillite basement (Devonian or older).	Poor gas shows; plugged and abandoned.
Kugrua Test Well No. 1.	67 miles SW of Barrow.	2-13-78	5-30-78	12,588	Lisburne Group (Mississippian).	Dry; plugged and abandoned.
Inigok Test Well No. 1.	60 miles S of Lonely.	6- 7-78	5-22-79	20,102	Kekiktuk Formation (Mississippian).	Encountered hydrogen sulfide and sulfar at 17,570 feet; poor gas shows; plugged and abandoned.
Tunalik Test Well No. 1.	22 miles SE of Icy Cape.	11-10-78 1-27-79	1- 7-80	20,335	Argillite basement	Gas test; plugged and abandoned.
Peard Test Well No. 1.	25 miles NE of Wainwright.	1-27-79	4-13-79	10,225	----do----	Poor gas shows; plugged and abandoned.
Ikpikpuk Test Well No. 1.	42 miles SW of Lonely.	11-29-78	2-28-80	15,481	----do----	Oil and gas shows; plugged and abandoned.
East Simpson Test Well No. 1.	55 miles SE of Barrow.	2-19-79	4-10-79	7,739	----do----	Do.
J. W. Dalton Test Well No. 1	3 miles E of Lonely.	5- 7-79	8- 2-79	9,367	----do----	Oil and gas shows; some heavy oil recovered during testing; plugged and abandoned.
Lisburne Test Well No. 1.	110 miles SW of Umiat.	6-11-79	6- 2-80	17,000	Lisburne-Endicott Group.	Shows of gas; plugged and abandoned.
Seabee Test Well No. 1.	1 mile NW of Umiat.	7-1-79	4-16-80	15,611	Basal Cretaceous	Gas test; plugged and abandoned.
Walakpa Test Well No. 1.	15 miles S of Barrow.	12-25-79	2- 7-80	3,666	Argillite basement	Shows of gas; plugged and abandoned.
West Dease Test Well No. 1.	28 miles SE of Barrow.	2-19-80	3-26-80	4,170	Argillite basement (Devonian or older).	Poor shows; plugged and abandoned.
East Simpson Test Well No. 2.	50 miles SE of Barrow.	1-28-80	3-15-80	7,505	----do----	Do.
Koluktak Test Well No. 1.	75 miles S of Smith Bay.	Being planned.	---	[2] 4,500	Torok Formation (Cretaceous).	Planned for drilling in fiscal year 1981.
Awuna Test Well No. 1.	150 miles S of Barrow.	3- 1-80	---	[2] 15,000	Lisburne Group (Mississippian).	Suspended at 5,300 feet; to be reentered and completed in fiscal year 1981.
Kuyanak Test Well No. 1.	38 miles S of Barrow	Being planned.	---	[2] 6,700	Argillite basement	----
Walakpa Test Well No. 2.	17 miles S of Barrow.	--do--	---	[2] 4,500	----do----	----
North Inigok Test Well No. 1.	45 miles S of Lonely.	--do--	---	[2] 10,800	----	----
Tulageak Test Well No. 1.	26 miles SE of Barrow.	--do--	---	[2] 4,500	----do----	----

[1] Drilling began. [2] Projected.

Barrow Area Gas Development Activities

The Geological Survey continued to operate and maintain the South Barrow gas field which supplies gas to the village of Barrow as well as Federal installations in the Barrow area (see table). Construction and installation of a production system at the newer East Barrow gas field is nearing completion which will double the amount of natural gas available to the Barrow area.

In compliance with Congressional direction, no new wells were drilled during fiscal year 1979 while studies of alternative fuel sources for Barrow were made. The studies were completed and established that the continued development of local gas reserves is the most cost-effective manner of providing energy to the Barrow area. Three wells are scheduled to be drilled in the East Barrow field during fiscal year 1980; the first well, Barrow Well No. 20, was suspended after producing oil on a drill stem test. Two additional wells are scheduled, Barrow Well No. 15 and Barrow Well No. 18, but drilling has not yet begun. An all-weather road network now connects the wells in the two fields, increasing the safety and efficiency of the Barrow gas field operation immeasurably.

Summary of drilling in the Barrow area by The Department of the Navy and the U.S. Geological Survey

Name	Location	Date spudded[1]	Date completed	Total depth, in feet	Deepest horizon attained	Remarks
South Barrow No. 13.	5 miles SE of Barrow.	12-17-76	1-16-77	2,535	Argillite Basement (Devonian or older).	Shows of gas; suspended as marginal gas well.
South Barrow No. 14.	12 miles ESE of Barrow.	1-28-77	3- 3-77	2,257	Sag River Sand (Triassic).	Completed as a gas well.
South Barrow No. 16.	6 miles E of Barrow.	1-28-78	2-18-78	2,400	Argillite basement (Devonian or older).	Dry; plugged and abandoned.
South Barrow No. 17.	13 miles ESE of Barrow.	3- 2-78	4-13-78	2,382	----do----	Suspended; edge well; produces water with gas.
South Barrow No. 19.	11 miles ESE of Barrow.	4-17-78	5- 1-78	2,300	----do----	Completed as a gas well.
South Barrow No. 15.	10 miles ESE of Barrow.	7- 1-80		[2] 2,400	Argillite basement [2]	----
South Barrow No. 18.	12 miles ESE of Barrow.	8-19-80		[2] 2,400	----do[2]----	----
South Barrow No. 20.	11 miles ESE of Barrow.	4- 7-80	5-10-80	2,356	----do----	Shows of gas; suspended as nonproducer.

[1] Drilling began. [2] Projected.

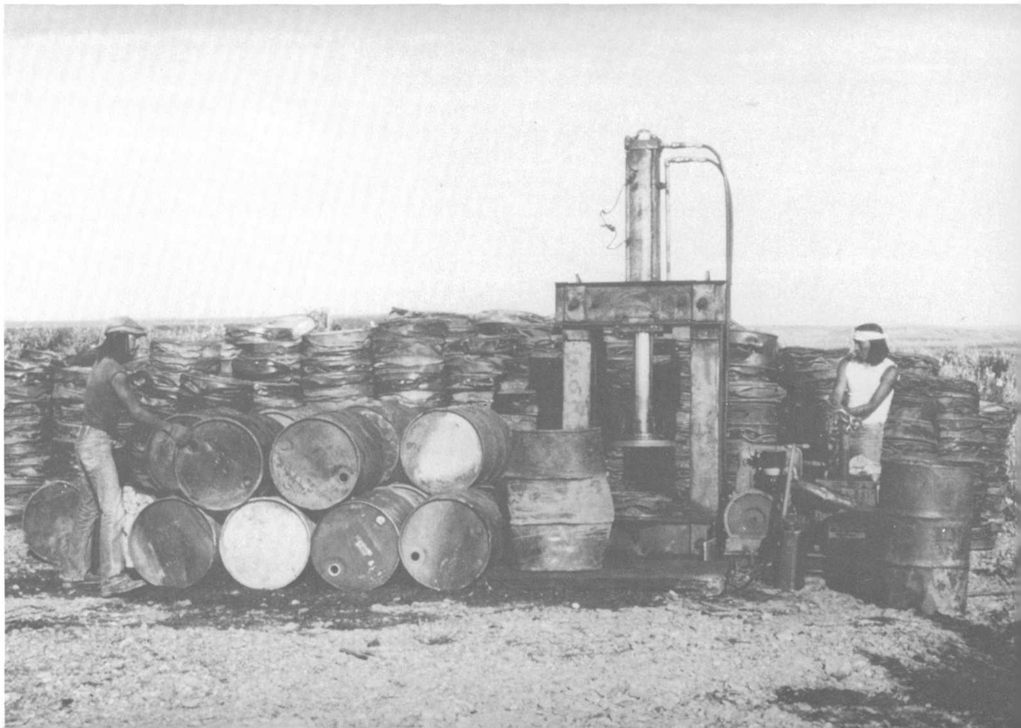
Environmental Rehabilitation on NPRA

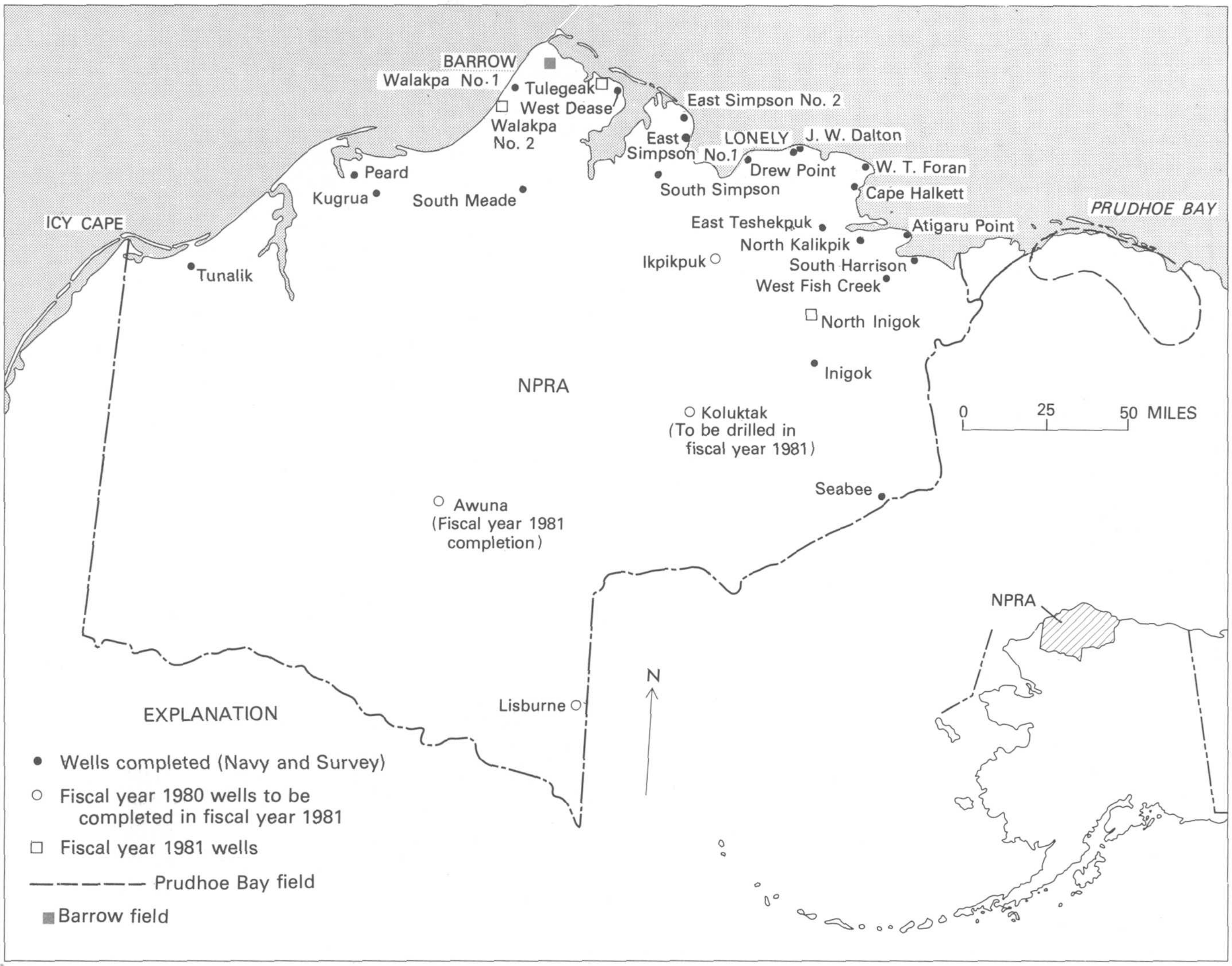
The U.S. Geological Survey environmental rehabilitation program at National Petroleum Reserve in Alaska consists of two parts, the collection and consolidation of litter and debris left from previous construction and oil exploration activities and the cleanup and revegetation of current drilling sites.

Early oil exploration and construction activities were accomplished with little consideration for environmental protection or effects of drilling operations on the tundra environment. Fuel drums, abandoned equipment and supplies, and other litter of exploration and construction were left in place at many sites. During fiscal year 1980, the Geological Survey collected over 1,760 tons of debris and waste materials from numerous old sites on and adjacent to the Reserve, including 10,400 old barrels. These materials were consolidated and stockpiled at several collection points on the Reserve.

Current program site rehabilitation consists of an initial recontouring and revegetation of drilling sites with a second reseeding during the following year. During fiscal year 1980, initial rehabilitation work was performed at eight sites, and followup reseeding and refertilizing was completed at six sites. Seed and fertilizer were set out for next year's use at nine sites. Both cleanup and rehabilitation activities are accomplished by contract personnel.

Crushing empty fuel drums during environmental rehabilitation operations on the NPRA, summer 1980. (Photograph courtesy of Husky Oil NPR Operations, Inc.)

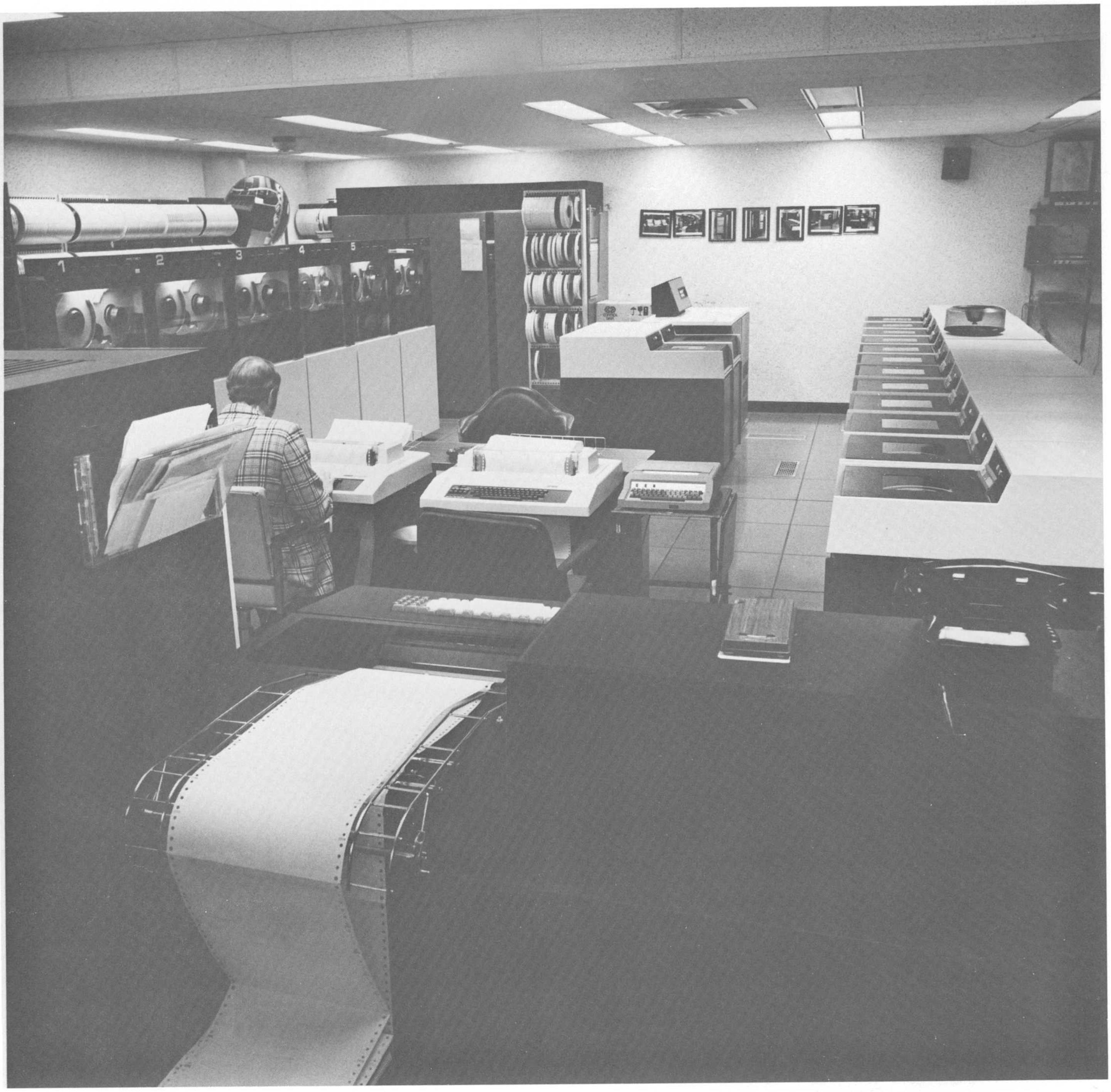




Map showing location of NPRA. ▲

▼ *Access road from South Barrow gas field to East Barrow gas field.*

Program Support Divisions



Computer Center Division

The use of automatic data processing (ADP) and data communications technology continues to grow at the U.S. Geological Survey. The acquisition and use of computers by the Survey to manipulate and to store the constantly enlarging volumes of digital data are increasing. During fiscal year 1980, the Computer Center Division achieved significant objectives in several areas, including advances in ADP management, hardware acquisition, and software development.

In fiscal year 1980, the Survey contracted with the Federal Computer Performance Evaluation and Simulation Center (FEDSIM) to develop and to demonstrate a formal methodology for ADP planning and management. FEDSIM is a Federal computer systems center that provides reimbursable technical assistance, support, and services for the simulation, analysis, performance evaluation, and management consultation for Federal Government computer systems. FEDSIM is a suitable consultant for the Survey effort to reduce costs of procuring and using complex computer and communications systems and to improve the productivity and efficiency of the systems. To accomplish its objectives, FEDSIM conducted interviews with data processing, project, and procurement personnel at the Survey in Reston, Va., Rolla, Mo., Lawrence, Kans., Denver, Colo., Flagstaff, Ariz., and Menlo Park, Calif. The purpose of these interviews was to acquire an indepth knowledge of the types, locations, uses, policies, procedures, constraints, and limitations affecting the existing computer configurations, as well as any planned acquisitions of the computers, software, and data communications equipment within the Survey. Having acquired this information during fiscal year 1980, FEDSIM is currently developing a methodology for management planning that considers large, small, and special-purpose computers; for local, regional, and national data; for computing and data communications requirements; and for developments in ADP and data communications technology.

Along with planning activities, other events occurred that affect the administration of ADP services at the Survey. During fiscal year 1980, the functions and responsibilities of the Washington Computer Center (WCC) were transferred to the Computer Center Division. WCC was under the supervision of the Office of the Assistant Secretary for Policy, Budget, and Administration. The transfer of WCC to the Computer Center Division entailed a review of management positions, administrative and technical support positions, and programming positions to propose an initial organizational integration of WCC into the Survey. During these organizational and functional reviews, the Computer Center Division cited significant opportunities for improving the management of the ADP services supplied to the Department and to the Survey.

During fiscal year 1980, in accordance with the General Services Administration's Federal Property Management regulations and in compliance with the Secretary's memo on information technology policy, the Division planned for the collocation of the WCC with the Reston facility of the Computer Center Division. The majority of WCC's functions and personnel will be transferred to Reston. However, onsite ADP support will continue to be provided at the Interior Building for the Office of the Secretary and other Departmental offices. The remaining support group will serve as a field site, similar to the existing Denver, Menlo Park, and Flagstaff sites. Collocation of general-purpose computer centers, such as WCC and the Division, encourages more effective sharing of ADP resources; saves money, space, and energy; and does not require extensive changes to operational management.

Another area for improvement of ADP management services is the Departmental Integrated Payroll/Personnel Service (DIPS). The DIPS system provides services to over 50,000 employees, primarily in the following organizations: the Department of Interior, Office of the Secretary; the U.S. National Park Service; the U.S. Geological Survey; the Fish and Wildlife Service; and the Environmental Protection Agency. These services are provided on a biweekly basis and produce over 150 reports. The system provides data needed to prepare payroll, tax, retirement, and statistical reports. During fiscal year 1980, the agency created the position of DIPS manager, who will report to the Chief, Computer Center Division. The DIPS manager will have complete responsibility for all aspects of DIPS including the coordination and direction of all efforts within the Survey and the Department of the Interior relating the DIPS. This position represents a significant advancement in the administration of the DIPS system. The transfer of the operation of the DIPS system to the Geological Survey offers the opportunity to solve problems with the system management that have been identified by the Survey and other user bureaus and by the consulting firm of Arthur Young and Company.

The accomplishments of an ADP center depend on physical considerations as well as administrative ones. During fiscal year 1980, the Survey procured an Amdahl 470V/7 computer to replace the IBM 370/155's. The Amdahl provides more computer power and will enable the Division to install up-to-date operating system software to meet the increasing needs for computer services.

The Computer Center Division also accomplished significant advances in the area of ADP software development. During fiscal year 1980, a new level of Multi-trieve, an interactive retrieval and report generation package for the Multics computer system developed by the Division, was released. With the new level of Multi-trieve, a user can develop any type of report format desired, in addition to using the standard column-type report facilities. The new level provides the user with considerably more power for designing the appearance of a report than was previously available.

During fiscal year 1980, the Division completed the final developmental work for a file-management system called TARUS, and the initial version was released. TARUS satisfies the need for an efficient easily expandable facility for file maintenance and is especially useful for handling a combination of variable- and fixed-length records. Previous file-management systems for Multics were only suited for handling one type of record. In developing TARUS, the Division emphasized user-computer interface techniques, such as frequent prompting for the user, allowing easier computer access for scientists and administrators. Several groups within the Survey are using TARUS. The Technical Editing Unit, Geologic Division, uses TARUS to maintain lists of Survey publications and to produce catalogs of publications by State and year published. The Geographic Names Branch, National Mapping Division, produces catalogs from a TARUS data base. In addition, the Consolidated Universities of Bath, Bristol, and Avon in England requested a demonstration of the TARUS system.

At the request of the Survey's Data Base Administrator (DBA), the Division assisted in the investigation of all current and major Data Base Management Systems (DBMS) to determine which system was best suited to meet agency needs. Model 204 was selected as the system that would best meet the requirements of the DBA, and it was acquired for the Amdahl. Model 204 is the only DBMS available that provides a single user language for data base creation, querying, and report writing. This unique qualification enables casual users to learn one language for all aspects of their data manipulation. In a scientific environment, the ease of use of the DBMS, as with any ADP software tool, is of paramount importance.

The accomplishments of the Computer Center Division for fiscal year 1980 represent significant initial steps toward providing an effective information technology in support of Departmental and Geological Survey goals. Fiscal year 1980 saw growth in the ADP fields through organizational and management advancement, both in the short, and long term, as well as acquisition of more efficient machinery (hardware) and development or acquisition of more effective software for the Survey computer systems.

Administrative Division

General Administration

The cost of executive direction and coordination of U.S. Geological Survey programs and administrative services provided by the Administrative Division is funded by General Administrative Expenses. During fiscal year 1980, these expenses amounted to 2.7 percent of the Survey's budget. This funding was derived from the following sources: the General Administration budget activity, $3.8 million; assessments on the directly appropriated activities, $12.9 million; and assessments on the reimbursable programs, $4.3 million. No assessments are made on cooperative funds from State and local governments.

Administrative Management

The activities of the Administrative Division are carried on at Survey Headquarters in Reston, Va., and at three major Regional Centers—Eastern Region, also headquartered in Reston, Central Region, headquartered in Denver, Colo., and Western Region, headquartered in Menlo Park, Calif. Field offices are located in five areas: Atlanta, Ga., Rolla., Mo., Metairie, La., Flagstaff, Ariz., and, Anchorage, Alaska. Principally, these offices provide support to Survey installations in the immediate or nearby areas on matters relating to personnel, facilities, procurement, and supply management.

During fiscal year 1980, the Administrative Division implemented and coordinated a variety of facilities, procurement, personnel, energy conservation, and financial management improvements. Highlights associated with these management improvements follow.

Facilities Improvements

The EROS (Earth Resources Observation Systems) Data Center is located on the outskirts of Sioux Falls, S. Dak. It is a special-purpose scientific facility primarily involved in remote sensing and satellite image data interpretation and application. In addition, during fiscal year 1980, the facility became a model demonstration project for both solar-energy and waste-water recycling techniques.

- *Solar-energy application.*—The EROS Data Center uses more than 1 million gallons of water per month in photographic reproduction and development processes. The original oil-fired system for heating water required 8,000 gallons of fuel oil per month. Its replacement, a solar hot-water heating system began operation in January 1980. It is one of the largest of its type in the United States and uses 9,200 square feet of solar energy collectors. The gross projected savings in the first year resulting from the conversion is currently estimated to be $100,000. These savings will produce a 6-year payback to the EROS Data Center for its solar hot-water heating system. This project represents the U.S. Department of the Interior's principal solar-energy model for demonstrating the practical application of solar energy for heating special-purpose as well as domestic water.
- *Waste-water recycling.*—A second natural-resource conservation project completed at the EROS Data Center is for recycling waste water for reuse in film processing and for use in connection with the air-conditioning system. Because of periodic near-drought conditions in the Sioux Falls area, the need to conserve water is at times extremely important. Waste water, photograph processing water, and sanitary waste is now collected in a series of biologically treated ponds with a capacity of 40 million gallons. The recycling system generates water with a quality that approximates the city water supply. The recycled water also meets the guidelines established by the photograph-processing industry for film development. The waste-water recycling system produces 12 million gallons of water annually for reuse purposes. Such a guaranteed water supply is essential for the increasingly specialized scientific programs of the EROS Data Center.

Civil Service Reform Continues

The Survey's performance appraisal system required by the Civil Service Reform Act was approved by the Department in May 1980. The system contains innovative provisions that have attracted attention from the Office of Personnel Management and other Federal agencies with research employees. A key element in the successful implementation of the Survey's performance appraisal system was the training provided to supervisors on how to develop performance standards using task-based job analysis. From February to August 1980, over 60 training sessions in 25 locations across the country were conducted for more than 1,400 supervisors. In addition, the Bureau's Performance Appraisal Task Force (an inter-Division work group which was responsible for planning, developing, and implementing Survey's performance appraisal system) produced a handbook which included sample performance standards for the most populous occupational groups. With this training tool, which was made available to supervisors in August 1980, and with the classroom training provided, Survey supervisors and managers were exceptionally well-prepared to document employee performance standards by the Department's October 1, 1980, deadline.

As of July 31, 1980, all employees in grades GS-13 through GS-15 had received notices from their Division management of the determination as to whether their positions would be covered by or excluded from the merit pay system. Scheduled for implementation during fiscal year 1981, this system provides that pay for supervisors and management officials in the covered grade range will be determined based on performance appraisals which will be made as of June 30, 1981. The first payouts will be effective the first pay period on or after October 1, 1981. So that these important and innovative changes could be implemented smoothly in the next fiscal year, indepth orientation to the features of both the merit pay and performance appraisal systems were planned for covered employees and their supervisors.

Advances in Procurement Activities

The Survey's fiscal year 1980 procurement activity was highlighted by continued support of the minority business program and by the full implementation of an advance procurement planning system.

- *Minority business.*—Building on impressive fiscal year 1979 minority business contractual awards totalling $9.2 million, the Survey's support of this special-emphasis program increased to $13.7 million. The Survey was the recipient of a special Departmental commendation for being the first Bureau to access the Small Business Administration's Procurement Automated Source System (PASS). PASS was developed to give Federal agencies a quick reference of over 23,000 small businesses, 4,400 minority businesses, and 1,800 women-owned businesses in connection with agencies' requirements for contractual support services. The firms included in PASS can be screened by commodity or service and by geographic area. The Survey continues to build an impressive small and disadvantaged business record. PASS utilization exemplifies the versatile approach taken by the Bureau in support of the Federal-wide minority business enterprise program.

• *Advance procurement planning.*—The advance procurement planning system led to better communication and coordination in the processing of over $150 million in contracts, grants, and cooperative agreements. The new system has already gained Departmental recognition. It is viewed as a highly successful model whose components have improved the scheduling and subsequent timely award of contracts, grants, and cooperative agreements. Refinement of the system and full automation of the data elements involved in the advance-procurement planning cycle are expected to further streamline an already effective and efficient approach to simplifying the entire procurement activity.

Other Highlights

• *Facilities planning.*—An initial effort in developing a 5-year (fiscal years 1982-86) facilities improvement plan for major construction, repair, and alteration projects for Survey-owned and other Survey-occupied facilities was completed. This first-time planning schedule included priority ranking for fiscal year 1982 facilities projects. The facility requirements plan will provide top management with information required to make future construction, repair, and alteration decisions essential to the successful accomplishment of Survey research and scientific activities.

• *Half-fare airline coupons.*—Big savings were reported by the Survey in its final report on the use of the half-fare coupons offered by United and American Airlines during late fiscal year 1979 and early fiscal year 1980. Total net savings realized totalled over $105,000, which accounted for nearly one-fourth of the total savings compiled by the entire Department.

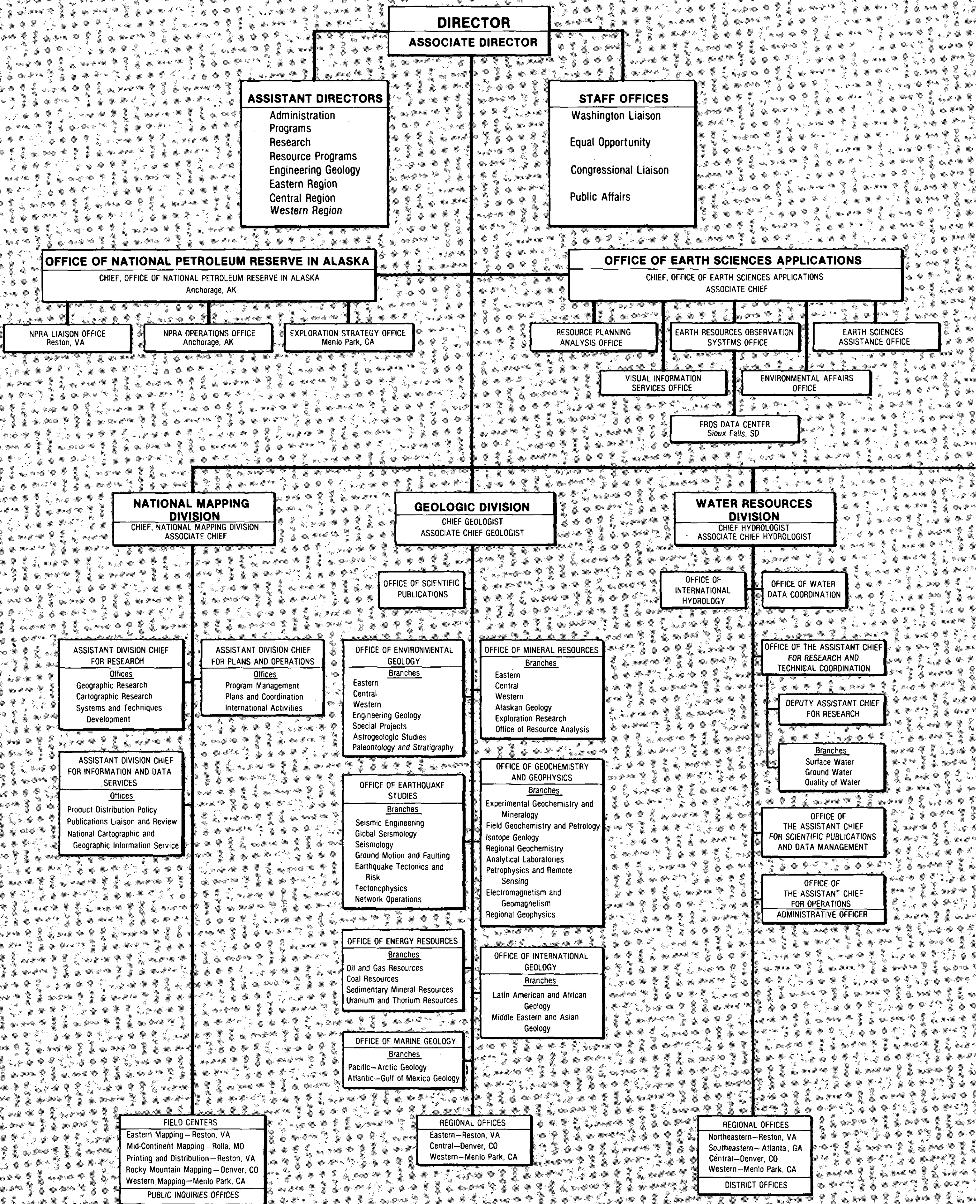
• *Energy conservation results.*—The Survey surpassed the President's goals for reducing energy consumption in fiscal year 1980. Shown below are the results of the Bureau's energy-conservation effort relative to White House directives and goals.

Energy reductions, fiscal year 1980
[In percent]

Energy reduction	Reduction goal	Actual performance
Overall	5	12.2
Automative fuels	10	18.7
Mileage	10	12.0

The Survey's facilities and automative operations continue to focus on energy conservation opportunities. The Bureau plans to continue to give energy conservation activities high priority and will continue to improve its already aggressive approach to energy conservation.

• *Financial management improvements.*—Major changes in the Bureau's automated Financial Management System to enhance reporting capability in budget formulation, financial planning, and funds control were implemented. In fiscal year 1980, our financial reports have been expanded to reflect the border range of financial management requirements which face the Survey now and in the 1980's. A long-term contract was awarded in September 1980, to streamline this automated system, to develop revised guidelines and procedures for its use, and to conduct training sessions for managerial and technical staff.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ENVIRONMENTAL AFFAIRS OFFICE
EROS DATA CENTER
Sioux Falls, SD
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CHIEF, NATIONAL MAPPING DIVISION
ASSOCIATE CHIEF
ASSISTANT DIVISION CHIEF FOR RESEARCH
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Cartographic Research
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Mid-Continent Mapping—Rolla, MO
Printing and Distribution—Reston, VA
Rocky Mountain Mapping—Denver, CO
Western Mapping—Menlo Park, CA
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Tectonophysics
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Middle Eastern and Asian Geology
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ASSOCIATE CHIEF HYDROLOGIST
OFFICE OF INTERNATIONAL HYDROLOGY
OFFICE OF WATER DATA COORDINATION
OFFICE OF THE ASSISTANT CHIEF FOR RESEARCH AND TECHNICAL COORDINATION
DEPUTY ASSISTANT CHIEF FOR RESEARCH
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Ground Water
Quality of Water
OFFICE OF THE ASSISTANT CHIEF FOR SCIENTIFIC PUBLICATIONS AND DATA MANAGEMENT
OFFICE OF THE ASSISTANT CHIEF FOR OPERATIONS
ADMINISTRATIVE OFFICER
REGIONAL OFFICES
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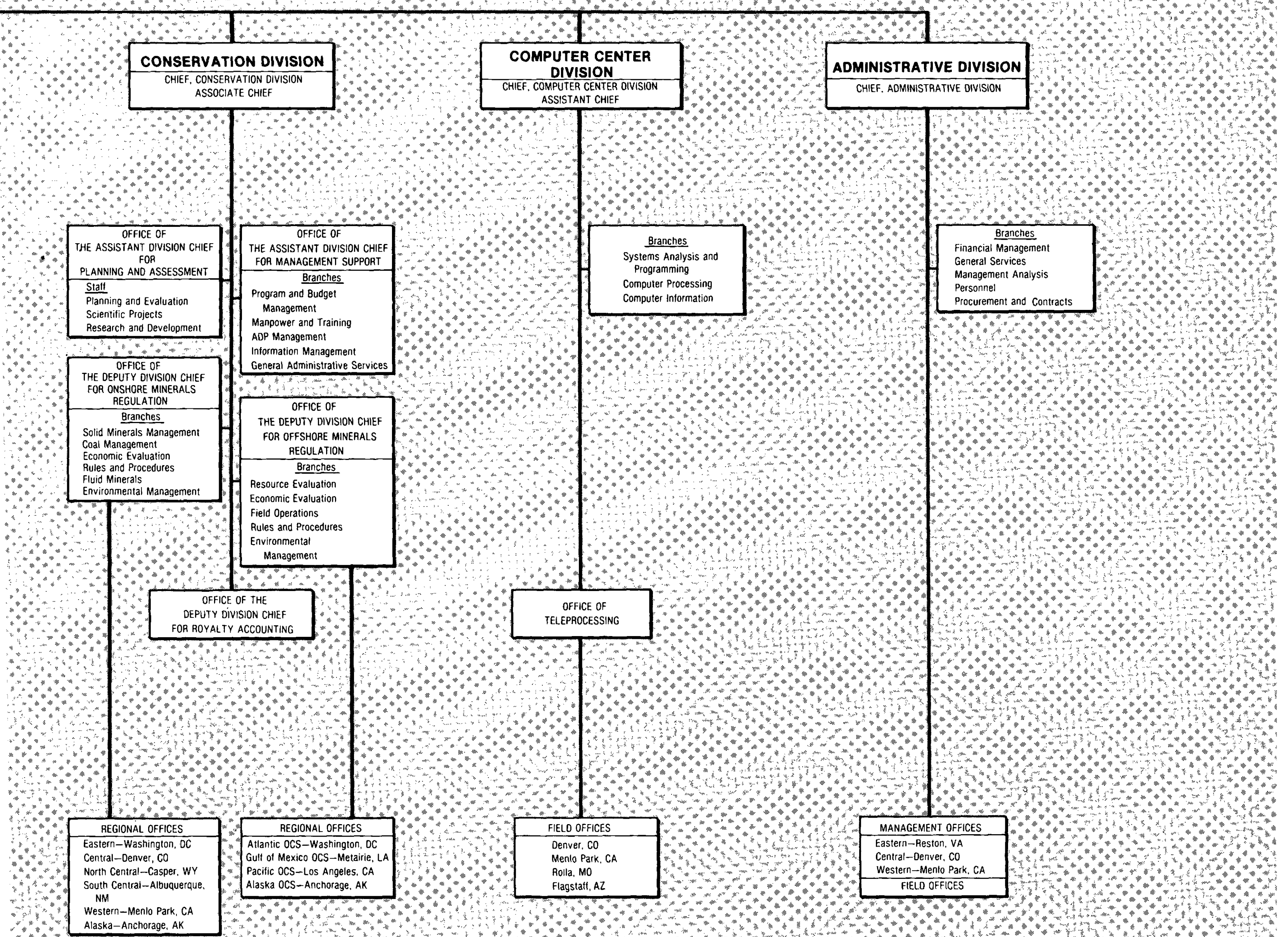
Southeastern—Atlanta, GA
Central—Denver, CO
Western—Menlo Park, CA
DISTRICT OFFICES

ORGANIZATIONAL AND STATISTICAL DATA

U.S. Geological Survey

Chart of Organization

As of September 30, 1980



U.S. Geological Survey Offices

Headquarters Offices

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

As of September 30, 1980.

Office of the Director

Official	Name	Telephone number	Address
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Associate Director	Doyle G. Frederick	(703) 860-7412	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	Robert L. Wesson	(703) 860-7488	National Center, STOP 104
Assistant Director for Resource Programs	George H. Davis	(703) 860-7481	National Center, STOP 171
Assistant Director for Engineering Geology	James F. Devine	(703) 860-7491	National Center, STOP 106
Assistant Director for Administration	Edmund J. Grant	(703) 860-7201	National Center, STOP 201
Assistant Director for Programs	Dale Bajema	(703) 860-7435	National Center, STOP 105
Assistant Director—Eastern Region	Betty M. Miller	(703) 860-7414	National Center STOP 109
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Congressional Liaison Officer	Talmadge W. Reed	(703) 860-6438	National Center, STOP 112
Chief, Public Affairs Office	Frank H. Forrester	(703) 860-7444	National Center, STOP 119
Staff Assistant (Special Issues)	John N. Fischer, Jr.	(703) 860-7413	National Center, STOP 121
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Associate Chief	Roy R. Mullen	(703) 860-6232	National Center, STOP 516
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Assistant Division Chief for Plans and Operations	Peter F. Bermel	(703) 860-6281	National Center, STOP 514
Assistant Division Chief for Information and Data Services	Gary W. North	(703) 860-7181	National Center, STOP 341

Geologic Division

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Associate Chief Geologist	Gordon P. Eaton	(703) 860-6532	National Center, STOP 911
Deputy Chief Geologist, Operations	Penelope M. Hanshaw	(703) 860-7429	National Center, STOP 911
Deputy Chief Geologist, Program and Budget	David A. Seyler	(703) 860-6544	National Center, STOP 910
Office of Scientific Publications, Chief	Robert E. Davis	(703) 860-6575	National Center, STOP 904
Office of Environmental Geology, Chief	Douglas M. Morton	(703) 860-6411	National Center, STOP 908
Office of Earthquake Studies, Chief	John R. Filson	(703) 860-6471	National Center, STOP 905
Office of Energy Resources, Chief	[Vacant]	(703) 860-6431	National Center, STOP 915
Office of Marine Geology, Chief	Terence N. Edgar	(703) 860-7291	National Center, STOP 915
Office of Mineral Resources, Chief	A. Thomas Ovenshine	(703) 860-6561	National Center, STOP 913
Office of Geochemistry and Geophysics, Chief	Robert I. Tilling	(703) 860-6584	National Center, STOP 906
Office of International Geology, Chief	John A. Reinemund	(703) 860-6418	National Center, STOP 917

Water Resources Division

Official	Name	Telephone number	Address
Chief Hydrologist	Philip Cohen	(703) 860-6921	National Center, STOP 409
Associate Chief Hydrologist	R. Hal Langford	(703) 860-6921	National Center, STOP 408
Assistant Chief Hydrologist, Scientific Publications, and Data Management	Robert J. Dingman	(703) 860-6877	National Center, STOP 440
Assistant Chief Hydrologist, Operations	Thomas J. Buchanan	(703) 860-6801	National Center, STOP 441
Assistant Chief Hydrologist, Research and Technical Coordination	Leslie B. Laird	(703) 860-6971	National Center, STOP 414
Office of Water Data Coordination, Chief	Porter E. Ward, (Acting)	(703) 860-6931	National Center, STOP 417
Office of International Activities, Chief	Della Laura, (Acting)	(703) 860-6548	National Center, STOP 470

Conservation Division

Official	Name	Telephone number	Address
Chief	Don E. Kash	(703) 860-7581	National Center, STOP 610
Associate Chief	Hillary A. Oden	(703) 860-7581	National Center, STOP 610
Deputy Division Chief, Offshore Minerals Regulation	Robert L. Rioux	(703) 860-6141	National Center, STOP 640
Deputy Division Chief, Onshore Minerals Regulation	John J. Dragonetti	(703) 860-7533	National Center, STOP 650
Assistant Division Chief, Management Support	James V. Fare	(703) 860-6486	National Center, STOP 630
Assistant Division Chief, Planning and Assessments	Junius Walker	(703) 860-7591	National Center, STOP 620

Office	Name	Telephone number	Address
Office of Earth Sciences Applications			
Chief	Gene A. Thorley	(703) 860-7471	National Center, STOP 703
Associate Chief	[Vacant]	(703) 860-7471	National Center, STOP 703
Earth Resources Observations Systems Office, Chief	Gene A. Thorley	(703) 860-7471	National Center, STOP 703
Resource Planning Analysis Office, Chief	Ethan T. Smith	(703) 860-6717	National Center, STOP 750
Environmental Affairs Office, Chief	Richard V. Watkins, (Acting)	(703) 860-7455	National Center, STOP 760
Earth Sciences Assistance Office, Chief	Jerry C. Stephens	(703) 860-6961	National Center, STOP 720
Visual Information Services Office, Chief	Theresa M. Sousa	(703) 860-6981	National Center, STOP 708
Office of National Petroleum Reserve in Alaska			
Chief	George Gryc	(907) 276-7422	*2525 "C" St., Suite 400 Anchorage, AK 99503
Technical Officer	Valentine Zadnik	(703) 860-6208	National Center, STOP 151
Program Officer	Keith M. Beardsley	(703) 860-6208	National Center, STOP 151
Computer Center Division			
Chief	Carl E. Diesen	(703) 860-7106	National Center, STOP 801
Office of Teleprocessing	Ralph N. Eicher	(703) 860-7119	National Center, STOP 805
Administrative Division			
Chief	Edmund J. Grant	(703) 860-7201	National Center, STOP 201
Administrative Operations Officer	George F. Hargrove, Jr.	(703) 860-7204	National Center, STOP 203
Personnel Officer	Maxine C. Millard	(703) 860-6127	National Center, STOP 215
Contracts Officer	William Burk	(703) 860-7261	National Center, STOP 205

Selected Field Offices

National Mapping Division

Regional Centers

Eastern	Roy E. Fordham	(703) 860-6352	National Center, STOP 567
Mid-Continent	Lawrence H. Borgerding	(314) 364-3680	1400 Independence Road, Rolla MO 65401
Rocky Mountain	John D. McLaurin	(303) 234-2351	Box 25046, STOP 510, Denver, Federal Center, Denver, CO 80225
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District of Columbia	Bruce A. Hubbard	(202) 343-8073	1028 GSA Bldg., 19th and F Sts., NW, Washington, DC 20244
Texas	John P. Donnelly	(214) 767-0198	1C45 Fed. Bldg., 1100 Commerce St., Dallas, TX 75242
Utah	Wendy R. Mabey	(801) 524-5652	8105 Fed. Bldg., 125 S. State St., Salt Lake City, UT 84138

* Office of National Petroleum Reserve in Alaska is headquartered in Anchorage, Alaska.

Selected Field Offices—Continued

Office	Name	Telephone number	Address
Virginia	A. Ernestine Jones	(703) 860-6167	1C402 National Center, STOP 302, 12201 Sunrise Valley Dr., Reston, VA 22092
Washington	Eula M. Thune	(509) 456-2524	678 U.S. Courthouse W. 920 Riverside Ave., Spokane, WA 99201
Distribution Branch Offices			
Alaska	Natalie Cornforth	(907) 452-1951	101 12th Ave., Box 12 Fairbanks, AK 99701
Western	Dwight F. Canfield	(303) 234-3832	Box 25286, STOP 306, Denver Federal Center Denver, CO 80225
Eastern	George V. DeMeglio	(703) 557-2781	1200 S. Eads St., Arlington, VA 22202
Geologic Division			
Regional Offices			
Eastern	Avery A. Drake, Jr.	(703) 860-6631	National Center, STOP 953
Central	William R. Keefer	(303) 234-3625	Box 25046, STOP 911, Denver Federal Center Denver, CO 80225
Western	Joseph I. Ziony	(415) 323-8111	345 Middlefield Rd., Menlo Park, CA 94025
Water Resources			
Regional Offices			
Northeastern	James E. Biesecker	(703) 860-6985	National Center, STOP 433
Southeastern	James L. Cook	(404) 861-4395	1459 Peachtree St., NE, Suite 200, Atlanta, GA 30392
Central	Alfred Clebsch, Jr.	(303) 234-3661	Box 25046, STOP 406, Denver Federal Center Denver, CO 80225
Western	John W. Wark, (Acting)	(415) 323-8111, ext. 2337	345 Middlefield Road, Menlo Park, CA 94025
District Offices			
Alabama	Charles A. Pascale	(205) 752-8104	P.O. Box V, 202 Oil and Gas Board Bldg., University of Alabama, University, AL 35486
Alaska	Harry Hulsing	(907) 277-5526	218 E St., Anchorage, AK 99501
Arizona	Robert D. Mac-Nish	(602) 792-6671	Federal Bldg., 301 W. Congress St., Tucson, AZ 85701
Arkansas	Richard T. Sniegocki	(501) 378-5246	2301 Federal Office Bldg., 700 W. Capital Ave., Little Rock, AR 72201
California	Richard M. Bloyd	(415) 323-8111, ext. 2326	855 Oak Grove Ave., Menlo Park, CA 94205
Colorado	James F. Blakey	(303) 234-5029	Box 25046, STOP 415, Denver Federal Center, Denver, CO 80225
Connecticut	David McCartney	(203) 244-2528	135 High St., Rm. 235 Hartford, Ct 06103
Delaware	Herbert J. Freiberger	(301) 828-1535	See Maryland District Office
District of Columbia	Herbert J. Freiberger	(301) 828-1535	See Maryland District Office
Florida	I. H. Kantrowitz	(904) 386-1118	325 John Knox Rd., Suite F-240, Tallahassee, FL 32303
Georgia	John R. George	(404) 221-4858	6481 Peachtree Industrial Blvd., Suite B, Doraville, GA 30360
Hawaii	Benjamin L. Jones	(808) 546-8331	P.O. Box 50166, 300 Ala Moana Blvd., Honolulu, HI 96850
Idaho	Ernest F. Hubbard, Jr.	(208) 384-1750	Box 036 Federal Bldg., Rm. 365, 550 W. Fort St., Boise, ID 83724

Office	Name	Telephone number	Address
Illinois	Larry G. Toler	(217) 359-3918	P.O. Box 1026, 605 N. Neil St., Champaign, Il 61820
Indiana	Dennis K. Stewart	(317) 269-7101	1819 N. Meridian St., Indianapolis, IN 46202
Iowa	Donald K. Leifeste	(319) 338-0581, ext. 521	P.O. Box 1230, 400 S. Clinton St., Iowa City, IA 52240
Kansas	Joseph S. Rosenshein	(913) 864-4321	1950 Ave. A, Campus West, University of Kansas, Lawrence, KS 66045
Kentucky	Philip A. Emery	(502) 582-5241	572 Federal Bldg., 600 Federal Pl., Louisville, KY 40202
Louisiana	Albert N. Cameron	(504) 389-0281	P.O. Box 66492 6554 Florida Blvd., Baton Rouge, LA 70896
Maine	Ivan C. James II	(617) 223-2822	See Massachusetts District Office
Maryland	Herbert J. Freiberger	(301) 828-1535	208 Carrol Bldg., 8600 La Salle Rd., Towson, MD 21204
Massachusetts	Ivan C. James II	(617) 223-2822	150 Causeway St., Suite 1001., Boston, MA 02114
Michigan	T. Ray Cummings	(517) 372-1910, ext. 561	6520 Mercantile Way, Suite 5, Lansing, MI 48910
Minnesota	Donald R. Albin	(612) 725-7841	1033 Post Office Bldg., St. Paul, MN 55101
Mississippi	Garald G. Parker, Jr.	(601) 969-4600	430 Bounds St., Jackson, MS 39206
Missouri	Donald L. Coffin	(314) 364-3680	1400 Independence Rd., STOP 200, Rolla, MO 65401
Montana	George M. Pike	(406) 449-5263	Federal Bldg., Rm. 428 301 S. Park Ave., Drawer 10076 Helena, MT 59601
Nebraska	William M. Kastner	(402) 471-5082	406 Federal Bldg. and U.S. Courthouse, 100 Centennial Mall North, Lincoln, NE 68508
Nevada	Timothy J. Durbin	(702) 882-1388	227 Federal Bldg., 705 N. Plaza St., Carson City, NV 89701
New Hampshire	Ivan C. James II	(617) 223-2822	See Massachusetts District Office
New Jersey	Donald E. Vaupel	(609) 989-2162	P.O. Box 1238, 436 Federal Bldg., 402 E. State St., Trenton, NJ 08607
New Mexico	James F. Daniel	(505) 766-2246	P.O. Box 26659, Western Bank Bldg., Rm. 809, 505 Marquette, NW., Albuquerque, NM 87125
New York	Lawrence A. Martins	(518) 472-3107	P.O. 1350, 343 U.S. Post Office and Courthouse Bldg., Albany, NY 12201
North Carolina	Ralph C. Heath	(919) 755-4510	P.O. Box 2857, Rm. 432, Century Postal Station Raleigh, NC 27602
North Dakota	Grady Moore	(701) 255-4011, ext. 601	821 East Interstate Ave., Rm. 332, New Fed Bldg., 3d St. and Rosser Ave., Bismark, ND 58501
Ohio	Steven M. Hindall	(614) 469-5553	975 West Third Ave., Columbus, OH 43212
Oklahoma	James H. Irwin	(405) 231-4256	201 NW 3d St., Rm. 621, Oklahoma City, OK 73102
Oregon	Stanley F. Kapustka	(503) 234-3361, ext. 4776	P.O. Box 3202, 830 NE Holladay St., Portland, OR 97232
Pennsylvania	David E. Clock	(717) 782-3468	P.O. Box 1107, 4th Floor Federal Bldg., 228 Walnut St., Harrisburg, PA 17108

Selected Field Offices—Continued

Office	Name	Telephone number	Address
Puerto Rico	Craig B. Bentley	(809) 783-4660	P.O. Box 34168, Bldg. 652, Ft. Buchanan, PR 00934
Rhode Island	Ivan C. James II	(617) 223-2822	See Massachusetts District Office
South Carolina	Rodney N. Cherry	(803) 765-5966	2001 Assembly St., Suite 200, Columbia, SC 29201
South Dakota	Richard E. Fidler	(605) 352-8651, ext. 258	P.O. Box 1412 200 4th St., SW, Rm. 308, Huron, SD 57350
Tennessee	Stanley P. Sauer	(615) 251-5424	A-413 Federal Bldg., U.S. Courthouse, Nashville, TN 37203
Texas	I. Dale Yost	(512) 397-5766	649 Federal Bldg., 300 E. 8th St., Austin, TX 78701
Utah	Theodore Arnow	(801) 524-5663	8002 Federal Bldg., 125 St. State St., Salt Lake City, UT 84138
Vermont	Ivan C. James II	(617) 223-2822	See Massachusetts District Office
Virginia	William E. Forrest	(804) 782-2427	200 W. Grace St., Rm. 304, Richmond, VA 23220
Washington	Charles R. Collier	(206) 593-6510	1201 Pacific Ave., Suite 600, Tacoma, WA 98402
West Virginia	David H. Appel	(304) 343-6181, ext. 310	3017 Federal Bldg. and U.S. Courthouse 500 Quarrier St. E., Charleston, W VA 25301
Wisconsin	William B. Mann IV	(608) 262-2488	1815 University Ave., Rm. 200, Madison, WI 53706
Wyoming	William W. Dudley, Jr.	(307) 778-2220, ext. 2153	P.O.Box 1125, 2120 Capitol Ave., Rm. 5017, Cheyenne, WY 82001

Conservation Division

Regional Offices

Eastern/Atlantic OCS	George F. Brown	(202) 254-3137	1725 K St., NW, Suite 204, Washington, DC 20006

Office	Name	Telephone number	Address
Central	John B. Trippe	(303) 234-2855	Box 25046, STOP 609, Denver Federal Center, Bldg. 85, Denver, CO 80225
North Central	Dwayne E. Hull	(303) 265-5550, ext. 5746	100 East B St, Rm. 4130, Casper, WY 82601
South Central	James W. Sutherland	(505) 766-2841	P.O. Box 26124, 505 Marquette, NW #815 Albuquerque, NM 87125
Gulf of Mexico Outer Continental Shelf (OCS) Operations	Lowell G. Hammons	(504) 837-4720, ext. 9381	P.O. Box 7944, 434 Imperial Office Bldg., 3301 N. Causeway Blvd., Metairie, LA 70010
Pacific OCS	Reid T. Stone, (Acting)	(213) 688-6875	244 Federal Bldg., 1340 West 6th St. Los Angeles, CA 90017
Alaska/Alaska OCS	Joseph M. Jones, (Acting)	(907) 271-4304	800 "A" St. Suite 201, Anchorage, AK 99501
Office of Earth Sciences Applications			
Earth Resources Observation Systems Data Center			
South Dakota	Allen H. Watkins	(605) 594-6123	EROS Data Center, Sioux Falls, SD 57198
National Petroleum Reserve in Alaska			
District Offices			
NPRA Operations Office	Max Brewer	(907) 276-7422	2525 "C" St., Suite 400, Anchorage, AK 99503
Exploration Strategy Office	Arthur Bowsher	(415) 323-2917	345 Middlefield Rd., Menlo Park, CA 94025
Administrative Division			
Regional Management Offices			
Eastern	Roy Heinbuch	(703) 860-7691	National Center, STOP 290
Central	Jack J. Stassi	(303) 234-3736	Box 25046, STOP 201 Denver Federal Center, Denver, CO 80225
Western	Avery W. Rogers	(415) 323-2211	345 Middlefield Rd., STOP 11, Menlo Park, CA 94025

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 1980. 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:
c—Conservation Division
e—Office of Earth Sciences Applications
g—Geologic Division
n—National Mapping Division
w—Water Resources Division

Federal Cooperators

Council on Environmental Quality (e)

Department of Agriculture:
Economics, Statistics, and Cooperatives Service (n)
Forest Service (e, n, w)
Graduate School (w)
Science and Education Administration (w)
Soil Conservation Service (g, n, w)

Department of the Air Force:
AFWL/PRP Kirtland Air Force Base (g, w)
Air Force Academy (w)
Headquarters, AFTAC/AC (g)
Vandenberg Air Force Base (w)
Wurtsmith Air Force Base (w)

Department of the Army:
Corps of Engineers (e, g, n, w)
Electronic Proving Ground (e)
Fort Belvoir (n)
Fort Carson Military Reservation (w)
Rocky Mountain Arsenal (w)

Department of Commerce:
Coastal Plains Regional Action Planning Commission (g)
Four Corners Regional Commission (e)
National Bureau of Standards (g)
National Oceanic and Atmospheric Administration:
National Environmental Satellite Service (e)
National Marine Fisheries Service (w)
National Ocean Survey (n)
National Weather Service (g, w)
Old West Regional Action Planning Commission (e)
Pacific Northwest Regional Action Planning Commission (e)
Southwest Border Regional Action Planning Commission (e)

Department of Defense Agencies:
Defense Advanced Research Projects Agency (g)
Defense Mapping Agency (n)
Defense Nuclear Agency (g)

Department of Energy:
Albuquerque Operations Office (g, w)
Argonne National Laboratory (c)
Bonneville Power Administration (w)
Brookhaven National Laboratory (c)
Chicago Operations Office (w)
Grand Junction Office (g)
Idaho Operations Office (g, w)
Lawrence Livermore Laboratory (g)

Department of Energy—Continued
Los Alamos Science Laboratoy (g, w)
Morgantown Energy Technology Center (g)
Nevada Operations Office (g, w)
Oak Ridge Operations Office (g, w)
Office of Energy Research (g)
Office of International Affairs (g)
Richland Operations Office (c, g, w)
San Francisco Operations Office (g, w)

Department of Health, Education, and Welfare (w)

Department of Housing and Urban Development (w)

Department of the Interior:
Alaska State Office, Natural Gas Pipeline (g)
Bureau of Indian Affairs (e, g, n, w)
Bureau of Land Management (e, g, n, w)
Bureau of Mines (e, g, n, w)
Heritage Conservation and Recreation Service (e)
National Park Service (e, g, n, w)
Office of the Secretary (e, g)
Office of Surface Mining Reclamation and Enforcement (e, g, n, w)
Trans-Alaska Pipeline (e)
U.S. Fish and Wildlife Service (e, g, n, w)
Water and Power Resources Service (e, g, w)

Department of the Navy:
Naval Oceanographic Office (n, w)
Naval Weapons Center, China Lake (g, w)
U.S. Marine Corps, Camp Pendleton (w)

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

Department of Transportation:
Federal Highway Administration (g, w)
St. Lawrence Seaway Development Corporation (w)

Environmental Protection Agency (n):
Corvallis Environmental Research Laboratory (w)
Office of Energy, Minerals and Industry (g, w)
Office of Monitoring and Technical Support (w)
Office of Research and Development (c)

General Services Administration (w)

National Academy of Sciences Marine Board (c)

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

National Science Foundation (g)

New England River Basin Commission (e)

Nuclear Regulatory Commission (g, w)

Tennessee Valley Authority (n, w)

United States Arms Control and Disarmament Agency (g)

Water Resources Council (e, w)

State, County, and Local Cooperators

Alabama:
- Alabama Highway Department (w)
- Geological Survey of Alabama (c, n, w)
- Jefferson County Commission (w)

Alaska:
- Alaska Department of Fish and Game (w)
- Alaska Department of Natural Resources (w):
  - Division of Forests, Lands, and Water Management (w)
  - Division of Geological and Geophysical Surveys (w)
  - Division of Policy Development and Planning (e, w)
- Alaska Department of Transportation and Public Facilities (w)
- Alaska Power Authority (w)
- City and Borough of Juneau (w)
- City of Craig (w)
- Department of Environmental Conservation (w)
- Fairbanks North Star Borough (w)
- Kenai Peninsula Borough (w)
- Municipality of Anchorage (w)
- Thomas Bay Power Commission (w)

Arizona:
- Arizona Bureau of Geology and Mineral Technology (e)
- Arizona Department of Health Services (w)
- Arizona Department of Water Resources (w)
- Arizona Game and Fish Department (w)
- City of Flagstaff (w)
- City of Safford (w)
- City of Tucson (w)
- Flood Control District of Maricopa County (w)
- Gila Valley Irrigation District (w)
- Maricopa County Municipal Water Conservation District No. 1 (w)
- Metropolitan Water District of Southern California (w)
- Pima County Board of Supervisors (w)
- Salt River Valley Water Users' Association (w)
- San Carlos Irrigation and Drainage District (w)
- Show Low Irrigation Company (w)
- University of Arizona (w)

Arkansas:
- Arkansas Department of Pollution Control and Ecology (w)
- Arkansas Soil and Water Commission (w)
- Arkansas Geological Commission (g, n, w)
- Arkansas State Highway and Transportation Department (w)

California:
- Alameda County Flood Control and Water Conservation District, Zone 7 (w)
- Antelope Valley-East Kern Water Agency (w)
- California Department of Conservation (g):
  - Division of Mines and Geology (g)
- California Department of Fish and Game, Region 2 (w)
- California Department of Boating and Waterways (w)
- California Department of Transportation, District 3 (w)
- California Department of Water Resources (n, w)
- California Regional Water Quality Control Board (w):
  - Colorado River Basin Region (w)
  - Lahontan Region (w)
  - North Coast Region (w)
  - San Francisco Bay Region (w)
  - Santa Ana Region (w)
- California Water Resources Control Board (w)
- Carpinteria County Water District (w)
- Casitas Municipal Water District (w)
- City and County of San Francisco (w):
  - Hetch Hetchy Water and Power (w)

California—Continued
- City of Los Angeles (w)
- City of Merced (w)
- City of Modesto (w):
  - Public Works Department (w)
- City of Santa Barbara (w):
  - Public Works Department (w)
- City of San Diego (w)
- City of Thousand Oaks (w)
- Coachella Valley County Water District (w)
- Contra Costa County Flood Control and Water Conservation District (w)
- County of Modoc (w):
  - Public Works Department (w)
- County of San Diego (w):
  - Department of Sanitation and Flood Control (w)
  - Planning and Land Use (w)
- County of San Joaquin (w):
  - Flood Control and Water Conservation District (w)
- County of San Mateo (w):
  - Department of Public Works (w)
  - Planning Department (w)
- Crestline-Lake Arrowhead Water Agency (w)
- Desert Water Agency (w)
- East Bay Municipal Utility District (w)
- East Bay Regional Park District (w)
- Fresno County, Department of Public Works (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 Planning Consortium—Central California (w)
- Indian Wells Valley County Water District (w)
- Kern County Water Agency (w)
- Kings River Conservation District (w)
- Lake County Planning Department (w)
- Los Angeles County Flood Control District (w)
- Los Angeles Department of Water and Power (w)
- Madera County Flood Control and Water Conservation Agency (w)
- Madera Irrigation District (w)
- Marin County Department of Public Works (w)
- Marin Municipal Water District (w)
- Mendocino County Department of Public Health (w)
- Merced Irrigation District (w)
- Mojave Water Agency (w)
- Montecito Water District (w)
- Monterey County Flood Control and Water Conservation District (w)
- Monterey Peninsula Water Management District (w)
- Napa County Flood Control and Water Conservation District (w)
- Orange County Environmental Management Agency (w)
- Oroville-Wyandotte Irrigation District (w)
- Pancheco Pass Water District (w)
- Rancho California Water District (w)
- Paradise Irrigation District (w)
- Placer County Water Agency (w)
- Riverside County Flood Control and Water Conservation District (w)
- Sacramento Regional County Sanitation District, Department of Public Works (w)
- San Benito County Water Conservation and Flood Control District (w)
- San Bernardino Valley Municipal Water District (w)
- San Francisco Water Department (w)
- San Luis Obispo County (w):
  - Engineering Department (w)

State, County, and Local Cooperators—Continued

California—Continued

- Santa Barbara County Flood Control and Water Conservation District (w)
- Santa Barbara County Water Agency (w)
- Santa Clara Valley Water District (w)
- Santa Cruz City (w):
  - County Community Resources Center, Zone 4 (w)
- Santa Cruz County (w):
  - Flood Control and Water Conservation District (w)
- Santa Maria Valley Water Conservation District (w)
- Santa Rosa Band of Mission Indians (w)
- Siskiyou County Flood Control and Water Conservation District (w)
- Sonoma County Planning Department (w)
- Soquel Creek County Water District (w)
- South San Joaquin County (w)
- Terra Bella Irrigation District (w)
- Tulare County Flood Control District (w)
- Turlock Irrigation District (w)
- United Water Conservation District (w)
- University of California (w):
  - Division of Environmental Studies (Davis) (w)
  - Los Alamos Scientific Laboratory (c)
  - School of Forestry and Conservation (Berkeley) (w)
  - University of California (Santa Barbara) (c)
- Ventura County Flood Control District (w)
- Western Municipal Water District (w)
- Woodbridge Irrigation District (w)
- Yolo County Flood Control and Water Conservation District (w)

Colorado:

- Adams County Board of Commissioners (w)
- Arapahoe County (w)
- Arkansas River Compact Administration (w)
- Central Yuma Ground Water Management District (w)
- Cherokee Water District (w)
- City and County of Denver (w)
- City of Aspen (w)
- City of Aurora (w)
- City of Colorado Springs (w):
  - Department of Public Utilities (w)
  - Office of the City Manager (w)
- City of Glenwood Springs (w)
- City of Idaho Springs (w)
- City of Northglenn (w)
- Colorado Department of Health (w):
  - Water Pollution Control Division (w)
- Colorado Department of Highways (w)
- Colorado Department of Local Affairs (n)
- Colorado Division of Water Resources (w):
  - Office of the State Engineer (w)
- Colorado Division of Wildlife, Department of Natural Resources (w)
- Colorado Geological Survey (w)
- Colorado River Water Conservation District (w)
- Colorado Water Conservation Board (w)
- Denver Regional Council of Governments (w)
- Eagle County Commissioners (w)
- Elbert County Planning Department (w)
- El Paso County (w):
  - Board of Commissioners (w)
- Frenchman Ground Water Management District (w)
- Larimer—Weld Regional Council of Governments (w)
- Marks Butte Ground Water Management District (w)
- Metropolitan Denver Sewage Disposal District No. 1 (w)
- Northern Colorado Water Conservation District (w)
- Pikes Peak Area Council of Governments (w)
- Pitkin County Board of County Commissioners (w)
- Pueblo Area Council of Governments (w)

Colorado—Continued

- Purgatoire River Water Conservancy District (w)
- Rio Grande Water Conservation District (w)
- Sand Hills Ground Water Management District (w)
- St. Vrain and Left Hand Water Conservancy District (w)
- Southeastern Colorado Water Conservancy District (w)
- Southwestern Water Conservation District (w)
- Trinchera Conservancy District (w)
- Uncompahgre Valley Water Users (w)
- Upper Arkansas River Water Conservancy District (w)
- Urban Drainage and Flood Control District (w)
- White River Soil Conservation District (w)

Connecticut:

- City of New Britain (w)
- City of Torrington (w)
- Connecticut Department of Environmental Protection (g, n, w)
- Midstate Regional Planning Agency (w)
- Northwest Regional Planning Agency (w)
- Town of Fairfield (w)
- Town of Manchester (w)
- Town of Southbury (w)
- Town of South Windsor (w)
- Town of Woodbury (w)

Delaware:

- Delaware Geological Survey (n, w)
- Department of Natural Resources and Environmental Control (w)
- New Castle County, Public Works Department (w)

District of Columbia:

- Department of Environmental Services (w)

Florida:

- Big Cypress Basin Board (w)
- Brevard County (w):
  - Board of County Commissioners (w)
- Broward County (w):
  - Environmental Quality Control Board (w)
  - Water Management Division (w)
- City of Boca Raton (w)
- City of Bradenton (w)
- City of Cape Coral (w)
- City of Clearwater (w)
- City of Cocoa (w)
- City of Fort Lauderdale (w)
- City of Fort Walton Beach (w)
- City of Gainesville (w)
- City of Hallandale (w)
- City of Hollywood (w)
- City of Pensacola (w)
- City of Perry (w)
- City of Pompano Beach (w):
  - Water and Sewer Department (w)
- City of Quincy (w)
- City of St. Petersburg (w)
- City of Sarasota (w)
- City of Tallahassee (w)
- City of Tampa (w)
- Collier County (w)
- Consolidated City of Jacksonville (w):
  - Department of Health and Environmental Services (w)
  - Department of Public Works (w)
- Coordinating Council on the Restoration of Kissimmee River Valley and Taylor Creek-Nubbins Slough Basin (w)
- Englewood Water District (w)
- Escambia County (w):
  - Board of County Commissioners (w)
  - County Utilities Department (w)

Florida—Continued

- Flagler County (w)
- Florida Bureau of Water Resources Management (w):
  - Florida Department of Environmental Regulation (w)
- Florida Department of Natural Resources (n)
- Florida Department of Transportation (w)
- Florida Division of Recreation and Parks (w)
- Florida Keys Aqueduct Authority (w)
- Hillsborough County (w)
- Jacksonville Electric Authority (w)
- Jupiter Inlet District (w)
- Lake County (w):
  - Board of County Commissioners (w)
  - Pollution Control Department (w)
  - Water Authority (w)
- Lee County (w):
  - Board of County Commissioners (w)
- Leon County Public Works (w)
- Manatee County Board of County Commissioners (w)
- Marion County Board of County Commissioners (w)
- Metropolitan Dade County (w):
  - Department of Environmental Resources Management (w)
  - Planning Department (w)
  - Public Works Department (w)
- Miami-Dade Water and Sewer Authority (w)
- Monroe County Board of County Commissioners (w)
- Nassau County (w):
  - Ocean Highway and Port 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)
- Pinellas County Board of County Commissioners (w)
- Polk County Board of County Commissioners (w)
- Reedy Creek Improvement District (w)
- St. Johns County (w)
- St. Johns River Water Management District (w)
- Sarasota County (w)
- South Florida Water Management District (w)
- Southwest Florida Water Management District (w)
- Sumter County Recreation and Water Conservation and Control Authority (w)
- Suwannee River Authority (w)
- Suwannee River Water Management District (w)
- Tampa Port Authority (w)
- Town of Highland Beach (w)
- Town of Juno Beach (w)
- Volusia County (w)
- Walton County (w)
- West Coast Regional Water Supply Authority (w)
- Winter Haven Lake Region (w)

Georgia:

- Bibb County Board of Commissioners (w)
- Chatham County Board of Commissioners (w)
- City of Albany (w)
- City of Brunswick (w)
- City of Covington (w)
- City of Valdosta (w)
- Clayton County Water Authority (w)
- Consolidated Government of Columbus (w)
- Department of Natural Resources (n, w):
  - Environmental Protection Division (w)
  - Geologic Survey (n, w)
- Department of Transportation (w)
- Macon-Bibb County Water and Sewage Authority (w)

Hawaii:

- City and County of Honolulu (w):
  - Board of Water Supply (w)
  - Department of Public Works (w)
- State Department of Health (w)
- State Department of Land and Natural Resources (w):
  - Division of Water and Land Development (w)
- State Department of Transportation (n)

Idaho:

- Idaho Department of Fish and Game (w)
- Idaho Department of Health and Welfare (w):
  - Bureau of Water Quality (w)
- Idaho Department of Transportation, Division of Highways (w)
- Idaho Department of Water Resources (w)
- Idaho Water District No. 1 (w)
- Idaho Water Resources Board (w)

Illinois:

- Bloomington and Normal Sanitary District (w)
- City of Springfield (w)
- Cook County (w):
  - Forest Preserve District (w)
- DuPage County Highway Department (w)
- Illinois Environmental Protection Agency (w)
- Illinois Institute of Natural Resources (w):
  - State Water Survey Division (w)
- Illinois State Geological Survey (e, n)
- Kane County Highway Department (w)
- McHenry County Regional Planning Commission (w)
- Metropolitan Sanitary District of Greater Chicago (w)
- Northeastern Illinois Planning Commission (w)
- State Department of Transportation (w):
  - Division of Highways (w)
  - Division of Water Resources (n, w)

Indiana:

- City of Chicago, Board of Sanitation (w)
- City of Columbus (w)
- City of Fort Wayne (w)
- City of Hammond (w)
- City of Indianapolis (w)
- City of Logansport (w):
  - Department of Public Works (w)
  - Flood Control Commission (w)
- Elkhart Water Works (w)
- Indiana Board of Health (w)
- Indiana Department of Natural Resources (w)
- Indiana Geological Survey (e)
- Indiana Highway Commission (w)
- Indiana University School of Public and Environmental Affairs (e)
- Town of Carmel (w)
- Vincennes Water Department (w)

Iowa:

- City of Ames (w)
- City of Cedar Rapids (w)
- City of Charles City (w)
- City of Clear Lake (w)
- City of Des Moines (w)
- City of Fort Dodge (w)
- City of Harlan (w)
- City of Iowa City (w)
- City of Marshalltown (w)
- City of Sioux City (w)
- City of Waterloo (w)
- Des Moines Water Works (w)

State, County, and Local Cooperators—Continued

Iowa—Continued
- Iowa Department of Transportation (n, w):
  - Highway Division (w)
  - Highway Research Board (w)
- Iowa Geological Survey (n, w)
- Iowa Natural Resources Council (w)
- Iowa State University (w):
  - Department of Agricultural Engineering (w)
  - Iowa Agricultural Experiment Station (w)
- Ottumwa Water Works (w):
  - Sewage Disposal Plant (w)
- University of Iowa (w):
  - Institute of Hydraulic Research (w)
  - University Physical Plant (w)
- West-Central Iowa Rural Water Association (w)

Kansas:
- City of Wichita (w)
- Kansas Department of Transporation (n, w)
- Kansas Geological Survey (n, w)
- Kansas-Oklahoma-Arkansas River Commission (w)
- Kansas State Board of Agriculture (w):
  - Division of Water Resources (w)
- Kansas Department of Health and Environment (w)
- Kansas Water Resources Board (w)
- Southwest Kansas Ground Water Management District No. 3 (w)
- Western Kansas Ground Water Management District No. 1 (w)

Kentucky:
- City of Louisville (w)
- Kentucky Department of Commerce (w):
  - Division of Research and Planning (w)
- Kentucky Department for Natural Resources and Environmental Protection (w):
  - Division of Conservation (w)
  - Division of Water Quality (w)
  - Division of Water Resources (w)
- Kentucky Department of Transportation (w):
  - Division of Design (w)
- Kentucky State Geological Survey, University of Kentucky (e, n, w)

Louisiana:
- Capital Area Ground Water Conservation Commission (w)
- City of Parish Government (w)
- Louisiana Office of Highways (w):
  - Department of Transportation and Development (w)
- Louisiana Office of Public Works (n, w):
  - Department of Transportation and Development (w)
- Sabine River Compact Administration (w) (*see also* **Texas**)

Maine:
- Androscoggin Valley Regional Planning Commission (w)
- Cobbossee Watershed District (w)
- Maine Department of Conservation (w):
  - Geological Survey (n, w)
- Maine Department of Environmental Protection (w)
- Maine Public Utilities Commission (w)
- Town of Wilton (w)

Maryland:
- Anne Arundel County (w)
- Baltimore County (w):
  - Department of Permits and Licenses (w)
  - Department of Public Works (w)
  - Office of Planning and Zoning (w)
- Calvert County (w)
- Caroline County (w)

Maryland—Continued
- Carroll County (w)
- Howard County (w)
- Maryland Department of Health and Mental Hygiene (w)
- Maryland Department of Transportation (w):
  - The State Highway Administration (w)
- Maryland Energy Administration (w)
- Maryland Geological Survey (e, n, w)
- Maryland Water Resources Administration (w)
- Montgomery County (w)
- St. Mary's County (w)
- Town of Poolesville (w)
- Washington Suburban Sanitary Commission (w)
- Upper Potomac River Commission (w)

Massachusetts:
- Barnstable County (w)
- Cape Cod Planning and Economic Development Commission (w)
- Department of Public Works (g, n, w):
  - Division of Research and Materials (w)
- Executive Office of Energy Resources (w)
- Lower Pioneer Valley Regional Planning Commission (w)
- Metropolitan District Commission (w)
- New England Interstate Pollution Control Commission (w):
  - Water Division (w)
- State Water Resources Commission (w):
  - Division of Water Pollution Control (w)
  - Division of Water Resources (w)

Michigan:
- Branch County (w)
- City of Ann Arbor (w)
- City of Battle Creek (w)
- City of Clare (w)
- City of Coldwater, Board of Public Utilities (w)
- City of Flint (w)
- City of Jackson (w)
- City of Kalamazoo, Department of Public Utilities (w)
- City of Lansing, Board of Water and Light (w)
- City of Mason (w)
- City of Portage (w)
- City of St. Johns (w)
- City of St. Louis (w)
- City of Ypsilanti (w)
- Department of Agriculture (w):
  - Soil and Water Conservation Division (w)
- Department of Natural Resources (e, n, w):
  - Bureau of Management Services (w)
  - Geological Survey Division (e)
- Department of Transportation (w)
- Dickinson County Board of Road Commissioners (w)
- East-Central Michigan Planning and Development Region (w)
- Genesee County Drain Commission (w)
- Huron-Clinton Metropolitan Authority (w)
- Imlay City (w)
- Kalamazoo County Metropolitan Planning Commission (w)
- Kent County Airport (w)
- Macomb County (w)
- Oakland County Drain Commission (w)
- Otsego County Road Commission (w)
- Roscommon County Board of Commissioners (w)
- Van Buren County Road Commission (w)
- Village of Clarkston (w)
- Washtenaw County (w)

Minnesota:
- City of Apple Valley (w)
- City of Eagan (w)
- City of Lakeville (w)
- Coon Creek Watershed District (w)

Minnesota—Continued
- Elm Creek Conservation Commission (w)
- Metropolitan Council of the Twin Cities Area (w)
- Metropolitan Waste Control Commission (w)
- Minnesota Department of Health (w):
  - Division of Environmental Health (w)
- Minnesota Department of Natural Resources (w)
- Minnesota Department of Transportation (w)
- Minnesota Pollution Control Agency (w)
- Minnesota State Planning Agency (e)
- Red Clay Project (w)

Mississippi:
- City of Jackson (w)
- Department of Natural Resources (w):
  - Bureau of Geology and Energy Resources (w)
  - Bureau of Land and Water Resources (w)
  - Bureau of Pollution Control (w)
- Harrison County (w):
  - Board of Supervisors (w)
  - Development Commission (w)
- Jackson County (w):
  - Board of Supervisors (w)
  - Port Authority (w)
- Mississippi Research and Development Center (n, w)
- Mississippi State Highway Department (w)
- Pat Harrison Waterway District (w)
- Pearl River Valley Water Supply District (w)

Missouri:
- City of Springfield (w):
  - Sanitary Services Department (w)
- Department of Natural Resources (w):
  - Division of Environmental Quality, Laboratory Services Program (w)
  - Division of Geology and Land Survey (n, w)
- Little River Drainage District (w)
- Missouri Department of Conservation (w)
- Missouri State Highway Commission (w)
- St. Louis County (w):
  - Department of Highways and Traffic (w)

Montana:
- Department of Natural Resources and Conservation (w)
- Montana Bureau of Mines and Geology (c, w)
- Montana Department of Health and Environmental Sciences (w)
- Montana Department of Highways (w)
- Montana Fish, Wildlife, and Parks (w)
- Montana State University (w)
- Wyoming State Engineer (w) (*see also* **Wyoming**)

Nebraska:
- Central Platte Natural Resources District (w)
- Kansas-Nebraska Big Blue River Compact Administration (w)
- Lower Loup Natural Resources District (w)
- Lower Republican Natural Resources District (w)
- Nebraska Department of Environmental Control (w)
- Nebraska Department of Water Resources (w)
- Nebraska Natural Resources Commission (w)
- University of Nebraska (w):
  - Conservation and Survey Division (w)
  - Water Resources Center (w)

Nevada:
- Carson City Department of Public Works (w)
- Clark County, Department of Comprehensive Planning (w)
- Douglas County, Department of Planning (w)
- Nevada Bureau of Mines and Geology (g, n, w)

Nevada—Continued
- Nevada Department of Conservation and Natural Resources (w):
  - Division of Environmental Protection (w)
  - Division of Water Resources (w)
- Nevada Department of Transportation (w)
- Washoe County (w)

New Hampshire:
- New Hampshire Water Resources Board (w)

New Jersey:
- Bergen County (w)
- Camden County (w):
  - Board of Chosen Freeholders (w)
- Delaware River Basin Commission (w) (*see also* **Pennsylvania**)
- Morris County Municipal Utilities Authority (w)
- New Jersey Department of Agriculture (w):
  - State Soil Conservation Committee (w)
- New Jersey Department of Environmental Protection (w):
  - Bureau of Fisheries (w)
  - Division of Fish, Game, and Shell Fisheries (w)
  - Division of Water Resources (w)
- North Jersey District Water Supply Commission (w)
- Passaic Valley Water Commission (w)
- Somerset County (w):
  - Board of Chosen Freeholders (w)
- Township of Bridgewater (w):
  - Environmental Commission (w)
- Township of Cranford (w)
- West Windsor Township (w):
  - Environmental Commission (w)

New Mexico:
- Albuquerque Metropolitan Arroyo Flood Control Authority (w)
- City of Albuquerque (w)
- Costilla Creek Compact Commission (w)
- Elephant Butte Irrigation District (w)
- New Mexico Bureau of Economic Development (e)
- New Mexico Bureau of Mines and Mineral Resources (c, w)
- New Mexico Environmental Improvement Division (w)
- New Mexico Natural Resources Department (w)
- New Mexico State Highway Department (w)
- Pecos River Commission (w)
- Pueblo Indians of Zuni (w)
- Rio Grande Compact Commission (w)

New York:
- Central New York State Park and Recreation Commission (w)
- City of Albany (w):
  - Department of Water and Water Supply (w)
- City of Auburn (w)
- City of New York (w):
  - Department of Environmental Protection (w)
- City of Rochester (w):
  - Department of Public Works (w)
- County of Chautauqua (w):
  - Department of Planning and Development (w)
- County of Cortland (w)
- County of Duchess (w)
- County of Monroe (w):
  - Water Authority (w)
- County of Nassau (w):
  - Department of Public Works (w)
- County of Onondaga (w):
  - Department of Public Works (w)
  - Water Authority (w)
- County of Oswego Planning Board (w)
- County of Putnam (w)

State, County, and Local Cooperators—Continued

New York—Continued
- County of Rockland (w):
  - Drainage Agency (w)
- County of Suffolk (w):
  - Department of Health Sciences (w)
  - Water Authority (w)
- County of Ulster (w)
- County of Westchester (w):
  - Department of Public Works (w)
- Hudson River-Black River Regulating District (w)
- Irondequoit Bay Pure Waters District (w)
- Long Island Regional Planning Board (w)
- New York State College of Agriculture and Life Sciences (w)
- New York State Department of Education (w):
  - Museum and Science Service (w)
- New York State Department of Environmental Conservation (w) (*see also* **Pennsylvania**):
  - Bureau of Standards and Compliance (w)
  - Division of Water (w)
- New York State Energy, Research and Development Authority (w)
- New York State Department of Health (w):
  - Division of Sanitary Engineering (w)
- New York State Department of Transportation (w):
  - Bridge Planning and Railroads Bureau (n, w)
- Oswegatchie River-Cranberry Reservoir Commission (w)
- Power Authority of the State of New York (w)
- Susquehanna River Basin Commission (w) (*see also* **Pennsylvania**)
- Town of Clarkstown (w)
- Town of Warwick (w)
- University of Virginia (w) (*see also* **Virginia**):
  - Departmentof Environmental Sciences (w)
- Village of Nyack (w)

North Carolina:
- Agricultural Experiment Station (w)
- City of Burlington (w)
- City of Charlotte (w)
- City of Durham (w):
  - Department of Water Resources (w)
- City of Greensboro (w)
- City of Raleigh (w)
- City of Rocky Mount (w)
- State Board of Transportation, Division of Highways (w)
- State Department of Natural Resources and Community Development (n, w)

North Dakota:
- North Dakota Geological Survey (w)
- Oliver County Board of Commissioners (w)
- State Department of Health (w)
- State Water Commission (n, w)

Ohio:
- City of Canton (w):
  - Water Department (w)
- City of Columbus (w):
  - Department of Public Service (w)
  - Division of Water (w)
- Cuyahoga County (w)
- Geauga County (w)
- Miami Conservancy District (w)
- Northeast Ohio Areawide Coordinating Agency (w)
- Ohio Department of Natural Resources (w):
  - Division of Geological Survey (w)
  - Division of Reclamation (w)
  - Division of Water (w)
- Ohio Department of Transportation (n, w):
  - Division of Highways (w)
- Ohio Environmental Protection Agency (w)

Oklahoma:
- Central Master Conservancy District (w)
- Cherokee Indian Tribe (w)
- City of Ada (w)
- City of Altus (w)
- City of Claremore (w)
- City of Edmond (w)
- City of Guthrie (w)
- City of Lawton (w)
- City of Oklahoma City (w)
- City of Sapulpa (w)
- City of Tulsa (w)
- Foss Cobb Reservoir Master Conservancy District (w)
- Lugert-Altus Irrigation District (w)
- Oklahoma Department of Highways (n)
- Oklahoma Department of Transportation (w)
- Oklahoma Geological Survey (w)
- Oklahoma State Health Department (w)
- Oklahoma Water Resources Board (w)

Oregon:
- Burnt River Irrigation District (w)
- City of Corvallis (w)
- City of Eugene (w):
  - Water and Electric Board (w)
- City of Lakeside (w):
  - Lakeside Water District (w)
- City of McMinnville (w):
  - Water and Light Department (w)
- City of Medford (w):
  - Public Works Department (w)
- City of Portland (w):
  - Department of Public Utilities (w)
  - Department of Public Works (w)
- City of Reedsport (w)
- City of Salem (w)
- Confederated Tribes of Umatilla Indian Reservation (w)
- Confederated Tribes of Warm Springs Indian Reservation (w)
- Coos Bay-North Bend Water Board (w)
- Coos County (w):
  - Board of Commissioners (w)
- Douglas County (w):
  - Department of Public Works (w)
- Lane Council of Governments (w)
- Lane County (w):
  - Office of the Chief Administrator (w)
- Mid-Willamette Valley Council of Governments (w)
- Multnomah County (w):
  - Board of Commissioners (w)
- Oregon Department of Environmental Quality (w)
- Oregon Department of Fish and Wildlife (w)
- Oregon Department of Geology and Minerals (w)
- Oregon State Highway Division (w)
- Oregon Water Resources Department (w)
- Rogue Valley Council of Governments (w)
- Wasco County (w):
  - Planning Office (w)

Pennsylvania:
- Allegheny County (w):
  - Department of Planning and Development (w)
- Chester County (w):
  - Board of Commissioners (w)
  - Health Department (w)
  - Water Resources Authority (w)
- City of Bethlehem (w)
- City of Harrisburg (w):
  - Department of Public Works (w)

Pennsylvania—Continued

City of Philadelphia (w):
  Water Department (w)
Delaware River Basin Commission (w) (*see also* **New Jersey**)
Delaware Valley Regional Planning Commission (w)
Green County Commissioners (w)
Letort Regional Authority (w)
New York State Department of Environmental Conservation (w) (*see also* **New York**)
Pennsylvania Department of Environmental Resources (w):
  Bureau of Surface Mine Reclamation (w)
  Bureau of Topographic and Geologic Survey (n, w)
  Bureau of Water Quality Management (w)
  Office of Resources Management (w)
Pennsylvania Department of Transportation (w)
Pennsylvania State University, Department of Agriculture, Economy and Rural Sociology (e)
Slippery Rock State College (w)
Susquehanna River Basin Commission (w) (*see also* **New York**)
Warminster Township (w)

Rhode Island:

City of Providence (w):
  Department of Public Works (w)
State Department of Environmental Management (w):
  Division of Land Resources (w)
  Division of Water Resources (w)
State Water Resources Board (w)
University of Rhode Island Center for Ocean Management Studies (e)

South Carolina:

City of Lancaster (w)
City of Myrtle Beach (w)
Commissioners of Public Works (w):
  Spartanburg Water Works (w)
State Appalachian Council of Governments (w)
State Department of Highways and Public Transportation (w)
State Geological Survey (w)
State Health and Environmental Control (w)
State Public Service Authority (w)
State Water Resources Commission (w)

South Dakota:

Black Hills Conservancy Subdistrict (w)
City of Sioux Falls (w)
City of Watertown (w)
East Dakota Conservancy Subdistrict (w)
South Dakota Department of Transportation (n, w)
South Dakota Department of Water and Natural Resources (w):
  Division of Geological Survey (w)
  Division of Water Rights (w)
South Dakota School of Mines and Technology (w)
South Dakota State University (n)

Tennessee:

City of Franklin (w)
City of Lawrenceburg (w)
City of Memphis (w):
  Light, Gas and Water Division (w)
  Public Works Division (w)
  Water Division (w)
Lincoln County Board of Public Utilities (w)
Metropolitan Government of Nashville and Davidson County (w):
  Department of Public Works (w)
Murfreesboro Water and Sewer Department (w)
Shelby County (w)

Tennessee—Continued

Tennessee Department of Conservation (e, w):
  Division of Geology (e, n, w)
  Division of Water Resources (w)
Tennessee Department of Public Health (w):
  Division of Water Quality Control (w)
Tennessee Department of Transportation (w):
  Bureau of Highways (w)
  Bureau of Planning and Programming (w)
  Office of Research and Planning (w)
University of Tennessee (w)

Texas:

Athens Municipal Water Authority (w)
Bexar-Medina-Atacosa Counties Water Improvement District No. 1 (w)
Bistone Municipal Water Supply District (w)
Brazos River Authority (w)
City of Abilene (w)
City of Alice (w)
City of Arlington (w)
City of Austin (w)
City of Brady (w)
City of Cleburne (w)
City of Clyde (w)
City of Corpus Christi (w)
City of Dallas (w)
City of El Paso (w)
City of Garland (w)
City of Gainesville (w)
City of Graham (w)
City of Houston (w)
City of Nacogdoches (w)
City of San Angelo (w)
City of San Antonio (w):
  Engineering Department (w)
  Public Service Board (w)
City of Wichita Falls (w)
Colorado River Municipal Water District (w)
County of Dallas (w)
County of Orange (w)
County of Wood (w)
Edwards Underground Water District (w)
Franklin County Water District (w)
Greenbelt Municipal and Industrial Water Authority (w)
Guadalupe-Blanco River Authority (w)
Harris County Flood Control District (w)
Harris-Galveston Coastal Subsidence District (w)
Labaca-Navidad River Authority (w)
Lower Colorado River Authority (w)
Lower Neches Valley Authority (w)
Mackenzie Municipal Water Authority (w)
North Central Texas Municipal Water Authority (w)
Northeast Texas Municipal Water District (w)
Nueces River Authority (w)
Palo Pinto County Municipal Water District No. 1 (w)
Pecos River Commission (w)
Reeves County Water Improvement District No. 1 (w)
Sabine River Authority of Texas (w)
Sabine River Compact Administration (w) (*see also* **Louisiana**)
San Antonio City Water Board (w)
San Antonio River Authority (w)
San Jacinto River Authority (w)
Tarrant County (w)
Texas A & M (e)
Texas Department of Water Resources (n, w)
The University of Texas at Austin (w)
Titus County Fresh Water Supply District No. 1 (w)

State, County, and Local Cooperators—Continued

Texas—Continued
- Tom Green County Water Control and Development District No. 1 (w)
- Trinity River Authority (w)
- Upper Guadalupe River Authority (w)
- Upper Neches Municipal Water Authority (w)
- Upper Trinity Basin Water Quality Compact (w)
- West Central Texas Municipal Water District (w)
- Wichita County Water Improvement District No. 2 (w)

Utah:
- Bear River Commission (w)
- Salt Lake County (w):
  - Board of County Commissioners (w)
  - Department of Water Quality and Water Pollution Control (w)
- State Department of Natural Resources (w):
  - Division of Water Resources (w)
  - Division of Water Rights (w)
  - Division of Wildlife Resources (w)
  - Utah Geological and Mineral Survey (c, g, n. w)

Vermont:
- Agency of Environmental Conservation (n)
- State Department of Water Resources (w)
- Town of Springfield (w)

Virginia:
- City of Alexandria (w):
  - Department of Transportation and Environmental Services (w)
- City of Newport News (w):
  - Department of Public Utilities (w)
- City of Roanoke (w):
  - Utilities and Operations (w)
- City of Staunton (w)
- Southeastern Public Service Authority of Virginia (w)
- University of Virginia (w) (see *also* **New York**):
  - Department of Environmental Sciences (w)
- Virginia Department of Conservation and Economic Development (w):
  - Division of Mineral Resources (n)
- Virginia Department of Highways and Transportation (w)
- Virginia Polytechnic Institute and State University (e)
- Virginia State Water Control Board (w)

Washington:
- City of Bellevue, Public Works Department (w)
- City of Everett (w)
- City of Seattle (w):
  - Department of Lighting (w)
  - Water Department (w)
- City of Tacoma (w):
  - Department of Public Utilities (w)
  - Department of Public Works (w)
- Clallam County Board of Commissioners (w)
- Clark County (w):
  - Department of Public Works (w)
  - Public Utility District (w)
- Cowlitz County Public Utility District (w)
- Hoh Indian Tribe (w)
- Intercounty River Improvement (w)
- Island County Planning Department (w)
- King County Department of Public Works (w)
- Lewis County Board of Commissioners (w)
- Makah Tribal Council (w)
- Muckleshoot Indian Tribe (w)

Washington—Continued
- Municipality of Metropolitan Seattle (w)
- Nisqually Indian Community Council (w)
- Pend Oreille County Public Utility District No. 1 (w)
- Pierce County Board of Commissioners (w)
- Quinault Indian Business Council (w)
- Shoalwater Bay Tribal Council (w)
- Skagit County (w)
- State of Washington (w):
  - Department of Ecology (w)
  - Department of Natural Resources (g)
- Town of Fircrest (w)
- University of Washington, Fisheries Research Institute (w)
- Walla Walla County Board of Commissioners (w)
- Washington Public Power Supply Service (w)
- Washington State Department of Fisheries (w)
- Washington State Department of Natural Resources (e, n)
- Washington State Department of Transportation (w)
- Washington State University (w):
  - Department of Agricultural Engineering (w)
- Whatcom County Board of Commissioners (w)
- Yakima Tribal Council (w)

West Virginia:
- City of Buckhannon (w)
- City of Morgantown (w):
  - Water Commission (w)
- Upshur County (w)
- West Virginia Department of Highways (w)
- West Virginia Department of Natural Resources (n, w):
  - Division of Forestry (w)
  - Division of Water Resources (w)
- West Virginia Geological and Economic Survey (n, w)

Wisconsin:
- Brown County Regional Planning (w)
- City of Middleton (w)
- Dane County (w):
  - Department of Public Works (w)
  - Regional Planning Commission (w)
- Madison Metropolitan Sewage District (w)
- Madison Water Utility (w)
- Sokaogon Chippewa (Mole Lake) Community of Wisconsin (w)
- Southeastern Wisconsin Regional Planning Commission (w)
- State Department of Natural Resources (g, n, w)
- State Department of Transportation (n, w):
  - Bridge Section (w)
  - Division of Highways (w)
- Town of Schleswig (w)
- University of Wisconsin—Extension Geological and Natural History Survey (n, w)
- Village of Oregon (w)

Wyoming:
- Cheyenne Board of Public Utilities (w)
- University of Wyoming (e, w):
  - Water Resources Research Institute and Institute for Policy Research (e, w)
- Wyoming Department of Agriculture (w):
  - Wyoming Conservation Commission (w)
- Wyoming Department of Economic Planning and Development (w)
- Wyoming Department of Environmental Quality (w)
- Wyoming Game and Fish Department (w)
- Wyoming Highway Department (w)
- Wyoming State Engineer (n, w) (see *also* **Montana**)

Other Cooperators and Contributors

Government of American Samoa (w)

Government of Guam (w)

Government of the Northern Mariana Islands (w)

Government of Saudi Arabia (w)

Missouri River Basin Commission (e, w)

New England River Basin Commission (e)

Old West Regional Commission (e)

Puerto Rico:
- Puerto Rico Aqueduct and Sewer Authority (w)
- Puerto Rico Department of Agriculture (w)
- Puerto Rico Department of Health (w)
- Puerto Rico Department of Natural Resources (w)
- Puerto Rico Department of 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 Land Authority (w)
- Puerto Rico Planning Board (w)
- Puerto Rico Sugar Corporation (w)

Southwest Border Regional Commission (e)

Trust Territory of the Pacific Islands (w)

United Nations:
- United National Development Program (w)

Virgin Islands:
- College of the Virgin Islands (w)
- Virgin Islands Department of Public Works (w)
- Virgin Islands Planning Office (w)

Budgetary and Statistical Data

[Data in these tables may differ slightly from data in the individual division chapters because of rounding; and totals may sometimes not add because of rounding]

TABLE 1.—*Geological Survey budget for fiscal years 1975 to 1980, by activity and sources of funds*

[In thousands of dollars]

Budget activity	1975	1976	Transition quarter	1977	1978	1979	1980
Total	**$338,764**	**$353,970**	**$102,858**	**$433,403**	**$698,272**	**$764,718**	**$782,136**
Direct program	253,605	264,434	77,570	319,460	576,393	634,886	639,143
Reimbursable program	85,159	89,536	25,288	113,943	121,879	129,832	142,993
States, counties, and municipalities	35,124	35,006	8,956	39,621	40,784	44,124	46,849
Miscellaneous non-Federal sources	6,399	7,923	1,991	10,229	12,825	15,789	16,817
Other Federal agencies	43,636	46,607	14,341	64,093	68,270	69,919	79,327
Alaska Pipeline Related Investigations	**344**	**287**	**85**	**317**	**272**	------	------
Direct program	344	287	85	317	272	------	------
Reimbursable program	------	------	------	------	------	------	------
Other Federal agencies	------	------	------	------	------	------	------
National Mapping, Geography and Surveys	**52,597**	**52,220**	**13,289**	**57,073**	**69,520**	**74,566**	**82,683**
Direct program	45,350	43,354	11,548	50,311	61,356	65,584	72,759
Reimbursable program	7,247	6,866	1,741	6,762	8,164	8,982	9,924
States, counties, and municipalities	4,995	3,675	882	3,268	3,320	3,371	3,083
Miscellaneous non-Federal sources	594	501	133	601	499	597	610
Other Federal agencies	1,658	2,690	726	2,893	4,345	5,014	6,231
Geologic and Mineral Resource Surveys and Mapping[1]	**114,477**	**115,554**	**32,194**	**130,269**	**163,193**	**178,556**	**193,652**
Direct program	89,018	92,322	24,829	100,007	123,830	134,846	146,963
Reimbursable program	25,459	23,232	7,365	30,262	39,363	43,710	46,689
States, counties, and municipalities	1,550	1,467	383	1,403	956	584	640
Miscellaneous non-Federal sources	3,751	4,936	1,120	6,439	8,510	10,914	11,258
Other Federal agencies	20,158	16,829	5,862	22,420	29,897	32,212	34,791
Water Resources Investigations[2]	**101,437**	**112,480**	**30,716**	**131,509**	**146,014**	**168,598**	**184,871**
Direct program	53,420	57,176	15,916	68,555	[3] 78,487	96,847	108,664
Reimbursable program	48,017	55,304	14,800	62,954	67,527	71,751	76,207
States, counties, and municipalities	28,546	29,735	7,672	34,761	36,457	40,156	43,126
Miscellaneous non-Federal sources	901	940	260	1,331	1,429	1,673	1,778
Other Federal Agencies	18,570	24,629	6,868	26,862	29,641	29,922	31,303
Conservation of Lands and Minerals[4]	**36,082**	**41,677**	**13,386**	**67,427**	**77,409**	**85,484**	**106,395**
Direct program	36,032	41,489	13,375	67,239	77,299	85,362	105,928
Reimbursable program	50	188	6	188	110	122	467
Miscellaneous non-Federal sources	4	1	------	16	9	------	12
Other Federal agencies	46	187	6	172	101	122	455
Office of Earth Science Applications	**16,994**	**17,278**	**8,919**	**23,476**	**23,226**	**23,965**	**23,734**
Direct program	15,461	14,908	7,795	17,698	18,132	19,959	18,935
Reimbursable program	1,533	2,370	6,124	5,778	5,094	4,006	4,799
States, counties, and municipalities	33	130	19	189	51	13	------
Miscellaneous non-Federal sources	1,093	1,496	469	1,741	2,153	2,333	2,808
Other Federal agencies	407	744	636	3,848	2,890	1,660	1,991
National Petroleum Reserve in Alaska	------	------	------	**9,154**	**202,704**	**216,886**	**169,845**
Direct program	------	------	------	2,079	202,598	216,886	169,845
Allocation transfer	------	------	------	7,063	106	------	------
Reimbursable program (Federal)	------	------	------	12	------	------	------
General Administration[5]	**3,671**	**3,398**	**1,491**	**3,760**	**3,650**	**3,661**	**3,776**
Direct program	3,671	3,398	1,491	3,760	3,650	3,661	3,776
Facilities	**10,309**	**9,500**	**2,530**	**9,494**	**10,769**	**11,741**	**12,273**
Direct program	10,309	9,500	2,530	9,494	10,769	11,741	12,773

See footnotes at end of table.

TABLE 1.—*Geological Survey budget for fiscal years 1975 to 1980, by activity and sources of funds*—Continued

Budget activity	1975	1976	Transition quarter	1977	1978	1979	1980
Miscellaneous services to other accounts	**$2,853**	**$1,576**	**$253**	**$924**	**$1,515**	**$1,261**	**$4,907**
Reimbursable program	2,853	1,576	253	924	1,515	1,261	4,907
Miscellaneous non-Federal sources	56	49	10	102	225	272	351
Other Federal agencies	2,797	1,527	243	822	1,290	989	4,556

[1] Includes: Mineral Discovery Loan Program activity for fiscal year 1975; and parts of Geothermal Investigations. Minerals Policy, and Arctic Environmental Studies components of the Special Resource and Environmental Projects activity for fiscal year 1975. Funds exclude the Land Resource Analysis program for fiscal years 1974 to 1976.

[2] Excludes Employee Compensation Payments subactivity for fiscal years 1975 to 1976.

[3] Funds for the Airborne Positioning System, appropriated to Water Resources Investigations are included as obligations of Topographic Surveys and Mapping ($2,172 Thousand).

[4] Includes parts of Geothermal Investigations component of the Special Resource and Environmental Projects activity for fiscal year 1975.

[5] Budget activity funds are reconstructed for fiscal year 1975 and include: Earth Resources Observation System activity for fiscal year 1975; Urban Area Studies and Energy Impact Evaluation components of the Special Resource and Environmental Projects activity for fiscal year 1975. Land Resources Analysis Program of the Geologic and Mineral Resource Surveys and Mapping activity for fiscal year 1975; and the Land Use Data and Analysis activity for fiscal year 1975.

[6] Funds include Employee Compensation Payments subactivity of the Water Resources Investigations activity for 1975 to 1976.

TABLE 2.—*Geological Survey Federal-State Cooperative Program funds for fiscal years 1975 to 1980, by State*

[In thousands of dollars]

State	1975	1976	Transition quarter	1977	1978	1979	1980
Total[1]	**$70,151**	**$69,252**	**$17,482**	**$79,163**	**$80,598**	**$86,962**	**$91,090**
Total State share[2]	35,124	35,007	8,956	39,622	40,784	44,123	46,849
Alabama	**1,212**	**1,124**	**171**	**1,234**	**1,074**	**1,075**	**1,134**
State share	623	550	87	607	532	537	569
Alaska	**1,162**	**782**	**202**	**1,141**	**1,275**	**1,421**	**1,675**
State share	410	407	101	561	654	753	903
Arizona	**1,248**	**1,255**	**335**	**1,393**	**1,552**	**1,721**	**2,229**
State share	646	639	177	700	783	878	1,165
Arkansas	**887**	**811**	**190**	**1,033**	**1,118**	**1,315**	**1,224**
State share	410	371	94	481	543	695	639
California	**4,690**	**4,825**	**1,271**	**5,336**	**6,079**	**6,003**	**5,768**
State share	2,337	2,473	675	2,714	3,091	3,135	2,963
Colorado	**2,445**	**2,199**	**662**	**3,052**	**3,036**	**3,581**	**3,244**
State share	1,324	1,196	349	1,564	1,561	1,784	1,598
Connecticut	**1,069**	**858**	**241**	**871**	**864**	**1,242**	**1,164**
State share	523	415	108	421	411	576	678
Delaware	**194**	**213**	**54**	**225**	**192**	**157**	**127**
State share	106	116	30	121	109	92	64
District of Columbia	**3**	**3**	**1**	**4**	**4**	**4**	**4**
State share	1	2	------	2	2	2	2
Florida	**5,575**	**5,763**	**1,481**	**6,428**	**7,219**	**7,415**	**8,118**
State share	2,781	2,851	735	3,202	3,667	3,819	4,428
Georgia	**3,083**	**2,510**	**552**	**2,452**	**1,706**	**1,919**	**2,129**
State share	1,531	1,243	275	1,209	866	942	1,174
Hawaii	**697**	**896**	**191**	**897**	**1,000**	**1,294**	**1,368**
State share	341	501	101	460	518	646	699
Idaho	**749**	**852**	**223**	**952**	**1,131**	**1,024**	**1,234**
State share	366	417	111	465	611	480	617
Illinois	**645**	**848**	**208**	**1,109**	**1,092**	**1,324**	**1,299**
State share	323	459	120	592	575	718	717
Indiana	**1,288**	**1,519**	**366**	**1,987**	**2,006**	**2,210**	**1,893**
State share	632	779	182	981	1,078	1,107	1,058
Iowa	**617**	**822**	**241**	**1,004**	**1,031**	**1,060**	**1,102**
State share	302	405	121	494	521	531	646
Kansas	**1,424**	**1,525**	**442**	**1,721**	**2,237**	**2,378**	**2,295**
State share	716	752	220	849	1,113	1,163	1,237
Kentucky	**2,728**	**2,828**	**717**	**3,015**	**2,407**	**1,425**	**1,242**
State share	1,229	1,300	297	1,433	1,018	709	665
Louisiana	**1,740**	**1,694**	**440**	**2,628**	**1,856**	**2,027**	**2,146**
State share	902	862	227	1,319	929	1,015	1,148

See footnotes at end of table.

TABLE 2.—*Geological Survey Federal-State Cooperative Program funds for fiscal years 1975 to 1980, by State*—Continued

State	1975	1976	Transition quarter	1977	1978	1979	1980
Maine	**$ 248**	**$ 313**	**$ 89**	**$ 333**	**$ 382**	**$ 566**	**689**
State share	127	181	50	179	191	290	369
Maryland	**1,011**	**1,016**	**243**	**1,176**	**1,174**	**1,393**	**1,559**
State share	530	517	125	602	605	706	805
Massachusetts	**1,618**	**1,627**	**368**	**1,402**	**1,593**	**1,837**	**1,461**
State share	810	779	191	684	801	847	903
Michigan	**1,054**	**1,078**	**252**	**1,101**	**1,203**	**1,497**	**1,280**
State share	505	521	123	541	596	761	700
Minnesota	**1,639**	**1,191**	**320**	**1,082**	**1,759**	**2,330**	**1,614**
State share	817	625	198	566	949	1,249	938
Mississippi	**743**	**646**	**170**	**713**	**754**	**747**	**817**
State share	415	316	85	349	407	374	413
Missouri	**678**	**642**	**207**	**827**	**635**	**713**	**763**
State share	337	316	105	420	316	341	446
Montana	**587**	**596**	**146**	**1,330**	**676**	**734**	**800**
State share	287	301	76	673	338	402	417
Nebraska	**731**	**785**	**187**	**957**	**1,048**	**1,175**	**1,176**
State share	358	396	95	469	522	579	582
Nevada	**846**	**922**	**244**	**1,063**	**1,440**	**1,488**	**1,151**
State share	332	367	103	415	456	535	676
New Hampshire	**172**	**230**	**63**	**248**	**187**	**150**	**176**
State share	73	99	28	103	92	68	88
New Jersey	**977**	**1,090**	**276**	**1,269**	**1,437**	**1,427**	**1,404**
State share	501	565	143	642	851	800	723
New Mexico	**1,439**	**1,510**	**338**	**1,537**	**1,621**	**1,841**	**1,841**
State share	714	768	175	778	838	942	939
New York	**2,977**	**2,822**	**727**	**3,008**	**3,363**	**3,871**	**4,083**
State share	1,585	1,615	407	1,573	1,893	2,377	2,363
North Carolina	**1,885**	**1,462**	**379**	**1,805**	**1,713**	**1,633**	**1,523**
State share	942	724	197	894	858	817	910
North Dakota	**998**	**990**	**246**	**834**	**1,023**	**1,029**	**1,101**
State share	489	489	125	408	505	498	572
Ohio	**1,093**	**1,255**	**336**	**1,598**	**1,799**	**1,962**	**1,885**
State share	563	671	175	838	973	1,075	1,093
Oklahoma	**748**	**786**	**196**	**846**	**936**	**1,131**	**1,078**
State share	368	386	98	414	462	577	582
Oregon	**902**	**899**	**287**	**1,230**	**1,214**	**1,391**	**1,551**
State share	443	449	163	639	610	674	817
Pennsylvania	**2,415**	**2,510**	**554**	**2,718**	**2,688**	**2,847**	**2,766**
State share	1,209	1,269	284	1,365	1,366	1,301	1,470
Rhode Island	**110**	**124**	**31**	**145**	**160**	**233**	**260**
State share	54	60	16	72	80	117	130
South Carolina	**574**	**557**	**142**	**603**	**625**	**832**	**967**
State share	284	272	71	296	329	363	506
South Dakota	**515**	**528**	**146**	**562**	**662**	**766**	**1,048**
State share	251	259	73	275	331	382	546
Tennessee	**952**	**1,035**	**280**	**1,255**	**1,383**	**1,509**	**1,612**
State share	470	508	139	615	686	729	804
Texas	**4,261**	**4,351**	**1,102**	**4,621**	**4,525**	**4,588**	**4,276**
State share	2,100	2,148	550	2,354	2,244	2,299	2,140
Utah	**1,361**	**1,314**	**334**	**1,631**	**1,451**	**1,657**	**1,955**
State share	838	745	186	810	726	842	1.094
Vermont	**130**	**138**	**28**	**134**	**142**	**166**	**173**
State share	64	68	14	70	70	81	90
Virginia	**858**	**737**	**142**	**768**	**778**	**897**	**813**
State share	442	378	78	393	397	548	477
Washington	**2,208**	**2,115**	**509**	**3,271**	**2,537**	**2,859**	**2,782**
State share	1,104	1,066	265	1,653	1,243	1,378	1,453
West Virginia	**775**	**716**	**175**	**830**	**688**	**752**	**694**
State share	448	418	105	472	388	402	369
Wisconsin	**1,706**	**1,874**	**552**	**1,703**	**1,883**	**1,969**	**1,953**
State share	883	999	297	935	1,026	1,022	1,074
Wyoming	**853**	**754**	**167**	**903**	**901**	**819**	**859**
State share	514	397	86	391	381	412	437

TABLE 2.—*Geological Survey Federal-State Cooperative Program funds for fiscal years 1975 to 1980 by State—* Continued

State	1975	1976	Transition quarter	1977	1978	1979	1980
American Samoa	**70**	**40**	**9**	**60**	**64**	**47**	**50**
State share	32	20	4	30	32	23	25
Guam	**$ 65**	**$ 68**	**$ 18**	**$ 70**	**$ 85**	**$ 104**	**$ 123**
State share	32	33	9	33	47	56	80
Northern Marianas	------	------	------	------	**18**	**40**	**42**
State share	------	------	------	------	9	21	21
Puerto Rico	**1,293**	**1,016**	**185**	**843**	**922**	**1,083**	**1,344**
State share	585	451	84	396	459	518	691
Trust Territories	**170**	**170**	**44**	**173**	**180**	**184**	**196**
State share	84	84	22	84	90	92	98
Virgin Islands	**33**	**18**	**2**	**32**	**70**	**94**	**78**
State share	31	9	1	16	35	43	39

[1] Includes Federal Funds from direct program.
[2] Includes reimbursable program funds from States, counties, and municipalities.
[3] Included with Puerto Rico funds.

TABLE 3.—*Geological Survey reimbursable program funds from other Federal agencies for fiscal years 1975 to 1980, by agency*

[In thousands of dollars]

Agency	1975	1976	Transition quarter	1977	1978	1979	1980
Total	**$43,636**	**$46,607**	**$14,347**	**$57,017**	**$68,164**	**$69,919**	**$79,326**
Appalachian Regional Commission	179	------	------	------	------	------	------
Department of Agriculture	891	2,008	605	2,130	2,727	2,619	3,878
Department of Commerce	154	2,205	36	334	183	141	276
National Oceanic and Atmospheric Administration	434	1,513	772	1,947	1,708	1,464	2,388
Ozarks Regional Commission	49	------	------	------	------	------	76
Department of Defense	11,247	11,965	3,195	12,308	15,655	16,760	17,447
Department of Energy[2]	3,854	4,704	1,926	8,573	14,980	15,338	14,406
Bonneville Power Administration	(105)	(130)	(32)	(141)	(138)	(48)	(61)
Department of Housing and Urban Development	3,069	4,624	1,873	6,003	3,789	1,967	302
Department of the Interior	9,361	6,290	2,362	12,186	16,528	17,746	
Bureau of Indian Affairs	697	759	277	915	2,385	4,345	9,295
Bureau of Land Management	5,114	3,682	1,467	9,011	10,791	9,712	7,807
Bureau of Mines	1,735	148	------	200	108	240	297
Bureau of Reclamation	721	790	267	1,199	1,871	1,975	2,257
National Park Service	617	576	230	542	791	771	818
Office of the Secretary	------	------	44	------	------	82	203
Office of Surface Mining	------	------	------	------	135	21	1,563
U.S. Fish and Wildlife Service	372	205	45	178	447	600	686
Department of State	1,698	949	221	1,075	1,010	1,455	2,449
Department of Transportation	4	470	240	313	193	149	291
Environmental Protection Agency	1,389	1,921	777	2,137	3,074	2,873	2,645
National Aeronautics and Space Administration	3,449	3,584	1,051	2,648	2,763	4,033	2,793
National Science Foundation	1,928	1,650	40	2,712	848	896	1,211
Nuclear Regulatory Commission	1,195	1,439	427	1,758	1,318	1,583	1,325
Tennessee Valley Authority	252	216	70	297	216	261	243
Miscellaneous Federal agencies	1,686	1,542	499	1,774	1,882	1,645	2,105
Miscellaneous services to other accounts	2,797	1,527	253	822	1,290	989	4,556

[1] Included in miscellaneous Federal agencies.
[2] Shown as Energy Research and Development and Federal Energy Administration prior to October 1, 1977; includes Atomic Energy Commission funds for fiscal year 1974. See also funds from Nuclear Regulatory Commission in fiscal year 1975.

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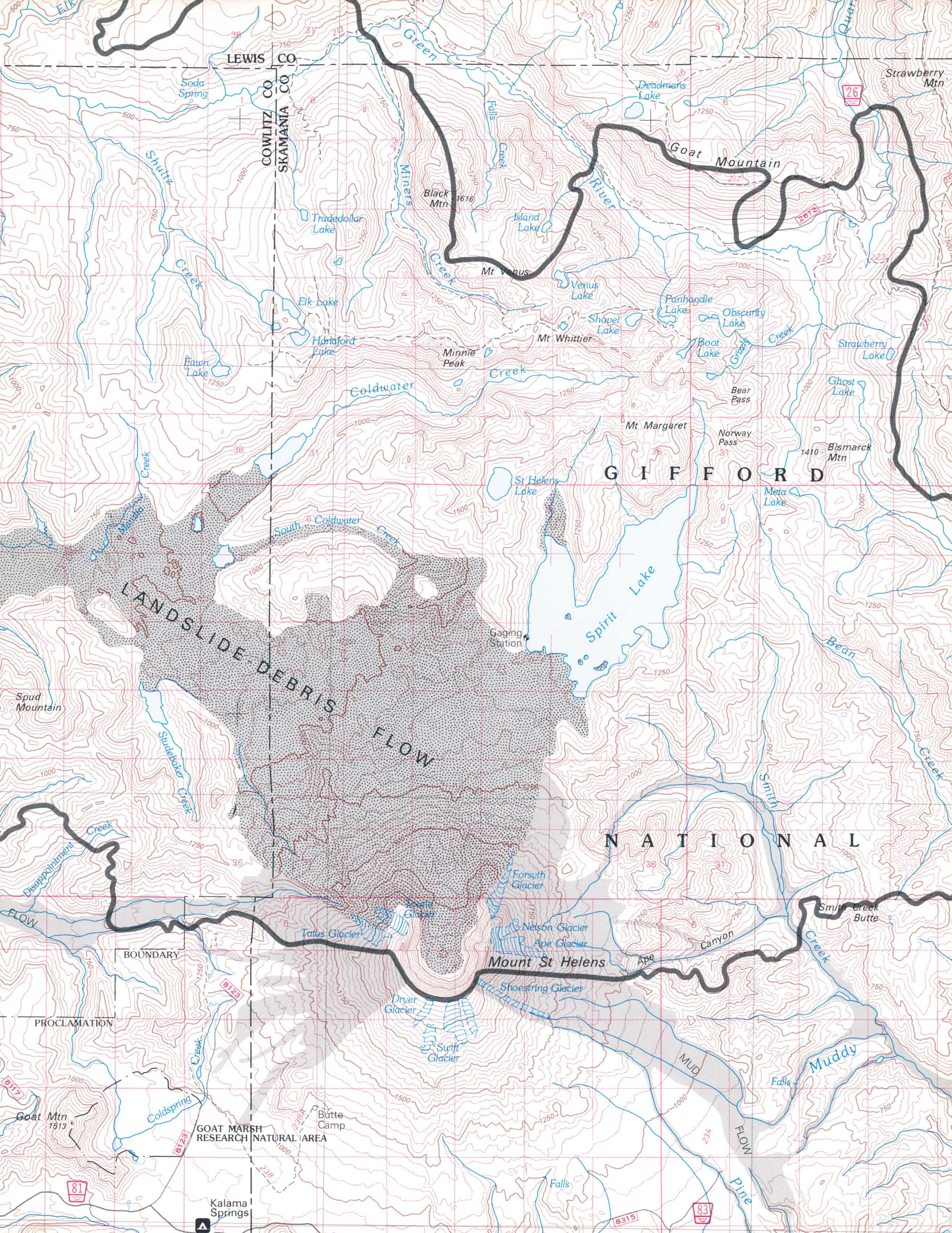
As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental 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.



LEWIS CO
COWLITZ CO
SKAMANIA CO
Soda Spring
Shultz Creek
Tradedollar Lake
Elk Lake
Hanaford Lake
Fawn Lake
Black Mtn 1616
Miners Creek
Green River
Falls Creek
Island Lake
Mt Venus
Venus Lake
Deadmans Lake
Goat Mountain
Strawberry Mtn
Panhandle Lake
Obscurity Lake
Shovel Lake
Mt Whittier
Minnie Peak
Boot Lake
Grizzly Creek
Strawberry Lake
Ghost Lake
Coldwater Creek
Bear Pass
Mt Margaret
Norway Pass
Bismarck Mtn 1410
St Helens Lake
Meta Lake
GIFFORD
South Coldwater Creek
Maratta Creek
LANDSLIDE-DEBRIS FLOW
Gaging Station
Spirit Lake
Bean Creek
Spud Mountain
Studebaker Creek
Smith Creek
Disappointment Creek
NATIONAL
FLOW
Forsyth Glacier
Toutle Glacier
Talus Glacier
Nelson Glacier
Ape Glacier
Smith Creek Butte
Ape Canyon
BOUNDARY
Mount St Helens
Shoestring Glacier
Dryer Glacier
Swift Glacier
PROCLAMATION
MUD FLOW
Muddy
Falls
Coldspring Creek
Goat Mtn 1513
GOAT MARSH RESEARCH NATURAL AREA
Butte Camp
Kalama Springs
Pine
Falls